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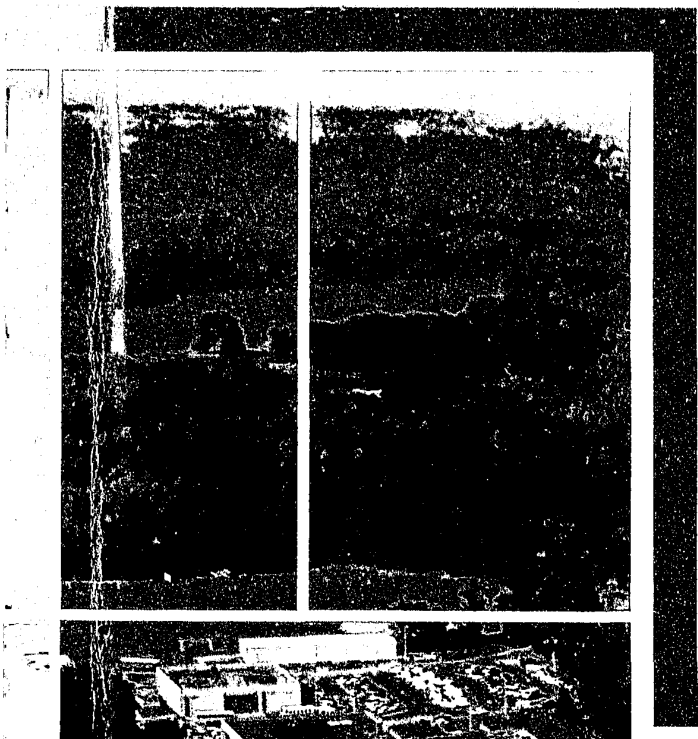

PROCEEDINGS OF THE INTERNATIONAL FORENSIC SYMPOSIUM ON LATENT PRINTS

FBI ACADEMY
QUANTICO, VIRGINIA
JULY 7 - 10, 1987

Proceedings of the International Forensic Symposium on Latent Prints

Host

Laboratory and Identification Divisions
Federal Bureau of Investigation

July 7 – 10, 1987

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FOREWORD

On July 7–10, 1987, the FBI Laboratory and Identification Divisions cohosted the "International Forensic Symposium on Latent Prints." The symposium was held at the Forensic Science Research and Training Center, Quantico, Virginia, and in attendance were 270 scientists representing industry, university and government laboratories in the United States, Australia, the British West Indies, Canada, Costa Rica, the Federal Republic of Germany, Finland, Israel, Italy, Japan, Norway, Switzerland, Thailand and the United Kingdom.

The symposium program included lectures by prominent scientists on such topics as: the biologic and chemical aspects of latent print development, the various methods of latent print development including the use of lasers and the development and current technology for using automated fingerprint identification systems. In addition, short oral and poster presentations were given on techniques for the detection and enhancement of latent prints using unique chemical reagents and lasers. The effectiveness of various state automated fingerprint identification systems was the topic of a panel discussion.

The symposium provided for an exchange of ideas which, it is hoped, will generate future research and strengthen the scientific merit of the forensic applications of latent print detection, processing and identification. Consequently, I believe the objectives of this symposium, to gather respected scientists together to discuss the latest aspects of latent print technology, were met.

On behalf of the FBI, I would like to thank all those who participated in the symposium.

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HISTORICAL OVERVIEW OF LATENT PRINT DETECTION

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We may be fingerprint experts, but we need raw materials with which to work. In this instance, the raw materials are the friction ridged skin surfaces on people's hands and feet. My friend and colleague, Mr. John Berry, has formulated a theory about the early use of our raw material.

The earliest dated prints of the ridged skin on human hands and feet were made about 4,000 years ago during the pyramid building era in Egypt. In addition, one small portion of palmprint, not known to be human, has been found impressed in hardened mud at a 10,000-year-old site in Egypt.

Mr. Berry, other members of the Hertfordshire Constabulary Fingerprint Bureau and I began to study the fingerprints of primates in 1975 because we knew so little about them. With the assistance of Professor and Mrs. Napier, we examined the ridged skin of about 200 species of primates from the tree shrew to the gorilla. After we convinced ourselves that all primates had fingerprints like our own and that their prints were also unique, Mr. Berry thought that we should be able to trace the evolution of ridged skin back to the first primates. Primates vary physically by normal evolution depending on their habitat— South America, Japan, Sumatra, Celebes, Madagascar and so on. Mr. Berry selected Madagascar for study, an island that became detached from East Africa about 50 million years ago. Being isolated, Madagascan primates differ physically from their African mainland cousins, but all share ridged skin on the hands and feet.

One fingerprint pattern shared by all primates worldwide is the elliptical whorl. Both mainland and Madagascan primates have elliptical whorls. Mr. Berry suggested that only two theories could account for this:

1. Before Madagascar separated from the mainland (say 75 million years ago), ridged skin was already present on the hands and feet of those primates who were trapped on the new island and who were beginning their own individual journey of evolution.
2. Primates all over the world suddenly developed ridged skin on their hands and feet when homo sapiens arose.

Mr. Berry dropped the second theory and wrote to Professor Beigert, who had published a number of books about ridged skin on the hands and feet of primates and is an authority on the subject. He replied, saying, "I agree with you that dermatoglyphics on palma and planta of primates have to be dated very early. In my opinion in the Paleocene, 50 million to 60 million years ago." Fired with enthusiasm, Mr. Berry also approached Professor Napier with the same theory, and he replied, "I am quite sure that fingerprints are as old as you suggest, particularly if the evolution of the monkeys is put back to the Eocene. The chances of evolving the human primate pattern are very high by means of the simple process of evolutionary convergence which your thesis strongly suggests . . . it is obviously a basic pattern of nature."

Since then Mr. Berry has published his ideas in many places. On behalf of Mr. Berry I propose our theory to you, that our raw material originated in our subprimate ancestors about 75 million years ago to facilitate grip through friction, sweat pores and heightened sense of touch.

More recently, major pioneering researchers who paved the way for modern fingerprint science and latent print detection quantified and classified our raw material so that we might use it successfully. These researchers often worked in a vacuum, ignorant of the effect their work would have on that of other unknown researchers and often unaware that latent fingerprints were there for the finding. However, all of them stumbled on some aspect of a natural and infallible method of personal identification and, whether their goal was purely anthropological or criminal investigation or both, they made useful contributions.

Dr. Nehemiah Grew, born in 1641 at Mancetter, Warwickshire, in the English Midlands, was the first dermatoglyphicist. Grew graduated from Cambridge University in 1661 and became the first English plant anatomist and the foremost botanist of his day. He was a Fellow of the College of Physicians and subsequently a Fellow of the Royal Society, becoming its Secretary in 1677. These positions gave him access to the Royal Society microscope, a device that had only recently been invented. Grew observed in 1684 that:

> if any one will but take the pains, with an indifferent Glass, to survey the Palm of his Hand very well washed with a Ball, he may perceive

(besides those great Lines to which some men have given Names, and those of a middle size, called the Grain of the skin) innumerable little Ridges, of equal bigness and distance, and everywhere running parallel one with another . . . . Upon these Ridges stand the Pores, all in even Rows, and of that magnitude, as to be visible to a very good Eye without a Glass. But being viewed with one, every Pore looks like a little Fountain, and the sweat may be seen to stand therein, as clear as rock water, and as often as it is wiped off, to spring up within them again.

Professor Marcello Malpighi, a plant morphologist at the University of Bologna, performed research similar to Grey's and published similar findings in his 1686 publication *De Externo Tactus Organo*. This anatomical treatise, though less detailed about the surface of the hand than that of Dr. Grew, delves further beneath the surface. Malpighi's anatomical work was so outstanding that one of the layers of the skin was named "stratum Malpighi" after him.

In 1823, Professor Johannes Evangelist Purkinje published the most detailed description of fingerprints to have appeared anywhere up to that time. Perhaps his work led fingerprint science to become fingerprint identification. Professor Purkinje's thesis entitled *A Commentary on the Physiological Examination of the Organs of Vision and the Cutaneous System* describes, with illustrations, nine fingerprint patterns classified in Latin. From his illustrations, it can be seen that the Latin classifications refer to what Henry would later name arches, tented arches, loops, whorls and twinned loops. Purkinje's research was purely anatomical, and he made no mention of individuals being identified by the patterns that he described. However, he recommended further research, and others soon took up this challenge.

The greatest advances in fingerprint science in the late 19th and early 20th centuries were made by Dr. Henry Faulds, a Scottish missionary doctor of the United Presbyterian Church. Dr. Faulds is important because he was the first to publish his findings about the identification afforded by ridged skin on the hands of individuals. In so doing, he made others aware of the value of their own work on the subject and in a sense he began a race to produce a "fingerprint system" for police, military and government use. By publishing his findings first, Dr. Faulds took his place in our history.

Faulds first became interested in fingerprints after 1874 while working at the hospital he established in Tsukiji, Tokyo, Japan. He claimed that his interest in fingerprints was aroused by impressions he found in broken pottery on the beaches of the Bay of Yedo. The fact that some impressions were repeated on different bits of broken pottery caused him to make a study of fingerprints, and in this he seems to have found many willing helpers among the Japanese students. After careful experiment and observation, he became convinced that fingerprint patterns did not change, that the fingerprint patterns on the fingers were highly variable and that superficial injury did not alter them—they returned to their former design as the injury healed.

In a letter written to *Nature* in October 1880, Faulds relates how he took many sets of fingerprints and palmprints and studied them, as Grew had done, with a botanical lens. He further described the pattern formations on the fingers, referring to "loops" and "whorls" and stating how good sets of fingerprints may be obtained by the use of "A common slate or smooth board of any kind, or a sheet of tin, spread over very thinly with printers' ink." This technique, still in use today, appears to be a botanical technique called nature-printing. Faulds' most important conclusion was that fingerprints do not change and that fingermarks (that is, latent prints) left on objects by bloody or greasy fingers "may lead to the scientific identification of criminals." This was a totally new concept in 1880, and it was voiced by the man who was also the first to identify a criminal by fingerprints left at a crime scene and the first to eliminate a suspect from police inquiries by the use of fingerprints. The circumstances of these two events follow.

A thief left sooty finger marks on a whitewashed wall not far from where Faulds lived. His interest in fingerprints was well known locally, and so he was informed and visited the scene. A man had been arrested by the police and Faulds obtained permission to take the man's fingerprints by nature-printing. He then compared them with the sooty marks on the wall. They were not identical, but the sooty fingermarks were still believed to be those of the thief in this case. Faulds insisted that the prisoner in police custody could not be that thief. Some days later, a further suspect was arrested, and Faulds confirmed that this second prisoner had indeed made the sooty marks on the wall.

On another occasion, Faulds was actually called in by the police and found a complete hand impression on a mug involved in a crime. He realized for the first time that fingers did not have to be bloody, greasy or sooty to leave a "print" behind. An impression in sweat could be as distinct as one in soot or ink. On this occasion, Faulds was also able to assist the police by identifying a suspect by his fingerprints.

On his return to England, Faulds suggested to New Scotland Yard that he might be allowed to set up a fingerprint office, at his own expense, to assist the Metropolitan Police, but he was not allowed to do so. He also founded the first fingerprint based magazine entitled *Dactylography* that ran for seven issues. Although Faulds was not able to convince New Scotland Yard in 1886, others continued his efforts.

Although Faulds' attempts at fingerprint classification did not attract popular support, he was in London discussing the matter 2 years before Francis Galton began the same journey and achieved some of the same results. Memorials to Dr. Faulds commemorating his place in our history now exist in Tokyo, Japan, and Wolstanton, Stoke on Trent, England.

Faulds' letter to *Nature* immediately brought a response from Herschel and began their controversial correspondence. Herschel was in the Indian Civil Service when he corresponded with Faulds. He held this post from 1853 to 1878 and, during that time, expanded upon the local custom of sealing official documents with a finger- or handprint in ink as a signature because of the high level of illiteracy in India and frequent attempts at forgery. Herschel also began fingerprinting all prisoners in jail, a procedure that not only proved identity but also previous convictions.

Herschel's main role as a fingerprint pioneer lies in the area of the immutability of ridged skin also mentioned by Faulds. Throughout his life, Herschel took his own fingerprints and noted that no change had occurred in them in over 50 years. He also had a small collection of about 20 sets of fingerprints and used his technique of handprinting to detect forgeries of legal documents. The fingerprints taken from prisoners were also of great interest to him, and he had the opportunity to see the same prisoners fingerprinted several times over a number of years with no change occurring in their fingerprints. Although his interest in fingerprints predates that of Faulds, Herschel did not make his feelings known and did not suggest that he had developed a method of registering and identifying criminals, nor did he foresee any crime scene application as Faulds had done.

Herschel later gave his personal fingerprint collection to Sir Francis Galton to assist him in his research, and it still exists at the Galton Laboratory in London. Sir Francis Galton, our next pioneer, corresponded with Herschel after reading his letter to *Nature*. Galton, like his predecessors, went first into medicine, but his interests were broader and he had a fine academic mind. His research culminated in his book *Fingerprints*. His investigations into dermatoglyphics were as thorough as those of Faulds had been enthusiastic. Words like ridge-ending, spur and bifurcation, the ridge characteristics or minutiae now second nature to us all, were first stressed by Galton. He borrowed Faulds' idea of classifying fingerprint pattern types in broad groups of arches, loops and whorls but further divided loops into "i" or "o" groups, depending on the side to which the loops opened.

Compared with Herschel's fingerprint collection, Galton's was quite large, beginning with an initial collection of 2,500 thumbprints only. By 1890, however, he began collecting 10-finger sets of prints by the nature-printing method described by Faulds, increasing his collection by 500 sets. The study included palms and soles of feet, and from this he was first to deduce that sweat pores and extra nerve endings at the summits of the ridges on the surface of the hand and foot assisted grip and touch. Galton's study also showed that loops were the most common pattern, so he was forced to further divide these by ridge counts from core to delta—more Galton terminology. Patterns were shown by Sir Francis to be hereditary, but, perhaps for lack of information, he stated that the patterns never blend. We now know that perhaps the greatest triumph of the Henry Classification System is that it can easily cope with blended or transitional fingerprint patterns.

Being a prominent figure in the British scientific establishment, Galton was able to be more influential than Henry Faulds had been and, indeed, was called before a government committee to report his work. The committee found that the classifying of a large number of sets of fingerprints would be difficult, if not impossible, with Galton's method (as it had been with that of Faulds), and the matter was put into the hands of a man who was pro-Bertillonage and antifingerprints. (Bertillonage refers to the identification method devised by M. Alphonse Bertillon in Paris which was used before fingerprinting. This method involved measuring the bones of the body, head and limbs, and it survived until the death of Bertillon in 1914.) Sir Francis was undeterred, and, knowing fingerprint identification to be superior to Bertillonage, he carried on his work, producing a second book, *Fingerprint Directories*, in 1895. By this time, his collection had increased to 2,000 sets, but he had not been able to produce the breakthrough in classification that would be required.

I have visited the Galton Laboratory and seen his fingerprint collection, including the few supplied by Herschel and the equipment he used. It was interesting to see that an item Galton had adapted to his own use, the linen-tester magnifying glass, is now used by every fingerprint officer in the United Kingdom.

At that time, the single problem preventing the full judicial use of fingerprints for the identification of criminals was purely one of filing and retrieving. In other words, how to find one particular set among thousands of others. Finally, two men achieved this independently. One was an Indian Police Official working for Henry in India, and the other was Dr. Juan Vucetich. Vucetich set up the first police fingerprint department, at his own expense, in Buenos Aires, Argentina, in 1891. Although he was not Spanish, his system is only used in Latin American countries. The system is perfectly sound, and perhaps only poor communications in those days made it necessary for the Henry system to be developed about 9 years later in another country.

Vucetich was initially attracted to fingerprint identification by reading an article by Sir Francis Galton. When he solved the problem of classification of 10-finger sets of fingerprints, he sold many of his own personal possessions to raise money for filing cabinets and equipment to install the fingerprint system in Police Headquarters, Buenos Aires. His faith was justified almost immediately by his spectacular solving, using fingerprints, of the murder of two small children. He was able to show that their mother, not a local man whom the police had in custody, had killed them.

Back in England, the pressure was still on to solve how to file and retrieve a single fingerprint form at will. Henry joined the Indian Civil Service, an extension of the British Government. In 1891, he was appointed Inspector-General of Police in India and in Bengal, where he found Herschel's fingerprint system in use. No classification system was then in use, and after a year's assignment to South Africa, he returned to England where he took fingerprint instruction from Sir Francis Galton. It was now 1894, and, convinced of the usefulness of fingerprints, Henry returned to India with the idea of trying to improve on Herschel's scheme by using the Galton classification method. Many letters passed between Galton and Henry, but the final answer still eluded Henry. Between 1894 and 1897, Inspector General Henry employed a Indian Police Officer in Bengal named Khan Bahadur Azizul Haque, who had an interest in mathematics. Henry charged Haque with the task of helping him create a fingerprint classification system.

Haque developed the mathematical formula that has become known as the Henry System and was characterized by 10 finger forms being subdivided by primary classification into 1,024 pigeonholes. (One million forty eight thousand, five hundred and seventy six in the Vucetich system). Henry grasped this as just what he was looking for, and local use in India proved that Haque had indeed solved all the remaining problems. By 1899, fingerprint identification had become a reality, being used by the Government in India as a replacement for Bertillonage. That same year Henry returned to England bringing "his" new system with him.

Although Henry always loudly applauded Haque's efforts in India, when he appeared in London before a governmental committee headed by Lord Belper, he stated that the system was his own idea. Haque's name also does not appear in Henry's book *Classification and Uses of Fingerprints* published in 1900. In 1901, Henry was appointed Assistant Commissioner of Police at New Scotland Yard and began to introduce his fingerprint system into that institution. By the end of that year, the Fingerprint Office at New Scotland Yard was fully functional, the first British Court conviction by fingerprints being obtained in 1902.

I can find nothing to suggest that Henry did any work on latent, bloody or sooty fingermarks as Faulds and Vucetich had done, this work being undertaken by the three men first employed in the new office. These were Detective Inspector Steadman, Detective Sergeant Collins and Detective Constable Hunt, whose early experiments on powdering latent fingerprints with brush and lycopodium blossomed into the many techniques used around the world today. However, Henry deserves the credit for introducing fingerprint work into Britain and for founding the Department in which I began my own career.

After 1901, the transatlantic interchange of ideas began. Many police officers in the United States took an interest in the published results of the Fingerprint Office at New Scotland Yard. The first American to my knowledge who traveled to England to learn firsthand the new skill was Dr. Henry P. DeForest, Medical Examiner for the New York Civil Service Commission. D. S. Collins was his tutor, and Dr. DeForest returned, convinced, to New York.

Two years later in 1904, Inspector John K. Ferrier traveled to the World's Fair Exposition, St. Louis, Missouri, as part of New Scotland Yard's guard for the Crown Jewels that were to be displayed there. Inspector Ferrier was a member of the Fingerprint Office at New Scotland Yard and, while in St. Louis, gave lectures on his work to nine pioneering students of fingerprint identification. In this way, Inspector Ferrier became the first man to lecture in the United States on this subject. One of the nine students was Captain Edward Foster of the Canadian Police, who was himself so successful that he went on to become known as the Father of Canadian Fingerprinting.

Research still continues. Dermatoglyphics, Professor Cummins' term, has come to mean the scientific, clinical and genetic study of fingerprints and palmprints and in this too, one English name is prominent. The late Dr. Sarah Holt came to prominence in academic circles with her genetic studies and took a particular interest in dermatoglyphics. She built up an extensive palmprint collection from people affected by various congenital deformities and used these in her studies, sometimes sharing the same podium at conferences with Professor Cummins whom she knew well. In academic circles, Dr. Holt is widely published, having several papers to her credit, and a book, *The Genetics of Dermal Ridges*, published in 1908. The Dermatoglyphics Association based in the United States continues the work of Cummins and Holt, although this Association suffers from the lack of input by Fingerprint Experts from the Police Service. Perhaps this situation will change.

In police circles too, researchers push back the barriers of latent print detection and development, and the pioneers' claims and counter claims of priority go on. Professional Associations like the International Association of Identification and the Fingerprint Society of which I am a founding member have disseminated information so that today's researchers need not stumble in the darkness of ignorance as the early pioneers were forced to do.

DISCUSSION

Question: Who would you say is the "Father of Fingerprints" and why?

Haylock: That is a very difficult question because it is unfair to single out one person as the "Father of Fingerprints." A lot might not have happened if Dr. Faulds had not published first, but he was not the only pioneer in this field. The matter of being able to classify fingerprint forms so that we can use them to identify criminals was a side issue. I would put Haque, Faulds and Goldson together because Haque made it possible for us to use fingerprints, and Faulds and Goldson discovered that fingerprints could be used as an infallible method for identification. Without the classification system, we could never have used fingerprints successfully for identification.

Question: Was Inspector Hunt the first to try powdering latent prints?

Haylock: Hunt, Collins and Steadman were the first police off icers assigned to the new Fingerprint Office at New Scotland Yard. They experimented with using powder on latent prints. It is not clear that Faulds used powder on a print, but he did identify a criminal by a latent print.

Question: With 23 years of fingerprint identification experience, I have found that the number of fingerprint identifications that we do not take to court in the United Kingdom because the identifications do not have all 16 ridge characteristics is less than 2% of the total fingerprints identified. I believe the 16 characteristics are a good standard and should be maintained.

Haylock: I am not going to argue with you about the standard because we have seen what has happened in other parts of the world where a standard does not apply. I would prefer, however, to have the standard reduced to 12 ridge characteristics. I believe the experience of the expert is more important than the actual identification standard, because not only do we have to meet the 16 ridge characteristics in the United Kingdom, but every identification has to be checked by 2 other experts.

Question: What is the least amount of points that you use for a court conviction?

Haylock: I believe 10. Ridge characteristics are far less common than other characteristics. If a small portion of fingerprints have cross-overs and spurs and unusual characteristics, they are more easily identified than if the fingerprints have just a few ridge endings and a bifurcation. It is important not to find a single ridge characteristic that does not agree.

Warboys: In the United Kingdom 16 points are found 98% of the time. We are prepared to go to court with less than 16 ridge characteristics if the circumstances are warranted, and we have such an agreement with the Association of Chief of Police Officers. The 16 point standard was raised from 12 in 1924 by Mr. Collins, who at that time was head of the Fingerprint Bureau at New Scotland Yard. Also, Dr. Lockard was doing some powdering experiments in 1890.

Question: Was Dr. Faulds' involvement to eliminate a suspect and the identity of a true suspect in a latent case by the soot impression around the same time as the Dr. Vucetich murder case? Which one could be construed as the first latent case to prove guilt or innocence?

Haylock: I believe Dr. Faulds' involvement was before the Vucetich murder case. Of course, there was no communication between Japan and Argentina then.

Question: Is there any truth to the story about how Henry and Haque came up with the idea leading to the development of the fingerprint classification system?

Haylock: I don't believe so. I think there were a couple of other police officers who were also involved, and Haque came up with the ideas.

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BIOLOGIC AND CHEMICAL ASPECTS OF LATENT FINGERPRINT DETECTION

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There are now many effective ways to visualize latent fingerprints, for example the use of high powered light sources for fluorescence techniques, ninhydrin, physical developer, cyanoacrylate fuming and many more. But we are all aware that for surfaces such as skin and fabrics, no visualization method is reliable. Existing methods may not be effective even on surfaces we know have been handled. In such cases, the factors affecting success include the type of surface, condition of surface, environmental conditions to which the article has been exposed, the lack of sensitivity of the techniques used or the use of an inappropriate method. To overcome these problems, we need a wide range of effective techniques for all possible surfaces. Additionally, it would be an advantage if each method reacted with different fractions of the latent fingerprint deposit. For particular surfaces, successive employment of methods used in strict sequences (so as not to interfere with successive treatments) maximizes the chance of revealing latent fingerprints. Examples of such sequences for a wide range of surfaces have been published by Goode and Morris (1983), Menzel (1983) and more recently in the British Home Office's comprehensive *Manual of Fingerprint Development Techniques*.

The sequential approach depends on surface examined. For paper, the sequence would be visual examination, use of high powered light sources to detect fluorescent contaminants, ninhydrin to reveal amino acids and physical developer to visualize lipids. The success or failure of this method depends not only on its sensitivity but also on the relative proportions present of fluorescent contaminants, amino acids and lipids which may vary widely from individual to individual. However, if the paper exhibit is wet or damp, then ninhydrin treatment will be ineffective because amino acids are water soluble. On the other hand, physical developer is still effective, since lipids are unaffected by water. Similar judgments must be made for other surfaces. For example, the sequence for polythene-type articles would include visual examination, high powered light sources for fluorescence examination and metal deposition or cyanoacrylate fuming.

To increase the chance of visualizing latent fingerprints, it is necessary to increase the sensitivity of existing techniques and to introduce techniques that exploit differences in the various fractions that make up the latent fingerprint deposit. In the following pages, I will describe research undertaken in the Home Office Forensic Science Service into new detection methods involving highly sensitive biologic methods and also into the development of an iodine solution for revealing latent fingerprints at scenes of crime.

BIOLOGIC METHODS

Techniques using antibodies, lectins and enzymes are currently employed in forensic science laboratories to determine the blood group and enzyme types of various body fluid stains. Such methods are noted for their great sensitivity. We have attempted to modify some of these techniques for fingerprint detection, with the aim of developing methods that could overcome some of the shortcomings of existing fingerprint detection systems.

Antibodies are proteins that may be released into the bloodstream of an animal when it is injected with a foreign substance, for example, foreign red blood cells. These antibodies recognize particular components of the injected foreign substance—termed the antigen—and can bind to them. In the case of red blood cells, the binding of antibodies causes the red cells to clump, a process called red cell agglutination. The red cell agglutination technique is commonly used in forensic science and elsewhere to determine blood group types, for example, ABO and Rhesus blood types.

Lectins are proteins isolated chiefly from the seeds of various plants. They have been found to possess combining sites that can recognize and bind to certain sugars present on the surface of red blood cells (Sharon and Lis 1972). If a particular lectin can bind to a sugar, then that lectin may be able to cause agglutination. For example, a lectin isolated from seeds of the gorse plant *Ulex europeus* can bind to a sugar present on the surface of human blood group O cells and is capable of agglutinating human group O red cells.

The ABO system is based on the presence in the red cells of three types of antigens, namely, A antigen, B antigen and H antigen. Individuals of group A carry antigen A on their red cells, group B individuals carry the B antigen and group O individuals carry antigen H. Antigen A and antigen B are both made in the body by modification of antigen H, and thus individuals of group A and B may also carry some antigen H that has not yet been modified. Group O individuals carry only the H antigen.

In humans, the A, B and H blood group substances are not only found on the surfaces of red cells but also in various body secretions including saliva, tears, semen and vaginal fluid. Individuals who secrete ABH material in their body fluids are known as secretors and represent approximately 80% of the British population. The remaining 20% are termed nonsecretors, and very little ABH material can be detected in their body fluids.

Ishiyama *et al.* (1977) and Okada and Ohrui (1978) have demonstrated the presence of ABH material in fingerprint deposits by using antibodies and the lectin isolated from *U. europeus*. The technique used was essentially an agglutination reaction, and it involves incubating the fingerprint with either anti-A or anti-B serum or with *U. europeus* lectin. If the ABH blood group substance is present in the fingerprint, then antibody or lectin is bound to the print. The prints are then washed to remove excess unbound antibody or lectin and then incubated with an appropriate red cell suspension, producing the agglutination of cells along the fingerprint ridges. The print is revealed after unbound red cells are washed from the substrate. A feasibility study confirmed that ABH blood group substances could be detected in fingerprint deposits with this technique and that the method could occasionally reveal useful fingerprint ridge detail for identification purposes from latent prints laid on adhesive tapes. In light of these findings, the detection of latent fingerprints using antibodies and lectins seemed to warrant further investigation.

Fingerprints were laid on a variety of different porous and nonporous substrates by a number of donors of known ABO blood group type. Commercially available anti-A and anti-B sera and various monoclonal antisera (Table 1) were then used to detect these prints through the use of the agglutination technique. It soon became apparent that, although the method could retrieve quality prints from both fresh and old marks, it had severe limitations. In general, the method could not produce useful prints on porous substrates such as papers. The most suitable substrates were found to be polythene, polyvinyl chloride (PVC), adhesive tapes, metal foils and cellulose acetate. As expected, no prints laid by group O donors could be detected by either anti-A or anti-B serum, and very few prints laid by nonsecretors were revealed. Since group 0 individuals make up 45% of the British population and nonsecretors approximately 20%, this technique is obviously of limited value as a general fingerprint detection system. It is worth emphasizing, however, that the mere fact that fingerprints can be detected demonstrates the very high sensitivity of the method. When one considers that the amount of ABH blood group substance present in a fingerprint is minute compared with the total amount of material present, that prints can be detected at all is remarkable and encourages further experimentation.

Table 1. ANTI-A, ANTI-B AND MONOCLONAL ANTISERA USED FOR DEVELOPING LATENT FINGERPRINTS

Lorne Laboratories:	Anti-A (human) antiserum
	Anti-B (human) antiserum
Cell Tech:	Anti-A (monoclonal) antiserum Code 3D3
	Anti-A (monoclonal) antiserum Code 6D4
	Anti-B (monoclonal) antiserum Code NB1
CNTS:	Anti-A (monoclonal) antiserum Code AB6/96A3
	Anti-A (monoclonal) antiserum Code AB5/49A1
	Anti-A (monoclonal) antiserum Code AB6/104A1O
Chembiomed:	Anti-H (monoclonal) antiserum Lot No. A407/149H

As explained previously, H substance is present in the body fluids of group O, group A and group B secretors. Therefore, it may be possible to visualize latent prints by detecting H substance visualization of latent fingerprints, irrespective of ABO donor group. Lectin obtained from seeds of the plant *U. europeus* binds with H substance, and recently highly potent monoclonal anti-H has been produced by specialized techniques. Accordingly, a range of lectins (Table 2), in addition to *U. europeus* and monoclonal anti-H, has been tested by the agglutination technique for their ability to reveal latent fingerprints. The results showed that both lectins and monoclonal anti-H revealed good fingerprint ridge detail irrespective of ABO blood group on nonporous surfaces such as polythene, PVC and metal foil. On occasion, prints from nonsecretor donors were also revealed. Poor results were obtained on porous surfaces such as writing paper and checks.

Monoclonal anti-H was the most consistently effective in revealing latent fingerprints. Both techniques are being assessed against standard methods,

Table 2. LECTINS USED TO REVEAL LATENT FINGERPRINTS

Lectins Examined	Fingerprints Revealed By
Canavalia ensiformis	X
Codium fragile	X
Lens culinaris	
Maclura pomifera	X
Phaseolus vulgaris (erythroagglutinin)	
Phytolacca americana	
Pisum sativum	X
Solanum tuberosum	X
Tetragonolobus purpured	X
Triticum vulgaris	
Vicia faba	X
Ulex europeus (type I, UEA 1)	X
Wisteria floribunda	

but early indications show they may be particularly useful for heavily plasticized surfaces such as PVC and food wrapping.

A problem, common to both methods, was that red cells were bound not only to the fingerprint ridges but also to the entire surface of the treated articles. This was overcome by adding "Tween" 80 surfactant to the lectin and monoclonal anti-H solutions (Hussain and Pounds 1984).

The detection of fingerprints by methods involving antisera and lectins illustrates the very high sensitivity of the technique. However, if antibodies were available to major constituents of the fingerprint deposit such as triglycerides or wax esters, detection of fingerprints might be considerably increased. Preparing such antibodies is not straightforward because injecting animals with lipid components present in the fingerprint deposit will not produce an immune response. However, to overcome this problem we can combine a particular lipid with a larger molecule that is known to be immunogenic and inject this into an animal. The animal should then produce antibodies against both compounds. We have now prepared conjugates for cholesterol, wax ester and oleic acid. For each compound, sheep have been injected over a period of time, and, to date, an immune response has been obtained for the wax ester.

When antibodies are available, they can be employed for fingerprint detection in antibody-coated latex particles that can be fluorescent, radioactive or colored.

CHEMICAL METHODS

Developing latent fingerprints is one of the most important tasks investigators carry out at scenes of crime. Powders have been particularly successful for hard nonporous surfaces but are ineffective on surfaces such as wallpaper and emulsion painted walls. A reagent based on the well-established iodine development method has been created for use on these problem surfaces.

The use of iodine vapor is one of the oldest methods known for revealing latent fingerprints, and an application of the technique has been described as far back as the last century (Forgeot 1891). Olsen (1978) reviewed methods developed since that time in which iodine has been applied to exhibits. For example, samples may be exposed to the vapor in a cabinet by the use of a fuming pipe, by chemical reactions that liberate iodine or by dusting with ground iodine crystals. In these techniques, a surface is saturated and the excess iodine is allowed to evaporate until optimum contrast is achieved. This method is of limited value because of the rapid fade of the developed marks and because photography is not always successful due to poor contrast. In addition, latent prints more than 3 days old may not be revealed. However, rapid fading and poor contrast may be overcome by fixing the fugitive fingerprint. Early fixation methods have included the application of mercurous chloride and starch solutions, but more recently tetrabase (Trowell 1975) or 7,8-benzoflavone (Mashiko and Ishizaki 1977) have been used. These chemicals produce a dark blue fingerprint.

The use of 7,8-benzoflavone has led researchers to modify the technique by incorporating the development agent, iodine, into the fixation solution. Using this approach, Hague and coworkers (1983) found that fingerprints several weeks old could be revealed on various porous surfaces such as paper and cardboard. Compared with standard iodine fuming, this reagent showed improved sensitivity.

Since this method seemed to overcome many of the problems associated with the use of iodine vapor, we decided to investigate its potential as a reagent at the scenes of crimes. A simple two-solution system was devised to avoid problems of weighing out iodine crystals at crime scenes. One is a 10% solution of 7,8-benzoflavone dissolved in dichloromethane, and the other is a 0.1% solution of iodine in cyclohexane. Both solutions are prepared in the laboratory, and the working reagent is prepared at the crime scene by simply mixing 2 ml of the benzoflavone solution with 100 ml of the iodine solution. After the reagent stands for 10 minutes, it is applied by brushing over the surface under investigation. Fingerprints are revealed as dark blue images when the solvent evaporates, normally in a minute or two. The technique is particularly effective for revealing fresh marks, that is, under a week old. With older marks, the efficacy of development decreases. When this reagent is used, the surface under investigation often acquires a background coloration, but this may be removed from emulsion painted walls and wallpaper with an antistatic foam cleanser.

Fingerprints have been revealed at scenes of crime on emulsion painted walls and wallpaper, two areas where we have previously had considerable difficulty. It is on these surfaces that the iodine formulation has been particularly successful. The reagent is ineffective on vinyl wallpaper.

To date, 61 scenes of serious crime have been examined with iodine solution. These include 28 murders, 11 rapes, 16 burglaries (including aggravated burglaries) and 6 other offenses. The number of fingerprints recorded were 35 from a total of 20 scenes (that is, a 33% success for scenes examined).

Crimes for which the reagent at scenes of crime include:

1. A rape in which fingerprints were revealed on an emulsion painted wall above a bed where the offense took place. Although other fingerprints were found about the house with aluminum powder, the position of the fingerprints revealed by iodine solution was highly significant.

2. An arson attack on a school that was substantially damaged. A fingerprint was revealed in the headmaster's study above a door, on white emulsion paint, just below where part of the ceiling had been removed by intruders to allow access to the rest of the school.

The reagent can also be used successfully on documents in the laboratory; however for this use, the iodine concentration is decreased to 0.025%. The mixed solution is allowed to stand for 10 minutes and then filtered. For the best contrast, the paper is immersed in this reagent for no longer than a second or two. The iodine reagent does not interfere with subsequent use of standard techniques (such as ninhydrin and physical developer) used for porous surfaces.

An iodine formulation containing a fixation solution is useful for revealing fingerprints on porous surfaces, particularly at scenes of crime on emulsion painted walls and wallpaper. Until now, there has been no really effective reagent for these surfaces. It is also a useful adjunct to normal laboratory methods of revealing fingerprints on documents. Details of this method are at present being drafted for inclusion in the Home Office's *Manual of Fingerprint Development Techniques*.

We are currently conducting research on the preparation of novel reagents that give fluorescent species with components of latent fingerprints. Such methods involving fluorescence are potentially very sensitive, especially as we can now illuminate with high intensity light generated by lasers and xenon arc lamps. Cyclohexane vapor is harmful and highly inflammable. Due precautions must be taken to ensure that cyclohexane vapor is not inhaled or ignited.

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DISCUSSION

Jackson: Have you tried this iodine reagent on cloth and if so, what results have you obtained?

Pounds: The iodine reagent would be of no use on cloth.

Jackson: Have you had any results using the antibodies on cloth?

Pounds: The results from using the antibody technique on cloth were disappointing. It is very difficult to detect latent prints on cloth.

Lee: In addition to human blood, other body secretions have antigenic materials that have binding activity or give agglutination. How do you handle this nonspecific binding?

Pounds: An 80% solution of "Tween" surfactant is used to get rid of this nonspecific binding to the surface of the substrates.

Lee: Also, some of those antigenic materials are water soluble and will wash away. Which one would you choose first when you can do only one grouping at a time, anti-A, anti-B, anti-H or lectin?

Pounds: Using anti-A and anti-B antibodies is not a viable technique for developing fingerprints because they are blood group specific and before the technique can be used, the blood group of the donor must be known. Anti-H and lectin are not blood group specific and can be used to develop fingerprints irrespective of ABO blood group.

Lee: If you can determine an individual's blood group by your technique, it would be helpful for the investigation.

Pounds: Yes, if you were interested in knowing what the blood group of a fingerprint was, you could use the anti-A and anti-B technique. In fact, the Japanese originally did their research not to develop fingerprints but to determine the blood group of a fingerprint.

Saviers: I have read about use of 7,8-benzoflavone solution in conjunction with iodine and that it is very toxic. Could you comment on toxicity or health hazards of this and the other solutions you have discussed?

Pounds: We use a 10% solution of 7,8-benzoflavone dissolved in dichloromethane. We have tried to decrease the amount of dichloromethane in the reagent because dichloromethane appears on banned chemical lists occasionally. We also use a 0.1% solution of iodine and cyclohexane which is prepared in a laboratory in a fume cupboard. Caution must be taken at crime scenes that vapors from this solution are not inhaled. One hundred milliliters of 0.1% solution of iodine and cyclohexane (which is flammable), which would cover approximately 1 square meter, creates a great deal of vapor. Vapor buildup at crime scenes is a potential hazard.

Mayberry: Why would you use the ninhydrin process before the physical development of a latent print and risk destroying the iodine print? Also, you mentioned that your iodine solution does not reveal a print that is older than 3 days or 2 weeks. The Israelis have successfully developed 110-day-old prints. Did you do any dating or test prints on surfaces to arrive at that time period?

Pounds: For paper, it may be inevitable that the next technique you use is going to destroy the fingerprint you previously developed. After every stage of development, the fingerprint must be photographed. There appears to be no way of avoiding this problem.

I believe the Israeli study involved an iodine steam technique used to detect fingerprints over 100 days old. In our lab, we can detect prints that are 2-3 weeks old. Humidity plays a role in the quality of the prints that are developed. Generally, the sooner you get to the crime scene, the better the quality of the fingerprints that are detected.

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METHODS OF LATENT PRINT DEVELOPMENT

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Fingerprints are one of the most valuable types of physical evidence in the field of forensic science. In general, three types of fingerprint evidence may be found at a crime scene: visible prints, impression prints and latent prints. This paper is concerned with latent prints, which, as the name suggests, are ordinarily less visible and thus require some means of development and enhancement for their visualization. Researchers have continually explored new and improved techniques for the development and recovery of latent prints. In recent years, new dimensions in latent print technology have been opened, revolutionizing the field of fingerprint identification. New techniques have been developed not only for latent fingerprint detection but also for latent fingerprint comparison. These developments have significantly improved the efficiency of criminal investigation and personal identification. The following are brief descriptions of some of the methods currently in use for developing and enhancing latent fingerprints.

In the past, powder dusting, ninhydrin spraying, iodine fuming and silver nitrate soaking have been the four most commonly used techniques for latent print detection (Olsen 1978; FBI 1977; Hazen 1986; DeForest *et al.* 1983). These conventional techniques are quite effective in the recovery of latent prints under ordinary circumstances. However, latent prints are often deposited on wet surfaces, multicolored backgrounds, surfaces contaminated with blood or other body fluids, objects with unusual shapes or contours, waxed surfaces, fabrics or untreated wood, varnished surfaces, human skin, cardboard boxes, porous and nonabsorbent surfaces and so on. Under these conditions, traditional methods of latent print detection are ineffective. At times, application of the wrong procedures may even destroy potential latent print evidence.

Over the years, scientists have continually sought new or improved methods to visualize latent fingerprints. Research efforts have focused on developing techniques that may be successfully applied to unique and difficult surfaces and that offer increased sensitivity over conventional techniques. These new procedures include new chemical reagents for latent print visualization, instrumental methods for developing or enhancing latent prints and systematic approaches involving combinations of methods for latent fingerprint development. The scope of this paper will be limited to a discussion of chemical methods and systematic approaches for the enhancement and visualization of latent fingerprints.

Powder Dusting

Powder dusting is the simplest and most commonly used procedure for latent fingerprint development. It is a physical enhancement method that relies on the adherence of fingerprint powders to the moisture and oily components of fingerprint residues. Application of powder to latent prints by brushing is a simple technique but also has its disadvantages. Contact of the brush with the fingerprint ridges has an inevitably destructive effect. There are, in general, four classes of fingerprint powders: regular, luminescent, metallic and thermoplastic.

Regular Fingerprint Powders

Regular fingerprint powders consist of both a resinous polymer for adhesion and a colorant for contrast. Hundreds of fingerprint powder formulas have been developed over the years. A detailed discussion of fingerprint powder formulas and their preparations can be found in the first edition of *Scott's Fingerprint Mechanics* (Olsen 1978).

Many commercial fingerprint powders contain inorganic chemicals such as lead, mercury, cadmium, copper, silicon, titanium and bismuth. Many of these metals are toxic, and long-term exposure to them may present a health hazard. The use of organic fingerprint powders for latent print dusting was suggested by Kerr *et al.* (1983a, 1983b). They reported that corn starch-based fingerprint powders have yielded excellent results in developing latent prints on nonporous surfaces.

Luminescent (Fluorescent and Phosphorescent) Fingerprint Powders

Many types of powders contain natural or synthetic compounds that fluoresce or phosphoresce upon exposure to ultraviolet light. These types of fingerprint powders are useful for visualizing latent prints deposited on multicolored surfaces that would otherwise present a contrast problem if developed with regular fingerprint powder. Luminescent fingerprint powders have rarely been used in the field. However, with the advent of laser detection, dusting the latent prints with fluorescent or phosphorescent powders was found to greatly enhance laser examination.

Acridine yellow, acridine orange, Coumarin 6, Crystal Violet, *p,p'*-dichlorodiphenylmethyl carbinol, 3,3'-diethyloxadicarbocyanine iodide, 3,3'-diethylthiatricarbocyanine iodide, Merocyanine 540, Nile Blue perchlorate, Rhodamine B, Rhodamine 6G, phenothiazine and many other luminescent dyes and pigments have been reported useful as luminescent dusting powders for laser examination (Menzel and Duff 1979; Menzel 1979, 1980; Menzel and Fox 1980; Thornton 1979).

Metallic (Magnetic, Fine Lead and Metal Evaporation) Fingerprint Powders

Magnetic powders are fine ferromagnetic powders that are applied with a magnetic applicator (MacDonnell 1961). They are particularly successful in recovering latent prints from certain surfaces such as leather, plastics, walls and human skin. Fine lead powder has been used for latent print detection with X-ray electronography and autoelectronography (Graham 1966). Cadmium, zinc and gold/zinc metals have also been used by vacuum metal deposition techniques for latent print detection (Theys *et al.* 1968; Kent *et al.* 1976).

Thermoplastic Fingerprint Powders

Thermoplastic powder dusting techniques involve powders such as Xerox toners or dry inks (Micik 1974; Rhodes 1940). Latent fingerprints developed with such materials become fused to the surface upon exposure to heat.

CHEMICAL FUMING

Iodine Fuming

The iodine fuming technique has been used for latent print development for almost five decades. Several variations of the fuming procedure have been proposed over the years (Olsen 1978; Rhodes 1940; Bridges 1963; Moenssens 1971). The mechanism of the iodine fuming reaction was initially thought to involve the reversible addition of iodine to the double bonds of the unsaturated fatty acids in fingerprint residue by the process of halogenation. More recent research suggests that the mechanism of interaction involves physical absorption rather than a chemical reaction (Almog *et al.* 1979). Although the iodine fuming technique is simple to use, it suffers from several disadvantages: the vapors are toxic and corrosive, iodine-developed latent fingerprint images fade away rapidly upon standing in air and old latent prints are difficult to develop. A method that controls the addition of water vapor to the iodine fumes seems to be the solution to the aging latent print problem (Almog *et al.* 1979).

Methods do exist for fixing iodine-developed fingerprints. These methods include starch spray (Larsen 1962), silver plate transfer (Foley 1974), tetrabase solution (Trowell 1975) and benzoflavone reagents (Mashito and Makoto 1977; Hague *et al.* 1983).

Cyanoacrylate Fuming

In 1982, latent fingerprint examiners working at the U. S. Army Criminal Investigation Laboratory in Japan and in the Bureau of Alcohol, Tobacco and Firearms Laboratory introduced a novel procedure to this country. This procedure employs alkyl-2-cyanoacrylate ester (Super Glue) as a means of developing latent prints. The method was first devised by the Criminal Identification Division of the Japanese National Police Agency in 1978. Since its introduction into the United States, the method has received much attention from researchers who have evaluated it and attempted to improve its sensitivity and extend its range of applications (Kendall 1982; Bensonsen 1983; Olenki 1983; Kendall and Rehn 1983). The principles underlying the cyanoacrylate fuming method and its reaction have also been discussed (Lee and Gaensslen 1984).

Cyanoacrylate fuming has been successfully used to develop latent prints on surfaces as diverse as plastics, electric tape, garbage bags, styrofoam, carbon paper, aluminum foil, finished and unfinished wood, rubber, copper and other metals, cellophane, rubber bands and smooth rocks. It is also an excellent method for processing vehicles and limited areas of enclosed space at crime scenes. In addition, cyanoacrylate-developed latent prints may be further enhanced by staining with either Gentian Violet or Coumarin 540 laser dye (Kobus *et al.* 1983a), by dusting with fluorescent powder, and in combination with the ninhydrin/zinc chloride method together with laser examination (Menzel *et al.* 1983).

Fluorescent Chemical Fuming

Some of the fluorescent reagents have low sublimation temperatures, that is, these chemicals will (like iodine) vaporize appreciably at temperatures below their melting point. The fluorescent reagent vapors can thus be used for developing and visualizing latent fingerprints in a manner similar to that of iodine fuming. Almog and Gabay (1980) tested eight fluorescent chemicals (anthracene, anthranilic acid, perylene, Rhodamine B, Rhodamine 6G, 7-diethylamino-4-methylcoumarin, triphenylcarbinol and antimony trichloride) that sublime readily. They found that all eight chemicals produced clear impressions of the latent prints under ultraviolet light. The best results for fresh fingerprints were obtained with anthranilic acid. For older prints, anthracene produced somewhat better results. The results with Rhodamine B and Rhodamine 6G were less satisfactory.

Other fluorescent chemicals such as 8-hydroxyquinoline and dimethoxycoumarin have also been reported as useful fuming reagents for latent fingerprint detection (Forensic Science Institute, People's Republic of China, personal communication). 8-Hydroxyquinoline has been used as a field fuming reagent in searching for latent prints at crime scenes.

Other Chemical Fuming Techniques

Fumes of many other materials, such as camphor, pine tar, nitrocellulose, magnesium and titanium tetrachloride, can be generated by heating such materials. These fumes have been used to detect latent fingerprints (Olsen 1978; Corr 1956; Vandiver 1973). However, the fuming mechanism of these techniques is different than that of iodine fuming, and most of these fuming techniques have only historical interest.

Radioactive sulfur dioxide gas fuming has also been reported as a useful technique to detect latent fingerprints on a variety of surfaces including paper, adhesive tapes and fine fabrics (Spedding 1971). After an exhibit has been exposed to radioactive sulfur[^{35}S] dioxide, the presence of fingerprints may be detected and recorded by autoradiography. Nitric acid fumes have been used to detect and visualize latent fingerprints on brass casings and metal objects under special conditions (Given 1976).

Ninhydrin and Chemical Alternatives

As early as 1913, Ruhemann in England and Abderhalden and Schmidt in Germany reported that *alpha*-amino acids, polypeptides and proteins formed color products upon reaction with ninhydrin. In 1954, two Swedish scientists, Oden and von Hofsten, advocated the use of ninhydrin for developing latent fingerprints. In 1955, Oden patented the process as a latent fingerprint technique (Oden and von Hofsten 1954). Various concentrations of the ninhydrin solution ranging from 0.2% to 1.5% have been suggested (Moenssens 1971; Speaks 1964; Shulenberger 1963; Mooney 1966). Various solvents, such as acetone, methanol, ethanol, ethyl ether, ethylene glycol, petroleum ether, naphtha and Freon 113 (trichlorotrifluoroethane) (Mooney *et al.* 1977) and combinations of solvents have been used (Mooney 1973; Crown 1969; Linde 1975; Mooney *et al.* 1977; Morris and Goode 1974). Although controversy still exists over the optimum concentration and the ideal solvent for the ninhydrin solution, the best results may ordinarily be obtained with concentrations ranging from 0.6% to 1.0% in Freon 113. Selecting the appropriate concentration and solvent to use for latent fingerprint detection depends upon the type of material being processed and if there is any writing on the material.

Ninhydrin solutions may be applied by spraying, swabbing or dipping. Postprocessing treatment by application of heat can be used to accelerate the reaction. Various temperatures and means (such as ovens, irons, steam irons, hair dryers or microwaves) have been suggested for postprocessing heating. Optimum results have been obtained when ninhydrin treated documents were heated at 26.6° C (80° F) and 80% relative humidity (Olsen 1978).

Ninhydrin has traditionally been the most common reagent employed for processing latent prints on paper. The ninhydrin method, however, has several limitations, such as the sensitivity of ninhydrin, background colors of the matrix surface, background coloration after ninhydrin treatment and certain nonreactive surface materials. Numerous chemicals have been reported as potential substitutes for ninhydrin in the detection of latent fingerprints. These chemicals can be divided into two categories: new reagents for amino acid detection and ninhydrin analogs.

In recent years, fluorescamine (Ohki 1976), *o*-phthalaldehyde (Mayer *et al.* 1978) and NBD chloride (7-chloro-4-nitrobenzo-2-oxa-1,3-diazole) (Stoilovic *et al.* 1984), NBD fluoride (7-fluoro-4-nitrobenzo-2-oxa-1,3-diazole) (Forensic Science Laboratory, Taiwan

Criminal Investigation Bureau, personal communication), 4-dimethylaminocinnamaldehyde (Sasson and Almog 1978) and dansyl chloride (Lee and Attard 1979a) have been suggested as substitute reagents for ninhydrin. These reagents react with amino acids in the fingerprint residues and produce fluorescent products, thus rendering the latent print pattern visible. Studies have shown that these reagents not only have a greater sensitivity than ninhydrin but also work well for the detection of latent fingerprints on multicolored materials (Mayer *et al.* 1978; Stoilovic *et al.* 1984; Forensic Science Laboratory, Taiwan Criminal Investigation Bureau, personal communication; Sasson and Almog 1978; Lee and Attard 1979a, 1979b). An additional advantage of the treatment of latent prints with fluorescamine, *o*-phthalaldehyde and NBD chloride is that they can subsequently be further enhanced with laser light, xenon arc light or other light sources (Menzel and Duff 1979; Menzel 1979; Warrener *et al.* 1983). The principal disadvantages of these fluorogenic reagents are that they are not very stable in solution and sometimes produce interfering background luminescence.

Almog *et al.* (1987) have synthesized a new series of fluorogenic reagents. Five nitrobenzofurazanyl ethers, 4-methoxy-7-nitrobenzofurazan, 4-ethoxy-7-nitrobenzofurazan, 4-(2-hydroxy)-7-nitrobenzofurazan, 4-(methoxyethoxy)-7-nitrobenzofurazan and 4-phenoxy-7-nitrobenzofurazan have been prepared and examined as potential reagents to detect latent fingerprints on paper. All five reagents developed latent prints with a high sensitivity similar to that of the parent compound. These reagents can also be used in vapor phase development. The study indicates that vapor phase development techniques have advantages, such as avoiding the use of solvents and reducing the background fluorescence and discoloration.

Almog *et al.* (1982) synthesized several ninhydrin analogs: benzo[*e*]ninhydrin (2,2-dihydroxybenz[*e*]-indane-1,3-dione), benzo[*f*]ninhydrin (2,2-dihydroxybenz[*f*]-indane-1,3-dione) and 2,2-dihydroxy-5-chloro-6-methoxyindane-1,3-dione. These ninhydrin analogs were tested for their applicability to latent print detection. It was found that these ninhydrin analogs developed latent prints with a sensitivity similar to that of ninhydrin and that the quality of development was independent of the age of the latent fingerprints.

In 1981, German (1981) reported using laser examination of ninhydrin-treated latent prints. Kobus *et al.* (1983b) reported a simple postninhydrin treatment using zinc chloride and xenon arc light to yield luminescent latent print images. They found that this method improved visualization of latent prints on paper where ninhydrin alone gave poor results. Herod and Menzel (1982a) found that latent prints that did not develop well with ninhydrin could be brought out under dye laser light. Subsequently, they suggested two modified treatments for using ninhydrin to develop latent fingerprints (Herod and Menzel 1982b; Menzel *et al.* 1984): pretreatment with trypsin and posttreatment with metal salts.

In the first modification, latent prints were treated either by spraying with a methanol solution containing both ninhydrin and trypsin or by spraying first with a water solution of trypsin and then with ninhydrin under room light. The samples sprayed first with trypsin and then with ninhydrin showed a somewhat better development than those treated either by the combined solution or ninhydrin alone. Results under dye laser examination essentially showed no dramatic improvement. In the second modification, ninhydrin-developed latent prints were sprayed with solutions of nickel nitrate, zinc chloride and cadmium nitrate.

These posttreated latent prints were subjected to further argon laser examination. A combination of the ninhydrin-zinc chloride procedure and argon laser has yielded the most promising results by far.

Stoilovic *et al.* (1986) reported a method to improve the enhancement of ninhydrin-developed fingerprints by cadmium complexation using low temperature photoluminescence technique. Everse and Menzel (1986) further reported that there was pronounced enhancement of detectability of latent prints by combinations of pretreatment with trypsin or pronase and posttreatment with zinc chloride followed by argon laser examination.

Recently, researchers in Australia have found that metal complexes formed by using Group IIb transition metals show favorable luminescence properties at low temperatures (77° K) and that considerable enhancement of ninhydrin-treated fingerprints can be achieved (Lennard *et al.* 1987). The structure of the metal complexes formed between Ruhemann's purple and group IIb metal salts was also studied.

Enhancement Procedures for Latent Fingerprints

Occasionally, latent prints are deposited on unique surfaces or under unique conditions. Special techniques are often required to successfully develop such latent prints (Thomas 1975; Jones 1983; Goode and Morris 1983). The following are several special types of enhancement techniques for visualizing fingerprints under unique conditions.

Bloody fingerprints can often be found deposited on weapons, victims' bodies and objects at crime scenes. In many cases, these bloody prints require enhancement to increase contrast and make them more readable. In the past, reagents prepared using benzidine were the most popular for bloody print enhancement (Conley and Andes 1959). However, benzidine was found to be carcinogenic and thus extremely hazardous. Since 1974, the use of benzidine has been banned for all practical purposes by the U. S. Occupational Safety and Health Administration (Lee 1984a). A number of safer chemicals can be substituted for benzidine in the enhancement reagent, including tetramethylbenzidine, phenolphthalein and leucomalachite green (Lee 1984b). In addition, many general protein stains such as Amido Black (Jones and Pounds 1982), ninhydrin, Crystal Violet and Coomassie Blue have been reported to work very successfully in the enhancement of bloody fingerprints.

In 1981, a method was published for the visualization of latent fingerprints on the sticky surfaces of adhesive tapes (Arima 1981). Crystal Violet or Victoria Blue dye solutions have been used to enhance the fingerprints found on sticky sides of adhesive Kraft paper tapes and cellophane tapes, so long as these tapes were not of a dark color. For dark-colored tapes including electric tape and black tape, prints can be visualized by treatment with Mikephor BS, a fluorescent brightener and subsequently viewed under ultraviolet light.

Over the years, various procedures have been suggested to visualize and recover latent fingerprints on human skin. Methods such as dusting with magnetic powder (Reichardi *et al.* 1978), Kromekote card lifting (Graham and Gray 1966), electronography (Graham and Gray 1966), iodine-silver plate transfer (Adcock 1977; Gray 1978; Gelinas 1977), laser detection by inherent luminescence (Dalrymple 1979), dusting with fluorescent powder or evaporative staining with fluorescent dyes, followed by laser examination (Menzel 1982) and Super Glue fuming have all been investigated.

The iodine-silver plate transfer method is considered to be a practical technique for recovery of latent print on skin (FBI 1976). In this method, the skin area with the suspected latent print is first fumed with an iodine fuming gun. Once the latent print image is developed, the image is transferred onto a silver plate. The transferred image is then exposed to strong light and subjected to evaluation. Other methods, such as cyanoacrylate fuming, and dusting with Mars Red fluorescent powder or staining with Rhodamine 6G, followed by laser examination have also shown a certain degree of success. In general, the areas with smooth skin and free from hairs on a fresh body are more likely to yield identifiable latent prints. However, there has yet to be a single, effective procedure developed.

Stabilized physical developer (SPD) has been found to offer considerable potential for detection of latent prints on surfaces that have been exposed to water (Morris 1975). The SPD reagent consists of a solution containing ferrous ammonium sulfate and ferric nitrate, silver nitrate, citric acid buffer and two surfactants, laurylamine acetate and Lissapol. The development process is carried out under tungsten light, which reduces random background deposition over the entire surface (Pounds and Jones 1981).

Small particle reagent was recently reported to be superior to SPD in terms of reagent stability and simplicity of procedure. The SPD reagent consists of a suspension of fine molybdenum disulfide particles in detergent solution. The particles adhere to the fatty constituents of latent print residues and form a gray molybdenum disulfide deposit. The deposited particles may be lifted for photographic documentation (Goode and Morris 1983).

INSTRUMENTAL METHODS FOR ENHANCEMENT OF LATENT FINGERPRINTS

As early as 1937, scientists suggested that alternative light sources (other than room light) could be used for the enhancement and visualization of latent fingerprints. High intensity lamps, ultraviolet light sources, lasers and xenon arc lamps have been utilized in the development of latent prints (Menzel and Duff 1979; Menzel 1979, 1980; Menzel and Fox 1980; Thornton 1979; Lee and Attard 1979a, 1979b; Dalrymple *et al.* 1977; Duff and Menzel 1978). These light sources have produced better latent print images than does regular room light.

The most recent important development in the latent fingerprint field is the use of lasers for latent print detection. Dalrymple *et al.* (1977) first reported the technique of laser detection of latent fingerprints by their inherent luminescence. Subsequently, a number of alternative procedures were suggested. Various fluorescent powders such as Mars Red, high intensity fingerprint powder, Red Lake C and Naphthol Red B (2′-naphtholazo-1-bromo-2-naphthol-1′-sulfonate) have been employed to enhance the detection sensitivity of the laser procedure.

Other fluorogenic dyes such as Coumarin 6, Rhodamine 6G, Rhodamine B, Nile Blue A perchlorate and 3,3′-diethylthiatricarbocyamine iodide have also been used to enhance laser light detection of latent prints (Menzel and Duff 1979; Menzel 1979, 1980; Menzel and Fox 1980; Thornton 1979). In addition, pretreatment of latent evidence with chemicals such as *p*-dimethylaminocinnamaldehyde, fluorescamine and *o*-phthalaldehyde has been used with laser illumination. These chemicals react with components in fingerprint residues to form luminescent reaction products. Other types of lasers such as dye lasers and copper vapor lasers have also been used for latent print detection.

In 1968, Theys *et al.* reported that it is possible to detect the presence of fat films on some surfaces by the selective condensation of metals under vacuum. Since that time, a range of metals has been investigated as possible reagents for the delineation of latent fingerprints. It was reported that a combination of gold followed by cadmium treatment produced excellent results (Kent *et al.* 1976). Since cadmium is toxic, zinc and the combination of gold and zinc were suggested (Kent 1982).

Nolan *et al.* (1984) reported that latent prints developed by small particle reagents are easily imaged by the back-scattered electron image mode of the scanning electron microscope (SEM). Low SEM magnifications have permitted the recording of single complete fingerprints on checks, newsprint and other surfaces. In addition, X-ray radiography and infrared microscopy have also been suggested to detect latent fingerprints (Lail 1975; Hussain and Pounds 1984).

The blood group substances of a latent print can be detected by serological methods. Hussain and Pounds (1984) reported that a modified mixed agglutination reaction could detect latent prints left on various substrates.

SYSTEMATIC APPROACHES TO LATENT PRINT PROCESSING

A review of the literature showed that there are more than a hundred reported techniques for development and visualization of latent fingerprints. Each method has its advantages and performed well under certain conditions. The application of the correct technique for a particular surface or given set of conditions is extremely important. Using a wrong or inappropriate procedure might actually destroy the latent print evidence and obviate any chance for visualization by another technique.

Several investigators have suggested different logical schemes for the sequential development of latent prints (Home Office Research and Development Branch 1986; Lee and Gaensslen 1985a, 1985b). Figures 1 through 6 represent some of the systematic approaches currently used at the Connecticut State Police Forensic Science Laboratory. Figure 1 represents a general approach for detecting latent fingerprints. Figure 2 is a scheme for enhancing bloody fingerprints. Figure 3 shows the approach for detecting latent fingerprints on nonporous surfaces. Figure 4 is the procedure used to visualize latent fingerprints on greasy or waxed surfaces. Figure 5 shows the systematic approach for detecting latent fingerprints on adhesive tape. Figure 6 is the procedural scheme for developing latent fingerprints on paper products. These logical schemes are primarily suggestions to examiners on the sequences to use for applying a series of techniques to process latent prints. They are not to be regarded as complete or perfect. The systematic

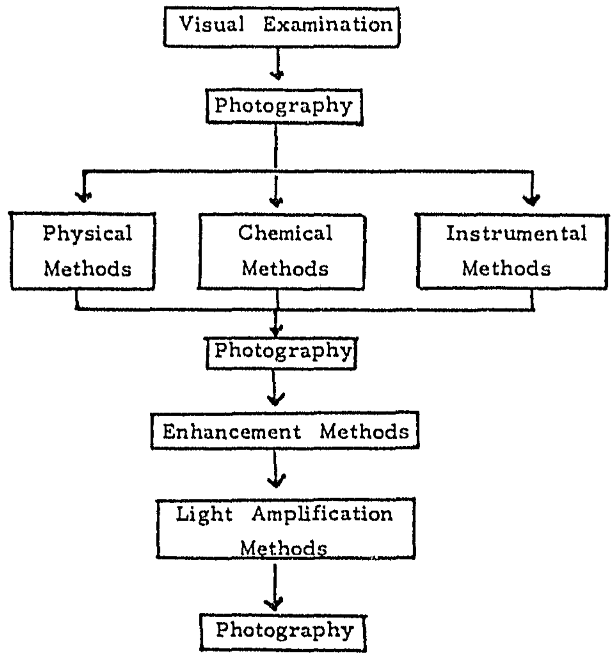

Figure 1. General approaches for the detection of latent fingerprints.

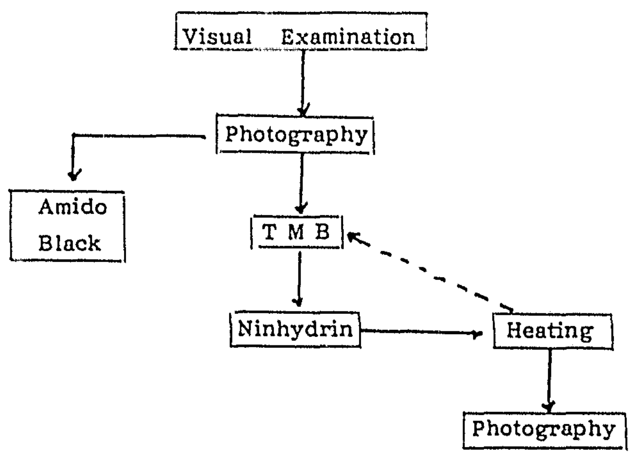

Figure 2. Fingerprints in blood.

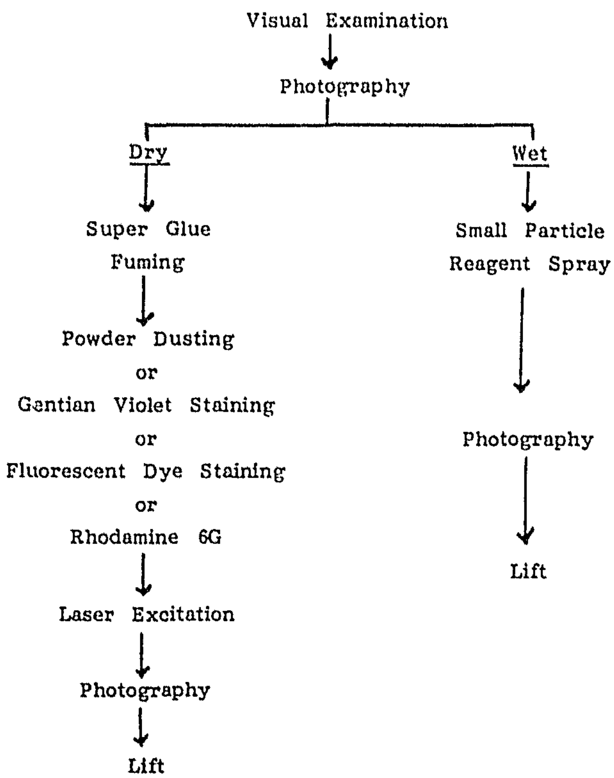

Figure 3. Nonporous surfaces.

approaches should be continuously modified and refined as new procedures, chemical reagents and approaches are developed.

In summary, revolutionary changes have occurred in the fingerprint field during the last 10 years. With the newly developed technologies and techniques, such as latent print enhancement procedures, automated fingerprint identification systems and fingerprint image transmission, a fingerprint examiner can no longer depend on powder and brushes to carry out his or her job. Knowledge of chemistry, instrumentation and computers has become a necessity. At the same time, fingerprint examiners can no longer be regarded as second class citizens in the forensic sciences field. They have regained the leadership role in the criminal investigation.

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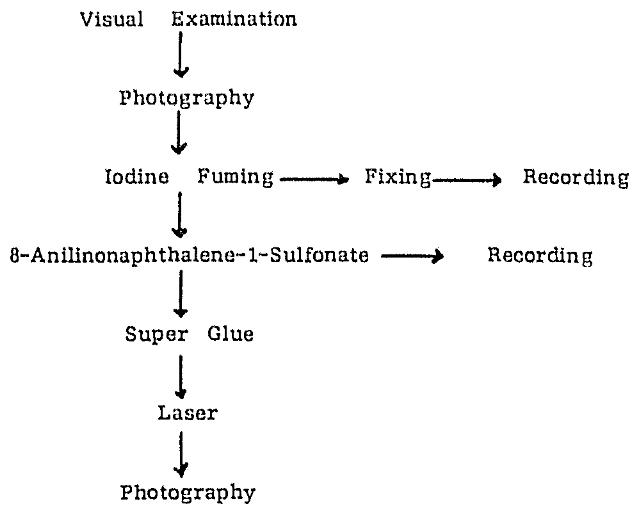

Figure 4. Greasy or waxed surfaces.

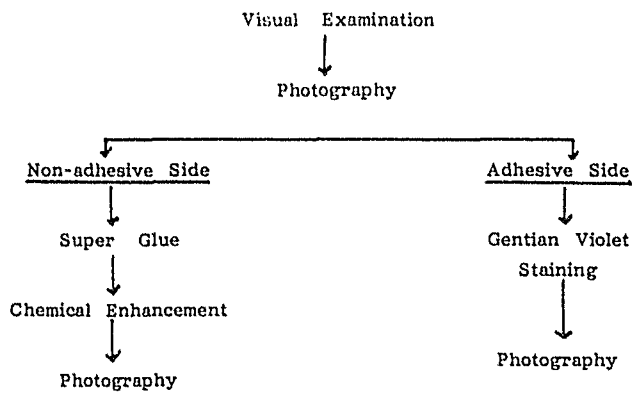

Figure 5. Systematic approach for latent prints on adhesive tape.

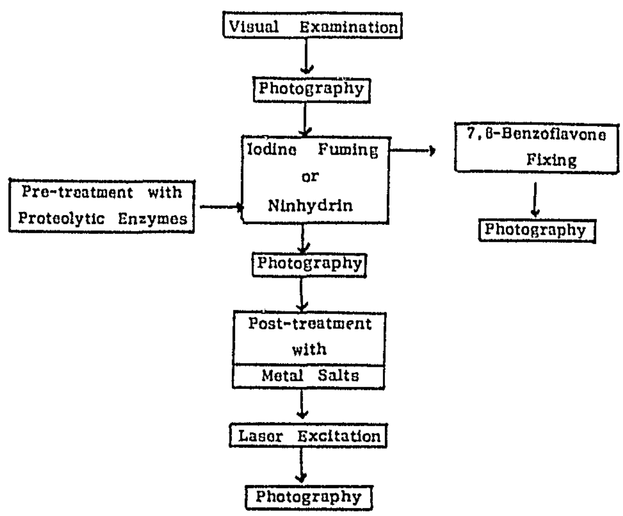

Figure 6. Paper products.

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DISCUSSION

Jackson: What was the power of the laser that was used for the ninhydrin prints that were treated with zinc chloride and then exposed to laser light as shown in your slide?

Lee: We used a Spectra-Physics 18 W laser.

113 510

LASER FINGERPRINT DETECTION AND DEVELOPMENT

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The laser latent fingerprint development method is now about 11 years old (Dalrymple *et al.* 1977). Much has happened in the areas of research and development since its inception, particularly for routine research and development since its inception, particularly for routine procedures used for evidence examination. Much work remains to be done on nonroutine methods used for special situations.

Latent fingerprint examiners normally do not have a technical background or become involved in research and development. Until recently, the same was true of many areas of criminalistics (such as fiber analysis and document examination). In the United Kingdom, the Forensic Science Service and the Central Research Establishment, both branches of the Home Office, have conducted criminalistics research and development for a number of years. In the United States, a similar effort began with the establishment in 1981 of the Forensic Science Research and Training Center at the Federal Bureau of Investigation (FBI) Academy. No doubt because of budget and personnel limitations, the fingerprint field is not an area of major emphasis in the FBI Center's research strategy. Several procedures for fingerprint detection on special surfaces have been developed in the United Kingdom, including autoradiography and metal deposition *in vacuo*. These procedures are not routinely used in law enforcement at the present time.

Researchers outside the criminalistics field have made significant contributions to fingerprint development methods, such as the ninhydrin procedure, first reported by Swedish biochemists Oden and von Hofsten (1954). The laser method for fingerprint development is also nonforensic in origin. Unfortunately, because of the poor support of forensic physical science research by the Federal granting agencies (Sensabaugh 1986), research-oriented establishments such as universities or national laboratories in the United States are not inclined to conduct such research. This has severely hampered the development of criminalistics technology. In the area of latent fingerprint development, research support in the United States has recently fluctuated between no funding and $50,000 per year. One finds no more than 10 original research articles per year worldwide on fingerprints in the three major forensic science journals (Journal of Forensic Science, Journal of the Forensic Science Society and Forensic Science International). The United States does not have a single forensic science educational college or university curriculum with substantial technologic content. In spite of this gloomy scenario, the laser latent fingerprint development method has, since its inception in 1976, made good progress. It has benefited from attention by investigators from a number of countries. At the time of this writing, close to 100 law enforcement agencies in the United States possess lasers for fingerprint work. This number is still small compared with the 17,000 law enforcement agencies in the United States and the effectiveness and compatibility of laser procedures (namely, detection by inherent fingerprint fluorescence [Dalrymple *et al.* 1977], ninhydrin/zinc chloride treatment [Herod and Menzel 1982], and cyanoacrylate ester/dye staining [Menzel *et al.* 1983]) with conventional procedures. The cost of fingerprint lasers is low compared with some of the instrumentation, such as scanning electron microscopes or high pressure liquid chromatography systems, found in many crime laboratories.

THE ESSENCE OF LASER FINGERPRINT DEVELOPMENT

Detection of latent fingerprints by laser-excited luminescence is applicable to all types of surfaces and fingerprints of any age. It is thus a general method rather than a procedure, such as dusting or the ninhydrin treatment, specialized to certain situations. Moreover, the laser method relies on a different physical principle than the conventional procedures. Imagine, for example, a latent print on white paper developed with black powder. Ambient light is diffusely reflected from the paper surrounding the fingerprint and ridges but not from the ridges themselves because the black powder absorbs the incident light. The light reflected from the ridge surroundings reaches the eye or camera to reveal the print. Absorption/reflectance constitutes the essence of conventional fingerprint development. In the case of a faintly developed print, when very little powder adheres, the fingerprint ridge sites reflect incident light only very slightly less than the surrounding paper. Thus, the detection of the print amounts to detection of a small difference between two large signals, and this is generally a poor detection technique.

Now consider the opposite situation, in which the eye or camera sees only light coming from the ridges of the fingerprint, not from the surroundings of the latent print. In this situation, detection of a weakly developed print means detection of a small signal. This is far easier to accomplish than the detection of a small difference between two large signals. Human observation supports this conclusion. One easily sees stars at night but not in daylight. Laser-induced fluorescence can be used to solve the problem. With this method, the laser light scattered from the examined surface is blocked by a filter that transmits the fingerprint fluorescence, light only from the fingerprint ridges reaches the eye or photographic camera. Thus, fluorescence (or more generally photoluminescence) provides intrinsically greater sensitivity than absorption/reflectance, as is also the case in many fluorescence spectroscopic techniques in the fields of physics, chemistry and biology.

Latent print examiners often mistakenly regard laser latent fingerprint detection as a supplement to conventional procedures. Because of its inherently superior sensitivity, the laser method should replace conventional approaches whenever possible. For example, applying black powder to evidence can occasionally make it inaccessible to subsequent laser examination. Fortunately, ninhydrin and cyanoacrylate fuming are compatible with subsequent application of the laser method, so there is no need to decide whether to use the conventional procedures or the laser method. At the same time, there are practical limitations to the use of laser methods.

First, the method must be simple to use. Commercial lasers used for fingerprint work are easy to operate, and the observation of fingerprint luminescence is straightforward. The illuminating laser beam is dispersed to cover an area typically 10-20 cm in diameter which is viewed through a filter that blocks reflected laser light but transmits fingerprint fluorescence. Bandpass filters are at times also used to reduce background fluorescence. Once a fingerprint is observed, it is photographed through the same filter. The examination is conducted in a darkened room. Laser beam dispersion is accomplished by a divergent lens or, very conveniently for examination of cumbersome items, by passing the laser light through a flexible fiber optic cable. The original and still most widely used laser for fingerprint detection is the argon laser. More recently, powerful copper-vapor, portable frequency-doubled neodymium:yttrium aluminum garnet (Nd:YAG) and portable argon lasers have started to find use as well.

Fluorescence detection of latent fingerprints at liquid nitrogen temperatures has been investigated (Kobus *et al.* 1983, Stoilovic *et al.* 1986) because lowering the temperature increases fluorescence efficiency. However, only articles of limited size and shape can be examined at these low temperatures. Thus, fingerprint work at cryogenic temperatures is generally impractical.

Second, highly flammable, corrosive or explosive solvents (such as ether) need to be avoided as much as possible. A fume hood should be used, and gloves should be worn routinely. Chemical safety handbooks should be consulted for potential carcinogenicity or toxicity of reagents.

Third, in principle, compatibility with conventional procedures is not necessary, since the laser method should be the preferred one to apply. However, many latent print examiners will continue to use the customary procedures and rely on laser examination only when other methods fail. Moreover, evidence processed by conventional means in agencies not equipped with lasers will at times be sent to laser laboratories for further examination. Thus, compatibility of laser and conventional procedures is vital.

Fourth, electronic image recording and image processing by optical or digital means will eventually become commonplace in the fingerprint field. However, at present, laser examination of physical evidence (particularly bulky or odd-shaped items) demands that latent prints be visually observable so that they can be subsequently photographed or otherwise recorded. This requires a strong, monochromatic light source. As early as 1976, the replacement of the expensive fingerprint laser by far cheaper conventional (xenon) lamps was explored (Dalrymple *et al.* 1977). However, lamps were found not to be economical. In England, Canada and Australia, efforts have continued to find a lamp to replace lasers. So far, these efforts have failed (Menzel 1980). Kobus *et al.* (1983) lowered the temperature of samples treated by ninhydrin/zinc chloride to 77° K because insufficient fingerprint fluorescence was generated to make their lamp system useful at room temperature. The same situation was also found for post-ninhydrin treatment using cadmium salts (Stoilovic *et al.* 1986). The vigorous advocacy of xenon lamps over argon lasers by the Australian investigators is based on arguments that are specious. Their own results very clearly show that argon lasers (with powers of 5 W or greater) yield far greater sensitivity. A generally useful device for fluorescence detection of latent prints should not be specialized to small paper items but should be applicable to all kinds of articles. Low price is not a substitute for sensitivity. After all, the dusting brush and jar of powder are difficult to compete with on the basis of cost.

MATURE PROCEDURES FOR LATENT FINGERPRINT DEVELOPMENT BY LASER

Inherent Fingerprint Fluorescence

One of the initial goals of early laser detection research was to develop a nondestructive technique, that is, one that would not interfere with other subsequent procedures used for latent print development or with other evidence analyses, such as serology. The early work concentrated on fluorescence because of the ingredients found in latent fingerprint deposits. Fingerprint residue, like many organic compounds, absorbs light primarily in the ultraviolet range at wavelengths shorter than 300 nm. This spectral region is not suitable for fingerprint work because fluorescence, even with a large Stokes shift, would be in the ultraviolet range also and thus be invisible to the eye. In addition, no commercially available lasers suitable for fingerprint work operate in this region. Lasers that can be used for fingerprint detection must either be continuous wave (CW) or pulsed with a repetition rate of at least 20 Hz, and they must be powerful, with powers of at least 5 W for CW lasers and pulsed lasers of high repetition rate, and of 20 mJ/pulse or greater for pulsed lasers of low repetition rate (approximately 20-40 Hz).

Latent fingerprint residue shows some absorption in the blue-green spectral region (Menzel 1980) arising from compounds such as riboflavin. In 1976, the only laser suitable for fingerprint work in this spectral range was the argon ion laser. Thus, the early studies concentrated on detection of inherent fingerprint fluorescence under illumination with this laser, and subsequently developed treatments also tended to be tailored to it. It was found that latent prints could be detected by inherent fluorescence in some instances when conventional procedures failed. Figure 1 shows an example of latent print detected by inherent fluorescence.

The first successful laser criminal case examination was conducted in my laboratory at the Xerox Research Center of Canada (Menzel 1980). To the best of my knowledge, the oldest (40 years) latent print identified in a criminal case was also achieved by laser. It involved an examination conducted at the FBI's laser facility in Washington, DC. The case concerned Valerian Trifa, former archbishop of the Rumanian Orthodox Church of America, suspected of having been responsible for the death of thousands of Jews during World War II in Rumania. The item of evidence was a postcard he allegedly wrote to Heinrich Himmler on June 14, 1942. The postcard, examined by laser, revealed a latent print identified as belonging to Trifa, who as a result was deported to Portugal (Stames 1984).

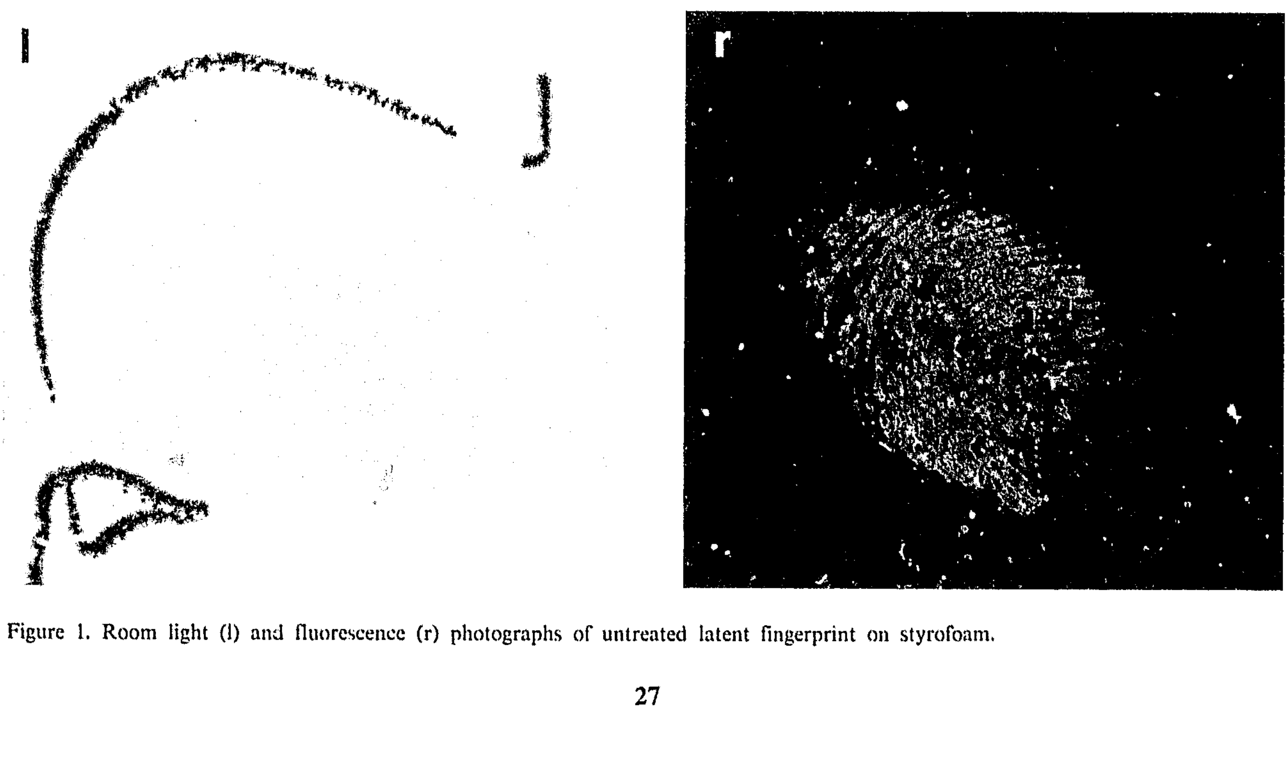

Figure 1. Room light (l) and fluorescence (r) photographs of untreated latent fingerprint on styrofoam.

The detection by laser of latent fingerprints via their inherent fluorescence often fails because of strong fluorescence of the substrates on which the prints are located. In such instances, one applies a range of physical or chemical treatments that yield fluorescence strong enough to show up over the background or a color that differs from that of the background fluorescence so that filters can be employed. Nonetheless, evidence examination for inherent fingerprint fluorescence, or for latent prints that might fluoresce because of contaminants on the finger, should routinely be the first step in evidence examination step regardless of the nature of the substrate. It should be followed by the procedures presented in the following pages.

Salares *et al.* (1979) reported that a laboratory study using paper and glass substrates had a considerably lower success rate for laser fingerprint detection by inherent fluorescence than did initial studies (Dalrymple *et al.* 1977). Several factors must be weighed when these laboratory are evaluated. First, the background fluorescence of paper can vary tremendously and can affect the detection of inherent fingerprint fluorescence. Second, fluorescence of fingerprints on glass is very faint because only light directly incident on fingerprint ridges can cause fluorescence. On paper and styrofoam, scattered laser light can also reach ridges and thus increase the fluorescence intensity. However, photography of fluorescent fingerprints on glass often yields exquisite detail if it is done carefully. Third, since palmar perspiration is adrenalin-induced, fingerprint deposition improves with fright, anger and excitation. Indeed, the early survey results obtained with ninhydrin were quite disappointing because the emotional element that affects fingerprint deposition was overlooked.

A more meaningful survey was conducted by the FBI in the early 1980's. Three thousand actual case histories were examined. Fingerprints were detected by ninhydrin in 930 instances, by dusting in 242 and by laser in 214 (inherent fingerprint fluorescence only). The laser-detected prints were not amenable to the conventional procedures. This means that laser detection, even when conducted only in its most basic form (that is, without the application of the excellent ninhydrin/ zinc chloride and cyanoacrylate ester/dye staining procedures), is comparable in success to dusting (one of the two most widely used latent print procedures) and improves overall success by 15%. After examining about 400 articles of evidence, most considered unsuitable for treatment by conventional procedures, Creer (1982) reported obtaining identifiable fingerprints on about 30% of them. (The exacting standards of the United Kingdom demand 16 characteristics for identification.) Creer's high success rate was in no small measure due to very meticulous and skillful evidence examination and photography. Laser latent fingerprint detection by inherent fingerprint fluorescence has by now proven its value in many crime laboratories. If this were the only mode of laser fingerprint detection, the method would probably be on its way to obscurity. However, used with the other mature procedures, its success is so dramatic that even the expense of lasers should not stand in the way of the method's general adoption.

Dusting with Fluorescent Powder

Powders can easily be prepared to have conventional color and adherence properties as well as strong fluorescence under laser illumination. Thornton (1978) reported a procedure for preparing nonmagnetic fluorescent powder which could also be adapted for fluorescent magnetic powder (Menzel 1980). Such powders can reveal latent prints under the laser when room light inspection fails. Most articles of evidence are examined in crime laboratory settings, where more sensitive procedures can be used. However, fluorescent dusting powders should be very useful for crime scene work with a portable laser. Few good laser-compatible fluorescent dusting powders are commercially available, and fluorescent powders are seldom prepared by law enforcement laser users. Thus, this mature procedure unfortunately tends to be neglected. However, with the proliferation of portable fingerprint laser systems for crime scene work, dusting with fluorescent powder will probably assume growing importance in the years to come. Figure 2 shows a latent print detected by dusting with commercially available fluorescent powder.

Cyanoacrylate Ester Dye Staining

Staining biological tissue with fluorescent dyes to reveal elusive features has been practiced for many years and would seem an obvious approach to laser fingerprint development. Indeed, such staining was used in the early days of latent print detection (Dalrymple *et al.* 1977). However, the dye solvents tended to wash away the latent print deposit, and dye staining was abandoned until the advent of cyanoacrylate ester fuming. This procedure involves the use of

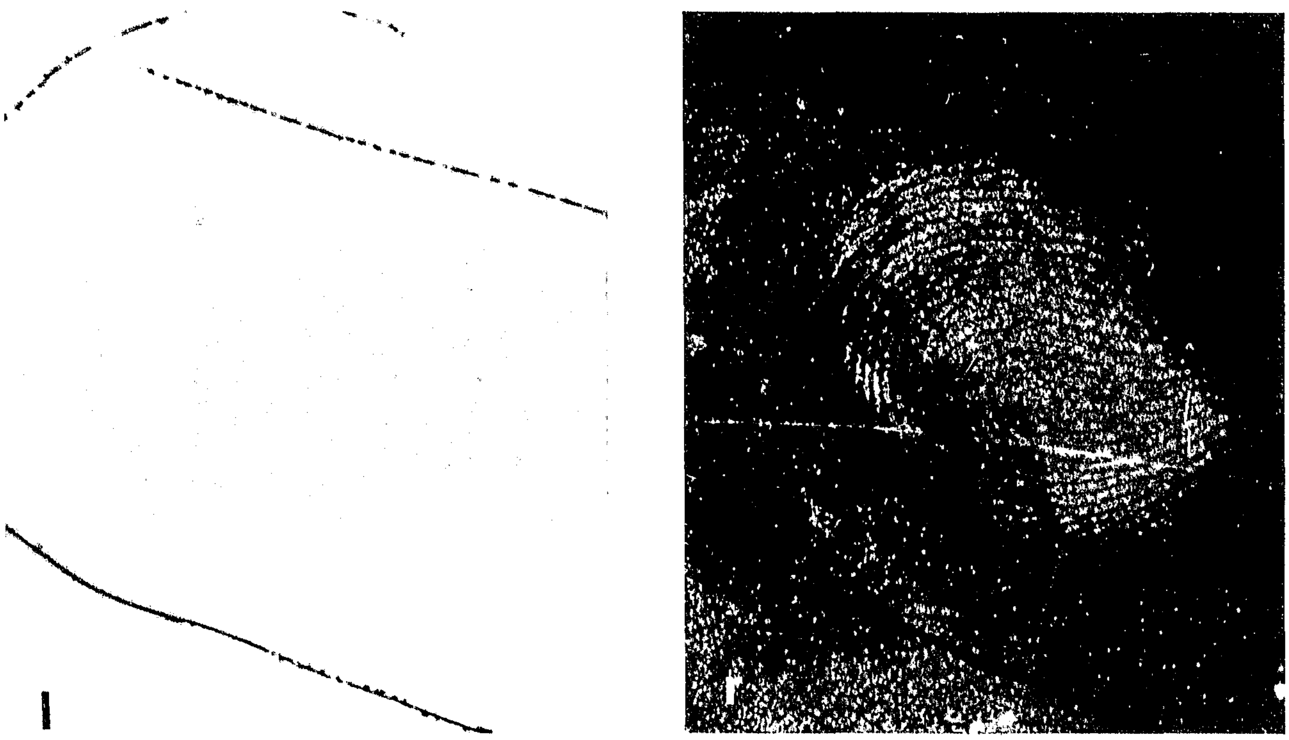

Figure 2. Room light (l) and fluorescence (r) photographs of latent fingerprint on white plastic dusted with Mars Red.

glues containing methyl or ethyl cyanoacrylate ester as the active ingredient. Such glues come under a variety of trade names, including Super Glue and Wonder Bond. Articles to be examined are placed in a closed container together with a few drops of the glue. The cyanoacrylate vapors (vaporization can be accelerated by heat or sodium hydroxide-soaked cotton) are adsorbed at fingerprint ridge sites and, in the presence of moisture, form a white polymer via which latent prints become visible. The polymerization reaction has been described by Lee and Gaensslen (1984). Packages for cyanoacrylate fuming that require no heat or sodium hydroxide-treated cotton are commercially available. The cyanoacrylate ester process stabilizes latent prints so that they become quite resistant to solvent application. Moreover, staining dyes are preferentially adsorbed by the cyanoacrylate polymer. One of the best staining dyes in this respect is Rhodamine 6G. Rhodamine 6G staining in concert with Super Glue fuming was first explored by Menzel and coworkers (1973). Rhodamine 6G is superbly matched in absorption to the argon, copper vapor and frequency-doubled Nd:YAG lasers used for fingerprint work and has very high fluorescence efficiency. Laser-equipped law enforcement laboratories began using a methanol solution of Rhodamine 6G in 1982 to examine smooth surfaces, and it is presently the most successful laser procedure. In many instances, the cyanoacrylate ester polymer formation is too faint to reveal latent prints under room light, but it is sufficient to stabilize the print so that dye staining followed by laser examination is successful. Figure 3 illustrates this procedure.

Some surfaces that are too porous for solution staining (the dye adheres everywhere rather than to latent prints) can be evaporatively stained with a

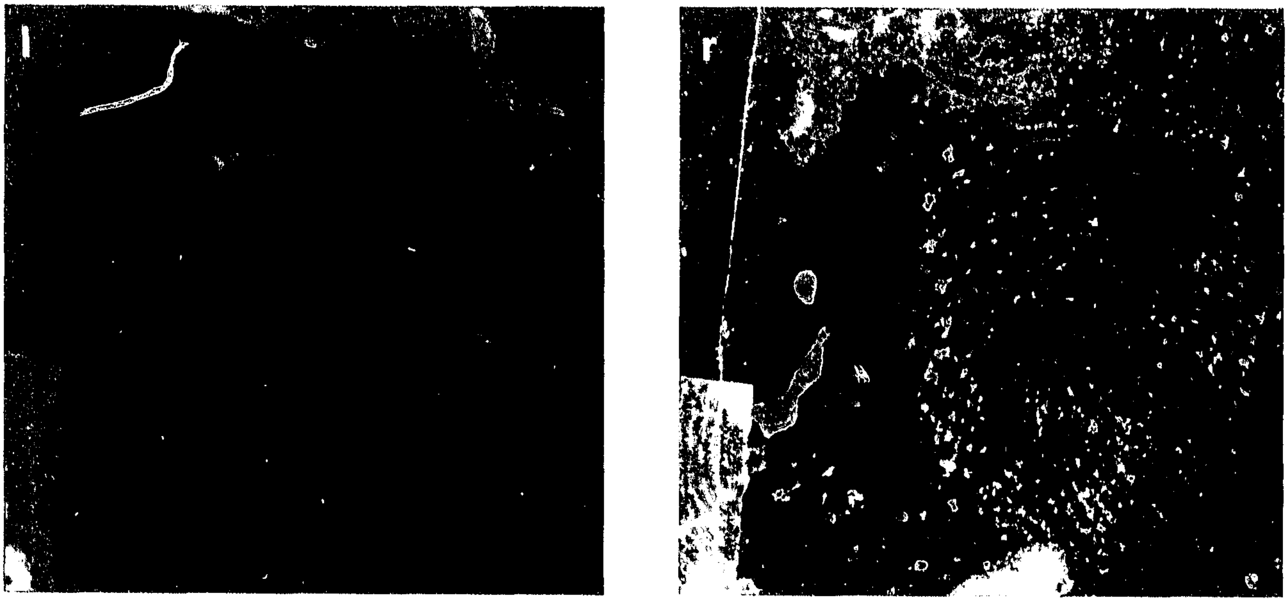

Figure 3. Room light (l) photograph of latent print on black polythene after fuming with cyanoacrylate ester, and same under laser after Rhodamine 6G staining (r).

number of dyes. Evaporative dye staining is not routinely used in law enforcement agencies. Details of solution and evaporative dye staining have been described in several articles (Almog and Gabay 1980; Menzel 1980; Burt and Menzel 1985; Menzel 1985).

Crystal Violet (Gentian Violet) is often used to develop latent fingerprints on adhesive tape, and fluorescence can enhance the sensitivity of this method. However, the sample must be exposed to yellow orange light from a copper vapor laser using the 578 nm line or from a dye laser (usually pumped by an argon laser). To make latent prints on adhesive tape amenable to fluorescence detection using green laser excitation, a staining dye similar in structure to Crystal Violet, namely Basic Fuchsin, has been investigated (Figure 4). This compound has adhesive properties like those of Crystal Violet, but it has an absorption maximum at about 500 nm. That is, it is compatible with green excitation, under which it shows orange fluorescence. Figure 5 shows the fluorescence development of latent prints on the adhesive side of black electric tape under yellow copper vapor laser light with Crystal Violet treatment and under green copper vapor laser light with Basic Fuchsin application. Figure 5 indicates that Basic Fuchsin can be an effective substitute for Crystal Violet and can provide good sensitivity in concert with laser examination.

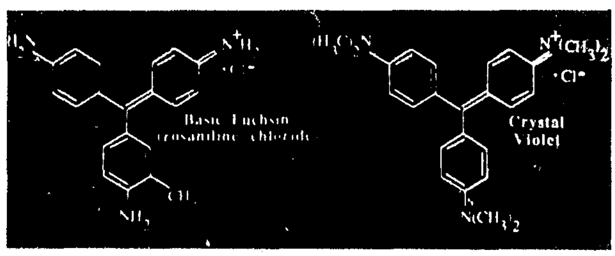

Figure 4. Dyes for development of latent prints on adhesive tapes.

Ninhydrin/Zinc Chloride

The previously discussed ninhydrin treatment is the standard method for developing latent fingerprints on porous items (mostly paper). Unfortunately, Ruhemann's purple, the reaction product of ninhydrin with amino acid (Ruhemann 1910), is not compatible with argon laser excitation. (Its first excited singlet state absorption occurs at about 580 nm.) Dye laser excitation at 580 nm does not produce appreciable visible luminescence either. However, if the ninhydrin-amino acid reaction is followed by treatment with a zinc salt (typically zinc chloride), the purple product is converted to an orange one that is highly fluorescent

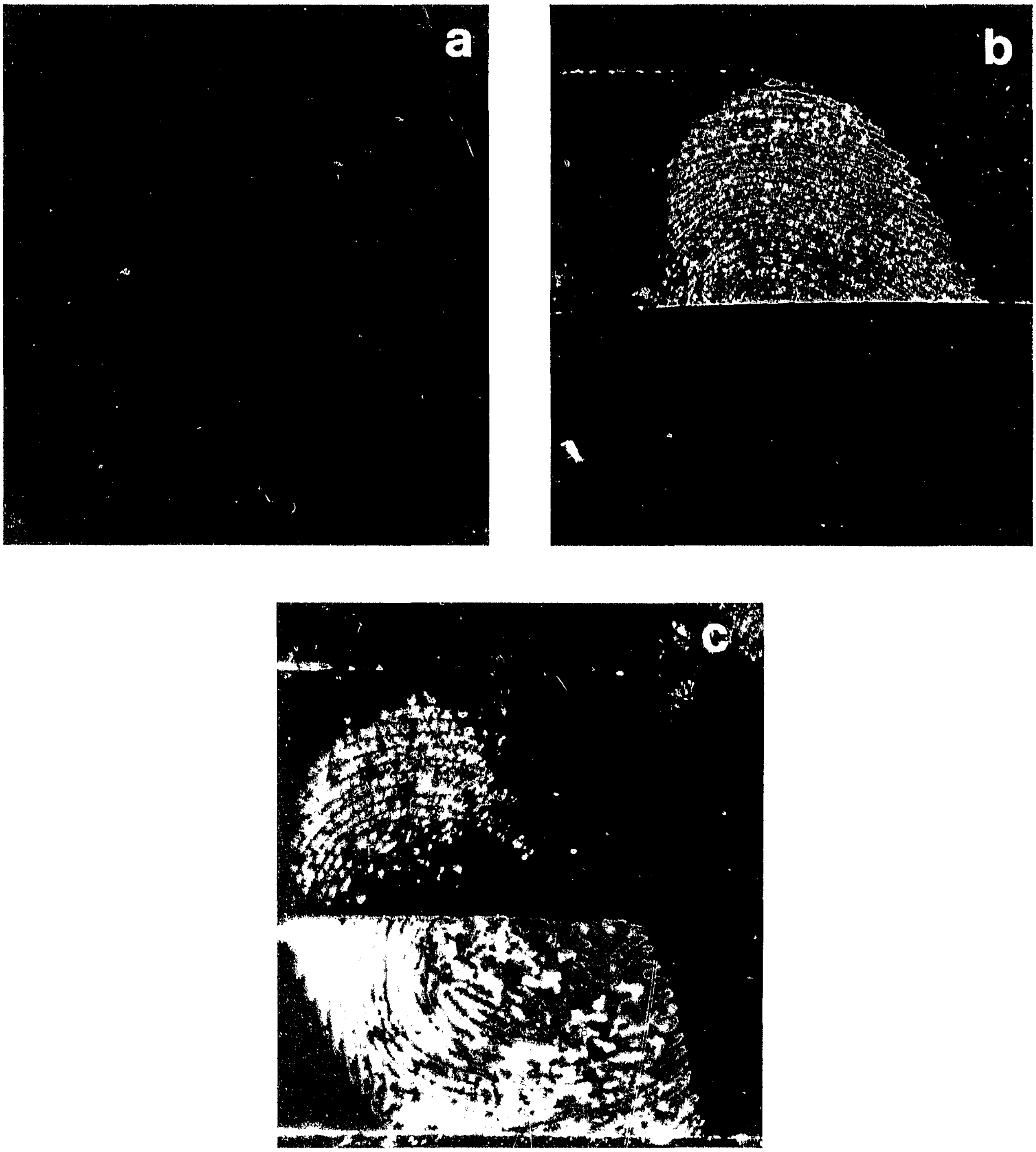

Figure 5. Room light photograph (a) of black electric tape first fumed with cyanoacrylate ester and then stained with Crystal Violet (top) and Basic Fuchsin (bottom), and same under yellow (b) and green (c) copper vapor laser excitation.

under argon laser illumination. Thus, even if the ninhydrin reaction does not yield visible detail, the subsequent zinc chloride reaction and laser-excited fluorescence will often reveal latent prints (Herod and Menzel 1982). Figure 6 compares the enhanced sensitivity of laser detection with the conventional treatment. The zinc chloride reaction modifies the spectral features of Ruhemann's purple, forming a complex that may be like the one shown in Figure 7. The ninhydrin/zinc chloride procedure is now routinely used with good success in laser-equipped law enforcement laboratories. Stoilovic *et al.* (1986) advocate the use of cadmium salts over that of zinc salts. They base their preference on the fluorescence of the cadmium reaction product with Ruhemann's purple at 77° K. Since the efficiency of fluorescence increases as the temperature is lowered, it is not accurate to compare results obtained with cadmium at cryogenic temperatures with those obtained with ninhydrin/zinc chloride at room temperature. When both are evaluated at room temperature, the zinc product performs better. Indeed, when the results of Kobus *et al.* (1983) are compared with those of Stoilovic *et al.* (1986), it becomes apparent that the zinc salt yields more intense fluorescence. Thus, cadmium salts are potentially useful only when background fluorescence interferes too strongly to make zinc chloride treatment applicable. (The cadmium treatment leads to a fluorescence that is red-shifted with respect to that obtained with zinc.) According to Stoilovic *et al.*, the cadmium product shows no fluorescence at room temperature. This is incorrect because the cadmium product does display room temperature fluorescence, although not as well as the zinc product (Everse and Menzel 1986). Because cadmium has a higher atomic number than zinc, it causes greater spin-orbit coupling, hence faster intersystem crossing, and this quenches fluorescence. The advocacy of the cadmium salt treatment is placed in perspective once one recognizes that it is based on the advocacy of the xenon lamp instead of the superior

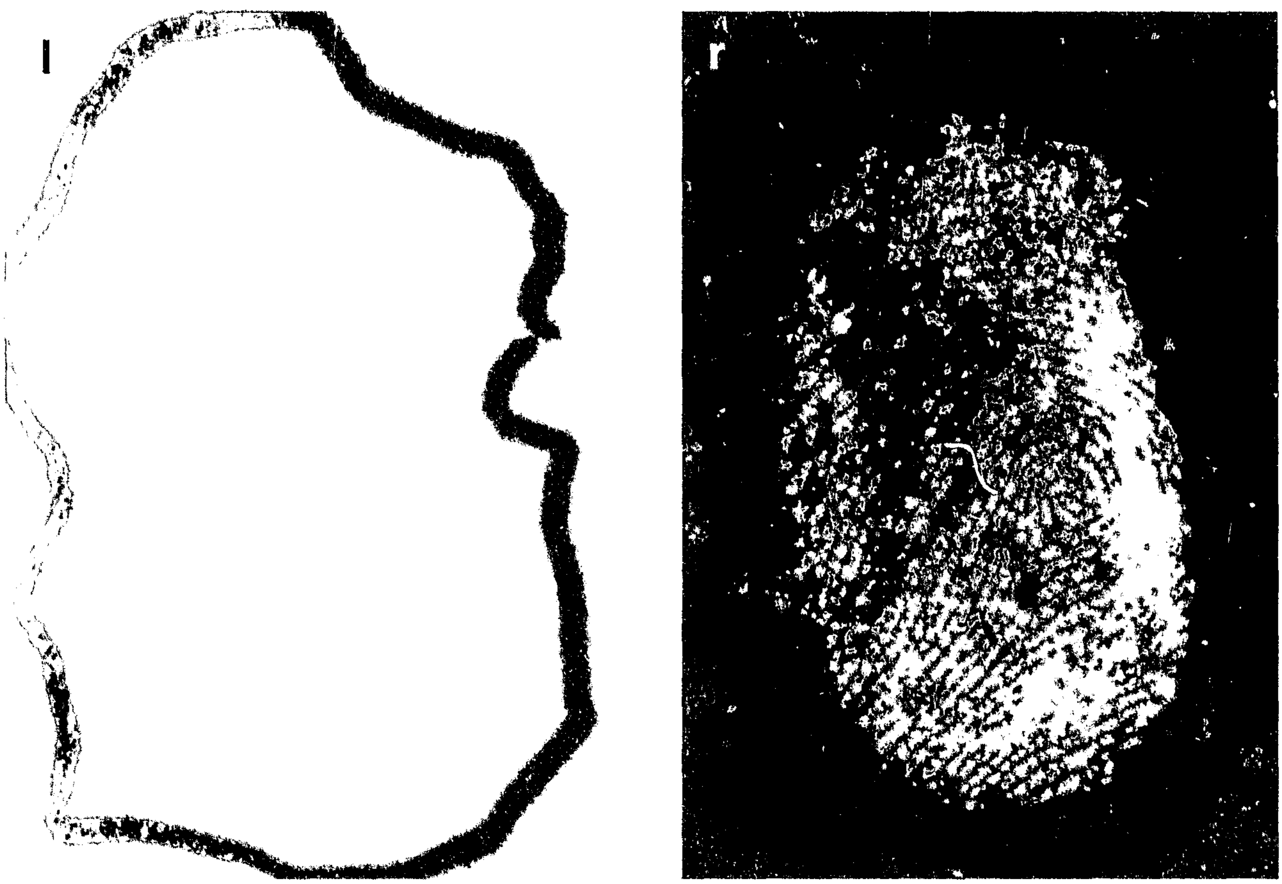

Figure 6. Room light photograph (l) of latent print on paper treated with ninhydrin, and same under argon laser excitation (r) after zinc chloride treatment.

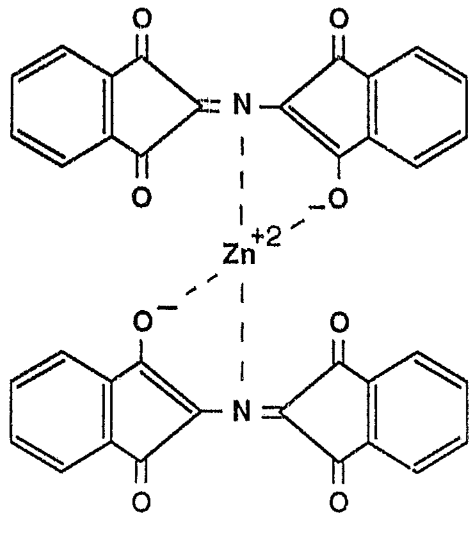

Figure 7. Postulated structure of complex formed by ninhydrin/zinc chloride fingerprint treatment.

laser. As long as one has humidity and slightly elevated temperature and as long as zinc chloride is not applied in great excess, the ninhydrin/zinc chloride procedure is reliable and easy to use. Most of the time, normal ambient conditions are quite adequate for the zinc chloride treatment. With laser use, there is no need for cryogenic temperatures.

SPECIAL PROCEDURES

Inherent fingerprint fluorescence, dusting with fluorescent powder, cyanoacrylate ester/dye staining and ninhydrin/zinc chloride are the mature procedures used for general laser detection of latent fingerprints. Several other procedures have been developed for use in special situations. Benzoninhydrin treatment, enhancement of latent print development by enzymes and vapor staining with ultraviolet-responsive dyes are particularly noteworthy.

The first procedures for laser latent fingerprint detection were tailored to use of the argon laser, since this was the only practical laser type at the time. Since then, copper vapor and frequency-doubled Nd:YAG lasers with the requisite pulse repetition rate and power have become commercially available. These laser types are now also used by a number of law enforcement agencies. The Nd:YAG laser, although only marginal in power and repetition rate, is portable and therefore useful for crime scene work. Copper vapor and argon lasers of the required power are not portable. The green copper vapor laser line (511 nm) occurs in the same spectral region as the strongest argon laser line. Thus, procedures tailored for argon laser use are compatible with the copper vapor laser. However, the operating wavelength of the frequency-doubled Nd:YAG laser (532 nm) is substantially different, so that some of these procedures are not compatible with its use. The ninhydrin/zinc chloride treatment is the most important example. The ground to first excited singlet state absorption, by which the fluorescence is produced, occurs at about 490 nm. It is well matched to the argon laser but poorly suited to the Nd:YAG laser. It is therefore useful to modify the spectral features of the ninhydrin/zinc chloride procedure to tailor it to the Nd:YAG laser. This is achieved by replacing ninhydrin with the analog benzo[*f*]ninhydrin (Menzel and Almog 1985). When this analog reacts with amino acid, a dark green product is obtained. Its ground to first excited singlet absorption is red-shifted with respect to Ruhemann's purple from about 580 to about 630 nm. This red shift arises from greater electron delocalization due to the two additional aromatic ring structures, and it can be understood by analogy to the particle-in-the-box of elementary quantum theory. The larger the box, the lower the energies of transitions between states. Chelation, involving two molecules, results from subsequent reaction with a zinc salt. The presence of the zinc cation in the complex causes strong localization of electrons and a large blue shift in absorption (from about 580 to 490 nm for ninhydrin and from about 630 to 530 nm for benzo[*f*]ninhydrin). Both ninhydrin and benzo[*f*]ninhydrin are compatible with argon laser excitation, but only benzo[*f*]ninhydrin/zinc chloride produces adequate fluorescence under the frequency-doubled Nd:YAG laser.

Amino acid reagents, such as ninhydrin, are excellent for latent fingerprint development. However, there may not be enough amino acid in the latent print residue to produce adequate detail even after zinc chloride reaction and laser examination. To enhance the sensitivity of latent print detection by amino acid reagents, researchers have explored the use of hydrolytic enzymes that cleave proteins to produce amino acids. Good enhancement has been obtained with a lyophilized preparation of the pancreatic enzyme trypsin (Everse and Menzel 1986). Enzyme application in latent fingerprint development is not a routine procedure, but it could be valuable when very thorough evidence analysis is required.

Surfaces such as leather and wood, which fluoresce intensely under blue-green illumination, defying normal laser examination, can be successfully treated by evaporative staining with 9-methylanthracene and

Coumarin 535 in concert with cyanoacrylate ester fuming (Burt and Menzel 1985). These dyes respond to near-ultraviolet excitation by an argon laser or ultraviolet lamp, under which many surfaces show relatively little luminescence. Although not routinely used in evidence examination, these dyes should be kept in mind for treatment of difficult surfaces. Similarly, dusting powders that respond to ultraviolet excitation may be useful.

RARELY USED AND OBSOLETE PROCEDURES

In some instances, laser illumination can improve visual and photographic contrast in the conventional sense, for example, when the fingerprint appears dark on a fluorescent background (Menzel 1980; German 1981). For special surfaces such as brown paper or cardboard treated with ninhydrin, this approach to fingerprint detail enhancement should be kept in mind. As a general approach to fingerprint development, it lacks the sensitivity provided by fluorescence of fingerprints for reasons previously explained.

Almost from the very beginning of laser fingerprint development, reagents for amino acid assay which might be suitable replacements for ninhydrin were explored. Well known reagents in this category include *o*-phthalaldehyde (Benson and Hare 1975), fluorescamine (Udenfriend *et al.* 1972) and dansyl chloride (Seiler and Wiechmann 1966; Gray and Hartley 1963) which react with amino acid to produce substances that fluoresce under ultraviolet illumination with either an ordinary ultraviolet lamp or an argon laser operating in the ultraviolet range. Fingerprints can be detected with these reagents. However, for general purposes they are not as practical or as sensitive to use as ninhydrin/zinc chloride. Thus, they are used only when background fluorescence renders ninhydrin/zinc chloride useless. 7-Chloro-4-nitrobenzo-2-oxa-1,3-diazole (NBD chloride) is a reagent for amino acids that produces fluorescence under blue illumination (λ max $\simeq$ 470 nm) (Salares *et al.* 1979; Warrener *et al.* 1983; Stoilovic *et al.* 1984). Stoilovic *et al.* (1984) show that NBD chloride produces only marginal improvement over detectability by ninhydrin in the conventional sense. Thus, this method fails from the standpoint of practicality, since it demands replacement of ninhydrin. Moreover, it is not competitive in sensitivity with the ninhydrin/zinc chloride procedure. The NBD chloride procedure must thus be considered obsolete, except when background fluorescence is not compatible with ninhydrin/zinc chloride use.

4-Dimethylaminocinnamaldehyde reacts with urea of fingerprint residue to form a product that fluoresces orange under green illumination. It was investigated some time ago as an alternative to ninhydrin in the conventional sense (Sasson and Almog 1978) and for purposes of laser examination (Menzel and Duff 1979). This reagent is not competitive in sensitivity with the subsequently developed ninhydrin/zinc chloride procedure and is thus obsolete.

CURRENT AREAS OF RESEARCH

A major effort is currently underway to detect latent fingerprints on difficult surfaces, such as cloth. Physical treatments such as dusting or dye staining are useless, since the applied substance adheres everywhere rather than just to latent fingerprint residue. Chemical reagents applied in solution tend to cause catastrophic smudging because of capillarity and surface tension. Except for occasional success with latent prints on very fine weave synthetic fabric (Menzel *et al.* 1983), cloth articles remain intractable unless blood prints are involved. This situation is frequently found in serious crimes, and progress is being made. Blood print development by laser techniques on ordinary cotton cloth (such as bed sheets or shirts) is feasible (Everse and Menzel 1987). Skin is also another difficult surface. Although no truly effective procedure has been developed, evaporative dye staining shows some promise for effective laser examination (Menzel 1982).

Fluorescence can be used to detect trace amounts of a substance by exploiting its intensity, color and lifetime. In fluorescence detection of latent fingerprints, only the first two properties have been exploited to date. The third is just beginning to be explored by time-resolved imaging. The background emission that often overwhelms latent fingerprint luminescence is fluorescence with a nanosecond lifetime. Latent print treatment using delayed fluorescence or phosphorescence (with a lifetime of milliseconds) permits time-resolved photography to eliminate the interfering background (Menzel 1979). Since no chemical or staining treatments with long luminescence lifetimes are available, time-resolved imaging on the nanosecond and subnanosecond time scale is needed.

If the lifetime of the latent fingerprint fluorescence is substantially longer than that of the background, then contrast improvement by a factor approaching e^{t/T_b} is possible, where T_b is the lifetime of the background fluorescence and t the delay time between cessation of the illuminating laser pulse and the onset of imaging (Menzel *et al.* 1987). The imaging will likely involve a gated microchannel plate image intensifier followed by a video camera. If the lifetime of the background luminescence is longer than that of the latent print, then a contrast improvement approaching T_b/T_F may be achieved with excitation of suitably short pulse width, where T_F is the fingerprint fluorescence lifetime. Some very preliminary work along this line was done by cavity-dumped argon laser a few years ago (Frizzell 1982). Mode-locked and cavity-dumped laser excitation will no doubt be explored in conjunction with fingerprint treatments that yield short lifetimes, such as ninhydrin/zinc chloride (Menzel *et al.* 1987). A recent study shows that the background fluorescence lifetimes for difficult surfaces are short and that gated imaging is therefore the proper approach in many cases (Menzel *et al.* 1987). Future research will probably focus on designing fluorescent compounds with long lifetimes to optimize time-resolved imaging. This imaging requires pulsed or chopped laser excitation. The copper vapor laser and frequency-doubled Nd:YAG laser pulses are of suitable length. However, the copper vapor laser pulse cutoff time is rather long (20-30 ns), and this poses problems unless molecules with unusually long lifetimes can be designed. The cavity-dumped argon laser pulses are somewhat short, but chopping CW argon laser light by electro-optic modulator remedies this situation. The low repetition rate of the frequency-doubled Nd:YAG lasers used in fingerprint work will likely preclude their use in time-resolved imaging.

Laser Application to Other Criminalistic Areas

Although lasers are used in law enforcement primarily in development of latent fingerprints, laser-excited fluorescence can also be valuable in fiber analysis, document examination, serology and paint identification. Fibers that would elude normal visual inspection can be revealed by laser examination (via fiber fluorescence). Until now, this has been the only use of lasers in fiber analysis. However, laser excitation coupled with spectroscopic measurements will eventually yield quantitative data that will greatly enhance the probative value of fiber analysis.

The discrimination between similar inks in document alteration is generally done by thin-layer chromatography (TLC) (if enough ink sample is on hand), infrared luminescence or absorption microspectroscopy. Sinor *et al.* (1986) have shown that laser-fluorescence spectroscopy can discriminate between inks that are not distinguished by the conventional methods. Ink fluorescence intensity can be enhanced *in situ* (at room temperature) by a treatment designed to reduce fluorescence quenching mechanisms. The treatment involves coating the writing on the document with a formulation of resins, polymers and a volatile solvent. These ingredients form a viscous liquid that is applied with a brush. Rapid solvent evaporation leaves a solid coating into which some of the ink has dissolved, but it does not obliterate the calligraphic features of the writing. Fluorescence intensity increases in the following manner. Inks consist of suspensions of dye or pigment particles of colloidal or larger size. Molecules in such particles are very close to each other, so that radiationless dipole-dipole intermolecular energy transfer, known as Forster transfer (Forster 1948), occurs with great efficiency. An excited molecule at the surface of an ink particle (light absorption is most pronounced for molecules at the surface) thus tends to lose its excitation energy very rapidly, with the energy transferred on the average into the bulk of the particle. Photons emitted by molecules in the bulk will tend to be reabsorbed before reaching the particle surface. The consequence is a quenched fluorescence efficiency. For the same reason, a laser dye such as Rhodamine 6G fluoresces very strongly in solution, where molecules are relatively far apart, but poorly in powder form. When this coating procedure is used, visual discrimination of similar inks by laser may improve quite dramatically, and this is important from the standpoint of practicality, since spectroscopic machinery is not customarily available in document sections (but usually on hand somewhere in major crime laboratories). This coating approach may also be used in latent fingerprint development. Fluorescence intensity of inks can also be increased by lowering the sample temperature to 77° K. The items to be tested are usually flat and not overly large, so the method is practical to use. A styrofoam tray is quite adequate as the container for the document, and it can be secured with pins or masking tape. Liquid nitrogen is poured over the document until it is fully submerged. The tray is covered with glass and warm air is blown over it to prevent fogging. The information obtained from the low temperature examination often is complementary to that gained from the coating procedure (Sinor *et al.* 1986). When both are used in concert, the discriminatory capability of laser document examination is substantially improved.

Ink differentiation sometimes is performed by TLC. The sensitivity of TLC can be dramatically enhanced by subjecting TLC plates to laser illumination and fluorescence observation (Duff and Menzel 1978; Creer 1982; Sinor *et al.* 1986). Similar sensitivity enhancement can be obtained in laser examination of electrophoresis plates used in forensic serology. Creer (1982) describes a wide range of evidence examinations in which lasers have found utility. Since fibers, inks and paints come in all colors, a generally useful laser system for forensic examination must provide laser colors from near ultraviolet to red. Argon laser/dye laser systems should therefore begin to see use in law enforcement laboratories. The yellow (578 nm) line of the copper vapor laser is also very useful for such evidence examinations.

Fingerprint Lasers

In 1976, argon lasers were the only CW lasers with enough power in the blue-green spectral region to be useful for detection of latent fingerprints via their inherent fluorescence. Argon laser powers of at least 5 W were considered necessary to detect latent prints with generally adequate sensitivity. Certain fingerprint treatments specialized to difficult surfaces (Burt and Menzel 1985) require ultraviolet excitation, which can be obtained from some argon laser models and by ultraviolet lamps. Some fingerprint treatments, such as Gentian Violet for development of prints on adhesive tapes, require yellow-orange excitation. This color of laser light is also useful for fluorescence excitation in fiber analysis, document examination and serology. Thus, one can expect argon laser/dye laser systems to see increasing use.

In the early 1980's, copper vapor lasers, originally designed for isotope separation, became commercially available. They, too, were useful for fingerprint development. Copper vapor lasers are pulsed, with repetition rate of roughly 5 kHz, amply fast. The average power (5-25 W in the green at 511 nm and 3-15 W in the yellow at 578 nm) is also adequate. The yellow copper vapor laser line finds use in evidence examination in connection with dye lasers. Copper vapor lasers are thus quite versatile for evidence examinations.

The frequency-doubled Nd:YAG lasers with the requisite pulse power in 1976 had low repetition rates. In the early 1980's, portable systems with 20 Hz repetition rates became commercially available and started to be used for fingerprint detection. These lasers were primarily intended for crime scene use, but they are often used as laboratory fingerprint lasers. The average power of current systems (approximately 400 mW to 1 W, depending on manufacturer) represents a significant sacrifice in sensitivity to achieve portability. The laser light and fluorescence flicker is bothersome to many latent print examiners.

Crime scene work to detect not only fingerprints but also fibers, shoeprints and biologic fluids has prompted manufacturers to offer systems that use portable argon lasers (with powers of roughly 150 mW). These systems sacrifice considerable sensitivity but are easily portable. The Nd:YAG systems are more clumsy.

Some portable systems feature video cameras are designed to provide images that exceed what one sees visually in contrast and sensitivity. These cameras tend to be too cumbersome to search effectively for prints at crime scenes because their depth of field is very low at the required magnification. Once a print has been located they can be quite useful, particularly in concert with computer image processing. Image processing will no doubt become common in fingerprint work in the years to come.

The mature laser procedures just discussed permit detection of latent fingerprints on many surfaces. However, a number of substrates, such as cloth, skin, leather and brown cardboard still pose much difficulty. Time-resolved imaging and excitation with subnanosecond pulses appear to offer the best prospects for detection of latent prints on these recalcitrant surfaces. Computer image processing should be very useful in latent fingerprint work. In areas such as fiber analysis and document examination, the use of lasers is still in its infancy. If the research support for criminalistics technology continues to be as low as it is at present, progress will be slow because of the difficult problems of laser applications. In spite of this potentially dismal prognosis, laser-excited fluorescence is destined to revolutionize many areas of physical evidence analysis. Latent fingerprint development is assuming greater importance than ever because of the proliferation of fingerprint computers that permit cold searching, so that one can now identify latent prints even when a suspect has not been developed beforehand.

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DISCUSSION

Stoilovic: What do you think is the substance in a latent fingerprint deposit which fluoresces inherently?

Menzel: One substance is probably riboflavin. Since I am not an analytical chemist, I have not explored this area in depth, but we have performed some spectroscopy on fingerprint residue and compared it with riboflavin spectra.

Stoilovic: I am confused with the slide presentation concerning fluorescence and the slide that shows black ridges on a white background. I expected to see white ridges on a black background.

Menzel: The slide that was shown is a negative slide rather than a positive slide.

Almog: In response to Dr. Stoilovic's question, based on our experience, it is mostly environmental contamination that fluoresces, rather than anything excreted from the body. Certain medications such as riboflavin are fluorescent. Soaps that contain fluorescein will leave a residue that will cause fingerprints to fluoresce.

Menzel: No doubt there is a lot of foreign contamination, but there is also inherent fingerprint fluorescence.

ALTERNATIVE LIGHTING METHODS OF DETECTING LATENT PRINTS

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A light source is a necessary tool used in the detection of latent fingerprints, but how it is applied to an individual surface is an important factor when determining which method to use. What counts most of all is the thoughtful and ordered sequence of methods applied to each individual surface. Bearing that in mind, it is likely that in the future more of these methods will be fluorescent ones. Fingerprint detection has been, and always will be, a problem of contrast. Reflectance in the best of circumstances has limited contrast. The light reflected off a very shiny surface such as a mirror is 95%, or with magnesium oxide it is 98%, of the incident light. The reflection from white paper is only about 72%. It is very difficult to make a totally nonreflective surface. Black ink on paper or dull black paint still has about 5% reflectance. Some soots can be as low as 1% or 2%. The point is that there is a practical limit to this signal to background ratio, say 20%, even under the most favorable circumstances.

But surely this ratio is enough? It obviously is, if we are dealing with black inked prints on white paper where almost all the ridge area is black, but the ratio can be very much less on latent prints. A latent print does not usually deposit all of its material uniformly across the ridge. Figure 1 shows a few ridges of a print deposited on specially cleaned glass. It is photographed (untreated) under a microscope using dark field illumination. The droplet structure is clearly visible. Figure 2 shows the same print developed with cyanoacrylate and photographed in the same way. There is now far more material on the slide, but the reproduction of the print down to the smallest droplet is perfect. As less material is deposited on glass or if the surface is rough (as on paper), the area occupied by the droplets can decrease greatly, and this will decrease the ratio of the signal to the background in proportion.

The virtue of fluorescence as a detection method is that theoretically the background can be zero and the contrast can be infinite. There are some practical limits, but the method offers very high contrast as well as high sensitivity under favorable circumstances. Increasing the power of the incident light will make the signal brighter, but it does not alter the contrast. Fluorescent sensitivity can be increased by reducing the background. An analogy would be the detection of the Milky Way with the stars representing the bright

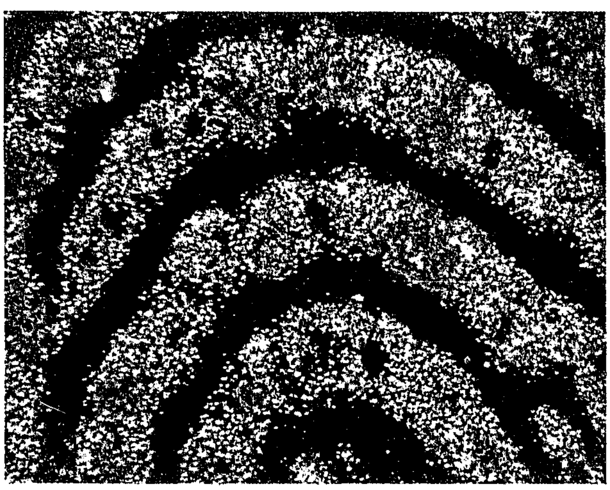


Figure 1. Ridges of a print deposited on specially cleaned glass under a microscope using dark field illumination.

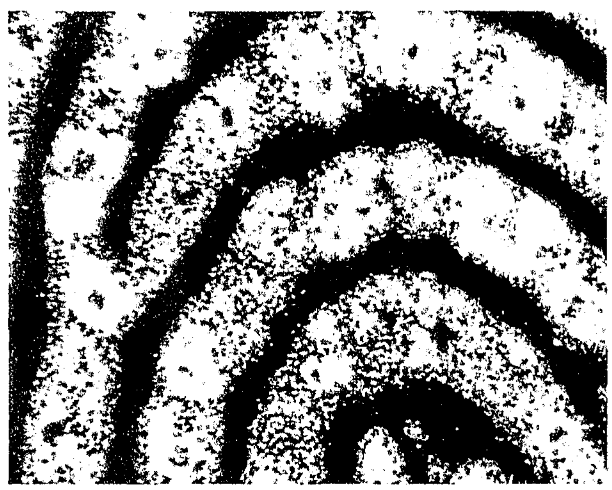


Figure 2. Ridges of a print deposited on specially cleaned glass, developed with cyanoacrylate, under a microscope using dark field illumination. Same print as in Figure 1.

fluorescent droplets and the whole area a fingerprint ridge. The Milky Way can be seen only when the background sky is dark enough. When observed by the naked eye, which does not have enough visual acuity to detect the individual stars, the contribution of each star is merged and the Milky Way appears as a faint ridge or brighter area.

PROPERTIES OF LIGHT NEEDED FOR FLUORESCENT PRINT DETECTION

A light source used to excite fluorescence must emit at a wavelength reasonably near the excitation maximum of the fluor, it must have enough power to reveal a fingerprint to a dark adapted eye and it must be pure enough to avoid reducing the contrast. These are not qualities unique to laser-produced light. They can be produced by other sources.

Three types of background fluorescence reduce contrast. The first is not really fluorescence at all but stray light in the source. If there is any light in the source at the same wavelength as that emitted by the fluor, it will be reflected off the surface and appear to be fluorescence. Thus, the purity of the exciting source is a major consideration. The second source is any fluorescence originally present on the surface on which the print is deposited. Nothing can be done about this directly, but, if a fluorescent dye is to be used, it may be possible to select one that fluoresces at a wavelength where the background fluorescence is relatively low. The third problem occurs if a fluorescent dye has been applied to the surface and some has attached to the surface as well as to the print. Reducing this background depends on the ability of the chemist to select a fluor with suitable solubility properties and in the relative attack of the solvent on the fingerprint droplets compared with the substrate.

DEVELOPMENT OF LIGHT SOURCES

The 18 W argon ion laser, as used by Menzel and Dalrymple when they introduced it to fingerprint work, has three virtues. First, it produces light at two very narrow wavelengths which is essentially pure. There being no light at longer wavelengths, no filters are needed. Second, the wavelength of emission corresponds well to the excitation wavelength of natural fluorescence and to many fluorescent dyes that can be used. Third, the very low divergence of the beam is useful in that it enables the beam to be focused to a very small point and thus enter a small diameter single fiber for convenience in transmission.

The coherence of the laser light (a most valuable property in other applications and essential for holograms) is a nuisance for fingerprint work. It is bulky, expensive and requires water cooling that makes it nonportable. Other types of lasers are also large for their power output. Small portable lasers have small power outputs, and there are several of them on the market.

Although the large laser a useful tool, its size and cost have prevented it from becoming available routinely to every identification officer. The potential of lamps to fulfill this need has been recognized since the laser was introduced. The late commercial availability of these lamps indicates that the technical problems in their development have not been trivial.

Development of sources is a matter of the cost and convenience of competing technologies. To summarize, a laser is costly in power and money, but the light produced is ready to use. Light from lamp sources is much easier to obtain but needs troublesome collecting, collimating and filtering. At present, it appears that equivalent lamps will cost only 10%-20% of a large laser.

Three lamps are currently available for fingerprint use. The "Unilite" designed at the Australian National University, the "Quasar" designed at the Scientific Research and Development Branch of the United Kingdom Home Office and the "Lumaprint" designed at the National Research Council of Canada.

It is impractical to design totally new light sources for fingerprint work. A selection must be made from existing sources. Some of these are listed in Table 1. It is an advantage to have a very small source of high brightness or luminance. There is a law of

Table 1. TYPICAL LIGHT SOURCE PERFORMANCE DATA[a]

SOURCE TYPE	LUMENS/ WATT (1 pw)	APPARENT COLOR TEMP (°K)	SOURCE SIZE OR TYPE	AVERAGE LUMINANCE (cd/mm²)
High Intensity Discharge (HID)				
Clear Mercury (400W)	52	6000K	20x68mm	1.5
Metal Halide (400W)	85	4500K	20x40mm	4.2
High Pressure Sodium (400W)	125	2100K	8.8x87mm	6.5
Low Pressure				
Fluorescent (cool white)				
430 ma	80	4300K	T12 Bulb	0.008
800 ma	82	4300K	T12 Bulb	0.011
1500 ma	70	4300K	T12 Bulb	0.017
Sodium	150	1700K		0.1
ENCLOSED ARC				
Compact High Pressure				
Mercury (100W)	20	8000K	0.25x0.2mm	1700
Mercury (200W)	50	8000K	0.6x2.2mm	400
Mercury Xenon (1000W)	50	7000K	1.5x4.2mm	350
Xenon (150W)	19	6000K	0.5x1.9mm	180
Xenon (1600W)	37.5	6000K	1.4x4.0mm	800
Xenon (20,000W)	57	6000K	3x11mm	4800
MARC 300	45	5000K	1x3mm	400

[a] From 1986 *Photonics Design and Application Handbook*. Reprinted with permission of Laurin Publishing, Inc., Pittsfield, MA.

physics which says brightness cannot be magnified or concentrated. Since these sources emit light in all directions instead of in a tight beam like the laser, it has to be collected. An elliptical reflector will collect about three times the light of the fastest lens. A rule of thumb for efficient reflectors is that they should be at least 12 or 15 times the size of the source.

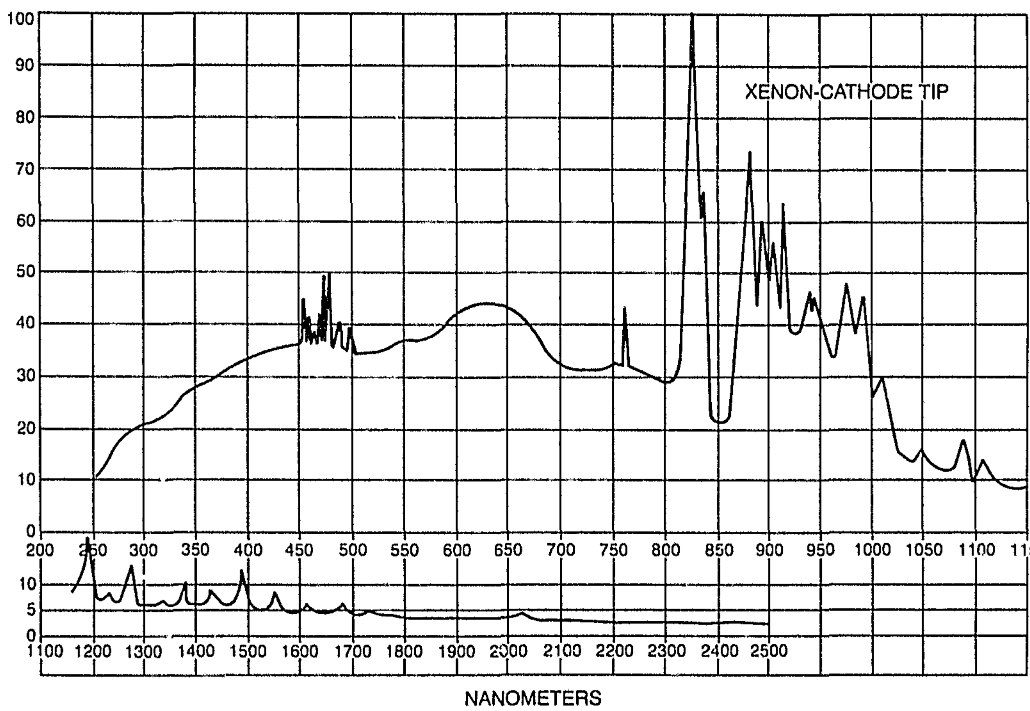
A laser produces light in extremely narrow wavelength lines. This is no particular advantage for fingerprint work. However, a light source that produced most of its output near one wavelength would have the advantage of electric efficiency and easier filtering.

All light sources produce a continuum of light, even if most of their output is in many spectral lines such as the mercury lamps. This continuum must be well blocked by filters, especially at the fluorescent emission wavelength. Large sources mean large expensive filters must be used. Small intense sources can use smaller filters, but then cracking and durability in the transmission of the intense power become a problem.

Some types of fluorescent tubes have narrow line phosphors that emit in the visible range. They are cheap and electrically efficient. However, their very low luminance makes it impossible to deliver a bright light onto a print.

Clear mercury sources can be mounted in reflector spot bulbs, and these are frequently found as cheap sources of medium intensity ultraviolet light for such uses as crack detection with fluorescent dyes that absorb in the ultraviolet range. In 1980, I built a lamp using a 2 cm × 5 cm metal halide source that had an indium iodide filling so that most of the visible output was near 451 nm. These lamps have a 15,000 hour lifetime, and are cheap, and their AC arcs run on cheap ballasts. However, the problems of a large reflector led to a bulky nonportable lamp. It had a filtered output of 2 W of very good quality blue light from a 400 W input.

The designers of the three commercial lamps have all accepted the problems of expensive DC power supplies and shorter lifetimes in order to obtain a small bright arc. The Unilite and Quasar use an xenon source whose output spectrum is shown in Figure 3. The broad output from the ultraviolet to the near infrared ranges gives a versatile lamp that can be filtered to obtain output anywhere in this spectrum. However, this means only a small output at any



WAVELENGTH NANOMETERS	% OUTPUT
250 - 300	2.489
300 - 350	3.504
350 - 400	4.577
400 - 450	5.245
450 - 500	5.626
500 - 550	5.214
550 - 600	5.729
600 - 650	6.472
650 - 700	5.649
700 - 750	4.682
750 - 800	4.682
800 - 850	8.914
850 - 900	6.284
900 - 950	6.788
950 - 1000	5.848
1000 - 1050	2.871
1050 - 1100	1.953
1100 - 1150	1.402
1150 - 1200	1.593
1200 - 1250	0.846
1250 - 1300	0.896
1300 - 1350	0.705
1350 - 1400	0.931
1400 - 1450	0.919
1450 - 1500	1.118
1500 - 1550	0.701
1550 - 1600	0.513
1600 - 1650	0.515
1650 - 1700	0.552
1700 - 1750	0.428
1750 - 1800	0.345
1800 - 1850	0.306
1850 - 1900	0.306
1900 - 1950	0.306
1950 - 2000	0.268
2000 - 2050	0.345
2050 - 2100	0.230
2100 - 2150	0.230
2150 - 2200	0.230
	100.000

Figure 3. Spectral emission curve for xenon compact arc lamps. Reproduced with permission of Photon Technology International, Inc., Princeton, NJ.

desired wavelength. For example, only about 6% of the radiant output is emitted between 450 nm and 500 nm.

The Lumaprint uses a MARC lamp whose visible output spectrum is shown in Figure 4. There is very little ultraviolet in the lamp and only a little violet. There is more infrared radiation not shown on this chart. The filters cut off at 520 nm, so that we can use about 40% of the visible output of the lamp. The lamp was originally designed for use in the cinema where white light is desired. We are now contracting with the lamp manufacturer for an enhanced blue version of the source.

The source has to be filtered to remove the unwanted light. The development of these filters has been the most difficult part of the whole lamp. The requirements are severe. To detect natural fluorescence, the blocking or optical density of the filter from 550 to 600 nm has to be only 10^{-7} to 10^{-8} of the incident light, otherwise the yellow light of the lamp will compete with that of the fingerprints. The sensitivity of the eye falls off rapidly above 650 nm, so that yellow fluorescence can be distinguished against a faint red background.

However, we expect closed TV systems to be used more and more for fingerprint recording and enhancement in the future. The new vicon TV tube is sensitive up to 900 nm, and the CCD chips used in black-and-white solid state cameras are sensitive to 1,100 nm. If there is any light at these wavelengths when the camera iris is wide open to detect weak fluorescence, the background will be recorded by reflected light. Therefore this 10^{-7} blocking level must be continued throughout the near infrared.

Our first attempts using commercially available filters failed. Inevitably, the filters cracked or came apart or failed to transmit enough light. The present custom designed filters are a composite of six functions and succeed in passing 85% of the light in the 450-520 nm band for a total of 15 W. The output then falls very sharply until the 10^{-7} blocking is achieved at 580 nm, and this blocking is maintained far into the infrared.

The MARC lamp is reflected and focused to a 9 cm diameter circle at about 30 cm working distance in front of the apparatus. A fan provides cooling air that holds the outside temperature to 50° C. As it is only 15 cm in diameter, 30 cm long and weighs 4 kg, it is handheld and portable for use at the scene of a crime. The power supply that draws 350 W is separate (Figure 5).

USE OF LIGHT SOURCES

Because of the excellent blocking and 200 mW/cm^2 power density in a uniform 9 cm circle and also because of its portability, the lamp can be used to search a crime scene for natural prints. As they are very faint, natural prints can usually be seen only where the background has a very low fluorescence, such as on black or metal surfaces. However, fingers often pick up some contaminating fluorescent material, and these prints may be seen. In addition, the lamp will reveal hairs, semen stains and many small fluorescent objects.

It can be used to excite any fluorescent dyes that have some absorbance in the blue and fluoresce in the yellow or orange above 550 nm. Such fluorescent dyes are now being used on faint cyanoacrylate developed prints with great success. I like to use the laser dye 4(Dicyanomethylene)-2-Methyl-6-(*p*-dimethylaminostyryl)-4-*H*-pyran (DCM) because I can transfer it to cyanoacrylate in moments and no background develops on metal or polyethene bags. It also excites Rhodamine 6G well.

A third major use is in exciting fluorescence at room temperature in ninhydrin developed prints that have subsequently been treated with zinc chloride. They are excited around 490 nm. Because many papers contain optical brighteners that are excited by ultraviolet and violet light, the background will fluoresce too, leading to reduced contrast. This can be greatly reduced by adding a long pass blocking filter that cuts off the exciting light shorter than 470 nm. This wavelength band also works well in exciting the zinc complex formed by developing prints with the newly synthesized ninhydrin analog, 5-methoxyninhydrin.

The availability of these relatively cheap sources should stimulate the development of new fluorescent methods of latent fingerprint detection.

DISCUSSION

Stoilovic: On which surfaces can you detect pure, natural fluorescence? A large difference in order of magnitude exists between natural and contaminated fluorescence.

Watkin: Natural fluorescence can be detected only because it is so weak on the surface it has

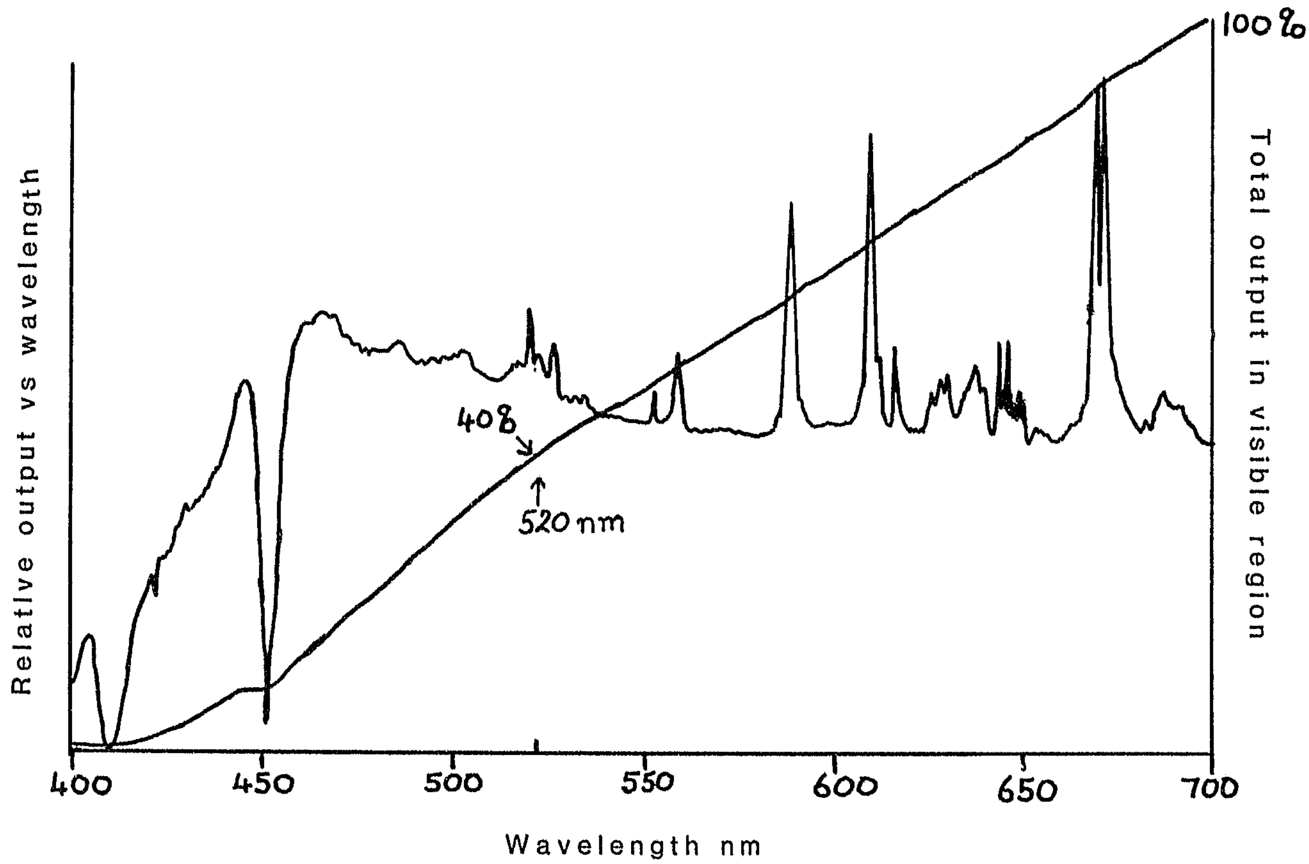


Figure 4. Output spectrum of high intensity indium lamp in nm.

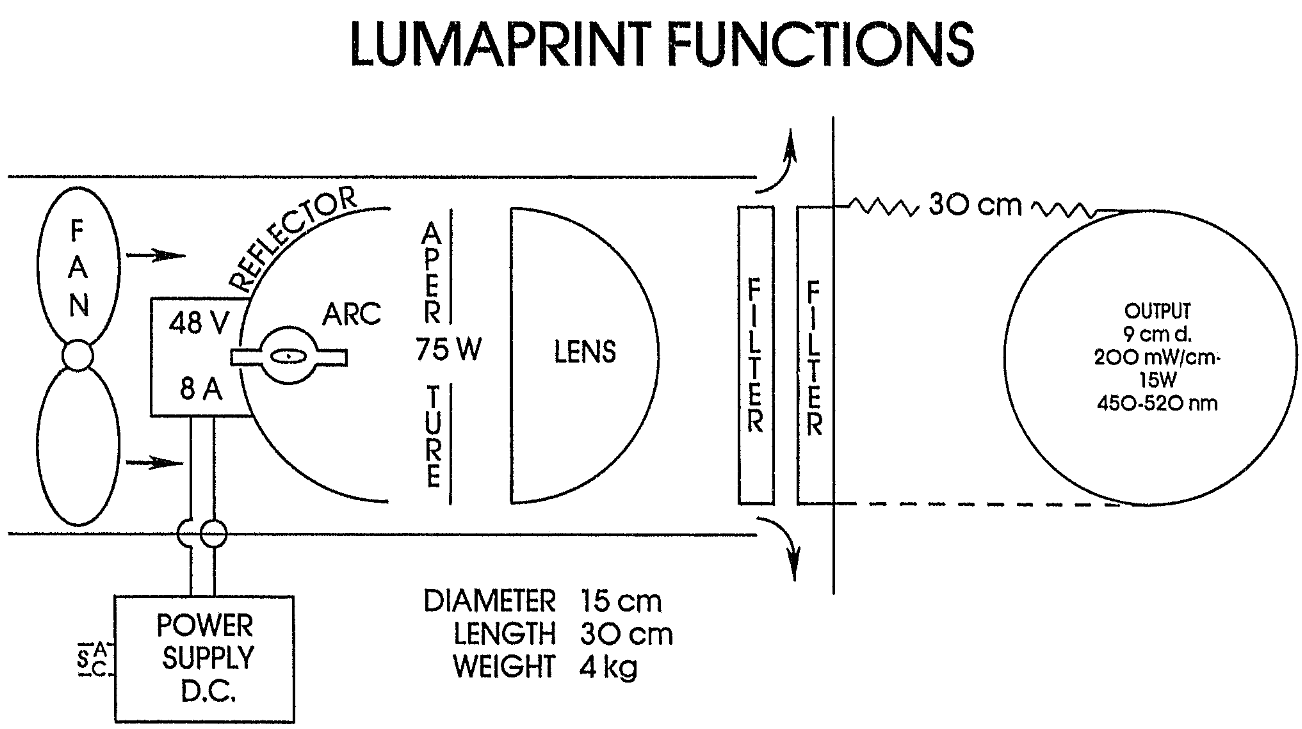


Figure 5. Diagram of the portable MARC lamp.

practically no fluorescence of its own. Therefore, it is useful only on such things as a black material on the surface of a gun. I have discovered fluorescence of this sort on black fingerprint tape used on bombs and other low fluorescent surfaces. Trying to detect natural fluorescence on paper or varnished wood is useless, but you may find contaminating fluorescence that is bright enough to detect.

German: In detecting inherent or natural luminescence from latent prints, I have found that the substrate the print is on is just as important as what contaminants might be on the finger. If half of a styrofoam cup is covered with aluminum foil and a fingerprint is deposited on the cup such that half is on the foil and half on the styrofoam, no latent print will glow on the aluminum foil 99% of the time. If an Oreo cookie package is examined under a laser or arc lamp, you will find beautiful latent prints by inherent luminescence wherever the white lettering is, but you will find nothing on the rest of the package.

Watkin: I agree.

Jackson: What is the life expectancy of your arc lamp?

Watkin: Short, because of the high operating temperature of this lamp. For use in cinemas, the lamp is rated for 50 uses of 2 hours each. We are getting more use than that, but we are not prepared to claim how much more. The new blue light that we are trying to develop may have a longer life.

Jackson: How do the Royal Canadian Mounted Police know that the latent print they developed is 28 years old?

Watkin: They recognized the print, and the man that left the print had not been there for 28 years.

Jackson: What is the replacement cost of your lamp?

Watkin: Three hundred dollars.

LUMINESCENT ENHANCEMENT PROCEDURES FOR THE DETECTION OF LATENT FINGERPRINTS

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Luminescent methods of latent fingerprint detection are more sensitive than conventional techniques. Inherent luminescence exploits the presence of luminescent compounds within the deposit, and therefore no chemical treatment of the deposit is necessary. In practice, only some fingerprints exhibit useful inherent luminescence, and in many cases, some treatment of the fingerprint is necessary if identification information is to be obtained.

Processing large volumes of casework by a luminescent technique can be tedious, and it is efficient to use these procedures as a secondary treatment to enhance marks already developed by an existing technique. The luminescent method is therefore used only on marks that require improvement, the good quality marks being processed in the normal way. Two techniques that are particularly suitable to luminescent enhancement are the ninhydrin method and Super Glue (cyanoacrylate) fuming. Ninhydrin is used universally for detecting fingerprints on documents, and Super Glue fuming is becoming increasingly popular for detecting latent prints on surfaces where powders lack sensitivity.

The basic item of equipment required for luminescence is a light source, and lasers have received considerable attention for fingerprint work. Lasers are expensive, and not many operational laboratories possess one. To bring luminescent techniques into operational fingerprint bureaus in Australia, some of our research effort was directed towards investigating an alternative light source to a laser.

ENHANCEMENT OF NINHYDRIN PRINTS

The effect of various metal ions on the color of ninhydrin fingerprints has been known for some time. For example, zinc produces an orange color and cadmium, uranium and nickel, a red color. These colored compounds are due to the formation of a coordination complex between the purple amino acid-ninhydrin compound (Ruhemann's purple) and the metal ion. It is the zinc and cadmium complexes that are effective in the enhancement of ninhydrin fingerprints.

To produce consistently good results with the secondary ninhydrin treatments, the initial ninhydrin processing must be done under controlled conditions to prevent high background. Excess heat must be avoided, and it is preferable to allow prints to develop at room temperature at a relative humidity of 60%-80%. If accelerated development is essential, this can be achieved by using a microwave oven containing a water-soaked pad (Stoilovic *et al.* 1986). Further curing at room temperature improves the results. It is important to appreciate that the enhancement procedures are to improve weak fingerprints, not to improve ones that have been processed by a poor technique. Good technique not only improves the result obtained by zinc or cadmium complexation but also improves the initial ninhydrin fingerprint quality.

Zinc Chloride Treatment

Herod and Menzel (1987) showed that the orange zinc/Ruhemann's purple complex formed when ninhydrin fingerprints were treated with a zinc chloride solution was luminescent when illuminated by light from an argon ion laser. In this way, weak ninhydrin fingerprints could be enhanced.

Our investigations of this complex showed that the luminescence was significantly improved if the fingerprint was cooled to 77° K (the temperature of liquid nitrogen) (Kobus *et al.* 1983a). At this temperature, the luminescence could be produced through the use of a xenon arc lamp with appropriate filters instead of a laser. Significant enhancement of weak ninhydrin fingerprints was obtained as illustrated in Figure 1. No observable difference has been noted between the quality of prints visualized at 77° K under xenon arc illumination and that obtained by laser illumination. Such a comparison is shown in Figure 2, where even in the weak areas of the fingerprint, no difference in detail can be seen.

[illegible]

Although the use of liquid nitrogen [illegible] complicates the procedure [illegible] presents no difficulties. The document bearing the latent prints is placed in a tray [illegible] covered with the liquid nitrogen, and [illegible] photographed [illegible]. As with the luminescent technique [illegible] with the method is essential to [illegible] good results.

This technique has been used successfully on [illegible] in Australia. However, some problems [illegible] experienced [illegible] of the [illegible] papers such as newsprint [illegible] paper. These problems [illegible] related to the [illegible] of moisture [illegible].

Although [illegible] (Schumann's [illegible]) [illegible] humidity [illegible] 1990) [illegible] these problems do not occur on good quality [illegible] paper but the [illegible] quality papers such as newsprint [illegible] poor results obtained on these surfaces.

[illegible] the chemistry controlling the [illegible] of the zinc complex is not simple and [illegible] difficult to control [illegible]

[illegible]

[illegible]

[illegible]

(a) (b)

Figure 3. Comparison of ninhydrin fingerprint on newsprint after treatment with zinc chloride (a) and cadmium nitrate (b).

different spectroscopic properties. One of these analogs, benzo[*f*]ninhydrin, was also evaluated by Jones and Pounds (1982), who agreed with Almog that its sensitivity was comparable to that of ninhydrin.

The benzo[*f*]ninhydrin/amino acid complex formed in the fingerprint also reacts with zinc chloride to produce a luminescent product. Menzel and Almog (1985) in a study of neodymium:yttrium aluminum garnet (Nd:YAG) lasers for fingerprint development found that this complex was well suited to excitation by this type of laser, since its excitation maximum of 530 nm coincided with the laser emission (532 nm). Lennard (1986) synthesized 13 ninhydrin analogs and evaluated their performance as fingerprint reagents in comparison with ninhydrin. He found that two of the analogs, 5-methoxyninhydrin and benzo[*f*]ninhydrin, produced complexes with zinc and cadmium that had greater luminescent intensity than did the corresponding ninhydrin complexes. With these complexes, luminescence was produced at room temperature using xenon arc lamp illumination.

Thus, there appears to be potential in casework for analogs of ninhydrin, and an operational evaluation of benzo[*f*]ninhydrin and methoxy ninhydrin would be most useful.

ENHANCEMENT OF SUPER GLUE PRINTS

Fuming with Super Glue has become a popular technique for developing latent fingerprints on a range of surfaces. It has been particularly useful on polythene bags and on nonabsorbent surfaces usually amenable to powders. In common with vapor techniques in general, it offers improved sensitivity over powder techniques.

The color of fingerprints developed with Super Glue can vary from white to almost transparent, depending on the quality of the original deposit. Weak prints are often difficult to discern, especially those on white and light colored surfaces, and enhancement of the marks is needed in these cases.

Polymerized Super Glue can absorb dye solutions and therefore is amenable to staining with a luminescent compound. The laser dye Coumarin 540 in ethanol has been shown to be a useful reagent for the enhancement of Super Glue and is particularly effective on reflective surfaces such as aluminum foil (Kobus *et al.* 1983b) using a xenon arc lamp as an excitation source.

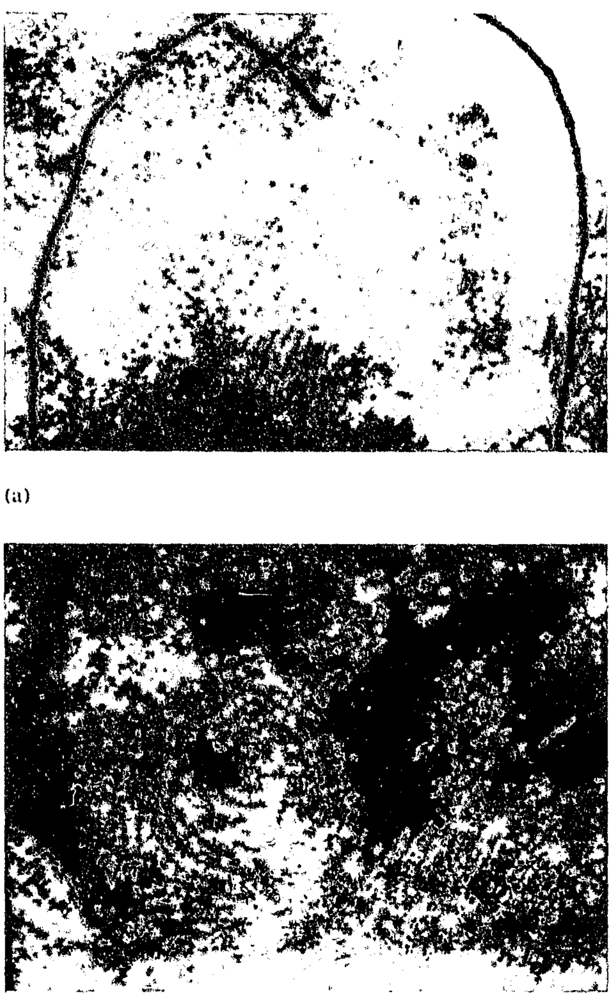
Burt and Menzel (1985) achieved luminescent enhancement of Super Glue prints using Rhodamine 6G either as a dusting powder with magna powder or as a staining solution in methanol in combination with argon ion laser excitation. Recent work by Stoilovic has indicated that Rhodamine 6G in acetonitrile instead of ethanol has improved selectivity for Super Glue.

Yong (1986) recently completed an extensive investigation into reagents designed to color or impart luminescent properties to the Super Glue prints. Of the luminescent stains, he found that one prepared from NBD chloride and ethanolamine was very effective and offered distinct advantages over Coumarin 540. He also synthesized analogs of cyanoacrylate esters in an attempt to make the polymer inherently colored or luminescent. One compound that showed promise was synthesized to include a 7-chloro-4-nitrobenzo-2-oxa-1,3-diazole (NBD) chloride/ethanolamine tag on an anthracene/2-cyanoacrylate adduct. The compound showed good luminescent properties and reasonable selectivity for fingerprints. Unfortunately, volatility is reduced when the basic cyanoacrylate molecule is modified. One of the properties of Super Glue that contributes to its success is its inherent volatility. However, this work shows great promise and could be the forerunner to a range of tailormade compounds suitable for vapor processing of latent prints.

A CASE EXAMPLE OF LOW TEMPERATURE LUMINESCENT ENHANCEMENT OF A NINHYDRIN FINGERPRINT

In a case of fraud in Western Australia, it was alleged that gold was purchased with a stolen check. The check had been processed with ninhydrin and a weak fingerprint developed. The check was submitted to the Forensic Science Research Unit in Canberra by the fingerprint bureau in Western Australia so that we could attempt to enhance the print.

The check was treated with zinc chloride solution and the luminescent print photographed at 77° K under xenon arc illumination. Significant enhancement of the fingerprint was obtained, particularly in the region of the delta as shown in Figure 4. An accused person was identified, and this fingerprint evidence was subsequently used in a successful prosecution.



(a)

(b)

Figure 4. Fingerprint on check developed with ninhydrin (a) and after enhancement by the zinc chloride process (b).

This case is specially interesting because some time after the conviction of the accused, the fingerprint was said to be a forgery. It was claimed that the accused had a number of silicone rubber replicas of his own fingers which had been made from a latex mold. It was further claimed that these were seized by the police and used to forge the fingerprint. Support for the allegation of forgery came from identification experts outside Australia.

Some silicone fingers were produced by the accused using his manufacturing process. These fingers showed detailed ridge structure and could be used to produce fingerprints that responded to ninhydrin development and the zinc chloride enhancement.

A crucial issue in the evaluation of the case was that the fingerprint photograph used in the trial was actually a reversal of the original photograph taken of the luminescent fingerprint. This was done quite innocently so that the ridges were black in the manner usually encountered. This reversal had not affected the identity of the fingerprint in any way but had resulted in much of the background of the check being lost. It was this reversed photograph on which opinions of forgery were based. When the original luminescent photograph was examined, features that may have been interpreted as damage or imperfections in the ridge pattern due to the latex mold could be explained as due to the check background. In addition, there were variables characteristic of the inflexible nature of the rubber finger that were not on the crime mark and also characteristics of a genuine print such as pore marks that were present on the crime mark.

In light of this information, there appeared to be no scientific evidence to support the accusation of fingerprint forgery. After an extensive enquiry, the Attorney General of Western Australia decided there was no case of forgery to be answered.

In summary, it was vital for original fingerprint material to be examined, and an understanding of the scientific procedures used was necessary to appreciate the features of the luminescent mark.

DISCUSSION

The potential is great for the use of luminescent procedures to enhance fingerprints previously developed with ninhydrin or Super Glue. In each case, an existing highly successful technique is maintained, and a second chance of producing a result is created. If this is preceded by an initial search for inherent luminescence in important cases, there would be three opportunities for a result on the same print. Since a xenon arc lamp provides an effective and cheaper alternative to a laser, these systems could be introduced into operational laboratories.

The detection and identification of latent fingerprints are parts of an analytical science in their own right. They require the use of sound scientific procedures and logical scientific reasoning, points that are well illustrated by the case example given. Fingerprints remain the only form of trace evidence which provides unique identity, and the field deserves as much research attention as any other area of forensic science. A great opportunity exists for scientists and identification experts to work together to further the development of this important subject.

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AN HISTORICAL OVERVIEW OF AUTOMATED FINGERPRINT IDENTIFICATION SYSTEMS

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Fingerprints and the science of fingerprints have been around for many years. Law enforcement fingerprint experts, both 10-print and latent, have worked wonders for years with this science, identifying even criminals who have scarred and mutilated their fingertips to avoid identification. Latent print experts have accomplished equally remarkable feats. For example, latent print experts put together the composite of a fingerprint of Martin Luther King's killer and searched through thousands of fingerprint cards to finally find a match. Spectacular cases like these, as well as the many day-to-day cases, illustrate both the strengths and the weaknesses of the fingerprint identification science over the past 40 years.

The principal strength of a fingerprint was that, once a candidate identification was found, the examiner had the skill and tools to positively identify the criminal. The principal weakness was that the file sizes were continuously growing, and searching these files for a possible identification, whether for 10-print files or latent prints, was slow, painstaking work. Crime rates, meanwhile, increased more rapidly than the ability of law enforcement authorities to meaningfully index fingerprints. In the courts, the need for fingerprint identifications increased as other forms of evidence were undermined by adverse court decisions.

Although advances have been made in the detection of latent prints, little else has changed to help the fingerprint examiner cope with the ever increasing file sizes. Other factors, such as increased mobility of criminals, make identification harder. The Federal Bureau of Investigation's (FBI) Identification Division was one organization hard pressed by this situation, and it decided to see if something could be done about it. Today we have a whole family of automated fingerprint identification equipment capable of searching millions of fingerprint cards and finding the one candidate. None of these systems replace the need for trained fingerprint examiners and latent print experts, but they greatly extend their effectiveness by allowing them to search large files quickly and accurately.

The contributions of Automatic Fingerprint Identifications have been dramatic. Serial murderers in California have been caught because of these new systems; the crime could not have been solved without this new technique. Old crimes, on the books for years, are solved because this new equipment can quickly, accurately and economically search large files of criminals for a match.

THE FBI'S START

In 1934, the Identification Division began its first experiments in the use of computers to search and match fingerprints. Data from fingerprint cards were keyed into punched cards, and a card sorting machine was used to sort through the punched cards. After multiple passes, cards of a certain class were extracted and their corresponding fingerprint cards examined for an identification. However, these punched card machines could only sort through the card classifications and possessed no matching capabilities. This effort was not successful and was soon abandoned. It did provide Hollywood with film footage showing the FBI searching fingerprints which was shown for decades after it was no longer operational. Hollywood has finally updated itself to keep pace with law enforcement. The new movie "Beverly Hills Cop II" shows Eddie Murphy developing a latent fingerprint on a matchbook using Super Glue and searching the resulting fingerprint using a NEC automated fingerprint system.

In the early 1960's, Carl S. Voelker was the Section Chief and Robert Payne the Assistant Section Chief of the Technical Section of the FBI Identification Division. Voelker realized that, as the workload of the Identification Division grew, either many more people would be needed (which would require added space) or some of this workload would have to be automated. In 1963, representatives of the FBI Identification Division approached scientists at the National Bureau of Standards (NBS) to request advice regarding the feasibility of automating the ID's fingerprint identification operations. Voelker was the main contact between the FBI and NBS. Joseph H. Wegstein, a NBS mathematician, and Raymond T. Moore, a NBS scientist, began helping the FBI explore the feasibility of automating its fingerprint identification operations.

Between 1963 and 1966, a study of the overall problem of automatic fingerprint identification was undertaken jointly by the FBI and NBS. This study included a review of available image processing and pattern recognition technologies, as well as a study of the efforts of organizations outside of the FBI to automate their fingerprint processing. As a result of this study, it was concluded that automatic fingerprint identification would be feasible only if the following two capabilities could be demonstrated:

1. Inked fingerprints must be scanned and the minutiae (ridge endings and bifurcations) automatically detected and their relative positions and orientations recorded.

2. Computer programs must be developed to match the minutiae from two fingerprints and tell if they were likely to have come from the same finger.

It was decided to turn to industry for a demonstration of the first of these capabilities, while Wegstein would personally attempt to develop and demonstrate the second.

In December 1966, a Request for Quotation was submitted to industry asking for the development and demonstration within 12 months of an engineering model (laboratory demonstration) that would automatically read, locate and record fingerprint minutiae directly from individual inked fingerprints on a standard fingerprint card. A preproposal conference was held in January 1967 at FBI Headquarters to discuss the engineering model fingerprint reader. This conference was attended by representatives of more than 30 interested companies. As a result of proposals submitted, two identical contracts were let in June 1967 to build an engineering model of an automatic fingerprint reader. One contract was with Cornell Aeronautical Laboratory, Inc. (now Calspan Corporation), of Buffalo, New York, and another was with the Autonetics Division of North American Aviation, Inc. (now Rockwell International) of Anaheim, California. Clarion Swonger was the Department Head at Cornell Laboratories, and I became the project engineer on this contract. S. M. Fomenko and J. A. Luisi were principally involved in the work at North American Aviation. While this reader development work was going on, Wegstein and Moore at NBS, assisted by John Rafferty, began developing software programs to match (compare) the fingerprint data to be derived from these engineering model readers. Later, Walt Penzak, a fingerprint examiner at the FBI, joined the NBS team to help in fingerprint matters and computer coding.

In these early years, the contact between engineers and scientists on one side and the fingerprint experts on the other was reserved and somewhat formal. We asked questions about all aspects of both 10-print and latent fingerprint identification but could answer few of the experts' questions. The FBI's fingerprint experts felt a natural skepticism that the tasks that had taken them years to learn could be accomplished by a computer. This was accompanied by concern that this automation effort might make the experts unnecessary.

By 1969, both Cornell Laboratories and North American Aviation had built engineering model automatic readers that could read fingerprints with enough precision to warrant proceeding to the next step. In addition, Wegstein at NBS had successfully demonstrated computerized procedures for matching fingerprint data produced by both readers and had also begun to devise automatic procedures to find the center and orientation of each fingerprint. It was time to move out of the laboratory and into the operational area. In 1970, the FBI evaluated both fingerprint reader efforts and awarded Cornell Aeronautical Laboratories the contract to build the first prototype automatic fingerprint reader. The prototype was supposed to:

1. Evaluate, test and perfect reader equipment so specifications could be developed for production models to be used in daily Identification Division operations.

2. Acquire a data file of sufficient size to test and perfect other portions of an overall automatic fingerprint identification system for the ID.

I was the project manager for a team of engineers and programmers that included Tom Liesing, Carol Ripley, George Jackson and Drs. Roy Wass and Phil Fischer. During these early years, the work done by Wegstein and Moore of NBS reached into every corner of the technical work being carried on by the FBI. Wegstein, the mathematician, led the efforts to develop matching, registration and classification algorithms, aided by analysis of results and constructive criticism by Moore. Moore interacted heavily with the contractors to aid in directing their efforts to develop readers to enhance the fingerprint image and locate the minutiae. No technical activity was carried out at the FBI without their counseling, and no activity by the contractors went on for long without their probing and evaluation.

With the fingerprint reading and matching development under way, the FBI now turned to studying the system aspects of automation. They awarded a contract in 1971 to North American Rockwell Information Systems Company, later to be called Rockwell International, to conduct an 8-month systems requirements study of the Identification Division to identify the manual work procedures that could be automated, as well as to plan for the eventual incorporation of an automatic fingerprint scanner into the system. The study team from Rockwell included Project Manager Richard McCord, Dick Gibbons, Ward Trumbel, George Aubrey, Frank Torpey and Walter Johanningsmeier. The findings of the study were submitted later in 1971. Rockwell found that the automation of the Identification Division was technically and economically feasible. They also recommended that, because of the large file size and heavy workload, the system should be implemented in three phases called AIDS-I, AIDS-II and AIDS-III. Automated Identification System (AIDS) was the overall project name. There was no warning of the new meaning that would befall this name before the century was out.

The FBI extended the 1971 study contract with Rockwell to allow for followup efforts for detailed systems design specifications. Some of the Rockwell people involved in this subsequent study work included Tom Hansen, Michael Ferguson, Odell Hamilton, Jack Burgard, Mike Gilchrist, Jerry Knaup, Ron Hilderbrand and Art Rabinowitz. The pace of the automation effort picked up in 1972, both with development of the fingerprint reader and in the startup of the automated record keeping system known as AIDS-I. The prototype fingerprint reader from Cornell Laboratories was delivered and installed at the FBI's Identification Division in Washington in August and September of 1972. It became a showpiece at the Identification Division, even attracting the attention of the Director, and its presence helped lend credibility to the whole automation program. It was also a main attraction on the FBI tour when the International meeting of the International Association of Identification was held in the summer of 1973. Some test fingerprint data bases were read using this equipment, but extensive testing had to wait until a staff could be assembled.

The FBI was primarily interested in 10-print identifications. That is their main mission, in spite of the very fine latent print operation that they have. In these early years, and in the years to come, the Identification Division management has directed their resources toward the 10-print goal, even when it meant sacrificing a latent print system. It was a conscious decision to allocate resources in the direction of the greatest public good. One might ask why, in the context of automated fingerprint identification, we are talking about the development of a 10-print system? In both the development and the operation of an automated system, latent and 10-print searching are tied together. The early decision to develop a minutiae based system was made because it allowed the 10-print and latent systems to use the same technology, and an effective latent print search system cannot exist if it is not supported by a carefully managed 10-print operation to establish and update the file of active criminals against which to search the latent prints. For these reasons, every agency involved in development of automatic fingerprint identification must eventually address the 10-print operation, even if their major objective is latent searches.

OTHER EARLY RESEARCH WORK ON AUTOMATIC FINGERPRINT IDENTIFICATION

The FBI's work may have started serious research in fingerprint identification, but others were also trying to turn the computer's speed to advantage for searching fingerprints. A variety of technical questions distinguished some of these approaches. The FBI had as its objective solving the manpower problem for the 10-print search, but it had directed its efforts so that it could also use the techniques for latent print searches. The key to this was selection of a minutiae based system. However, others were searching for solutions using other techniques. In the early 1970's, laser scientists at KMS Inc., in Michigan, wanted to use the ability of a laser image processor to compare two images. They built a device to search a whole file of images through an optical comparitor. The inherent distortion in the rolled print and the inability to address the problem of latent print searches eventually decreased the interest in these devices. Another laser approach was advanced by McDonnell Douglas, and this approach, as well as the KMS system and a system by Sperry, were evaluated by an independent organization called the Search Group in 1971. The McDonnell Douglas system was later put into limited operation in New York City, where it was used to solve crimes involving latent prints. It made several identifications but was eventually abandoned. Both the KMS and McDonnell Douglas systems use comparison of whole images rather than detection and comparison of minutiae. These are not, therefore, minutiae based systems in our usual context. The laser based approach by Sperry was developed by Dr. Donald McMahon and differed somewhat from the KMS and McDonnell Douglas approaches. Here, the laser was used to read the ridge flow of the fingerprint, and that information was then converted to digital form. Several pattern flow features were developed from the pattern information, and these were stored and later matched against similar features read from a search print. This technique was used to search rolled fingerprints on a 10-print card, but it could not be used for latent prints since it was not minutiae based.

The Search Group and the Law Enforcement Assistance Administration (LEAA) sponsored an operational test of the Sperry system in Arizona in 1976. The system had poor selectivity, which resulted in a large number of possible hits being dropped, and the image retrieval system on microfilm was slow and suffered from poor image quality. Its inability to search latent prints was probably the biggest problem and eventually doomed this approach when other techniques showed promise for working with latent prints.

In March 1972, Joe Wegstein of NBS was asked to put together a session at the Carnahan Conference in Louisville, Kentucky, then the premium conference on electronic security measures. Papers were presented on the fingerprint developments by KMS, McDonnell Douglas, Sperry, New York State and the FBI's system under development at Cornell Laboratories. The 1972, Carnahan Conference was one of the first sessions in which competing systems could be compared, if only during discussion, and the various approaches to fingerprint reading and matching debated. Benchmarking a system by reading and matching a fixed set of cards was discussed, but no one was ready to take that plunge. All participants had learned that the superficially simple task of reading and matching fingerprints was in fact deceptively difficult.

Work at New York State

One of the early research efforts by a state identification bureau to investigate the use of automated fingerprint data was started at the New York State Information and Identification System (NYSIIS), in Albany. Dr. Charles Kingston began a research effort in 1965 into the use of minutiae to classify and search fingerprints. This was essentially a manual effort of extracting minutiae data from enlarged fingerprints using overlays. Computer analysis of the data was utilized. From 1967 to 1970, work on minutiae extraction and search programs continued at NYSIIS, utilizing a Calma digitizing unit and a model of a rear projection magnifying unit. Tracing fingerprints to obtain minutiae data was replaced with the use of a rear projection system of enlarged fingerprints via 35 mm microfilm. Work concentrated on reading of minutiae data rather than on matcher development. The NYSIIS Criminalistics Research Bureau, under the direction of Frank Madrazo, contracted with General Dynamics in 1971 to develop a computer controlled semiautomated fingerprint encoding system that would interactively obtain minutiae data. Work into minutiae based fingerprint identification systems at NYSIIS ended about 1974 because of a budget decision, although later automation work was done to enhance their computer based fingerprint classification and indexing system. It is interesting to note that a new administration in Albany initiated an effort in 1985 to introduce a large scale minutiae based automated fingerprint identification system (AFIS) to automate both their 10-print and latent print operations.

Fingerprint Developments in Japan

The National Police Agency (NPA) of Japan started their development effort in 1969 with a request to NEC, a very large Japanese electronics and computer firm, to study the problem of automatic fingerprint recognition. This was followed in the same year with a visit to the FBI, where the NPA and NEC discussed the FBI effort with C. S. Banner of the FBI and Joe Wegstein and Ray Moore of the NBS. Mr. K. Kiji of NEC, then at the NEC Central Research Laboratory, and Mr. Kawashima of the NPA were the early leaders in this effort. Also working at NEC on development of algorithms was Mr. K. Asai.

This development work continued at NEC through the 1970's, accompanied by visits by Mr. Kiji and Mr. Y. Hoshino to the FBI and to the Home Office in London. The NPA issued an additional directive in 1975 for implementation of a system. This system was defined by NEC late in the 1970's using a minutiae based approach that combined detection of the minutiae and the development of the relation data between neighboring minutiae. Relation data are the counts of ridge crossings between nearby minutiae, and they are features in the fingerprint which are judged to be less subject to distortion when matching latent or poor quality prints. A matcher was developed that used the minutiae and relation data to compute a match score.

The NPA's early development efforts were aided by a unique arrangement whereby they placed two guest workers with Wegstein and Moore at the NBS. During 1978, Masatada Seta of the NPA spent a year helping Wegstein evaluate matcher modifications, while in the 1980-81 period, Masashi Takashima worked with Wegstein and developed a latent matching algorithm. When Takashima returned to Tokyo, the NEC system was being installed, and he aided the NPA in preparing for the NEC system.

The first NEC system was installed at the NPA, and conversion commenced in September 1981. Conversion was done in-house, by age, and by October 1982 a large enough file had been converted to allow latent print searches to commence operationally. Over 3 million of the targeted 6 million cards had been converted by June 1987, and both 10-print and latent print operations are continuing.

In October 1983, NEC installed its first system in the United States at the San Francisco Police Department, under the direction of Captain Henry Eidler and Sergeant Ken Moses. This system became operational in March 1984 and made many spectacular early hits, solving old crimes that had been on the books for years. An additional system was soon installed in Alaska, under the direction of State Police Deputy Director James Vaden. A new era began when the California Department of Justice decided to award NEC a contract for a statewide system that would include many remote entry terminals as well as interconnected full use systems. These terminals and full use systems were to be tied to a central system and data base at the California Department of Justice in Sacramento through a remote access network called RAN. This system, now operational but still growing, appears to show the direction of AFIS systems of the future.

Research in the United Kingdom

The early research work carried out in London by the Police Scientific Development Branch of the Home Office reflects the greatly different operational objectives of New Scotland Yard (NSY) and the London Metropolitan Police. In the United Kingdom, 10-print searching activity is not as widely used as in the United States, but heavy emphasis is given to use of latent prints (called scene-of-crime-marks or simply marks in the United Kingdom).

Work started in the late 1960's at the Home Office, which does the development work for NSY, on automating the latent print searching process, but little emphasis was given to the problem of rapid acquisition of a large data base of 10-print data. The scanner mechanism developed by Ferranti, Ltd., for the Home Office was very basic and required almost all fingerprints, latent and rolled, to be first traced. The Home Office sponsored a conference in 1974, the first such international conference specifically for latent prints, which was a valuable mechanism for exchange of information and ideas among the various persons working on fingerprint automation throughout the world. Alan Rapsey was a prime mover in that conference, having seen some of the activity taking place in the United States at the Carnahan Conference in 1972.

The Home Office work was evaluated in 1976 in a pilot test at NSY, where a file was converted and a large number of known and unknown latent prints were searched. On the basis of this test, a system was procured from the Logica Company of London for operational use in London. Ken Millard of the Home Office was in charge of this design, and this system was in full use when the Home Office again hosted a conference on fingerprints in London in 1984.

THE IMPLEMENTATION PHASE AT THE FBI

The first stage of the FBI automation work ended in 1973 and the second stage began. The demarcation is arbitrary, but two things happened in 1973 which moved the FBI out of research and into the development stage. First, in March they hired the start of a professional research and development staff to direct their automation effort by hiring me from Cornell Laboratories. This provided the FBI with the start of an in-house research and development staff to direct contracts, do engineering work, and plan the many steps necessary for operating an automated fingerprint system. The NBS scientists were still involved, but this in-house staffing indicated the FBI's commitment to the work still to be done, to prove the effectiveness of this new technology and to initiate large scale operations. Later in 1973, I was joined by Dick McCord of Rockwell, who ran the AIDS-I operation, and Frank Torpey, also of Rockwell, who joined the computer staff of the FBI to support the Identification Division's automation effort. In 1974, Walt Johanningsmeier joined the automation staff to aid in directing the implementation of AIDS-II, and in 1977 Stan Zack joined from Rockwell to aid in implementing some of the special hardware necessary for fingerprint reading and matching. Second, the FBI started their operation of the AIDS-I system for automated recordkeeping. Although there were contingency plans and backup plans, everyone knew that they were committed and there was no turning back.

My first assignment at the FBI was to direct the evaluation of the prototype fingerprint reader that I had designed and built at Cornell Laboratories. It seemed inconsistent to me that I would be both the builder and the evaluator of this first fingerprint reader, and a more arms-length relationship would have been desirable for these two jobs. However, in practice, Wegstein and Moore provided my conscience for the job, and I had no trouble with conflict between builder and user. A more difficult problem in those early days was finding any measures to use to evaluate a reader that was the only one in the world. Given two readers, we could have easily devised tests to find which was best, but having only one reader, we struggled to determine if it was a solid foundation upon which to build our automated identification system. My next assignment was to plan the procurement and write the specifications for the production fingerprint readers. In many respects, it is easier to build the reader than to tell someone how you want it built. In June 1974, the FBI awarded a contract to build the required five production-model automatic fingerprint readers to Rockwell International of Anaheim, California. These were to be delivered to the FBI over the next 2 years. The design of these production model readers was based on the image scanner, image processor and minutiae detection techniques developed at Cornell Laboratories, but an extra computer was added to process the ridge flow and minutiae data through Wegstein's R92 Registration algorithm. Even I was surprised that the FBI had finally committed itself to fingerprint automation, but none of us realized how much further we had to go.

Automatic Classification Work

During 1973 and 1974, Wegstein at NBS was developing an automatic classification technique using the data produced by the prototype Cornell Laboratories reader. A fingerprint examiner could easily determine the pattern type after looking at the ridge flow data produced by the reader, and so it seemed reasonable that a computer program could also determine this. When we looked at the workforce doing classification of fingerprints and the processing advantages that would result from automation, we found incentive to develop this automatic technique.

In 1975, we decided to augment Wegstein's work in automatic classification by starting a parallel effort at Rockwell, under contract to build the production readers. This work was to use the ridge flow data available from these production readers. Under the direction of Dr. John Riganatti, this work continued in phases up to 1978, when we took a critical look at the chances for success. We decided that, for the file sizes and work loads involved for the FBI's work, we could not achieve our goal. Since the reader had not been designed initially to accomplish this difficult task, the result was not surprising. However, we had anticipated that this might happen and had designed a semiautomatic 10-print searching system that used the manual National Crime Information Center classification for our file conversion and subsequent pilot search system.

In 1983, I was able to initiate a new phase of automatic classification development aimed at defining a new reader that would be specifically designed to do automatic classification. The first phase of that work was completed before funding was interrupted, but much more must be done before the difficult goal of automatic classification is achieved.

The FBI's Production Readers and File Conversion

The first production model Automatic Fingerprint Reader Systems unit was delivered to the FBI by Rockwell in November 1975. The remaining four units were delivered between this date and August 1977. This equipment was used initially in evaluation and training in preparation for the massive file conversion ahead. To begin the conversion of the Criminal Master Fingerprint File into an automated data base, it was necessary to develop processes to be followed and then train a group of personnel in those processes. This training included the operation of the fingerprint readers and the manual steps necessary to prepare fingerprint cards for conversion. A study of the fingerprint file was initiated in 1975. This study showed that, at that time, 94% of all activity in the criminal file was caused by arrestees born on or after January 1, 1929. The size of this portion of the file was estimated to be approximately 13.5 million fingerprint cards. With five readers converting up to 1,000 cards per hour, we estimated it would require 300 employees 3 full years to complete this conversion. The conversion would have to be done on a two-shift per day basis with 150 employees assigned to each shift. As a result of this study, a request to Congress was prepared asking for 300 employees per year for 3 years beginning October 1, 1977. Only 290 work years were approved, and we never had more than 240 people on board at any time. Dick McCord was the chief manager of this conversion project.

The original concept of the FBI's system was that not all rolled fingerprint cards could be read by the automatic reader, and a semiautomatic reader would be necessary to handle these poor quality cards. This same reader, with different software, would also be used to read latent prints. We defined such a reader and in January 1976 bought the hardware to put together a prototype model of a semiautomatic fingerprint reader system. This allowed skilled fingerprint operators to examine a 10X enlargement of a fingerprint on a cathode ray tube (CRT) screen and point out identifiable minutiae within the print. The resulting digitized information from the fingerprint was functionally the same as that produced by the automatic reader.

Wegstein of NBS had developed an algorithm for a high speed minutiae matcher that had been extensively tested in software on data from the prototype reader. We needed a hardware version, much faster, to test larger data bases and to develop the pilot system. In October 1976, the Calspan Corporation delivered to the Identification Division a high speed prototype M41 fingerprint matcher (called the Wegstein Matcher in honor of Joe Wegstein) for comparing minutiae data from an incoming inked fingerprint card against the automated data base of minutiae from fingerprint cards on file. A fingerprint examiner will then visually verify if the listed candidate(s) is identical to the person represented by the incoming fingerprint card.

One of the distinct features of this matcher was that it was designed to work only with 10-print data and not latent print data. Joe later designed a M82 matcher that would do both 10-print and latent print matches. Although this first unit was a prototype, it was used to implement the total 10-print searching system in which up to 14,000 fingerprint cards were fingerprint searched each day with this one unit.

The large scale file conversion started at the FBI in March 1977, using the production fingerprint readers to convert fingerprint data to digital form. On September 30, 1980, this conversion project was completed after the conversion of approximately 14.3 million fingerprint cards into a digital data base. Of course, once the conversion was started, all of the new additions to the file had to be converted also, so the total number of cards converted was larger than the file size when we started. In addition, a conversion operation has to continue until a full sized search operation is implemented to keep the converted file up to date.

The Ten-Print Pilot and Production Search Systems

Before a 10-print search system could be used online for doing production searches, it was necessary to run a pilot operation in parallel with the manual searching system. It was necessary to learn how to operate such a complex system, but more important, it was necessary to prove to fingerprint examiners and management that the automated search was an accurate and viable system. The pilot system started in 1979 was named the Automated Technical Search Pilot System, and results of parallel tests proved that the automated system could do a more consistent and more accurate search than the examiner alone. Walt Johanningsmeier had direct Identification Division management responsibility for this project.

The pilot system was such a resounding success, both from the accuracy achieved and the manpower savings, that it was expanded to all searches in the main fingerprint file at the Identification Division. First the pilot was expanded to include several other portions of the fingerprint file, especially the hard portions where searching is difficult because many people have the same fingerprint class. Then a whole new software system was written to handle the total file. By March 1983, the total fingerprint file of all criminals born after 1928 was on-line, and all searches were routinely done in this new system. The original plan did not call for that to be accomplished until the advent of AIDS-III, so this new system beat its planned birth date by about 5 years.

THE FIRST LATENT PRINT SYSTEMS IN THE UNITED STATES

The work done for the FBI between 1967 and 1975 put two American companies in the business of building fingerprint identification equipment. In 1973, the Calspan Corporation had left its status as a not-for-profit research laboratory, and its management was anxious to find commercial ventures that would broaden its government business picture. At that time, it was the only company doing business with the FBI in the field of fingerprint reading and matching. Robert Kelso, then president of Calspan, set up a commercial venture called Calspan Technology Products to sell its fingerprint reader systems to state and local governments, but the FBI, by means of a competitive procurement, awarded a contract in June 1974 for five production fingerprint readers to Rockwell International and thereby put a second American company in the fingerprint business. Richard Snyder at Rockwell saw the opportunity and set up the Printrak Division to define and sell fingerprint products to state and local police agencies.

The ready availability of money from the Federal government for law enforcement assistance made all of this possible. This was handled through the LEAA of the Department of Justice, and 90% of the cost of each of these early systems was paid for by Federal funds. The competition between these two companies was fierce but relatively short lived. With no systems in actual operation and no equipment upon which to benchmark their performance, the claims and counter claims of accuracy and performance were beyond any range that seemed reasonable to those familiar with automated fingerprint approaches.

Of course, both companies basically used the reader design developed for the FBI by Cornell Laboratories. Calspan was competing against its own reader design. This was made possible because of a clause in the FBI contract whereby the FBI retained a royalty free license on any patents for the use of any government agency in any country in the world. Since all uses being considered in this market were government uses, the Cornell Laboratories patents were, in effect, in the public domain. The two companies were trying to make claims of superior performance when both used the same reader design. The matcher designs were different, but we now know, in hindsight, that the matcher performance is heavily dependent on the type and quality of data being read by the automatic reader.

The Rockwell people installed a prototype system in the San Jose Police Department where operational experience and some latent fingerprint hits were gained. It is reported that this early prototype equipment was unreliable and was later changed to a more updated Printrak system. This installation continues to be the only site in California with a Printrak system, although the California Department of Justice operated a Printrak system for years before changing to the NEC system presently installed there.

The next Rockwell system was installed at the Royal Canadian Mounted Police (RCMP) in Ottawa, Canada. This was a special system and was not partially paid for by LEAA funds.

The first regular Rockwell system operational in the United States was the MAFIN system, used by the Minneapolis Police Department, the St. Paul Police Department and the Minnesota State Crime Bureau. Joe Corcoran at Minneapolis and Dick Cich at St. Paul were instrumental in starting this operation in February 1979. This was followed in March 1979 by a system shared by the Montgomery County and Prince Georges County police departments in Maryland. Paul Smith and Henry Jones were the key latent print people to bring up this system. In October 1979, Peggy James brought the Houston Police Department's system into operation. Two systems were put into operation in Brazil at Bahia and Sao Paulo in October and November 1979, respectively. A system in Miami, Florida, was made operational in December 1980 under the direction of Chris Nasberg. Finally, a system became operational in 1981 at the California Department of Justice. It was used for latent print searches only. Then the LEAA money ran out. To some, it spelled the end of the AFIS era, for without the Federal money, how could any local police agency afford the million dollars or more that was required to obtain even a small system? There was a pause of several years, during which no new systems were sold, and both Rockwell and Calspan sold their fingerprint operations to others. When Calspan could not obtain even one contract against the much larger Rockwell, the Calspan management decided in 1977 to get out of that business. Soon after that, Calspan sold the remaining prototype equipment to Fingermatrix, Inc., and the parent Calspan company was bought by Arvin Industries. Calspan has continued to do engineering work for the FBI, but it is not active in manufacturing and marketing fingerprint identification equipment. Rockwell had, on the other hand, been too successful, and they had sold systems that it was having difficulty delivering. The Printrak operation was transferred to the Collins Division of Rockwell, who decided to get out of the business. The lack of LEAA money was definitely a factor in that decision. Management changes took place, and eventually Rockwell found a buyer who would assume its obligations to its existing customers. The Thomas DeLaRue Company of London took over the Printrak operation about 1980.

The impact of these first systems on the future of AFIS cannot be underestimated. Their successes helped pave the way for new systems, but these users suffered through years of operations when their contractor openly wanted to dump them. It is worth pausing to look at these first latent print operations in the United States. The latent print examiners and operational people who had managed to buy one of those earlier systems had to fight, as all first timers have to, in order to convince others that it is worthwhile to buy this new technology. Most of them literally had put their jobs on the line when they asked for their systems. Fortunately, with that criteria to obtain a system, these people could stand the subsequent pressure, and none of these early systems went under. They had to work hard to make their systems do the job under difficult conditions. The Printrak users organized themselves into a group to exchange data on how to operate these systems and how to get the most number of matches from their searches. Their first meeting, however, was for a different purpose. In April 1978, the officials of the Montgomery County Police Department invited all buyers of Printrak systems together to discuss the problem of how to get Rockwell to deliver on their promised system accuracy. Enough was known to indicate that the systems would not perform as promised. They were told, by the temporary Rockwell management, that if they did not like what was to be delivered, they could sue. Most of the users had committed themselves to this new technology, and so they accepted their systems and worked to make them perform as well as possible. Subsequent meetings of the Printrak Users Group have been more harmonious, with the Printrak staff hosting the meetings in Anaheim, California, and the user group exchanging information on operations and maintenance. This user group has done much to promote the use of automated fingerprint systems and has devoted a portion of its annual meeting to an open forum designed to help educate outsiders on how to specify, buy, test and use their automated system. One of the early attendees at these Users Group meetings was Sgt. Ken Moses of the San Francisco Police Department. Since he had arrived on the scene after the end of LEAA money, he was faced with the dilemma of how to raise the money to buy a system for San Francisco. He presented papers to the user group on how to raise both money and citizen awareness for an AFIS system. Eventually, Moses accomplished his goal, and in 1983 San Francisco bought a NEC AFIS system.

The Royal Canadian Mounted Police System

The RCMP has done much to contribute to the automation of fingerprint searching, and the techniques that they have used in their development are different and interesting. It is worth considering them as a special case, because the system they operate is not duplicated anywhere in the world. The RCMP first automated in 1970 under the direction of Supt. Chris Tiller by bringing in an Ampex Videofile system. The images of several fingerprints on the card were captured on the old 2-inch variety of video tape, and the 10-print classification was used to index this image on tape. Because of the size of the file, many tapes were required, and only a few could be on-line at one time. When a search was performed, the search card was classified, and a computer program determined all 10-print classifications that should be examined as possible matches. This possible list was then run at night against the whole file of video tapes, and those images that should be examined were read from the storage tape onto a work-in-process (WIP) tape. The next day this WIP tape was run and fingerprint examiners looked at video images and picked out the matches. This appears to be the first large scale operation in which verification of fingerprint matches was done using a CRT screen. The RCMP made this work efficiently for them, but two factors caused them to look elsewhere for better automation. First, the Videofile equipment is analog, not digital. The recording on tape, after being read many times, has to be regenerated, and each successive regeneration of the tape degrades the image a small amount. Digital signals can be regenerated infinitely without being degraded. The RCMP Videofile is now in its 8th regeneration. Secondly, the large number of video tapes that must be loaded every night presents an operational difficulty. More important, it limits the accessibility of the file. In general, identification bureaus are going to on-line files and near instantaneous replies to serve law enforcement better and more economically. The RCMP upgraded their operation in 1978 with the addition of a Printrak search system. Their present operation, under Inspector Bruce King, runs a mixed 10-print and latent print search operation, using Videofile images to verify 10-print searches and digital images to verify latent print searches. In 1985, RCMP took delivery of a digital image retrieval system from Printrak which is able to accept images both from a direct scanner of the fingerprint card and from a Videofile tape. The video image is digitized and stored on a very high density optical disk.

The Explosion of AFIS Procurements

The forecasters who thought that the end of Federal funds for fingerprint systems would doom this infant industry were wrong, and 1986 seems to be the year that proved the point. After NEC installed the San Francisco Police Department's system in late 1983, the publicity and public pressure for these systems mounted. The ability of the state and municipal agencies to choose between vendors has been a positive factor that has helped many agencies proceed with their system procurements. The activity on AFIS procurements seems to have peaked in 1986 with a frenzy of Request for Procurements and benchmark tests by many agencies that managed to obtain funds to buy their fingerprint systems. These new systems usually have dual capabilities, for 10-print and latent print searches, and they have digital image retrieval systems for the storage and quick retrieval of fingerprint images. If there is one system of this later group which is a trend indicator for the future, it is California's Cal-ID system. This progressive system uses a large data base of both minutiae and digital images, located in Sacramento, that is available on-line to a network of remote terminals for both searching and image retrieval. For large users, such as Los Angeles County, a full use system is defined that has a local data base and matcher, but it can also communicate with the State system for more extensive searches. This network system, called Remote Access Network, or RAN, appears to make the best use of central facilities while allowing municipal police departments to implement systems to handle their particular crime problems. Key architects in the development of this system at the California Department of Justice have been Tony Doonan, Gary Cooper and Fred Wynbrandt.

The First Federal AFIS System

Considering the number of police departments in the United States and the political diversity of their direction, it is not surprising that the first truly Federal system did not get implemented in the United States but rather overseas. It was not in England, which has only recently implemented a system in London and is still struggling to identify the direction it would take for a Federal system. It is not Japan, which has the political arrangement of a unified federally directed police. Japan has implemented the system only in their central Tokyo prefecture, although sometime in the future they will carry it out to all prefectures. The first federal system is in Australia, where a system set up in New South Wales serves all of the states of Australia as a Federal data base and identification clearinghouse. This NEC system has a single central data base and terminals for entry of 10-print and latent print searches in the states of Victoria, Queensland, Western Australia, Southern Australia, Northern Territory, Tasmania and A.F.P. The system was installed in May 1986 and became operational all through the country in August 1987.

THE NEXT CHAPTER

I have attempted to lay out the brief history of the development of AFIS. This is only the first chapter of what is sure to be a very long book. That book will eventually tell of the many crimes solved with the present and future AFIS systems. It will also tell of the new applications found for this AFIS technology in the field of personal identification. This future book will tell of the terrorists caught, the drug smugglers found, the illegal aliens turned back and the frauds of the world uncovered with this computerized technology. One of the elements that is critical for all persons who would prey on civilization is that they must hide their true identity. When we can routinely take that ability to hide away from them, they can no longer prey as easily upon us.

DISCUSSION

Kobus: A nationwide NEC system has recently been set up in Australia with a central data base in Sydney, and all the major centers are hooked in by terminals. The system has proved its worth in a number of identifications already where people have identified interstate criminals from their terminals.

Stock: I know about the Australian system, and I apologize for not mentioning it specifically. There are a number of systems that I did not have time to mention. I could write a book on this whole subject. I understand the Australian system is a very fine operation.

IMAGE ANALYSIS AND PATTERN RECOGNITION TECHNIQUES IN FINGERPRINTS

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Matching fingerprints to help identify individuals has been successfully pursued over many decades by local, state, civil and military authorities. In recent years, much emphasis has been placed on applying computer technology to automate the processing of fingerprints. The incentive is the burgeoning volumes of fingerprint records building up in collections, which need to searched to identify individuals. Much has been achieved in the refinement of effective systems to gather and handle fingerprint information, but formidable problems remain.

One basic problem is the inability to process poor quality fingerprints. Existing systems still cannot match the ability of an expert human examiner to identify successfully the ridge pattern and to separate it from the many distortions and imperfections present in all fingerprints.

Another problem is that although effective automated fingerprint matching systems based on the comparison of minutiae are commercially available, automated matching minutiae is not identical to the pattern matching performance of the human examiner who utilizes higher level pattern features in addition to minutiae. Numerous variations on the Henry classification system established in the last century have evolved into efficient schemes for partitioning large collections into subunits amenable to efficient and reliable searching.

APPROACHES TO BINARIZATION

The binarization of the fingerprint is the first step in any automated procedure for extracting feature information. An inked fingerprint may typically be digitized at a spatial resolution of 500 lines to the inch, with 64-256 levels of intensity quantization. Figure 1(a) shows an example of such a digital image, together with the gray- level histogram in Figure 1(b). This example illustrates some of the problems with nonuniform contrast conditions between left and right portions of the fingerprint.

A variety of thresholding algorithms may be used to achieve a binary image. An automated thresholder of this kind may use various measures in the global histogram. A useful criterion for picking the threshold is to maximize the sum of the sub- and superthreshold entropies in the histogram (Kapur *et al.* 1985). The result of such an automatic binarization is shown in Figure 1(c). This criterion is based on the assumption that an essentially binary image filed has been degraded by the processes for which no *a priori* information is available.

Whatever single threshold criterion is used, the result is generally unsatisfactory, since the local contrast conditions vary substantially between and within inked fingerprints. Consequently, locally adaptive strategies are called for. Figure 1(d) shows an attempt to binarize the fingerprint by employing a maximum entropy criterion to histograms computed in local regions. In this case, the local entropy was computed for 64×64 pixel regions and results rendered on centered 32×32 pixel sections. Fifty percent overlapping was used to produce the final mosaic reconstruction.

This kind of binarization is a great improvement, but it does not exploit fully the common characteristics of all fingerprints to separate ridge features from the other confusing structures. For example, the ridge structures have characteristic thickness and spacings.

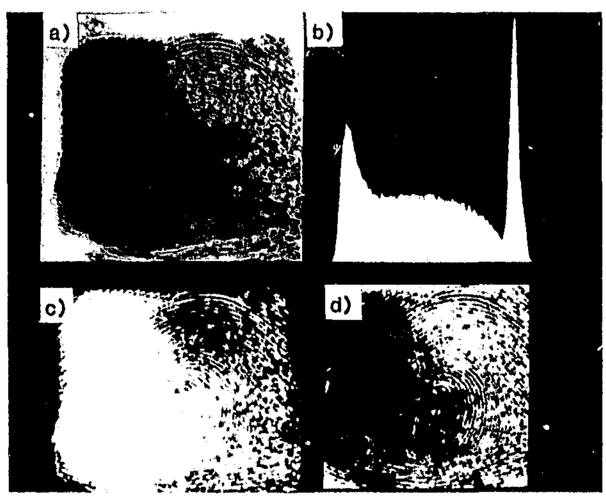

Figure 1. (a) Digital fingerprint quantized at 500 pixels/2.5cm, 8 bits/pixel. (b) Corresponding gray level histogram. (c) Global entropy threshold. (d) Local entropy threshold.

The next step in the improvement of the binarization comes from the use of a spatial frequency filter to preserve only the ridge-like features aligned to prominent flow patterns.

Figure 2(a) shows a 512×512 pixel power spectrum. At this scale, the spectrum betrays only global structure. Figure 2(b) shows a local 128×128 pixel power spectrum, revealing more detailed ridge flow. Figure 2(c) shows a mosaic of a 32×32 pixel power spectrum. At this scale, the ridge flow conditions within each block are relatively simple for most regions of the print. Figure 2(d) shows the result of plotting the directions corresponding to the maximum value computed for the 32×32 pixel local power spectrum. The flow patterns may be reliably detected in regions that exclude the focal points (core or deltas) or regions of poor quality.

A binarizer may be created to exploit such information directly by employing a template to provide the basis for deciding how to remap gray-scale pixels to binary values. Figure 3 illustrates such a template.

The goal here is to create a rectangular template aligned orthogonally to the direction of flow. Flow direction may be readily computed from energy concentration in a local power spectrum. (It is typically computed from a 32×32 pixel neighborhood.) This template is used to gather local contrast information from which a decision may be made about the polarity of the center pixel. Many different kinds of templates have been used successfully. In the example shown in Figure 3, the template is separated into two regions. The center pixel is mapped to black if the average value in the center region is lower than that for the peripheral regions, and the converse occurs for the white pixels. The slit may be given finite thickness. If the thickness is too great, more distortion occurs for highly curved ridges. Figure 4(a) shows the effect of such a filter using a template size of 14×3 pixels.

Immediate improvements may be seen over the local thresholding approach. The limitation with such a filter is that the geometry of the template must be accurately matched to the ridge pattern. Unfortunately, fingerprints vary greatly in ridge spacing between the extreme of a male thumb and a female little finger.

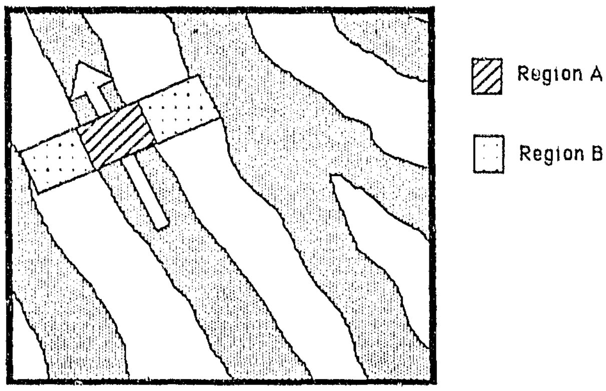

Figure 3. Rotating Slit template for binarization.

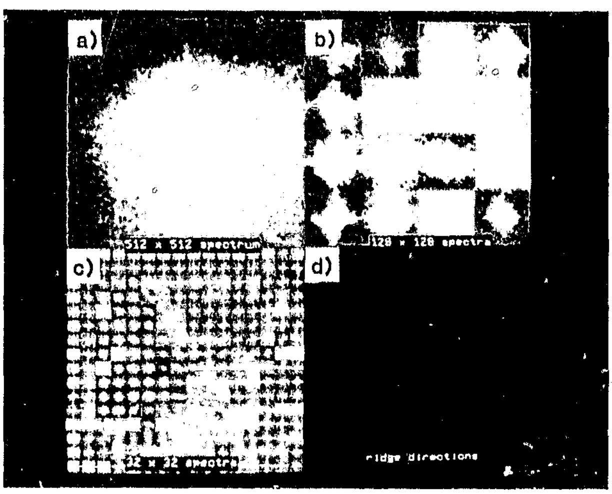

Figure 2. Fourier power spectral data from Figure 1(a). (a) A 512 × 512 pixel power spectrum. (b) 128 × 128 pixel power spectrum. (c) 32 × 32 pixel power spectra. (d) Local ridge directions.

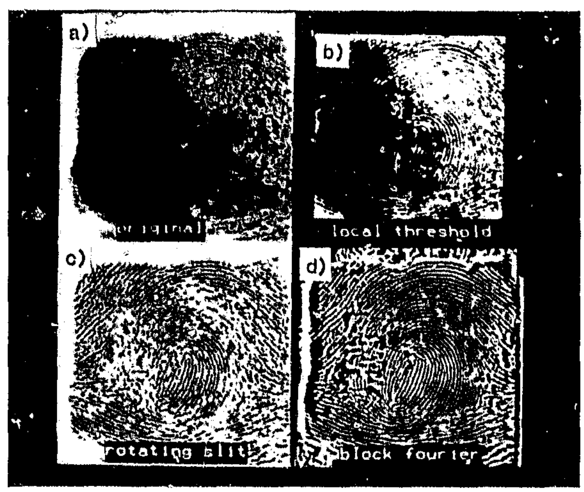

Figure 4. Comparison of different binarizers. (a) Original fingerprint. (b) Local entropy threshold. (c) Rotating Slit binarizer. (d) Block Fourier amplitude boosting binarizer.

Even within a single fingerprint, the variations from one side to the other are often significant, leading to distortions in the resulting binarization. Another problem is that the geometry of the template is optimized to particular kinds of ridges, for example, those of low curvature. In the important focal point regions, considerable distortions may be created in the binary image. Finally, any asymmetric template approach places heavy reliance on the accuracy of the local ridge direction computation. In regions of poor quality, this information may be in error, and in high curvature regions no well defined direction exists.

Further improvements in performance are obtainable by employing aggressive filtering that is more naturally adaptive to changing local conditions. This method makes direct use of the properties of the Fourier transform. A common characteristic of all fingerprints is that they exhibit strong local periodicity in almost all regions. Figure 2(c) illustrates this by the concentration of energy in locally computed power spectra. An effective enhancement of the fingerprint may be achieved by selectively boosting features associated with locally periodic components and suppressing other features. Moreover, by applying the enhancement locally, the results may be adapted to locally varying conditions. Figure 5 shows the steps involved in the Block Fourier filter.

The Fourier transform is computed for a 32×32 pixel section, and the amplitudes of the transform are boosted in a nonlinear fashion. Features that are already prominent will be disproportionately boosted, and periodic features will be emphasized. Various different boosting regimes have been tested and optional results achieved by cubing the amplitudes. Figure 5 summarizes the attention that must be given to the windowing, overlapping and band-pass filtering of a large number of local regions. It is useful to suppress spatial frequencies outside the range of valid ridge-to-ridge spatial frequencies expected for fingerprints. The suppression of low spatial frequencies corresponds to the control of local contrast variation, and the suppression of high spatial frequencies removes noise. For a 512× 512 pixel fingerprint image, a total of 1,024 overlapping 32×32 pixel transforms must be computed.

Figure 4(d) shows the combined effect of these operations. This filter demonstrates aggressive ridge reconstruction even in extremely poor quality regions. Some distortion remains in high curvature regions where the periodicity is not so pronounced.

The block spatial frequency filtering approach offers promise for further enhancing the binary image by taking account of the flow conditions in extended neighborhoods. Figures 6, 8, and 10 show further comparisons of the Rotating Slit and Block Fourier binarizers. If the quality is good (Figure 6), the differences are minimal. Poor quality (Figure 8) and the intrusion of defects such as creases (Figure 10) reveal the superiority of the Block Fourier approach.

Another promising avenue for improving the binary image lies in the direction of interpreting information from minutiae to rectify degradations. For example, one may detect the presence of break pairs, deliberately fix the break by altering the original gray-scale image and refilter that region. The beneficial effects of doing this are propagated beyond the initial repaired region by boosting the periodicity within a local region.

MEASUREMENT OF QUALITY

Methods for measuring fingerprint quality are just as important as the algorithms for automated

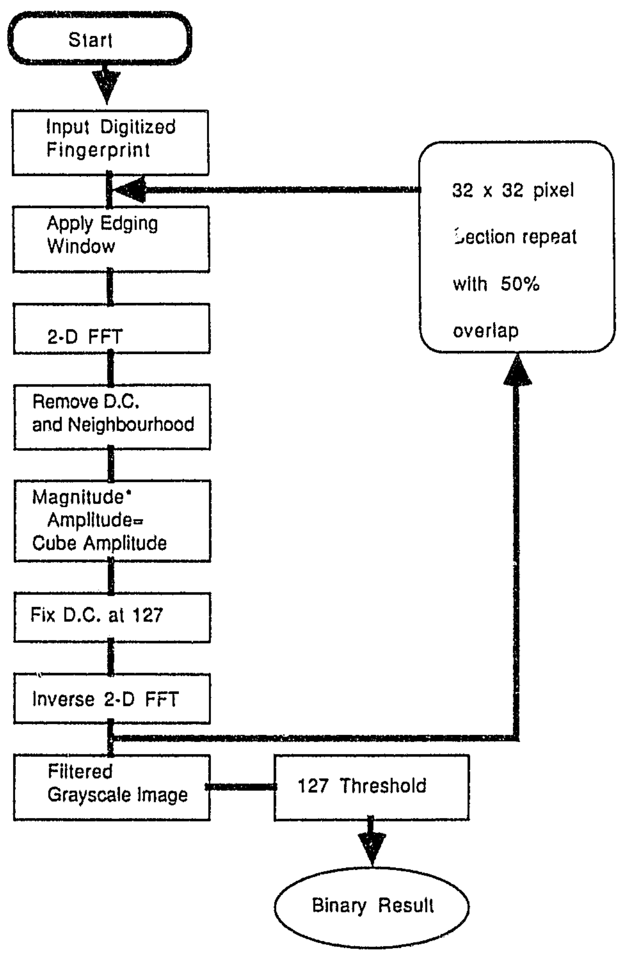

Figure 5. Basic steps for implementing Block Fourier binarizer.

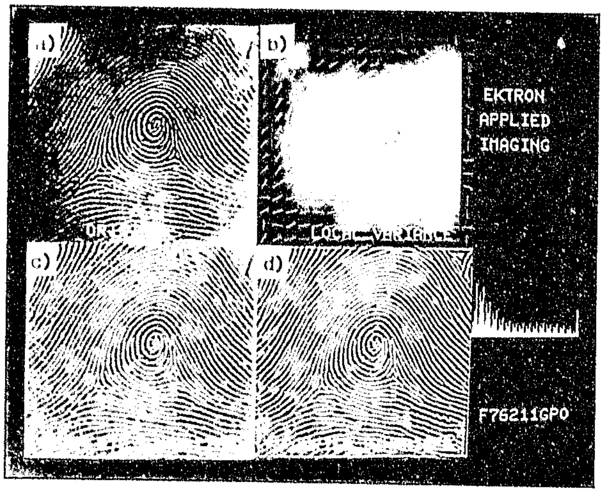

Figure 6. Preprocessing algorithms applied to fingerprint case 12(a). (a) Original. (b) Local variance map and superimposed ridge directions. (c) Rotating Slit binarizer. (d) Block Fourier binarizer.

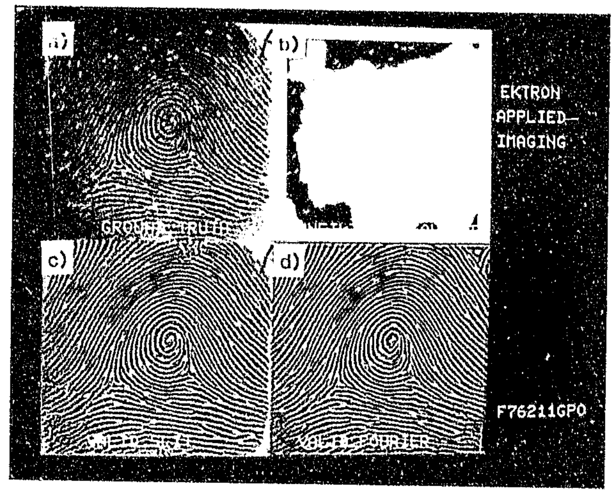

Figure 7. Minutiae data case 12(a). (a) Original fingerprint with ground truth minutiae superimposed. (b) Quality map with angle discrepant, break pair, and valid minutiae superimposed. (c) Valid minutiae from Rotating Slit binarizer. (d) Valid minutiae from Block Fourier binarizer.

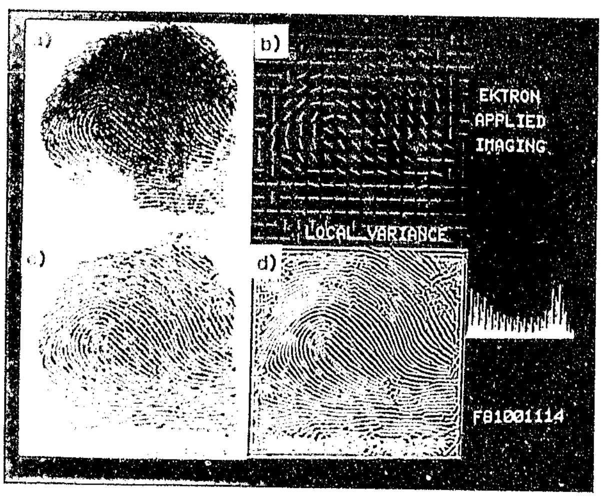

Figure 8. Preprocessing algorithms applied to fingerprint case 10(b). (a) Original. (b) Local variance map and superimposed ridge directions. (c) Rotating Slit binarizer. (d) Block Fourier binarizer.

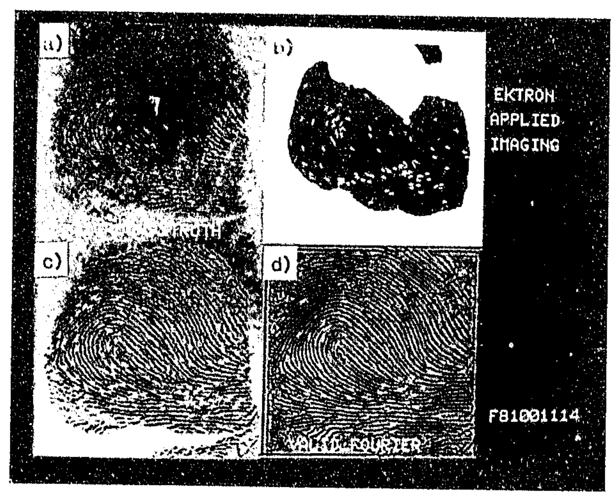

Figure 9. Minutiae data for case 10(b). (a) Original fingerprint with ground truth minutiae superimposed. (b) Quality map with angle discrepant, break pair and valid minutiae superimposed. (c) Valid minutiae from Rotating Slit binarizer. (d) Valid minutiae from Block Fourier binarizer.

feature extraction. Inked fingerprints are notoriously variable in quality because of a variety of problems, including underinking, overinking, and the presence of extraneous printed features.

Fingerprint quality can be quantified by measuring the local variance found in an enhanced gray-level image from which all features dissociated from ridges has been removed. Figures 6(b), 8(b) and 10(b) show the result of plotting the local variance of a 64 × 64 pixel region, spanning each pixel in a Block Fourier filtered image. High intensity in the variance map is associated with good ridge contrast. A threshold may be set below which the ridge-to-ridge spatial frequency content is not considered high enough to qualify as a sufficiently high quality region. The correct threshold may be set heuristically by examining a large number

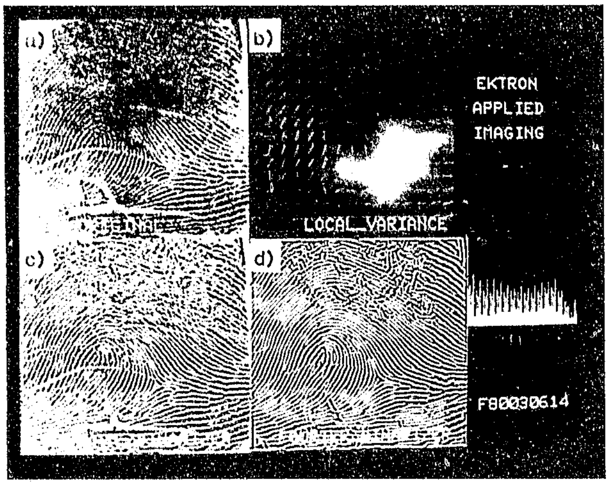

Figure 10. Preprocessing algorithms applied to fingerprint case 8(a). (a) Original. (b) Local variance map and superimposed ridge directions. (c) Rotating Slit binarizer. (d) Block Fourier binarizer.

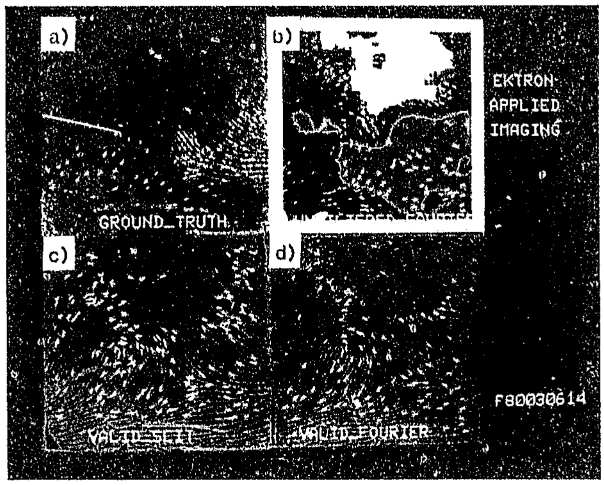

Figure 11. Minutiae data for case 8(a). (a) Original fingerprint with ground truth minutiae superimposed. (b) Quality map with angle-discrepant, break pair and valid minutiae superimposed. (c) Valid minutiae from Rotating Slit binarizer. (d) Valid minutiae from Block Fourier binarizer.

of fingerprints suffering from a variety of problems. This sort of quality index will map the limits of the pattern area. Figures 7(b), 9(b) and 11(b) indicate two threshold levels for variance. The lighter shade corresponds to a variance of 40 or less and the darker shade, a variance of 128 or less.

The notion of quality is linked to the particular feature of interest. For instance, the quality of mapping produced by such a simple scheme does not provide a totally reliable basis for selecting valid minutiae, and it is necessary to add further constraints. One often used method is to define additional poor quality regions corresponding to minutiae which exceed a heuristically determined threshold.

DETECTION OF MINUTIAE

Minutiae are the principal basis on which fingerprints are handled in current automated systems. The detection of the positions and angles of ends and bifurcations is based on well known algorithms (Banner and Stock 1975) that use the small features found in local (typically 16 × 16 pixel) regions.

Relatively simple pattern recognition concepts are utilized to determine candidate minutiae features and to subject them to a series of qualification tests based on area, perimeter-to-area ratios, consistency of angle with local ridge flow direction and the presence of breaks. In the process of creating minutiae lists for the purpose of fingerprint comparison, it is important to remove items corresponding to regions of poor or unreliable quality. The quality mapping methods previously discussed, for example, serve as a good first step in the elimination of false minutiae. It is necessary to augment this by further criteria for the removal of spurious minutiae. One satisfactory method is to eliminate minutiae that appear in clusters exceeding heuristically determined spatial density.

Although minutiae represent the lowest level patterns found in fingerprints, they may be used to compare the efficacy of different binarization schemes. Figures 7, 9 and 11 compare the application of a minutiae detector embodying only the local variance threshold rejection criterion, as applied to a local slit binarized fingerprint and a comparable Block Fourier binarized fingerprint. Such comparisons have been performed on a set of 13 pairs of variable quality fingerprints ranging from good to extremely poor. In each case, an expert human fingerprint examiner supplied ground truth data to locate the discernable minutiae. Table 1 summarizes the minutiae hit and miss rate statistics found for this collection. It should be emphasized that these fingerprints represented many cases of extremely poor quality. In the process of matching to ground truth data, the criterion for match was a positional tolerance of ± 5 pixels and an angular tolerance of ± 20 degrees.

In all cases, the number of hits recorded for Block Fourier derived minutiae exceeded those taken from a Rotating Slit binary image. In 3 of 26 cases, the number of misses from Block Fourier filtered data exceeded those from Rotating Slit binarized data.

Another way of expressing these comparisons is to construct hit and miss ratios as shown in Table 1. These figures indicate that on average the hit ratio for Block Fourier compared with Rotating Slit derived minutiae is 1.35, and comparable ratios for misses are 0.69. These trends indicate that there is a decisive advantage to using the Block Fourier binarizer for fingerprints exhibiting serious degradations.

The benefits of such aggressive filtering extend beyond the effects on minutiae detectability. One may see from Figures 8 and 10 that the pattern area accessible after binarization may be extended. This has important implications for the extension of fingerprint matching schemes beyond the use of minutiae.

A GOAL FOR THE FUTURE: AUTOMATIC CLASSIFICATION

The next major innovation in the handling of fingerprints will occur in the creation of automated classifications systems to mimic the currently used Henry systems. This is a difficult problem because the need to interpret detail in critical portions of the fingerprint is bound up with the assessment of overall pattern flows.

The basic objective in such a pattern classifier is the accurate determination of core and delta positions. The subsequent steps of tracing (in the case or whorls) and ridge counting are relatively simple.

To make progress in the implementation of such a system, it will be necessary to apply the most advanced concepts currently available in the field of artificial intelligence to interpret knowledge about different aspects of fingerprints. It will be necessary to form hypotheses about the expected structures that may drive lower level interpretation algorithms.

A reasonable next step may be taken by combining the capabilities of current rule-based expert systems with a variety of lower level image analysis tools.

Table 1. COMPARISON OF MINUTIAE HIT AND MISS (FALSE MINUTIAE) RATES USING ROTATING SLIT (R) AND BLOCK FOURIER (F) BINARIZERS

Case	GT	F hits	S hits	F miss	S miss	F/S hit	F/S miss
1a	22	9	1	183	166	9.0	1.1
1b	30	9	7	47	156	1.3	0.3
2a	73	23	14	85	174	1.6	0.5
2b	57	20	10	80	170	2.0	0.5
3a	83	29	18	123	166	1.6	0.7
3b	23	5	5	72	90	1.0	0.8
4a	51	15	10	105	194	1.5	0.5
4b	81	24	21	107	192	1.1	0.6
5a	20	6	5	49	83	1.2	0.6
5b	54	15	9	73	118	1.7	0.6
6a	11	5	2	139	184	2.5	0.8
6b	56	18	11	126	182	1.6	0.7
7a	13	2	1	133	183	2.0	0.7
7b	51	12	3	86	122	4.0	0.7
8a	47	9	8	106	195	1.1	0.5
8b	56	16	4	221	170	4.0	1.3
9a	75	22	12	111	190	1.8	0.6
9b	97	30	19	113	182	1.6	0.6
10a	104	32	30	99	144	1.1	0.7
10b	67	13	5	72	103	2.6	0.7
11a	97	20	22	52	67	0.9	0.8
11b	116	31	34	59	93	0.9	0.6
12a	126	30	29	70	80	1.0	0.9
12b	86	28	31	115	157	0.9	0.7
13a	90	23	21	83	155	1.1	0.5
13b	43	8	4	198	185	2.0	1.1
mean	62.7	17.5	12.9	104.1	150	1.35	0.69

GT REPRESENTS NUMBER OF GROUND TRUTH MINUTIAE.

ACKNOWLEDGMENTS

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AUTOMATED FINGERPRINT IDENTIFICATION SYSTEM OPERATION IN CANADA

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Fingerprints, the most positive means of personal identification known to humanity, are the backbone of every criminal recordkeeping system in the world. Additionally, the ability to link a suspect to the scene of a crime by fingerprint identification is one of the most sought after and valuable pieces of evidence tendered before criminal courts. Too often, the absence of fingerprint evidence means that criminal offenders are not convicted and are free to continue preying on society. Millions of dollars are spent annually by Canadian police departments to record, search, store, compare and identify fingerprints.

Electronic scanning and data processing have made rapid automated fingerprint searching and matching possible in a large collection. The development of the digital optical disk has added a capability to store and transmit high resolution fingerprint images, allowing police agencies to improve efficiency by automating their fingerprint searching procedures and to establish a network (via a communication link) with other automated bureaus.

Order-in-Council Number PC 1614 (1908) sanctioned the use of a system of identification known as fingerprints and ordered that the provisions of the Identification of Criminals Act be made applicable to the said system. In 1911, the Canadian Criminal Identification Bureau was formed with an initial collection of 2,042 sets of fingerprints and conviction records. The Dominion Police was the first custodian of the original collection and remained so until the amalgamation of the Dominion Police and the Royal Canadian Mounted Police (RCMP) in 1921. Fingerprints were classified, searched and stored using hard copy and the Henry Classification System. This system, which used a formula for each set of fingerprints, provided a capacity to file and subsequently search fingerprints without access to a name. This prevented criminals from successfully using an alias to avoid detection of a previous criminal record under another name if they were fingerprinted for further offenses. In 1931, the central repository started a single fingerprint collection where scenes of crime (latent) prints could be searched manually against a collection filed by the Battley classification formula. The Battley formula is a system used for searching a single crime scene fingerprint.

In 1970, the first phase of fingerprint automation in the RCMP was implemented with the acquisition of an Ampex Videofile System for storage, search and retrieval of fingerprint records. Videofile, through batch searching and rapid retrieval, drastically reduced search time. It eliminated manual search of hard copy masters and reduced the workload by 60 person years while still allowing the daily workload of the Fingerprint Bureau to be completed. Although Videofile represented a major breakthrough in the processing of fingerprints, there was still a need to improve the accuracy of 10-print (rolled inked set of a person's 10 fingers on a fingerprint card) searching and to develop a process by which poor quality latent prints could be searched rapidly and accurately through a large collection of criminal fingerprints. In the early 1970's, several companies, funded in part by Federal Bureau of Investigation grants, explored computer scanning and minutiae match as a means to automate fingerprint operations. One of these companies, Rockwell International, Inc., entered into contracts with six police forces, including the RCMP, to develop, fabricate and deliver systems that came to be known as 250 Printrak Scanning Systems. The Force took delivery of this pioneering system in December 1978 and almost immediately began to reap benefits in latent searching which saw unidentified crime scene fingerprint identifications rise from 50 per year to 132 during the first year of operation.

Ten-print searching, using automatic classification and minutiae matching, failed to produce accurate results. In 1980, attempts to use the automatic classifier were abandoned because the sixth generation analog signal, received from Videofile at the print processor, could not be accurately interpreted for ridge structure and minutiae plotting. It was therefore necessary to continue with manual classification descriptors as a major filter before minutiae matching. Improperly recorded fingerprints were a dominant factor in this problem.

By 1983, the Videofile System was rapidly becoming cost prohibitive to maintain, and it was obvious that a replacement for this 1968 technology was essential to the successful continuation of the automation program. De La Rue Printrak, Inc. (DLRP), the company that purchased the fingerprint technology from Rockwell in December 1981, offered to research and develop an image storage system using a new technology that could interface with the existing search system. In August 1984, a contract was signed for a digital optical disk processing and image retrieval system (PAIRS) to replace Videofile.

On April 1, 1877, a contact for Phase IV of Fingerprint Automation was awarded by the Canadian Government to DeLaRue Printrak for an upgrade to their Orion generation automated fingerprint identification system (AFIS) for the RCMP. This project will improve existing 10-print and latent print searching services but also provide the capacity to efficiently and effectively network remote computer-compatible AFIS equipment.

EVIDENTIAL IMPACT OF FINGERPRINTS

Ten-Print Records

A form C-216 is used to record the fingerprints to provide positive identification of the person and to provide personal and criminal record information. This information forms a criminal history record for use in the judicial system.

Police agencies use fingerprint records to compile criminal history profiles, determine outstanding warrants and provide information on suspects in investigations. Courts are informed of record information primarily for sentencing purposes. The dissemination of record information is achieved almost instantaneously by Canadian Police Information Center (CPIC) terminals. The CPIC is RCMP's computerized national repository of all police information. However, these data do not provide the identity of an individual when in dispute. Ideally, the ability to provide 10-print search results while a suspect is in custody would give police and courts the complete and accurate information needed to prevent suspects from slipping through their fingers. Incidents of this nature not only have a negative impact on the judicial process but also attain media attention and generate adverse publicity.

Latent Prints

In this era of new civil rights legislation, physical evidence will play a key role in the successful prosecution of criminal offenders. Some statements and other evidence, which previously was considered admissible in court, will come under close scrutiny in the future. Scenes of crime in Canada are visited by trained identification specialists who are dispatched to thoroughly examine a crime scene for physical evidence. The detection of fingerprints is one of the most valuable pieces of evidence obtainable to link a culprit with an offense. Having found fingerprints at a scene of crime, an identification specialist compares these prints with those of known suspects. If no identification is made at this point, further processing of this evidence is not always completed in an efficient and productive manner. Manual searching, always involving a small percentage of a department's file and usually carried out with good quality latent prints, is time consuming and often fruitless and therefore slips in priority due to the pressure of other duties. Although accurate statistics are not available, as many as 60,000 searchable unsolved latent prints per year are not forwarded for search to the central system. Even if only 3% of these prints could be identified, this represents a loss of 1,800 investigative leads for police. However, if this evidence could be linked to a suspect on the day of detection, investigative time would be drastically reduced, stolen property recovered and other offenses avoided or solved. Often a single impression linked to a culprit has a considerable spin off effect, clearing numerous other offenders and linking other individuals to various crimes after further investigation. The reasons for not forwarding all unsolved latent prints to Ottawa vary, but usually not enough people are available to process the evidence.

CURRENT CENTRAL SYSTEM OPERATION AND CONFIGURATION

The RCMP Fingerprint Bureau is the national repository for fingerprints in Canada and is located at the RCMP Headquarters in Ottawa. The Fingerprint Bureau services all police agencies and government departments in Canada as well as outside police agencies on request.

The Fingerprint Bureau maintained by the RCMP processes fingerprints, both latent and 10-print, through combined manual and automated systems. The fingerprint master collection of 18 million images is archived on digital optical disks by filing the digitized images of the thumb, index, middle and ring fingers of both hands for each record with the Fingerprint Section (FPS) number and finger number embedded into each image during the filing process.

Each optical disk surface has a storage capacity of 100,000 fingerprint images in a compressed state of 25:1. Each compressed image can be decompressed as required for viewing purposes; hence, our current library size for the archive master collection is 176 disks.

A second and third set of image disks are built concurrently with the archive master image disk set, and they represent the 10-print and latent fingerprint image working disks, respectively. The 10-print working image collection is contained on 44 disk surfaces, since only the images for the right and left thumbs are stored and used for image retrieval/verification of 10-print searches.

The latent fingerprint image collection of 370,000 records represents a subset of the master collection and contains suitable prints represents a subset of the master collection and contains suitable prints of criminals up to 20 years old regardless of charge and prints of criminals from 20 to 30 years old if they have been arrested for specific charges such as robbery, breaking and entering or possession. The latent working image collection is stored on 30 disk surfaces and contains the images of the thumb, index, middle and ring fingers of both hands and is used for image retrieval/verification of latent searches.

The RCMP Fingerprint Bureau's operational duties are carried out by the following sections:

1. Criminal Name Index Section
2. Classification Section
3. Quality Control Section
4. Data Control Section
5. Automated Fingerprint Systems Section
6. Certification Section
7. Latent Fingerprint Section

All incoming fingerprint sets, criminal and noncriminal, first go to the Criminal Name Index Section, which attempts to link them to a criminal history (FPS) file by name, using data entry terminals. The terminal operators, who are qualified fingerprint technicians, query the following information if available: names, signature, date of birth, apparent age and sex with a query value derived from the information entered. Respondents, if any, generated by the name search are given a score relative to the query value and the respondent FPS numbers are displayed on the terminal screen in descending score order complete with the 10-finger classification. The operator immediately compares the respondent information against the incoming fingerprints to determine if an identification has been made. If an identification is made at this point, the operator records the FPS number on the fingerprint form and it goes for certification. Fifteen hundred name searches for criminal and noncriminal prints are processed each day, and approximately 30% result in identifications against Criminal History (FPS) files. The remaining 70%, consisting of 700 criminal prints and 450 noncriminal (civil) prints that do not get identified by a name search, are then prepared for a technical search through the AFIS. The criminal prints are reviewed by technical search through the AFIS. The criminal prints are reviewed by latent fingerprint examiners for selection of those to be added to the latent image and minutiae data bases. Those selected are assigned a geographic region indicator and forwarded to the Classification Section, together with the remainder of the criminal and noncriminal prints.

When prints are received, a technician classifies all 10 fingers using Henry classification rules to determine how the fingerprints will be filed and/or searched using pattern types, ridge counts/tracings and the year of birth. A file/search form is then completed by using the derived classification information and converting it to numerics using a predetermined alpha to numeric code for computer system compatibility.

The technician will also indicate on the file/search form whether the fingerprint set will be added to the 10-print or latent image and minutiae data bases by using a specified code. The completed file/search form is attached to its corresponding fingerprint set and forwarded to the Quality Control Section, where a fingerprint section number (FPS#) is assigned to the criminal fingerprints and selective case numbers are assigned to noncriminal (civil) prints. The FPS# is the control number used on criminal prints for conducting a 10-print search and filing the fingerprint records to the archive image data base and the 10-print and latent working image and minutiae data bases for storage/retrieval purposes. The selected case numbers are used as a control number for searching purposes only, since noncriminal (civil) prints do not get added to the 10-print or latent files. The Quality Control Section technicians have sole control and responsibility in the assignment of FPS and case numbers. They also control the operation of a bar code printer that generates bar code labels containing the FPS# or case number which are affixed at the top of the corresponding fingerprint forms. The bar code labels are both human and machine readable and are used for record input in the AFIS.

The Quality Control technicians also review hundreds of FPS files on a daily basis, ensuring that the best possible video and classification for each file is consistent with the records filed on the automated system and controlling record purging from all data bases. Once the FPS and case numbers are assigned to the incoming fingerprints, they are grouped according to category and forwarded to the Data Control (data entry) section. The data entry operators, who are also fingerprint technicians, use data entry terminals for descriptor-classification input and search parameter input from the file/search forms attached to the fingerprint forms. The data entry terminals are linked with the AFIS, and all entered data are stored on a disk file under a specific job name for filing or searching operations. They are also responsible for data entry for all record purging, record classification changes and latent print searches conducted on the AFIS.

The AFIS Section consists of two automated systems, the PAIRS and the Printrak 250 Scanner System, both of which are integrated into a single unit. The PAIRS is an image archive system for storage and retrieval of fingerprints containing the following hardware elements and peripheral equipment:

1. A central processing unit (CPU)-VAX 11/750 processor with 8 megabytes of memory, including these CPU peripherals:

An RA81 456 megabyte Winchester system disk, which holds all system and application software.

An RA81 image index disk, which holds the index to all optical

disk records, including working disks (latent and 10-print) and archival disks (off-line backup).

Work in Progress (WIP), which holds all images input for searching and all respondent images retrieved for viewing. It acts as queue storage for display. Images are stored in compressed form on this disk.

A backup RA60 202 megabyte removable disk, which provides removable media for backup of image index and system and contains young offenders' fingerprint images.

A UDA50 intelligent disk controller with two high speed microprocessors to handle up to four disk drives.

A TU 80 magnetic tape unit (1600 bit/inch record), which supports daily backup and software update. In the streaming mode, it runs at 100 inches/second.

A DHU11 asynchronous multiplexer, including 16 lines with an 8-port Decserver 100. It is used for Display/Edit station communication, handles operator input requests, and controls video communication and camera mix for latent image input. The unit has a parallel interface for a printer and provides interface for data entry stations. It supports descriptor and classification input and search parameters. The equipment provides control of a High Speed Card Reader and interface to and control of the Bar Code Label Printer.

2. A Deuna Dec-Net Link (Ethernet) that connects the VAX to the PDP11 and provides a communication path between PAIRS and the Scanner 250 search processor.

3. An image buffer that provides intermediate image storage and processing between the image source and the system bus, supports the image conversion rate, accepts digitized image data from the image processor and performs image digitizing, calibration, location, windowing, annotation and formatting.

4. A rabbit compressor that provides image compression of 25:1 and reconstructs a high quality gray-level image from compressed data file.

5. An optical disk subsystem with 1 gigabyte capacity per disk surface (100,000 fingers) and manual spin up and spin down (front panel switch) computer spin up/spin down.

6. A display subsystem that supports up to six display stations, displays fingerprint images from search and file records, displays minutiae, provides a display station with a camera for capture of latent images and allows operator controlled image enhancement for latent mode.

7. An image processor that performs minutiae detection/editing.

8. A high speed card reader with a dual CCD camera to capture images for filing. Cameras are automatically adjusted to record format. Bar code labels are used for record input.

9. A bar code label subsystem with a dedicated cathode ray tube terminal and bar code label printer (Intermec 8625). Both units are interfaced with the VAX CPU. The printer is a thermal label unit. Labels are both machine and human readable. The operator requests starting FPS# and quantity, and the VAX generates check digit and prints labels.

10. A library handler (Jukebox), including an optical disk library management system.

The Printrak 250 Scanner System digitally stores fingerprint minutiae characteristics and descriptor/classification data on 300 megabyte disk packs for retrieval and matching during the scanner fingerprint searching process.

The 2.2 million 10-print sets that are image archived on optical disks have their corresponding 10-finger Henry classification together with sex, year of birth, FPS number and minutiae of each thumb digitally stored on three 300 megabyte disk packs on the scanner system.

The incoming 10-print searches received from Data Control are filed through the high speed card reader on PAIRS by reading the affixed bar code label containing the FPS#/Case# with a laser. After the label is read, the fingerprint automatically advances, the images are captured and minutiae are detected for all eight fingers, and then they are staged with corresponding descriptors on the PAIRS WIP. All the 10-print searches are grouped as criminal or noncriminal, and the batches are processed separately. The search mode is initialized on the scanner 250 system search processor under the specified job name used by

Data Control when entering the file/search data for the corresponding fingerprints. This information, along with the corresponding minutiae detected during the filing process through the high speed card reader, is sent to the scanner search processor via Decnet, which links the PAIRS and scanner system. The search is then conducted, producing a hard copy match report on the scanner system line printer for each print searched. When the search is completed, the search mode is terminated and the match reports are transferred to PAIRS (VAX) for respondent retrieval from the 10-print image working disks. A saved tape is generated on the scanner search processor containing the minutiae of the search records. An updated version is run using the designated job name by data entry from the searches processed. The job name file descriptors/classification is sent to the search processor and merged with the corresponding minutiae on the save tape, updating the scanner minutiae base and generating an update output tape. A second update version is run which adds the new records flagged for latent prints to the scanner latent minutiae base.

A matching program is then run on the PAIRS system, which retrieves all respondent images from the 10-print image working disks and stages them on the PAIRS WIP. At the operator's request, the search and respondent images are sent to the display stations for verification.

Upon case disposition, the operator can either delete the search and file identified prints from the WIP or replace the file/respondent print images with the search print. If no identification is made, the search print will be added to the image data bases and the case deleted from the WIP. The search cases without respondents are automatically queued for writing to optical disk. Noncriminal (civil) search prints are not added to the data base. Any 10-print search that results in an identification being made is tagged with an "ident by search" tag and forwarded to the Certification Section.

The certification technicians certify all identifications made in the Name Index Section and AFIS Section by certifying the incoming search print to the master print file. All incoming fingerprints that contain an FPS number when received are also certified by the Certification Section. About 1,100 certifications are processed daily by the Certification Section.

The Latent Fingerprint Section examiners review all incoming criminal 10-print searches to choose the ones they want added to the image and minutiae latent data bases. The 370,000 records with the images stored on the latent image disks in PAIRS have the minutiae (a maximum of 94 per finger), descriptors, classification and FPS number digitally stored on three 300 megabyte disk packs used for searching purposes on the scanner system. Latent search submissions are sent to the Latent Fingerprint Section from RCMP detachments and local police forces across Canada. Each submission may contain from one to a dozen latent fingerprints taken from a variety of crime scenes. When received, the submissions are dated, entered into a daily ledger and given a case number for searching.

A technician then determines how the fingerprint will be searched. The probable finger or fingers are determined by the information supplied by the contributor about the origin of the print and its relationship to other prints. If possible, the contributor will enclose an overall photo of the location. The pattern determination is derived by using the Henry Classification System. Various areas of Canada will be searched. The country is divided into regions and given a numeric value, for example, Quebec is represented by a "2" and the Western provinces by a "4." A latent print, for example, searched in British Columbia and the Yukon would also be searched in the transient collection. A search in "0" region will include a search against the entire latent data base. Murders and drug cases are searched in all regions, as are all submissions from Alberta because of the heavy transient population.

This information is entered on a worksheet, and the latent print is taped on the reverse for encoding and search by the scanner. If there are additional latent prints present to form a cluster, they are also included in the search. The worksheet and attached latent search are taken to the scanner system to be encoded. This entails entering all the search address information at a latent print terminal and manually plotting the minutiae present, such as bifurcations, ridge endings, lakes and islands. Once this information is received, the scanner searches and compares the latent print with each corresponding print on the minutiae file.

The FPS numbers of the first 11 of the most likely respondents are then printed out on a hard copy match report. Each respondent is given a numerical score in relation to the match of information and minutiae. If there is a significant disparity in score between the first and succeeding respondents, that master set of prints is drawn and compared with the latent immediately. If no such disparity occurs, the match reports are sent to PAIRS for the retrieval of respondent images, and they are staged to the WIP disk and downloaded to the verification stations upon operator's request for viewing.

The display station operator can capture the image of the latent print search submission on the display station monitor for respondent comparison/identification purposes or can have the hard copy of the latent print available for viewing through a fingerprint glass. An operator controlled image enhancement option is also available at each display edit station.

All the encoding data entered on first searches at the Model 30 latent print terminals of the scanner system are stored on a separate 300 megabyte disk called an ELF (encoded latent file) by case number and month searched. This disk controls an automatic research mode in which all first search submissions are researched every 6 months for up to 2 years against only the new records added since the last search was conducted.

If the submission is not identified, it is returned to the contributor, who is advised of the negative results and that the file will be researched automatically every 6 months for 2 years. Murder cases are researched indefinitely until contributors cancel the search.

Approximately 7,000 new files are added to the latent print data base each month, and approximately 1,000 cases (first search and researches) are searched daily. The 10-print data base has approximately 12,000 new records added monthly from the 1,200 ten-print searches (criminal and civil) processed daily.

DEFICIENCIES IN THE CURRENT CENTRAL SYSTEM

Ten-Print Searching

Ten-print searching by classification descriptor and minutiae match produces several respondents that require retrieval of images for viewing by fingerprint technicians. Unfortunately, the hard copy cannot be delivered to the central site for search purposes quickly enough for a police agency holding an unknown suspect in custody.

Latent Print Searching

Long delays, approximately 1 month from the time a scene of crime impression is developed until search results are received by contributor,

impede the investigative process. In addition, poorly rolled fingerprints produce an inferior scan. This creates inaccurate data resulting in the latent print not being identified. Furthermore, the system can not search incoming daily 10-print cards against a data base containing all unsolved latent prints. The central system researches all latent prints at 6-month intervals over a 2-year period. Latent prints from major crimes continue to be searched until the case is concluded. Researching produces a significant number of identifications. However, there could be a 6-month delay in the identification if the criminal's prints were added to the data base immediately after search. The inability to search a single latent print through the entire 10-print collection for major crimes makes credibility of system suspect to both police and public. Finally, prints of the little fingers are neither stored nor searched.

Automated System Searches

The current data base was constructed by scanning sixth generation video images that produced poor quality fingerprint information for minutiae match. In addition, the current system configuration cannot consider provide unlimited remote search access because the present workload already uses all available system time.

FUTURE CONCEPTS FOR THE ROYAL CANADIAN MOUNTED POLICE

To continue to reap the benefits of new generation AFIS technology and to have improved services with reduced resources, Phase IV of fingerprint automation is being added to the RCMP central system in Ottawa. This project began on April 1, 1987, and is divided into three stages.

First, two library handler subsystems will be installed to manage 2,500,000 ten-finger image file. Second, two system 400 search processors configured for concurrent 10-print and latent searching will be installed. At the same time, the Contextual Enhancement Processor (CEP) Image Processor will be added, enabling card conversion through CEP. Third, two Orion latent print terminals and a communications controller will be added to network remote systems into the central site.

The Phase IV upgrade is designed to:

Eliminate manual classification for 10-prints, thereby reducing human resource requirements in identification services by 15 person years.

Increase current latent searching capabilities by allowing a single latent print on a major crime to be searched through the entire criminal collection and providing the capability to search 10-prints, at time of receipt, against an unsolved latent file.

Bring all data bases on-line to allow concurrent searching, remote access and reduce turnaround time.

Stage One

The installation of library handlers into the image retrieval system will provide the capacity to archive the entire 2 million plus criminal fingerprint file. This step is necessary to achieve the proposed networking and turnaround times emanating from stages two and three.

Stage Two

At present, all data bases have been converted from video tapes. The sixth generation analog signal is injected through the print processor, where ridge flow and minutiae detection are determined Images are digitized, compressed and stored on digital optical disk at the rate of 14,000 bytes per image. Since the data obtained from the videotape are less than ideal, it was decided that a hard copy conversion would be conducted through a CEP, creating new minutiae and image data bases. This portion of the project is scheduled to begin in December 1987, with completion targeted for October 1988.

Two additional search processors will be added to provide the capacity for performing the following functions:

1. Twelve hundred 10-print cards will be searched against a 2 million item criminal 10-print data base. Ten-print searches originating from remote computer equipment capable of producing compatible autoclassification descriptors, minutiae and images (compressed 25:1) will be turned around in 2 hours. Ten-print searches received via mail will be turned around in 24 hours.

2. Ten-print cards, at time of receipt of hard copy, will be searched against the unsolved latent print file. This function will be performed once a day with unsolved latent prints being searched against a data base comprising all 10-prints received on that particular day.

3. Latent prints from minor crimes will be searched against a criteria loaded data base (estimated to be 500,000 individuals) consisting of persons deemed most likely to leave fingerprints at the scene of a crime. Surveys conducted in Canada over the past 5 years indicate that between 89% and 94% of persons linked to a criminal offense by fingerprints have a criminal history profile within the limits of the criteria established for the latent print data base. Latent prints received for search from either a remote system or terminal on a minor crime will be turned around within 24 hours. Unidentified latent prints will be placed in an unsolved latent file.

4. Latent prints from a major crime will be searched against the entire criminal collection of 2 million 10-prints and if unidentified placed in an unsolved latent file. Turnaround time for latent print searches on major crimes will be 4 hours.

Stage Three

Existing latent print terminals will be replaced with the latest DLRP Orion latent print terminals. In essence, the entire Phase IV project is structured around DLRP's Orion product line. The standardization of equipment and processing procedures is essential to a future of low cost upgrades and enhancements.

A communications controller will be installed in 1988 to interface with the CPIC Integrated Data Network (IDN). The IDN is a project currently being implemented in the Informatics Directorate of RCMP to provide a single, secure, high speed, transparent layered data network to users of CPIC and RCMP data center applications.

CONCLUSION

The ability to store and search fingerprints electronically has made a major impact on the law enforcement process. At present, numerous police agencies are reaping the benefits of some form of electronic fingerprint scanning to link a criminal to either an existing record or an unsolved crime.

This rapidly improving technology has already resulted in several thousand criminal cases coming to trial in various countries. These cases may have remained unsolved forever. The AFIS technology has resulted in the RCMP being able to process twice the number of 10-prints (from 77,000 per year to 144,000 per year) against a doubled data base (from 1 million to in excess of 2 million). Latent print searching has increased thirteenfold (from 1,000 cases per year to 13,000 per year) with identifications escalating by 2,000% (from 40 per year to over 800 per year). At the same time, human resource requirements have been reduced by 47 person years (from 144 employees to 97). The future offers more opportunities for progressive police departments to improve their efficiency by ensuring that all fingerprint information and evidence are rapidly and accurately processed.

DISCUSSION

George: Is the reject rate you mentioned the rejection of fingerprints that can not be put on the automated fingerprint identification system (AFIS)?

King: No, the reject rate I referred to is the fingerprint that the AFIS will not plot sufficient minutiae for, so it is plotted manually. You are thinking of those fingerprints that don't go into our latent print collection because the prints are of such poor quality that they are not included in the latent print system. That has been decreasing gradually as the quality of the fingerprints has been improving.

Question: I'm thinking of the rejects in the 10-finger system where the inked fingerprints have not been taken properly.

King: The reject rate for unsuitables has gradually dropped from 10% to approximately 3%.

Question: So you are able to deal with many more prints than you were 3 or 4 years ago.

King: Yes, we have implemented a massive education program. The Ontario Provincial Police helped us produce an excellent video presentation about the importance of having good fingerprint quality which was distributed across Canada.

Those of you who have departments with a pyramidal structure where you control all of the identification, from the fellow on the street who picks up the evidence to the people who are rolling the fingerprints, have the best setup. It is difficult to control a state or federal agency with 5,000 people from various departments and agencies taking fingerprints across Canada on any given day.

Zoner: You mentioned concerning the remote processing that agencies will be able to submit the minutiae directly through their automated systems. Will they still be submitting a paper copy to Ottawa for record purposes or will everything be done electronically?

King: They will be submitting the hard copy to Ottawa for record purposes because we will not allow our agencies to alter the criminal record file. This is to maintain the credibility of that record file.

Question: What is your annual budget?

King: I don't know. The maintenance budget is relatively low. Our downtime is very low.

113516

AUTOMATED FINGERPRINT STORAGE, RETRIEVAL AND SHARING IN CALIFORNIA

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Ever since the development of computers, law enforcement has tried to figure out how to automate the fingerprint search process. As early as 1955, the California Department of Justice (DOJ) investigated the use of electronic punchcard readers. In 1966, State Attorney General Thomas C. Lynch said that study projects underway included Electronic Scanning and Classification of Fingerprints and Rapid Identification and Automatic Transmittal of Fingerprints. However, it was not until 1976 that the technology had been developed to fully automate fingerprint identification systems, and the State planned to convert the manual fingerprint card file to a new automated system. That same year, a pilot automated latent print operation was successful, and in 1979 our department purchased a limited capacity system for latent print searching that became operational in 1980. However, California had to wait until 1983 before technologic advances allowed the creation of a new full capacity latent print system as well as automation of our central card file. It was not until 1986, after a long and difficult battle in California's legislature, that a fast communication system for digitized fingerprints became a reality for all of our police agencies.

The DOJ Criminal Identification Program processes rolled fingerprint cards and lifted latent prints. There are over 7.5 million fingerprint cards in our card file, and we receive over 5,500 criminal and applicant print cards each workday. (Over half of these require a card file search.) We currently receive a daily average of 150 latent prints from over 500 law enforcement agencies throughout the State. Although these figures may sound high, they are only a fraction of the processing capability of the statewide system after full implementation. The central California Identification (Cal-ID) System alone can process 4,000 10-print and 280 latent print searches daily.

As you may suspect, our reported crimes and arrests are also high. According to the Federal Bureau of Investigation Crime Index generated by the Uniform Crime Reporting Program, California had approximately 1,825,000 crimes reported in 1986. Arrests reported to our department totaled close to 1,794,000.

The Cal-ID System is an automated fingerprint processing system using minutiae (fingerprint ridge characteristics) matching technology, an image system and a networking capability for law enforcement agency access to DOJ data bases. Law enforcement agency personnel can conduct 10-print and latent fingerprint searches against data bases of known subjects and verify/eliminate search results without referring to hard copy fingerprint cards submitted to DOJ.

The Cal-ID provides an automated means of processing fingerprint comparisons of 10-print to 10-print cards (fingerprints rolled on cards 10 at a time against a file of already identified print cards), and latent to 10-print records (unknown fingerprints or fingerprint fragments lifted at crime scenes against known identity fingerprint records). The Cal-ID has five components that operate independently but may be used in concert to provide rapid and accurate identification of both known and unknown subject prints.

1. The Master Name Index (MNI) contains over 16 million names and known aliases, dates of birth and physical descriptions for persons with applicant or criminal records on file at DOJ. Local on-line access to MNI has been available since January 1985 through the California Law Enforcement Telecommunications System (CLETS). The CLETS lines handle over 700,000 messages daily and are the primary access to the State's Automated and Manual Criminal History System records.

2. The Automated Fingerprint Identification System (AFIS) stores minutiae data from two fingers (thumbs) for 10-print cards on file for each person with a date of birth in 1940 and after. The 1940 cut-off date was decided on because the most active criminals are usually younger, and eventually all file activity will be for persons born after 1940. The recording of two thumbs instead of all 10 prints was decided on to save data base space and because identification from submitted rolled cards can be made with 95% accuracy using only the thumbs.

The Department began processing incoming fingerprint cards on October 9, 1985. Currently 80% of all incoming fingerprint cards are being processed using AFIS. When fully implemented during 1987, an estimated 90% of all incoming fingerprints will be searched using AFIS, and by 1990 the Department's entire fingerprint workload will be processed using the automated system.

3. The Automated Latent Print System (ALPS) allows single lifted prints to be matched in a latent-cognizant file. The Cal-ID/ALPS stores the minutiae data from eight fingers (omitting the little fingers of both hands) of known subjects and is used to conduct no-suspect cold searches of latent prints. Prints from the little fingers appearing on ALPS-cognizant fingerprint cards are not included because of their very low probability of discovery at crime scenes. Fingerprints of known subjects stored in the Cal-ID/ALPS data base (ALPS-cognizant offenses derived from incoming fingerprint cards at DOJ) are matched with incoming latent prints. Subjects are eliminated when file prints do not match incoming latent prints.

The Cal-ID/ALPS data base became operational on October 9, 1985. During the first year of operation, over 300 law enforcement agencies used the system to identify criminal suspects. Suspects have been identified in cases ranging from 1-day-old to 13-year-old investigations. For the more timely cases, agencies have saved countless hours of investigative time. For the old cases, where case leads had long been exhausted, new leads reopened cases that might never have been solved. From the very first search of a partial latent print on Cal-ID/ALPS, the results have been phenomenal. In August 1985, DOJ interrupted early testing of the Cal-ID/ALPS System and matched a latent print to a serial murder case suspect. As the system became operational and the data base increased in size, more apparently dead end homicide cases have been cracked. A few examples from the many cases follow:

In 1980, a 75-year-old man from Long Beach was found bludgeoned and killed in his television repair shop. It was not until October 1985, when Cal-ID/ALPS matched a latent print lifted at the repair shop, that a suspect was identified and arrested.

In October 1985, the Los Angeles Police Department used Cal-ID/ALPS to identify and arrest four suspects in the vicious kidnapping and cold-blooded, execution-style killings of two college students. A single latent print was matched to one of the suspects. The print had been lifted from the victim's vehicle that had been torched.

In May 1986, Cal-ID/ALPS scored its first out-of-state latent print identification in a homicide case submitted for searching by the Oregon State Police.

In August 1986, the Los Angeles Police Department identified three suspects by using Cal-ID/ALPS in a drug related execution-style double homicide case.

In September 1986, the San Diego County Sheriff's Department used their locally installed terminal to search Cal-ID/ALPS with a print related to a 3-year-old rape case. A suspect was identified and arrested. After the arrest, 10 victims of rape over the last 3 years identified the criminal through the routine police line-up process.

In November 1986, the Los Angeles Police Department used Cal-ID/ALPS to identify a suspect in the ax attack and robbery of California Secretary of State March Fong Eu. The suspect was arrested and linked with numerous other robberies and burglaries.

From the beginning of Cal-ID/ALPS through the end of May 1987, DOJ analysts have conducted 16,700 searches for 14,800 cases submitted by over 300 different law enforcement agencies. There have been 1,725 suspect identification matches in 1,700 of the cases submitted. These cases were for the following crimes:

Crime Category	Number of Cases	Percent
Felony burglary	1,160	68.2
Robbery	168	9.8
Auto theft	131	7.7
Homicide	123	7.2
Rape/sex crimes	35	2.1
Grand theft	35	2.1
Assault	9	0.6
Narcotics	8	0.5
Forgery	7	0.4
Attempted homicide	6	0.3
Other felony/misdemeanor	18	1.1
TOTAL	1,700	100

A 15% "hit" rate is anticipated for Cal-ID/ALPS when the final data base reaches 1.5 million and the Remote Access Network (RAN) becomes fully operational statewide.

The DOJ's experience with Cal-ID/ALPS led to improved methods that increased speed, accuracy and processing capability. A region search of the Cal-ID/ALPS data base procedure was implemented to increase processing capability. By first searching incoming property-type case prints against data base subjects previously arrested in the case geographic area, the system processes significantly more cases with a minimal risk of not including the subject in the search population.

4. The Digital Image Retrieval System (DIRS) is the storing, retrieving and displaying component of Cal-ID for all AFIS and ALPS subjects. The DIRS has an optical disk feature that contains digitized fingerprint images for cards converted from the DOJ central file and for incoming prints being added daily.

5. The RAN is the combination of communication lines and computer equipment that connects local

law enforcement agencies with Cal-ID data bases. This fast communication capability enables agencies to identify persons in custody and from latent prints discovered at crime scenes. New RAN communication lines from Sacramento to each county are provided at State expense to transmit digital images of fingerprints.

Currently, RAN includes two types of remote access equipment: Verification Only Terminals (VOTs) and Local Input Terminals (LITs). There is also a combination of VOTs, and LITs, with local independent data base and automated search processors referred to as Full Use Access Agency (FUAA) installations.

A VOT retrieves images contained in DIRS and displays them on screen or prints them on paper. Since a VOT cannot input fingerprint minutiae to conduct searches, it is used following a name inquiry on MNI to confirm the identity of persons in custody or to identify a person from a list of known suspects as the person leaving a latent print at a crime scene.

An LIT allows the input of fingerprint minutiae to match file records contained in AFIS or Cal-ID/ALPS at the State level and FUAA data bases at the local level. The LITs can retrieve and display DIRS fingerprint images to verify the results of fingerprint and latent print searches.

An FUAA has access to Cal-ID data bases and maintains its own automated search processor and independent fingerprint identification data base for persons with criminal records in a city, county or other limited geographic region. The FUAAs support a network to permit VOTs and LITs in the vicinity to access the FUAA data base and the Cal-ID base through the FUAA.

Although early planning included as many as 62 VOTs, 29 LITs and only 1 FUAA, system implementation experience led to changes. We found many police agencies either had insufficient funds for even the least expensive equipment option or they simply wanted other equipment configurations to provide a higher level of service. Therefore, the DOJ began testing other equipment than that originally planned for. These new options should become available through the State and RAN.

We are looking at these new equipment options from our original perspective of sharing a central statewide data base with local law enforcement. The Department is exploring the feasibility for adding point-of-booking terminals, live-scan equipment and facsimile-type devices to RAN. In our State, police agencies have very different identification service needs that will be better served by providing a wide variety of RAN equipment options.

Thus far, I have given you an overall description of our system in California, the system that allows law enforcement personnel to conduct fingerprint and latent print searches against data bases of known subjects without referring to hardcopy cards submitted to the State. What is most revolutionary in these systems is the sophistication and intricacy of the mapping algorithm, which reflects the unique spatial relationship among fingerprint ridge characteristics. Equally sophisticated is the search algorithm, which converts the characteristics into a unique binary code that is used in the search. The computer is not actually comparing fingerprint images in a search. It is conducting a mathematic search that provides a candidate list of codes most similar to the code used in the search.

It is important to realize that only a fingerprint expert can verify a candidate print with a file print. The computer does not make the identification decision. The computer simply reduces millions of prints to a workable list of candidates for comparison by the fingerprint expert.

Keep in mind that the backbone of this system is its RAN that has the ability to share its data base with agencies anywhere in the world through communication lines. The value of this capability is directly dependent on the accuracy and acceptance of the digital image process. Although that technology is here, it is yet to receive complete acceptance. Nevertheless, even with its questionable future, some law enforcement agencies are only months away from eliminating rolled fingerprint impressions from their files and installing live-scan processing, a digital creation of a fingerprint. Since this technology is here to stay, we can no longer refuse to recognize its existence, and we certainly do not want to be ignored during its development. We all must now to work together to direct the development of the digital process to ensure its value and acceptance.

If you are planning to invest in one of these systems, you must determine the purpose to be served by implementing these systems and their value. In other words, how useful is an automated latent print system?

Before we were automated, we at the State level did not have a single cold search on record. A latent print had never been identified which was submitted without some other accompanying clues as to its identity. The world of latent print identification just did not exist in the real world—perhaps on television or in the movies, but not in our department. If we are identifying more criminals, arresting more criminals, convicting more criminals and getting them in jail or prison, then I cannot imagine anyone questioning the usefulness of what we are doing with these systems.

Eliminating the mailbox as our way to communicate fingerprints and installing telephone lines for digital image transmission are the most useful improvements made to identifying criminals quickly. However, if these systems are to be valuable, they must be accepted by fingerprint experts. I am not aware of a single court case where a fingerprint identification made by computer searching of data bases has not been successful or, at least, the fingerprint identification evidence and testimony in these cases remained unquestionably accepted.

There is, perhaps, some question concerning comparison of digitized images created from lifted latent prints that are transmitted over digital communication lines and searched against digital image data bases. These questions are being raised by latent print experts within our own criminal justice community, and that is where the question should be raised. However, I feel very strongly that since the accuracy of computer searching, the accuracy of digital data bases and the accuracy of digital scanning or reading devices so far exceed manual accuracy, experts will soon be able to testify (as they do after the current comparison of rolled inked cards and lifted latent prints) that " . . . there is no doubt in my mind that the digital images are from the same person." However, to reach this point, we must not close our eyes to this new technology. We must embrace it and work towards its acceptance by the fingerprint experts in the identification community.

I would now like to highlight one or two points in the area of cost and staffing at the State and local government level in California. We will be saving over $2 million annually by reducing our manual card file staff by 90 positions. On the other hand, our automated latent print staff has increased by four positions because of the new latent print workload. Of course, there is an expected dramatic impact at the local government level because more latent print identifications create more leads for investigation by more investigators and detectives. They make more arrests that require more prosecutors to handle more cases. This results in more convictions, which creates the need for more jails and prisons.

The cost for "more" throughout the criminal justice process is yet to be determined. I believe the expenditures will be more than justified after system payoffs can be calculated. Specifically, we need to reach some understanding of how safe our communities were before and after automation of fingerprints.

That leads me to one of the final points, a lesson learned in California: Include a system for tracking the criminal careers of persons identified by computer latent print hits. As early as possible, start tracking what convictions have resulted from what arrests from what identifications. We did not do this in California early enough, and today we are struggling to recover and trace these cases. This information has been demanded by people whose political support was critical to our successful system development after legislative authorization. Everyone wants to be associated with fighting crime with the most advanced crime-fighting tool. Therefore, start early in your tracking and gathering of statistics. It is part of the process that must be planned early to show the benefits of the system and to gain support for advances in upgrading your system.

There is a final point to remember. Equipment vendors are in business to make money. Your first objective is identifying criminals. Set your system criteria high, and let the vendors design a system to meet your specifications. Try to anticipate the future needs and desires of your criminal justice agencies. Do not settle for a system that may shortly need a costly update. Most reputable computer companies have their upcoming models or enhancements available or close to being available. Adopt the latest technology, not something that may soon be replaced with something better.

DISCUSSION

Question: If a local jurisdiction sent a latent print to the California Department of Justice (DOJ) for automated identification and the DOJ was unable to identify it, would you sent the latent print on to the FBI for possible identification or send the print back to the local authority?

Cooper: We do not send the latent print on to the FBI for identification but send it back to the local jurisdiction. If the print is from a murder case, we register it in our file and maintain it at the DOJ. If it is from a less serious crime, we do not register the print.

Question: A Texas man imprisoned for rape was released on parole. Recently he went to California and murdered nine women before killing himself. Do you believe his fingerprints should have been forwarded from Texas to California and inserted in the DOJ files when he moved to California while on parole from a Texas prison? Also, would it not be more efficient for the DOJ, which has received a latent print for possible identification from a local jurisdiction, to forward the print to the FBI rather than return it to the local jurisdiction if the DOJ was unable to identify the print?

Cooper: That is a good question. If a person is released on parole for a serious crime from one state and moves to California, we definitely would want to include the latent prints in the DOJ automated fingerprint identification system (AFIS). Whether the DOJ sends prints submitted by local jurisdictions to the FBI or returns them to the local agency is a policy decision that should be worked out between the DOJ and the local jurisdiction.

Hamilton: From what I hear about the DOJ AFIS, it appears that the Henry system of fingerprint classification and files is being phased out.

Cooper: I eliminated the statewide training on the Henry classification last year, but I reimplemented the training this year because latent print examiners were informing me that the history of fingerprint identification and other background information was critical to their profession. We are phasing the Henry classification system out for the 10-print search, but we are continuing training in the Henry system.

King: The Royal Canadian Mounted Police (RCMP) previously put all scenes of crime technicians through the Fingerprint Bureau for 2 years. Now we use a basic course, but we have lost some expertise by changing the training program. The biggest problem facing people in AFIS is training new technicians. Latent print examiners must be experienced. We still Henry classify today, but RCMP is phasing it out. The AFIS is not Henry searchable.

Cooper: We still Henry classify today. The DOJ AFIS is not Henry searchable. We file numerically by identification number. The Henry file is maintained only for those records that are not on the AFIS.

Question: Did I understand that you said the State has taken over the training of all fingerprint examiners in California?

Cooper: No, the DOJ is taking a lead in the fingerprint training program by requesting staff to do fingerprint training, but we like to keep local agencies involved in their training programs. We encourage the local agencies through our statewide advisory group.

Question: Has the California legislature appropriated 70% of the financing for these small departments?

Cooper: Yes.

Question: Is that coming from a special tax in California?

Cooper: No, it is out of the general fund. The DOJ includes it in my budget, and we allocate the money according to the statewide master plan. The DOJ does have a $5 surcharge for processing applicants' prints which is paying for the AFIS. The latent prints system is paid for out of the general fund.

Question: If the AFIS vendors were able to provide the technology in your equipment to give you the ability to use Henry classification for searching prints, would you restructure your files to be searchable by Henry classification?

Cooper: I don't think so. We would like to get away from the qualifiers and do a straight search of everything.

Question: What kind of backup system do you have when your system is down?

Cooper: We don't have a backup. We have an impressive uptime of 98%. It is very expensive to maintain dual files.

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AUTOMATED FINGERPRINT IDENTIFICATION STANDARD AND PERFORMANCE BENCHMARKS

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During the past two decades, the fingerprint identification process has become increasingly automated. Computer based systems are now being used extensively to search both latent and 10-print inquiries against machine readable files of fingerprint data. When these searches result in candidate identifications, the fingerprint images are referred to human examiners for verification. Work on the development of these automated fingerprint identification systems (AFISs) began in France, Great Britain and the United States in the 1960's. A parallel effort was initiated in Japan a few years later.

Each effort had its own driving force, and although these were similar they were not the same. For example, the main thrust of the development effort directed by the British Home Office was the automation of latent fingerprint identification. The Federal Bureau of Investigation (FBI), on the other hand, was most concerned with automating their high volume 10-print identification workload. The French and the Japanese efforts were intended to address both of these tasks.

In each case, the goal is to scan inked fingerprint images electronically and to identify minutiae based features. Data about these features are extracted and recorded. As a minimum, the relative position in X and Y and the relative orientation, theta, is recorded for each detected minutia. Some of the systems also determine and record the ridge counts between selected minutiae.

MAJOR TYPES OF AUTOMATED FINGERPRINT IDENTIFICATION SYSTEMS

Given the relatively independent nature of these development efforts and their differing objectives, it should not be surprising that there are differences in the descriptive metrics and coordinate system that each system uses. Some of these differences are illustrated in Figures 1-5.

Logica, Ltd., developed and constructed the British Home Office's system. The scanning resolution of the fingerprint reader is 480 pixels per inch (18.9 pixels per mm). It detects both minutiae and the ridges between minutiae. The position and orientation of minutiae are recorded using the coordinate system and units of measure shown in Figure 1. Here, the small circle marks the position of a ridge ending or bifurcation, and the short line attached to the circle shows the orientation of that minutia. For each minutia, ridge counts are also recorded to the five nearest neighboring minutia to its right.

The FBI system is designed primarily for the high volume, 10-print workload. About half of this workload consists of criminal inquiries. The other half are civil inquiries related to applicants for jobs, licenses or security clearances.

The fingerprint scanning resolution is 500 pixels per inch (19.7 pixels per mm). The automatic fingerprint readers quantize the gray-scale reflectance of each pixel to six bits (64 levels of gray). The original flying spot scanners are now being replaced with higher performance solid state scanners, which have higher resolution and quantize the reflectance of each pixel to eight bits (256 levels of gray). The gray-scale data are digitally filtered and converted to a binary image. A moving window is used to detect the minutiae in this binary image. After scanning eight fingerprints on the card (omitting the two little fingers), the minutiae detections are automatically edited. Multiple detections of the same minutia are consolidated, and certain false detections are deleted. The position and orientation of the minutiae are reported using the coordinate system and metrics shown in Figure 2. Ridge counts are not recorded.

The DeLaRue Printrak, Inc., fingerprint reader systems are evolutionary descendants of the FBI system. The scanning of fingerprint cards is done at a resolution of 500 pixels per inch (19.7 pixels per mm). The scanner is a linear solid state array. The gray-scale reflectance of each pixel is quantized to eight bits (256 levels of gray). In the past, the binarization of the gray-scale image and the minutiae detection processes have been similar to those used in the FBI system. The position and orientation of each minutia is reported using the coordinate system and units of measure shown in Figure 3. The system does not record ridge counts between minutiae.

Morpho Systemes (North American Morpho Systems, Inc., Tacoma, WA) is the French entrant in the

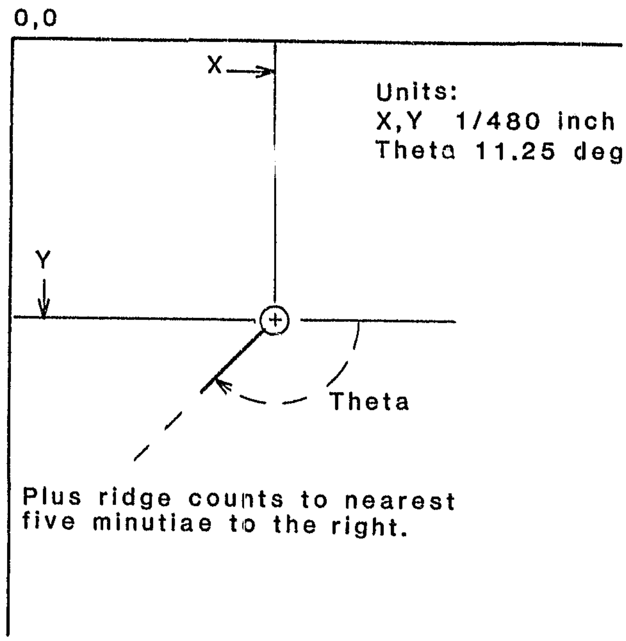

Figure 1. Logica coordinate system and units of measure.

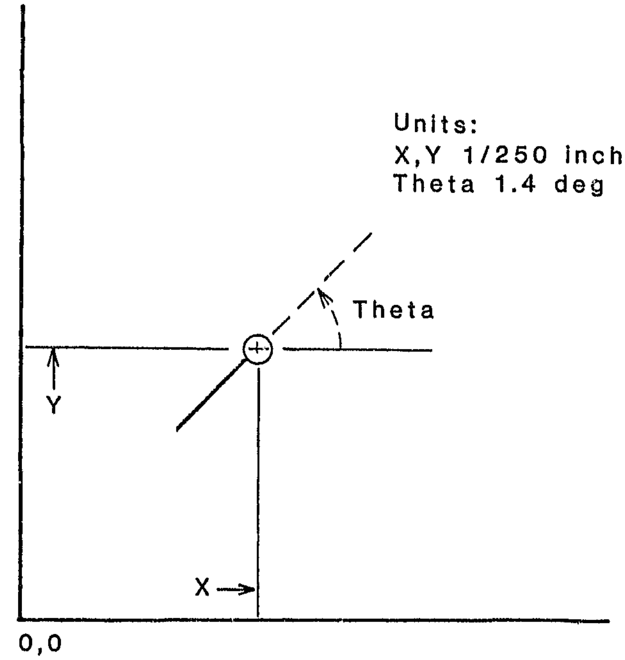

Figure 2. FBI coordinate system and units of measure.

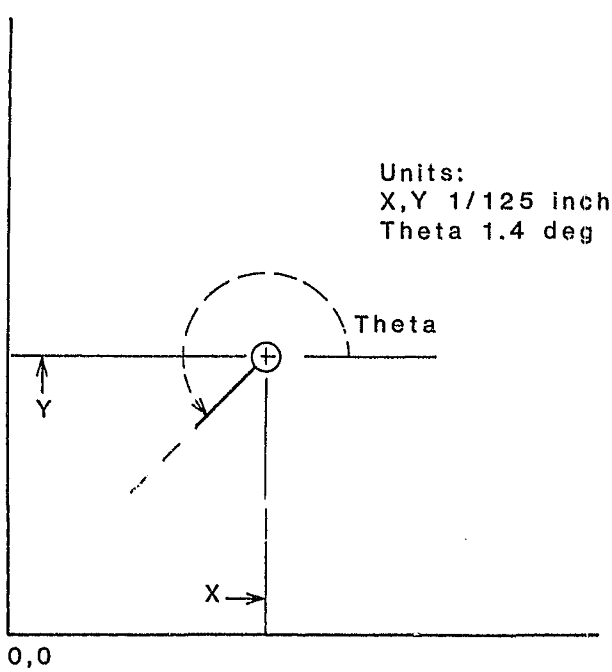

Figure 3. DeLaRue Printrak coordinate system and units of measure.

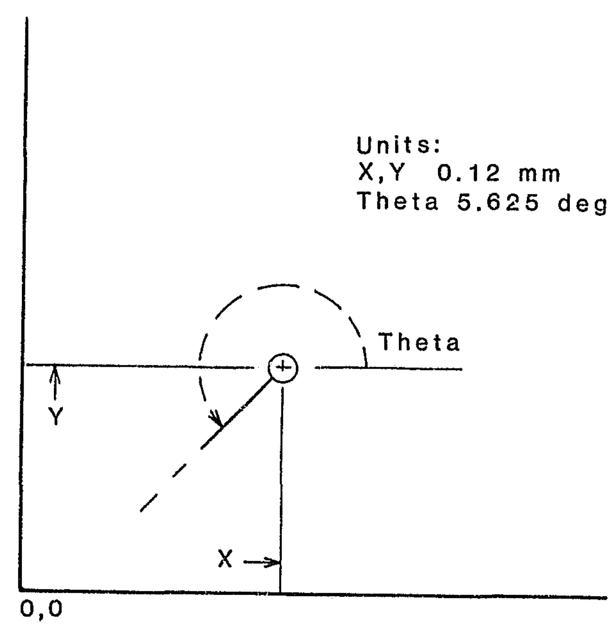

Figure 4. Morpho Systems coordinate system and units of measure.

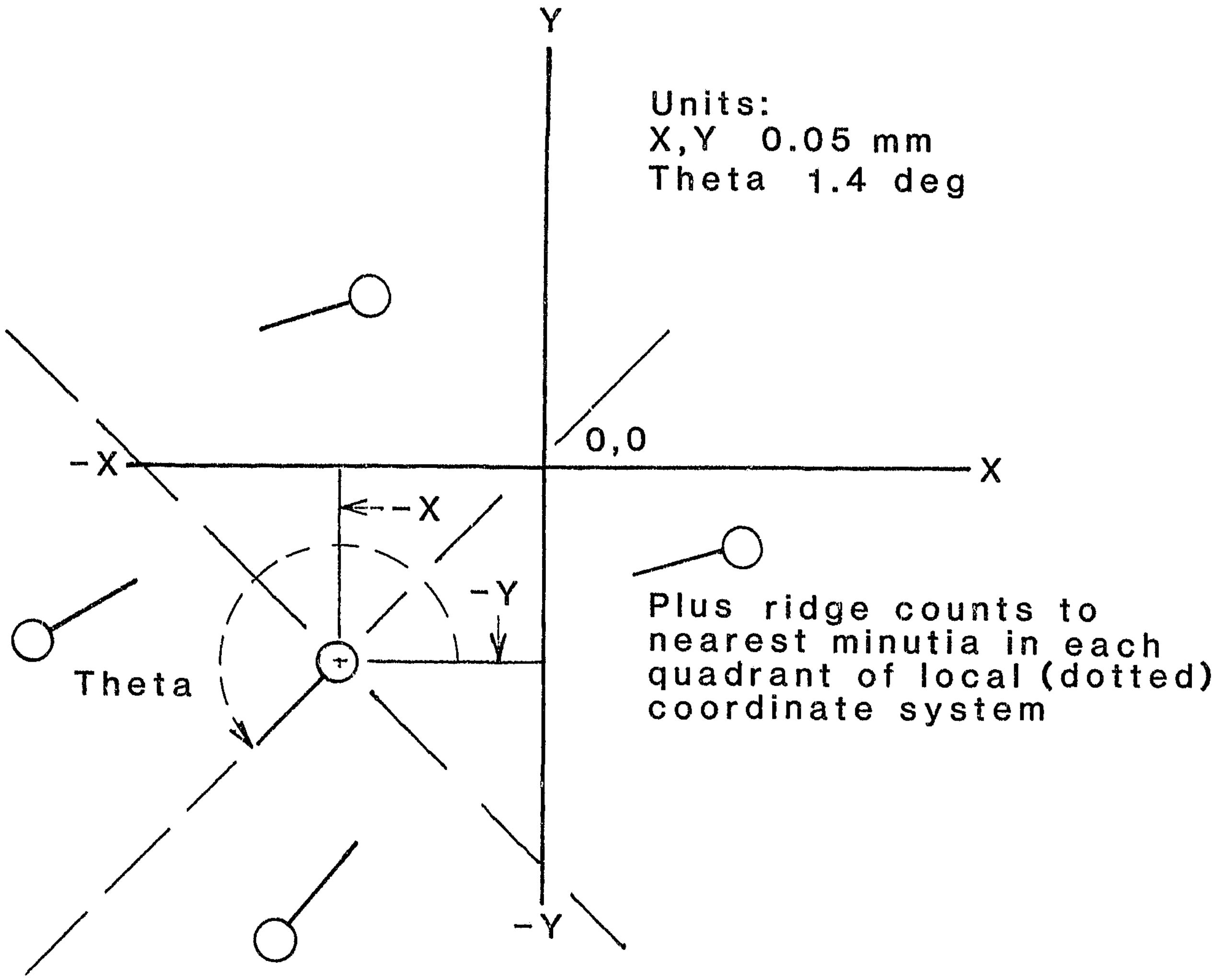

Figure 5. NEC coordinate system and units of measure.

field of automatic fingerprint identification system suppliers. Their scanner works at a resolution of 20.5 pixels per mm. Quantization is to eight bits (256 levels) of gray scale. The image is enhanced and binarized. Then, minutiae are detected using moving windows. Their reader assigns each minutia a type designation and a quality measure. The minutiae are recorded in the coordinate system and with the units of measure shown in Figure 4.

The NEC Information Systems fingerprint reader scans images at a resolution of 20 pixels per mm. The scanner is a solid state linear array photodetector. Movement of the card under this scanner provides the second axis of the two dimensional scan of the fingerprint. The coordinate system and metrics shown in Figure 5 are used for reporting their position and orientation.

In addition to the primary coordinate system, a secondary coordinate system is set up around each detected minutia. Ridges are counted from each central minutia to the nearest neighboring minutia in each of the four quadrants of the secondary system. The broken lines in Figure 5 show this arrangement.

There are additional systems from vendors that are just entering or planning to enter the market. Some of these are expected to use metrics that are different from any of those just described.

THE AMERICAN NATIONAL STANDARD INSTITUTE DATA FORMAT

Because of the need for communications between these different systems, work was initiated early in 1985 to develop a standard data format for fingerprint information. This would facilitate the exchange of fingerprint information between these various systems. The canvas method was used to demonstrate the consensus approval by all affected interests of the standard that was developed. Under this procedure, all suppliers, users or general interests that might be materially affected by the proposed standard are invited to become canvasees. As such, they are given the opportunity to review and comment on drafts of the standard under development. They cast letter ballots to approve the final document that is proposed as a standard.

Results of the balloting together with details of the entire development process are reviewed by the American National Standards Institute (ANSI). When they determine there has been compliance with all applicable requirements, the document is accepted as an American National Standard. The ANSI/NBS-ICST 1-1986, American National Standard for Information Systems—Fingerprint Identification—Data Format for Information Interchange received final approval on August 25, 1986. It is available from the ANSI Sales Department (1430 Broadway, New York, NY 10018).

The standard defines four types of records that may be used in the exchange of fingerprint information. The Type-1 record is used in all transactions. From 0 to 10, Type-2, Type-3 or Type-4 records may also be used for each subject. The quantity depends on both the number of fingerprints available for processing and the options that are selected.

The Type-1 record contains information about a transaction and about the other records that may accompany it. It also identifies the agency that prepared the file and contains descriptive information about the subject. The various items of information are placed in numbered and numerically ordered fields. The use of several of these fields is optional.

The Type-2 record contains the minutiae-based data that the fingerprint reader has extracted from the fingerprint. For each minutia, the position and orientation are listed using the coordinate system and units of measure shown in Figure 6. These units are smaller and have higher precision than those used by any of the current systems. Thus, their use in converting between the units used in different systems does not degrade accuracy. They permit each system to use a single software package to convert data between its native format and the standard format. In this way, any system can exchange data with any other without having to use a different software conversion routine for each different exchange participant.

Each detected minutia in a fingerprint is assigned an arbitrary reference number for identification. This number is included as a part of the Type-2 record. The systems that employ ridge count information use these reference numbers to identify the pairs of minutiae that are associated with each ridge count value that is recorded.

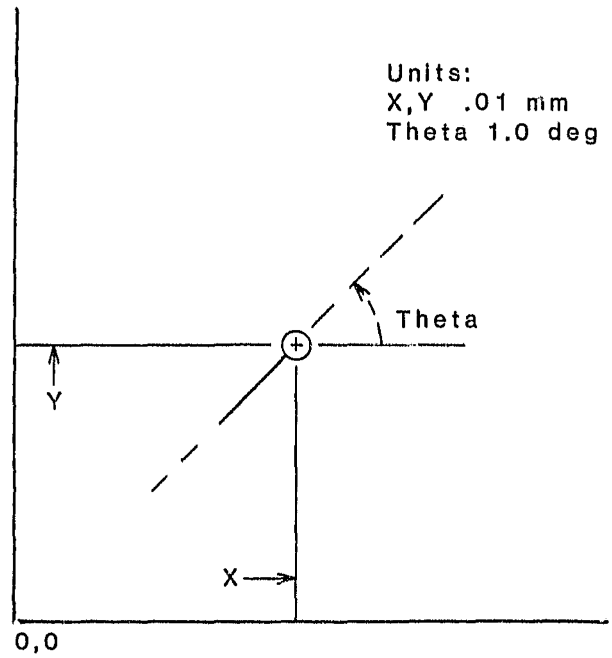

Figure 6. ANSI coordinate system and units of measure.

The Type-3 and Type-4 records contain fingerprint image data that are intended to be used as input to a participating agency's fingerprint reader system. An agency with a system that does not record ridge count information may use its reader to prepare a digital image for transmission to an agency using a system that requires ridge count information. The receiving agency can process this image data just as if were the output of their scanner. The results are virtually the same as if that agency had directly scanned the fingerprint.

The Type-3 record has a nominal resolution of 10 pixels per mm and a Type-4 record has a nominal resolution twice as great. The housekeeping information necessary to decode these graphic records is contained in the accompanying Type-1 record.

This data format standard provides a variety of methods for the interchange of fingerprint information. By selecting the appropriate method, any AFIS user can effectively exchange data with any other AFIS user.

PERFORMANCE BENCHMARK TESTING

Performance benchmark testing is another area where standards development efforts can be beneficial. Potential users of automatic fingerprint identification systems must choose which system best meets their requirements. Benchmark performance testing can help their decision process.

Any reasonable benchmark must address the relative performance of alternative systems rather than attempting to develop absolute measures that are representative of an operational environment. The reasons for this are practical considerations. Many site-specific factors strongly influence the performance of any given operational system. These factors include operator training. skill and motivation, the volume and distribution of workload and the quality of the file data base. Even the physical layout and arrangement of system components influence some aspects of system performance. Any benchmark test program that attempts to accommodate all of the possible variables quickly grows to an unmanageable size and becomes unacceptably large.

Benchmark tests to determine relative performance can be much simpler and more directly focused on the area of principal user concern. That area is the reliability and selectivity with which both latent and rolled fingerprints are identified using only the matching of their minutiae based features. Here, reliability is defined as the probability that the correct candidate is selected by the system for review and verification by an expert fingerprint examiner. Selectivity is measured by the number of candidates that the expert fingerprint examiner must review as a result of the system's selection process.

With respect to system performance on latent prints and on rolled fingerprints, latent print performance is more demanding. In searching rolled fingerprints, information about classification and descriptive demographic data is normally used to limit the search area to a small part of the total file. The finger position is normally known, and the minutiae data may even be positioned in a standardized location and orientation in the field of view. Usually the rolled print provides a generous number of minutiae. With any of the current state-of-the-art systems, the image quality of the search and file fingerprints usually sets the limits of performance. With fingerprints of reasonably good quality, matching only one or two of a subject's fingerprints will make a hit if the matching card is in the file. With poorer quality fingerprints, more fingers may have to be used. Nearly any desired system operating point can be selected. Judicious choice of scoring threshold and number of fingers matched will fix the operating point on the reliability and selectivity curve at the selected value.

Searching latent fingerprints is a much more difficult task. Often the number of minutiae on a latent print is severely limited. Frequently, the pattern type and finger position are unknown. The image quality of latent fingerprints is nearly always inferior to that of rolled fingerprints. In many instances, machine reading of latent prints can be accomplished only with some form of assistance from a human expert. The time and manpower needed for this function are items of considerable interest. The performance of an automatic fingerprint identification system with latent prints is nearly always inferior to its performance with rolled fingerprints. Reliability is lower, and selectivity is poorer. Relative performance differences between automatic fingerprint identification systems are more easily observed with latent prints matched against rolled fingerprints than with rolled prints matched against rolled prints.

In making relative performance comparisons, it is essential that the same data sets be used with each system. The differences between data sets, especially small data sets, may be greater than the differences in performance of the automatic fingerprint identification systems that are under evaluation. Under some circumstances, this need for common data may even extend to the individual minutiae that are encoded from the latent prints. This should be considered when human assistance is used to read the latent fingerprints. Unless the same minutiae from the latent prints are used in each test, the latent fingerprint examiner's skills may bias the results. On the other hand, if the system is supposed to read the latent prints automatically without human assistance, then its ability to perform that function is one of the factors to be evaluated.

The measurement of relative system performance required a careful review of the factors involved in matching and comparing minutiae-based fingerprint features. Different automatic fingerprint identification systems employ different sets of these features. They may differ in the consistency with which they detect or fail to detect these features. They use different algorithms to develop scores to represent how well feature sets from different pairs of fingerprints correlate.

The number of features involved in the matching comparisons for a given latent fingerprint depends on a number of variables, including the usable area, the image quality, the feature richness of that fingerprint and the consistency of the reader in scanning the fingerprint and detecting these features. On any system, the scores that each latent print in a series makes with its mate may vary by an order of magnitude. This can occur even when all of the latent prints score in rank with one with their mates. Also, different systems use different rules for calculating matcher scores. As a result, the direct comparison of scores (but not score ranking) produced by different systems is meaningless. This is true even when a common set of latent fingerprints and file fingerprints are used.

A useful estimate of relative system performance can be developed by matching each latent print in a search data set against every fingerprint in a file data set. The matching is done using only the minutiae-based features employed by the system. Screening by pattern type or finger position or other demographic data is excluded. The top ranking scores developed by each latent print are examined to determine if they were produced by the mating file fingerprint(s).

The desired statistic is the probability that a latent print will score in rank one with its mate. If there is only a single mate in the file, only the top score is considered. If the file contains more than one mating fingerprint for any latent print, the value of the statistic is incremented when the latent print also develops a second rank score with the second mating file fingerprint, a third rank score with its third mating file fingerprint and so on. The statistic is not incremented when the mating fingerprint scores lower in rank that a nonmatching, imposter fingerprint.

Evaluating performance by matching scores other than those in rank one is not recommended when benchmark tests are conducted using search and file data sets of limited size because score ranking can be a sensitive function of file size. Performance expectations that are based on mating scores of less than first rank and that are developed in tests conducted with limited size data bases are unlikely to be met when larger data bases are used.

An important AFIS performance measure is an estimate of the consistency of reader performance. This measure can be obtained by reading the file set of mating fingerprints a second time and repeating the matching process. If the reader is completely consistent, most of the same latent prints would again score in rank one with their mates. Small differences may occur solely because the pixels in the second reading may not exactly overlay the pixels in the first reading, but larger differences may be caused by reader inconsistencies. Generally, readers fail to detect all true minutiae based features and produce some false detections. This variability in performance can change the identity of the latent prints that score in first rank with their mates during a particular reading of the file fingerprints.

Another useful performance measure is an estimate of the reliability and selectivity curve of the system as developed from the common benchmark data base. To get such a curve, it is very helpful to normalize the matcher scores. If properly normalized scores are available, the probability density functions of mating and nonmating comparisons can be plotted. The results will be similar to those in Figure 7. From these data it is possible to calculate and plot a curve showing reliability versus selectivity.

Matcher scores can be normalized by using the mathematically rigorous procedure introduced by Sparrow and Penelope (1985). Unfortunately, this procedure cannot be readily implemented on some AFISs. With it, each latent fingerprint is first matched against itself. To do this, it may be necessary to make minor modifications to the system's normal score calculating algorithm. These changes may be needed to ensure that no saturation or overflow occurs. It may also be necessary to disable any other score normalization routines that are already included in some matching algorithms. For example, one scoring routine accumulates points based on the closeness of fit of minutiae based features. This accumulation of points is then arbitrarily normalized by dividing it by the product of the number of minutiae in the search and file fingerprints.

When native normalization procedures are disabled, the score that results when a latent print is matched against itself is the perfect score for that latent print. This score is the highest score that latent print can possibly make. The scores for all other matching comparisons with other fingerprints are compared with that perfect score. They are expressed as a percentage of that score, and all will fall in the range of 0-100.

When the distribution of mating and nonmating scores is plotted as shown in Figure 7, a perfect or ideal system (probably unrealizable) would show a separation rather than an overlap of the two curves. In such a system, the mates would always score higher than the nonmates. A hit would be a certainty if the mate were in the file, and false candidates would never be selected.

Real systems will show some overlap of the two curves. This area is hatched in Figure 7. This hatched area represents the minimum total error that results when the optimum cut-off point is selected. This minimum total error is defined as the minimum value taken by the sum of the percentage of misses and false drops when the selection threshold is set at the optimum cut-off point.

Evaluating the relative minimum total error areas of AFISs is important, but it may not always be

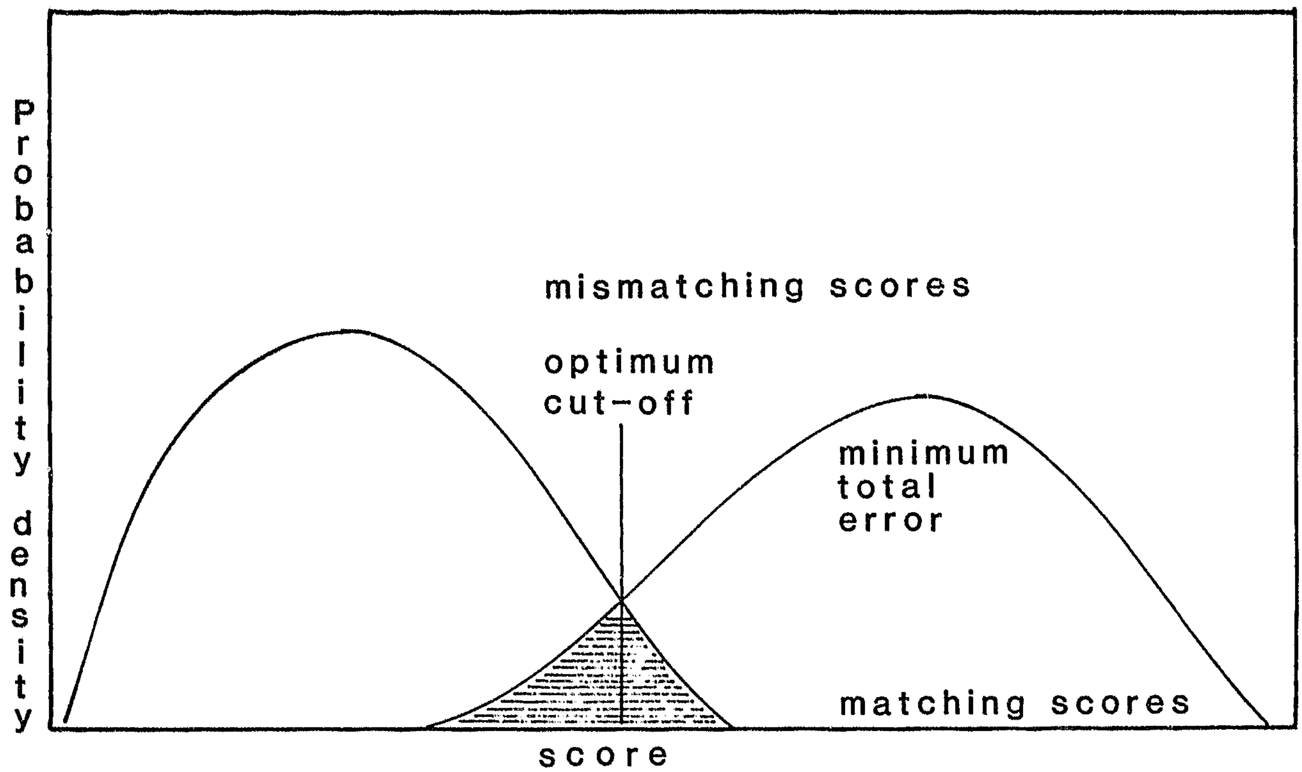

Figure 7. Theoretical match and mismatching score distributions.

appropriate to operate at the optimum cut-off point. Sometimes the scoring threshold for latent prints is set to the left of the optimum cut-off point. This provides a lower miss rate at the cost of examining more false drop candidates. Selection of an appropriate operating point requires careful examination of the tails of distribution curves that have been plotted from the user's data, not from benchmark data sets.

Selecting an appropriate operating point may also depend on file size. If the file is small, selecting an operating point to the left of optimum cut-off may not produce an unmanageable number of false drops. Hits may be made on candidates that do not rank first in score. With larger files, the mating prints that scored in ranks two and three with a small file will quickly drop in rank by large amounts. As a result, the larger the file that a latent print is searched against, the more likely it becomes that, if the mating print is found, it will score in rank one. For example, suppose a latent print is matched against a file and develops a score of 30% with its mate. Suppose also that the probability density distribution curves show there should be 1% of the nonmating file which is expected to score higher than 30%. If the latent print is searched against a file of 100 fingerprints, there is likely to be only one nonmating print with a score higher than 30%. Then the score of the latent with its mate at 30% is likely to be no lower than rank two. If that same latent print is searched against a file of 100,000 fingerprints, there are likely to be 1,000 (again 1%) of these that score greater than 30%. The latent print score with its mate might now be in rank 1,001.

Knowledge of the distributions of normalized matching and nonmatching finger scores developed from the user's operational data bases is important. With this information, you can construct curves that show the reliability and false drop rate for any operating point that is selected. Although similar curves may be constructed from a benchmark data set, they will differ from the operational curves. The differences will be related to the way a benchmark data set differs from the operational data base.

Selecting an optimum operating point as a function of the size of the file to be searched may maximize the hit rate from a system while using a fixed amount of latent print examiner manpower.

Work is currently underway to develop an ANSI standard performance benchmark test for AFISs. The proposed standard will be based on some of the concepts presented in this paper.

CONCLUSIONS

When new technology becomes more widely used, the need for standards relating to its application are generally recognized and appropriate standards are developed. The fingerprint data interchange and AFIS performance benchmark standards development work described in this paper are expected to be only the forerunners of a possible family of AFIS related standards. At least two candidates for future consideration already can be identified. Current efforts to develop an inkless process for taking fingerprints are providing a driving force for developing fingerprint image quality standards. These could help ensure that fingerprint image data produced by these systems are satisfactory for use as AFIS input and for verifications of candidate identifications. Also, the increasing use of automated image retrieval systems suggests that a standard data compaction algorithm might be useful. Other requirements will undoubtedly be identified as AFIS use continues to grow.

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THE WORK OF THE SERIOUS CRIMES UNIT

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The Serious Crimes Unit (SCU) within the Metropolitan Police Forensic Science Laboratory began in 1981 with the acquisition of a 2 W argon ion laser in the photographic section. Although it was not purchased for fingerprints, the laser could detect prints when traditional methods could not.

In 1983, a Home Office chemist joined the unit and helped demonstrate the advantages of sequential techniques (Home Office, 1986). When a chemist was able to work alongside the photographers, the number of enhancement techniques quickly grew, and today we have approximately 25 methods for the detection, development and enhancement of fingerprints on a wide variety of surfaces (Pearson *et al.* 1984). Of course, many surfaces, such as skin, leather and heavily plasticized polyvinyl chloride, still present problems.

The demand for the unit's services grew at such a pace that the Fingerprint Branch at New Scotland Yard assigned two fingerprint officers to the unit to scrutinize prints, work with the scientists in the development of prints and advise scientists in other parts of the Laboratory on fingerprint matters.

The following figures on the unit's yield of prints for exhibits shows the return when items are selected for their importance and all possible techniques are applied. With last year's staffing levels of two photographers, two scientists and two fingerprint officers, we have reached saturation because approximately the same number of prints and sequences were photographed in 1985 and 1986. Notice that the number of prints per exhibit increased between 1984 and 1985, when sequencing of treatments was implemented.

Year	Exhibits	Prints
1982	428	126
1983	976	322
1984	2,567	978
1985	3,065	1,757
1986	2,618	1,831

The use of lasers for the detection and development of latent prints is well established (Dalrymple *et al.* 1979; Menzel 1979, 1980; Salares *et al.* 1979; Creer 1983, 1987). Our Laboratory now has four lasers, the 2 W and 12 W Spectra Physics argon ion lasers, a transportable frequency-doubled neodymium:yttrium aluminum garnet (Nd:Yag) laser by Spectron Laser Systems and an Omnichrome 1,000 portable 200 mW argon ion laser. The most recent addition is a 200 W mercury vapor lamp with a liquid light guide delivery system and narrow band pass filters supplied by Ultrafine Technology. Both the mercury lamp and the Omnichrome laser are useful at crime scenes. Currently more marks are found with the ultraviolet lamp than with the Omnichrome laser on emulsion painted walls. There appears to be no correlation between marks detected with either the laser or the ultraviolet lamp and those developed by chemical means.

At first only the Nd:Yag laser was available for scene work. Although bulky, it showed that marks such as aluminum powder, which did not develop with traditional methods, could be detected. During an initial experimental period (Pounds, personal communication), 23 scenes were visited and 53 fingermarks were found in addition to the 325 detected by powdering. Obviously, powdering is still the most effective technique used at the crime scene. Of the 53 extra marks, 22 were revealed by the Nd:Yag laser on gloss painted doors and frames and Melamine surfaces, Melamine being a poor surface for powder. None of these 22 marks subsequently powdered. Many of the other extra marks were produced on emulsioned walls and wallpaper by a solution of iodine and naphthoflavone.

The laser and mercury lamp not only reveal fingerprints but also detect other types of forensic material, including blood splashes, fibers, shoeprints, unknown fluorescent stains and marks on bodies, such as subcutaneous bruising and jotting made on the back of the hand with a writing instrument. All of these marks were either not visible to the naked eye or were greatly enhanced by these specialized lights.

The SCU's main objective is to become involved in as many major crime cases as feasible and treat targeted items from these cases. Items submitted for treatment are often selected as a result of discussions at the scene between SCU and fingerprint personnel. If appropriate, all scientists involved are invited to a case discussion with the fingerprint officers at the laboratory when the items arrive. This establishes an order of examination, for example, a ransom note would be subjected to the following sequence:

Handwriting examination and photography
Laser and ultraviolet (UV) examination
Electrostatic detection for indented impressions and fingerprints
Saliva taken from envelope flap and stamp for grouping
Ninhydrin plus humidity (double dip)
Zinc chloride and liquid nitrogen plus laser
Physical developer
Scanning electron microscope (SEM)

The importance of humidity in the ninhydrin treatment has been demonstrated on several occasions (Figure 1). A child's exercise book was dipped in ninhydrin solution, treated at 80° C for 5 minutes and left for 7 weeks before being submitted to the SCU for photography. Before physical development was attempted, the book was treated in the humidity oven (80° C and 80%) for just 2 minutes. The result is shown in Figure 1(b), which clearly shows the strong enhancement of the ridge detail.

Normally, for a single sheet of paper, 5 minutes at this elevated temperature and humidity will produce all the ninhydrin prints. However, lower quality paper and wood can require up to 30 minutes. Double dipping in ninhydrin is preferred to prolonged exposure to the reagent, as the latter can often produce over-developed backgrounds.

Another case illustrating the importance of humidity involved a parking attendant who was shot and left to bleed to death. His wooden hut was transported to the laboratory and placed in the basement car park last January when the temperature in the car park remained a few degrees above freezing for weeks, but the humidity was high, approximately 60%. Two days after ninhydrin solution was painted on, useful ridge detail developed on bare wood inside the hut.

A greater success rate with the zinc chloride treatment (Herod and Menzel 1982a) is achieved if, after being sprayed with the solution, the document is returned to the humidity oven for a short period, typically 30 seconds. The ninhydrin product, Ruhemann's purple, is toned orange and fluoresces under argon ion laser excitation. Immersion in liquid nitrogen (−196° C) frequently enhances the fluorescence of the print (Kobus *et al.* 1983) with respect to the background. If a freshly treated ninhydrin print is cooled in liquid nitrogen and excited with the 514.5 nm line of the argon ion laser, the Ruhemann's purple product will fluoresce red. Older prints do not fluoresce as strongly even if rehumidified and cooled. Herod and Menzel (1982b) previously reported fluorescence from nonvisible ninhydrin treated prints in the red and near infrared when stimulated by the 570-590 nm dye laser light. The zinc chloride treatment not only enhances weak ninhydrin prints but also develops additional prints, even after double dipping in ninhydrin and humidification (Figure 2).

Although physical developer (PD) is time consuming to use, it can produce marks not detectable by the laser or ninhydrin methods because it interacts with the greasy, lipid material derived from forehead perspiration and transferred to the fingers (Home Office, 1986). Normally the PD prints will photograph well, especially if the paper fluoresces (Figure 3), but occasionally against a background such as newsprint it is necessary to use the SEM, which can contrast the silver of the PD print with the carbon black of the newsprint (Figure 4).

Polyethylene carrier bags are second only to paper in frequency of occurrence. The bags are subjected to the following sequence:

Laser and UV examination (Figure 5)
Metal deposition (MD)
Super Glue (cyanoacrylate)
Staining

For example, a faintly discernible print was visible in normal light on a blue and white Woolworth's carrier bag (Figure 6). Excitation with the 514.5 nm line

Figure 1. Ninhydrin (a). Humidification (b).

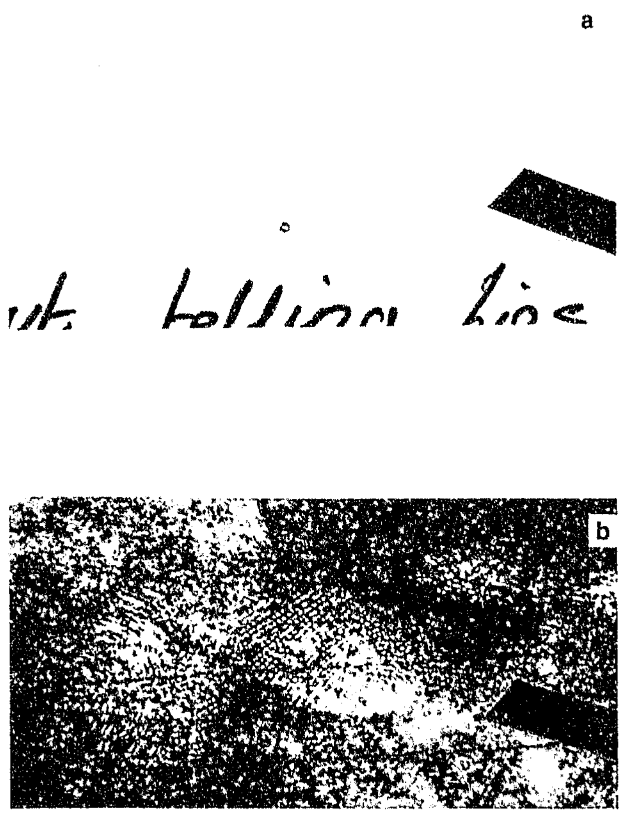

Figure 2. Ninhydrin (a). Zinc chloride (b).

Figure 3. Ninhydrin (a). Physical developer (b).

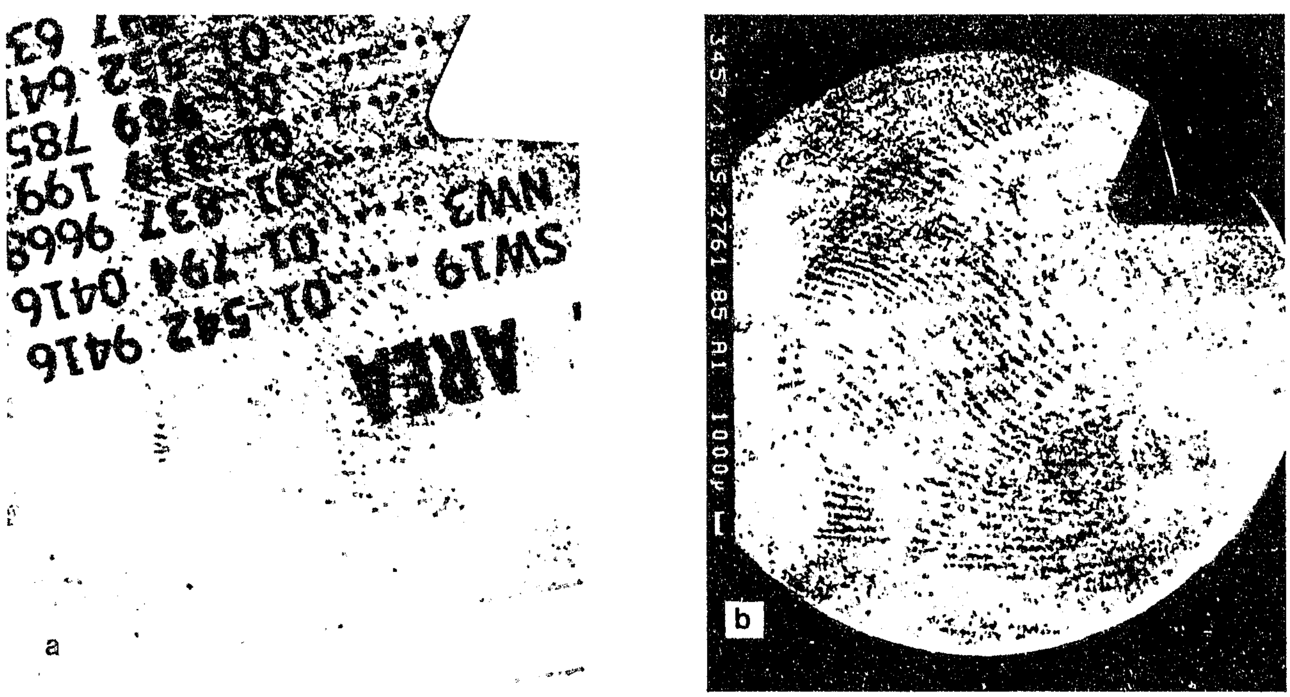

Figure 4. Normal light (a). Scanning electron microscope (b).

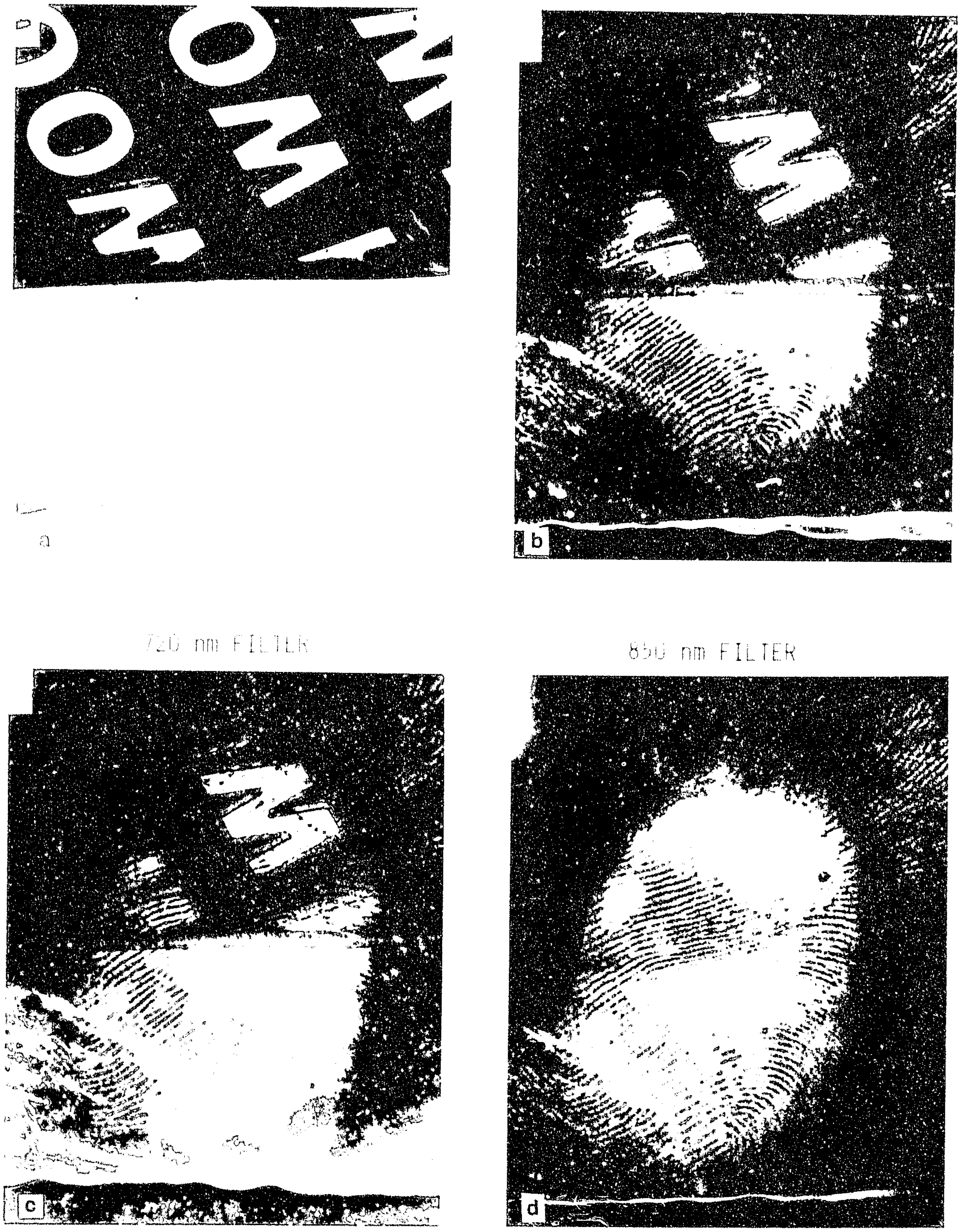

Figure 5. Normal light (a). With 550 nm filter (b). With excitation laser at 514.5 nm (c and d).

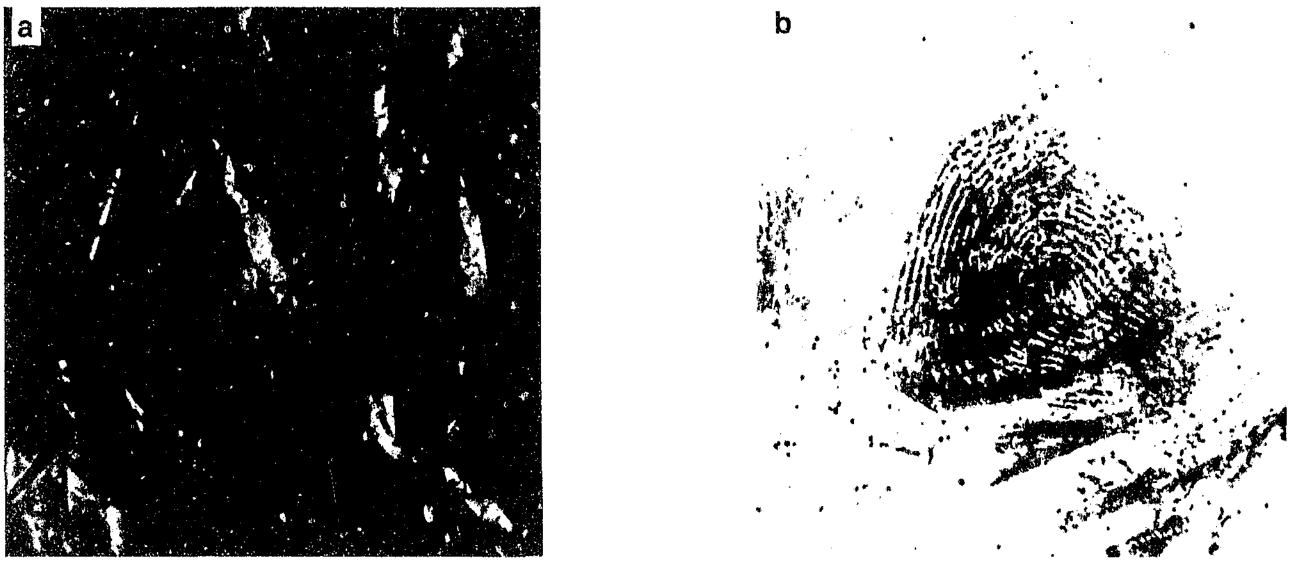

Figure 6. CNA (a). CNA plus R6G (b).

produced the displayed results as progressively longer wavelength filters were selected to isolate the emitted radiation.

The unit has a range of Super Glue cabinets. The largest measures 1.8×0.9×4.6 m and has taken items as large as an adult's bicycle. To obviate the risk of overfuming, just 0.5 g of liquid ethylcyanoacrylate ester is heated to 120° C inside the cabinet. Fuming lasts for approximately 20 minutes at about 70% humidity inside the cabinet.

After being treated with cyanoacrylate, bags are stained with a 10^{-4}% (0.0001 g in 100 ml of methanol) solution of Rhodamine 6G (Figure 6) and blown dry with compressed air. Moderate and high room humidities slow down the evaporation of the solvent and can leave severe solvent marks on the bags. Water based dyes can produce similar if not worse solvent marks. If the zinc coating of the MD process causes a problem, it can be removed simply with a dilute acid wash (Figure 7). For instance, the 2% maleic acid solution used as a prewash to the PD process was used on the access card.

The unit has tested alternatives to Rhodamine 6G, including DCM (10^{-4}%) and Crystal Violet (0.3%), both in methanol. Their efficiencies of staining are comparable with that of Rhodamine 6G. The selection of either a fluorescent or visible stain for cyanoacrylate treated prints is dictated solely by the background; hence, the choice of stain for each exhibit is discussed first with the photographer.

Some rough textured plastic surfaces have responded to cyanoacrylate fuming followed by treatment with 7-chloro-4-nitrobenzo-2-oxa-1,3-diazole

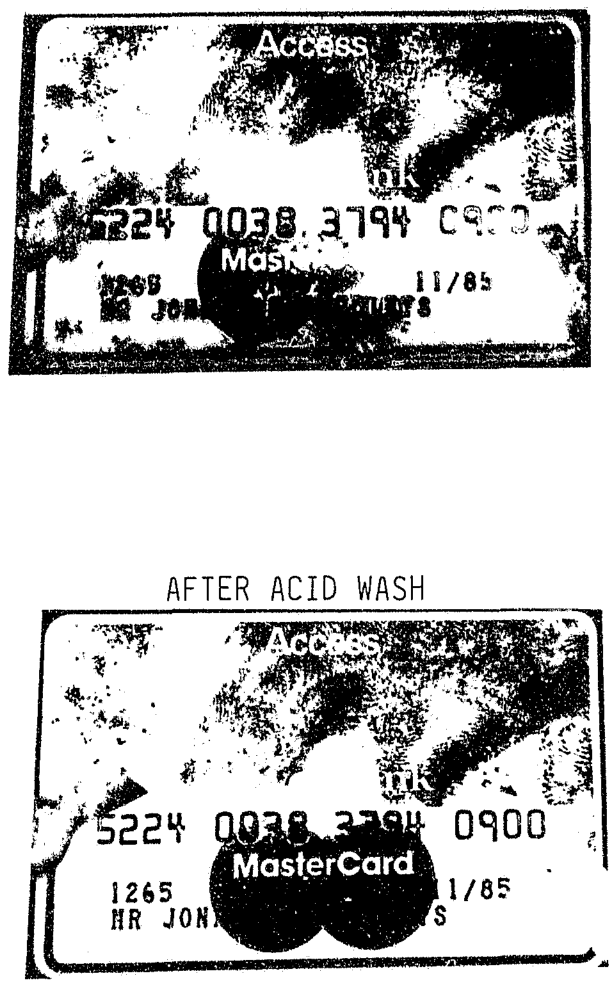

Figure 7. MD plus CNA.

(NBD chloride) (Salares *et al.* 1979; Stoilovic *et al.* 1987) solution (0.06% NBD chloride in Fluorisol, heated dry at 75° C for 30 minutes). The prints are excited by the argon ion laser and fluoresce strongly in the yellow-green spectrum. When a print on a black surface (Figure 8) was immersed in liquid nitrogen to prevent heat damage by the laser during the long photographic exposure required, the fluorescence was found to have shifted to the orange region after it was warmed and reexamined. This shift is believed to have been caused by water condensing on the print, since the black surface had been removed from the liquid nitrogen and allowed to reach room temperature.

Later experiments with the humidity oven confirmed the observation and showed that for the orange shift to occur, both the matrix of cyanoacrylate ridges and humidification are necessary, that is, humidification alone will not shift the fluorescence of NBD chloride.

Adhesive tapes are used on many surfaces, and before tape is removed, the outer surfaces are examined with the laser and UV radiation and then fumed with cyanoacrylate. After removal, the tapes are then subjected to radioactive sulfur dioxide gas and autoradiographed for approximately one week. Gentian Violet, the most effective treatment for the adhesive side of tape, is followed by transfer onto processed photographic paper if the tape is black and nonfluorescent. Strong Gentian Violet prints contrast well against a fluorescent background. For example many black plastic handled kitchen knives fluoresce strongly and can therefore be successfully treated with Gentian Violet.

A 0.5% solution of Tergitol 7 detergent (BDH Ltd.) detergent in water is the most effective wetting agent for the transfer process. There appears to be no time limit to this transfer process, as prints have been successfully lifted from black tape treated with Gentian Violet 6 months previously. Occasionally, we have observed fluorescence from weak Gentian Violet prints in the region of 730-750 nm (Figure 9) using 514.5 nm laser irradiation.

In general, finding prints on smoke-damaged items is very difficult. However, in a few instances, prints have been developed with Gentian Violet. This has entailed prolonged immersion in the Gentian Violet solution, sometimes overnight. Phenol is one of the ingredients of the Gentian Violet solution added to solubilize fats within the fingerprint material. In the case of smoke-damaged items, it may be acting as a crude detergent, cutting through the greasy smoke deposits.

Fingerprints in blood submitted to the Laboratory are normally examined with the laser and UV lamp. Prints can be enhanced by stimulating the background to fluoresce, or occasionally "thin" blood marks have been found to fluoresce strongly in the yellow-orange region. It is believed that this is caused by a predominance of plasma over red cells. These plasma-rich prints could result from shed blood that has had time to clot or from pressure on a wound expressing the less viscous plasma in preference to the red cells. Removal of the red cells by centrifugation or chemically by washing with sodium methoxide solution (1% sodium hydroxide in methanol) shows conclusively that the red cells quench the strong yellow fluorescence of the

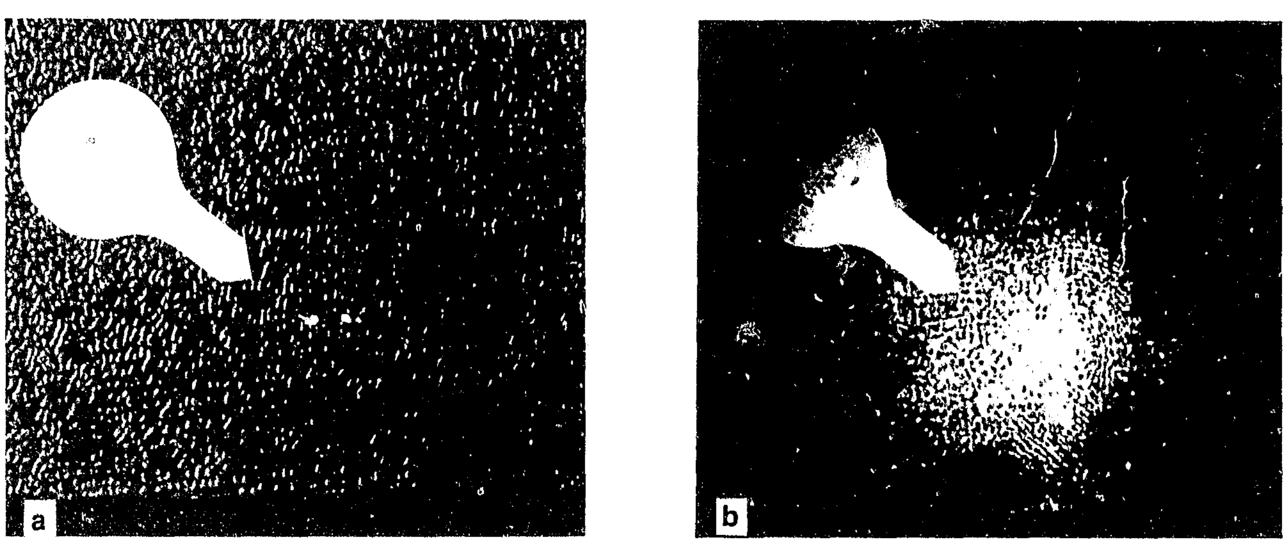

Figure 8. Normal light (a). CNA plus NBD and liquid nitrogen (b).

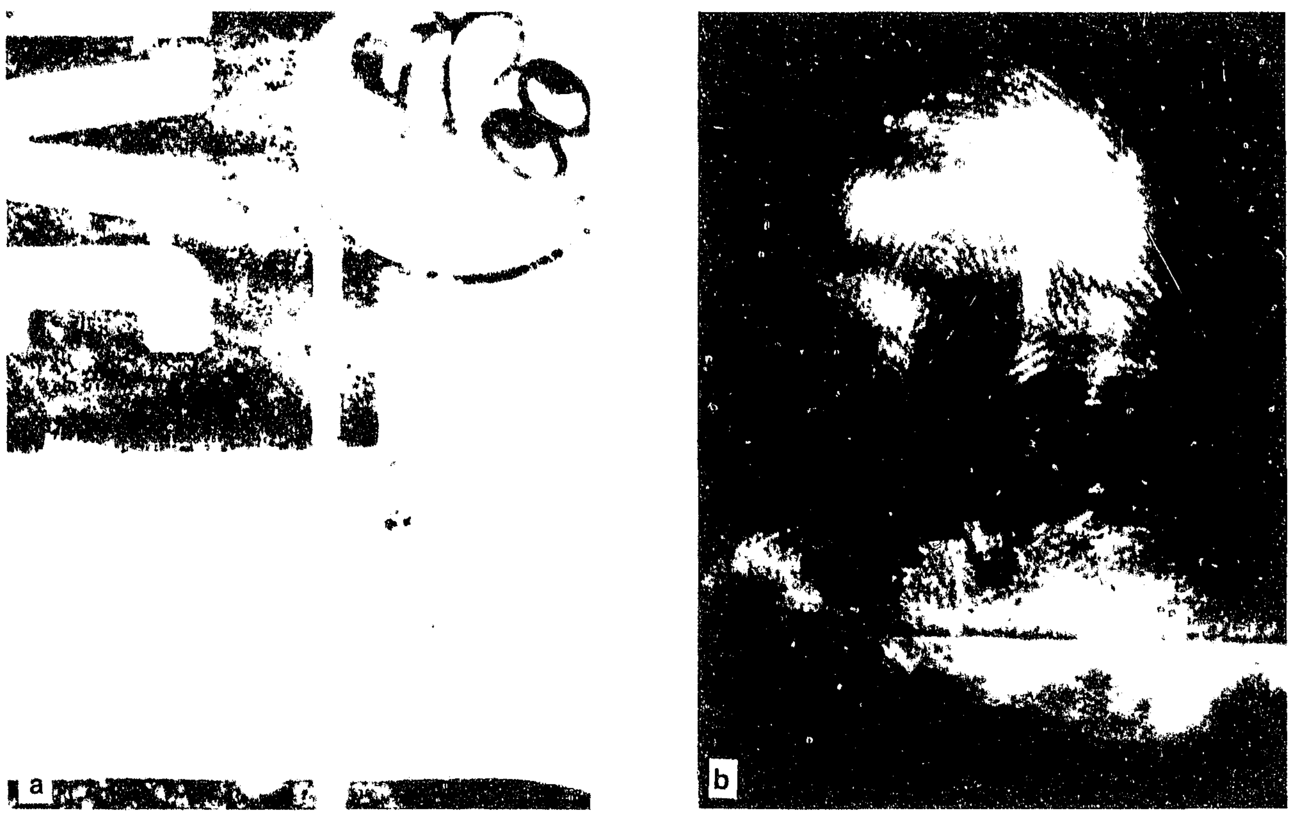

Figure 9. Plastic bottle examined under normal light (a) and fluorescence from weak Gentian Violet print, at 730–750 nm using 514.5 nm laser irradiation and liquid nitrogen (b).

plasma. The plasma fluorescence increases in intensity with age and shifts to the red end of the spectrum, that is, it becomes orange. However, with the advent of the Omnichrome laser and mercury vapor-lamp, there are very few occasions in the laboratory or at scenes when subsequent chemical treatment of whole blood marks has produced more detail than that achieved by skillful, patient scientific photography with the aforementioned light sources. There are occasions when whole blood has been diluted, for example, in an attempt to wash down a scene with water. The diluted blood, although visibly diminished, reacts strongly with Amido Black solution. During the dilution, lysis occurs, that is, the red cells swell and rupture through the absorption of water (osmosis). This increases the concentration of the protein material available for reaction with the Amido Black solution.

CRIME SCENE WORK

Since May 1985, the SCU has attended nearly 100 major crime scenes, nearly 50 of these in 1986. Our aim has been to provide an advanced technologic service to the fingerprint and investigating officers. Once staff arrive at the scene, a conference is called. For example, in the case of a murdered 9-year-old girl the officer in the case, the senior fingerprint officer, the forensic intelligence officer (FIO), the SCU photographer and scientist and the pathologist all met to discuss the examination of the scene. The girl was last seen alive talking to her school janitor. Her body was found the next day in a black plastic bin liner concealed in a rubbish bin in the school playground. The janitor, who was a strong suspect, denied any involvement.

The girl's body was removed from the bin liner and examined under both laser and UV radiation on a body sheet in the school playground. Her clothing was removed and packaged during the examination. Fibers found around her mouth, not visible under normal light, fluoresced under laser radiation and were later matched to fibers from a carpet in the janitor's house. A fluorescing partial thumb mark was found on the girl's neck under laser radiation. There was insufficient detail for comparison purposes, but it did help the pathologist determine that the cause of death was manual strangulation. A powder that fluoresced blue under UV radiation was found on the soles of the girl's shoes. This was similar to fluorescent poster paint powder found on the floor of the janitor's room.

A yellow fluorescing stain was found on the girl's leg with the laser. This was sampled in the hope that it might help show where the body had been stored, but the substance was not identified. The plastic bin liner was rushed to the laboratory, where a second team of SCU personnel examined it under both laser and UV radiation before treating it with metal deposition followed by cyanoacrylate and Rhodamine 6G. Fingerprints developed by both metal deposition and by cyanoacrylate and Rhodamine 6G were identified as belonging to the school janitor.

In the janitor's house, many childrens' fingerprints were developed by laser, iodine and aluminum powder. All of the iodine prints and a number of others were identified as belonging to the victim. A stain that fluoresced under UV radiation was found on a carpet in the back bedroom. This proved to be saliva of the same grouping as the victim. Fibers from the carpet fluoresced under the laser with the same color as those around the victim's mouth and were later matched positively.

Twenty-three hours of continuous duty were required to carry out this full examination. The laser examination of the house and the body were carried out during the night when the dark conditions were ideal for fluorescence examination. The janitor was later convicted of murder and sentenced to life imprisonment. This case illustrates how a multidisciplinary team can retrieve evidence that assists both the investigative and corroborative sides of police work.

Another case attended by the SCU was the murder of a 19-year-old girl. Her father found her dead, slumped against her bed. She had been strangled and stabbed. The father was disturbed by a noise during the night. He checked downstairs, drank a cup of coffee and went back to bed, not realizing that the murderer was probably in his daughter's bedroom.

The scene was preserved until the SCU arrived, and then the FIO conducted the team through the scene, explaining in detail how the police viewed the events of the night. The SCU worked closely with the senior fingerprint officer and the FIO to examine the scene with nondestructive methods first, that is, the laser, UV and electrostatic lifting of several floors for shoeprints.

The murderer had entered the house via a small kitchen window above the cooker. He had removed several saucepans and left these outside on the grass. A laser examination of the window and opening edges revealed a fluorescent three finger sequence, possibly caused by grease contaminants from the saucepans. The paint on this window was old, and consequently the prints did not respond to aluminum powder. The sequence was searched on the Police National Computer (PNC), and the suspect was quickly identified. His only previous conviction was for larceny of car parts. The combination of SCU and fingerprint expertise again saved considerable police time.

Many fingerprints found in the girl's bedroom were in blood. These were found on the inside of the door, the bed headboard, a chest of drawers and on the window frame at the point of exit. These prints were partially developed with aluminum powder and photographed, and some were further enhanced with leuco-malachite green (LMG) spray (Patty and Giberson 1987). The marks were rephotographed through various filters with a variety of lights, including both the laser and a UV lamp. Although not conclusive, reaction with LMG indicates the presence of blood, thereby assisting the fingerprint branch in the selection of the most relevant prints from the bedroom to search. Some of the prints were later identified as the suspect's after he had been identified on the PNC.

An alarm clock was found under the body. During a joint examination at the laboratory, the biologist took a sample of blood from a print on its side before enhancement with Amido Black. The sampling of the blood was discussed with the fingerprint officer to minimize the loss of ridge detail. The blood was the same group as the girl's, and the print was identified as the suspect's.

Written on the back of the girl's right hand was the word "HELP," visible only under the laser. It later transpired that she worked for a local newspaper and was preparing an article on a charity called Helpline. However, at the scene all present were deeply affected by this eerie find. On other occasions, jottings on the hand have been of great assistance to police investigations.

A swimsuit, similar to one worn by the victim in a glamour photograph, was recovered from the suspect's home. Laboratory examination and comparison with control swimsuits from the manufacturer proved conclusively that the position of the stripes of the pattern and stitching faults matched between the recovered swimsuit and the suit in the glamor photograph.

At his trial, the suspect claimed the girl had invited him in while her parents were asleep, although climbing through a small kitchen window would seem an odd mode of entry. He claimed he found her already dead, attempted to revive her, panicked and left via the bedroom window. He denied stealing anything including the swimsuit. Found guilty, he was sentenced to life imprisonment.

In conclusion, the SCU's reason for success is teamwork. Without careful matching of personalities, good management and cooperation all our efforts would be futile.

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DISCUSSION

Haylock: When you were discussing staining Super Glue, what precautions do you take when you are using Rhodamine 6G?

Brennan: We don't take any precautions because we use a very low concentration of 0.001 g, and we do not use Rhodamine 6G very often. Many people use a 1% concentration, so ours is much weaker. I am more worried about methanol. Methanol can be very damaging. We need to find a safe substitute for methanol.

Stoilovic: What is the temperature in your humidifying cabinet?

Brennan: Seventy-five to 80 degrees Centigrade.

Kobus: Your lecture illustrates quite well the wide variety of techniques that need to be used all the time for detecting latent prints. It is fantastic to see a forensic science laboratory so intimately involved in fingerprint work. I desperately try to preach that in Australia, and no one at the forensic science operational level really gets involved. Concerning black staining, we also have found that the weaker the fingerprint in blood, the better it works.

I noticed your Super Glue chamber does not have any windows. Do you fume the latent print for a specified time and then look at it, or do you check it from time to time.

Brennan: We hang a test strip in view inside the cabinet and look at that. It is very easy to overdo Super Glue.

Almog: Can physical developer be used after a ninhydrin zinc chloride treatment?

Brennan: Yes.

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EMPLOYEE ORIENTATION TO AUTOMATED FINGERPRINT IDENTIFICATION SYSTEMS

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Automated fingerprint identification systems are at the very forefront of modern technologic progress, but employees cannot be forced to use them to make identifications and solve crimes. Anyone who manages people knows that they can achieve what is seemingly impossible if they are well motivated and understand what is required of them. We also know that people can be extremely stubborn and resistant to change when they find the reasons for change difficult to accept. This paper describes New Scotland Yard's experience concerning employee reaction to the introduction of fingerprint computer systems and particularly to the Automatic Fingerprint Recognition System (AFR) installed in 1984.

It is easy to underestimate the complexities and problems of integrating automated processes such as AFR into the work of a large staff who have been highly successful without the aid of high level technology. Compared with the technicalities of computer design, construction and performance evaluation, getting people to use systems effectively might seem to be a minuscule problem. However, preparing people to use a computer system requires more extensive education than just training staff to use the equipment according to the manufacturer's handbook. Computerized systems are installed to increase efficiency and effectiveness, but performance will not improve unless the staff using it are wholeheartedly behind the idea of its use and unless they trust it. They will trust it only if they have been consulted and involved in its design and testing and understand and accept the organizational philosophy surrounding it. Getting a return on our investment in AFR requires not only technical preparation but also subtle staff conditioning.

To understand our staff's reactions to computers, one has to review the history and traditions of fingerprint identification work at New Scotland Yard. Most people know that the use of fingerprints for identification purposes officially began in the United Kingdom in July 1901. In that year, a small classified collection of fingerprint forms of recidivists was established. Although the collection was intended primarily as an infallible key to individual criminal records, it was also almost immediately used for attempting to identify fingerprints retrieved from crime scenes. The first case based on the identity of a fingerprint found at a crime scene was heard by a Court a few months later, in 1902, and the first murderer was hanged on the strength of fingerprint evidence in 1905. The original small size of the classified collection meant that it could be searched quickly by trained personnel, even when only a single fingerprint was retrieved from a crime scene. This created a tradition that persisted even when the collection grew into hundreds of thousands and ultimately millions of prints. In the 1950's and 1960's, before computerization, it was not uncommon for us to assemble 100 fingerprint officers on a series of Sundays for the task of cold searching a single murder print through large parts of the collection, which by then contained 3 million forms. In about 50% of the cases, an identification was established, but cold searching on such a massive scale could not be undertaken for prints found at routine burglaries and the like. Nevertheless, a tradition of limited cold searching for any crime was also established early in the century. Selected subsets of the whole collection were established for offenses such as burglary and robbery. From the 1920's to the 1950's, the subsets were organized as collections of subclassified single prints. In the 1960's, subsets became based on geographic criteria. This change helped to improve identification results. The total number of scene print identifications (for the London metropolitan area only) was raised from 3,826 in 1968 to 6,000 in 1971. Seventy percent of those identification totals came from manual cold searching. The other 30% came from named suspects specified by investigating police officers.

The escalating success of identifying fingerprints found at crime scenes led in the early 1970's to an increase in the number of crime scene examiners and an increase in the number of fingerprint staff. It prompted the British Home Office to try to build a computer that would emulate human cold search successes. That led to the present Home Office AFR search algorithm. The most successful year was 1980, when 9,350 identifications of scene prints for the London area were made largely by manual cold search.

Despite this success, other factors were at work in the 1950's and 1960's that gradually interfered with the goal to increase crime scene fingerprint identification. The national collection had grown so large that it had to be computerized purely for recordkeeping purposes. A large back conversion exercise lasting 8 years swallowed up a considerable number of fingerprint staff. A huge increase in the number of scenes examined brought a commensurate increase in the number of cases for cold search but at the same time (probably through greater public awareness, among other things), the average number of prints retrieved from each crime scene was diminishing. The average of six prints per case in 1968 (after elimination of persons with legitimate access) had dropped to about two per case by 1982. Each mark found was, on average, less well defined than its counterpart in the 1960's. Taken together, all these factors made manual cold searching far more time consuming and made the improvement of identification results far more difficult to achieve. There were two ways to proceed: recruit and train more staff or develop a computer system proficient enough to emulate the capabilities of the human fingerprint staff. Because of the financial limitations in the 1980's, the more costly option of extra staff was out of the question, and staff was even reduced. Therefore, a decision was made to purchase, for the modest price of 2 million pounds, an AFR system with a data base size and comparison capacity capable of dealing with the sort of prints from crime scenes which could not be economically cold searched manually. Our AFR system was delivered in January 1984 and started working in August of the same year.

I have made this excursion into history to show that New Scotland Yard has a strong tradition of successfully cold searching scene of crime prints not only from high profile cases but also from run-of-the-mill burglaries and robberies (Figure 1). That tradition has led the fingerprint staff to expect that the work would be hard but that it would include a very high level of job satisfaction at a personal level. Fingerprint officers spend many years perfecting their personal comparison and identification ability. They are tremendously proud of it and have tended to see

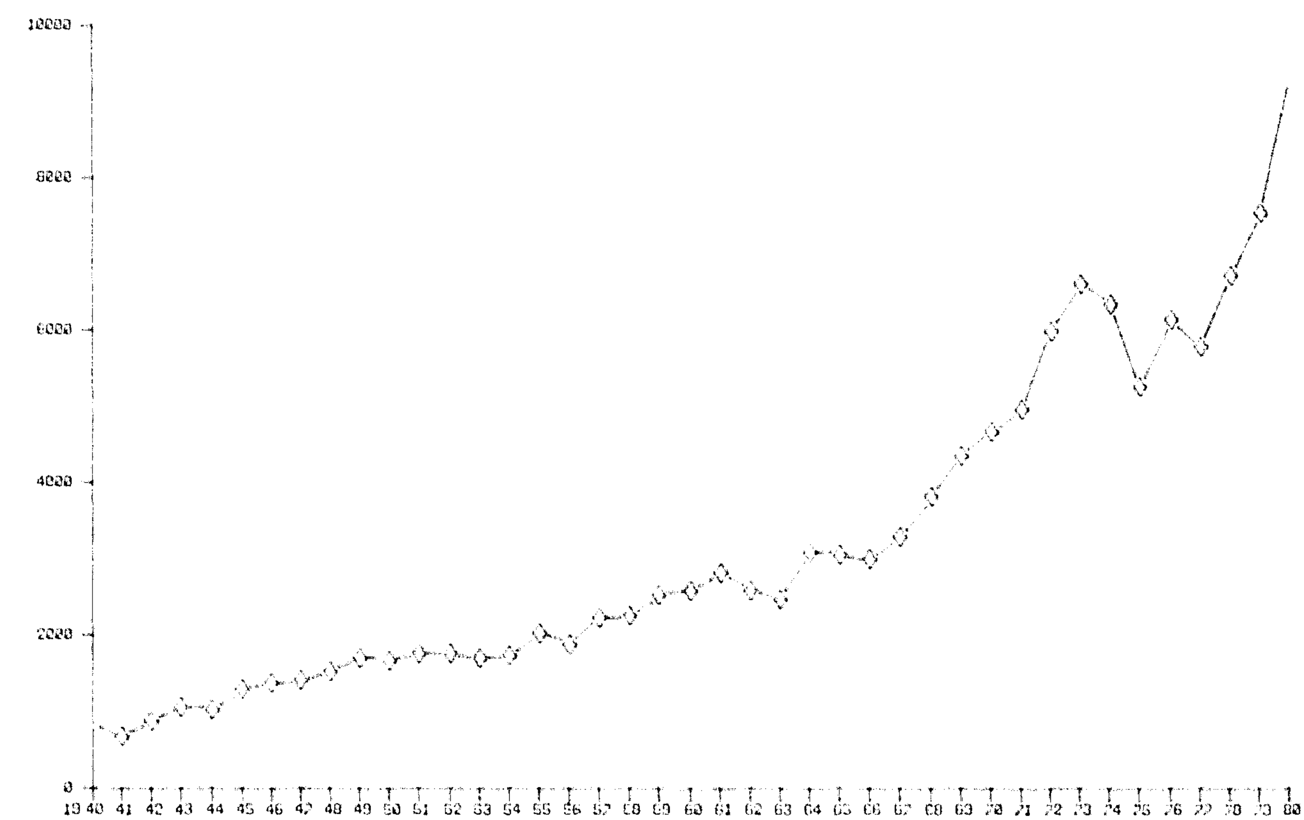

Figure 1 Crime scene fingerprint identifications, New Scotland Yard, 1940 1980

computers as a potential threat to the exercise of their hard-won personal skills. If computerization of fingerprint work was to be successful, the staff had to appreciate the advantages it brought and integrate the system willingly into their work processes.

The fingerprint management system of the early 1970's did not appreciate that need when the first two computer based fingerprint systems were established at New Scotland Yard: the Police National Computer (PNC) (Fingerprint Application) which became operational in 1976 and the Videofile graphic retrieval system which became operational in 1977.

The PNC data base consists of alpha-numeric descriptors of sets of 10 prints. The long back conversion period was heartily detested by most officers as was the ongoing daily need for the painstaking manual production of alpha-numeric descriptors for each new set of prints for search and inclusion. The PNC also produced very long lists of responses for checking if prints were in any way substandard. There was some disillusionment over PNC, which led to a strong skepticism when Videofile was introduced. Videofile was a commercial reel-to-reel videotape product modified to provide the graphic retrieval on terminals of any set of fingerprints in the national data base. It had a batch-mode operation that normally required an overnight wait. This wait was unpopular, and the flickering image produced by a low level screen refresh rate did nothing to enhance its image in the eyes of staff. These problems were corrected, but the staff also felt that they had not been consulted about the system in the design and procurement stage or when the performance had been assessed and the work rates and throughput timings were calculated and specified.

We learned much from all our early mistakes in the introduction of PNC and Videofile. We learned that systems should not be designed or built without active and vigorous staff participation or without theoretical throughput calculations being checked in practice by people who would be doing the job on a daily basis. We also realized that the staff needed to be trained and encouraged to adjust their work habits so that they were compatible with the computer system.

When we purchased the AFR system in 1984, we put all our remedial measures into practice: the requirement for human action at the input stage was minimized, the back conversion was cut to a few months, and the effectiveness of the equipment and the programs was extensively tested under working conditions.

Ordinary staff members were used in a 6-month operational working trial on a pilot system so that realistic throughput timings could be made and manpower productivity and the likely increase in identifications could be efficiently calculated. In spite of all this, we still met problems.

The effectiveness of the search algorithms indicated that we needed to examine more crime scenes to produce more material. This meant allocating more staff to crime scene examinations. We also found some gaps in the population of the data base because some types of young offender were not being fingerprinted when taken into custody. As previously mentioned, a number of prints being retrieved from scenes were not good enough for the machine to process with extensive interpretative help of the human eyes. Action is under way to deal with all these matters.

There is still a machine acceptance problem. Figure 2 shows the cold searching done in the scene fingerprint context from approximately 1983 to 1986. For the first 18 months, most of the total searching was performed manually, as indicated by the diamond-shaped points of the graph. The line made up of triangular points shows the small number of cases (300 or 400 per month) searched by means of PNC. The AFR came into use in August 1984 and is represented by the hourglass-shaped points in the line. Total searching quickly increased to an average of about 3,500 per month, but manual searching dropped to 500-1,000 per month and PNC searching dropped slightly. After the initial increase, AFR searches settled at an average 2,500 per month.

The figure shows that there was a dip in AFR searching in the first few months of 1985, with a commensurate rise in the number of manual searches being done. This occurred because in December, some problems arose with the AFR program functioning which made us question whether the machine was recording detail correctly. The dip in machine use and the rise in manual searching seem to reflect a crisis of confidence on the part of the staff using the system. After so short a time, they had not developed trust in the machine. They were wary, and as soon as this problem occurred, they seemed to conclude that the system was not as good as they first thought and that they must go back to their old methods for results.

Figure 3 shows the cold search identification results over the same period. They deal with prints from crime scenes that were searched against the data base of selected London criminals. (Two thirds of the identifications obtained at New Scotland Yard are obtained by the cold search process.)

Before AFR, most of the cold search identification total (the diamond-shaped points), came from the manual component (the square points), but with the advent of AFR (the hourglass-shaped points), total identifications surged initially to new high levels of

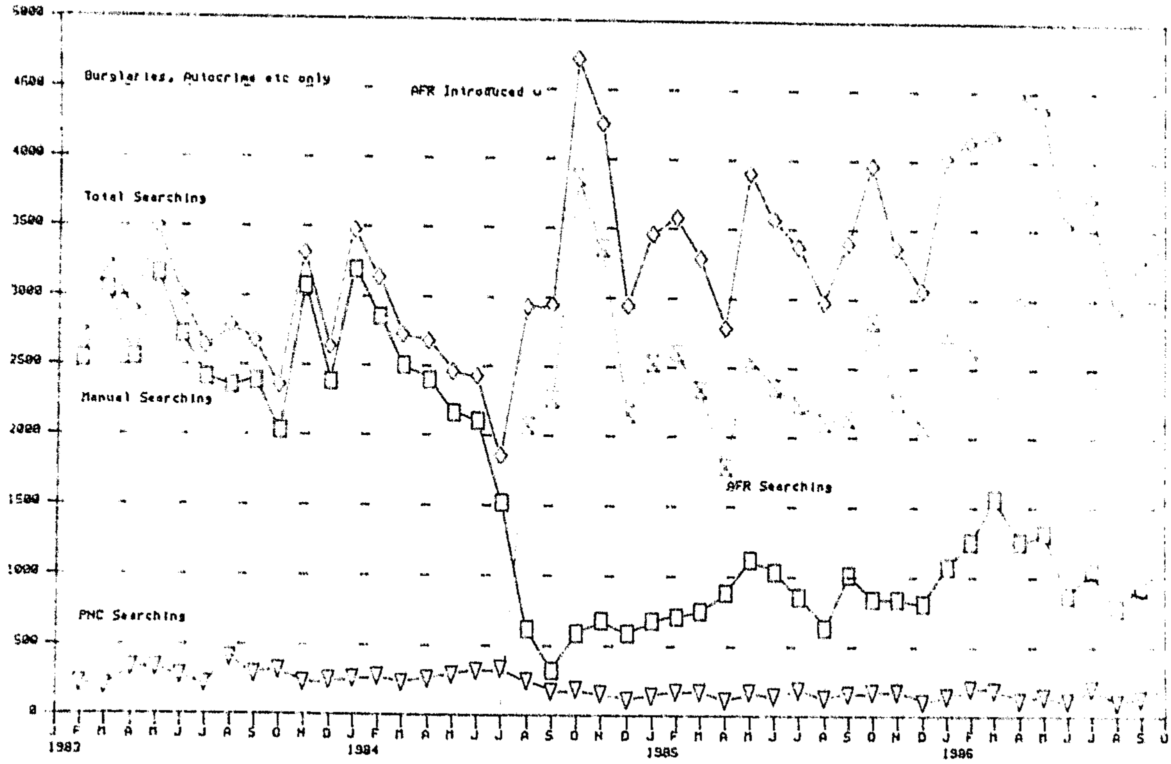

Figure 2. Crime scene fingerprint searches against fingerprint collections, New Scotland Yard, January 1983–October 1986

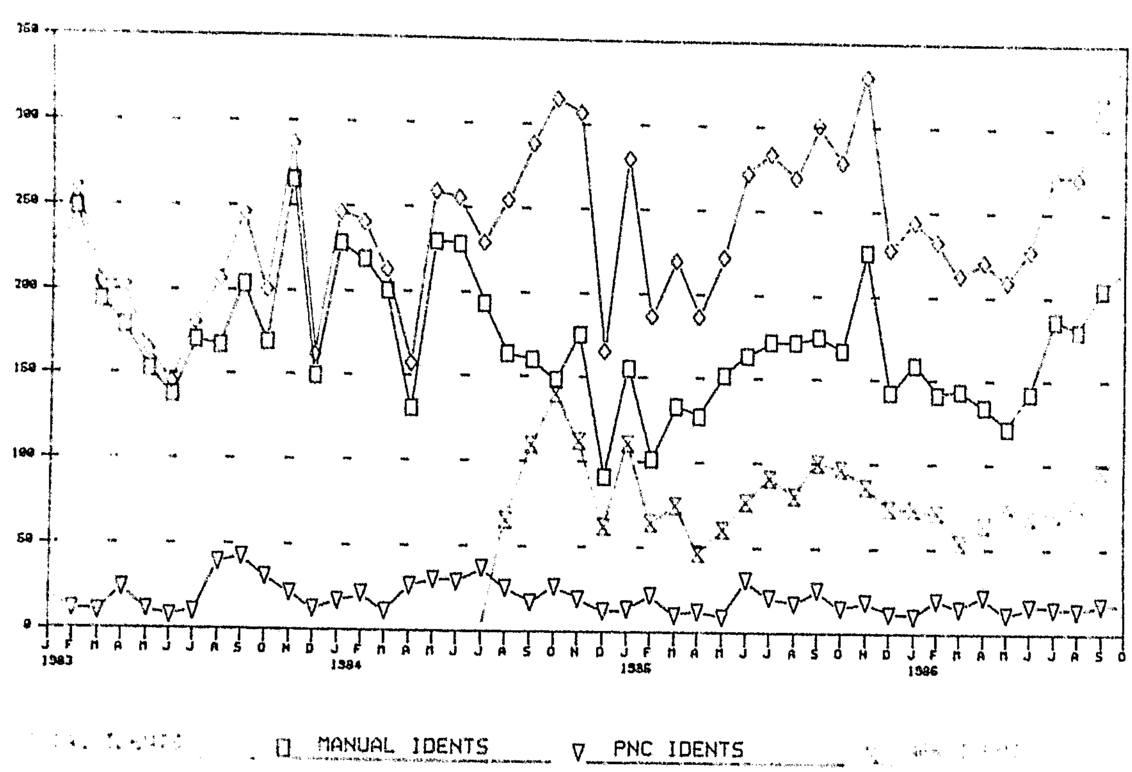

Figure 3. Crime scene fingerprint identifications, New Scotland Yard, January 1983–October 1986.

over 300 per month. The manual component dropped but still remained higher than other search results.

The effect of the crisis of confidence can also be seen in Figure 3, which shows the drop in the AFR component of identifications. Even now, with all those initial problems behind us, there is some residual resistance to the use of the system.

The manual component now represents quick cold search identifications. These are good quality prints which, if they belong to a recidivist, can be identified rapidly by a quick look through local paper files. The AFR identifications now come mainly from those prints which, although amenable to cold search, could not be identified without computer aid.

Supervisors are allowed to use equipment and staff as they think fit. They are judged by the way they manage their workloads and by their results. Eventually, as the caseload pressure builds up, I expect to see manual searching drop further and the AFR search time going up. This will lead to the AFR identification overtaking the manual component. The AFR work rate will grow, the data base will grow and the quick manual advantage will gradually recede. We are already planning upgrades to the system to accommodate more intensive use across a wider part of the mark spectrum. As the system grows, I expect the total identifications to rise to about 500 or 600 per month. All this tends to show that if staff's confidence in the machine is shaken, it takes time for that to be rebuilt and we must allow time for that process to occur naturally. The identifications illustrated in Figure 4 are the material from which confidence grows.

Of course, we have had many other problems, including staff getting red faces (physically) when working at terminals, the costs of creating and maintaining computer environments and the need to cope with the staff feeling a lessening of job satisfaction. As highly skilled identifiers, they hand over their work to the machine reluctantly, but we have also had great successes, as shown in Figure 5.

Overall, the incorporation of computer systems into the fingerprint environment has not only increased efficiency and effectiveness but also laid firm foundations for a tremendous escalation in effectiveness of crime scene print identification in the future. The potential power of AFRs is such that, eventually,

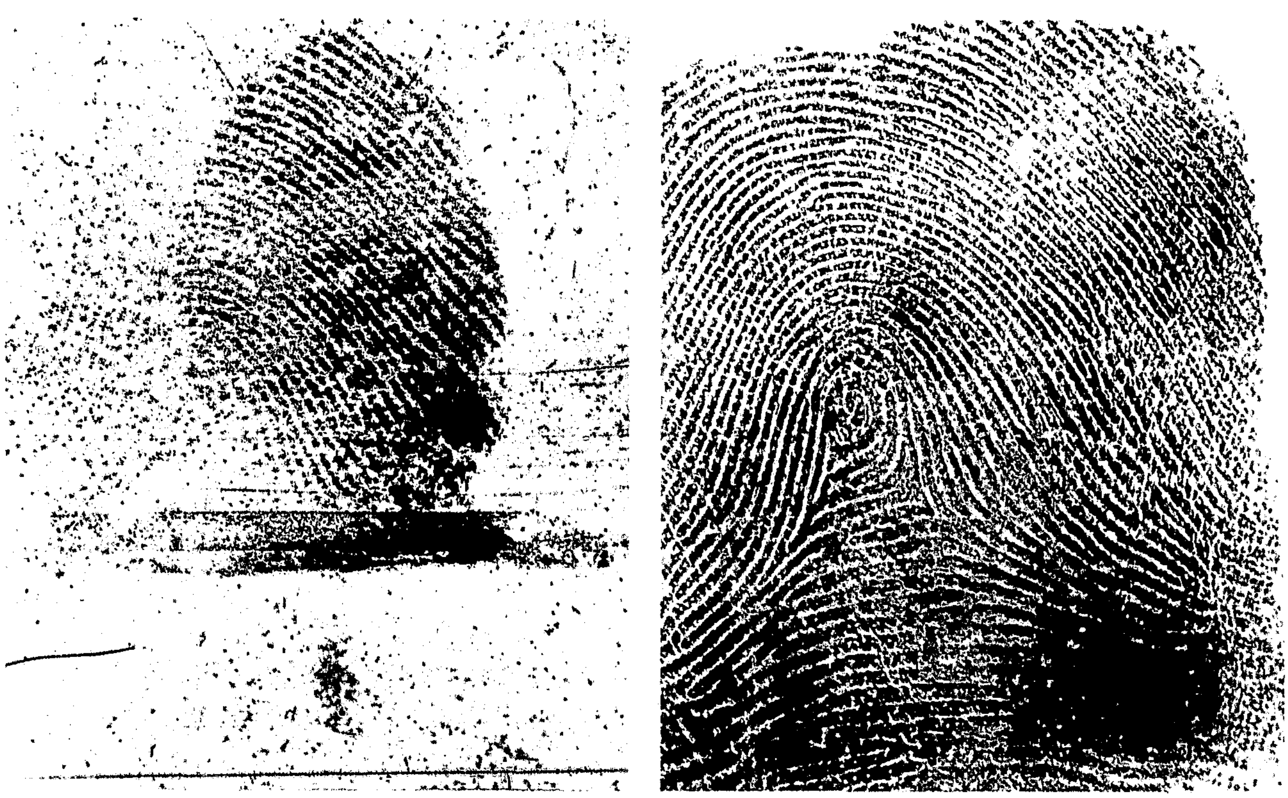

Figure 4. AFR identification, example 1.

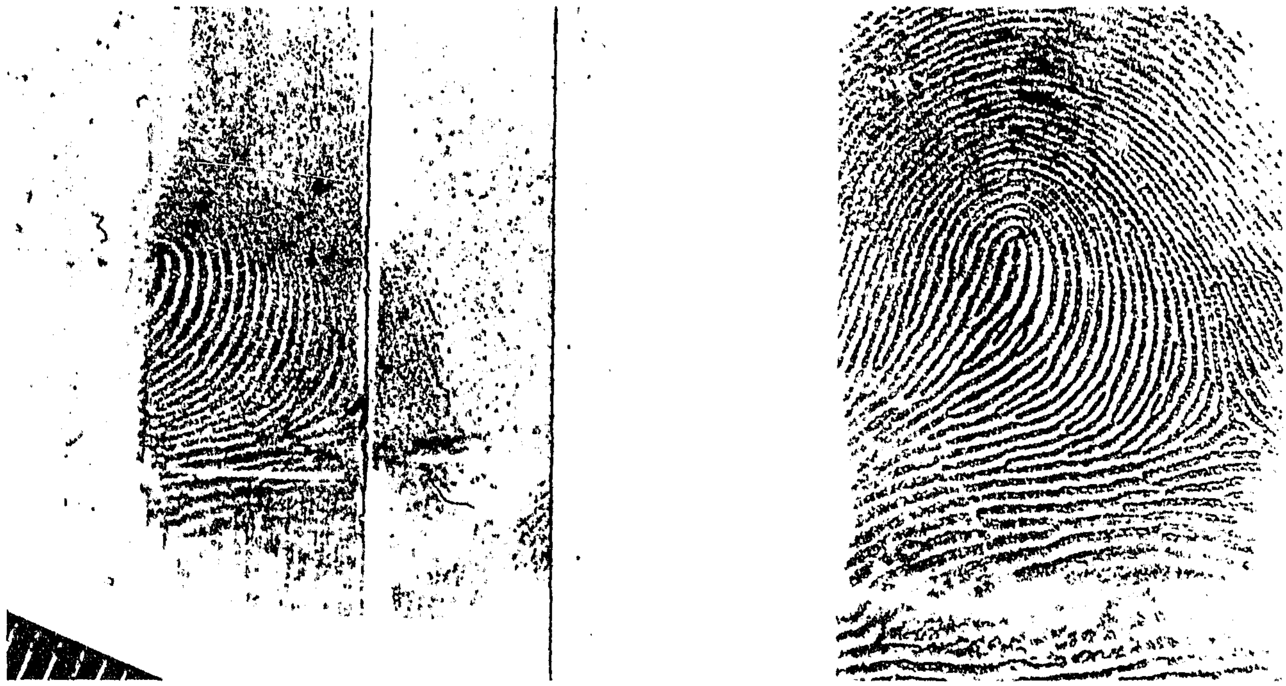

Figure 5. AFR identification, example 2.

few responses will need to be checked by humans. Even for scenes of crime prints, there is likely to be an eventual one-for-one response level. The power of the computer will allow blanket search coverage so that all prints found at a scene can be searched against the national data base (in the United Kingdom) or against a relevant subset. If the full benefit is to gained from such systems, fingerprint staff must be properly trained and motivated to make maximum use of their potential.

We have at New Scotland Yard a highly dedicated, motivated and extremely proficient group of fingerprint employees. That proficiency and the pride it brings, coupled with the long tradition of cold searching success, have made the successful introduction of AFR a delicate maneuver. When you are dealing with a highly skilled group, directives and coercive actions are totally out of the question. Retention of good will is vital. We have aimed our efforts at convincing staff of the worth and utility of the system, at getting them to use it as an optional tool to complement their own abilities and at building up trust in it. It has been essential to ensure that we do not undermine employees' pride in personal achievement and their job satisfaction. Performance monitoring combined with specified identification targets for teams of staff has been the major stimulus we have applied, and this has been successful. Increases in identifications of more than 10% per annum have been achieved, even though we have had to reduce the number of staff cold searching marks by 17%. The use of the equipment was necessary for remaining staff to increase their identification rate to the target levels specified. At the same time, we started a program of putting more qualified fingerprint experts in the field to examine crime scenes and to start a retraining program for all those currently in the field to improve the quality and quantity of material retrieved from crime scenes. This is proving effective.

It was always a mistaken assumption that staff highly skilled and successful in making identifications of scene prints wholly by their own efforts would wholeheartedly welcome fingerprint computer systems. The good human searcher with his inbuilt interpretative ability and flexibility of mind knows that he can still beat any computer system in terms of accuracy, but he knows that he cannot beat the machine's speed or its indefatigability. In introducing AFR, we have avoided making sudden radical changes and have concentrated on allowing staff to find out the best and most efficient way to incorporate use of the system into their work routines. Our reward has been significant increases in identifications. We are now in the process of increasing the capacity and power of the system, but we are adhering to high standards of personal training and skill. We want machines to be seen to be complementing rather than replacing human expertise.

In the long term, the main human involvement and expertise will be exercised at the crime scene. The time must come when the images of prints found at scenes are transmitted from video cameras direct from the scene into AFRs. When that time comes, it will be essential for the scene examiner not only to have fingerprint identification skills but also to know exactly how AFR works and what it can achieve. The need for fingerprint knowledge will have shifted almost entirely into the scene examination role. Our staff accepts this premise, and they are cooperating with us in a scheme to combine the tasks of fingerprint expert and scene examiner to lay foundations for the future, and we have ambitious plans to retrain most of our existing staff.

DISCUSSION

Zoner: You mentioned in your historical survey about the decrease in the number of marks found at a crime scene. Do you attribute that to smarter criminals or fewer marks actually being picked up by the investigators processing the scene?

Warboys: I believe it is a bit of both.

Zoner: Since the fingerprint identification system has become automated at the London Metropolitan Police, have you noticed any difficulties or advantages in retraining or recruiting new staff.

Warboys: No. We recently needed to recruit 50 more people, and we received 2,000 applicants. I do anticipate we are going to have difficulty retraining some crime scene examiners to become fingerprint experts.

George: At the Ontario Police College in Canada, I am now training scenes of crime officers to do only crime scene work. This will free up the identification officers to do more of the comparison work back at the office.

Warboys: I have 200 scene examiners for the London metropolitan area, and approximately 40 of them are fingerprint experts. If you look at the figures over the years, it is quite clear that those with fingerprint knowledge retrieve evidence much more effectively than those without fingerprint knowledge. Therefore, we have decided that all our staff will have fingerprint identification and crime scene abilities. We are the forerunners in the country with this idea, and the British Home Office is encouraging other forces to do the same thing.

George: Perhaps we had better rethink our programs.

Hamilton: With the advent of automation of the fingerprint system, have you done away with your Henry files or Henry classification?

Warboys: No, we are still using the Henry files, but since we started the Videofile system, we have kept our file in numerical order rather than Henry order. The files are no longer being classified by Henry classification.

When we had the Police National Computer alpha-numeric data base, we could file the prints in Henry order because built into the program was an automatic generation of the Henry code.

Hamilton: Are your fingerprint personnel being trained in Henry classification?

Warboys: Yes, they are still trained in Henry classification, but they don't have to generate it routinely from any given set of prints.

Jackson: What prior experience or qualifications did you seek from the 50 new employees recently hired?

Warboys: We hired untrained people and will train them from beginning to end. It is the only source we have in the United Kingdom. We train them to a certain level, and then county forces offer them better terms of service and they go to work for higher paying agencies.

Jackson: We have the same problem. However, we have found that we have better results hiring photographers because that is one less skill we have to train, and there are a lot of photographers who want real jobs. Are there specific skills that you favor?

Warboys: We consider level of education and type of educational background, and whether the person has exhibited perseverance with a hobby or previous job. The whole training process is in-house.

QUALITY ASSURANCE IN LATENT PRINT IDENTIFICATION CERTIFICATION PROGRAM

George J. Bonebrake

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Certification Program for Latent Print Examiners
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The presentation of fingerprint testimony in a court of law is opinion testimony to everyone but the expert. The fingerprint expert should be so convinced of the identification that he could not be more sure if he had been present and observed the defendant placing the particular latent print on the object in evidence. Why is the expert so sure? For over 100 years of recorded fingerprint history, the recording and study of millions upon millions of fingerprints, the manual comparison of this vast accumulation of fingerprints and now the use of automated fingerprint identification systems (AFISs) in our analysis all confirm and substantiate the basic hypothesis that the ridge detail on every finger, palm, toe and foot is unique. All we need are the skills to analyze and correctly interpret what is provided.

What makes fingerprints so ideally suited for the identification process? First, fingerprints are easily recorded and the cost of equipment is nominal. Although each fingerprint is different in detail, there is enough similarity to permit grouping by shape and size. This is especially true when all 10 fingerprints are recorded in standard sequence on a fingerprint card. The use of Henry, Vucetich or similar classification provides for the orderly arrangement of a large number of these 10-print cards in a way that can readily be accessed when a fingerprint technician is transported to the latent print section where more sophisticated methods could be used. This initial step can have a great impact on the quality of the latent print or even if deciding a latent print is worth keeping. The crime scene officer makes countless decisions whether the latent print is worth preserving. If he decides it is not, there is normally no review, since no photographs are taken, no lifts made and the evidence not preserved. The processing of the item by the method most likely to develop latent prints and the proper preservation of the latent prints through photography or other means are critical. How many times have we as latent print examiners looked at a lift of a latent print and wondered what it looked like on the original evidence. Would a photograph of the latent print have shown more detail? Would some other processing technique have developed more or clearer detail?

Over the years, we have seen many new methods of visualizing latent prints on items of evidence. Thirty years ago, if the latent print did respond to powdering on nonporous surfaces or iodine fuming or silver nitrate on porous items, they were not developed. About 1957, the use of ninhydrin on porous items to develop latent prints came to our attention. Nine of every 10 latent prints developed on paper items today are developed using ninhydrin. It is inexpensive and easy to use and develops both recent and old latent prints. Other developments supplied us with a current 10-print card. This subdivision of the data base by fingerprint pattern and size is currently used by the automated systems to limit the match process.

The location of prior card or group of cards in the file that matches the classification of the current search card is only the initial step. The technician must then compare the characteristic ridge detail of the fingerprints on the current search card with the characteristic ridge detail on each card in the file that has the same general classification. This is usually quickly and easily accomplished when the technician has available 10 inked fingerprints clearly recorded on the search card to be compared with the corresponding 10 inked fingerprints on the file cards. A skilled technician can make a determination of either identification or nonidentification in a matter of seconds. The use of AFIS in the 10-print processing basically eliminates manually classifying the current card and searching the master file. This function is performed much more rapidly and with greater accuracy by AFIS, with the end product being at most one or two possibles to be checked by the technician, who determines if there is a match from ridge detail.

Ridge detail is known by several names: Galton details, points of identity, characteristic ridge detail and (with the advent of AFIS) minutiae. By whatever name, these ridge characteristics, their relationship with each other and their relative position are the elements of all identifications by the friction ridges on our fingers, palms, toes and soles of our feet.

This identification by characteristic ridge detail is raised to a higher degree of expertise in the comparison of latent prints. The 10-print technician matching a current fingerprint card with the master can range from one set of fingerprints to the other, looking for easily recognized characteristics in the ridge formations to make the identification or nonidentification. For latent prints, the examiner usually has one print of limited area with only a few of the 75-150 details that appear in a rolled inked fingerprint. It requires someone with training, experience, dedication and considerable patience to analyze latent prints for their identification value and to compare the latent prints with suspect prints.

Where does the latent print identification process begin? It begins at the crime scene, where many of the decisions as to the identification value of the latent print are made. The first decisions include whether to process the item for latent prints, the type of process to use, whether crime scene processing should include the laser and cyanoacrylate-ester. These and other techniques have added to our capabilities to develop more latent prints on more types of evidence. Research and development are still needed in this area. We all know of many cases wherein the evidence was handled by the individuals involved but our processing methods failed to develop any prints at all. It certainly raises the question as to the sensitivity of our processing methods and makes us ask if some other method of processing have developed latent prints on the item.

The developing of the best quality latent print preserving the latent print through photography or lifting is an essential first step. The print examiner must then closely review the latent print for details needed for subsequent comparison with suspects prints. How many of these details, minutiae and points are needed for the identification of a latent print?

The courts in the United States only have the authority to accept or reject the witness as qualified to express an expert opinion based on the qualifications as detailed in testimony. Once the witness is accepted by the court as an expert, he or she can testify about the results of the analysis without any constraints as to the number of points. The International Association of Identification (IAI) at its 58th annual conference in 1973 endorsed the opinion of its Standardization Committee, saying that, "no valid basis exist for requiring a predetermined minimum number of friction ridge characteristics which must be present in two impressions in order to establish positive identification."

This position by the IAI closely parallels the established procedure in the Federal Bureau of Investigation's Latent Fingerprint Section, where the experts base their opinion on the analysis of each latent print taken individually. Testimony as to the identification of latent print taken individually. Testimony as to the identification of latent fingerprints has been furnished in cases involving as few as seven points in the latent print. This testimony follows verification by another expert and, in those instances with less than 12 points, supervisory review and confirmation.

This policy of not requiring a minimum number of ridge characteristics is as it should be, but it places an awesome responsibility on the expert's analysis. Establishing a minimum number of characteristics would relieve the expert of considerable responsibility, but many valid identifications of less than the minimum number would be discarded and numerous cases left unsolved. It is important that we have well trained and experienced personnel conducting the examinations of the evidence, preserving the latent prints developed, determining their suitability for identification purposes and making the identification paramount.

To train latent print examiners, you need to establish and follow a detailed training program. Although background in 10-print (fingerprint card) work is beneficial, it does little to train the examiner to make latent print comparisons. The technician is accustomed to comparing two sets of inked fingerprints with 10 matching sets that can be reviewed for clear and easily distinguished details. In comparing latent prints, the examiner normally has a single latent print of limited area that was accidentally left on an object touched in passing. It is often fragmentary, with limited detail and ill defined points of reference to use as starting points. It is quite an adjustment for the 10-print technician. Training a new examiner in the proper methods of processing evidence and preserving the latent prints developed can be accomplished readily through classroom instruction and on the job with a competent instructor in a relatively short period of time. This training would also include court testimony through a series of mock trials. However, training the examiner in the analysis of the latent print and the location of details for comparison can only be accomplished by lengthy training involving interaction between the instructor and the trainee. The increased proficiency in an apt student becomes apparent after comparing the student's ability to locate points in a latent print at the outset of the training and this same capability after 6 months of concentrated training. The trainee develops comparison skills and learns to recognize differences in the appearance of two prints that may result from the developing or inking process as opposed to differences that denote nonidentity. The trainee examiner learns to locate points that allow for the ready elimination of nonmatches, the proper orientation of the latent print for comparison with the inked print and, most important, the analysis of the complete latent print with the inked print to ensure that there are no unexplainable differences in the two prints.

The examiner trainee learns further comparison skills as he or she gains experience. When a limited number of points in the latent print are concentrated near one another, the identification is enhanced when an additional point is located several ridges removed from the cluster. After all, points are ridges that end or bifurcate, and continuous ridges can add to the identification process. Any characteristic, chartable or not, should be used by the examiner to reach a determination. The skill of the trained examiner lies in recognizing what constitutes enough detail to ensure that the identification is positive. This skill can be gained only through experience, the analysis of numerous latent prints, and the comparison with inked prints and determining if there is an identification or nonidentification or if there simply is insufficient detail to make an accurate determination. These skills can be self taught, but interaction between a trainee examiner and an experienced instructor can shorten the process and produce very competent examiners in a reasonable period of time.

We are currently faced with an acute shortage of competent latent print examiners. This shortage seems to be more apparent over the last 5 years and can be attributed to several factors. One is the IAI certification of latent print examiners. A second factor is the current move toward automation. Almost every state bureau or major department either has an AFIS, is buying one or is trying to obtain funding for one. The larger systems, especially the state systems, have remote terminals tied to the central data base. These automated systems place additional demands on the latent print units. Having the ability to conduct searches of latent fingerprints in suspect cases against a large data base of 10-print cards is certainly a needed breakthrough in latent print processing. Typically, the latent fingerprint has to be prepared and entered into the system, with the results being a list of possibles. The length of the list is a policy decision, but normally there are 5-15 possibles, and that latent print examiner must compare the latent fingerprint with the suspect list. With new optical disk storage of fingerprint images, this comparison of the latent fingerprint can be done at the terminal on the cathode ray tube screen. The clarity of the images is quite surprising. Having this ability to conduct cold searches of latent fingerprints against a large data base soon produces identifications that encourage detectives and crime scene personnel to process more crime scenes and to do a better job. This leads to more case submissions to the latent print unit. This snowball effect on latent print casework places a heavy demand on the latent print unit, and to fully utilize the automated system requires an increase in the examiner staff. Many departments are now realizing that they need trained examiners to use these automated systems, that there are not enough examiners to fill the need and that training a latent examiner takes time.

We see departments hiring trained examiners from other agencies. In one instance, an examiner went from a city department to a county department to a state bureau in approximately 2 weeks with a salary increase of nearly $10,000. This is good in the sense that the competition for latent print examiners can lead to more equitable pay for a long underpaid profession, but it does not alleviate the shortage of skilled examiners.

The IAI recently has been approached to develop a training concept for latent print examiners. This is under consideration by a joint committee of the Certification Board and the Fingerprint Subcommittee. Recommendations will be made to the IAI Board of Directors at the annual conference. Recommendations could be in the form of the preparation of a training schedule or the actual training of latent examiners by IAI instructors. This training should not be confused with a training class but rather an intensive course lasting months.

Quality assurance in latent print identification is totally dependent on the training, experience and ability of the latent print examiner. At every step in the processing of the evidence, there is need for skill and training. There must be crime scene technicians who ensure that all evidence is properly processed to develop and preserve all possible latent prints. The latent print examiner must be able to properly analyze the latent print for comparison with those from suspects. We are all concerned that an inexperienced examiner will make an erroneous identification, but is it not as important as having all identifiable latent prints retained for comparison with the suspect's. It is criminal to discard identifiable latent prints because the examiner lacks the skills or desire to perform his functions properly. Supervisors need to guide examiners in using the proper processing techniques and ensure that all identifiable latent prints are retained and compared with suspects. There needs to be a well trained team available from the initial crime scene search to the final comparison and court testimony. There should be ongoing training and close supervision to ensure that each procedural step is followed.

THE IAI CERTIFICATION PROGRAM FOR LATENT PRINT EXAMINERS

The IAI program for the certification of latent print examiners was voted into being at the annual conference in New Orleans in August 1977. There are currently about 900 certified latent print examiners with new applications roughly equaling those who do not renew their certification. Applications for certification generally are received at the rate of 42 per year, except for the first year when qualified applicants were certified without testing, and the year before the Associate of Arts (AA) degree requirement was established, when 145 applications were received.

The requirements for certification are as follows:

1. Three years in fingerprint work with at least 2 of them in latent prints.

2. At least 40 hours of formal classroom training in both inked and latent prints.

3. Letters of endorsement from a supervisor in the department and from a certified latent print examiner.

4. An AA degree or equivalent (60 college credit hours). This 4-year degree will be effective August 4, 1987.

5. Each application must be reviewed and approved by the local certification committee. If the application is approved, then the applicant must satisfactorily complete the certification test. The test is given locally by the certification committee, and the initial three parts last 6.5 hours. The first part has 15 latent prints to be compared with 15 sets of fingerprints and/or palmprints and must be completed within 4 hours. The applicant must correctly compare 12 or the 15 latent prints with no erroneous identifications. The second part of the test is five fingerprint cards to be classified in 30 minutes. The third part is approximately 150 multiple choice and true-and-false questions to be completed in 2 hours. If the applicant completes these three portions in a satisfactory manner, and about 55% do, the applicant must participate in a mock trial as the fingerprint expert.

The success of the certification program is realized when one talks to the departments seeking latent print examiners. Although certification may not be a written requirement, it is used as a gauge of the qualifications of those applying. The department looks first for certified examiners and then for those who meet the requirements for certification. Others specify that the applicant must be certified within a given period of time. This use of certification as a requirement is usually accompanied by a salary adjustment. Those without certification are hired at the starting pay scale, and those with certification are started at the middle or upper steps of the scale. In some instances, entrance tests are not required for certified examiners but those not certified must take the test.

I recently had a call from a department wanting to hire a latent examiner and was advised that if the examiner was certified, the entry pay would be more than $3,000 a year higher. The caller then commented that having a certification card when applying for a latent print examiner position was like having a lucky gold card in your pocket.

It is apparent that the certification program will play an ever increasing roll in establishing the credentials of latent print examiners. This current shortage of latent print examiners with certification further emphasizes the advantages of the program.

DISCUSSION

George: Regarding the false identifications that were made, some people are form blind and are unable to distinguish between certain patterns that are located fairly close to each other. The Royal Canadian Mounted Police has developed a test for applicants at the Ontario Police College which will pick out this deficiency.

Bonebrake: It is interesting to note that Scotland Yard is hiring latent print examiners off the street for training. I think the advantages of using people who have been in 10-print work are that you may tend to eliminate hiring people with form blindness and you have a source of people who are willing to work in a tedious environment.

Wertheim: I want to relate an experience that my department had regarding a trend you had mentioned. Some departments require that an applicant become certified within a year after assuming employment. We hired a person who failed the certification test after the first year of employment and again after being given an extension. He resigned after 2 years of employment, but before doing so, put our department in a bind. I recommend that the qualifications or certification be met before a person is hired.

SECTION II

EXTENDED ABSTRACTS

LASER TECHNOLOGY AS UTILIZED IN THE DETECTION OF LATENT PRINTS AND TRACE MATERIAL

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The argon laser (Spectra-Physics, Mountain View, CA) produces high intensity light that detects latent prints and trace materials through inherent luminescence (Dalrymple *et al.* 1977). Many substances luminate, such as oils or salts in perspiration, grease, cosmetics, paints, dyes, hair and ink, and they can be detected through laser examination.

Any surface may be subjected to laser light, and latent prints (fingerprints, palmprints and soleprints) or trace material (fibers, hair, body fluids, bacterial residue, shoe track residue print and so on) may be detected. The procedures for detecting latent prints vary with the case. Visual examination would be examining an item under the high intensity light beam of the argon ion laser and detecting illuminating material. Super Glue (Loctite Corporation, Newington, CT) examination is used to develop and bond any material on the surface of a nonporous item.

Rhodamine 6G (Eastman Kodak Co., Rochester, NY) and Fluorescent Dye Pink (Lapine Scientific Company, Chicago, IL) are staining solutions used with the laser. Items are treated with the solutions, and any material present on the item is illuminated under the argon ion laser beam. Zinc chloride (Mallinckrodt, Inc., Paris, KY) solution is used on porous material such as paper. Salty perspiration or other residue on paper processed with zinc chloride may illuminate under the argon ion laser beam. Laser enhancement works well on visible prints (such as grease or body fluids) and latent prints that were previously developed with chemicals or powders. Prints from materials detected by laser are preserved by photographing them during the laser examination. Many cases have successfully used the argon ion laser when conventional methods such as chemicals and powders have failed.

Laser examinations have detected latent prints on vinyl, styrofoam and tape (Figures 1-3) and trace material on plastic and vinyl (Figures 4-5). Additional items in various cases included cloth, rubber, wood and rusted metals. Laser research has been conducted on human and animal skin (Figure 6) with positive results.

Testimony regarding laser examination on items of evidence has been given and accepted in criminal courts. The laser is accepted as an additional means for examining items of evidence and supplements the conventional methods.

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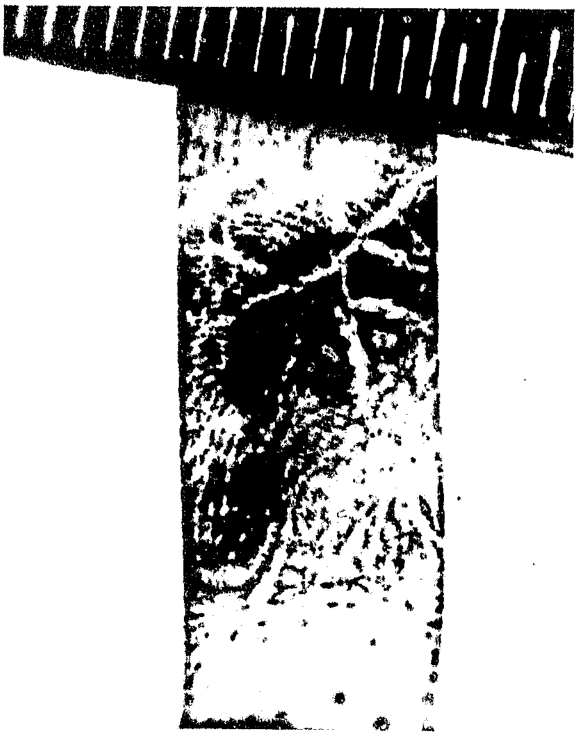

Figure 1. Marijuana case. Latent fingerprint detected on vinyl bag by argon ion laser. The bag contained marijuana.

Figure 2. Murder case. Latent fingerprint detected on white styrofoam cup by argon ion laser. Cup was previously processed with black magna powder with negative results.

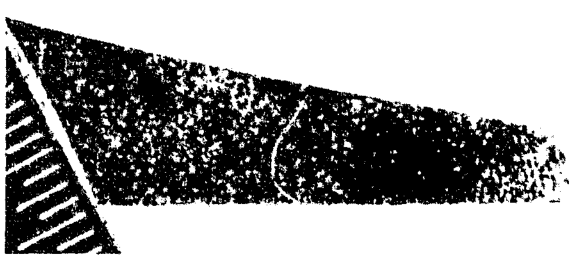

Figure 3. Marijuana. Latent fingerprint detected on adhesive side of duct tape by argon ion laser. Opposite side of tape was previously processed with powder with negative results.

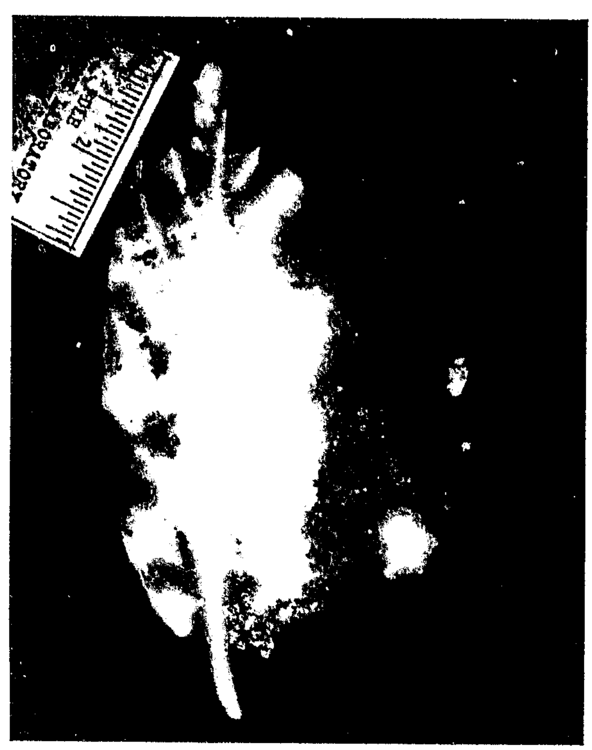

Figure 4. Murder case. Leaf outline on clear plastic caused by bacterial residue and detected by argon ion laser. Plastic was used to wrap victim. Powder failed to develop leaf outline.

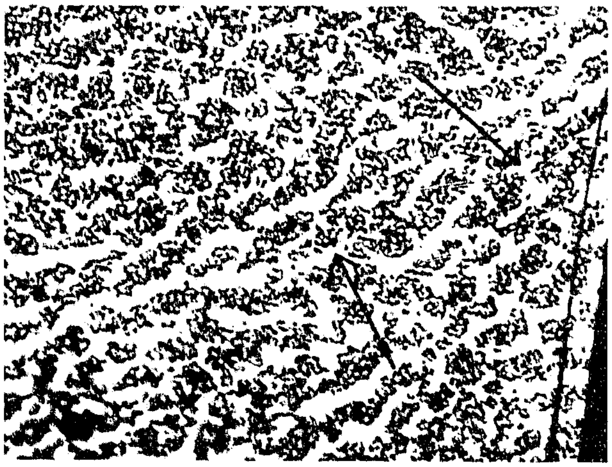

Figure 5. Rape case. Hair detected on victim's dark blue check book by argon ion laser. Hair was previously undetected due to the dark background.

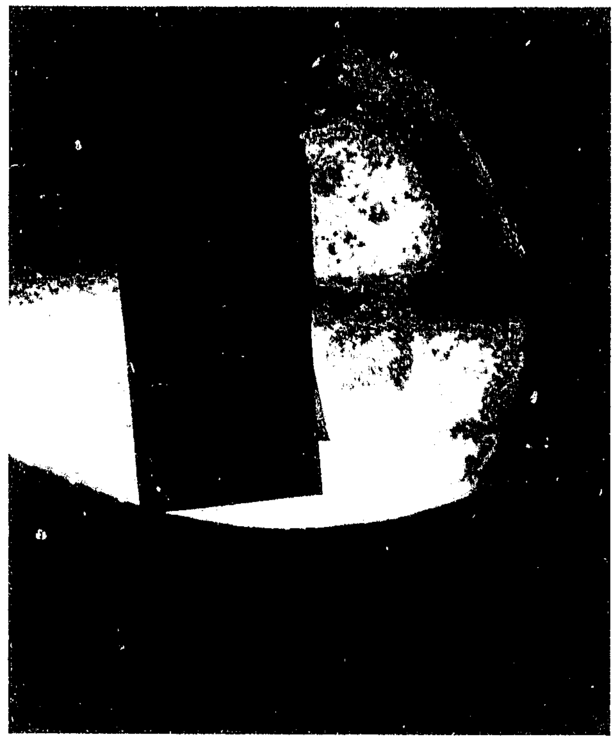

Figure 6. Research conducted on a pig's ear skin revealed a latent fingerprint detected by argon ion laser.

NONCARCINOGENIC, WATER SOLUBLE, FLUORESCENT PIGMENTS AS AN ALTERNATIVE TO RHODAMINE 6G

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Safe, aqueous dye stain solutions are necessary as an alternative to Rhodamine 6G (in methanol) to develop latent impressions on nonporous and semiporous materials. Some materials, such as fibrous tapes and leathers, normally exhibit a capillary effect when treated with rhodamine in methanol but remain clear of background interference when treated with an aqueous dye stain solution (German 1985). Solvents used to dissolve Rhodamine 6G may also dissolve lacquer coatings on guns and on somewhat porous plastics. In addition, analysts who process evidence with Rhodamine 6G subject themselves and others who subsequently handle the evidence to a carcinogen.

Commercially available Aquabest Orange fluorescent pigment in an aqueous solution appears to be a safe and reliable alternative to Rhodamine 6G. Aquabest solution adheres to cyanoacrylate ester-developed friction ridge detail, is noncarcinogenic and is water soluble.

MATERIALS AND METHODS

Aquabest fluorescent pigment was obtained from Radiant Color Co. (Richmond, CA). Ammonium hydroxide, 2-propanol and methanol were obtained from Fisher Scientific Co. (Itasca, IL). Rhodamine 6G was obtained from Sigma Chemical Co. (St. Louis, MO). Loctite Superbonder 495 was obtained from Berry Bearing Co. (Oak Park, IL). The laser used was a 10 W copper vapor laser manufactured by Plasma Kinetics Co. (Pleasanton, CA).

Aquabest Orange fluorescent pigment stock solution is prepared by slowly adding 5 g of the pigment to a premixed solution of 61 ml of tap water (containing 0.1 g per liter of sodium azide as preservative), 26 ml of 2-propanol and 8 ml of ammonium hydroxide. The premixed solution must be stirred continuously, and the temperature must be maintained at 150°–160° F while the pigment is added. The stock solution must be heated and stirred for about 45 minutes or until the solution is clear. The final pH of the stock solution should be in the range of 7.0-7.5. The working solution is then prepared by adding 50 ml of the stock solution to 1 liter of tap water (containing 0.1 g per liter of sodium azide as a preservative). A rhodamine solution was prepared by adding 0.1 g of Rhodamine 6G to 1 liter of methanol.

Latent palmprints were deposited on both sides of 10 plastic bags by 10 individuals. In addition, other items, such as styrofoam, aluminum foil, paper and a leather-like material, were handled by a number of different people. All of the items were fumed with cyanoacrylate ester by heating 10 drops of Loctite Super Bonder 495 in a watch glass over a standard 100 watt lightbulb in a chamber for 30 minutes. Half of the developed latent impressions on each item were treated with Aquabest solution and rinsed with tap water. The other half of the developed latent impressions on each item were treated with the rhodamine solution and rinsed with methanol. All of the items were then allowed to air dry for 1 hour.

RESULTS AND DISCUSSION

Examination of the developed friction ridge detail treated with Aquabest solution under copper vapor laser illumination revealed yellow-green fluorescence with a minimal amount of background illumination. The developed friction ridge detail treated with rhodamine solution exhibited typical green fluorescence with little or no background illumination. Additionally, the Aquabest solution adhered to the cyanoacrylate ester developed friction ridge detail evenly, as did the rhodamine solution, which facilitated subsequent photography.

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A TECHNIQUE FOR THE DETECTION AND ENHANCEMENT OF LATENT PRINTS ON CURVED SURFACES BY THE USE OF FLUORESCENT DYES AND PAINTING WITH THE LASER LIGHT (BEAM)

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Latent prints developed with cyanoacrylate fumes can be easily stained with fluorescent dyes to visualize the prints for photographic purposes or to locate them for dusting or lifting (Olsen 1983). The latent prints on curved surfaces such as metal, plastic, glass and rubber are sometimes difficult to see or photograph with regular photography when developed with cyanoacrylate and detected by inherent luminescence.

In 1983, the Tallahassee Field Office of the Federal Bureau of Investigation submitted a Browning magnum 12-gauge shotgun involved in a kidnapping in Mississippi and a murder in Santa Rosa County, Florida, to be examined for latent prints. I developed latent fingerprints on the barrel of the shotgun with cyanoacrylate-Rhodamine 6G methods and photographed them with illumination from laser light.

MATERIALS AND METHODS

This technique is an alternative to regular photography, and you can apply fluorescent dyes such as Pink fluorescent dye (La Pine Scientific Company, Chicago, IL), Rhodamine 6G (Eastman Kodak Company, Rochester, NY) or Rose Bengal dye [4,5,6,7-tetrachloro-2′,4′,5′,7′-tetraiodofluorescein (sodium or potassium salt)] (Sigma Chemical Company, St. Louis, MO) (Olsen 1983; Menzel *et al.* 1983; Fischer 1986).

After an item is processed with cyanoacrylate, the fluorescent dyes, such as Rhodamine 6G, Pink fluorescent dye or Rose Bengal, can be applied to the cyanoacrylate print by using them in the staining solution or powder form.

The staining solution is prepared by dissolving the fluorescent dyes with methanol or water (Fischer 1986; Olsen 1983; Menzel *et al.* 1983). The solution is applied to the cyanoacrylate treated surface by either spraying or pouring it over the surface. The surface should then be thoroughly dried by evaporation or by using a laboratory-type heat gun dryer or ordinary hair dryer. Dyes in powder form can be used alone or by mixing them with a magnetic dusting powder. The powder is applied to the cyanoacrylate treated surface with a camel hair brush or magnetic application wand.

The fluorescent dyes adhere to the cyanoacrylate print, and when examined with a laser or an ultraviolet light source, the latent print will fluoresce under the laser light or an ultraviolet light source (Fischer 1986; Fischer and Green 1980; Olsen 1983; Menzel *et al.* 1983).

The fluorescent latent print is photographed by painting the latent print with the laser light or an ultraviolet light source (Fischer and Green 1980). This technique is accomplished by moving the light beam from one side of the latent print on the curved surface to the other side slowly while photographing the latent print.

The camera used to photograph laser-detected latent prints is a 4×5 Polaroid MP-4, adjusted 1:1 with a 135 mm lens. The filter is the same as the filter used in the laser safety goggles. The different types of film that can be used are Trix-X ortho (ASA rating 320) or Contrast Process ortho (ASA rating 100). The exposure time can vary, depending on the type of film, surface, luminescence and fluorescence of the latent print.

RESULTS

Photographs in Figures 1, 2 and 3 show latent fingerprints developed and detected with the cyanoacrylate-Rhodamine 6G on a blue steel pipe 2 cm in

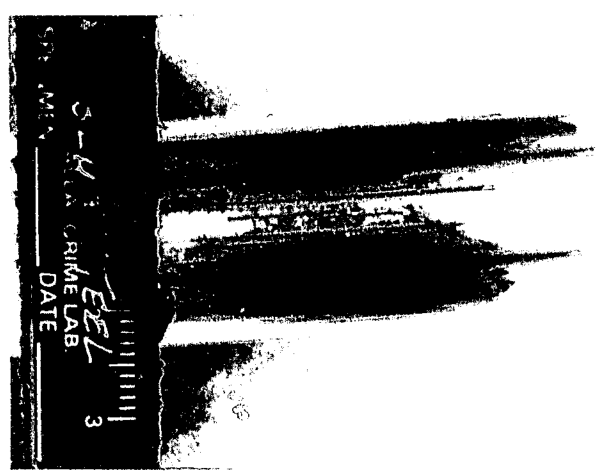

Figure 1. Regular photography.

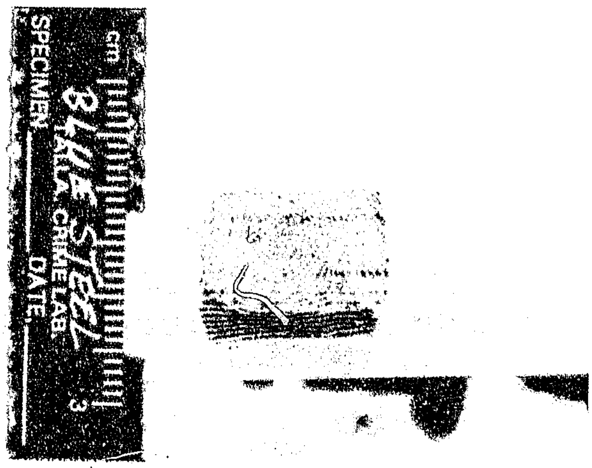

Figure 2. Normal laser photography.

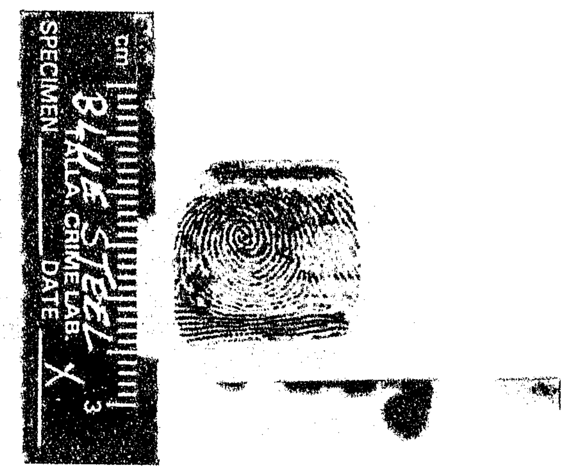

Figure 3. Painted laser light photography.

diameter by regular photography, normal laser photography and painted laser light photography. Photographs in Figures 4, 5 and 6 show latent fingerprints developed and detected with the cyanoacrylate-Rhodamine 6G method on a nickel plated barrel of a revolver by regular photography, normal laser photography and painted laser light photography. Photographs in Figures 7, 8 and 9 show some latent prints developed and detected from actual cases photographed by this technique in the Tallahassee Crime Laboratory.

CONCLUSION

This technique will eliminate hot spots and shadows on the latent print which cannot be eliminated with regular photography. Enhancement of the latent print by laser luminescence will eliminate the background somewhat, so the ridge detail will be more legible in contrast.

ACKNOWLEDGMENT

I wish to thank the members of the Latent Print and Forensic Photography Sections and the Tallahassee Regional Crime Laboratory, who contributed their assistance and service, especially my supervisor, Daniel Hasty, for his assistance and expertise.

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Figure 4. Regular photography

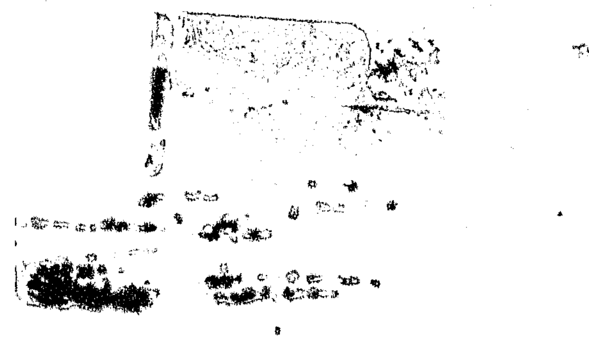

Figure 5. Normal laser photography

Figure 6. Painted laser light photography.

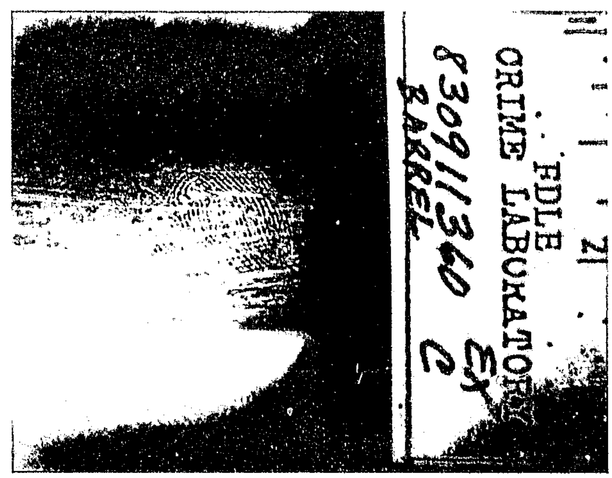

Figure 7. Murder and kidnapping.

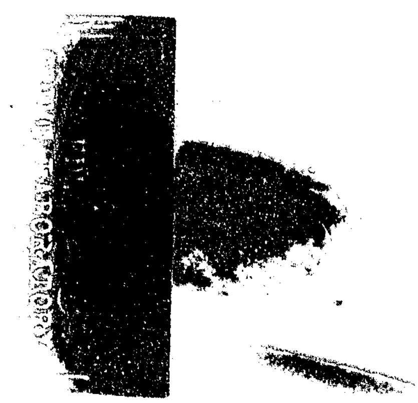

Figure 8. Murder

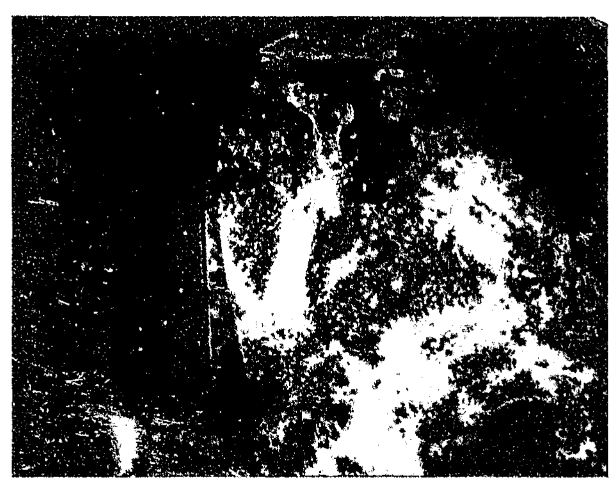

Figure 9. Murder

TRANSPORTING A LASER LABORATORY TO THE CRIME SCENE

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When we acquired a portable laser, we became aware of the need to develop safe and efficient methods to handle the following situations:

1. Getting the laser and video equipment to crime scenes.
2. Getting the laser in and out of the vehicle.
3. Making an 85 pound laser more mobile at the crime scene.
4. Transporting chemicals and supplies needed to conduct a laser examination.
5. Fuming surfaces of various sizes and shapes with cyanoacrylate in preparation for laser processing and examination.
6. Providing a safe and efficient substitute for Rhodamine 6G.

A van was purchased and outfitted as the Laser Fingerprint Detection Unit, and it was equipped with an electric wheelchair lift to facilitate loading and unloading of the laser and the custom-made laser cart. The cart was designed with a platform to carry supplies and is equipped with casters, enabling easier mobility in small spaces. Specially designed cabinets have been installed in the van to transport supplies, video and camera equipment, chemicals, cyanoacrylate fuming devices and a power generator for field use. A cellular telephone was also installed to allow direct communication between the department and crime scene personnel. It is possible to have the laser remain in the van when evidence is examined by placing a fiber optic wand through an opening in the back of the van into the interior of the van.

Since cyanoacrylate fuming of evidence is necessary for most chemical and powder processing, a versatile fuming chamber system was designed for field use to fume areas such as windows, walls and furniture. The fuming devices are constructed of wood doweling and polyvinyl chloride pipe fittings. Plastic sheeting is placed over the devices creating a chamber. Through the use of one of these fuming kits, chambers can be made 0.9 x 0.9 x 0.46 m or 0.9 x 1.8 x 0.46 m. This chamber can also be used to fume bodies.

Rhodamine 6G is used most often in laser processing as the fluorescing agent. However, since it is a suspected carcinogen, a replacement for it was needed in processing interiors of homes and vehicles. Through information obtained from the *Forensic Laser News* (Issue No. 4, p. 6), an orange pigment (Radiant Color Company, Richmond, CA) was chosen as a substitute for Rhodamine 6G. Although the orange pigment does not appear to be as fluorescent as Rhodamine 6G, it is still very efficient and so far has been determined to be nontoxic and noncarcinogenic.

The establishment of the Laser Fingerprint Detection Unit met the needs of the Orange County Sheriff's Department to implement effective crime scene laser capability, while protecting both the operator and citizen from potential danger.

INFANT FOOTPRINT IDENTIFICATION BY FLEXURE CREASES

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On occasion, questions of identity arise concerning infants who may be the victims of homicides and kidnappings or who might be abandoned. Whatever the case, one of the primary investigative considerations is to identify properly the unknown infant. Ridge structure is normally present in the feet of newborn infants, but the skin is so delicate that it may be impractical or impossible to make an identification. In such cases, it becomes necessary to use flexure creases to identify the infant.

Flexure creases have been an accepted means of identification at the New York City Police Department since 1959. Before that, in an attempt to determine the feasibility of flexure creases as a viable means of identifying infants, the Latent Print Unit studied footprints from 1,388 infants. Using the theory that flexure creases are unique to each foot, they discovered several facts.

In general, there are two types of creases, which may be classified as temporary creases and flexure creases. Temporary creases, although evident on the soles of the feet of newborn infants, should more accurately be called wrinkles because they disappear within a relatively short period of time. Flexure creases are more significant and are the basis for the positive identification of the infant. It must be emphasized that when enough ridge detail is evident, it should always be used instead of flexure creases as a means of identification.

Flexure creases are more permanent. As the child grows, the flexure creases also grow, and additional creases are added as the foot grows. Flexure creases are unique to the individual foot and remain relatively constant during the first few weeks of life. They do not change in direction or distance from each other. As the child continues to grow, there is a gradual change in the size, shape and quantity of flexure creases.

Flexure creases are not as widely accepted as ridge structures as an identifiable method. This is quite understandable, since the size and shape does change in time. Additionally, old creases disappear and new ones may form, thus putting a further burden on the examiner. The time factors are somewhat imprecise. My own experience leads to the conclusion that identifying infants by flexure creases can be made up to about the fifth year, but that view is disputable.

There is a need to underscore the problem of having a viable means of identification when alternate means to ridge structure are necessary. I have found that, of the numerous infant footprint comparisons I have completed, a large percentage of the prints have been taken improperly, that is, they lack sufficient ridge structure or flexure crease detail. Whether that deficiency is a product of apathy or insufficient training is uncertain, but the question needs to be addressed. I propose that, in addition to emphasizing flexure crease detail, two other areas of the foot should be examined: the great toe and the ball pattern zone. These areas have been selected for several reasons:

1. Both areas are large enough to reveal detailed ridge structure in most cases.
2. The great toe contains patterns similar to fingerprints.
3. Identification by ridge structure is more widely accepted than identifications using only flexure creases.
4. The inking and recording of the great toe and the ball pattern zone is relatively simple.

The benefits to be gained as a result of these advances cannot be quantified. In terms of peace of mind alone, it may well be worth the added effort.

FRICTION SKIN CHARACTERISTICS: A STUDY AND COMPARISON OF PROPOSED STANDARDS

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Latent print examiners agree that the science of friction skin identification is an exact science. However, very few examiners seem to agree on the number, names and definitions of the individual characteristics found in friction skin. Over 40 books, articles and studies have been written listing and defining the minutiae of friction skin. These authors list between 2 (Sannie 1948) and 22 (Hague 1986) basic characteristics. How can the science of friction skin identification be considered exact if there are no exact definitions of identification be considered exact if there are no exact definitions of basic characteristics?

Fifteen years ago, the Federal Bureau of Investigation (1972) and the International Association for Identification Standardization Committee (1972) proposed standards to be used by print examiners. Unfortunately, these two proposals did not agree with each other, and at least 17 books and articles have been written since that time which disagree or propose different standards.

Two authors (Hague 1986; Santamaria 1955) emphasize the importance of combination or composite characteristics versus simple or primary minutiae. Hague defined primary minutiae as single ridge characteristics that cannot be subdivided. He defined composite minutiae as specific ridge characteristics that are a combination of two or more (the same or different) primary minutiae. If his definitions are used, ridge endings, dots, circle ridges, bifurcations and angles would be primary minutiae and the other 17 listed minutiae would be composite (Table 1). Santamaria defined a value system based on the relative frequency of characteristics and concluded a minimum value must be reached before a positive identification can be made.

In the United States and Canada, the judicial system requires no minimum number of individual characteristics for a positive identification. Other countries do have set minimums. For example, France requires 17, the United Kingdom requires 16 and others require 12 or less (Berry 1987). However, Olsen (1978) states, "There is no valid scientific basis for requiring a minimum number of ridge characteristics which must be present in two fingerprints in order to establish positive identification." Even though most examiners in the United States agree with that statement, the courts seem to want a particular number of characteristics. Some even feel that the greater the number, the more positive the identification.

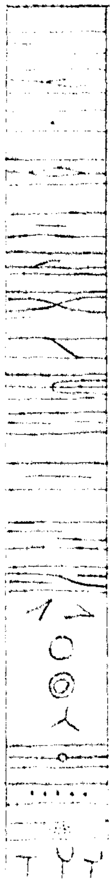
By counting all the minutiae as primary types, the total number of characteristics increases. The characteristics defined by Olsen (1981) and Hague (1986) were used and two prints were charted as might be done for a court presentation (Figure 1). Note that the number of marked minutiae on Olsen's print would total 18, enough for a court in any country. However, on Hague's print, the total is only six characteristics. A count of six characteristics should cause an examiner to hesitate reporting a positive identification that may send someone to prison.

On the other hand, some police investigators and district attorneys want to know the number of matching characteristics even when there is less than enough to make a positive identification. They may do this so as to make a "possible, probable or likely" judgment on a particular suspect. This idea or concept is in direct violation of Resolution VII, which was amended and passed in August 1980, by the International Association for Identification. They agreed unanimously that "friction ridge identifications are positive, and officially oppose any testimony or reporting of possible, probable or likely friction ridge identifications."

Long lists of minutiae descriptions seem to add confusion to the science and cause disagreement among examiners. Simplicity defuses arguments and causes the number of matching minutiae in print comparisons to be impressive to judges and juries. I recommend a standard of two basic characteristics: the ridge ending and the bifurcation. These characteristics are basic, common and easy to define. All other characteristics are combinations of these basic minutiae. It would be unnecessary to define or refine any other characteristics.

Currently, friction skin identification has become more important because of the new computer technology that will result in more identifications than could ever have been imagined. Now is the time to agree on standard definitions of characteristics before challenges occur in the court systems. If latent print examiners cannot agree on standard characteristics, perhaps the courts will take it on themselves to set definitions

Table 1. **PROPOSED STANDARDS OF FRICTION SKIN CHARACTERISTICS BY SELECTED AUTHORS**



HAGUE 1986	SCOTT 1951	OSTERBURG 1974	CHERRILL 1954	LAMBOURNE 1984	I.A.I. 1972	F.B.I. 1972	GALTON 1892	OLSEN 1981
Ridge Ending	Ridge Ending	Ridge Ending	Ridge Termination	Ridge Ending	Ridge Ending	Ridge Ending	Beginnings/ Endings	Ridge Ending
Bifurcation	Bifurcation	Bifurcation	Fork	Forking	Bifurcation	Bifurcation	Fork	Bifurcation
Dot	Dot/ Short Ridge	Dot	Island	Short Ridge/ Island	Island/Dot	Dot	Island	Dot
Enclosure	Enclosure/ Island	Enclosure	Enclosure Lake	Lake	Enclosure	Enclosure/ Island	Enclosure	
Short Ridge	Island Ridge	Short Ridge	Short Ridge		Short Ridge	Short Ridge		
Spur	Spur	Spur	Spur/Hook	Spur				
Ridge Crossing				Crossover				
Bridge		Bridge	Crossover					
Trifurcation		Trifurcation						
Interruption	Broken Ridge							
Long Ridge	Independent Ridge							
Deviated Break								
Changeover								
Angle								
Circle Ridge								
Bullseye								
Triradius								
Eyelet								
Row of Dots								
Pepper Dots								
T-Junction								

and also require a specific minimum number. The acceptance of standard definitions will make the science of friction skin identification an exact science and will validate the concept of not requiring a minimum number for a positive identification.

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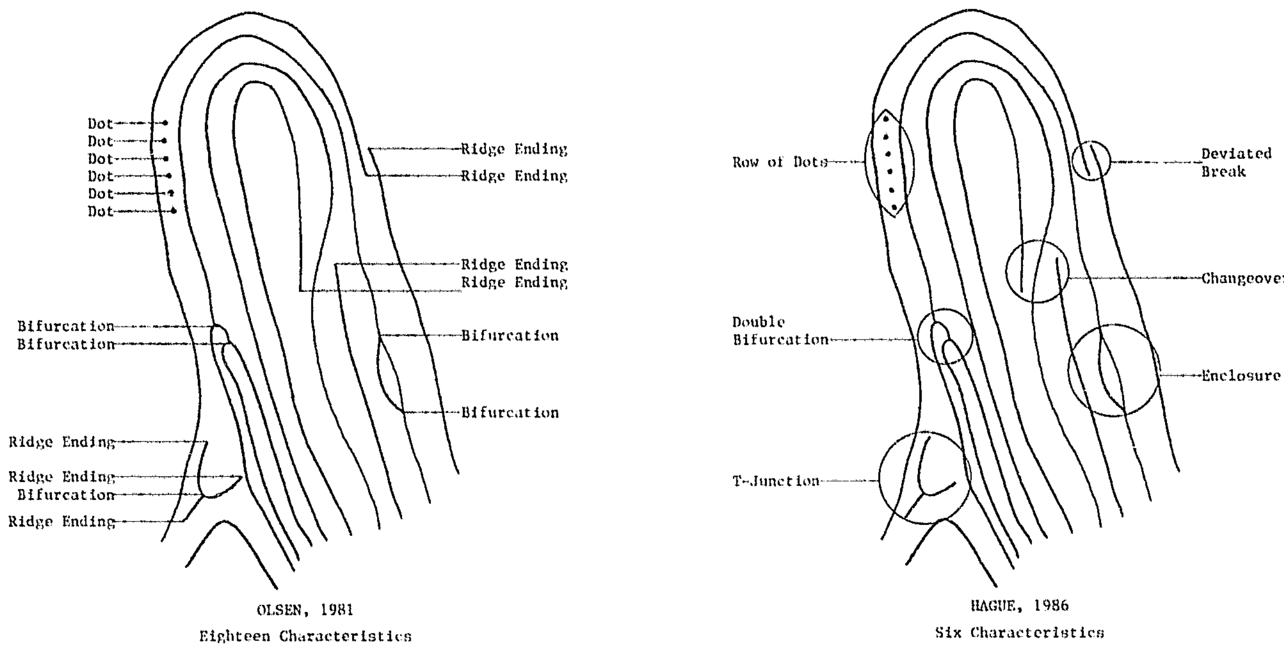

Figure 1. Example of court presentations using two proposed standards of friction skin characteristics.

A PRELIMINARY STUDY OF PHENOTHIAZINE DERIVATIVES USED IN CONJUNCTION WITH ARGON ION LASER EXCITATION FOR THE DETECTION OF LATENT PRINTS

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New reagent and procedures used with lasers have become effective means of developing latent prints. Such reagents include ninhydrin, zinc chloride (Herod and Menzel 1982) and *p*-dimethylaminocinnamaldehyde (Menzel 1980). Phenothiazines can also be added to this group. During previous research with phenothiazine that led to its suggested use as a reagent for enhancing blood prints (Fischer 1986), researchers found that, when it was combined with sodium nitrite and formic acid in methanol, a derivative was formed that reacted with fingerprint residue and fluoresced under argon laser illumination.

MATERIALS AND METHODS

Stock solutions are prepared by adding 1 g of sodium nitrite to a solution containing 2.5 g phenothiazine in 300 ml methanol, followed by 5 ml formic acid. This is allowed to stand at least 1 hour before the working solution is prepared by adding 5 ml of stock solution to 70 ml 1,1,2-trichlorotrifluoroethane, followed by addition of 20 ml of methanol and 5 ml of a 3% solution of sodium hydroxide in methanol.

Illumination of test fingerprints is performed with the 488 nm wavelength of an 8 W LPD-2000 argon laser (Laser Ionics, Orlando, FL) fitted with a Littrow prism. A series of long band-pass filters (Corion, Holliston, ME) ranging from 505 nm to 630 nm, together with argon antilaser goggles, permitted visualization of the latent print fluorescence.

RESULTS AND DISCUSSION

Various materials, such as paper, concrete blocks, plastics and some woods, frequently yielded strong fluorescent prints when treated with the phenothiazine reagent. Best results were obtained by light and repeated spraying. Excessive spraying could produce a background fluorescence. In one experimental application involving a problematic surface, 10 ml of the stock reagent was added to a 1,000 ml beaker containing paper that had been immersed in water for 27 days. Laser examination revealed numerous prints.

Analysis of extractions from volunteers' hands suggests that the reagent is reacting to lipid material that might be present in fingerprint residue. The phenothiazine products that are produced are believed to be dinitro- and/or trinitrophenothiazine, but this must be the subject of further analysis.

CONCLUSIONS

Applications demonstrate that phenothiazine derivatives used with the argon laser can increase the options available to the latent print examiner. Further research should be conducted, including the possible use of the reagent to determine the age of latent prints based on their lipid content.

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APPLICATION OF NINHYDRIN ANALOGS TO THE DEVELOPMENT OF LATENT FINGERPRINTS ON PAPER SURFACES

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Ninhydrin reacts with the amino acid component of a latent fingerprint to give an intensely purple product known as Ruhemann's purple. The secondary treatment of a ninhydrin-developed print with a group IIb metal salt solution changes the print color by the formation of a coordination complex (Lennard *et al.* 1987), and the print becomes photoluminescent under certain conditions. Considerable enhancement of ninhydrin-developed prints can be achieved in this manner (Stoilovic *et al.* 1986). On some surfaces, however, this enhancement technique is not effective because of the high background luminescence of the paper.

A range of ninhydrin analogs has been synthesized and evaluated as reagents for the detection of latent fingerprints on paper surfaces (Lennard *et al.* 1986). The ninhydrin analogs (Figure 1) included a number of compounds with either electron-withdrawing or electron-donating substituents and a number of compounds with extended aromatic systems.

A comparative standard for the colorimetric data of the ninhydrin analogs was obtained by reaction with the amino acid serine and measurement of the spectral characteristics of the resultant colored product. This was achieved by heating the ninhydrin analog with an excess of serine in ethanol. The visible absorption spectra of the resulting solutions were recorded at room temperature. Each solution then was treated with excess zinc or cadmium nitrate, and the fluorescence spectra of the corresponding coordination complex were recorded at liquid nitrogen temperature (77° K). The relevant spectral data that were obtained from this study are summarized in Table 1. These values were used to determine the optimum conditions required for the visualization of fingerprints developed with each reagent.

Latent fingerprints on a range of paper surfaces (including white paper, yellow and manila envelopes, cardboard and newspaper), aged from 6 to 12 months, were developed with each ninhydrin analog. Most of the analogs developed latent fingerprints with a sensitivity that appeared similar to that of ninhydrin itself. In each case, secondary treatment with a zinc or cadmium salt solution changed the print color in a manner similar to that observed for ninhydrin. Figures 2-7 demonstrate the range of print colors observed. A summary of the colors for prints developed with each ninhydrin analog, before and after metal salt treatment, is given in Table 2. The luminescence of the developed prints after metal salt treatment, using a modified xenon arc lamp as an excitation source, was compared with results obtained with ninhydrin itself. The effects of substitution on the ninhydrin skeleton were considered on the basis of the results obtained.

Two compounds in particular, 5-methoxyninhydrin and benzo[*f*]ninhydrin, showed operational advantages over ninhydrin. Fingerprints developed with either reagent and treated with a zinc or cadmium(II) salt solution exhibited stronger luminescence in comparison with ninhydrin, and this was an advantage on paper surfaces that have a high background luminescence. The red-shifted spectral characteristics of prints developed with benzo[*f*]ninhydrin were also found to be an advantage on a number of surfaces. 5-Methoxyninhydrin, however, was shown to offer a number of advantages over both ninhydrin and benzo[*f*]ninhydrin and therefore this compound is recommended as an effective alternative to the established ninhydrin reagent.

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Table 1. SOLUTION SPECTRAL DATA RECORDED FOR EACH NINHYDRIN ANALOG AFTER REACTION WITH SERINE. FLOUREXCENCE DATA RECORDED AFTER METAL SALT TREATMENT

Ninhydrin Analog	λ_{max}[a] (nm)	Zinc (II)[b] λ_{ex}	Zinc (II)[b] λ_{em}	Cadmium (II)[b] λ_{ex}	Cadmium (II)[b] λ_{em}
Ninhydrin	410,579	495	550	510	590
4-Methylninhydrin	411,576	500	555	505	590
5,6-Dimethylninhydrin	409,577	500	555	510	585
4,7-Dimethyl-5,6-diphenylninhydrin	418,578	510	560	525	600
4-Methoxyninhydrin	407,568	500	560	515	595
5-Methoxyninhydrin	410,579	505	540	520	585
5,6-Dimethoxyninhydrin	405,566	510	595	530	625
4-Nitroninhydrin	420,595	505	580	530	620
5-Nitroninhydrin	419,609	505	575	530	630
Tetrachloroninhydrin	425,598	525	595	545	615
Tetrabromoninhydrin	425,600	520	590	540	615
Benzo[*f*]ninhydrin	435,628	530	590	550	635
4,9-Diphenylbenzo[*f*]ninhydrin	465,653	540	605	565	660
Perinaphthoninhydrin	453	550	670	590	690

[a]Visible absorption maxima (± 2 nm).
[b]Fluorescence excitation and emission maxima recorded at 77° K (5 nm).

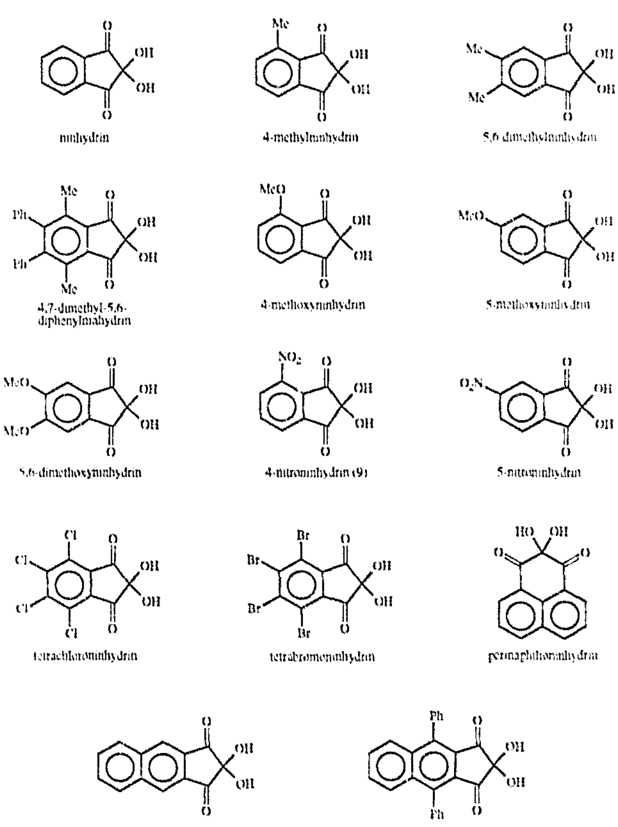

Figure 1. Structures of ninhydrin and the analogs synthesized for their potential application to latent fingerprint development.

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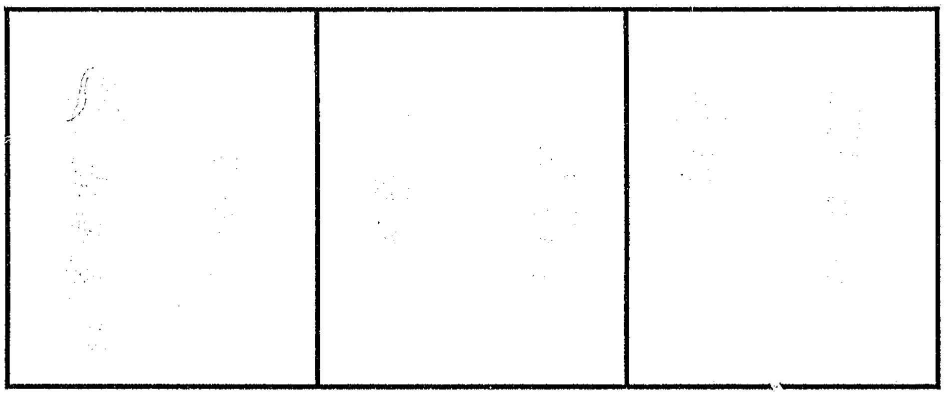
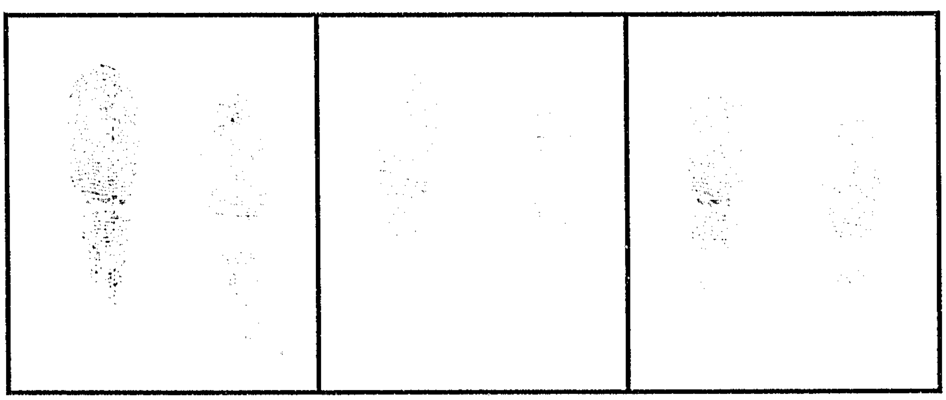


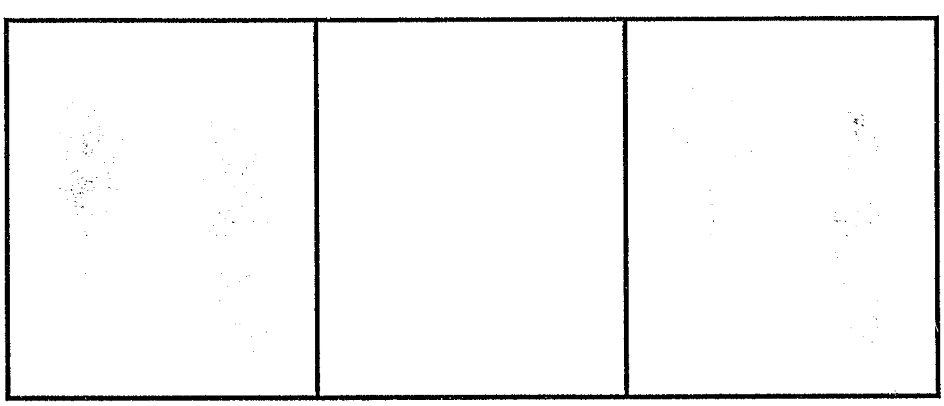
(a) (b) (c)

Figure 2. (a) Fingerprints developed on white paper with ninhydrin and, (b) and (c), similar prints after treatment with zinc(II) or cadmium(II), respectively.



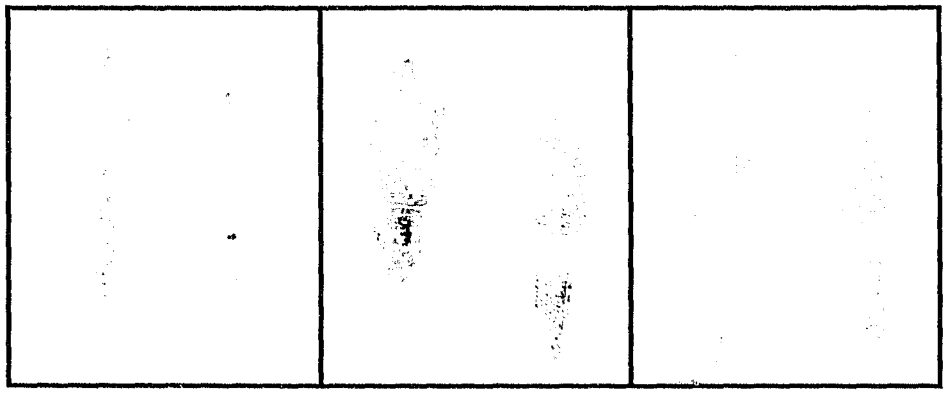
(a) (b) (c)

Figure 3. (a) Fingerprints developed on white paper with 5-methoxyninhydrin and, (b) and (c), similar prints after treatment with zinc(II) or cadmium(II), respectively.



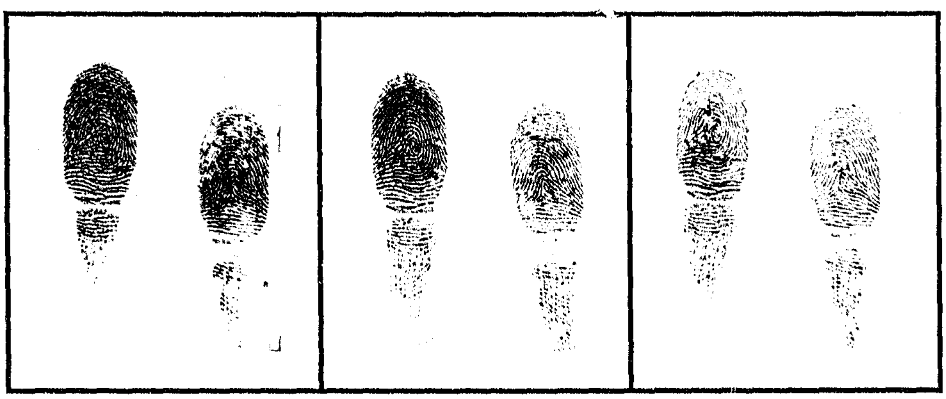
(a) (b) (c)

Figure 4. (a) Fingerprints developed on white paper with 5-nitroninhydrin and, (b) and (c), similar prints after treatment with zinc(II) or cadmium(II), respectively.



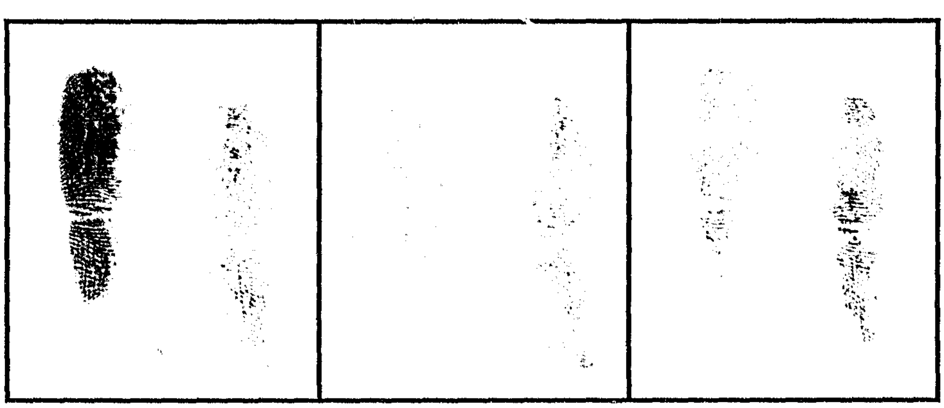
(a) (b) (c)

Figure 5. (a) Fingerprints developed on white paper with tetrachloroninhydrin and, (b) and (c), similar prints after treatment with zinc(II) or cadmium(II), respectively.



(a) (b) (c)

Figure 6. (a) Fingerprints developed on white paper with benzo[*f*]ninhydrin and, (b) and (c), similar prints after treatment with zinc(II) or cadmium(II), respectively.



(a) (b) (c)

Figure 7. (a) Fingerprints developed on white paper with perinaphthoninhydrin and, (b) and (c), similar prints after treatment with zinc(II) or cadmium(II), respectively.

Table 2. COLOR OF FINGERPRINTS DEVELOPED WITH EACH NINHYDRIN ANALOG BEFORE AND AFTER METAL SALT TREATMENT

Ninhydrin Analog	Fingerprint Color	Color after Treatment with	
		Zn(II)	Cd(II)
Ninhydrin	purple	orange	red
4-Methylninhydrin	purple	orange	red
5,6-Dimethylninhydrin	purple	orange	red
4,7-Dimethyl-5, 6-diphenylninhydrin	purple	orange	red
4-Methoxyninhydrin	pink-purple	yellow-orange	orange
5-Methoxyninhydrin	purple	orange	red
5,6-Dimethoxyninhydrin	pink-purple	red	pink
4-Nitroninhydrin	dk. grey-black	brown	red
5-Nitroninhydrin	dk. grey-black	brown	red
Tetrachloroninhydrin	dk. brown	brown	red
Tetrabromoninhydrin	dk. brown	brown	red
Benzo[*f*]ninhydrin	dk. green-black	red	purple
4,9-Diphenylbenzo[*f*]ninhydrin	dk. green	purple	blue
Perinaphthoninhydrin	dk. blue-green	blue-purple	green

SEQUENCING OF REAGENTS FOR THE IMPROVED VISUALIZATION OF LATENT FINGERPRINTS

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Latent fingerprints developed using a particular reagent may not show sufficient detail to allow an identification. Such prints may be enhanced by treatment with another reagent. With this approach, however, it is necessary to have an understanding of how the use of one reagent affects or precludes the later application of another. A number of short reagent sequences, such as iodine and ninhydrin, and silver nitrate and ninhydrin physical developer, are commonly accepted, but little additional information is available in the literature.

General reagent schemes have been developed (Figures 1 and 2) to extend the possibility of sequencing reagents for the improved visualization of latent fingerprints. These schemes have been generalized for application to wet and dry nonporous surfaces (Figure 1) and wet and dry porous surfaces (Figure 2). In all cases, prints are first detected by optical means when possible (such as with laser or arc lamp excitation) before proceeding to any other treatment. Standard safeguards should be employed, and prints developed at any stage of a sequence should be photographed under optimum conditions.

Since no technique has been shown to be effective after physical developer, it should be the last reagent

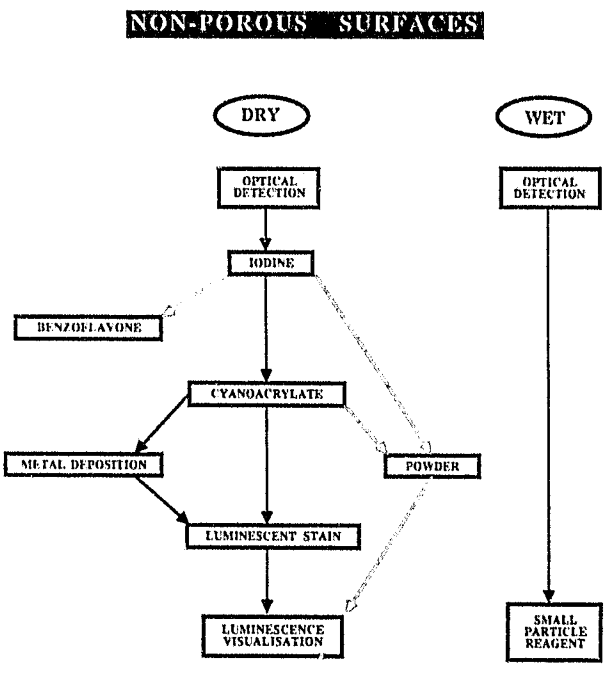

Figure 1. Recommended reagent sequence (solid line) for the development of latent fingerprints on wet and dry nonporous surfaces. (Notes: Exposure to iodine should be restricted to 5 minutes or less if cyanoacrylate treatment is to be later employed. Small particle reagent is the only treatment known to be effective on nonporous surfaces that are wet—if the object can be dried, then it can be treated as a dry surface.)

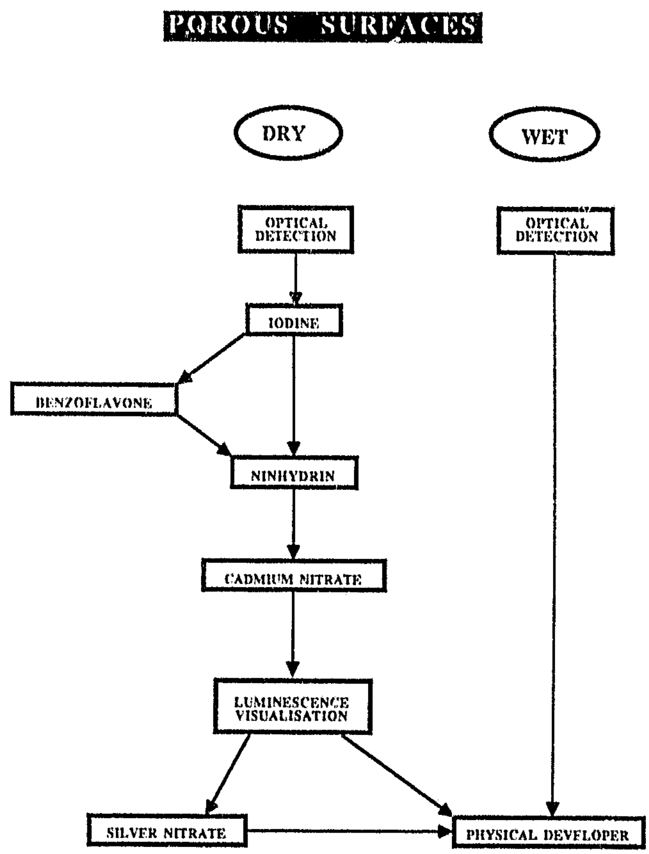

Figure 2. Recommended reagent sequence for the development of latent fingerprints on wet and dry porous surfaces. (Notes: Iodine exposure should not be excessive if the ninhydrin secondary treatment is to be employed. Physical developer is the only reagent known to be effective on porous surfaces that are or have been wet.)

used in a sequence. In addition, we have observed that prints developed with iodine and fixed with benzoflavone cannot be further developed with cyanoacrylate. Short exposure to iodine alone (up to 5 minutes in an enclosed system saturated with iodine vapor at room temperature) does not significantly affect the later development of prints with cyanoacrylate (on nonporous surfaces) or with ninhydrin (on porous surfaces). However, longer exposure to iodine can result in a poor development with cyanoacrylate in comparison with nonexposed prints. The effect of long iodine exposure times on ninhydrin development is less pronounced, but in some cases, weaker luminescence is observed after metal salt treatment in comparison with enhancement with luminescent stains. This technique (cyanoacrylate, followed by metal deposition and luminescent stain) has been shown to be particularly effective on surfaces that otherwise exhibit a high background luminescence after staining (Yong 1986).

The overall choice of a sequence, or a partial sequence, for a particular examination will depend on the nature of the article, the nature of the case and ultimately the time and resources available. For important cases, it is recommended that an exhaustive reagent sequence be employed, as this provides the greatest chance of detecting any latent fingerprints.

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RECOVERY OF LATENT PRINTS AND DRUG RESIDUES FROM PROBLEM POROUS SURFACES

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A previous paper (Nielson and Katz 1987) described results of experiments in which 30% cocaine:inositol residues and latent fingerprints were deposited on a wide variety of porous and nonporous surfaces. The protocol sought to optimize the possibility that both drug residues and latent prints could be recovered. On the basis of those investigations, a protocol summarized in Figure 1 was suggested.

Several related exhibits were subsequently received at this laboratory in the form of squares of white paper. The papers exhibited unusual porosity and allowed the cocaine residues to be trapped by the paper matrix. When the protocol failed to reveal the presence of significant amounts of drug residue, the papers were resampled by the following technique. The new procedure yielded amounts of cocaine sufficient for confirmatory identification.

MATERIALS AND METHODS

Sonication was performed using a Mettler Electronics Corp. (Anaheim, CA), Model ME 2.1 ultrasonic cleaner. Evaporation of the methanol (reagent grade) was performed with a Buchi/Brinkmann Instruments (Westbury, NY) model W240 Rotavapor-R rotary evaporator. Gas chromatography/mass spectrometry (GC/MS) was performed on a Hitatchi 663-30 gas chromatograph interfaced to an ELQ 400-1 mass spectrometer.

Ninhydrin:freon 113 (0.5%) (Tighe 1984) was used to conduct latent print examination. The established protocol for drug residue/latent print evidence (Nielson and Katz 1987) was followed initially.

After methyl alcohol swabbing to recover drug residues, the papers were subjected to latent print examination using ninhydrin:freon 113:methyl alcohol:ethyl acetate (0.5%). The papers were individually saturated by pipetting fresh solution onto the surface of each paper using a disposable Pasteur pipet. The amount of ninhydrin reagent was carefully controlled to allow for total saturation, with minimal runoff. Excess ninhydrin was collected and disposed of. By treating the papers individually with fresh reagent, the possibility of cross-contamination was eliminated.

Latent fingerprints were subsequently developed on a number of the paper squares. It was also determined that the previous drug sampling technique had failed to recover significant amounts of drug residues. The latent prints were preserved photographically, and areas containing latent prints were cut out. Papers containing latent fingerprints then were placed in the sonicator in 300 ml of methyl alcohol and sonicated for 5 minutes. During sonication, the purple amino acid:ninhydrin complex dissolved in the methyl alcohol. (Subsequent experimentation suggests that sonication of undeveloped latent prints would also destroy the impressions.)

The methyl alcohol was transferred to a 500 ml boiling flask and reduced to a volume of approximately 15 ml by rotary evaporation. In various cases, GC/MS injections were made using the concentrated methyl alcohol solution directly. In other cases, an acid-base extraction (sulfuric acid:sodium carbonate) was performed. For either procedure, strong confirmatory spectra were obtained (with no masking due to the ninhydrin in the neat samples) and with sufficient sample remaining to allow for retesting.

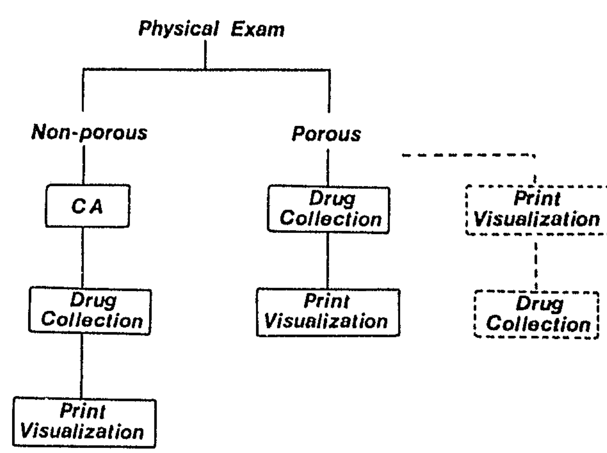

Figure 1. A protocol for recovery of latent prints and drug residues from problem porous surfaces (Nielson, J.P. and Katz, A.I.).

CONCLUSION

It is possible to obtain confirmatory GC/MS spectra from levels of cocaine which were not recovered by methyl alcohol swabbing, after ninhydrin:freon 113:methyl alcohol:ethyl acetate treatment. This was accomplished using the sonication procedure. It is suggested that when sonication is used, latent print examination precede sonication and that the areas containing latent prints be removed, since sonication destroys latent print impressions by removing the colored amino acid:ninhydrin complex. Ninhydrin should be applied by pipetting, using fresh ninhydrin to ensure that no cross-contamination occurs.

Because it is straightforward and yields results in the majority of cases when dealing with porous surfaces, the original protocol is recommended. When initial attempts fail to reveal residues, the procedure just described may yield results.

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SMALL PARTICLE REAGENT: TECHNIQUE FOR DEVELOPING LATENT PRINTS ON WATER SOAKED FIREARMS

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Small Particle Reagent (SPR) is a wet process for detecting the presence of latent fingerprints. Molybdenum, the powder in suspension, is very sensitive to lipid material found in fingerprint residue. Initially, SPR was developed for processing automobiles exposed to extreme moisture, such as dew or rain. Later, SPR was used for processing a variety of water soaked items. Processing wet plastic items with SPR offered best results, but it may be used on wax paper, glass, painted articles, ceiling tile and metals, such as firearms (Kent 1986).

When a wet firearm is received by a forensic laboratory, a plan must be established to maximize evidentiary potential. In the past, the evidence-receiving area was a battleground for opinions on which section should examine the firearm first. Firearms examiners expressed concern that corrosion would affect their examination and subsequent identification. Latent print examiners were concerned that valuable fingerprint evidence would be destroyed. Small Particle Reagent is a solution to these problems. Firearms can still be effectively processed for latent prints while the firearm is still wet, reducing effects of rust and corrosion.

MATERIALS AND METHODS

Molybdenum disulfide powder was obtained from Lightning Powder Co. (Salem, OR). Tergitol 7 (anionic) was obtained from J. T. Baker Co. (Glen Ellyn, IL). Choline chloride was obtained from Fisher Scientific (St. Louis, MO).

Small Particle Reagent is a mixture of a surfactant stock solution and molybdenum disulfide powder. The surfactant stock solution is prepared by combining 4 g choline chloride and 8 ml of Tergitol 7 in 500 ml of distilled water. A working solution is prepared by adding 10 g molybdenum disulfide powder to 50 ml of the surfactant stock solution to form a grey paste in which all the dried powder is dissolved. The paste is then added to 900 ml of distilled water to complete the solution (Grieve 1985).

Experimentation involved a side-by-side comparison of processing with SPR and cyanoacrylate ester fuming followed by black powder. Six firearms were submerged in water for periods of 8-35 days. They were processed by both methods. Both techniques were evaluated on their effect on firearms analysis and their ability to develop suitable impressions. Although the spray technique may be used to apply SPR, the firearms were processed by immersing the weapons in the working solution. After immersion, the excess particulate was rinsed off using a surfactant rinse.

RESULTS AND DISCUSSION

The results of the experiment are summarized in Table 1. Small Particle Reagent is the method of

Table 1. A COMPARISON: SMALL PARTICLE REAGENT AND CYANOACRYLATE ESTER/BLACK POWDER RESULTS FROM PROCESSING WATER SOAKED FIREARMS FOR LATENT PRINTS

Gun #1: Secret Service Special/32 Cal. Patina (Nonfinished with light rust)			
Days in water:	8	8-12	33-35
Processing:	CA-BP	SPR	SPR
Suitable prints:	0	0	0
Gun #2: Raven Arms Model MP-25/25 Cal. Chrome finish			
Days in water:	8	8-12	33-35
Processing:	CA-BP	SPR	SPR
Suitable prints:	3	5	5
Gun #3: H and R Model 930/22 Cal. Nickel plated finish			
Days in water:	8	8-12	33-35
Processing:	CA-BP	SPR	SPR
Suitable prints:	1	1	0
Gun #4: Clerke/32 Cal. Potmetal/chrome finish			
Days in water:	8	8-12	33-35
Processing:	CA-BP	SPR	SPR
Suitable prints:	0	3	0
Gun #5: F.I.E. Titan/25 Cal. Blued pot metal receiver, and chrome plated slide and barrel			
Days in water:	8	8-12	33-35
Processing:	CA-BP	SPR	SPR
Suitable prints:	1	3	1
Gun #6: Colt Detective Special. Blued steel finish			
Days in water:	8	8-12	33-35
Processing:	CA-BP	SPR	SPR
Suitable prints:	0	1	0

choice when processing water soaked firearms. In no instance did cyanoacrylate ester out perform SPR. Overall, SPR yielded more suitable latent prints than did cyanoacrylate ester and black powder. In some instances, processing with SPR revealed suitable impressions after the firearms were submerged in water for 1 month, whereas when processing with cyanoacrylate ester and black powder, fewer impressions were revealed after the firearms were submerged in water for only 1 week. Small Particle Reagent can be used on most types of wet surfaces and is a method I recommend for use in the laboratory as well as at the crime scene.

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ENHANCED LATENT PRINTS IN BLOOD WITH A NEW STAINING TECHNIQUE

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When it is necessary to enhance or develop blood impressions, a variety of methods are available to choose from. Many, including benzidine and *o*-tolidine, are recognized carcinogens requiring special safety precautions. Some, such as Amido Black B10 and ninhydrin, require that the article be subjected to a stabilization process to protect the print from dissolving by the application of chemicals. Coomassie Brilliant Blue R250 is a general protein stain used routinely in forensic serology. Coomassie is more sensitive than Amido Black and Crystal Violet stains, and it utilizes a destaining solution to clear the background.

MATERIALS AND METHODS

Coomassie staining solution is prepared by combining 0.44 g Coomassie Brilliant Blue R250, 40 ml glacial acetic acid, 200 ml methanol and 200 ml distilled water. Destaining solution contains 40 ml glacial acetic acid, 200 ml methanol and 200 ml distilled water.

Crowle's Double Stain, another newly developed stain that does not use methanol, reduces the running of some inks and prevents deformation of some plastic and acetate products. Crowle's Staining Solution contains 2.5 g Crocein Scarlet 7B, 150 mg Coomassie Brilliant Blue R250, 50 ml glacial acetic acid and 30 g trichloracetic acid. (It is diluted to 1 liter with deionized water.)

The article is placed in an inert tray (or container) with the staining solution and agitated. Depending on the type of surface and age of the print, development lasts from 2 to 30 minutes. The article is then placed in the destaining solution for about 1 minute and agitated until the background clears. The dark destaining solution is discarded, and the article is rinsed with fresh destain for a cleaner background. If more detail is required, the article may be restained and cleared numerous times. The solution may be continually poured or sprayed on large items until the prints are developed, although submersion is preferred.

RESULTS AND DISCUSSION

Because numerous techniques are available to enhance prints, the nature of the surface to be examined will have a determining effect on the choice of reagent to be used. Test prints should be used on a like surface before staining to determine surface suitability and stain time. Super Glue fuming before staining has not retarded, and in many instances has increased, ridge detail. Invisible fingerprints, footprints and shoe impressions have been developed on tile floors, masking tape, plastic bags and a metal cash box. Bloody latent prints on bed sheets, a nightgown, knives, wood and glass have been enhanced with Crowle's and Coomassie without washing away or damaging any visible prints. Coomassie and Crowle's have a distinct advantage for the enhancement and development of bloody prints, principally because of their stable shelf life, safety, high sensitivity and ability to destain the background. No serologic analysis can be performed after the staining of bloody prints. All serology samples must be removed before staining.

WASHINGTON STATE PATROL IDENTIFICATION AND CRIMINAL HISTORY SECTION: AUTOMATED FINGERPRINT IDENTIFICATION SYSTEM PERFORMANCE BENCHMARK TEST

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In 1986, the Washington Legislature unanimously passed the Substitute Senate Bill No. 4710, which instructed the State Patrol to develop a plan for and implement an automatic fingerprint information system (AFIS). The law directed the State Patrol to procure the most efficient system available. In July 1986, the Washington State Patrol Identification and Criminal History Section submitted a Request for Proposal to six vendors: DeLaRue Printrak, Fingermatrix, Inc., International Business Machines Corporation, Identification and Security Systems, Inc., NEC Corporation and North American Morpho System, Inc. During September, October and November 1986, the section conducted extensive performance benchmark tests on all responsive vendors, including DeLaRue Printrak, NEC Information Systems and North American Morpho Systems.

The benchmark test was designed to evaluate the processing capabilities of each system with primary emphasis on matching accuracy. The premise used during design stage was that all systems can correctly match excellent quality inked and latent prints. Test criteria were needed to evaluate each system's ability to correctly match lesser quality prints, the quality most commonly submitted for search. To assure consistent evaluation data, the data base and search prints were identical for all vendors.

The data base contained 2,000 fingerprint cards ranging from excellent to poor quality to represent the section's actual fingerprint file. To determine the effect of quality control on accuracy, data base cards requiring minutiae editing or special positioning of fingerprints in the blocks were entered a second time. The completed data bases contained approximately 2,010-2,500 cards. On all systems, test results indicated labor intensive quality control processes minimally affected the position of the correct match on the candidate list.

Two hundred inked print searches were conducted against the data base. The search cards included varying qualities of prints of the two index fingers used for searching. These searches included 150 cards with 3 matches each (450 matching cards in the data base) and 50 cards with no matches in the data base. Pattern type was not used in the search criteria.

One hundred latent print searches were conducted with 1-3 matches each (186 matching cards in the data base). The latent prints contained from 6 to 60 points of identification and a variety of focal points from 0 to all deltas or core. Pattern type was not used in searching latent prints.

The results indicated the effect on the accuracy rate of each system when matching good, average and poor quality prints against varying quality prints in the data base. As would be expected, the average to best quality prints obtained the highest accuracy rates, and lower accuracy rates resulted when both the search and file matching print were poor.

Multiple matches to each search provided 636 total inked and latent print searches for accuracy evaluation. These additional search/match data also reflected the system's ability to locate multiple records inadvertently created on one person.

Additional tests measuring throughput, image quality, no-hit thresholds, core/delta/axis independence and minutiae encoding consistency were conducted. Other areas evaluated by the benchmark team were methods, system ease to use, ergonomics and how each vendor responded to the benchmark testing requirements.

As a result of the entire selection process, the Washington State Patrol selected the NEC Information Systems for the State AFIS acquisition. Installation is expected in late 1987.

COMPUTER IMAGE ENHANCEMENT OF LATENT PRINTS AND HARD COPY OUTPUT DEVICES

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Analog digital image enhancement and recording of latent prints has been ongoing for more than two decades in activities such as ultraviolet (UV) excited luminescence, automated fingerprint identification systems, automated latent print systems and laser (or relatively monochromatic arc lamp) excited luminescence. Recently, it has been applied to the microcomputer based analog digital image processing system (ADIPS) and reflected UV imaging systems (RUVIS) (Otsubo and Nakamura, personal communication). Only now are these last two techniques forcing latent print examiners to seriously consider hard copy output devices as important equipment for their work.

In forensic photography it is said that, "If you can see it, you can take a picture of it." With almost all development procedures involving cyanoacrylate, dusting, dye staining, chemical processing of papers and so on, latent print examiners who are accomplished at using film to record impressions have proven conventional photographic methods to be significantly superior and more practical than analog recording. The spatial, radiometric and spectral resolution capabilities of analog or digital recording devices are typically inferior to the human eye and to conventional photography.

With the introduction of microcomputer-based ADIPS and RUVIS, the latent print examiner is forced to consider use of analog or digital image recording in the laboratory and at the crime scene. Because UV light is invisible to the human eye, with a RUVIS (Figure 1) the latent print cannot be detected unless imaged through a special video tube. Conventional photography is possible but complicated once a latent print has been imaged using a RUVIS. Optics used for conventional photography do not transmit UV light (special quartz optics are required), and the focal plane of UV light is not the same as visible light. Like RUVIS, the latent print enhanced or detected by a microcomputer-based ADIPS (Figure 2) leaves an examiner the choice of photographing the computer display screen or producing a useful image in a hard copy format.

An effective microcomputer-based ADIPS and RUVIS can be obtained for less than $30,000 without a hard copy output device. The ADIPS consists of an IBM PC based system with a 30 megabyte hard disk, 19-inch color monitor and ImagePro software. It is available from Comtal/3M (Pasadena, CA). Two Cohu cameras with 1-inch Newvicon tubes and verti-

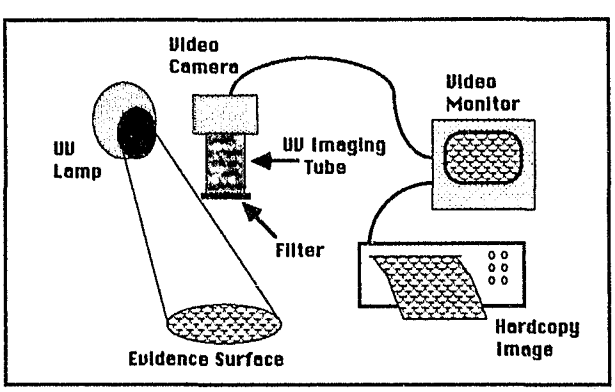

Figure 1. Reflected ultraviolet imaging system (RUVIS).

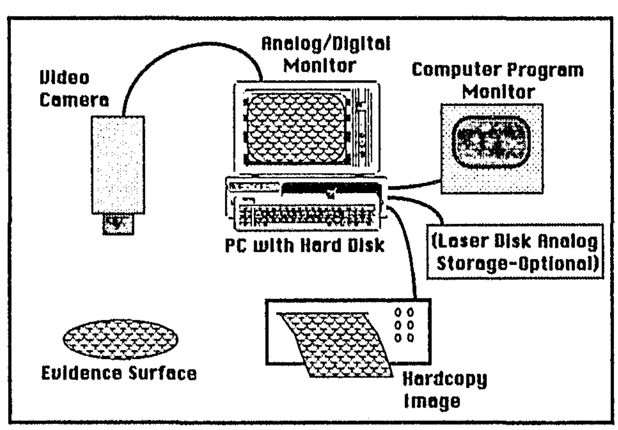

Figure 2. Analog digital image processing system (ADIPS).

cal copy stand masts and a Panasonic video mixer Model WJ-4600B are also required. The RUVIS is a portable crime scene system with improved model V1506 tube, Hamamatsu Corporation (Bridgewater, NJ). Since the hard copy hardware can cost from 1% to more than 100% of the ADIPS or RUVIS, it is a very significant and important consideration.

Hardware options to photographically recording computer monitors and analog enhanced display devices are available in a wide variety of formats. These are categorized as ink jet and dot matrix printers, thermal transfer devices and direct film, transparency or photographic print exposing devices. Problems exist in interfacing high resolution enhanced images with any of these hard copy devices in a manner that does not cause degradation. A compromise between spatial resolution, radiometric resolution and spectral resolution is usually necessary. Latent print examiners normally consider spatial and radiometric features as most important, whereas other forensic scientists (such as serologists, enhancing electrophoretic plates) need high spectral resolution.

Black-and-white thermal transfer devices are capable of providing excellent spatial resolution and acceptable radiometric resolution for latent prints applications (Figures 3 and 4). Mitsubishi model number P-60C (Mitsubishi Electric Sales America, Inc., Piscataway, NJ) or equivalent is recommended for crime scene use. Mitsubishi model number P-70U or equivalent is recommended for latent print office use. Because the spatial resolution of these devices is inferior to conventional film, large format high resolution printouts with potential for later reduction are advantageous.

If your hard copy output device serves an ADIPS in common use by serologists and other forensic scientists, Hitachi's Color Video Printer (TVR, White Plains, NY) or equivalent is recommended. Director color photography of the screen using conventional cameras, or automated film exposure systems (Autocam Computer Image Recorder, Focus Graphics, Inc., Redwood City, CA) are both acceptable but potentially more time consuming replacements for such a color video printer.

Figure 3. Black-and-white thermal transfer of latent print produced using a Model 4632 Video Hard Copy Unit (Tektronix, Inc., Norcross, GA).

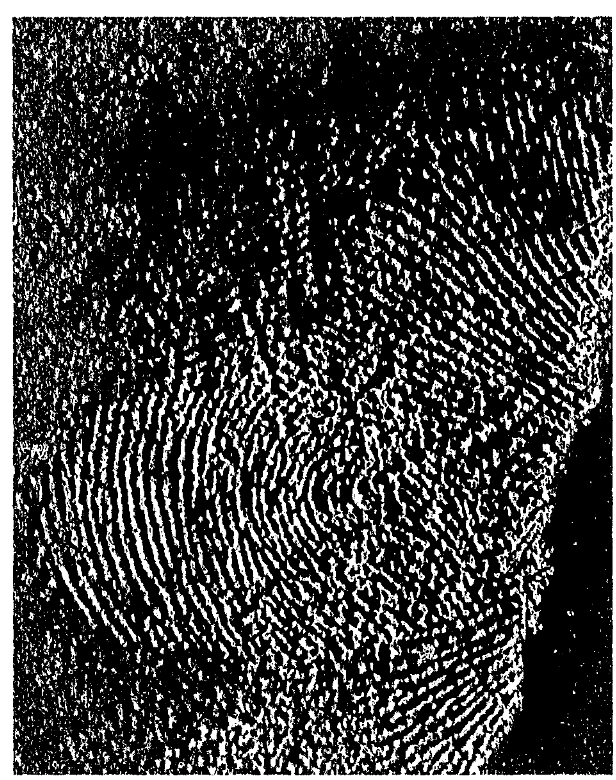

Figure 4. Black-and-white thermal transfer of latent print using edge enhancement produced with a Model 4632 Video Hard Copy Unit (Tektronix, Inc., Norcross, GA).

DESIGN OF A VERSATILE LIGHT SOURCE FOR FINGERPRINT DETECTION AND ENHANCEMENT

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Photoluminescent methods of latent fingerprint detection were first introduced in the last decade using an argon ion laser as a light source (Dalrymple *et al.* 1977). More recently, it was shown that a xenon arc lamp produced comparable results to those obtained with the laser in the detection of fingerprints developed with either 7-chloro-4-nitrobenzo-2-oxa-1,3-diazole (NBD) chloride or ninhydrin followed by zinc chloride (Kobus *et al.* 1983; Warrener *et al.* 1983). Based on the original results obtained with various arc lamp systems, a commercial unit (Unilite) was designed and constructed specifically for the enhancement and visualization of latent fingerprints. The Unilite has been produced by the Forensic Science Research Unit, Australian National University, and thoroughly field tested over the last several years. It is a unique system, capable of serving as an efficient and cost-effective alternative to the widely publicized use of lasers in this role.

The design of the Unilite incorporates a commercial arc lamp system in an air-cooled metal housing. The actual light source is a 150 W ozone-free xenon arc lamp that gives a very broad spectral output from ultraviolet (approximately 250 nm) to infrared (approximately 1,100 nm). Specific wavelengths can be selected on a filter wheel contained in the lamp casing. A wavelength not available on the filter wheel can be chosen by slotting an appropriate filter into the light path. In this manner, the lamp can be adapted to operate at any wavelength of the available spectrum. The filters themselves are high quality interference filters chosen to provide optimum conditions for the most modern fingerprint enhancement techniques. In addition to the filter selection system, the lamp casing is fitted with a special focusing and directional unit that allows change of direction and size of the irradiating beam to give an even field and to optimize the illumination of a given sample. Fluorescent powders, fluorescent stains, postninhydrin and ninhydrin analog treatments and other fluorogenic reagents can all be used with the Unilite system.

The versatility of the Unilite system means that it has application in ink analysis and document work as well as in the fingerprint area. This application in the field of document examination has already been demonstrated in a number of laboratory and casework examples.

The main physical differences between light produced by a laser and light produced by other sources such as Unilite is that the laser light is monochromatic and coherent and has a much higher intensity. The coherence of laser light is a property not used in fingerprint detection. The high intensity, on the other hand, is necessary when the compound of interest has a low photoluminescence yield. This high power is not necessary when optimum conditions are selected to favor an increased photoluminescence yield (Stoilovic *et al.* 1986). In addition, it has been observed that "fluorescence contrast, rather than laser power, is the critical issue in latent fingerprint detection" (Menzel 1985). The monochromaticity of laser light is only advantageous if the wavelength is at or near the absorption maximum of the compound under investigation. The selection of laser lines is often such that their wavelength is far from optimum in the excitation process. A loss of 50% or more in efficiency is therefore common, and only the high intensity of the laser light can compensate for its wavelength limitations. The argon ion laser, for example, is not an efficient light source for the excitation of fingerprints developed with benzo[*f*]ninhydrin and treated with a zinc of cadmium salt. The excitation efficiency can only be increased by using a second laser, such as a neodymium.yttrium aluminum garnet (Nd:YAG) laser (Menzel and Almog 1985) or using a different filter with the Unilite at a saving of up to $50,000. Furthermore, the portable Nd:YAG laser currently marketed for fingerprint detection has an effective average power of only 140 mW, whereas as much as 150 mW can be obtained with the Unilite filtered to operate at 505 nm.

The Unilite has been shown to be comparable with the laser for the detection of the types of prints where the laser was considered to have special advantages over traditional methods (Stoilovic *et al.* 1986). It is better suited for other techniques that require a different wavelength, since this can be selected easily and cheaply on a single instrument. Furthermore, at less than one-fifth the price of most lasers and with less stringent requirements of laboratory facilities and safety, Unilite is a cost-effective and versatile alternative.

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JUROR ATTITUDES TOWARDS FINGERPRINT EVIDENCE AND THE EXPERT FINGERPRINT WITNESS

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A search of the legal and scientific literature reveals that jurors' attitudes towards fingerprints and expert witnesses have never been formally studied. The major question I will address is: What are the underlying factors influencing juror attitudes towards fingerprint evidence and the expert fingerprint witness?

The survey research method was used to poll potential jurors in the jury assembly rooms of Federal and local courts in Salt Lake City, Utah. The instruments were administered by jury clerks before jurors were impaneled. Demographics for the jurors polled show that their average age is 40 years, 70% are employed, 75% are married, 95% are caucasian, 30% have been the victims of crimes and their average education is 14 years (high school plus 2 years of college).

Seven underlying factors influencing jurors' attitudes were identified. They are:

1. Experience of the expert.
2. Employment of the expert.
3. The expert's court testimony.
4. Fingerprint evidence.
5. Jurors' knowledge.
6. The expert's courtroom behavior.
7. Jurors' beliefs about fingerprint reliability.

These factors were isolated through 25 variables appearing in the instrument.

Jurors were also given the opportunity to write out any questions they had about fingerprints or expert witnesses. Almost 50% responded, and some 500 questions have been compiled. The most frequently asked questions are:

1. Accuracy: Have you ever made a mistake?
2. Duplication: Could two people have the same fingerprint?
3. Alteration: Can fingerprints be changed?

Additional questions dealt with latent print procedures, comparison techniques, filing and the expert's training and background.

In conclusion, jurors have specific preferences about how fingerprint evidence should be presented in court. They also have definite pretrial attitudes about the expert and his or her background. In addition, jurors have some misconceptions about fingerprints which are reflected in answers to questions in the survey.

This study may be used as a basis for prosecutors and expert witnesses to prepare for a more effective presentation of fingerprint evidence during trial. Elements of the survey may also be used by supervisors and instructors to train fingerprint examiners in courtroom presentations.

I strongly recommend that this study be duplicated in other areas of the country to see if similar results are achieved. This survey may also be expanded to include judges' attitudes towards fingerprints to give a more complete picture of the role of fingerprints and expert witnesses in the judicial process.

CADMIUM COMPLEXATION: AN IMPROVED FLUORESCENT TECHNIQUE FOR THE ENHANCEMENT OF WEAK NINHYDRIN-DEVELOPED LATENT FINGERPRINTS

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Ninhydrin has been used for developing latent fingerprints on paper and other porous surfaces since the early 1950's. The ninhydrin breaks the amino acids present in the latent fingerprint deposit, taking the nitrogen and forming a colored compound known as Ruhemann's purple. The problem arises when the latent fingerprint deposit is weak and thus low in content of amino acids (light deposit). The resulting ninhydrin-developed latent print is faint and lacking in identity details.

It has been known for a number of years that Ruhemann's purple forms stable colored complexes when treated with various metal salts. In 1982, Herod and Menzel reported that latent fingerprints developed with ninhydrin and treated with zinc chloride showed fluorescent properties when excited with a 488 nm line from an argon ion laser. In 1983, we reported (Kobus *et al.*) that photoluminescence efficiency of such treated latent fingerprints increases dramatically by cooling the exhibit down to the temperature of liquid nitrogen 77° K (-196° C). This allowed excitation to be achieved using conventional light sources.

MATERIALS AND METHODS

The nonflammable ninhydrin formulation reported by Morris and Goode (1974) was used by Australian fingerprint bureaus for a number of years, so our group has adopted the same formulation. No acceleration process was used for the ninhydrin development employed in any of the cases described herein.

It was found that the concentration of the cadmium salt used to produce the metal complex is not critical, nor is the nature of the counter ion. We used the following cadmium nitrate solution for all experiments and casework treatment: 1 g of cadmium nitrate tetrahydrate dissolved in a mixture of 12 ml of absolute ethanol and 2 ml of acetic acid made up to 100 ml with 1,1,2-trichlorotrifluorethane (Fluorisol). All reagents were laboratory grade.

RESULTS

Our research showed that only complexes made with metals of group IIb of the periodic table (zinc, cadmium and mercury) showed significant photoluminescence that could be used for enhancement of weak ninhydrin- developed latent fingerprints. Dramatic increase in photoluminescence efficiency by cooling is a common property of these complexes.

Among these three metals, cadmium makes the most stable complex and has the most suitable photoluminescent characteristics for enhancement of weak ninhydrin-developed latent prints when used at liquid nitrogen temperatures. Essentially, no photoluminescence is observed at room temperature even when the powerful 488 or 514.5 nm laser line from a 20 W argon ion laser is used for excitation. Examination of the cadmium complex shows the following characteristics:

1. Excitation spectra (maximum at 510 nm) and emission spectra (maximum at 580 nm) do not depend on which cadmium salt is used (Figure 1).
2. Some water is necessary for the formation of the complex (Lennard *et al.* 1987).
3. There is no shift of spectra or breakdown of the complex by excess of water (Stoilovic *et al.* 1986).

Efficient photoluminescence is achieved only at low temperatures such as that of liquid nitrogen. Results are then very rewarding: weak-ninhydrin developed latent prints with virtually no details could be enhanced to produce almost perfect prints (Figures 2 and 3).

A shift of the excitation band of only 20 nm towards the longer wavelength of cadmium complex compared with that of zinc complex makes a big difference in favor of the cadmium complex when high paper photoluminescence background prevents any selective photoluminescence from the zinc complex (Figure 4). For excitation of cadmium treated ninhydrin-developed latent prints, a 150 W Xenon arc lamp

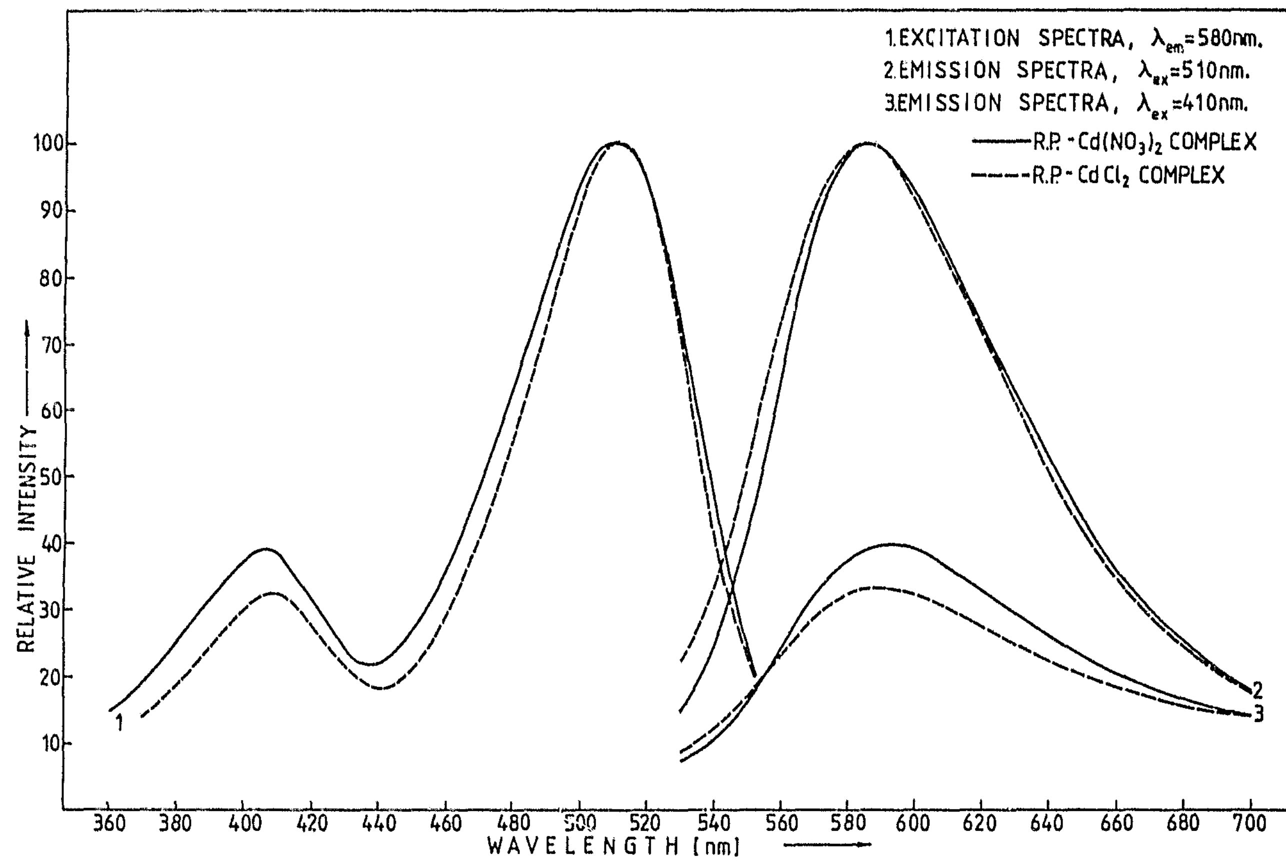
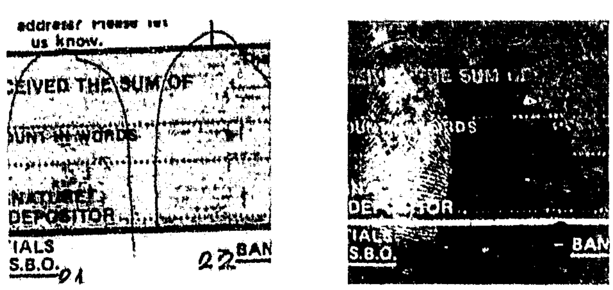
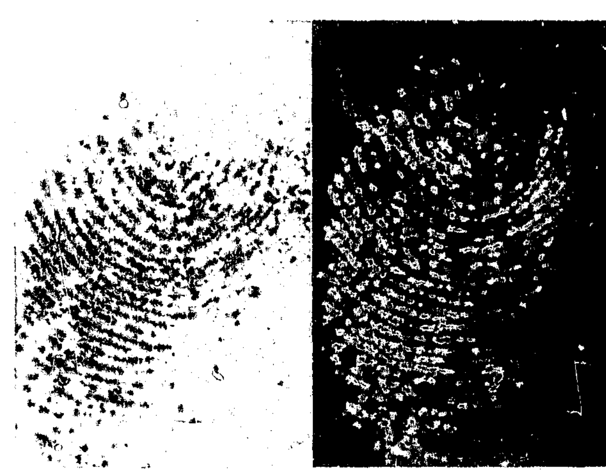


Figure 1. Photoluminescence spectra of Ruhemann's purple-cadmium salts complex.



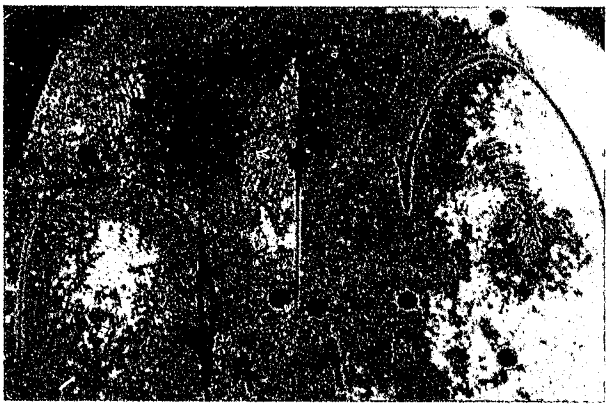
(a) (b)

Figure 2. Weak ninhydrin developed fingerprints (a): first impression (21) and second successive impression (22). After cadmium treatment & photoluminescence mode (b).



(a) (b)

Figure 3. Case FS 125. (a) Ninhydrin developed (b) Cadmium treated & photoluminescence mode.



(a) Cadmium treated Zinc treated

(b) Cadmium treated Zinc treated

Figure 4. Weak ninhydrin developed prints on high photoluminescence background paper: (a) excitation 505 nm, suits cadmium (b) excitation 485 nm, suits zinc.

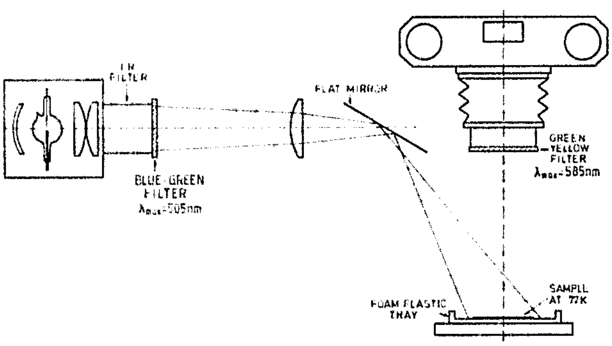


Figure 5. Schematic diagram of low temperature photoluminescence method using an Xenon arc lamp for excitation.

filtered with a bandpass filter maximum at 585 nm was used. A schematic diagram of the process is shown in Figure 5.

CONCLUSION

Cadmium complexation and low temperature photoluminescence showed the best characteristics, and they are recommended as a general method for enhancement of weak ninhydrin-developed latent fingerprints. The sample has to be submerged in liquid nitrogen to produce efficient photoluminescence regardless of the light source used.

The best results are obtained from latent prints where complexation occurs within 2-3 weeks of the ninhydrin treatment. If storage is required before complexation, this should occur in the absence of light (in a sealed envelope or similar container).

In relatively dry conditions (humidity less than 50%), it is recommended that the latent print of interest should be briefly steamed with hot steam after cadmium treatment. The excitation light source should be collimated and suitably filtered. A bandpass filter maximum at 500-510 nm is used, and the light source has an electric power rating of 100-200 W (xenon or quartz halogen). Both 488 nm and 514.5 nm of the argon ion laser line could be used successfully for excitation. In some cases, the 514.5 nm line is recommended to avoid high photoluminescence background. The all-lasing mode often produces only limited success, and it is not recommended, since the lines in the blue region of the all-lasing mode can produce a high photoluminescence background that prevents visualization of latent fingerprints.

For visualization of photoluminescence from treated latent prints, a bandpass filter with maximum at 585-595 nm is recommended. A 550-570 nm cut-off filter can be used, but it is not as successful.

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ENHANCEMENT OF BLOODY FINGERPRINTS ON TOOLBOX BY USE OF INFOSCAN™ EQUIPMENT

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During the course of a homicide investigation, a faint latent fingerprint was noticed in a blood stained area on a tool box. This fingerprint was treated with Super Glue fumes, and a lift was made. Observation of the lift showed a repeating random pattern from the textured surface of the tool box on which the print was made. The developed print lacked sufficient clarity of individual characteristics to enable an identification. Latent print examiners decided to attempt the Infoscan™ method of examination and enhancement to visualize additional latent print characteristics.

The technique of image enhancement was to be attempted to visualize additional individual characteristics (points of identification) in a latent fingerprint unsuitable for identification. The following evidence was used: photographs of lifted fingerprint and suspect fingerprint and enlargement of original bloodied print (all 20.3 mm X 25.4 mm).

PROCEDURE

Regarding direct enhancement of the latent print photograph, the conventional enhancement available on the Infoscan™ (Infrascan Inc., Richmond, BC) machine was attempted in order to clarify the image. It was noted that the fingerprint itself was enhanced, but the background pattern was also enhanced.

The image was then deliberately misfocused. This resulted in an overall softening of the details, making the fingerprint clearer even though no enhancement was provided. Comparison was made between this enhanced image and the suspect's inked print. Both overlay and alternation were used as a method of viewing the print.

OBSERVATIONS

The individual characteristics from the original photograph were obscured by the presence of the background interference. Enhancement attempts with the photograph in clear focus resulted in enhancement of both.

The latent print was deliberately brought out of focus. This showed more detail of the fingerprint and less detail of the background. Enhancement of this new image (misfocused deliberately) resulted in a latent print suitable for identification.

CONCLUSIONS

It appears from the procedure that, in some instances where a strong background is present, image enhancement of a photograph or the actual object also enhances the background interference. There is a very fine line between in focus and out of focus, and therefore sufficient misfocusing to distort the repeating pattern has little effect on the original faint or blurred ridge details. Enhancement at this particular point allowed for a much more detailed image without the strong overbearing background.

QUO VADIS, AFIS?: THE POSSIBLE EFFECTS OF AUTOMATION ON FINGERPRINT STANDARDS AND METHODS

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Automated fingerprint identification systems (AFISs) can provide a rapid and productive search of a latent print against a large 10-print card suspect file, provided certain factors are synchronic. The interrelationship of the factors involved is complex, but one factor that appears to have a direct correlation on the accuracy and effectiveness of an AFIS latent search is the quantity of individual characteristics, or minutiae, present in the latent print. The results of a benchmark test of 50 latent prints conducted by the Illinois Department of State Police on the NEC system revealed an overall accuracy of 70%. Latent print search output was tabulated according to the number of minutiae present in each latent print, the number of minutiae encoded, search present in each latent print, the number of minutiae encoded, search results as to hit, miss and score and modification to the original encoding if researched.

All 50 latent prints had matching 10-print card records. The initial search run produced 15 misses. Nine of these misses were researched with modifications made to axis angle or minutiae encoding, producing one additional hit. An analysis of the misses revealed that all but one contained 13 minutiae or fewer. Accuracy results for all latent prints in the group with less than 14 minutiae was 50%, and for those latent prints containing fewer than 12 minutiae, the hit rate declined to under 40%. All latent prints with 17 minutiae or more yielded a hit.

Exploration into the cause of each miss was attempted, and the reason for the miss could be, in many cases, determined and categorized. However, regardless of explanation, the reality that a correlation of latent print minutiae quantity and search accuracy was established.

Current standards in the United States maintain there is no scientific validity to a minimum requirement in the number of matching individual characteristics to effect an identification. Evaluations of latent prints as to their value for identification purposes traditionally has been determined by the type, clarity and relationship of the individual characteristics. Cost effectiveness and efficient use of a multipurpose AFIS may encourage a third classification of latent print suitability, that of meeting AFIS requirements. This segregation of latent prints below the threshold of break even accuracy levels may delegate fewer than 14 minutiae latents into an area of neglect, and, in the process, create a *de facto* standard with misleading inferences. Explainable and perhaps workable machine limitations may become confused with basic identification requirement tenets and give unwarranted support to the creation of an arbitrary minimum standard.

DIGITAL IMAGE PROCESSING AS A MEANS OF ENHANCING LATENT FINGERPRINTS

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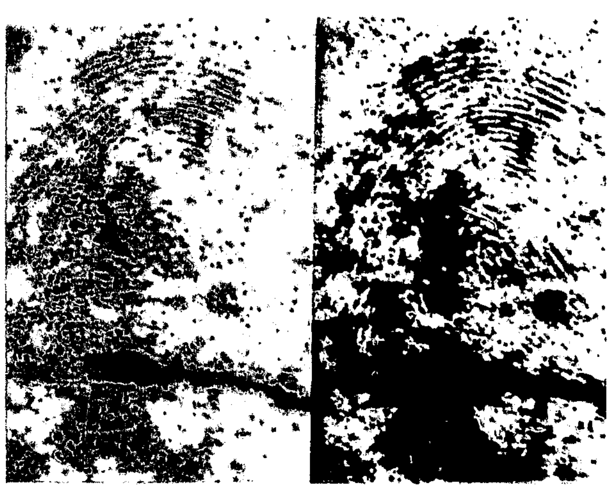
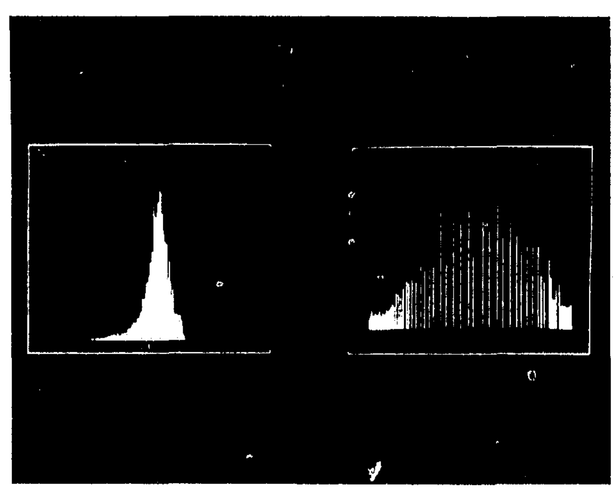
Digital image processing refers to picture analysis or manipulation by means of computer operations. The visual information is converted into a digital (numeric) format before the processing cycle is initiated. Each pixel (picture element) is given a digital location and intensity value. The digital information can be mathematically processed by different formulas to enhance the image and help us to discern minute detail within the image. In latent fingerprint examinations, a digital image processing technique known as contrast manipulation is of great value (Figure 1). The reason for its value is that the computer is better than the human eye at making distinctions between intensity levels (gray tones). A continuous tone black-and-white photograph can render approximately 40 shades (tones) of gray, whereas the human eye can only distinguish between 16 and 32. A computer with 8 bit quantization can discern and record 256 different shades. When examining prints that lack contrast, a histogram (a graph illustrating the distribution of tonal values) of the image will show where the high concentrations are located within a narrow range on the histogram (Figure 2). With this information, one can manipulate the gray tones represented by the histogram and disperse them along the scale so individual shades are more discernible. Using a computer to arbitrarily control the contrast in real, or near real, time is very beneficial. It allows one to evaluate the effects of the manipulation during processing.

Another type of enhancement that is suitable for latent print applications is edge sharpening. The effect of this technique is to create a more distinct edge to the detail within the image (Figure 3). This is accomplished by the computer's performing a neighborhood processing routine where a small group of pixels (for example, 3×3, 5×5) are examined (mathematically) for a line of transition from one tone to another. At this transitional point, mid range transitional tones are converted to the same tone as one of their neighbors. By eliminating the transitional tones, the edge is sharpened and more clearly visible.



(a) (b)

Figure 1. Unenhanced digital image of a latent print (a). Results of contrast manipulation (b).



(a) (b)

Figure 2. Histogram of the unenhanced photograph (a). Histogram of the enhanced image (b).

(a) (b)

Figure 3. Unenhanced digital image and 2× zoom inset (a). Results of edge enhancement and 2× zoom inset (b).

Latent print examiners across the country react differently when image enhancement of latent prints is discussed. Often, the initial reaction is one of disapproval. The concern is that nonexistent detail is added to the latent print. Image enhancement techniques are not designed to create detail but to improve images for human interpretation. Just as photographic techniques assist us in seeing various spectral ranges (such as infrared) and microscopes help us to see extremely small items, image enhancement techniques can help us to discern minute details within an image. Digital image processing has proven its laboratory value to the Los Angeles County Sheriff's Department Identification Unit.

NEW FINGERPRINT DEVELOPMENT PROCESS

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The use of cyanoacrylate (Super Glue) fuming for developing fingerprints gives excellent results on many surfaces that were previously difficult to process. However, contrast and photographic problems are sometimes encountered. The laser beam with Rhodamine 6G could be very useful in this case, but because of distance and the complexity of this equipment, not every police force can use the laser light. The purpose of the research was to find an inexpensive development process that yields excellent results.

The procedure is as follows: Expose the exhibit to cyanoacrylate (Super Glue) fuming. Soak it in 970-P-10 solution (Androx, Ltd., St. Catherines, Ontario) for approximately 10 minutes. The solution also may be sprayed on the surface and allowed to react for 10 minutes. Then, rinse it with tap water to remove the excess P-10. (Check with an ultraviolet light for P-10 residues.) Dry it with a dryer or hang it up to dry. At this stage, expose the exhibit to ultraviolet light and then photograph.

For the photography, we used an MP4 camera and Polaroid 55 and Kodak Tri-X Pan. The photographic process is as follows:

1. Use an ultraviolet light source, such as two 45.7 cm black light fluorescent tubes, to light the exhibit.

2. Focus with a Kodak filter number 47 on the lens; take it off after focus is made.

3. Place a Kodak 2E filter on the lens of the MP4 (or other camera) to take the photograph.

Exposure time is approximately 32 seconds at F-16 and may vary according to the quality of the light source. We also experimented with an electronic flash and on 18A filter on the flash.

When this method was used, fingerprints appearing with the use of P-10 and ultraviolet light gave us fingerprints with white ridges because the 2E filter absorbs ultraviolet light and lets only the fluorescence (white light) strike the film. At this stage, all we have to do is reverse the white ridges as depicted in Figure 1. Figure 2 is the known print. By comparing these two photographs, the points of identification can be noted.

The P-10 solution leaves yellow stains on skin, so you should wash thoroughly with warm water and soap. For the process, we strongly recommend that you wear surgical gloves and safety goggles (or a face shield) to protect you from the effects of the product. Work in a well ventilated area or in a laboratory exhaust fuming hood.

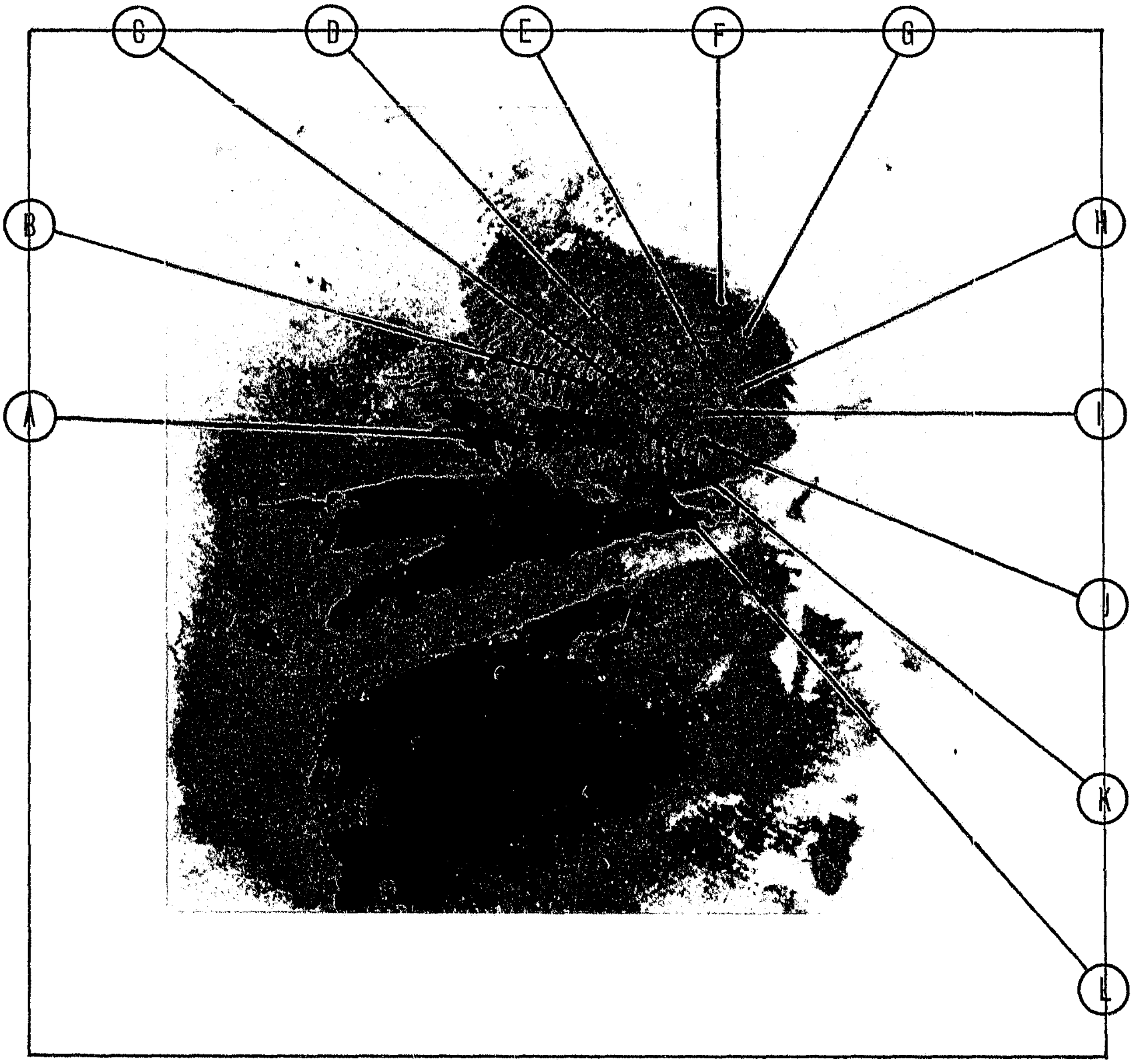

Figure 1. Reverse photograph of fingerprint following use of P-10, using ultraviolet light, 2E filter.

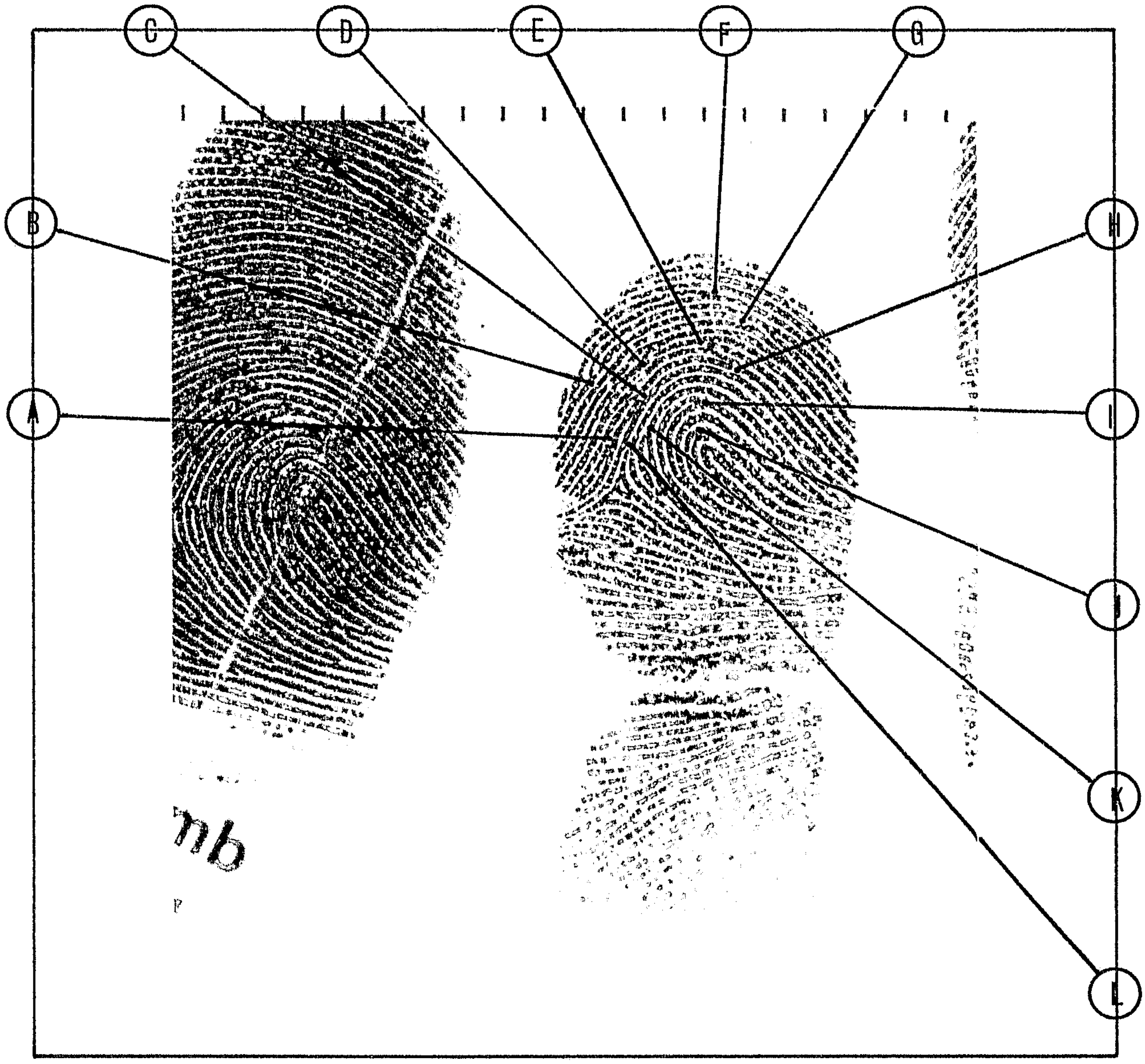

Figure 2. Known fingerprint with points of identification as appearing in Figure 1.

SUPER GLUE FUMING: A PORTABLE LOW COST FUMING CHAMBER WITH ACCELERATION DEVICE

P. W. Pfefferli

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Numerous techniques and methods to accelerate fuming development time have been published. A number of advantages and disadvantages are encountered in the practical use of each method, and they have to be considered when a Super Glue (cyanoacrylate) fuming kit is evaluated.

In 1986, our forensic science laboratory designed new, easy to use and low cost cyanoacrylate fuming equipment in place of a manufacturer supplied system we used before. This new kit should be versatile for laboratory as well as for field application and should offer fuming acceleration facilities.

APPARATUS

Various size plexiglass fish tanks are used as fuming chambers. The tanks are mounted with a small battery operated fan. This acceleration device will circulate the cyanoacrylate fumes and increase surface contact between the latent print and cyanoacrylate vapors.

When different types of battery operated fans were treated, especially fans for fingernail varnish drying, it was noted that the motor of the fan will be damaged by the cyanoacrylate fumes. Care therefore was taken to keep the motor outside of the fuming tank, only the propeller of the fan being in contact with the fumes (Figure 1).

The portable chamber is versatile for field application and on-site fuming. The plexiglass tank may even be placed upside down over the evidence, making an air tight system when using adhesive tapes are used to keep the assembled system in a certain position.

Used as a field kit outside the laboratory, the equipment requires 1.5 V DC. For laboratory development, an AC/DC power supply is connected to the motor unit.

RESULTS AND DISCUSSION

Practical application of the new Super Glue fuming kit has given proof of its services. Compared with commercially available systems, the kit has a number of advantages, for example, ease of use, portability and cost (about $50).

When residue buildup on the inside of the fuming chamber prevents us from observing the progress of the fuming, the plexiglass tank has to be replaced by a new one. In this case, the motor unit can easily be changed from one tank to the other, and all the fan components can be used for the new kit.

The fume circulation procedure has been shown to be a suitable technique when the equipment is used as a field kit. For laboratory examinations, a combination of circulation and heating is also possible with the same standard assembly.

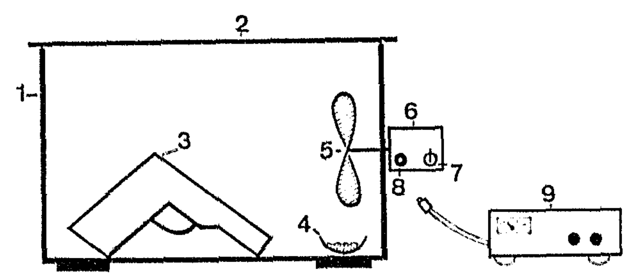

Figure 1. Fuming chamber. (1) Fuming chamber (plexiglass fish tank). (2) Plexiglass lid. (3) Evidence (4) Cyanoacrylate dish. (5) Fan propeller. (6) Motor unit. (7) Switch. (8) Socket for AC/DC power supply. (9) AC/DC power supply.

A PRACTICAL DESIGN FOR A CYANOACRYLATE FUMING CABINET FOR A MEDIUM SIZED POLICE LABORATORY

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Plano Police Department
Plano, Texas

Drawbacks to the common aquarium used in cyanoacrylate fuming include inadequate size of chamber for large items, difficulty of loading evidence through the top of the aquarium, poor viewing capability, uneven distribution of fumes and release of fumes into the laboratory. Solutions to these problems were the goal during the design, construction and modification of a fuming cabinet at the Plano, Texas, Police Department.

A front-loading cabinet 1.2 m high, 0.9 m wide and 0.3 m deep was built with a mirror for the back wall and plate glass for sides and doors (Figure 1). The top and bottom of the cabinet are wood with formica veneer. Four removable expanded metal shelves rest on brackets glued to the sides, and three cables are stretched across the top for hanging items.

Joints and seams are sealed with butyl caulk, duct tape and various types of weather stripping. To keep the cabinet sealed during fuming, wedges are inserted in grooves in both the top and bottom where the doors meet.

Several sizes of computer ventilation cooling fans were tried for exhausting the fumes, but they did not move enough air. Finally, a vacuum cleaner motor was attached with a hose through the bottom of the cabinet, and an exhaust hose was vented outside the building. An opening in the top of the cabinet is closed during fuming and opened during the exhaust cycle.

Large sodium hydroxide pads were used initially as an accelerant, but a heat source consisting of a 100 W light bulb and grill was found to be more effective (Besonen 1983). The light bulb assembly also generates a convection current that keeps fumes evenly distributed in the cabinet. Adding moisture to the fuming process by placing a glass of hot water next to the heat source enhances the quality of the prints compared with the quality yielded by dry fuming.

After the evidence is loaded into the cabinet, 50-60 drops of glue are placed in a foil dish on the grill over the light bulb. A glass of boiling water is placed next to the light, and the cabinet is closed. The light is then turned on with a switch mounted in the cabinet's base. Fuming time is as short as 3-5 minutes on some items but is normally about 15 minutes. Items have been left overnight without adverse results.

The cabinet is cleaned as needed by scraping the glass and mirror with a single edged razor. A canister vacuum is used during scraping to collect the residue film and prevent it from becoming airborne.

The cabinet can be built in one weekend with common tools. The total cost should be \$250-\$300, less if glass is used in place of the mirror. For ease of use, versatility and quality control, the cabinet is far superior to an aquarium.

REFERENCE

Besonen, J. A. (1983). Heat acceleration of the Super Glue fuming method for development of latent fingerprints, Ident. News 32.

MATERIALS AND TOOLS

The following materials are used to build the cabinet: two boards, 38×106.7×3.8 cm; two sheets of formica, 91.4×30.5 cm; formica adhesive; mirror, 91.4×121.9×0.64 cm; two sheets of plate glass, 30.5×121.9×0.64 cm; two sheets of plate glass, 45.7×121.9×0.64 cm; two all thread rods, 129.5×0.64 cm; two T-nuts; two wing nuts; two sets of plate glass hinges; two strips of angle aluminum, 121.9×1.3 cm; a tube of butyl caulk; 4.8 m of silver duct tape; weather stripping; two wooden wedges, 1.3 cm wide, thinning to edge, 2.5×7.6 cm.

For the base, these materials are needed: 2 boards, 2.5×10.2×81.3 cm; 2 boards, 2.5×10.2×27.9 cm; 4 boards, 5.1×5.1×45.7 cm; 16 dowels, 0.9×5.1 cm; wood glue.

The shelves and hanging unit are made from: 4 pieces of expanded metal, 25.4×90.8 cm; 8 pieces of angle aluminum, 1.3×90.8 cm; 16 pieces of angle aluminum, 1.3×25.4 cm; 2 tubes of rearview mirror adhesive; 9 small eye screws; 2.7 m of picture hanging wire; 32 small nuts, bolts and lock washers.

The heat source and exhaust device are made from a ceramic light holder with a 100 W bulb and a vacuum motor with two hoses, one for intake and one for exhaust. Two electric switches with switch plates are needed, plus one plug, and electrical wire as needed to reach the wall socket. A 453.6 g size coffee can with wire is used for the grill.

The cabinet can be constructed with a router, circular saw, drill, caulk gun, hack saw, jig saw, screw driver and crescent wrench.

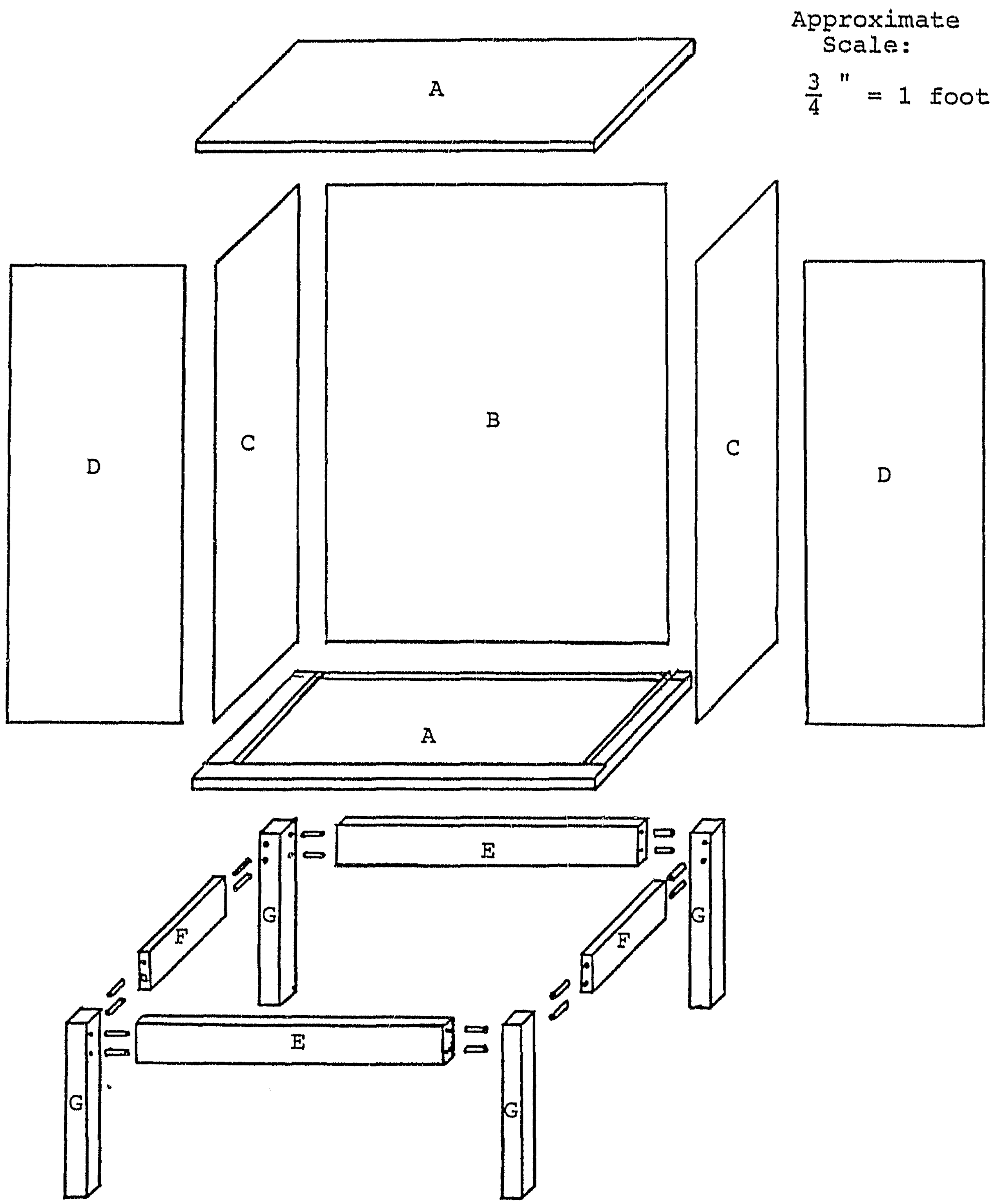

Figure 1. Wood and glass components of fuming cabinet.

A PORTABLE, ECONOMICAL AND VERSATILE FUMING CHAMBER FOR CYANOACRYLATE PROCESSING AT CRIME SCENES

G. R. Jackson

Orange County Sheriff-Coroner Department
Santa Ana, California

Cyanoacrylate (Super Glue) fuming is usually done in the laboratory inside a stationary tank or chamber large enough to hold most types of evidence collected and brought back for latent print processing in a laboratory. Such chambers are rather cumbersome or are too fragile to be brought out to the crime scene. Most of these laboratory chambers are usually too small to hold large items such as furniture and automobiles. There are also surfaces, such as window frames, counter tops and other immobile crime scene items, which would most effectively be processed on-site. To meet these various needs, staff members of the Sheriff-Coroner's Identification Bureau designed a portable fuming chamber system that they fondly refer to as the "Tinker Toys." This portable fuming chamber system is compact enough to be disassembled, easily carried in the trunk of an automobile and assembled in minutes at a crime scene by one person. It can be made large enough to accommodate evidence of almost any size or shape.

The basic design of the portable chamber consists of a combination of standard polyvinyl chloride (PVC) pipe joint fittings of various sizes, coupled with lengths of wood doweling and plastic sheeting. The pipe fittings and doweling are used to construct a framework that is then covered with the plastic sheeting, making an airtight chamber to be placed over the evidence or in which the evidence is placed. When laser processing may be necessary, black plastic sheeting can be placed over the framework, making a darkened enclosure required for this type of examination.

The standard portable fuming chamber are of two types. The first is for smaller objects, such as furniture, sections of walls and window frames, and is kept inside the mobile Crime Scene Investigation Units used by the Identification Bureau. The other one, made for processing larger items such as vehicles, is stored in the laboratory shop area where most of the larger items of this type are processed. It can be transported to a scene if necessary. The smaller of the two chambers is composed of 1.9 cm PVC pipe fittings, threaded pipe sections, and 1.9 cm wood doweling cut into 0.9 m long lengths. When assembled, they make a chamber that is 45.7 cm high, and either 0.9 × 0.9 m or 0.9 × 1.8 m. By adding additional pieces from other "kits," the size and depth of the chamber can be expanded as required. The larger "kit" is made up of 3.8 cm PVC fittings and 3.2 cm wood doweling that is cut into lengths ranging from 0.9 × 2.4 m long. This allows for the assembling of chambers as large as 4.3 × 2.1 × 1.8 m, large enough to accommodate most standard size automobiles. In addition to the components of the chambers, tool kits containing duct tape, staplers, miscellaneous hand tools and PVC cement were assembled to assist in the building of the chambers or for making repairs on broken components.

The total cost for the small "kits" was approximately $35 each for the framework and approximately $25 for each tool kit. The cost of the materials for the larger kit was approximately $100. The plastic material used was purchased in bulk for approximately $125 per roll.

As a result of building this system, the Sheriff-Coroner Department has been able to process a countless number of automobiles, motorcycles, furniture, stationary items and human bodies with very little wasted time and effort involved with site preparation.

FACTS RELEVANT TO THE METROPOLITAN POLICE DEPARTMENT'S AUTOMATED FINGERPRINT IDENTIFICATION SYSTEM

T. Burse, III

Metropolitan Police Department
Washington, D.C.

Since October 1983, the Metropolitan Police Department has utilized the DeLaRue Printrak 300, Automated Fingerprint Identification System. The Smart Matcher Controller Boards were installed on March 5, 1986. This increased the system's operational match rate speed from 350 matches per second to 2,000 matches per second and enabled us to read 120 ten-print cards per hour.

The system was purchased through a one time special funding from Congress, consisting of $1.8 million. All operational services for maintenance purposes are provided by an on-site Field Service Engineer Representative from the DeLaRue Printrak Company only, because of proprietary reasons.

The storage capacity of the system, which is composed of five disk drives, can adequately store 450,000 ten-print cards and 50,000 latent impressions. Monthly averages of 10-print cards range from 4,800 to 5,000. Latent prints encoded fall in the category of 440-450 per month, with an identification hit rate of 37-40 individual cases.

The Read/Edit and R-40 Latent terminals are located adjacent to one another to incorporate a greater degree of quality control of encoding latent and inked impressions. We currently use 6 operators to encode 10-print cards in the Read/Edit Terminal and 15 operators to enter latent prints in the R-40 Latent Terminal. All operators are qualified experts in the field of latent fingerprint identification.

The reason for implementing the procedure was to produce a significant degree of accuracy of all fingerprint data entered into the system on a very select basis, ultimately producing a high return of positive identification on both 10-print cards and latent print cases.

The District of Columbia, Maryland and Virginia inaugurated the first Networking Configuration ever utilized by the DeLaRue Printrak Company. Since this networking was established, we have assisted neighboring jurisdictions and outside agencies in closing over 80 separate latent print cases. We are exceptionally pleased with the 300 System manufactured by DeLaRue. In view of its past and present performances on a 24-hour basis, with very little downtime, we are very pleased to say that the Printrak System has overwhelmingly surpassed our expectations. We are extremely confident that we will continue to obtain higher goals using the system in the future.

SELECTING AND IMPLEMENTING A REGIONAL AUTOMATED FINGERPRINT IDENTIFICATION SYSTEM

A. J. Bush

Pierce County Sheriff's Department
Tacoma, Washington

In 1985, the Pierce County (Washington) Sheriff's Department and the Tacoma Police Department agreed to jointly acquire an Automated Fingerprint Identification System (AFIS) that would combine their respective fingerprint files, together consisting of approximately 300,000 ten-print cards and some 40,000 unsolved latent prints. The goal of the two agencies was to purchase a system that would handle both the latent and 10-print processing requirements in a cost effective, space efficient, user friendly manner, incorporating the most advanced available technology for fingerprint matching and image processing. Among the most important criteria were:

1. Accuracy of latent print and inked print matching.
2. Throughput capabilities.
3. Minimal required user intervention.
4. Gray-level image storage and retrieval.
5. The usefulness of quality control features.

After issuing a formal Request For Proposal, the agencies evaluated the proposals of three leading vendors, carefully analyzing their ability to satisfy these criteria. Each vendor was required to supply accuracy rates for both latent and 10-print matching which they would be willing to guarantee for various data base sizes and then demonstrate in an intensive benchmark test. This process resulted in the selection of the XL-AFISTM produced by North American Morpho Systems, Inc. (Tacoma, WA), as the apparent successful bidder. The confidence that the committee felt in their selection was borne out when the benchmark results significantly exceeded the accuracy rates (68% for latent prints; 98% for 10-prints) projected by Morpho for our data base. Additional selection criteria included:

1. High system throughput capacity with relatively low space and manpower requirements.
2. Software based design, allowing inexpensive, rapid upgrading to improved technologies.
3. Core-and-axis-independent minutiae matching.
4. Integrated workstations with desirable ergonomic features.
5. Large number of sophisticated image enhancement tools for marginal quality latent prints.
6. Capability of manually editing poor quality rolled prints resulting in improved data base quality with no rejections.
7. Sophisticated system architecture, in which maximum latent print search time is limited to approximately 17 minutes and averages just 5 or 6.

Conversion of 10-print cards from both agencies is progressing smoothly and is scheduled to be completed soon. In the interim, latent print searches are being conducted against a 130,000 card felony data base obtained from the Federal Bureau of Investigation and converted for use by the Morpho system. Operator experience over a period of time has confirmed the selection committee's evaluation in terms of user friendliness, ease of input and the value of the enhancement tools. We are confident that future acceptance testing will demonstrate the continued achievement of accuracy rates in accordance with those guaranteed. Pioneers in any computer application assume certain risks. We were very pleased recently to learn of a marketing and maintenance agreement completed between North American Morpho Systems and the International Business Machines (IBM) Corporation. In our opinion, this marriage mitigates many of the pioneering risks we assumed. Future Morpho systems will utilize IBM hardware and be able to take advantage of an excellent maintenance program.

AUTOMATED FINGERPRINT STORAGE, RETRIEVAL AND SHARING IN CALIFORNIA

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California Department of Justice
Sacramento, California

After 20 years of studying and testing the feasibility of computerizing the fingerprint identification process, the California Department of Justice has implemented a system that builds digital image data bases from fingerprint cards, that searches 10-print cards and latent prints against the data bases and that provides remote terminal searching over telephone lines.

After almost 2 years of the 4 year system implementation, the latent print component has recorded a 10% "hit" rate. Full implementation should raise the percentage to 15%. For fingerprint card searching, the automated system now processes 80% of all incoming cards. Complete workload processing is anticipated by 1990.

The State's over 500 police agencies have widely differing service needs. Therefore, the new system communication network was planned to provide a variety of equipment options. Even early equipment options are changing as more experience is gained. The Department of Justice is now exploring the use of live-scan equipment, facsimile-type devices and point-of-booking computer terminals.

Some fingerprint experts are raising a question concerning identification confidence when comparing digitized images created from lifted latent prints that are transmitted over digital communication lines and searched against digital image data bases. I contend that the very high accuracy of these digital image systems will be convincing. Fingerprint experts will soon confidently testify in court that, ". . . there is no doubt in my mind that these digital images are the same and created by the same person."

AUTOMATED SEARCHING OF 150,000,000 FINGERPRINTS AT THE FEDERAL BUREAU OF INVESTIGATION

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Federal Bureau of Investigation
Washington, D.C.

The Federal Bureau of Investigation (FBI) has digitized minutiae data on over 150,000,000 fingers of approximately 19,000,000 subjects with criminal records. The FBI has over 8 years of automated fingerprint searching experience on 10-print searches in this very large file. Approximately 14,000 ten-print searches per day are performed. To have a useful latent print automated search capability until a full capability latent search system can be obtained, the FBI has developed a capability to perform latent print searches of the file of the 10-print system.

The salient characteristic of the latent print search capability is its access to minutiae on over 150,000,000 fingers. The National Crime Information Center (NCIC) fingerprint classification and geographic area are normally used to limit the scope of a search. The number of latent print searches that can be performed per day is limited because the file is structured for 10-print searching and mainframe resources are available only during the evening and early morning hours.

Sustained effort on automated fingerprint identification system (AFIS) development by the FBI began in 1967. Shortly thereafter, minutiae extraction and matching was selected as the most promising approach. The AFIS technology available commercially today descended from the work by the FBI.

The first productive AFIS identification at the FBI occurred on March 26, 1979. Since then, over 600,000 identifications have resulted from FBI AFIS searches. The emphasis of automation at the FBI's Identification Division has been on processing the 30,000 fingerprint cards received per day. Table 1 summarizes the 20-year history of AFIS in the FBI.

A small experimental automated search system for latent fingerprint searches provided useful design information in 1984 and 1985. Since 1984, minutiae based latent fingerprint searches have also been performed in the massive files of the 10-print search system that now has minutiae on over 150,000,000 fingers of criminals. These are subjects of local and state arrests, as well as Federal. Minutiae are stored for eight fingers per subject for 10-print searching. Therefore, minutiae on eight fingers are already available for latent print searching also. The number of latent print searches that can be performed per day is limited because the file is structured for 10-print searching and mainframe computer resources are available only during the evening and early morning hours. This severely limits latent print search capacity and is being used as an interim measure pending availability of resources to develop a high capacity, efficient latent print search system.

The NCIC fingerprint class is used extensively in both 10-print and latent print searches. This limits the number of file accesses and the number of matches to be performed. Latent print searches are normally limited to geographic areas around the crime scene or to people with some suspected relationships to that location.

Starting in 1983, a feasibility study on automated fingerprint image retrieval was performed by the FBI. This extensive study, in which personnel from the California Department of Justice and Royal Canadian Mounted Police participated, concluded that the FBI's stringent quality requirements for fingerprint identification and verification could be met in an operationally and economically feasible system.

The extensive studies and operational AFIS experience of the FBI support the tremendous value of this technology to law enforcement. As rapidly as resources become available, a fingerprint image storage and retrieval system and a high capacity automated latent fingerprint searching system will be added to the current FBI capabilities. The capacity of the interim latent print search capability will be somewhat expanded within the next year.

Table 1. 20 YEARS OF AFIS AT THE FBI

10 Billion	automated finger matches
230 Million	fingers with minutiae read
150 Million	fingers with minutiae on file
19 Million	subjects with minutiae on file
13 Million	fingerprint card searches
600 Thousand	AFIS identifications

THE PROMISE FULFILLED: MAKING A LOCAL AUTOMATED FINGERPRINT IDENTIFICATION SYSTEM WORK

K. R. Moses

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San Francisco, California

Automated fingerprint identification systems (AFISs) are very costly, but proposals for their purchase by local agencies have largely been justified by their predicted negative impact on crime. Often quoted studies by Petersilia *et al.* (1975), Peterson *et al.* (1984) and Wilson and Woodard (1987) have shown that valuable latent print evidence is present but unexploited in nearly half of all crime scenes. More often than not, however, fingerprint systems once installed are vastly underutilized and fail to cause even a ripple in local crime statistics. My hypothesis is that such agencies pour resources into searching latent prints while continuing antiquated policies of investigating crime scenes to obtain those latent prints. Experts and specialists staff the computers, but amateurs and generalists process an overselective sample of scenes.

METHODS

In 1983 and 1984, the San Francisco Police Department established a total AFIS concept designed to take full advantage of its highly accurate NEC system. Features of this program design were:

1. The crime scene, the computer and all related functions were to be treated as a single "system" under one command.
2. A cadre of 15 officers were to serve as Crime Scene Investigators (CSIs) and latent print examiners. These CSI officers were to be responsible for processing scenes and entering any usable latent prints into AFIS.
3. All crime scenes in San Francisco with a potential for latent prints were to be processed only by CSI.
4. High budgetary priority was given to expanding, training, equipping and improving the working environment of the Crime Scene Unit.

PERFORMANCE MEASURES

Almost universally, burglaries account for greater than 90% of latent fingerprint cases. Because it is not unusual for a single burglar to commit 100 offenses per year, the identification and conviction of large numbers of burglars should have a clear and demonstrable impact on the local crime rate. More than any other crime, burglary rates present the fairest assessment of an AFIS/Crime Scene System.

RESULTS

After an initial startup and training period, the burglary rate began to drop in San Francisco and has continued to decline every month for the past 3 years that the program has been in effect. This decline is illustrated in Figure 1.

In the 1986-87 reporting year, CSI processed 7,000 of the actual 8,500 burglaries reported and lifted usable latent prints in 2,500 cases. Over 2,000 of these prints were searched in AFIS, resulting in 540 hits on 441 cases. More than 250 burglars were arrested and convicted, many on multiple counts. The average sentence was in excess of 3 years in the state prison. San Francisco's burglary rate has declined 25% as a direct result of this unified Crime Scene/AFIS approach.

CONCLUSION

The AFIS can reduce your local crime rate if the majority of all your actual burglaries are processed and searched by professional crime scene personnel.

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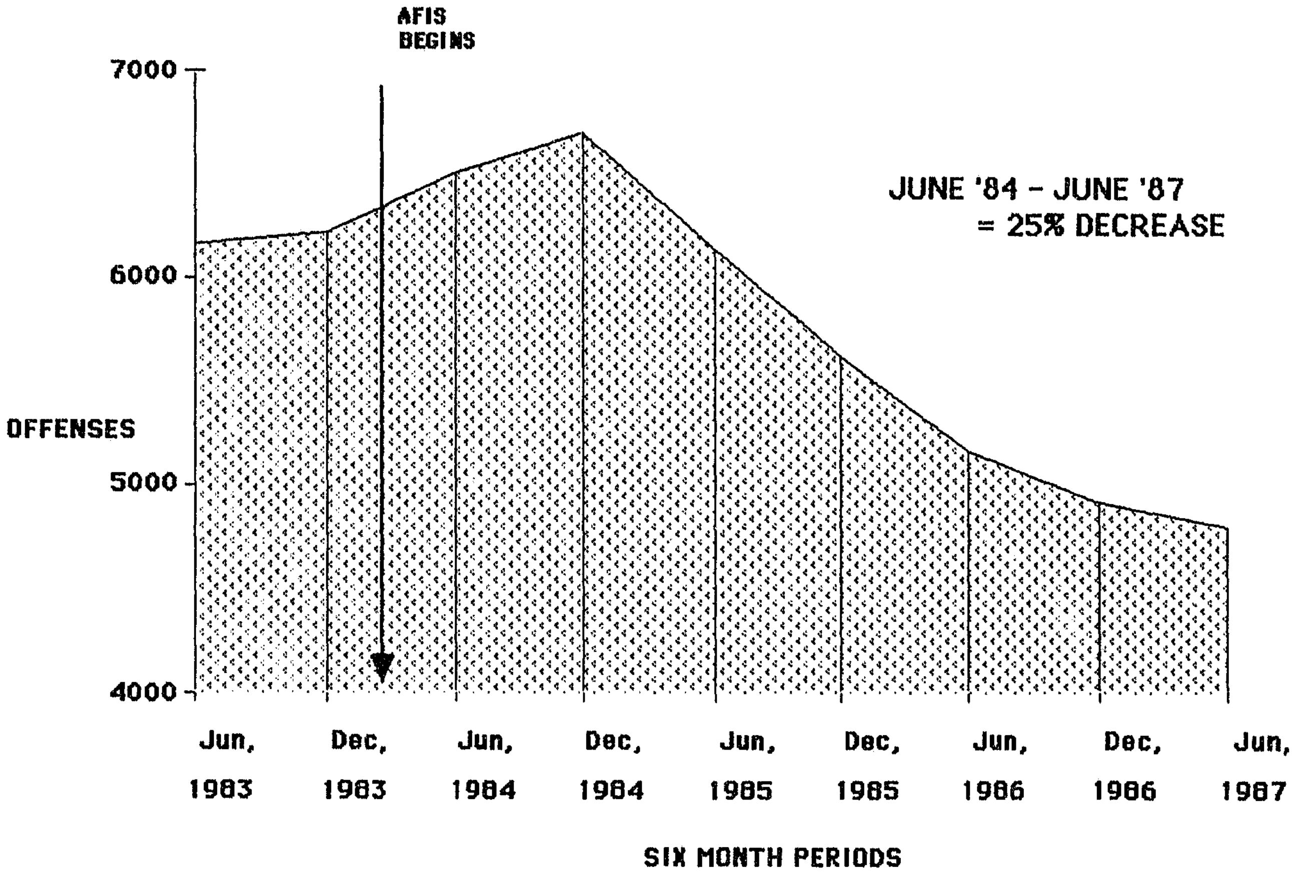

Figure 1. AFIS and burglary in San Francisco.

THE CURRENT STATUS OF AND PROBLEMS IN OUR AUTOMATED FINGERPRINT IDENTIFICATION SYSTEM

Y. Tatuzawa

National Police Agency
Tokyo, Japan

The Automated Fingerprint Identification System (AFIS) operates in the National Police Agency (NPA) of Japan, which acquired the system in October 1982 to improve its crime detecting capability. At present, AFIS is being used in the following fields:

1. Fingerprint registration, the process by which all the fingerprint cards stored by the NPA are read into a data base that we call the Fingerprint Master File.

2. Rolled fingerprint matching, the process by which fingerprints taken from arrestees by prefectural police forces are collated with those in the Fingerprint Master File to establish the particulars of the owner of the fingerprints and his criminal history.

3. Latent fingerprint matching, the process by which fingerprints detected at a crime scene are collated with the Fingerprint Master File to identify the offender.

4. Fingerprint matching for the exposure of hitherto covered crimes, the process by which the fingerprints of a first-time offender are collated with fingerprints originating in crime scenes and with those for offenses remaining to be solved to determine if the offender has perpetrated other crimes before his first arrest.

AFIS FEATURES

The components of the AFIS are shown in Figure 1. The AFIS has the following features:

1. Fingerprint registration by police officials. The machine reads fingerprint minutiae, but they may not be directly placed in the Fingerprint Master File without retouching. Staff intervene here and check the fingerprint details for any defects, which are corrected by using monitor units before registration. Visual inspection improves the quality of the data to be fed into the system. High quality input is a prerequisite that ensures a matching process with fewer flaws and more accuracy, so inspection by staff before registration is a necessary procedure. A poor quality fingerprint resulting, for example, from an inadequate impression will be replaced with a better version taken from the owner in a future offense.

2. Reading a tracing of a photograph enlarged fivefold. The machine cannot directly read fingerprints recovered from crime scenes because most of these prints are unclear. For example, they may be found on a printed page or they may be soiled. A preparatory process therefore is needed in which a tracing is prepared from a photograph five times as large as the original, natural fingerprint. It is only after this preregistration treatment that the reader is allowed to scan a fingerprint.

3. General inquiries and urgent inquiries. Inquiries about fingerprints are classified into two categories: general inquiries and urgent inquiries. General inquiries are processed on a first-in-first-out basis. An urgent inquiry enjoys a higher precedence and is allowed to break into the routine flow of general inquiries.

4. Division of Fingerprint Master File. There are two types of Fingerprint Master Files containing fingerprints for use in latent fingerprint matching: File B_1 relates to offenders whose latest records exist in the last 15 years, and File B_2 covers those who committed their last offenses before the 15 year period. Such a

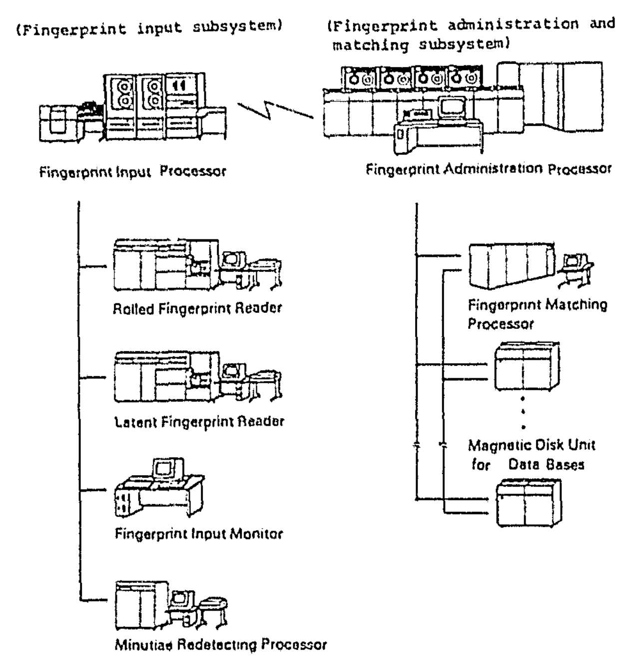

Figure 1. Components of AFIS.

division is justified by statistics revealing that there is a very low rate of recidivism after the passage of 15 years. To save time for the matching task, reference is first made to File B_1 and, only when necessary as in a case involving a serious crime, is reference made to File B_2.

SYSTEM EVALUATION

AFIS has met with the following successes since being installed:

1. In the latent fingerprint matching service, the number of suspects identified is now eight times larger than it was under the old system. The success is attributable to AFIS requiring a shorter period of time to complete matching and its ability to process a larger number of cards. The latent fingerprint matching service with the help of the AFIS began on October 15, 1983. In 1986, about 13,700 inquiries were received and about 1,500 offenders were identified. In 1982, before the adoption of the new system, about 3,500 were received and 200 were identified. This means that the number of inquiries the AFIS handles is about four times larger than that of the old system and, as the for the number of identified owners, there is an eightfold increase.

2. The new system can process a fingerprint with its middle portion blurred, which was not done with the old system. Under the new system, minutiae throughout the whole fingerprint, 191 at the maximum per finger, are filed, enabling us to answer an inquiry containing an incomplete fingerprint.

3. The other-crime reference service is successful. The fingerprints of first time offenders are collated with fingerprints in storage related to unsolved crimes. The persons who have committed other offenses, which may have been perpetrated before the one leading to his arrest, are found. This was not done under the old system because it took too much time, but it is now automatically accomplished upon the registration of the first time offender's fingerprints. Thanks to this automatic referencing, about 300 offenses unknown to the police surfaced in 1986.

4. The processing time has shortened in the fingerprint matching service. Under the new system, it takes about a day before an answer is made after receiving an inquiry a process that used to take an average of 3.5 days.

PROBLEMS

There is some fluctuation in AFIS's ability to detect fingerprint minutiae. The system contains a conversion stage in which an analogous image picked up by a sensor is subjected to conversion into numerical codes. Some errors happen in the process of conversion. A functional test of the reader has revealed a difference of 7% between the original fingerprint image and the image read into the system. This means that, out of 100 details, 93 are picked up correctly but the remaining 7 may not be read correctly. Such lack of consistency results in a defective memory and in low accuracy in the matching process.

A listing of near-hits bearing strong similarities with the specimen print is output after collation. The probability is 88.3% for the best candidate in the near-hit list to be the wanted one. It is 97.6% for the right one to be present in the top 10 near-hits. To improve the probability of success in locating what is wanted, more near-hits will have to be output for comparison. Yielding more near-hits, however, will demand more people and time. So, we narrow down the coverage of matching, depending on the seriousness of the crime involved. Today, we obtain an average of 20 near-hits in cases of larceny or fraud. We attain a high success rate of 98.9%.

The final matching of near-hits retrieved from AFIS storage with a specimen fingerprint collected from a scene is accomplished by police officials. They pick out the card carrying the fingerprint judged by AFIS to be the most promising one, and they visually compare the print on the card with the specimen fingerprint forwarded by the collector police organization. Thus, future increases in the number of inquiries will have to be met by an increased number of visual inspectors.

FUTURE TASKS

The primary task is to increase the number of inquiries for collation and to install additional fingerprint matching units. With AFIS successfully performing, we now accept a greater number of crime scene fingerprint inquiries form prefectural police forces. In 1986, we answered about 13,700 inquiries, three times more than we predicted in the days of AFIS's adoption. Furthermore, latent fingerprints are being collected across the country on 100,000 occasions every year. Conscious that we must ready ourselves for the great number of future crime scene fingerprints, we are planning to furnish ourselves with more fingerprint matching units.

We are also seeking higher efficiency in processing near-hits and would like to acquire an optical disk system. Today we manually process near-hits yielded after fingerprint collection by AFIS. It is therefore necessary for us to make some preparations for a computer-aided fingerprint processing system incorporating optical disks, in which fingerprint cards will be stored in optical disks that can be automatically retrieved for display on a screen. We believe this equipment will satisfy our future needs.

To confirm the identify of a fingerprint on screen, our staff will require a fingerprint image on an optical disk to meet several criteria. That is, it must have a resolution factor of 20 lines/mm, toned in 16 grades. Our storage need would become very large if all the fingerprints currently in memory at the NPA are transferred into state-of-art optical disks. An optical disk must be greatly improved to have a far larger capacity before optical disks are introduced into our Agency.

We would also like to establish a speedy latent fingerprint marching service and adopt a nationwide online system. At present, a fingerprint detected by a prefectural police force at a crime site is forwarded to the NPA generally by mail and by telephotography in case of urgency. The NPA prepares tracings of the fingerprints it receives and puts the tracings into the system. In the future, for a faster matching service, we need to provide the prefectural police with the ability to feed crime-scene fingerprints directly into the fingerprint matching system. The prefectural headquarters then will have to be connected directly with the Fingerprint Master File and furnished with facilities capable of reading, transmitting and receiving fingerprint information. We will need a nationwide on-line system whereby local police headquarters will be able to gain access directly to the Fingerprint Master File for fingerprint registration and acquisition of the outcome of the matching of the registered fingerprints.

SECTION III

PANEL DISCUSSIONS

PANEL DISCUSSION
PERFORMANCE AND EFFECTIVENESS OF VARIOUS AUTOMATED FINGERPRINT IDENTIFICATION SYSTEMS

MODERATOR: *Thomas Muller*, Baltimore Police Department

PANEL MEMBERS: *Tom Burse, III*, Metropolitan Police Department
Arnold Bush, Pierce County Sheriff
Walter Johanningsmeier, FBI Identification Division
Bruce King, Royal Canadian Mounted Police
Kenneth Moses, San Francisco Police Department

The purpose of this panel was to discuss automated fingerprint identification systems (AFISs). Shopping for an AFIS is similar to shopping for a new car. System reliability is a very important feature to consider when choosing an AFIS. Another important determination is whether a local, regional, state or federal system will best meet the law enforcement agency's particular needs. The number one priority with a local system is solving crime. On state and federal levels, there is greater concern about personnel costs and reducing the costs of 10-print searches because of the massive workload. A fringe benefit of an AFIS is the latent print feature. A major consideration for a law enforcement agency is to find out exactly what the department needs and demand that the vendor meet those needs.

The Pierce County Sheriff's Office in Tacoma, Washington, uses an AFIS manufactured by North American Morpho Systems, Inc. (Tacoma, WA). With a Morpho system, as the data base increases, the search time decreases because the system uses a distributed data base concept. Other AFISs use one matcher to search the entire data base, whereas Morpho breaks that data base down and assigns a certain number of cards to each matcher which is never exceeded in that grouping.

The FBI is developing a high capacity 10-print search system because that is where the bulk of their work has been. The FBI has five high speed card readers and is operating the system with one prototype matcher. The FBI performs 14,000 ten-print searches per day. The latent print search capability is piggybacked on the 10-print capability. The resources are not available to develop a full-blown latent print search capability, so approximately three latent print cases are searched per day. A system for 10-print searching is being built to support the latent print system in the same way that the latent print system was piggybacked in the past and to integrate previous systems, which include automated name search, arrest record processing and support of the Interstate Identification Index. The new system is a conversion from a batch process to an on-line process. Five fingerprint readers are being upgraded, and the prototype matcher is being replaced with a high speed matcher. The FBI intends to add fingerprint image, storage and retrieval and an automated latent print search capability in the future.

The Metropolitan Police Department, Washington, DC, has found that clustering minutiae around the delta and core areas is beneficial for searching with their AFIS. The Metropolitan Police Department uses a minimum of eight points for storage in the data base. For the San Francisco Police Department AFIS, which is manufactured by NEC, seven points widely distributed are more valuable for searching than seven points clustered at a delta.

Based on the experience of jurisdictions in Baltimore, Washington, DC, San Francisco, and Pierce County, Washington, the cost of AFISs for local jurisdictions averages approximately 1.8 million dollars. The burglary rate in San Francisco has dropped 25% during the 3 years that the AFIS has been in use. When the San Francisco AFIS went online, three additional assistant district attorneys were hired to prosecute AFIS cases and three more public defenders were hired to defend AFIS cases. The maintenance contract for Washington, DC, is approximately $72,000 per year for their AFIS, and field service engineers are on-site at all times. The Royal Canadian Mounted Police (RCMP) handle their own maintenance for their AFIS. The RCMP has successfully run tests over telephone lines using the latent print terminal and has used the Photophone device for searching.

Any latent print can be searched without descriptors, but it takes more time to perform the search. The use of any known descriptors will decrease search time, and for very poor quality prints, descriptors may be able to bring a hit, which would otherwise be buried, up to a number one position.

An important function of latent print operations is to identify deceased persons, so cards should not be purged out of the AFIS based on a person's age until the data base capacity is needed. The needs for a data base concerning automated latent print systems (ALPSs) differs greatly from the data base needs for a 10-print system. The Cal-ID system uses age 40 as the cut-off for inclusion in the AFIS because experience at the California Department of Justice (DOJ) indicates that 98.2% of individuals identified in crime situations were 39 or younger. The DOJ uses a region concept that accesses approximately one-third of the data base as a descriptor and results in a 5%-6% loss in accuracy. The DOJ knowingly gives away a small amount of accuracy in order to increase overall productivity of the AFIS.

Latent print specialists at the Metropolitan Police Department, Washington, DC, handle both manual and automated aspects of fingerprint identifications. The San Francisco Police Department assigns one qualified latent print examiner to go to the crime scene, enter data into the AFIS and eventually testify in court. They find an employee has more motivation if he is able to follow a case from start to finish. The RCMP does not have crime scene examiners that work out of the Ottawa area; crime scene examiners are located throughout Canada. The latent print technicians for the RCMP do not testify in court. The RCMP in Ottawa has a 10-print area, an AFIS area and a latent print area. The Baltimore Police Department has records personnel working with the 10-print process and latent print examiners in the laboratory working with the computer.

PANEL DISCUSSION
VIABILITY OF LATENT PRINT DETECTION METHODS

MODERATOR: *Robert Hazen*, FBI Identification Division

PANEL MEMBERS: *Colleen Mac Aas*, Oregon State Police
Ed German, U. S. Army Crime Laboratory
Terry Kent, Scientific Research and Development
Robert Olson, Kansas Bureau of Identification
Charles Pounds, Central Research Establishment

The purpose of this panel was to discuss the viability of latent print detection methods. The FBI dealt with 18,487 cases and examined 337,530 different latent fingerprint samples during fiscal year 1986 and developed 2,841 latent prints. Most prints were developed with the ninhydrin process. The FBI also developed latent prints using silver nitrate, laser technology or laser technology via zinc chloride. At FBI Headquarters, the emphasis is on developing as many latent prints as possible from each case.

The Kansas Bureau of Identification followed FBI principles until recently, when it began using many techniques of the British Home Office Manual for developing latent prints. The Kansas Bureau of Identification prefers using ninhydrin and the physical developer and limits the techniques used for latent print development, depending on the type of case involved.

The Army Crime Laboratory splits evidence for consideration into porous and nonporous surfaces. Approximately one out of five cases have latent prints photographed by laser. The Army Crime Laboratory finds the best chemical procedure to use on porous surfaces is ninhydrin and the best techniques to use on nonporous surfaces are cyanoacrylate ester fuming and powder development.

The Oregon State Police have recently obtained a laser for detecting latent prints, and they are eager to learn how to use it effectively. Most of the work performed by the Oregon State Police is done with powders or ninhydrin.

The Central Research Establishment (CRE) in the United Kingdom is a research organization. Operation work for latent print development is done at the scenes of serious crimes. In 1985 in the United Kingdom, 857,000 scenes of crime were examined and 254,000 fingerprints were found at those scenes. The CRE is researching reagents for use at scenes of crime, including a new dye specific for detecting blood fingerprints on porous surfaces. The new technique called tetra-amino-biphenol uses an insoluble dye that turns blood prints dark brown. The technique uses a solution of sulfur salicylic acid in water. The CRE also is investigating the transference of blood prints from difficult surfaces and is trying to increase the speed of the reaction for ninhydrin analogs. They also are attempting to make color type compounds to obtain the maximum contrast between the print and the background. Aluminum powder is used approximately 90% of the time in the United Kingdom for developing latent prints.

The Scientific Research and Development division in Sandridge (United Kingdom) finds Basic Yellow 40 dye very effective for detecting latent prints and recommends it as a substitute for Rhodamine 6G. Basic Yellow 40 dye is believed to be nontoxic, and it is readily available and can be used in either ethanol or water.

More than half the police forces in the United Kingdom use a physical developer for routine work. A physical developer detects fingerprints on paper that has been soaked in water, and it will detect fingerprints from approximately 90% to 95% of the population. Fingerprints can not be detected satisfactorily with ninhydrin for approximately 20%-30% of the population.

Two safety concerns for those working with the latent print process are possible exposure to polynuclear aromatic hydrocarbons (PNA) and the Acquired Immune Deficiency Syndrome (AIDS) virus. Polynuclear aromatic hydrocarbons found in fingerprint powders are a potential health hazard and have been removed from the powders by several manufacturers. The FBI recommends all latent print specialists wear a face mask, gloves and laboratory coat and work under a ventilating hood when processing prints using fingerprint powders.

The AIDS virus can live in a dried bloodstain for up to 15 days at room temperature. Thus, the FBI has established guidelines for case examination. If evidence of a case is known to have been contaminated by someone carrying the AIDS virus, the law enforcement agency must notify the FBI to obtain permission before the evidence can be submitted to the FBI for examination. The FBI must receive a letter from both the prosecuting attorney and defense attorney authorizing the FBI to conduct the examination under certain guidelines. All evidence related to that case is to be autoclaved. Any body parts that are to be submitted to the FBI must be tested for the AIDS virus. If the body parts are too badly decomposed to conduct the AIDS test, the parts must be placed in a 70% alcohol solution and submitted to the FBI.

In 47 years, the FBI Disaster Squad has responded to 150 disasters. The utmost caution must be taken by anyone identifying victims of a disaster. The FBI recommends moisture-repellant painters' coveralls, goggles, face mask, hat, paper shoe coverings and surgical gloves be worn at all times by anyone examining physical evidence at or from a disaster scene.

The FBI laboratory has done research that indicates that bombarding specimens with gamma rays will kill the AIDS virus without killing the proteins and accelerants which allow development of latent prints. As soon as this procedure is available, it will be announced via the Law Enforcement Bulletin and/or the Identification News. The FBI and the British Home Office in the Forensic Science Service are recommending all staff be vaccinated against hepatitis B.

There has been no development of protocol regarding the cleanup of residue left at crime scenes where the laser and chemicals such as Rhodamine 6G are used in occupied dwellings. In most situations, not enough of a known carcinogen is used to cause a potential health problem. If the FBI uses methanol and Rhodamine 6G to process a motor vehicle for fingerprints, the vehicle is purchased from the owner.

Examiners are beginning to be challenged in court if the crime evidence has not been processed with all available methods for detecting latent prints. In most cases, time and economic constraints limit the number of methods used for detecting latent prints.

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