THE STATE OF DEVELOPMENT OF THE FBI'S AUTOMATIC FINGERPRINT IDENTIFICATION SYSTEM

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INTRODUCTION – THE CHALLENGE

We have long taken for granted the ability of a fingerprint technician to classify fingerprints by their general ridge contours and identify them by their distinctive ridge detail. This feat is made all the more remarkable by the fact that in doing this he must make allowances for inconsistencies in the inked fingerprint impressions caused by such things as over- and under-inking, smudging, differences of positioning, mutilation by cuts and scars, and distortion caused by the pressures used in recording the prints.

The question arises: *"Can a machine duplicate these remarkable faculties of the human eye and brain?"* Over the past several years the FBI has pursued a program of research and development in an effort to find the answer to this question. The purpose of this paper is to report the progress we have made to date in resolving the question.

The FBI's decision to undertake a program of research and development was prompted by the ever-increasing demands being placed upon the FBI's Identification Division for fingerprint processing services. Since its establishment in 1924 as the nation's clearinghouse for fingerprint records, the volume of fingerprint card submissions has grown until now the Division receives between 20,000 to 30,000 fingerprint inquiries each day which must be searched against a file of arrest fingerprint cards representing approximately 20 million persons. This enormous task is presently accomplished manually by a staff of fingerprint technicians and clerks numbering over 3,000.

In order to meet its growing responsibilities and at the same time increase operating efficiency, thereby saving the Government money, the FBI in 1965 decided to embark on a program of research and development to find a way to automate its operations. Early, and wisely, the FBI sought and received the technical collaboration of the National Bureau of Standards. Since that time the National Bureau of Standards has not only participated in planning and monitoring the research program, but has made major technological contributions to the project as well.

STEPS TAKEN TO MEET THE CHALLENGE

The first task undertaken under the program was to examine the problem of automatic fingerprint identification and survey the available technology to establish a logical plan of attack. It was determined that this difficult and complex problem could be broken down into four more manageable components: (1) *reading*, the entry of fingerprint data into a computer; (2) *registration*, the normalization of the fingerprint data to a standard reference position; (3) *classification*, the assignment of the fingerprint data to a class or category for filing and retrieval purposes, and (4) *matching*, the comparison of the distinctive minute characteristics of one fingerprint with those of previously computerized fingerprints for the purpose of identification. Further, it was determined that in view of the technology then available, the two most critical areas to be addressed were reading and matching.

Therefore, in June, 1967, contracts were awarded to Cornell Aeronautical Laboratory, Inc., Buffalo, New York, and North American Aviation, Inc. (now North American Rockwell Corporation), Anaheim, California, to demonstrate the feasibility of automatically reading and recording the identifying characteristics of fingerprints appearing on inked fingerprint cards. The National Bureau of Standards had earlier begun work on devising computer logic and programs that would take the data generated by an automatic fingerprint reader and match it with previously computerized fingerprint data.

By 1969 both Cornell Aeronautical Laboratory and North American had demonstrated the capability of reading fingerprint cards of good quality through the use of optical flying-spot scanner and computer equipment. In 1970, Cornell Aeronautical Laboratory performed additional work to demonstrate that such equipment could read fingerprints of poorer quality, e.g., those with smudged or broken ridge structure. By 1970, the National Bureau of Standards had developed and successfully demonstrated computerized procedures for matching fingerprint data read by the Cornell Aeronautical Laboratory and North American experimental model equipment,[1] and had already launched into experiments to devise automatic procedures to register and classify fingerprints.

Based upon these successes, in September, 1970, the FBI contracted with Cornell Aeronautical Laboratory to design and construct prototype automatic fingerprint reader equipment incorporating the theories and procedures developed during the research program.[2] The prototype equipment was completed in August, 1972, and is presently undergoing extensive testing and evaluation at the FBI Identification Division in Washington, D.C.

THE FINDER SYSTEM

The prototype automatic fingerprint reader is called "FINDER," a contraction of *fin*gerprint rea*der*. Figure 1 is a photograph of the actual equipment, while Figure 2 is a drawing of the system with each major unit labeled. A functional block diagram of the equipment is shown in Figure 3.

In Figure 2, an operator is shown sitting at the *card-moving mechanism* loading standard fingerprint cards into card-holding trays. The operator places the trays onto a motor-driven belt which transports them to the scanner reading station. Figure 4 illustrates further details of the card-moving and scanner mechanisms. Each rolled fingerprint is scanned as the card-moving mechanism positions it under the scanner reading head. Once the card is completely scanned, the card tray is returned to the operator for unloading of the scanned card and reloading of a new card.

The *scanner* is a precision flying-spot scanner. This unit utilizes a moving ("flying") small spot of light (approximately .001 inch in diameter) which makes consecutive horizontal sweeps across the fingerprint working its way, line by line, from the top to the bottom of the print. As this tiny beam of light sweeps across the fingerprint, it encounters white (uninked), black (inked), and gray (partially inked) areas. The light beam is reflected when it passes over white areas, it is not reflected by black areas, and it is partially reflected by gray areas. Detectors that are sensitive to light record the variations of reflection encountered and pass this information on to the preprocessor.

The *preprocessor* contains special high-speed computer logic which takes the data generated by the scanner and produces an enhanced representation of the fingerprint. It does this by applying continuity logic to locate fingerprint ridges and then reinforcing their structure by eliminating small breaks resulting from improper inking, pore holes, and other imperfections in the inked fingerprint impression which was scanned; by separating ridges that are blurred; and by eliminating blank and smudged areas. Figure 5A shows a fingerprint as it appears on an inked fingerprint card, and Figure 5B shows the same fingerprint as it appeared on the operator display scope after being enhanced by the preprocessor.

The preprocessor uses the enhanced fingerprint representation to derive two types of information: (1) *ridge direction data,* which are later used for registration and classification purposes; and (2) *minutiae data,* which are subsequently used for matching purposes. The preprocessor collects ridge direction data by sampling the average direction of ridge flow at selected intervals across the print. Figure 6 shows the enhanced fingerprint representation with ridge direction data superimposed, as seen on the operator display scope.

The preprocessor also uses special detection logic to collect information regarding the distinctive minute details of the fingerprint, which are called "minutiae." Information on two types of minutiae is collected by the preprocessor—ridge endings and bifurcations (forks) in the ridges. The locations of these minutiae in an X-Y coordinate system and the angles (θ) they make in relation to the X axis are determined and recorded. This coordinate system is illustrated in Figure 7 using a ridge ending; however, since if one examines the negative of a photograph of a fingerprint, a bifurcation appears as a ridge ending, the same coordinate system can be and is used for bifurcations. Figure 8 shows a graphic plot of minutiae detected by the FINDER system. Figure 9 shows an enhanced fingerprint as seen on the operator display scope of the system with each recorded minutia indicated by a small white circle. Note that smudged areas at the top and bottom of the print have been edited out to avoid false minutiae detections in those areas. The preprocessor passes the detected ridge direction and minutiae information data (X, Y, and θ measurements) on to the computer. The preprocessor accomplishes all its

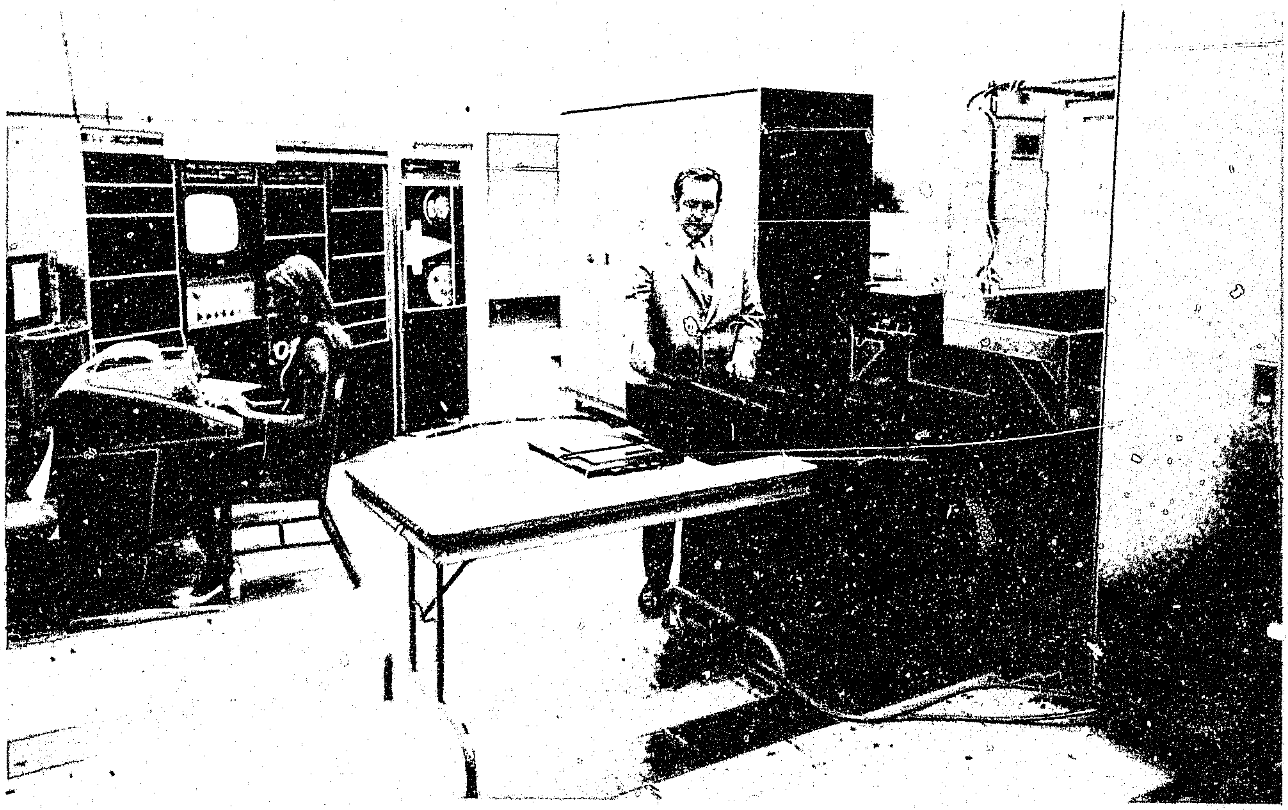


Figure 1 PHOTOGRAPH OF FINDER SYSTEM

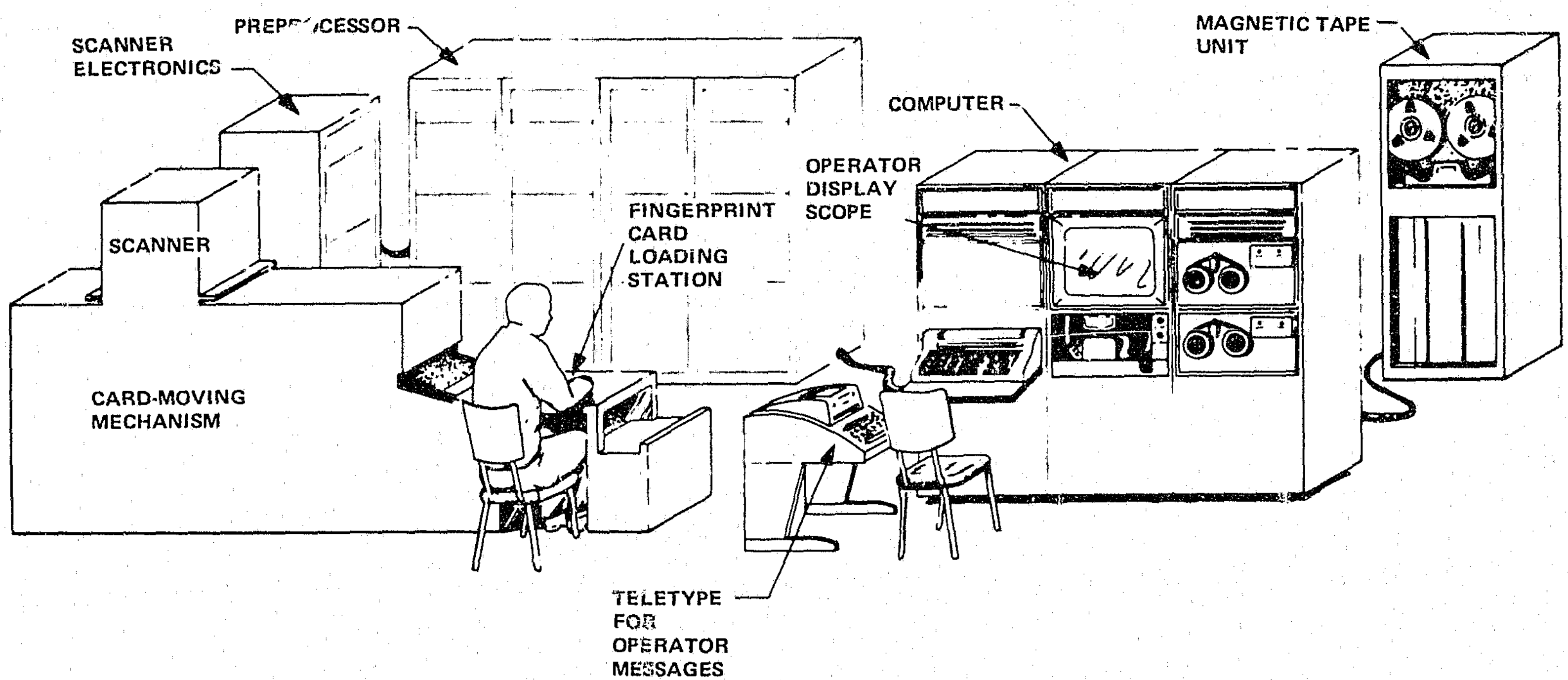


Figure 2 DRAWING OF FINDER SYSTEM

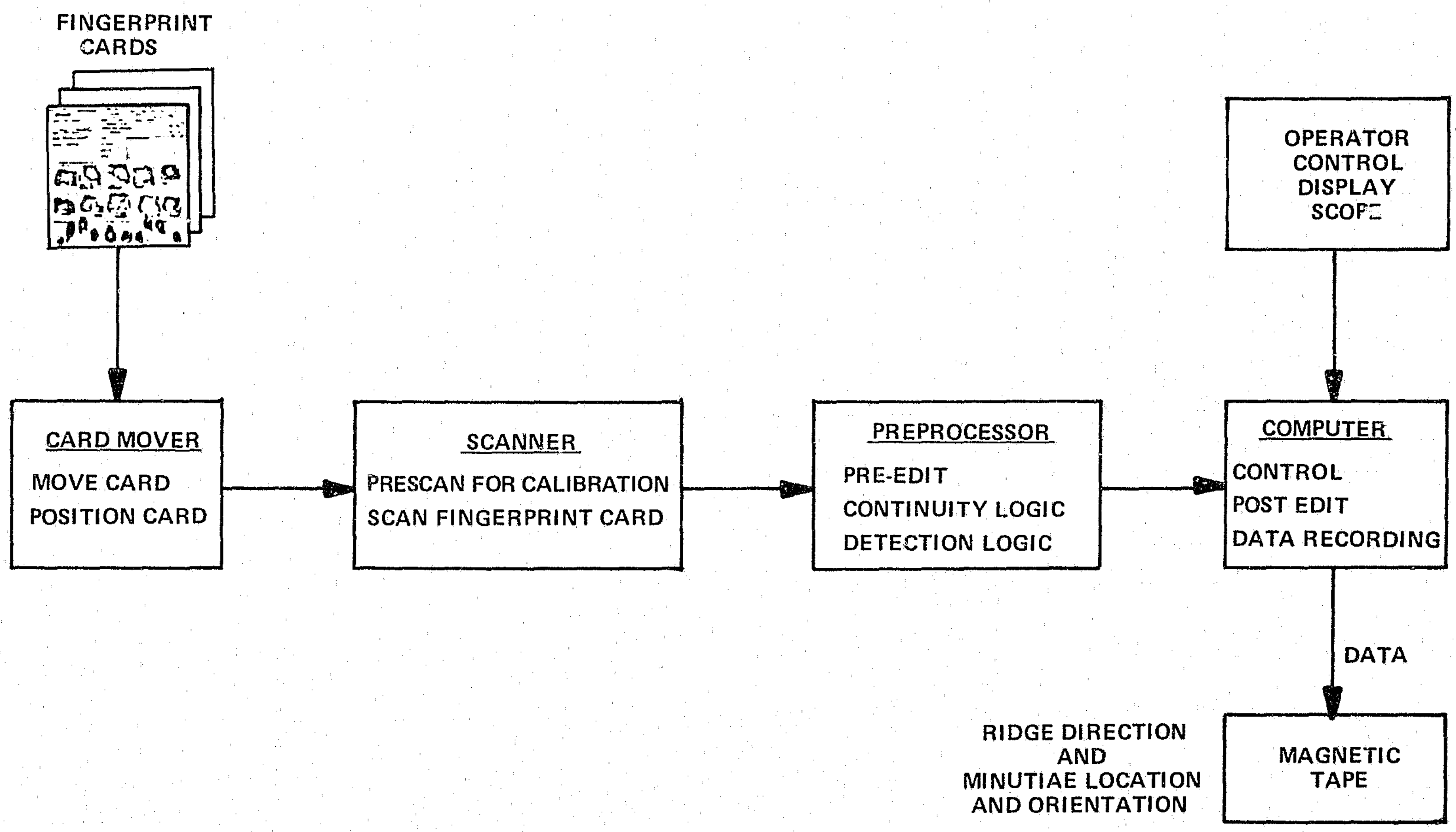


Figure 3 FUNCTIONAL BLOCK DIAGRAM OF FINDER SYSTEM

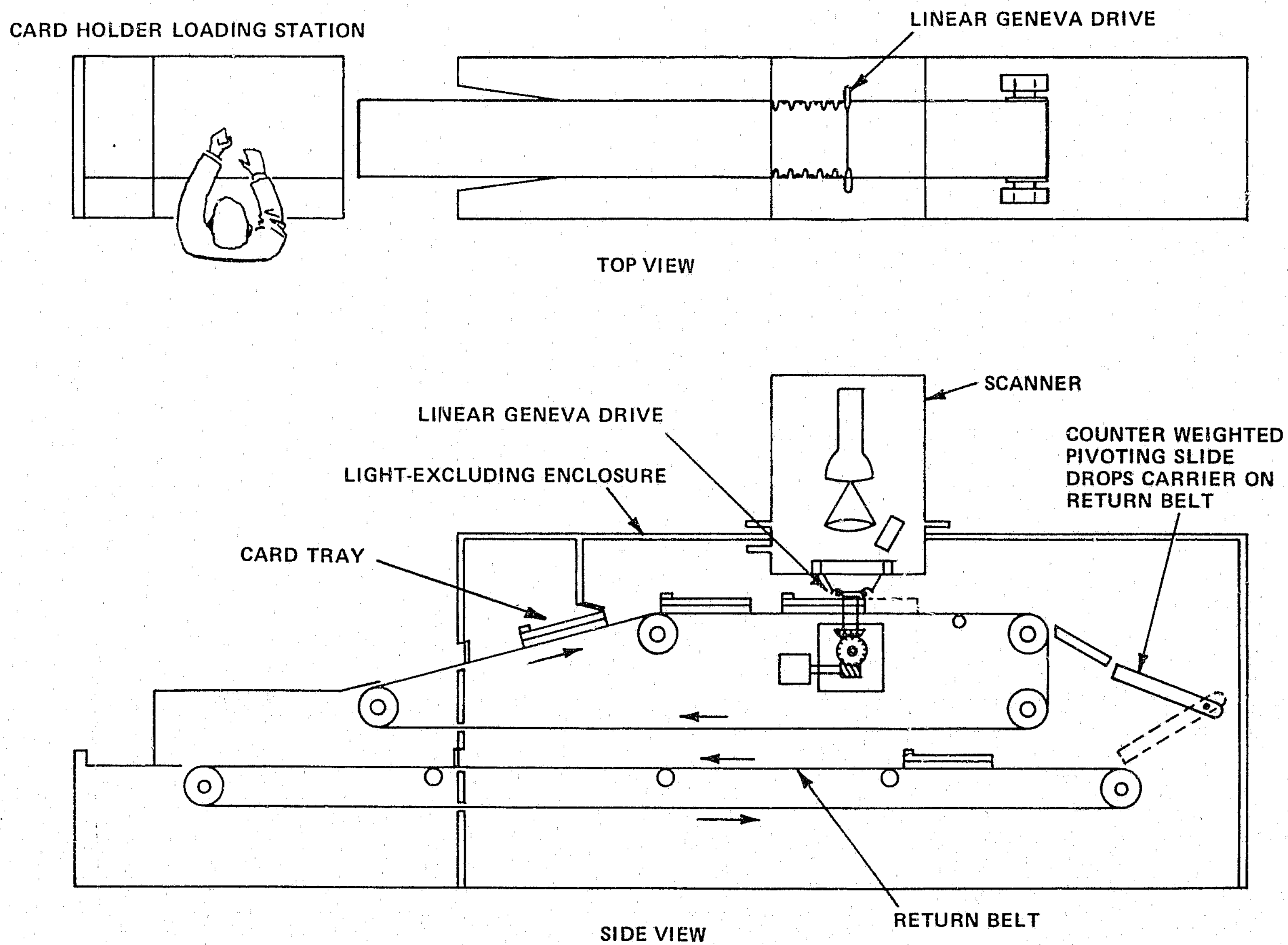
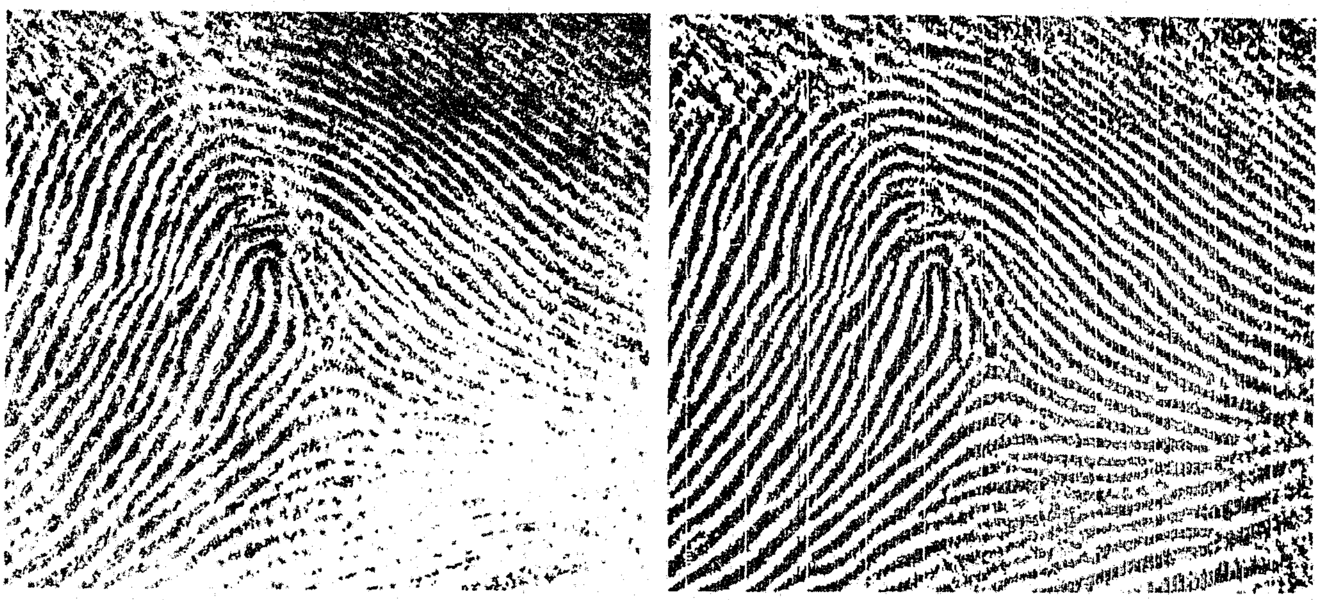


Figure 4 FINDER SYSTEM CARD MOVER AND SCANNER



A. INKED FINGERPRINT

B. ENHANCED FINGERPRINT

Figure 5 COMPARISON OF INKED PRINT AND ENHANCED PRINT SHOWING ENHANCEMENT OF RIDGE STRUCTURE BY PREPROCESSOR functions in an average one-half second per fingerprint.

The *computer* performs certain post-edit functions on the data it receives and records them onto magnetic tape for subsequent processing. The computer also performs the task of controlling the system's processes from the time a card is loaded into the card-moving mechanism until the fingerprint data read from the cards are finally recorded onto a magnetic tape.

COMPUTERIZED FINGERPRINT REGISTRATION, CLASSIFICATION, AND MATCHING

The magnetic tape containing the data collected and recorded by the FINDER system is next taken to a general purpose computer where the tape is processed by programs that register, classify, and match the data. The logic and procedures used in these programs were developed by the National Bureau of Standards.

The first processing task performed is that of *registering*[3] the fingerprint data to a standard reference position. This step is required before any meaningful classification or matching can be accomplished. This is because the manual procedures used in recording inked fingerprints result in variances in the location and angle orientation of the prints in the fingerprint blocks on the cards. The registration program uses the ridge direction data output of the FINDER system to compute a center point for each print and the angle through which the print must be rotated. These registration values are then used to translate and rotate both the ridge direction and minutiae data to a standard position.

The next step in the processing is *classification*. In this process the computerized fingerprints are assigned to preestablished classes or categories by which they can be addressed for filing and retrieval purposes. The use of a classification system precludes the necessity of searching the entire file each time a search is conducted, since through its use only that part of the file with the same classification needs to be searched.

The classification system presently under development uses the ridge direction data output of the FINDER system. Since the ridge direction data describes the contour of the ridge flow of a fingerprint, the data can be compared with a selection of basic fingerprint patterns to determine the pattern type of a questioned fingerprint. This procedure has been successfully used to identify fingerprints as whorls, arches, and ulnar and radial loops. From such a procedure it is apparent that the manual Henry classification system could be duplicated in several aspects. However, the wealth of information available in the ridge direction data holds promise of a great range of classification systems, ranging from a ten-finger scheme like the Henry system to entirely new systems using less than ten fingers.

After the registration and classification processes are performed, the ridge direction data are no longer needed. Therefore, they are discarded and only the classification codes and the minutiae data are retained for filing and matching purposes.

The final processing step is to *match* (i.e., compare) the retained data with computerized fingerprint data already on file. The classification codes previously derived from the search card ridge direction data are used to retrieve candidate file data with the same class codes. The specific data used for the matching process are the minutiae location (X, Y) and angle (θ) outputs of the FINDER system, as modified by the registration program. The matching program uses a statistical scoring procedure to determine the degree of correlation between the X, Y, and θ measurements for minutiae appearing in a candidate file fingerprint and those of a search fingerprint.

First the X, Y, and θ measurements of all minutiae in a candidate file fingerprint are subtracted from the corresponding measurements of the search fingerprint, giving the differences ΔX, ΔY, $\Delta\theta$. Only those pairs of minutiae which produce differences that satisfy previously set parameters for ΔX, ΔY, $\Delta\theta$ are given further consideration in the matching procedure. Those ΔX, ΔY, $\Delta\theta$ values that qualify are next examined in regard to how they would plot in relation to each other in space. Such values resulting from subtractions of minutiae involving nonmatching file and search fingerprints tend to plot as random points in space, while those from matching fingerprints tend to plot in one area as a cluster of points. The matching program is written to determine the presence of a cluster and to assign a score based on the density of the cluster. The higher the cluster score, the greater the probability of having achieved a match.

The described matching procedure has been used successfully with both manually recorded and machine read minutiae data from both rolled and plain fingerprints. Further, it has been demonstrated to be relatively unaffected by normal distortion of the fingerprints and by the presence of some uncorrelated minutiae caused by false detections or undetected true minutiae.

Figure 6 RIDGE DIRECTION DATA DISPLAYED OVER ENHANCED FINGERPRINT

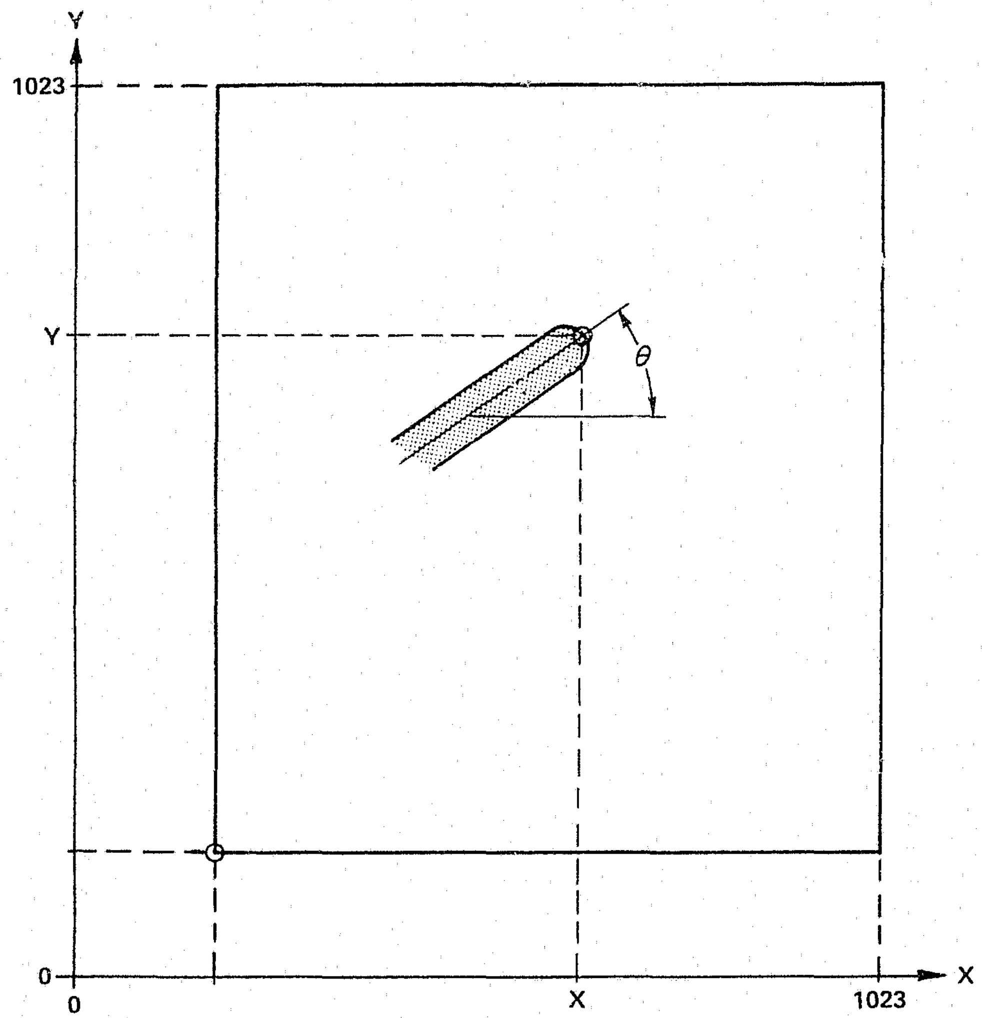


Figure 7 COORDINATE SYSTEM FOR MINUTIAE DETECTION AND LOCATION

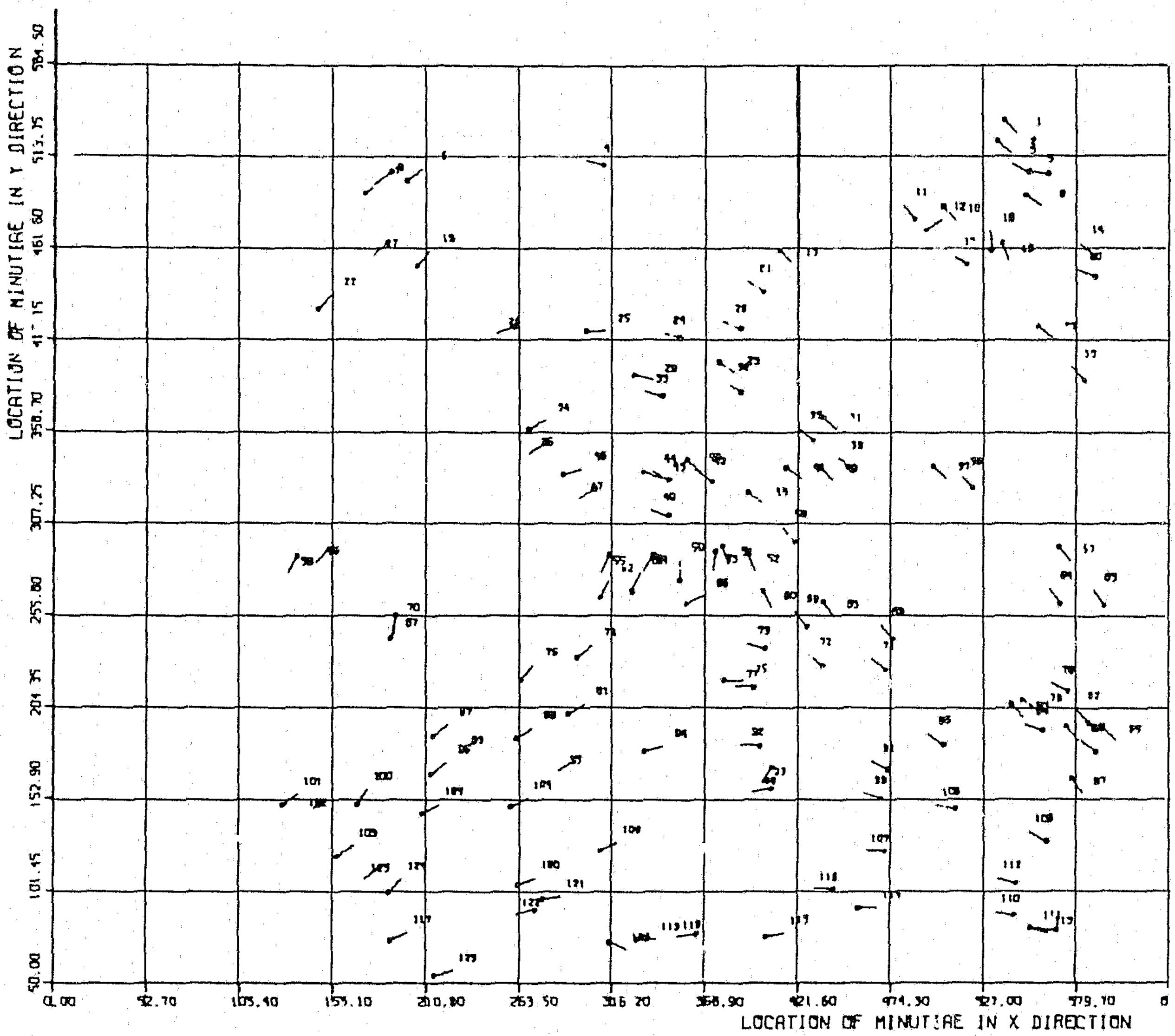


Figure 8 PLOT OF MINUTIAE FROM FINGERPRINT

Figure 9 ENHANCED FINGERPRINT WITH MINUTIAE DETECTIONS CIRCLED SHOWING PRE-EDITED AREAS AT TOP AND BOTTOM

In running the matching program on a general purpose computer (UNIVAC 1108), it has taken on the average a little less than one-tenth of a second to compare a pair of fingerprints. As this processing speed is too slow for searching any appreciable number of fingerprints, plans call for the development of a specially built processor which will perform the comparisons at a much higher speed. Preliminary designs have been drawn up for possible processors which would have the capability to perform fingerprint comparisons at speeds ranging from one comparison in one-thousandth of a second to a device which, if required, would perform a comparison in a few millionths of a second.

THE ENVISIONED FUTURE AUTOMATED FINGERPRINT IDENTIFICATION SYSTEM

The FINDER system has been designed to process ten-finger fingerprint cards. This is because FINDER is intended to be the prototype of eventual production model equipment which will be used to process the large quantity of fingerprint cards received daily at the FBI Identification Division. Figure 10 is a simplified functional block diagram of the future automatic fingerprint card processing system as currently envisioned.

As depicted in Figure 10, all fingerprint cards received will first undergo a computerized name search. This processing step corresponds to the name search procedure practiced in the manual records system presently employed at the Identification Division and is utilized for the same purpose. Experience in the manual system has shown that because of the high percentage of recidivism by criminals, it is cost/effective to perform a search of the names and other descriptive data appearing on incoming fingerprint cards against a name index file compiled from previously received arrest cards. A name search which leads to a positive match avoids the more complex and costly search by fingerprint characteristics. However, in order to insure the accuracy of such matches, each name search match must be verified by having a fingerprint technician visually compare the fingerprints on the search card with those on the matched prior arrest card.

Fingerprint cards that are not matched to prior arrest records by the computerized name search procedure, and those cards matched to records by name searching but failing subsequent visual fingerprint verification, will be sent on to the automatic fingerprint identification system for processing. Other inputs to the system are the general descriptive data (i.e., age, sex, etc.) previously digitized for use in name searching, but which can now be used to limit searches to special subdivisions of the computerized arrest fingerprint file.

The automatic fingerprint identification system will consist of several production model version FINDER fingerprint reader systems, a special purpose high-speed minutiae matching processor, a mass data storage and retrieval system, one or more medium- to large-scale general purpose computers, and related control and interface units. Fingerprint cards that are to be searched will be fed into fully automatic card-handling units of the fingerprint reader systems. Each fingerprint reader will scan all or a preselected number of fingerprints on the cards, extracting both the minutiae and ridge direction data from each fingerprint scanned. These data are passed on to a general purpose computer which utilizes the ridge direction data to register (i.e., normalize) the measured values of both the minutiae and ridge direction data to a standard positional reference system. The general purpose computer next derives classification codes from the registered ridge direction data and the general descriptive data. The resulting classification codes are then communicated to the mass data storage system for retrieval from the fingerprint minutiae file of all sets of minutiae data that fit the same classification codes.

The candidate sets of fingerprint minutiae retrieved from the file and the registered minutiae of the search fingerprint card are next sent to the special purpose high-speed minutiae matching processor, or "matcher." The matcher uses a statistical scoring scheme to measure the degree of correlation between the minutiae values of each fingerprint of the candidate file cards and those of the fingerprints of the search card. If a high degree of correlation is found between the minutiae values of a file fingerprint and a search fingerprint, a high matching score for the two fingerprints will result. These one-against-one matching scores calculated by the matcher are then transmitted to the general purpose computer. The computer selects candidate file cards that received consistently high matching scores on all ten, or other predetermined number of fingerprints, and combines the scores in such a way that the candidate file card that matched the search card with the best overall score will be identified as the match.

The automated fingerprint identification process will terminate with a verification step to insure the accuracy and integrity of the system. Present plans call for this step to be performed by a fingerprint

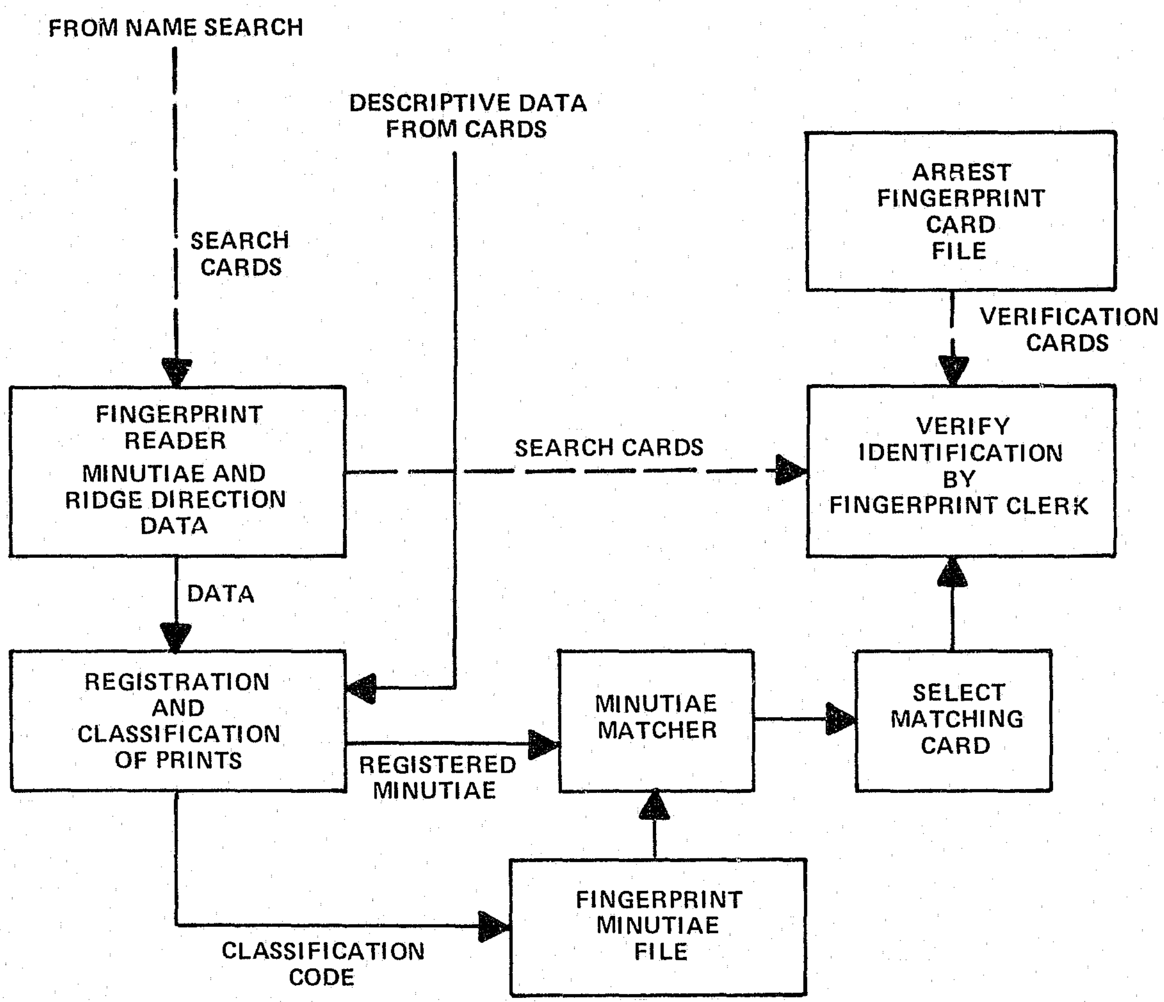


Figure 10 FUNCTIONAL BLOCK DIAGRAM OF THE AUTOMATIC FINGERPRINT IDENTIFICATION SYSTEM

technician who will conduct a visual comparison of the fingerprints appearing on the actual search card with those on the actual file fingerprint card that was identified as a match by the automated system. This is a duplication of the verification procedure presently practiced in the manual system; however, it is possible that at some future time an automated verification procedure will be developed and adopted.

CONCLUSION

It is apparent from the foregoing that much progress has been made toward finding the answer to the question of whether a machine can duplicate the fingerprint processing capability of the human technician. But, however tempting it might be to answer the question now in the affirmative, based upon the successes achieved in experiments to date, we feel compelled to refrain from doing so as it must be recognized that the experiments represent limited samplings and were conducted under laboratory conditions rather than production work conditions. Much additional research work remains to be accomplished before we will acquire the confidence to supply a conclusive answer.

However, with the acquisition of actual automatic fingerprint reading equipment, we have hastened the day when we will be in a position to supply a definite answer to the question. This is because the equipment provides us with the means by which we will be able to test thoroughly, evaluate, and perfect our theories on automatic fingerprint identification. For example, before we acquired the FINDER equipment we were unable to generate a large number of computerized fingerprints for use in experiments without incurring exorbitant processing burdens and costs. It previously took 1¾ hours for an IBM 360/65 computer to perform the functions that are now performed by the preprocessor unit of the FINDER system in one-half second. With the FINDER system we can now generate data bases of computerized fingerprints of whatever size required and this can be done economically.

As previously indicated, construction of the FINDER equipment was completed in August, 1972, and the equipment is presently at the FBI Identification Division in Washington, D.C., where it is undergoing extensive testing and evaluation. These tests include experiments to evaluate how well the FINDER equipment performs its assigned functions as well as experiments designed to evaluate and perfect the computer programs that are used to register, classify, and match the computerized fingerprint data generated by the reader equipment. We are unable to predict at this time how long it will take to complete this evaluation phase; however, it is clear from the complexity of the subject matter that a prolonged time period is involved. Further, our plans and timetable for the implementation of production model fingerprint processing equipment in the FBI Identification Division will depend, of course, upon the successful testing and perfection of the FINDER system.

Although the equipment is presently designed to process ten-finger fingerprint cards with the objective of reducing the amount of time and manpower presently expended in processing fingerprint inquiries at the Identification Division in Washington, D.C., we see even greater potentials for the equipment. One such potential is the possibility of searching latent fingerprints (i.e., fingerprints found at the scene of a crime) against the computerized fingerprint file. Traditionally fingerprint cards have been manually filed using ten-finger classification schemes, such as the Henry system. This has meant that in order to search efficiently the manual card file, information from all ten fingers is required. Consequently, it is not feasible to search a single latent fingerprint against a ten-finger manual card file of any significant size. The only alternative available to date has been to establish special single fingerprint files of necessarily limited size which are more amenable to searching latent fingerprints. But, preliminary studies indicate that, although latent fingerprints are not usually themselves readable by automatic fingerprint reader equipment because of their frequently poor quality and fragmentary nature, they can be coded through the use of manual or semi-automated equipment[4] and then searched against a ten-finger file of computerized fingerprint data produced by the FINDER system. The potential here not only involves a reduction of manpower effort with concomitant cost savings, but also involves a dramatic new capability to identify criminals who have heretofore gone undetected.

Another potential lies in the possible use of automatic fingerprint reader equipment as a means for transmitting fingerprint card data over long distances. There is presently a great deal of activity in the law enforcement community directed at finding ways to increase the speed by which information is communicated within the criminal justice system. Facsimile equipment is presently being employed, or considered, by several agencies as a means of increasing the speed of transmitting fingerprint card data. Until now the main impediment to the wide use of facsimile for such purposes has been the high cost of the communication facilities required to support high-resolution equipment. Since the FBI's automatic fingerprint identification system requires only certain selected data from fingerprints for registration, classification and matching purposes, complete fingerprints need not be transmitted to perform fingerprint identifications, as is the case with facsimile devices. Consequently, less data are required to be transmitted, resulting in shorter transmission times; and, since the data are in digital rather than analog form, they can be transmitted over less expensive, lower grade communication lines. This suggests that it may well be possible some day for distant law enforcement agencies to possess remote fingerprint reader terminals which would extract the needed characteristics from fingerprints and transmit them to the FBI Identification Division over the National Crime Information Center communications network for on-line searches of the FBI computerized fingerprint file.

The realization of these and other potential capabilities would result in immeasurable benefits to all of law enforcement. Our former FBI Director, the late John Edgar Hoover, assessed the value of a fully automated fingerprint identification system in these words, "Eventual success in this project will constitute the most significant advance in law enforcement since the adoption of fingerprints as a means of identification."[5] We believe you will agree.

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END