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A SEMI-AUTOMATED COMPUTER FINGERPRINT ENCODING AND MATCHING SYSTEM

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Introduction

One of the major problems facing society today is the high crime rate. Local, state and federal law enforcement agencies, restricted by limited budgets and manpower resources, have had a difficult time maintaining effective law enforcement. The use of advanced computer technology can aid in coping with the rising crime rate. The task of personal identification in law enforcement is a key function which fortunately can be assisted through the use of computer technology.

Fingerprints have long been recognized as one of the most effective means of personal identification. Since legal restrictions prevent the detainment of criminal suspects for long periods of time, it is vitally important to rapidly establish positive identification. The use of advanced computer technology can reduce the time required for search and retrieval of fingerprints in a large fingerprint file from several hours or several days down to several minutes at a substantial savings in cost and manpower. The use of the manual Henry classification system has impeded the development of automated computer fingerprint identification techniques. For several years, NYSIIS has been looking for a new fingerprint encoding and classification technique which is more compatible with automated computer processes. The goal of the work presented in this paper was to develop and evaluate several concepts and techniques for a semi-automated computerized system for the encoding of fingerprint data and for the search and retrieval of matching duplicate fingerprint cards from a large fingerprint file. The project demonstrated the feasibility of using a new set of fingerprint descriptors which is compatible with and can include the Henry classification.

The primary limitation of the presently used manual fingerprint classification systems, such as the Henry and American Systems, is that large fingerprint files are not sufficiently subdivided to allow for the quick retrieval of duplicate fingerprint cards. Extensive manual verification is required to locate the duplicate fingerprint card within the several thousand fingerprint cards that may be contained within an individual Henry classification subdivision. This project considered the use of several additional fingerprint descriptors to provide an expansion of the present classification systems to further subdivide large fingerprint files. These fingerprint descriptors were chosen on the basis of compatibility with present manual classification techniques and suitability for semi-automatic or automatic reading techniques.

The questions specifically addressed in this project were (1) do such additional fingerprint descriptors adequately characterize individual fingerprints and fingerprint cards; (2) is the process for encoding these additional fingerprint descriptors practical for manual, semi-automatic and automatic fingerprint identification systems and (3) can a sufficiently fast and accurate fingerprint search and matching process be implemented based on the use of these additional fingerprint descriptors. These questions were answered by evaluating the ability of the fingerprint descriptors to accurately match an inquiry card with the proper duplicate card in a fingerprint file. The fingerprint descriptors were evaluated on the basis of matcher performance on the individual descriptors and on various combinations of descriptors. Variations due to specific fingers, groups of fingers, and pattern type on the matcher performance were also considered.

The system implemented in this study characterizes a fingerprint in terms of several identifiable points and measurements on it. This data, from a set of several fingerprints from a card is used as a basis for matching the set with sets of previously encoded fingerprints contained in a fingerprint file. The data required to characterize a fingerprint is obtained semi-automatically. The core, delta(s) and two points on the crease are manually located using a cursor on an image of the fingerprint displayed on a grey scale TV monitor. The ridge count, distance and angle measures between these points are then automatically computed by a small computer. For loop and whorl type fingerprints, the fingerprint descriptors include the ridge count and distance between the core and delta(s), the distance between the core and the crease and the angle(s) formed by the core-delta line and the line through the core which is perpendicular to the crease. Similar measures are used to characterize arch type fingerprint patterns. Additional data for the fingerprint set such as sex, date of birth, and pattern type are entered manually. The sets of these descriptors from several fingerprints are then compared with corresponding descriptors from fingerprints within the file. If the differences between corresponding descriptors are within specified thresholds, the fingerprint sets are considered to match. The evaluation of the ability of the fingerprint to provide a unique characterization of a fingerprint card was based on 78 pairs of duplicate fingerprint cards arranged in groups according to the Henry classification.

The results of this study provide practical information that may be used in the selection of additional fingerprint descriptors in a fingerprint identification search and retrieval system. The results showing the types of descriptors that are generally usable, the effects of differences due to fingerprint ridge pattern types and the data on multiple finger matching systems may be applied to the design and development or selection of most types of fingerprint identification systems.

This project represents an initial study for the determination of the feasibility and the evaluation of fingerprint encoding and matching

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Fingerprint Technical Search Techniques

The process for performing a technical search of a large fingerprint file to find the matching card for an inquiry fingerprint card can be broken down into four main steps. The first step is to encode sufficient information about the fingerprints on the card to provide a basis for comparing the inquiry card with previously encoded cards in a fingerprint file. The second step is to search the fingerprint file and retrieve possible matching fingerprint cards. The third step is to match the inquiry card against each of the possible matching file cards that have been previously been retrieved. This process results in a selection of very few possible duplicate cards. The final stage is to verify the actual matching duplicate card.

In a totally manual fingerprint technical search system, the fingerprint card may be characterized by the determination of the Henry classification. The search and retrieval process is performed by manually pulling all the cards in the particular Henry classification. Each such card is manually matched against the inquiry card. The verification of the matching card is also manually performed. Large identification bureaus using this completely manual approach cannot be expected to adequately process the normal daily identification work loads as the rate of crime increases. One automation step which has been taken is to automate the search and retrieval process based on the use of a manually determined Henry classification. However, the matching and verification steps are still manually performed requiring much manual labor. Additional classification parameters are needed to reduce the number of fingerprint cards that are retrieved and hence reduce the manual labor required in the verification step.

The system evaluated in this research partially automates the fingerprint encoding process and evaluates this process within the framework of a completely automated search and matching operation. This approach is potentially a faster and more accurate means of encoding fingerprint data than current manual techniques. This approach also provides additional classification information not easily obtainable with a manual encoding system. The hardware necessary for the implementation of this semi-automatic approach is less expensive than the hardware required for a completely automated encoding system although it is one to two orders of magnitude slower. However, an interactive semi-automatic system can process poor quality or latent fingerprints more readily than present completely automated fingerprint encoding systems.

In the design and development of a semi-automatic fingerprint identification system, the necessary degree of automation is very dependent on the specific speed and file size requirements of the individual identification bureaus. Simple interactive encoding systems may provide for only the location of specific key points on the fingerprint whereas more sophisticated interactive terminals with image processing capability may find use as general identification encoding and matching systems capable of processing mug shots, signatures and handling other identification problems in addition to fingerprints. The approach evaluated in this research makes use of the manual location of key points on the fingerprint and of automated image processing techniques to provide an automatic determination of the ridge count. The advantages of such an interactive system is that it best utilizes the ability of a human to recognize specific patterns or locations on the fingerprint image while using the computer to accurately compute and record the measurements.

The general system configuration for an inter-

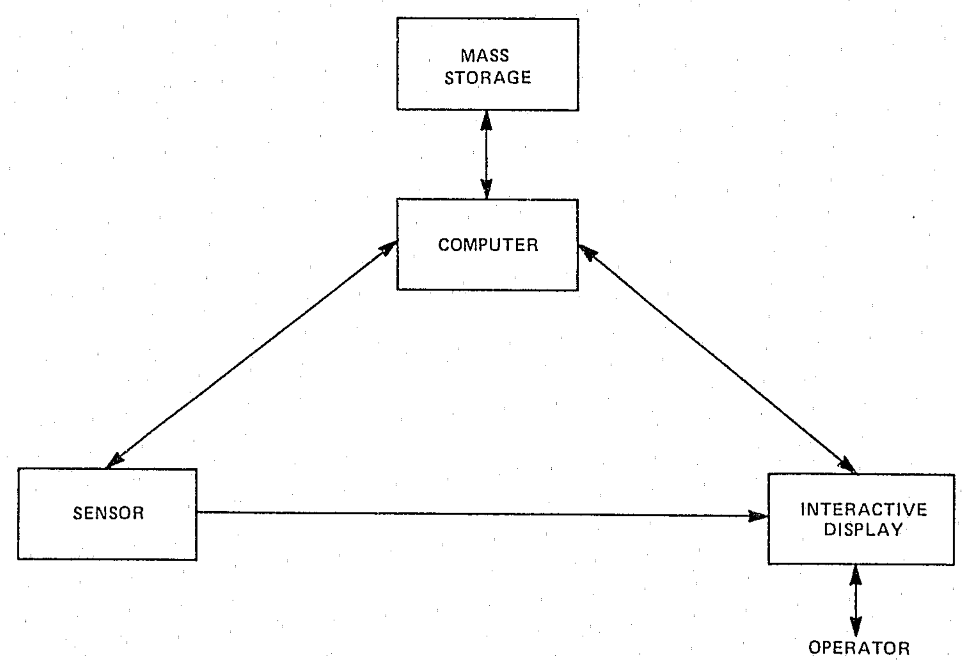


Figure 1 GENERAL CONFIGURATION OF AN INTERACTIVE FINGERPRINT ENCODING AND MATCHING SYSTEM

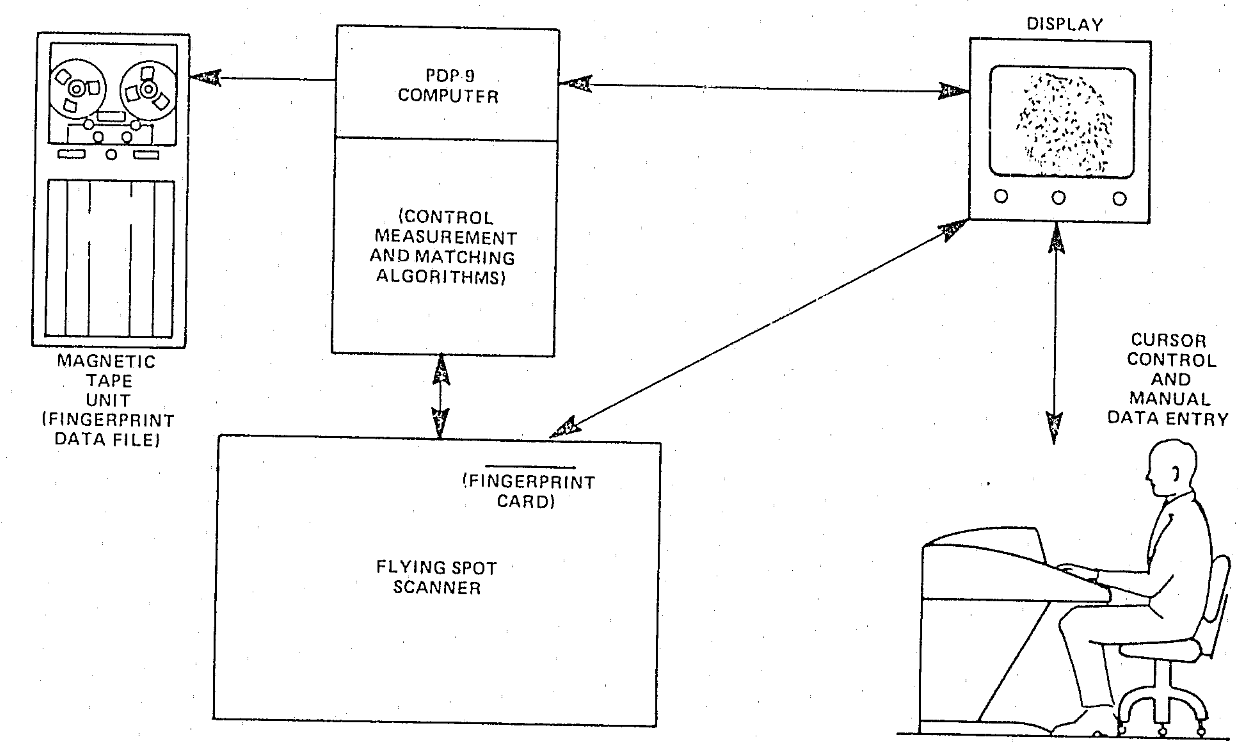


Figure 2 HARDWARE CONFIGURATION OF CALSPAN'S IMAGE PROCESSING LABORATORY FACILITY FOR THE FEASIBILITY DEMONSTRATION OF THE SEMI-AUTOMATIC FINGERPRINT READER

active fingerprint encoding and matching system is shown in Figure 1. The heart of the system is a small computer which performs the functions of control, message display and measurement computation. Additionally it also performs the functions of search, matching and retrieval of duplicate fingerprint cards. The sensor provides a means for reading the fingerprint image in order to display it on an interactive terminal upon which an operator can encode or locate specific points. The result of the encoding computation is the determination of the characterization of the fingerprint card. This characterization is either stored on a mass storage device such as magnetic tape for later processing in a general purpose computer or is used as the basis of a search of a fingerprint file which is resident on an on-line mass storage device such as a disk. Additionally, an operational fingerprint encoding and identification system requires a means of positioning the fingerprint card or fingerprint images sequentially under the sensor, a means of entering additional identification data, and other peripherial devices for system support.

The Experimental System Hardware

Figure 2 shows the hardware configuration for the implementation of the fingerprint identification system which was implemented and evaluated in this study. This system utilized a general purpose flying spot scanner for sensing the fingerprint image. The scanner samples the fingerprint image in a square array consisting of 1024 x 1024 points. Each point or sample of the fingerprint image is encoded into one of 64 possible values representing the grey level of the fingerprint image at that point. This digitized fingerprint image is displayed for the operator

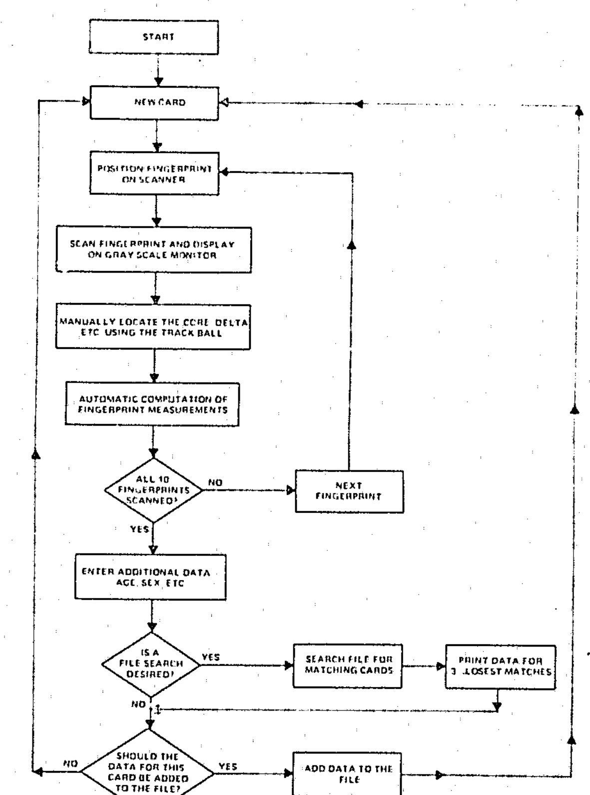


Figure 3 FLOW DIAGRAM OF THE FINGERPRINT DATA ACQUISITION AND MATCHING SYSTEM PROGRAM

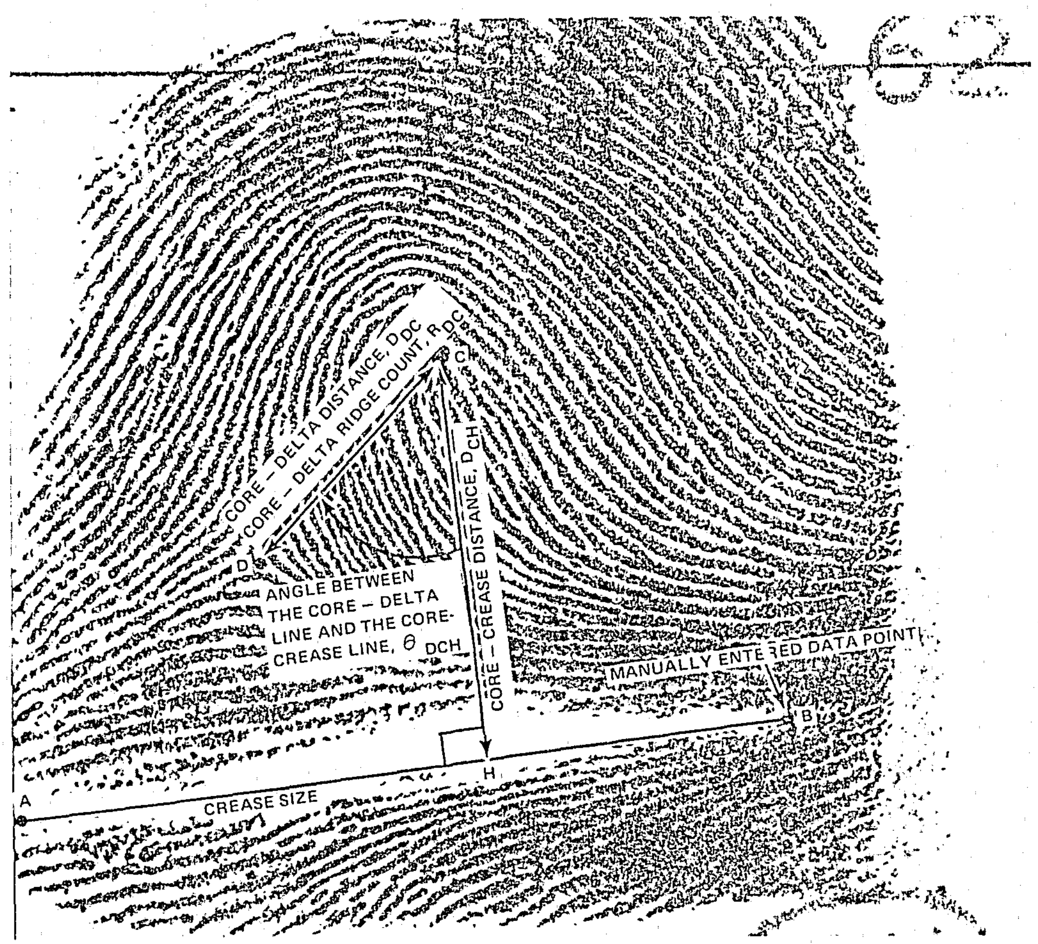


Figure 4 FINGERPRINT MEASUREMENTS FOR LOOP AND WHORL FINGERPRINTS

POINTS A, B, AND C ARE MANUALLY LOCATED. THE MEASUREMENTS INCLUDE THE CORE-DELTA RIDGE COUNT R_{DC}, THE CORE-DELTA DISTANCE D_{DC}, THE CORE TO CREASE DISTANCE D_{CH}, AND THE ANGLE BETWEEN THE CORE-DELTA LINE AND THE CORE CREASE LINE θ_{DCH}. WHORL FINGERPRINTS HAVE THE CORE-DELTA RIDGE COUNT, THE CORE-DELTA DISTANCE, AND THE CORE-DELTA, CORE CREASE ANGLE COMPUTED FOR BOTH DELTAS.

on a high resolution TV image storage display system. Superimposed on this image of the fingerprint is a cursor dot whose position is controlled by the operator by means of a track ball device. Messages are displayed for the operator on a storage oscilloscope and the data is entered through a teletype terminal. A Digital Equipment Corporation PDP-9 computer with 16,384 words of core storage controls all of the operational functions and performs the measurement tasks. The fingerprint data file is stored on 9 track magnetic tape with all automatic search and retrieval operations being performed by reference to this magnetic tape file.

Computation of the Fingerprint Descriptors

Figure 3 shows the flow of the encoding and matching process. The four basic descriptors computed for loop type fingerprints are shown in Figure 4. The distance and angle descriptors are computed from the manually entered locations of the key points. The ridge count between the core and the delta is computed by using image processing techniques. Fingerprints exhibiting two deltas, that is whorl and double loop type fingerprints, have the core-delta distance, the core-delta ridge count and the angle measurement computed for both deltas on the fingerprint. There are thus four descriptors characterizing loop type fingerprints and seven descriptors characterizing whorl type fingerprints.

The process for automatically counting the ridges is shown in Figures 5 and 6. Once the location of the core and deltas is manually determined, the fingerprint image is rescanned in a band between these two points. The actual scanning process involves moving a window containing a "ridge valley filter" process along a line between the core and delta. This process is used to enhance the ridge structure on the line between the core and delta. The enhancement converts the grey scale image to a binary image based on the fingerprint ridge information within the square window. This enhancement process was originally developed for use in a completely automated fingerprint minutiae reader built for the FBI[3]. The result of this enhancement operation is shown in Figure 6. This figure shows the original grey level of the fingerprint image and

the resultant binary produced by the ridge valley filter enhancement process. As implemented in this study, the process for counting the ridges is merely the process of counting the number of binary ridges produced by the ridge valley filter operation. Initial results on the accuracy of this process indicates that the occurrence of creases or scars across the line between the core and delta are not adequately considered. A more optimum implementation would include the information that the ridge width is approximately constant over the area between the core and the delta. However, the accuracy of the ridge counting algorithm was adequate for the purposes of this study.

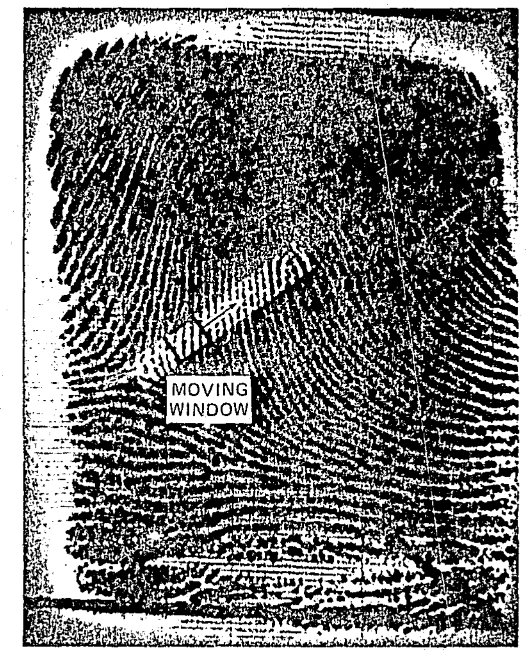


Figure 5 DISPLAY OF A LOOP TYPE FINGERPRINT SHOWING THE AREA OF THE FINGERPRINT USED IN THE DETERMINATION OF THE CORE-DELTA RIDGE COUNT

Since arch type fingerprints do not have a core or a delta, the four basic descriptors which are computed for loop type fingerprints cannot be made on arch type fingerprint patterns. To provide some information on arch patterns to provide for their use in a fingerprint identification system, several similar descriptors were considered. Figure 7 shows these descriptors. The operator initially enters the location of the point of maximum curvature of the ridge flow and two points on the crease. The three descriptors for arch fingerprints are the distance between the point of maximum curvature and the crease, the ridge count along this line and the angle formed between the ridge direction patterns on each side of this point of maximum curvature.

The arch type fingerprint shown in Figure 7 has a well defined point of maximum curvature. However, many arch type fingerprints exhibit patterns for which this point cannot be accurately selected manually. Hence, only limited accuracy in the computation of these arch descriptors would be expected.

The Fingerprint Matching Process

Since the purpose of this study was to evaluate the fingerprint descriptors, a fingerprint matching process was needed which would provide for the direct comparison of derived similarity scores when the scores were based on single fingerprints, groups of fingerprints, single measurements, etc. The similarity measure chosen for this function is the normalized average difference between corresponding descriptors from corresponding fingerprints. That is, the difference in the corresponding descriptors is computed and this difference value is normalized by dividing it by the average of these two descriptors values and then scaling the result by an appropriate factor. This similarity score is proportional to the percentage variation in corresponding descriptors from the mean value of those descriptors. Thus, even though the magnitude of the descriptors values varies considerably for the different types of descriptors, the value of the similarity scores for different types of descriptors are approximately in the same range for fingerprints that are matching and similarly for fingerprints that are not matching. Matching duplicate fingerprints would be expected to give very low similarity scores indicating the very high degree of similarity and non-matching fingerprints would be expected to give a high similarity score.

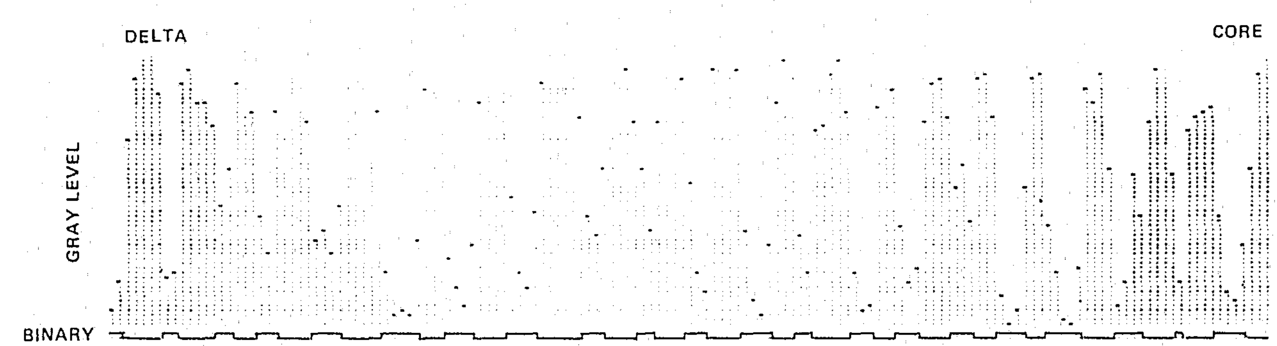


Figure 6 GRAY LEVEL AND BINARY PRODUCED BY THE RIDGE VALLEY FILTER ALONG A LINE FROM THE CORE TO THE DELTA ON THE FINGERPRINT SHOWN IN FIGURE 5

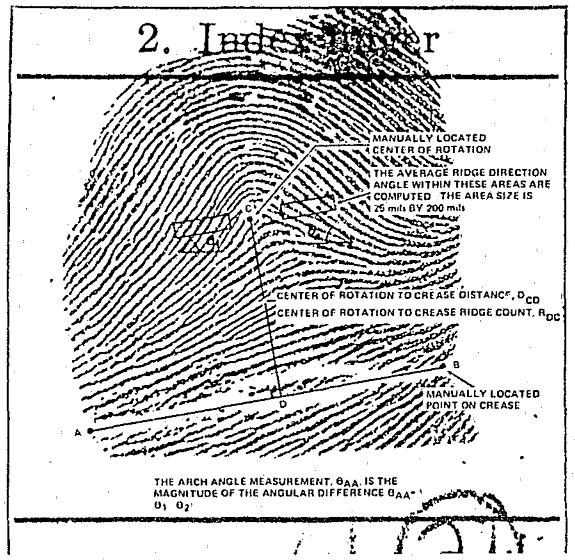


Figure 7 MEASUREMENTS FOR ARCH TYPE FINGERPRINT. THE POINTS A, B, AND C ARE MANUALLY LOCATED. THE MEASUREMENTS INCLUDE THE RIDGE COUNT BETWEEN THE CENTER OF ROTATION AND THE CREASE R_{DC} THE DISTANCE BETWEEN THE CENTER OF ROTATION AND THE CREASE D_{DC}, AND THE ANGLE FORMED BY THE RIDGE PATTERN IN THE VICINITY OF THE CENTER OF ROTATION C_{AA}.

The score of similarity is computed for each descriptor from each fingerprint in the sets being compared. A similarity score for individual fingers is computed by averaging the individual descriptor similarity scores. The similarity score for several fingerprints or all ten fingerprints is derived by averaging the similarity scores from the individual fingers that are being considered.

The similarity score for the angle type descriptors cannot be determined in the same way as for the other descriptors since the percentage variation of angles has a different meaning because of the sinusodial variation. Thus, the similarity score for angles is computed as the simple magnitude of the difference of corresponding angles scaled by an appropriate factor so that it is in approximately the same range for matching or for non-matching fingerprints as the similarity scores from the other descriptors. Therefore, in this study, when several different descriptors are used as a group to determine the average similarity score, each descriptor is equally weighted.

Figure 8 indicates the general flow of these search and matching process. This flow diagram assumes that at the beginning of the search process the inquiry card has already been encoded. Initially, the encoded data from a file fingerprint card is read from magnetic tape and a comparison of the fingerprint pattern classification between the inquiry and search cards are made. This classification test serves the same function in this study as the primary Henry classification would in a large system, that is, to reduce the amount of searching required for matching purposes. Next the similarity scores between corresponding descriptors of corresponding fingerprints are computed. When all ten fingerprints have been considered then the average similarity scores for the single individual fingers and for various groups of fingers, including all ten fingers, are computed and the scores are printed out. The process is repeated until all fingerprint cards in the fingerprint file on the file tape have been read and compared to the inquiry card. Finally, the identification of the three most likely matching fingerprint cards, that is, the three fingerprint cards in the file with the lowest similarity scores are printed out and the process is terminated.

The data that is printed out as a result of the search and retrieval operation is the similarity scores for each individual finger, the similarity scores for the combination of the two index fingers, the combination of the two index fingers and the two thumbs, the two index fingers, thumbs and middle fingers, for all eight fingers excluding the little fingers and for all ten fingers. For each run of the search and retrieval process the derivation of the similarity scores may be based on the use of an individual type of fingerprint descriptor or group of the different fingerprint descriptors, or an individual type of fingerprint pattern type or group of pattern types.

In evaluating the fingerprint descriptors in this study, the available data base was divided into three groups. The first group was composed of 28 pairs of duplicate fingerprint cards for which the pattern types were all loops on all ten fingers. The second group was composed of 20 pairs of duplicate fingerprint cards for which all fingerprints exhibited arch type patterns. The third group was a set of 20 pairs of duplicate cards of mixed pattern type with approximately 40 percent of the fingerprints being whorls, 35 percent being loops and 25 percent of the fingerprints being arches. Since these various subgroups of the data base represent different primary Henry formula classifications, they were considered separately. Thus the search and retrieval process using the fingerprint descriptors was evaluated on the basis of being able to select the proper matching card within a single Henry

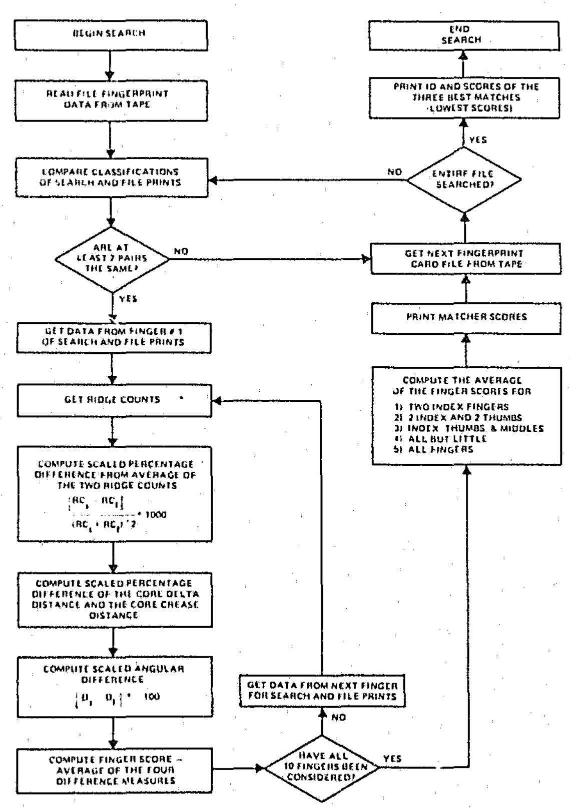


Figure 8 THE FINGERPRINT SEARCH AND MATCHING PROCESS

Table I

CONSISTENCY AND ACCURACY OF MANUALLY AND AUTOMATICALLY DETERMINED RIDGE COUNTS

	PERCENT DUPLICATE FINGERPRINTS WITH RIDGE COUNTS				
	SAME	DIFFERENT BY 1	DIFFERENT BY 2	DIFFERENT BY 3	DIFFERENT BY MORE THAN 3
MANUALLY COUNTED RIDGES ON DUPLICATE FINGERPRINTS (WRITTEN ON CARD)	67%	28.9% (95%)	3.3%	1.1%	0%
AUTOMATICALLY COUNTED RIDGES ON DUPLICATE FINGERPRINTS	19.4%	28.4% (47.8%) (71%)	23.2%	12.9%	17.6%
AUTOMATICALLY COUNTED RIDGES COMPARED TO MANUALLY COUNTED RIDGES ON THE SAME FINGERPRINT	26.0%	32.2% (58.2%) (79.1%)	20.9%	9.7%	11.3%

Table II

EVALUATION OF THE MATCHER PERFORMANCE OF THE INDIVIDUAL FINGERPRINT DESCRIPTORS AND GROUPS OF DESCRIPTORS

DESCRIPTOR	PERCENTAGE DUPLICATE[1] CARDS WITH THE LOWEST SIMILARITY SCORE	PERCENTAGE DUPLICATE CARDS WITH SIMILARITY SCORES THAT ARE ONE OF THE THREE LOWEST SCORES
FINGERPRINT CARDS COMPOSED OF ALL LOOP PATTERNS, ALL 10 FINGERS (28 DUPLICATE PAIRS)		
ALL MEASUREMENTS[2]	100.0	100.0
CORE DELTA DISTANCE ONLY	96.5	96.5
CORE CREASE DISTANCE ONLY	32.0	52.0
CORE DELTA RIDGE COUNT ONLY	87.5	98.3
CORE DELTA, CORE CREASE ANGLE ONLY	55.4	75.0
FINGERPRINT CARDS COMPOSED OF ALL ARCH PATTERNS, ALL 10 FINGERS (20 DUPLICATE PAIRS)		
ALL MEASUREMENTS[2]	12.5	30.0
ARCH ANGLE ONLY	10.0	27.5
CENTER OF ROTATION TO CREASE RIDGE COUNT ONLY	17.5	27.5
CENTER OF ROTATION TO CREASE DISTANCE ONLY	10.0	35.0
CENTER OF ROTATION TO CREASE DISTANCE AND RIDGE COUNT	20.0	35.0
FINGERPRINT CARDS COMPOSED OF LOOP, ARCH, AND WHORL PATTERNS, ALL 10 FINGERS (WHORLS 40%, LOOPS 35%, ARCHES 25% OF THE CARDS, 20 DUPLICATE PAIRS)		
ALL MEASUREMENTS[2]	100.0	100.0

NOTES:

1. THE DATA IN THIS TABLE WAS OBTAINED BY SELECTING A FINGERPRINT CARD AS AN INQUIRY CARD AND COMPUTING A SIMILARITY SCORE BETWEEN THIS CARD AND ALL OF THE REMAINING CARDS IN THE SUBSET OF THE DATA BASE BEING CONSIDERED (A DATA RUN). A DIFFERENT CARD IS THEN SELECTED AS THE INQUIRY CARD AND THE PROCESS IS REPEATED UNTIL ALL OF THE CARDS IN THE SUBSET OF THE DATA BASE HAVE BEEN SO SELECTED. THE PERCENTAGES OF THE DATA RUNS FOR WHICH THE CORRECT DUPLICATE FINGERPRINT CARD WAS MOST SIMILAR TO THE INQUIRY CARD (LOWEST SIMILARITY SCORE) AND ONE OF THE THREE MOST SIMILAR CARDS ARE THEN COMPUTED. THIS EVALUATION PROCESS WAS REPEATED SEPARATELY FOR VARIOUS DIFFERENT PATTERN TYPES, MEASUREMENT TYPES, AND COMBINATIONS OF FINGERS.

2. "ALL MEASUREMENTS" FOR LOOP TYPE FINGERPRINTS INCLUDE THE CORE TO DELTA DISTANCE, THE CORE TO DELTA RIDGE COUNT, THE CORE TO CREASE DISTANCE, AND THE ANGLE BETWEEN THE CORE DELTA LINE AND THE LINE FROM THE CORE TO THE CREASE. WHORL TYPE FINGERPRINTS HAVE THREE ADDITIONAL MEASUREMENTS RELATING TO THE PRESENCE OF THE SECOND DELTA, THAT IS, THE CORE TO SECOND DELTA RIDGE COUNT AND DISTANCE AND THE ANGLE BETWEEN THE LINE FROM THE CORE TO THE SECOND DELTA AND THE CORE TO CREASE LINE. THERE ARE THREE MEASUREMENTS FOR ARCH TYPE FINGERPRINTS. THESE ARE THE CENTER OF ROTATION TO CREASE DISTANCE AND RIDGE COUNT AND THE ANGLE FORMED BY THE RIDGE FLOW PATTERN NEAR THE CENTER OF ROTATION (THE ARCH ANGLE).

classification. These cards were supplied as Minolta copies of the cards and not the original inked fingerprint cards.

Results

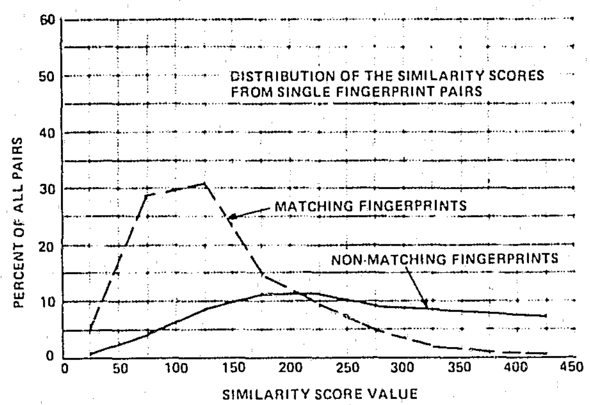
To fully understand the results of the fingerprint matching experiments, it is necessary to know the accuracy of the measurement computation. Generally, the distance and angle measures were accurately and repeatably computed. However, the ridge count measurement was not computed as accurately as is normally determined in a manual ridge counting process. While manual ridge counting results in approximately 95 percent of duplicate cards having ridge counts which are either the same or different by only one, only 47.8 percent of automatically counted ridges from duplicate cards had this accuracy. All of the duplicate cards on which manually counted ridges were shown within the available data base had ridge counts which were no different on duplicate cards than three whereas 17.6 percent of the duplicate prints had ridge counts different by more than 3 when automatically counted. These data are shown in Table I. Thus the automatic ridge count process as implemented in this experiment was not very accurate compared to manual ridge count processes.

Table II shows the results of the search and retrieval process as a function of the individual descriptors and combinations of descriptors for the three different data groups used. The results are expressed as the percentage of matcher runs in which the proper duplicate card was selected as the most likely matching card and the percentage for which it was selected as one of the three most likely matching cards. On loop type fingerprints using all four descriptors, there was 100 percent accuracy in selecting the correct duplicate card in the file. Considering each of the descriptors individually, the core delta distance and the core delta ridge count both produced a very high accuracy in the selection of the proper duplicate card. The distance measure was somewhat more accurate than the ridge count indicating the high degree of accuracy with which an operator can manually locate the key points. It is expected that a more sophisticated ridge count algorithm than the simple one implemented in this study should result in matching based on the ridge count alone should be of equal accuracy with the core to delta distance since these two descriptors are very highly correlated. The core to crease distance, when considered by itself, had very low accuracy in selecting the proper duplicate match from the file. Other data indicated that this measurement could be very accurately made between duplicate impressions of the same fingerprint. However, the difference in this descriptor between non-duplicate fingerprints was not significant enough to provide adequate discrimination of matching and non-matching fingerprints. Since the core-crease distance descriptor could be accurately computed, the consistency in locating or using the crease as a measure or feature is accurate enough to find use as the basis of other descriptors. The angle measurement for loops by itself also does not provide sufficient discrimination information between matching and non-matching fingerprints.

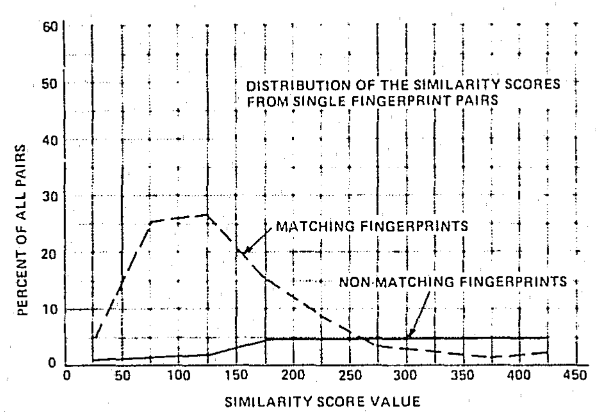
In considering the results on the duplicate pairs of arches, none of the cases resulted in adequate matching thus indicating that the set of features chosen for arches does not provide adequate matching information. In cases for which the arch angle measurement was not used, the combination of the center of rotation to crease ridge count and the center rotation to crease distance exhibits greater matching accuracy than is obtained when all three measurements are used. This indicates that the arch angle measurement is providing no matching information and is just adding noise to the matcher process thus somewhat masking the differences between matching and non-matching arch type fingerprint.

In considering the significance of the results on these arch type fingerprints it should be noted that arch patterns form only about 4 percent of all fingerprint patterns and cards containing all arches are only a small fraction of 1 percent of all fingerprint cards. Thus even though the matching results on arches indicate that these arch descriptors do not adequately characterize arch patterns for use in a fingerprint matching system, there is generally enough other information available for other type of patterns on a card to provide enough card matching information.

When considering the cards which included whorl, loop and arch type patterns with whorls being approximately 40 percent of the patterns



(a) SCORE DERIVED USING THE FOUR DESCRIPTORS FOR THE CARDS CONTAINING ALL LOOP TYPE FINGERPRINTS.



(b) SCORE DERIVED USING FINGERPRINT CARDS CONTAINING APPROXIMATELY 40% WHORL PATTERNS, 35% LOOP PATTERNS, AND 25% ARCH PATTERNS

Figure 9 THE DISTRIBUTION OF THE SIMILARITY SCORES FROM SINGLE FINGERPRINT PAIRS

Table III

PERCENTAGE OF FINGERPRINT CARDS FOR WHICH THE DUPLICATE CARD EXHIBITED THE LOWEST SIMILARITY SCORE AND WITHIN THE THREE LOWEST SIMILARITY SCORES FOR INDIVIDUAL FINGERS AND SELECTED GROUPS OF FINGERS. RESULTS BASED ON THE 28 DUPLICATE PAIRS OF LOOP DATA BASE CARDS.

FINGER OR GROUP	PERCENTAGE DUPLICATE CARDS WITH THE LOWEST SIMILARITY SCORE	PERCENTAGE DUPLICATE CARDS WITH SIMILARITY SCORES THAT ARE ONE OF THE THREE LOWEST SCORES
INDIVIDUAL FINGERS		
1 RIGHT THUMB	17.8	46.5
2 RIGHT INDEX	28.6	53.6
3 RIGHT MIDDLE	26.8	53.6
4 RIGHT RING	26.8	57.2
5 RIGHT LITTLE	14.5	37.5
6 LEFT THUMB	10.7	35.7
7 LEFT INDEX	26.8	57.1
8 LEFT MIDDLE	39.3	64.3
9 LEFT RING	25.0	50.0
10 LEFT LITTLE	26.8	44.6
COMBINATIONS OF FINGERS		
2, 7	64.3	75.0
2, 7, 1, 6	78.6	92.8
2, 7, 1, 6, 3, 8	87.5	96.4
2, 7, 1, 6, 3, 8, 4, 9	92.8	100.0
ALL 10 FINGERS	100.0	100.0

on these cards, very high matching accuracy was obtained. By comparing the distribution in Figure 9 for the case of all loops to the distribution for case of the multiple class data group which contained a large number of whorls, it can be seen that slightly better separation of the matching and non-matching groups were obtained for the multiple class case. In both cases very high matching accuracy was obtained. The case which contained many whorl type fingerprints would be expected to provide slightly better matching since whorls are characterized by seven descriptors rather than by four descriptors as for loops. Thus there is more matching information for whorl type fingerprints than for loop type fingerprints.

Table III shows the results of considering individual fingers or groups of fingers for the loop case using all four descriptors. The cases using the thumbs, fingers number 1 and 6, individually resulted in much lower probability of accurately matching on an individual finger basis than any other cases. This indicates that there is probably more plastic distortion in the thumbs due to the rolling of the inked impression than on the other fingers. Thus, a system based on the use of less than 10 fingerprints should avoid the use of the thumbs due to the increase in distortion. When considering the results of adding groups of fingers, the results indicate that groups with six fingers or with eight fingers may be sufficient to adequately characterize a fingerprint card for accurate matching.

Conclusions

The study reported in this paper is an evaluation of concepts for the semi-automatic characterization of fingerprint cards. The fingerprint descriptors that were considered provide more detailed fingerprint characterization information than is provided by the Henry or American classification systems but not as much detail as is provided by minutiae based fingerprint encoding systems. Thus, fingerprint descriptors, such as distance and angle measures between key points on the fingerprint may be used to enhance the Henry or American classification procedures without the need for the highly advanced computer systems required by the practical high-speed minutiae based encoding techniques.

The results of this study indicated that the use of the distance and angle measures as fingerprint descriptors is feasible for loop and whorl type fingerprints. The encoding of the descriptors has been shown to be practical from a time and cost point of view.

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