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Project Search —

AN ANALYSIS OF AUTOMATED AND SEMI-AUTOMATED SYSTEMS FOR ENCODING AND SEARCHING LATENT FINGERPRINTS

Final report on work performed under Law Enforcement Assistance Administration Grant No. 73-NI-99-0035-G, awarded to the California Crime Technological Research Foundation for Project SEARCH by the National Institute of Law Enforcement and Criminal Justice.

Submitted by the
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Section 1

EXECUTIVE SUMMARY

INTRODUCTION

This document reports the results of an analysis conducted by the Project SEARCH Committee on State Identification Bureaus.

Project SEARCH is a cooperative effort of the criminal justice systems of the 50 states, banded together to apply technology to the criminal justice system of the United States. The work reported in this document, as well as other efforts of Project SEARCH, were funded by grants from the Law Enforcement Assistance Administration of the U. S. Department of Justice. This particular task was funded by the LEAA National Institute of Law Enforcement and Criminal Justice (NILECJ).

The purpose of the project was to survey the state-of-the-art in automated and semi-automated methods of searching fingerprints and to evaluate their applicability to searching latent (crime-scene) fingerprints. This report contains the following key information:

- Descriptions of the technical approaches to fingerprint searching proposed and tested by seven governmental and private research organizations.
- Experimental results concerning accuracies of each approach.
- Comparative analysis of potential capabilities.
- Recommendations, submitted to NILECJ, for a coordinated program to foster further development of latent fingerprint systems' capabilities.

The members of the State Identification Bureau Project Committee Committee are shown in Exhibit 1-1. Gary D. McAlvey served as chairman of the Project Committee. Vincent Peterson served as chairman of the Latent Fingerprint Subcommittee (Exhibit 1-2) which directed the conduct of the project.

Project SEARCH

State Identification Bureau
Project Committee

Chairman: Gary D. McAlvey
Department of Law Enforcement, Illinois

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Department of Justice
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Administrative Staff: David G. Yamada
California Crime Technological Research Foundation
Sacramento, California

Technical Staff: Donald W. Ostrander
Public Systems, inc.
Sunnyvale, California

Exhibit 1-1: State Identification Bureau Project Committee

Project SEARCH

Latent Fingerprint Subcommittee

Chairman: Vincent Peterson
Division of State Police
New Jersey

Members

Donald L. Baker
Department of Justice
California

William Freele
State Police
Oregon

Stan Kimball
Department of Public Safety
Arizona

Gary D. McAlvey
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LEAA Representative: Ronald C. Allen
Washington, D. C.

National Institute Representative: William Saulsbury
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Administrative Staff: David G. Yamada
California Crime Technological Research Foundation

Report Staff: Gregory L. Campbell
Public Systems, inc.
Sunnyvale, California

Exhibit 1-2: Latent Fingerprint Subcommittee

Administrative services were provided by the California Crime Technological Research Foundation under the direction of Douglas E. Roudabush, Executive Director. David G. Yamada provided staff support.

Technical staff services for the project were provided by Public Systems incorporated, under the direction of Paul K. Wormeli, SEARCH Project Coordinator. Gregory L. Campbell acted as principal investigator for the project. Steven Patent and John McGuire provided technical support, and Deborah Stone prepared the manuscript.

STATEMENT OF THE PROBLEM

It is generally recognized that the major problem in searching latent fingerprints against a file of known offenders is the time-consuming process of manual classification and search of the fingerprints. Several research and development programs, in various stages of progress, are presently being conducted to automate fingerprint classification and search. Generally, the technologies employed in these efforts involve optical holography, or optical scanning followed by digital transformation of the fingerprint images.

Project SEARCH has sponsored several such projects through two major studies: a feasibility study of holographic assistance to fingerprint identification and a program to develop a prototype technical search system for state identification bureaus.

Because of the large number of different efforts and the lack of coordination among them, the National Institute of Law Enforcement and Criminal Justice has seen the need to review and assess the programs in order to enable NILECJ to plan future project support.

PROJECT SCOPE

Research and development programs directed toward either single finger or 10-finger identification which involve automated or semi-automated encoding and searching of fingerprints were the subjects of this evaluation project. A parallel effort to survey, document, and evaluate latent fingerprint systems currently in operation in law enforcement agencies was also undertaken by the State Identification Bureau Project Committee. A companion report documents the results of that effort.

Seven separate programs were identified by the Project Committee and NILECJ to fall within the scope of the project. The seven participants are listed in Exhibit 1-3. The FBI FINDER system, although within the scope of the project, was not included because the Committee felt that it was sufficiently documented in other publications.

ORGANIZATION	PRINCIPAL CONTACTS
KMS Technology Center Irvine, California	Joseph Robertson
First Ann Arbor Corporation Ann Arbor, Michigan	R. G. Eisenhardt
TRACOR Austin, Texas	John L. Furstenwerth
Argonne National Laboratory Argonne, Illinois	C. B. Shelman W. P. Lidinsky
Sperry Research Center Sudbury, Massachusetts	Donald McMahon Dale Shane
McDonnell Douglas Electronics Company Saint Charles, Missouri	William Boring L. L. Shaw
New York State Division of Criminal Justice Services Albany, New York	Frank Madrazo James Paley

Exhibit 1-3: Participants in the Review and Analysis of Automated Fingerprint Systems

METHODOLOGY

Data on the selected research and development programs were collected from three major sources:

- published plans, reports, and marketing materials;
- direct requests for information by telephone or correspondence;
- site visits to view experimental equipment and discuss programs in detail.

The primary emphasis of the data collection was the experimentally tested accuracy of prototype systems. Descriptive data concerning the technical approach and proposed system configurations were also collected along with as much cost data as could be obtained. These data are presented in Sections 2-1 through 2-7 of this report.

A comparative analysis of accuracies of the systems was performed, based on available experimental data. It should be noted that these results, as reported in Section 3, are not strictly comparable because of substantial differences in data bases and test sets. An analysis of the advantages and disadvantages of the various technical approaches as applied to latent fingerprint searching is presented in Section 4. Conclusions and recommendations derived from the available data and analyses are presented in Section 5.

SUMMARY OF KEY FINDINGS

The key findings of this study are as follows:

- An effective latent print search system is a valuable tool in further identifying possible criminal offenders and in clearing cases where no other useful evidence is available.
- Useful fully-automated latent print search systems are commercially available or close to becoming available and are becoming financially attractive.
- A latent system which will retrieve one true match in a file with close to 100% reliability is not currently near accomplishment.
- A potential cost savings, which justifies their development, is offered by automated systems over those requiring manual encoding.
- Adequate testing using actual or simulated latent prints has not been accomplished for most systems discussed in this report.

- A semi-automated minutiae encoding process appears feasible although its effectiveness in search procedures and its compatibility with automated encoding have not been tested.
- Many agencies and private organizations expressed interest in conducting and investing in further research and development on latent fingerprint searching.
- Fingerprint research activities and the acquisition of fingerprint devices by state and local law enforcement agencies should not be limited by the existence or expected implementation of the FBI FINDER system.

RECOMMENDATIONS

The following recommendations are presented for the consideration of the National Institute of Law Enforcement and Criminal Justice (NILECJ);

- Because of the recognized need for effective latent fingerprint searching systems and the encouraging results of experimental systems as described in this report, NILECJ should continue its support of latent fingerprint research.
- A coordinated program for supporting latent fingerprint research and development should be established and contain the following key features;

  1. NILECJ should sponsor an experiment to compare accuracies of prototype latent systems using a standard data base of fingerprint cards and a standard set of actual or simulated latent prints. The latents should represent a cross-section of prints found at crime scenes which are of sufficient minimum quality to serve as evidence in court.

     The experiment would accomplish the following;

     a. Assess on an equitable basis the present capabilities of manual, semi-automated, or full-automated systems.

     b. Assess the operational costs of latent systems.

c. Encourage the investment of private capital in latent fingerprint research and development.

d. Establish a data base and test set for evaluating improvements in latent systems for years to come.

All types of latent systems including manual, semi-automated, and fully-automated systems should be included in the experiment. A special effort should be made to include the FBI FINDER system in the experiment.

2. In conjunction with Part 1, a study should be undertaken to determine the composition of a representative sample of latent prints. Based on the results of the study, the latent print test set should be constructed from actual crime-scene latents, elimination prints, or purposely produced and lifted latents as deemed appropriate by the study. A master fingerprint library representative of the patterns and varying quality of fingerprint cards found in state or municipal identification bureau files should also be selected.

3. NILECJ should financially support research and development projects which demonstrate promising results in the experiment.

4. Based on the evaluation of user groups (such as Project SEARCH), LEAA should encourage the construction of prototype equipment for installation and test in operational agencies.

5. NILECJ should selectively support research and development projects which may greatly improve latent print searching systems in the long term even though they have not demonstrated a capability at the time of the experiment. As soon as possible, these systems should be tested with the standard data base and test latents developed for the experiment.

Section 2

AUTOMATED AND SEMI-AUTOMATED SYSTEMS FOR THE ENCODING AND SEARCH OF FINGERPRINTS

Section 2-1

KMS TECHNOLOGY CENTER

The KMS Technology Center was one of the three participants in the Project SEARCH holography study (Reference 5). In the study, KMS tested a device based on the matched filter optical correlation technique similar to that used by McDonnell-Douglas Electronics Company that will be described in Section 2-6. A description of the KMS system and the key experimental results are presented below.

Since the time of the SEARCH study, KMS has concentrated on the secure door lock application of their technique. Present management has indicated very little interest in pursuing further work on either latent or 10-finger identification for law enforcement applications.

SYSTEM DESCRIPTION

The KMS fingerprint searching system consisted of three steps: the production of a matched filter (hologram) of an inquiry fingerprint card; the calibration of the comparator system using an inquiry card with its corresponding matched filter; and the comparison of library microfilm images with the matched filter of the inquiry card to produce a list of probable matches.

The fingerprint cards were photographed by a 35 mm camera; then the microfilm was cut and mounted onto standard photographic slides. Library slides were placed in a slide carrousel tray, to be fed into the path of the light signal beam one at a time for searching. The slides made from the inquiry cards were used to generate holograms which were captured on specially treated glass plates.

The three steps in the system were accomplished on a single electro-optical device, the comparator. The machine consisted of a low intensity neon gas laser, beam splitter and several lenses, holders for photographic slides and glass plates, a sensing device to measure correlation voltage, and a closed circuit television camera to measure a correlation spot.

The beam splitter was used to split the laser into a signal and reference beam. The two beams were oriented so that the signal beam would pass through a photographic slide and converge with the reference beam on the glass plate. Matched filters of inquiry cards (all ten-fingers) were produced on the glass plates by exposing it for 1/16 second. The plates were photographically developed and then used for comparison.

To calibrate the system in preparation for search, the signal beam was passed through the inquiry card slide and the holographic plate made from this same fingerprint test card slide. The reference beam was shut off for this process. The system operator then observed this ideal match reading of the correlation voltage (read on an oscilloscope) and the brightness of the correlation spot (measurement of diffraction efficiency as detected by a television camera and read on a CRT screen). These readings served as the standard against which readings of all the library slides would be compared.

Once the ideal match reading was made, each one of the library slides was fed into the path of the signal beam (the reference beam was still blocked). Readings were made automatically on the oscilloscope and manually from the correlation spot picture which was the most accurate measure of the true correlation. Out of the library cards, the ten best matches were selected.

RESEARCH SUMMARY

Test Procedures

The holography test was conducted under the following procedures: A library of 10,000 fingerprint cards, 100 "tuning" cards and two test sets of 100 and 400 cards were selected from the files of the California Bureau of Identification. The cards were chosen to be representative of pattern type distribution and card quality found in the Bureau. All identification information was removed from each card except for a test sequence number and a manually derived Henry Primary classification annotated on the card. KMS further subdivided the 1/1 primary into 16 subcategories of their own design.

The file and the tuning set were made available to the test participants for filming according to their own specifications. The 100 tuning cards contained known matches in the file and were used by the participants to adjust system parameters to obtain the best possible performance.

At the conclusion of the tuning operation, Project SEARCH representatives visited each corporate participant's facilities with the test cards to be run. The tests were conducted as a "double blind" experiment where neither the corporate participants nor the SEARCH representative knew which, if any, of the cards in the test set had matches in the library. For each test card, a list of at most 10 possible matches was generated. The sequence numbers of the possible matches were recorded and submitted to Project SEARCH for analysis and report of performance.

In addition to performance statistics, costs of conducting the experiments were recorded and reported.

ACCURACY RESULTS

Statistics on the two test sets were generated separately. In the primary set, containing 100 cards with 82 true file matches, KMS correctly chose 71 (87%) and missed 11 (13%) on their lists of most probable matches. In the 400 card secondary experiment where there were 313 true matches, KMS hit 254 (81.2%) and missed 69 (18.8%).

The test results as stated in the Project SEARCH Technical Report No. 6 are shown in Exhibit 2-1-1. The results of McDonnell Douglas Electronics and Sperry Research Center are included for comparison in the exhibit.

The definitions used in Exhibit 2-1-1 follow:

- Correct Match (CM): the test card has a match in the library and the matching card is among the candidates identified by the participant.
- Mismatch (MM): the test card has a match in the library, the participant states that there is a match, but incorrectly identified the matching card.
- False Dismissal (FD): the test card has a match in the library, but the participant states that there is no match.
- False Match (FM): the test card does not have a match in the library, and the participant falsely identifies a match.
- Correct Dismissal (CD): the test card does not have a match in the library, and the participant correctly states that there is no match in the library.
- Not Processed (NP): the test card quality did not permit processing by the holographic system.

It should be noted that scores were awarded for correctly identifying correct dismissals, i.e., cards with no match in the file. Therefore, 10 possible match candidates were not always chosen. This may partially account for the relatively poor results of the participants.

In addition to the overall results, the results were analyzed on the basis of card quality and fingerprint class. (See Reference 5 for details.) No definitive conclusions were reached from these tests.

	KMS	MDEC	SRRC
CM	71	74	69
CD	8	13	8
FM	9	6	11
FD	4	4	3
MM	7	3	9
NP	1	0	0
TOTAL	100	100	100

Exhibit 2-1-1A. Primary Experimental Results

	KMS	MDEC	SRRC
CM	64	70	64
CD	8	13	8
FM	9	6	11
FD	4	2	2
MM	6	1	7
NP	1	0	0
TOTAL	92	92	92

Exhibit 2-1-1B. Primary Experiment Results Excluding Facsimile Sub-experiment.

	KMS	MDEC	SRRC
CM	254		280
CD	17		34
FM	58		41
FD	11		21
MM	58		24
NP	2		0
TOTAL	400		400

Exhibit 2-1-1C. Secondary Experiment Results

NOTE: MDED did not perform the secondary experiment.

	1	2	3	4	5	6	7	8	9
KMS	92	4	2	1	1	-	-	-	-
MDEC	99	1	-	-	-	-	-	-	-
SRRC	84	8	2	2	0+	0+	0+	2	0+

Exhibit 2-1-1D. Distribution of Ranks for CM Responses

NOTE: Entries show percentage of all CM responses by the corporate participants which are of the rank order indicated (rank 1 is the "most likely candidate").

Exhibit 2-1-1. Experimental Results of Holography Study.

Timing and Cost Results

The following timing and cost data were obtained from the experiment. Microfilming cost KMS $2,906 or approximately 28¢ per card; it took six days. The subcontracted slide mounting cost $769 (approximately 7¢ per card) and took three days. Dividing the library slides into Henry Primary (and then 1/1 into Henry Secondary) classes took 15 days and cost $3,463, or approximately 35¢ per card. Converting the test card slides into holographic plates took 17 hours and cost $964 ($1.93 per card). Finally, the file search required 24.5 mandays (one man for the total time) and cost $4,840 ($9.68 per test card).

GENERAL CONCLUSIONS OF HOLOGRAPHY TEST

The general conclusion of the holography test was that none of the systems tested was presently appropriate for 10-finger searching in a state identification bureau. The Sperry system was determined to be potentially within an acceptable operating cost range, but lacked sufficient accuracy. McDonnell Douglas demonstrated sufficient accuracy, but had unacceptably high costs. KMS was not acceptable on either criterion.

Section 2-2

FIRST ANN ARBOR CORPORATION

The First Ann Arbor Corporation conducted a project for the Project SEARCH State Identification Bureau Committee to determine the feasibility of FAAC's approach to an automated technical search system. As such, this project was one of a series of projects funded by Project SEARCH for the purpose of examining the applications of technology to activities of state identification bureaus.

The Identification Bureau Committee has recommended that Project SEARCH not continue support of FAAC's development, and that all reports and other materials be submitted to NILECJ for their consideration.

SYSTEM DESCRIPTION

The First Ann Arbor system involved five distinct steps:

(1) Masking of the individual fingerprint impression (the mask was a piece of cardboard with a die-cut circular aperture of diameter 1.5cm).

(2) Scanning of the masked impression.

(3) Conversion of the scan data from positions in the X-Y plane to patterns of wave frequencies.

(4) Computation of the print classifier from the frequency data.

(5) File searching.

Keys to successful system performance included accurate centering of the mask on the point of maximum ridge curvature by the technician and proper orientation of the scan direction. Separate tests were held on these features and the results are reported below in the section on accuracy of results.

The fingerprint scanning and digitization were performed by Data Dissemination Systems, Inc., of Los Angeles, using a linear array diode scanner. Pre-search software was divided into two parts. First, the scanned fingerprint data was read from magnetic tape and stored. Then transformation software was used to compute the two-dimensional spatial frequency pattern from the planar fingerprint data.

From the frequency distribution, software was used to compute the print classifier. Finally, the search was performed by matching print classifier data from the input card against classifier data from the file. Computers used for processing were a CDC 6600, an IBM 370/155, and a PDP-10 (Digital Equipment Corporation).

Matching was done on the basis of 35 frequency descriptors for each print. The absolute frequency values (occurrences ranging from -254 to +91) were divided into 5 cells or ranges as follows:

Cell	Frequency Descriptor Range
1	$-\infty$ to -174
2	-174 to -75
3	-75 to -12
4	-12 to $+40$
5	$+40$ to $+\infty$

A match required each of the 35 cell descriptors for a given print to match its corresponding descriptor for the print being compared. One descriptor that did not match was sufficient to dismiss the print as a non-match. However, the cell ranges were not ironclad. If the absolute frequency value fell within 3 to 4σ (standard deviations) of a cell boundary, both adjacent cells were considered as valid classifiers. The width of the cells were close to 11σ, where σ was the standard deviation based on scanning ten impressions of an arch and five impressions of a loop.

In searching prints, First Ann Arbor used "search indicators" to compensate for potential errors caused by frequency values near cell boundaries. Every one of the thirty-five digits used to classify a given print had a search indicator attached. This indicator signified if the frequency descriptor was in the mid-range of a cell (0), near the lower boundary of a cell (-), or near the upper boundary (+). The operating system, as envisioned by First Ann Arbor, would not store the search indicators for the library prints. This information would only be available for the inquiry print, and,hence, searching adjoining cells where indicated could only be performed for the values on the inquiry cards.

Before testing for file searching capability, FAAC performed several tests to measure the sensitivity of the fingerprint classification procedure to minor variations in print quality and operator technique. First, the same arch fingerprint was scanned at three different orientations about an arbitrary longitudinal axis. Then a left ulnar loop of ridge count 14 was scanned at five different orientations about an arbitrary longitudinal axis. Finally, this same ulnar loop was used for three different scans after moving the mask position each time. As a separate test on the question of effects due to different mask positions, First Ann Arbor had 4 test subjects locate mask centers on randomly selected prints.

The accuracy tests were performed on different impressions of the same fingerprint--five impressions of the same ulnar loop and ten impressions of the same arch. The system's ability to discriminate similar but not identical fingerprints was tested by comparison of two different left ulnar loops with a ridge count of 14.

RESEARCH SUMMARY

Test Procedure

Fingerprint cards were obtained from several sources. One set of 50 impressions of the same loop pattern was selected along with another set of 50 impressions of one arch. These prints were to be used in the repeatability tests (described below). These 100 prints were made by the Michigan State Police at their Ypsilanti, Michigan station.

A set of 150 left ulnar loops with a ridge count of 14 was supplied by the Illinois State Department of Law Enforcement. These prints were to be used in the test of the system's ability to discriminate among similar, non-identical prints. In addition, Illinois supplied a random selection of 40 prints, containing whorls, tented arches, central pocket loops, double loops and accidentals.

Finally, a set of 1200 randomly selected prints was used to test a technician's ability to properly locate a mask over a fingerprint. These last prints were not meant to be scanned and digitized, nor were they included as part of the file searching test.

First Ann Arbor encountered considerable difficulty in obtaining usable scans from their subcontractor. From the first 100 impressions, FAAC and Project SEARCH had selected 30 for scanning; 15 of the resultant scans were usable. From the set of 150 prints, 58 were selected for scanning and only two were usable.

Test Results

When identical prints were compared just within their own test group (i.e., those tested for effect of scan orientation compared against each other, or those tested for repeatability under different impressions of the same finger) all except one scan produced matches in all 35 digits of the classifier. The one scan that did not fully match was scan 8c, a test where the mask center had been displaced 1.2 mm from its original position in scan 8. Even after the search indicators had been used to determine which adjacent cells to search, 2 of the 35 digits did not match. In addition to this non-match, treating scan 8 as the inquiry card (used in the scan orientation and mask centering tests) and scan 13 (repeatability for different impressions test), produces a non-match even though both were taken from the same loop.

As noted above, the comparison of different impressions of the same print produced matches in all cases (5 of the loop and 10 of the arch). The discrimination test (comparison of two similar, non-identical loops), produced 9 and 5 digits not matching, depending on which print was considered the library print.

It should be noted that First Ann Arbor intended to make more extensive tests (e.g., discrimination among 58 different loops instead of two) but only 25 scans were of usable quality for all the tests performed. Hence, their results are severely handicapped by small sample sizes.

The results on the technician mask centering test were recorded after several trial runs. On the test run of 100 prints, 81 (81%) were centered within 0.5 mm of each other by the four test subjects, and 19 (19%) were centered beyond 0.5 mm. A summary is presented below:

Number of Prints	Variation in Mask Center Location Among all 4 Technicians
2	$\chi > 1.5$ mm
10	1.0 mm $< \chi <$ 1.5 mm
7	0.5 mm $< \chi <$ 1.0 mm
81	$\chi <$ 0.5 mm
100	

*χ = Maximum difference among 4 technicians.

The data indicate that the FAAC approach may suffer from problems in accurately locating the mask. The extent of this problem, if it exists, was not accurately measured.

Due to the insufficient size of the test (which was caused partially by the lack of acceptable scan data) the feasibility of the FAAC approach was not established. Tests with substantially larger data bases must be undertaken.

Cost and Storage

Due to the lack of scans and comparisons available, no meaningful cost data were established. However, data on the computer storage required were produced. To distinguish five cell numbers in binary code, three bits are needed (00, 01, 10, 11 provides only four cell types, so a third bit is required if anywhere from five to eight cells were to be used). Based on 35 digits (classifiers) per finger and the proposed 4 fingers per set or card, a set requires 3 x 35 x 4 = 420 bits of storage. First Ann Arbor Corporation has indicated that it may be possible to reduce the cell ranges from five to four and the fingers needed per set from four to two in which case only 2 x 35 x 2 = 140 bits would be needed.

Section 2-3

TRACOR

The Texas Department of Public Safety recently sponsored the feasibility test of TRACOR's Automated Fingerprint Searching System. TRACOR's technique relies on average measures of ridge slope within individual small squares of a grid network placed over the print surface (see Reference 14). This distinguishes it from the completely mechanical or holographic matching technique and from the minutiae technique. In addition to ridge slope, TRACOR's approach takes into account core to delta distances where they exist and also the number of deltas present.

The general conclusion of the Texas Department of Public Safety, as quoted from Dr. A.J. Welch's evaluation appended to the TRACOR report was that "...The procedure demonstrated by TRACOR is not suitable for locating a single fingerprint from a reasonable size library (greater than 10,000)." After considerable thought, DPS has decided not to fund Phase II, because they believe that the TRACOR's approach is the same as that of the Sperry Research Center which is one or two years further along in development.

SYSTEM DESCRIPTION

Fingerprint scanning was performed by the Argonne National Laboratories on their computer-coupled optical scanner system called ALICE. The main pieces of equipment that comprised ALICE were a PDP-10 digital computer (Digital Equipment Corporation), two CRT screens, a teletype and a reflected light scanner. Computer processing and file searching were performed on TRACOR's UNIVAC 1108 computer using magnetic tapes generated from the scan data.

The data for each fingerprint consisted of 64 values, each one representing an average slope value for the ridges in a square cell of 1 square millimeter in area. These grid values were taken for the cells surrounding the fingerprint core (i.e., they do not reach the edges of the fingerprint).

When comparisons were made between two fingerprints, a score was developed for the comparison based on 64 possible matches of ridge slope (slope recorded in 8 integer values, 1 thru 8, representing 22.5° each, i.e. 0° → 180°). Positional weighting was used to adjust the comparison scores, i.e., the weight assigned to a position was recorded for each successful slope comparison. (Exhibit 2-3-1 gives the positional weighting adopted by TRACOR after 12 different schemes were tested).

2	2	2	2	2	2	2	2
2	3	3	3	3	3	3	2
2	3	4	4	4	4	3	2
2	3	4	0	0	4	3	2
2	3	4	0	0	4	3	2
2	3	4	4	4	4	3	2
2	3	3	3	3	3	3	2
2	2	2	2	2	2	2	2

Exhibit 2-3-1

C=Position of Core

Exhibit 2-3-1: Positional weighting system adopted by TRACOR. Figure also represents the grid centered on the core in which angle measurements were made.

If the scan produced unreadable data for a particular position, a zero was recorded for that position. When comparing two prints, a zero for a particular position on either print was sufficient to delete that position from the comparison score. Hence, only positions where both prints had integers between 1 and 8 contributed to the score.

In order to account for possible errors due to distortion by plastic deformation of the finger during inking, allowances were made for slope numbers that did not match exactly. After trying five possible schemes, TRACOR decided to assign a "closeness weight" of 1 to a perfect match (i.e. identical slopes) and a"closeness weight" of .9 to slopes that differed by 1 unit. This factor was multiplied by the positional weight and then the product was added to the score.

Since the number of comparisons was not the same for each pair of prints (due to the variation in number and position of zero slopes for each print), TRACOR normalized the score. They kept a running total of "possible score", i.e., the score that would have been recorded if every non-zero position had a perfect match. The normalized score was computed as actual score divided by possible score, so that a perfect match (identical in all positions that were readable on both prints) would obtain a score of 1.0. All other normalized scores would fall between 0 and 1.0.

Core-delta distances were also considered. If the core-delta distances on two prints were within two millimeters of each other, 10 points were added to "actual score" (i.e., 10 would be added to "possible score" in all cases where both prints had core-delta measurements available). If the number of deltas on two prints matched, 15 points were similarly awarded.

When an inquiry point was searched against the library, a normalized score was obtained for each comparison with a library point. Then the scores were ranked in descending numerical order, and results were reported on the number of actual print matches appearing in the top ten candidates on the list.

RESEARCH SUMMARY

The prints provided by the Texas Department of Public Safety, (DPS) included a library set of 894 prints broken down as follows:

LIBRARY SET		
Print Type	Number	Percent
Ulnar Loop	291	32.6
Radial Loop	69	7.7
Plain Whorl	148	16.6
Central Pocket Whorl	90	10.1
Double Loop Whorl	90	10.1
Accidental Whorl	12	1.3
Tented Arch	87	9.7
Plain Arch	107	12.0
TOTAL	894	100.00*

*Percent column actually totals to 100.1%, due to round-off errors.

The inquiry set provided by DPS contained 122 prints, 83 of which had matches in the library set. In addition, DPS provided a set of eighty cards, called a duplicate set. These cards (ten prints to a card) were taken from five individuals over a period of several years. TRACOR used these duplicates to develop their identification algorithm.

Accuracy Results

The test results for accuracy are given in Exhibit 2-3-2.

The first test results are those reported by the Texas Department of Public Safety in their four-page summary of the TRACOR tests. TRACOR reported results[1] showing 45 of 83 matches in first place (54%) and 78 of 83 matches in the first ten places (93%) were achieved after a number of prints were redigitized, slope matrix cell weights were readjusted and prints were reclassified. (The above re-test conditions were noted by A. J. Welch on page eight of his evaluation of TRACOR's experiment.) Both Dr. Welch and TRACOR make reference at least once each to 84 prints with matches in the library. No explanation is given by either one for this apparent discrepancy.

In their report, TRACOR examined identification based on a multi-fingered system. Their key assumption was that there is statistical independence among fingers (i.e., knowing the pattern type of one finger gives one no information as to the probabilities of various pattern types occurring on the other

[1](p. 43 of TRACOR report)

Position on List	Results Reported by TEXAS DPS		Results Reported by TRACOR	
	Number of Matches	Cumulative % of Matchable Prints that were Matched	Number of Matches	Cumulative % of Matchable Prints that were Matched
1	32	38.6	45	54.2
2	9	49.4	11	67.5
3	5	55.4	7	75.9
4	1	56.6	1	77.1
5	3	60.2	3	80.7
6	1	61.4	1	81.9
7	1	62.6	1	83.1
8	2	65.0	4	88.0
9	1	66.2	1	89.2
10	4	71.0	4	94.0
1-10	59	71.0	78	94.0
1-5	50	60.2	67	80.7
Missed	24	28.9	5	6.0
TOTAL	83	100.0*	83	100.0

*Actual percent column total is 99.9% due to round-off error.

Exhibit 2-3-2: Accuracy Results of TRACOR Experimental Test. After the formal test for Texas DPS, TRACOR re-adjusted parameters and conducted the test again, resulting in the improved results as indicated.

fingers of the same person). Based on considerable experience with manual encoding systems, patterns on fingers have been shown to be highly interdependent. Hence, TRACOR's comments are on shaky ground. Tests with a large data base must be undertaken before conclusions concerning the multi-finger approach can be made.

Timing and Cost Data

No direct cost data for the performance of the contract was given. However, the data storage requirements were given as 216 bits for each finger. Each inquiry print was searched against the full library of 894 prints in an average time of eight seconds.

Section 2-4

ARGONNE NATIONAL LABORATORY

Fingerprint research at Argonne National Laboratory (a facility of the U.S. Atomic Energy Commission) began in 1963 soon after the completion of an image processing system called CHLOE. The machine's primary function was to analyze photographs of high energy particles in bubble chambers. However, personnel at Argonne, principally Mr. C. B. Shelman, soon became interested in attempting to scan and extract information from fingerprints.

The first research effort involved measuring average ridge angles in a matrix of positions on a fingerprint. A simple classification and comparison system using the slope matrix was developed (see Reference 10). The second early research effort was directed toward the problem of extracting minutiae (ridge endings and bifurcations) from a fingerprint pattern (see Reference 11). Both of these approaches were the first of their kind reported in the literature.

Because of limitations in the CHLOE equipment, fingerprint research was discontinued for about two years. In 1970, funds were provided by the Atomic Energy Commission to build a new image processing system. The design of the new system, called ALICE, was strongly influenced by the experience gained using the previous equipment. A description of the ALICE system and current fingerprint research activities follow. More details may be obtained from the papers presented to the 1973 Carnahan Conference (Reference 9) and the First International Conference on Electronic Crime Countermeasures, Edinburgh University, Edinburgh, Scotland, July 1973, (Reference 7).

In July, 1973, the Atomic Energy Commission terminated its support of fingerprint research at ANL in favor of higher priority projects.

ALICE IMAGE PROCESSING SYSTEM

ALICE is a general-purpose image scanning and processing system with provision for man-machine interaction. The system consists of an operator's console, a digital computer with peripherals, three scanning stations, and a general-purpose controller which can be connected to one scanning station at a time.

The operator's console contains two 21 inch, flat faced display CRT's, an operator controlled trackball, and a teletype data terminal. One display scope is slaved to a scanner through the controller and displays the scanner output. The other scope displays computer output and has character and vector generating capabilities. It is used to show enlarged portions of a pattern along with superimposed cross hairs which can be translated and rotated with the trackball. The trackball and the data terminal provide the primary means for man-machine interaction.

The computer is a DEC model PDP-10 (36-bit word length) with 43K of magnetic core storage. Peripherals include two tape drives (one seven-channel and one nine-channel), a card reader, a line printer, and the operator console equipment. All software is written in FORTRAN, making it easy to write and modify.

Three scanning stations, all built by ANL, are presently available. A light scanning microscope has the capability of digitizing images directly from biological slides. A film station can scan images from either 35 or 16mm film. A reflected light station (opaque scanner) has recently been built and is particularly useful for fingerprint work since it does not require filming. The station uses a 9 inch precision CRT (flying spot) as a light source which is focused by lenses onto the image. Reflected light is gathered by four photodetectors accurately spaced around the reflecting surface. All of the stations are capable of scanning in any orientation with any point spacing and line spacing up to 100,000 lines within the image area. Light intensity is measured to 64 grey levels.

A summary of the system's capabilities is presented in Exhibit 2-4-1.

FEATURE EXTRACTION AND CLASSIFICATION

Recent work at ANL has centered on the development of a 10-finger classification system which would segment a fingerprint file so that an exhaustive search with a detailed comparison, such as minutiae matchings, would not be necessary. Effort was directed toward the 1/1 Henry Primary Category since loop patterns, defined by ANL as having 1 or fewer deltas, are the most difficult to subdivide. Three systems were developed to divide loops

Some Features of ALICE Image Processing System:

--3 scanners available: microscope, 35 and 16mm film scanner, opaque scanner
--All functions software controlled for easy modification and testing
--Manual interaction capability at decision points if required
--FBI's FINDER system can be simulated
--Image processing software available
--Scanning done in any direction, thus eliminating problems of fingerprint rotation
--Scanning point and line spacing under software control
--Addressable scan points lie on 100,000 by 100,000 matrix
--All processing and searching can be done on PDP-10 computer

Exhibit 2-4-1: Summary of ALICE System Capabilities

into 6 categories. The third and most promising system was used to classify 200 sets of 1/1 Henry cards. The system showed good discrimination since only two pairs of cards had the same classification. However, to determine the system's real merit, tests with a larger data base and multiple impressions of the same person's fingerprints should be conducted. (See Reference 7 for details of the method and results.)

Feature Extraction

The proposed classification systems are based on fingerprint features which can be identified both by machine and a human operator. These include the fingerprint core, core orientation, delta, delta orientation, and average ridge spacing. Core and delta orientations are determined by the average slope of ridges entering the feature.

Software has been developed to locate these features. If the machine is unable to locate them or if the operator is dissatisfied with the machine derived locations, he may override the system manually.

Classification

The three proposed classification systems, which are variations of each other, use core-to-delta distance, CDD, and core-to-delta angle, CDA, (the angle between the core orientation line and the core-delta line). Each system basically segments the area of a fingerprint pattern which contains the delta into six regions determined by CDD and CDA. Approximately equal numbers of prints have deltas located in each region. The region number in which the delta is located thus becomes the classification.

A difficulty with this approach is the uncertainty in relative core and delta location. The problem is solved by introducing "zones of uncertainty" or overlapping areas in which two classifications must be checked in a fingerprint search. This complicates the system, but its significance cannot be determined without further study.

SYSTEM TIMING AND COST

Little meaningful cost data is available concerning the operation of the ALICE system because it is a highly flexible experimental system where speed is not an important consideration. Under fully automatic operation, scanning and classification as described above would require about 3-4 seconds per fingerprint or 30-40 seconds per card. With manual interaction, the time is increased to about 2 minutes per card.

It is estimated that a production system with minimum graphics and interactive capability would cost about $50,000 for hardware and labor to assemble the system. ANL could not manufacture such a system because it is a government facility. However, equipment designs can be made available to private industry through a technology transfer program

FUTURE RESEARCH

Lacking further funding, ANL has no immediate plans for further fingerprint research and will concentrate on other image processing applications of greater interest to the AEC. However, Mr. Shelman has expressed an interest in trying to use the ALICE system with its interactive capability to encode latent prints and to devise classification systems suitable for latent fingerprint searching.

Other researchers may also be able to use the system's capabilities, because it has recently been made available on a rental basis. By this means, TRACOR, whose work is described in Section 2-3, used the system to digitize fingerprints for their analysis.

Section 2-5

SPERRY RESEARCH CENTER

The Sperry Research Center, the research arm of the Sperry Rand Corporation, has participated in two Project SEARCH fingerprint studies, and has conducted internally funded projects directed toward both 10-finger and single finger identification. The results of the first contract are reported in Project SEARCH Technical Report No. 6, "An Experiment to Determine the Feasibility of Holographic Assistance to Fingerprint Identification," (Reference 5), while the results of the second contract and the internal single print program are summarized here. Details on the second contract can be found in the SRC Report, "Demonstration of Prototype Fingerprint File and Technical Search System," (Reference 16).

As a result of the second study, performed for the Project SEARCH State Identification Bureau Committee, the committee recommended that the Sperry 10-finger identification system be implemented in a state identification bureau.

THE PROTOTYPE 10-FINGER SYSTEM

System Description

The equipment used in the test consisted of a fingerprint digitizer and a Univac 418-III computer system. The print digitizer scanned microfilm images of fingerprint cards on 35 millimeter film. No manual alignment of the prints was required. The data obtained from the scanning were measurements of ridge orientation on a scale of 0° to 179°, in increments of 1°, at a 64 x 160 array of sample areas covering all the rolled impressions of a fingerprint card. This data was stored on magnetic tape, and then transferred to the UNIVAC 418 III computer for processing and searching.

The fingerprint search procedure was preceded by a "cleaning" of the digitized data. This included erasing additional lines, such as those caused by scratches on the microfilm. Erroneous or inconsistent angle measurements were removed next. Then holes left by removing data (or where no data initially existed) were filled by computer processing to produce a continuous, compact data set representing one fingerprint pattern.

After this smoothing procedure was completed, the fingerprint recognition and searching procedures were begun. The first task was locating cores and deltas. Once this was accomplished, the computer could both classify the pattern type and make continuous parameter measurements, e.g., the core-delta distance of loop patterns. Eight such measurements were made for each finger, so a maximum of eighty measurements per card were made.

Matching was performed on the basis of these pattern types and the eighty analog measurements. The input card was classified as loop (left or right), arch, whorl, or some combination if the pattern was not completely distinguishable. Then the analog measurements were compared one at a time between the input card and every library card with the same pattern type. A score was developed for each library card compared, based on these analog comparisons. Then the cards were ranked as probable matches in decreasing order of their scores.

Research Summary

A library of ten thousand fingerprint cards and two test sets of 100 and 500 cards were supplied from the files of the California Bureau of Identification. The cards had been microfilmed onto 35 millimeter microfilm with an 8.2x reduction factor by the California Department of Water Resources in Sacramento for use in the previously conducted holography study.

Several tests were run; in each case, a list of the 17 most probable match candidates for each test card were printed in order of decreasing probability of match. First a test of the machine classification was made, running all 600 test cards. This was followed by a test utilizing a manually derived Henry Primary classification on all 600 test cards. Finally, results for the searches in the 1/1 Henry Primary classification (2,761 cards out of the total 10,000 cards) were isolated from the library for the second test. All three sets of results are reported in Exhibit 2-5-1.

As shown in the exhibit, using the machine classification, 90.7% of the true matches appeared on the list of 10 most probable candidates and 78.8% appeared in the first position. Using the Henry Primary improved the results to 94.4% and 86.7% respectively. Performance in the 1/1 Henry Primary group was almost identical to that of the entire test with the machine classification.

Timing and Cost Results

During the conduct of the demonstration, operating times and costs were measured.

Rank of Match Candidates	Machine Classification Only: % of Matches in this Rank	Machine Classification Only: Cumulative %	Henry and Machine: % of Matches in this Rank	Henry and Machine: Cumulative %	III Henry: % of Matches in this Rank	III Henry: Cumulative %
1	78.81	78.81	86.7	86.7	78.0	78.0
2	7.42	86.23	3.8	90.5	7.1	85.1
3	1.69	87.92	1.7	92.2	3.0	88.1
4	.64	88.56	.8	93.0	1.8	89.9
5	.85	89.41	.6	93.6	1.2	91.1
6	.64	90.05	.2	93.8	.6	91.7
7	.21	90.26	.4	94.2	.6	92.3
8	.21	90.47	0	94.2	.6	92.9
9	.21	90.68	0	94.2	0	92.9
10	0	90.68	.2	94.4*	0	92.9
1-10	90.7		94.4*		92.9	
1-5	89.4		93.6**		91.1	
Matches Missed	9.3		5.6		7.1	

* Sperry Research reported this value as 94.7; presumably this discrepancy was due to round-off from hundredths of percent in the ten candidate rank values.
**Sperry Reports this as 93.8%

Exhibit 2-5-1: Results of Fingerprint Search Against a File of 10,000 Fingerprint Cards

Microfilming the 10,000 card library and the 600 card test set (10,600 cards) cost $1,060.00, or 10¢ per card.

The card library was digitized in advance of the test. The 10,000 card library took six (6) days to digitize at a rate of 350 cards per hour. During the monitored final test, the 600 card test set was digitized in two hours (300 cards per hour). No costs are given for this digitizing.

The pre-search processing by the Sperry software took 20 seconds of computer time per card, at a cost of $75/hour on the UNIVAC 418 III (or $0.42 per card). To this, Sperry added 8¢ per card of burdened labor cost, making the per card cost of 50¢. Hence, the software cost of preparing the digitized data for use in the 10,000 card library was $5,000.

The actual test of 600 cards searched against the 10,000 card library using machine classification took 102 minutes, or 3.5 x 10^6 card comparisons per hour. The test of 600 cards using machine classification in conjunction with Henry Primary classification took 66 minutes, or 5.4 x 10^6 card comparisons per hour. At the $75/hour cost of the UNIVAC 418 III, the search costs using machine classification and Henry Primary classification were .00214¢ per card comparison and .00139¢ per card comparison, respectively. The actual cost of searching one test card is thus proportional to library size. For example, the costs of searching one test card against a 1,000,000 card library would be $21.40 (machine classification) and $13.90 (Henry classification).

These costs are comparable to those experienced in identification bureaus using manual technical search. (see Reference 6)

SPERRY RESEARCH CENTER LATENT PRINT ACTIVITIES

As a continuation of this work of ten finger identification, the Sperry Research Center has been conducting an internally funded program to develop a single finger identification capability. To assess their present capability using existing equipment, SRC conducted a small test using a fingerprint file obtained in the Project SEARCH holography contract.

File Search Test

The fingerprint matching algorithm used in the test is based on a direct comparison of angles of the inquiry and file fingerprints. The technique is similar to the one used by Sperry

in the first Project SEARCH contract, as opposed to the data abstraction and classification techniques used in the second contract. To obtain a measure of closeness of match, each file print is mathematically rotated and translated with respect to the inquiry print until the score can no longer be improved. A list of the ten closest matching prints is maintained in the computer and printed at the end of the file search.

The fingerprint impressions used in the test were the 100-card test set for the first Project SEARCH contract. Each print on the cards was digitized resulting in a file of 1,000 individual patterns. The inquiry set consisted of a second digitization of the first 65 prints of the 1,000 card file to pass a minimum quality standard. (The standard required that at least 250 angle measurements could be made. About 95% of the inquiry prints met the standard.) For each inquiry print, a different impression of the print was digitized and added to the 1,000 card file.

When the test was run, the second digitization of each of the 65 inquiry prints always appeared on the list of 10 most probable matches and always appeared in the first position. This was not particularly surprising since the two patterns were identical, the differences in digitization being only a matter of translation. A much more meaningful comparison of that test is shown in Exhibit 2-5-2. As indicated, 59 (90.6%) out of the 65 possible matches occurred in the first position on the list of ten most probable matches, and only one correct match was missing from the list.

POSITION ON LIST OF 10 MOST PROBABLE MATCHES	NUMBER OF CORRECT MATCHES
1	59 (90.6%)
2	2 (3.2%)
3	1 (1.6%)
4	1 (1.6%)
5	1 (1.5%)
Missing	1 (1.5%)

Exhibit 2-5-2: Experimental Results of the Sperry Single Print Test Against a File of 1,000 Single Impressions.

Tentative Equipment Configuration

A basic latent print system configuration would consist of an opaque fingerprint digitizer capable of reading directly from fingerprint cards and latent lifts or photographs, a mini-computer with a teletype input/output device, and one or more disc files. A block diagram of such a system is shown in Exhibit 2-5-3.

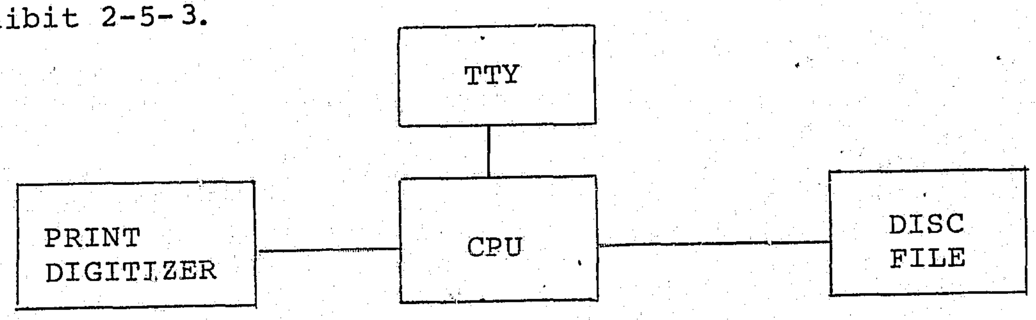


Exhibit 2-5-3: Block Diagram of a Simple Latent System Using the Sperry Print Matching Method

The cost of a minimum system with one disc pack and removable discs is estimated to be less than $50,000. Assuming 250 8-bit angle measurements per print and disc packs with capacity of 2.5 million 8-bit bites, a total 10,000 single print records could be stored per disc. Each disc, which costs $150, would probably represent a sub-file based on segmentation by geographical location of offender, finger number, pattern type of print, modus operandi, etc. File search speed is estimated to be approximately 36,000 comparisons per hour, resulting in one disc file being searched in approximately 15 minutes.

To maintain an entire fingerprint file on disc would require a larger and consequently more expensive computer system. The computer hardware to store and search a file of 100,000 individuals would cost between $150,000 and $200,000. To this would be added the cost of the scanner (perhaps $10,000), software development changes, and profit.

Further Research and Development

The eventual Sperry latent system will probably not be limited strictly to angle measurement. Sperry is presently experimenting with a digitizer which develops a complete binary representation of an entire fingerprint pattern. Software would then be used to make angle measurements. Because the scan contains the complete fingerprint pattern information, other measurements, such as average ridge spacing in various parts of the fingerprint, can be made. Eventually, even minutiae could be incorporated into a comparison system for latent prints using software process.

Section 2-6

McDONNELL DOUGLAS ELECTRONICS COMPANY

McDonnell Douglas Electronics Company (MDEC) has developed a system for automated search and recognition of latent fingerprints composed of electro-optical and photographic equipment. The system, which operates by measuring the similarity of fingerprints, determines likely matches from a microfilmed suspect file based on machine measurements and decisions. The cards from likely matches are segregated for examination and identification.

The system was developed by MDEC and first tested in the SEARCH holography study (Reference 5). In that study, the system was tested as a 10-finger identification system in which several fingers could be used to limit the number of candidates which must be visually reviewed. Results of more interest to the latent searching problem were presented in a paper at the 1972 Carnahan Conference on Electronic Crime Countermeasures (Reference 1). These results are presented here.

A contract has recently been negotiated between MDEC and the New York City Police Department for the construction and delivery of an automated latent system. The results of an acceptance test using actual latent prints and a test file of fingerprint cards are presented in Appendix B.

SYSTEM DESCRIPTION

The techniques employed in the MDEC system are based on properties of images formed using coherent (laser) light. If a photographic transparency (such as a fingerprint) is placed at the front focal plane of a lens and illuminated by a coherent light beam, the light pattern that appears at the back focal plane of the lens is a unique mathematical transformation of the input pattern, known as the Fourier transform. One of the properties of Fourier transforms is that the inverse transform of the product of the transforms of two patterns is a direct measure of their similarity, known as the correlation function. This fact together with the Fourier transforming properties of simple lenses, enables the design of electro-optical systems to directly measure the similarity of fingerprints or their patterns.

Some important properties of the Fourier transform technique include its insensitivity to relative translation of the two patterns to be compared and its insensitivity to small differences in the same pattern due to under- or over-inking, smudging, etc.

System Equipment

Using the principles and techniques described above, MDEC has developed a set of hardware which comprises a complete prototype Latent Fingerprint Recognition System. The elements listed and described below make up the system.

1. Microfilm Fingerprint File--Standard data processing cards, containing an aperture in which a microfilm image of a set of fingerprints is mounted, serve as the data base for the system. Up to 52 columns of keypunch information can be stored on each card. Thirty-two of the columns are used to describe the pattern classification of the set of fingerprints. The other 20 columns are used for subject ID or other data which could have pre-sort value.

2. Aperture Card Camera--This dual purpose unit produces microfilm aperture cards of both latent fingerprints and standard fingerprint cards to be added to the data base.

3. Filter Maker--This equipment creates a laser-generated matched filter of the latent fingerprint. The matched filter is in the form of a film transparency and is placed in position B-B in the schematic of Exhibit 2-6-1. A filter requires about 1 minute to be produced.

4. Latent Comparator--This unit shown schematically in Exhibit 2-6-2, automatically compares the latent print matched filter with aperture cards from the fingerprint file and automatically segregates probable match cards for further investigation.

5. Aperture Card Reader/Printer--The suspect aperture cards selected by the comparator are analyzed against the latent aperture card with this unit. Final determination is made by the fingerprint analyst. Preliminary screening can be performed on the viewer with final analysis done on a photostatic copy of both the latent and the file card provided by the reader/printer.

Peripheral equipment and facilities also employed with the system include aperture card copying, keypunching, possibly sorting equipment, and a standard photographic darkroom.

Exhibit 2-6-1

FILTER MAKER SCHEMATIC (Reference 1)

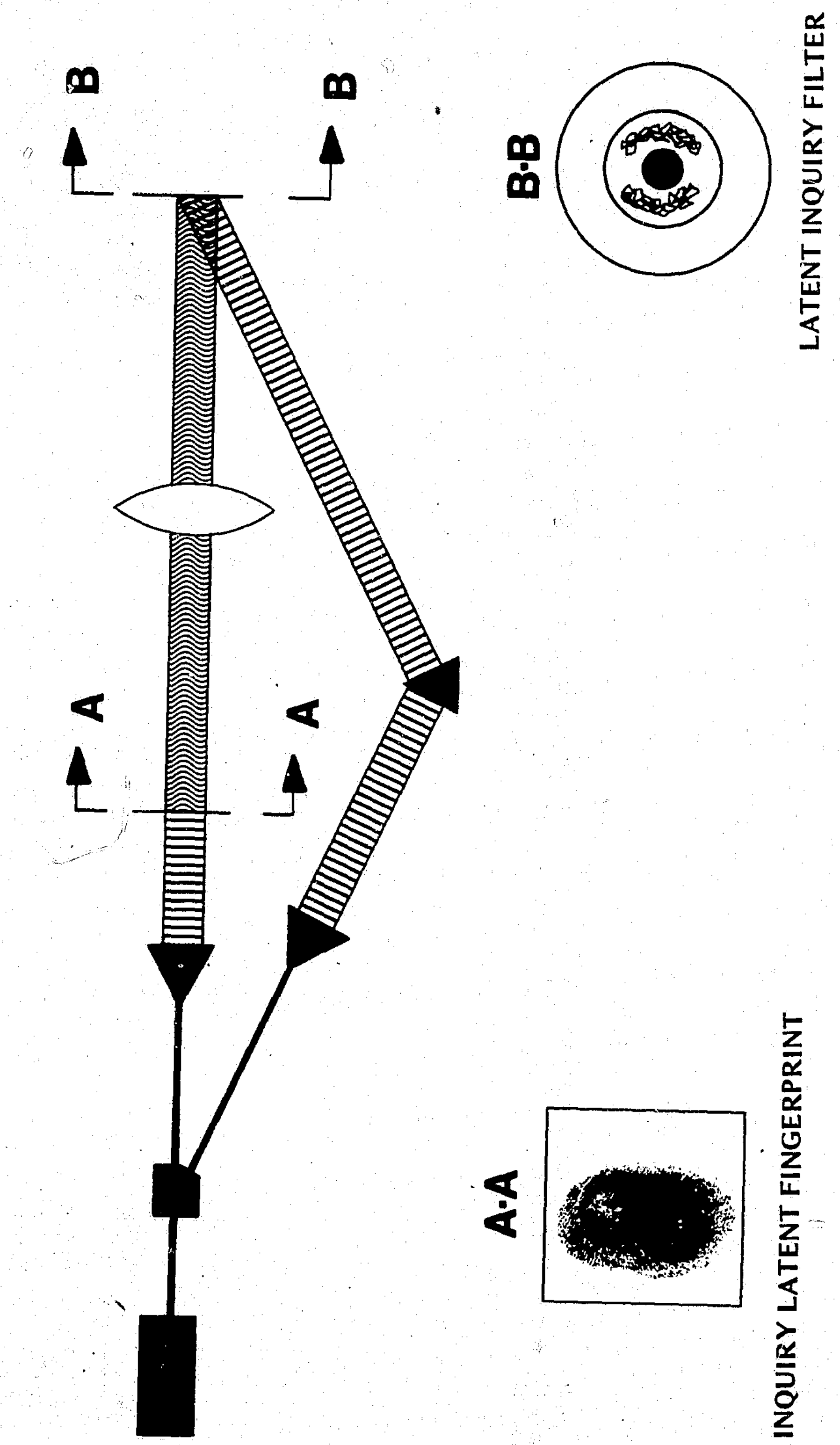
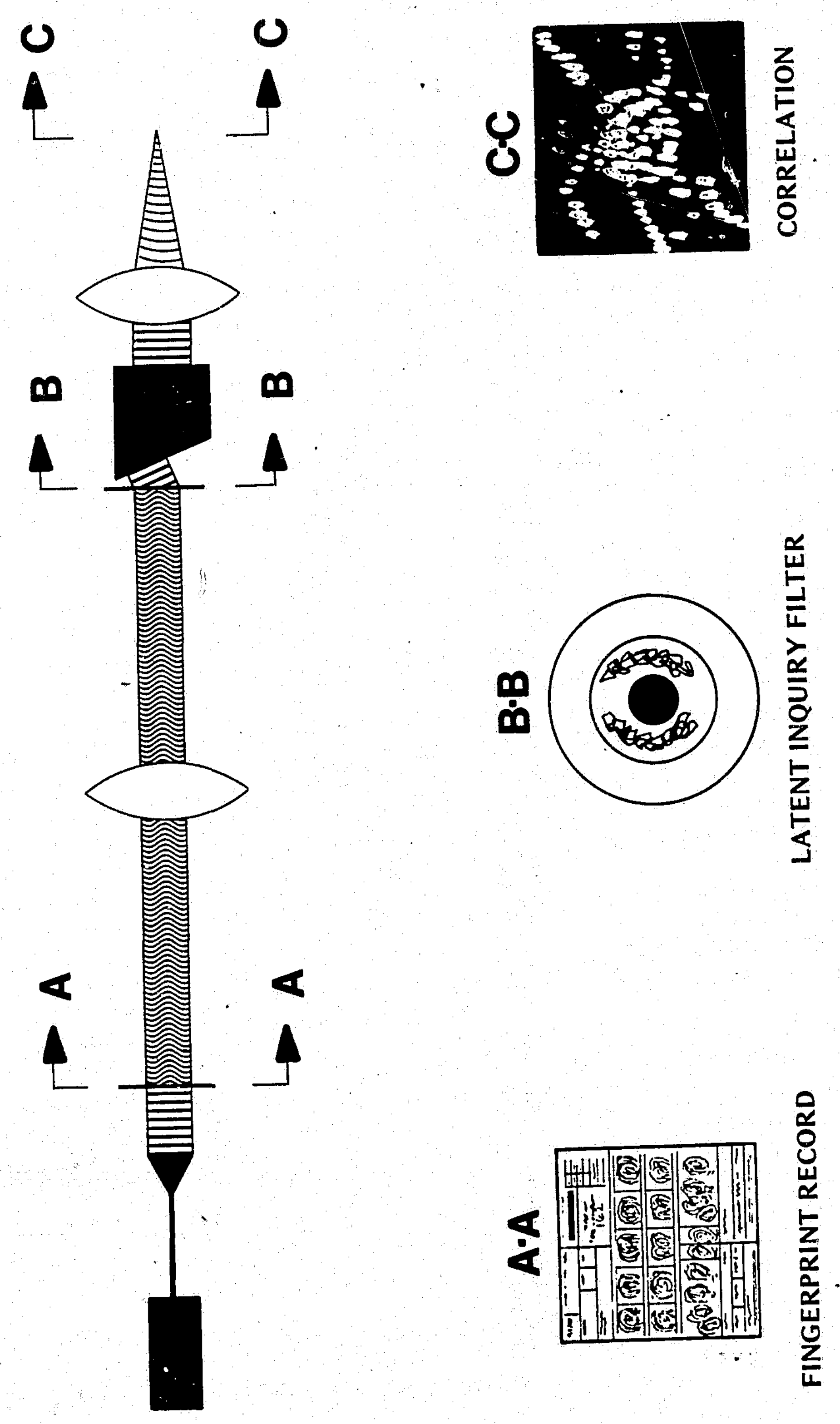


Exhibit 2-6-2

COMPARATOR SCHEMATIC (Reference 1)



Search Technique

The routine operations of the system involve:

- File updating--adding the fingerprint aperture cards of new subjects to the file;
- Preparing latent fingerprints for search--generating a microfilm image and filter using the filter maker.
- Searching the file against the latent fingerprint; and
- Expert examination of machine-indicated probable matches to make final identification.

The latent search activity is central to the system. The latent comparator automatically separates out sets of file cards which contain likely matches to the latent print into 4 separate bins ranked in order of similarity. To do this, the latent filter is first snapped into place in the comparator, and a file subset is selected. (The file can be physically segmented in any way desired, such as geographical area.) The operator selects a starting correlation value (voltage) threshold, enters pattern type information if appropriate and the subfile is run. (The equipment sets two other threshold levels for segmentation into the 4 bins.) Comparisons are made at the rate of four subjects per second cards for which the correlation on any finger exceeds a threshold are automatically segregated. These can then be rerun at stepped increases in threshold, with the result that the input subfile is sorted in order of machine-indicated probability of matching the latent.

In a separate operating mode, the TV monitor of the comparator can be used to determine which specific digits are matching on the more likely cards.

RESEARCH SUMMARY

Because of deviations such as inking variations, distortion of the finger skin, scars and blemishes of recent origin, etc., non-matching fingerprints often correlate as well as the true match. Thus, a number of false respondents must be removed before making the identification.

Large scale tests were performed on the MDEC system to determine the statistics concerning the incidence of false respondents. These statistics can be used to make inferences concerning the usefulness of the system in efficiently making identifications.

Test Procedures

The test (reported in Reference 1) involved searching 64 known and representative subjects against a base file of 10,000 representative subjects. The inquiry and base file cards were provided through the SEARCH holography study and were selected from the files of the California Bureau of Identification. The 64 inquiry cards were the tuning set made available to the study participants for the purpose of calibrating their systems. Both the base file and inquiry subjects had been manually assigned their appropriate Henry Primary classification. Searching was confined to the appropriate Henry file pocket.

Accuracy Results

For the 64 subjects, between one and four individual fingers were searched, for a total of 135 individual searches.

When the individual single fingers are considered independently, an estimate is made of the cumulative probability of a "hit" versus the number of extraneous cards reviewed by the fingerprint examiner. Exhibit 2-6-3 indicates this cumulative probability versus the amount of cards expressed as a percentage of the base file (Exhibit 2-6-3a) and as a percentage of the applicable file pocket (Exhibit 2-6-3b). From these graphs it can be seen that in 65% of the searches the ideal outcome resulted: the machine segregated a single card which was the correct match to the inquiry. In 90% of the searches, the matching card would be identified by reviewing (at most) 0.24% of the library (i.e., 24 cards).

To assess the system's capability as a single finger search system, the results of Exhibit 2-6-3b should be used. The system selectivity (proportion of file reviewed by examiner) cannot be calculated on the basis of the entire file because the Henry Primary uses information from all ten fingers, which is not available on a single print. Therefore, the data contained in the second exhibit is used in the accuracy analysis of Section 3.

Timing and Cost Information

The following times were reported for operation of the indicated system elements:

- The aperture card camera generates microfilm images mounted in aperture cards at the rate of 45 seconds per subject or 80 subjects per hour.

- The filter maker can prepare filters of the latent pattern at the rate of one per minute. Filters are prepared in batches which require a minimum of 45 minutes for developing.

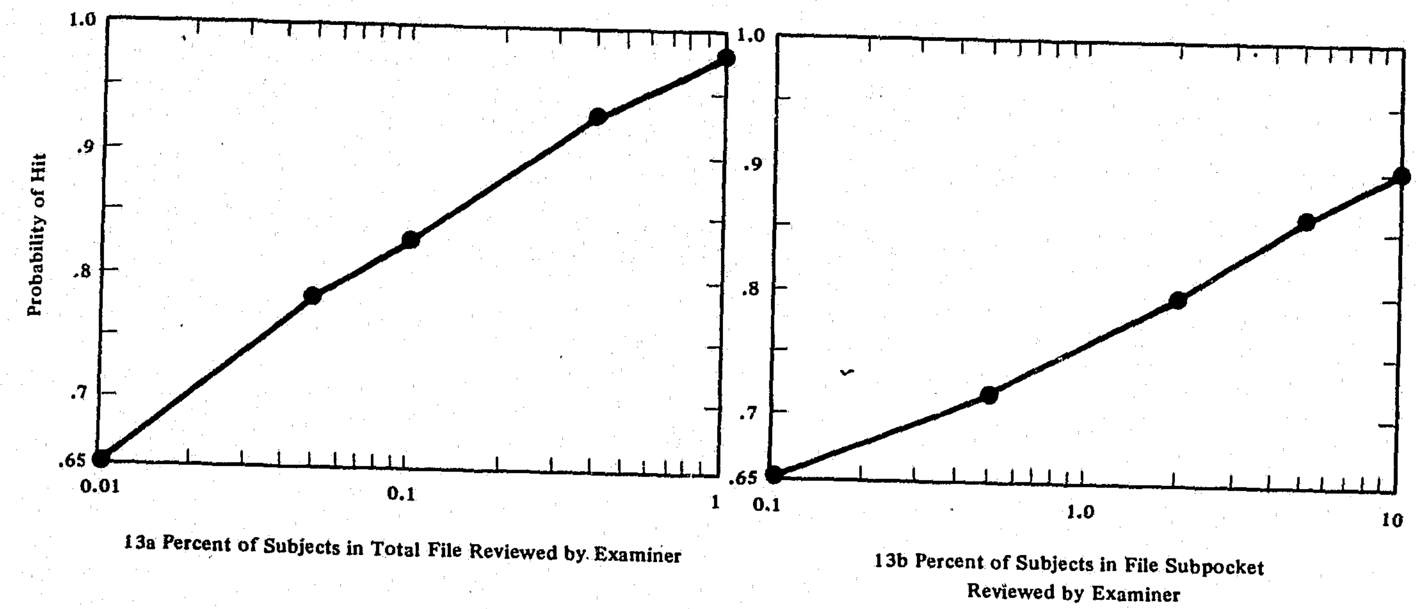


Exhibit 2-6-3

INDEPENDENT SEARCH HIT PROBABILITY ESTIMATE VERSUS
AMOUNT OF MACHINE-INDICATED RESPONDENTS REVIEWED BY EXAMINERS FINGERPRINTS

Fingerprints searched - 135
Base file size - 10,000 subjects

(Taken from Reference 1, page 36)

- The latent comparator compares aperture file cards with the latent filter at the rate of 4 subjects per second, independent of whether or not the finger number of the latent is known.

The following cost information was obtained from the holography study (Reference 5):

- The 10,000 card data base was filmed using commercial practices on 35 mm roll film. Two diazo copies were produced, cut, and mounted on aperture cards. The total cost was $2,000 or 20¢ per fingerprint card.

- 347 match filters were produced for the 100 card test set at a cost of $472.51 or $1.23 per filter.

Section 2-7

NEW YORK STATE DIVISION OF CRIMINAL JUSTICE SERVICES

Since 1969, the New York State Division of Criminal Justice Services (DCJS), with financial support from the National Institute of Law Enforcement and Criminal Justice, has been conducting research on a system for semi-automated encoding of fingerprint ridge minutiae (ridge endings and bifurcations). Two generations of encoding equipment have been designed and built, both assembled from primarily off-the-shelf equipment by General Dynamics Corporation. The second system, known as SAFES (Semi-Automated Fingerprint Encoding System), was delivered in May, 1973, and will shortly be put into operation.

Preliminary results of tests on the new system will be available in June, 1974, and therefore could not be included here. However, test results obtained on the old system (not previously published) are presented in Appendix A. These results are used in the accuracy analysis of Section 3.

One of the main hopes for the SAFES system is that it will be compatible with the FBI FINDER System. FINDER could then be used to encode the arrest card data base while SAFES could handle low quality latent prints unsuitable for automatic processing.

REAR PROJECTION INCREMENTAL DIGITIZER

The original latent fingerprint research was conducted using an incremental digitizer with rear projection of a microfilmed fingerprint image. The equipment displayed single fingerprint images at a magnification of 8 to 1 on a 20-inch square ground glass screen. A mechanical X-Y plotter stylus was attached to the display and could be positioned over the fingerprint pattern to encode fingerprint orientation and minutiae points.

Beginning at a preset reference point, the equipment recorded incremental movements in the X and Y directions which were printed as characters on magnetic tape. The tape was then analyzed by the general purpose computer system (Burroughs B-6500) available at the division. Several fingerprint search programs were written and tested using data collected on this apparatus. A presentation of the results of experiments using search software developed by Wegstein of the National Bureau of Standards is contained in Appendix A.

From their experiences with the rear projected plotter, DCJS in cooperation with General Dynamics of San Diego, designed new equipment to improve the collection of minutiae data. The new system, known as SAFES (Semi-Automated Fingerprint Encoding System), was delivered in May, 1973. From that time until February, 1974, the system has undergone substantial debugging in both hardware and software. Most of the problems have been solved now and it is anticipated that test data will be collected starting in March. A description of the new equipment and study objectives follow.

SEMI-AUTOMATED FINGERPRINT ENCODING SYSTEM

Equipment

The semi-automated encoder consists of four main components: a programmable mini-computer with a teletype, special input console and tape drive; a closed-circuit television camera with monitor; an X-Y digitizer; and an interface subsystem. The complete system cost approximately $130,000 to build.

The high resolution (1225 line) closed circuit television is used to display the fingerprints to the operator at a magnification of approximately 10:1. It also displays a superimposed cross hair, encoding circle and other encoding aids. The camera is mounted on a separate table next to the monitor console. The operator manually positions fingerprint cards or latents in the image plane of the camera. The cards are held in place with a vacuum system.

The X-Y digitizer, used to encode minutiae coordinates, consists of a magnetic stylus which can be moved on the flat surface directly below the television monitor. The position of the stylus is displayed on the television monitor in the form of a cross hair. Points are encoded by positioning the cross hair and pressing the appropriate button on the input console. During this process, error lights and messages are displayed if information is omitted or entered in the wrong order.

The mini-computer accepts X-Y minutiae coordinate information as well as identification number, reel and frame number, finger number, and finger type entered through the input console. The computer formats and outputs the coded information on 9-track, 800 bpi tape in a format compatible with the Burroughs computer. A teletype input/output device is also available for entering and modifying computer programs as well as printing error messages.

In addition to accepting and processing input, the mini-computer also formats the encoding aids for display on the television monitor. These aids consist of circles of various

diameters and small dots indicating previously encoded minutiae.

The interface subsystem consists of the operator keyboard, error indicator lights and the systems controller. The system controller provides all interface and buffering requirements between the computer, closed circuit television, keyboard, and X-Y digitizer.

The features of the SAFES equipment are summarized in Exhibit 2-7-1. Since the equipment is to be used by an operator, many of the features have been designed to maximize operator effectiveness while minimizing fatigue.

Latent Fingerprint Processing System

As conceptualized by DCJS, the latent print processing system consists of five major functions: Submission, Encoding, Search, Retrieval, and Verification.

Submission

The submission function includes submission of arrest cards for the data base file as well as latent print evidence. Since DCJS is a service bureau, designed to share information with all law enforcement agencies in the state, it can potentially receive arrest cards and latents from any law enforcement agency in the state. Because of the limited scale of their latent fingerprint activities, however, DCJS is concentrating on a regional area of the state which contains a large central city (the City of Rochester) and the surrounding suburban area. In addition to arrest cards and unidentified latents, cooperating agencies are submitting latents identified with suspects for use in research at the division.

Retrieval

After completing a fingerprint search, the general purpose computer (Burroughs B-6500) prints a list of potential matches with their corresponding identification numbers and reel and frame numbers for use in retrieval. At present, microfilm images are retrieved on a Kodak Miracode system. The corresponding reel and frame numbers are manually entered and candidate images are retrieved for visual examination by a fingerprint examiner. Several other types of micro-image retrieval systems could be used for this purpose.

Verification

After a tentative identification has been made on microfilm, the examiner may obtain a hard copy printout of the image or

As a display system, the closed circuit television offers the following advantages:

- -- no photographic processing required
- -- clarity of smudges and uneven inkings improved
- -- quality of lifted and photographed latents improved
- -- negative prints can be reversed
- -- prints can be magnified up to forty times
- -- minutiae previously encoded are indicated.

The minicomputer and system controller act as the system bookkeepers and offers numerous features:

- -- monitors operator procedure for errors
- -- indicates corrective action for errors
- -- formats and organizes encoded data
- -- accepts numeric and special fingerprint identifiers from the keyboard
- -- accepts up to 80 minutiae per print
- -- scales, rotates, and translates minutiae data to a standard coordinate system
- -- provides an encoding circle for operator
- -- provides an orientation circle to aid operator in determining the core direction
- -- allows operator to delete questionable minutiae
- -- allows operator to improve accuracy of a previously encoded minutia
- -- generates line between two specified points for ridge counting.

Operator fatigue is an important factor in all manual encoding systems. The following features reflect some of the human factors considerations:

- -- a treadle controlled vacuum system is provided to hold cards or photographs
- -- built-in calibration circuitry is provided for checking the closed circuit television
- -- the television camera is located on a separate table to minimize camera vibration
- -- error lights and system controls are easily accessible to the operator.

Exhbit 2-7-1: Features of SAFES, Semi-Automated Fingerprint Encoding System

retrieve the original hard copy for final verification. If a hit is made, the examiner may then either prepare evidence for court or notify the local police agency that an identification has been made and send supporting documentation to the agency.

Encoding

Along with searching, encoding is one of the key elements in a latent fingerprint system. Semi-automated encoding of fingerprint information is accomplished on the SAFES system as described above.

The encoding procedure involves finding the core location and orientation and delta location(s), orientations and minutiae locations. A circle of adjustable radius centered on the core delimits the area of the print in which minutiae are encoded. After a minutia point has been successfully encoded, the computer outputs a small dot at its location to prevent the operator from encoding the same point twice. At any time during the processing, if the operator is dissatisfied with his placement of a minutia location, he may delete that point or adjust its location a small amount.

The encoding process is estimated by DCJS to require somewhat less than 2 minutes per finger, or 8 to 10 minutes per fingerprint card. In addition to the minutia encoding capability, the equipment can perform ridge tracing and ridge counting. In the ridge tracing mode, the operator traces ridges with the cross hairs, while the computer incrementally outputs coordinate data. The eventual use of the ridge tracing information has not been decided but it is thought that it may be useful in developing a classification system. The ridge counting mode allows the operator to draw a line from the core to one or more deltas. He then counts the ridges either manually or by successively placing the cross hairs over each ridge along the ridge count line. Both the ridge counting and the ridge tracing modes will be used primarily for collecting research data.

Searching

Storing of the data base and file searching will be performed on the division's general purpose computer. Once a suitable data base and input latent fingerprints are encoded on the SAFES system, considerable development and testing must be done on the computerized search program. Two alternative programs have been written and tested (one at DCJS and the other at the National Bureau of Standards) using data obtained with the old digitizing system. As a starting point, these two programs will be retested with data obtained on the new system.

The basic search method of each of the search programs consists of an exhaustive comparison of minutia points between the inquiry latent and entries in the file to derive a matching score. In the search program developed by DCJS, the score is simply the proportion of minutiae points of the input argument that have a matching corresponding point in the file. The algorithm in Matcher 19 (the NBS Program) is somewhat more complicated in that a closeness score is derived for each matching pair of points. These scores are then combined to form a total resulting score. In an operational configuration, the computer would then output a list of most probable matches, which fingerprint examiners would verify using an automatic fingerprint retrieval device.

One of the central problems with an exhaustive search such as that described above is the considerable computer processing time involved. To improve processing time, classification information such as pattern type, ridge count, core delta distance, and ridge flow information could be used to divide the file into classification subpockets before the exhaustive search is conducted.

DCJS has yet to develop a satisfactory classification method using minutiae data. This, along with the most efficient use of classification type data, will be one of the highest research priorities at the division.

RESEARCH ACTIVITY

Research at DCJS in the near future will concentrate on three activities:

1. As soon as a substantial data base is encoded with the new system, an experiment of the type similar to that reported in Appendix A will be rerun, hopefully resulting in greater system accuracy.

2. A human factor analysis of the encoding equipment will be performed. The analysis will measure such things as sustained rates of coding, fatigue factors, effects of differences in room lighting, and the convenience of placement of the operator controls in the system. The result of the human factor analysis may be used to redesign the equipment for future modifications and possible production equipment.

3. A model operational system will be designed to include flowcharts of procedures and an analysis of time factor and workloads. The analysis will result in a detailed cost and personnel breakdown of the operations of a production system.

Long range research activity will include testing the compatibility of the SAFES system with the automatic encoding system at the FBI (the FINDER System). It is hoped that the two systems can be made compatible so that the FINDER system would be able to encode arrest card data bases automatically. The SAFES equipment would then be used to encode minutiae data from latent fingerprints which were of such poor quality that they would be unsuitable for automatic analysis. The use of automatic encoding of the data base would greatly reduce the workload of the SAFES system.

Another area of long range research will be the improvement in search algorithms and the more efficient use of gross descriptions and classification data. Eventually, it is hoped that the SAFES system will become an operational latent search and retrieval system to be operated by the New York State Identification Bureau for all cooperating law enforcement agencies in the state.

Section 3

ACCURACY ANALYSIS

The purpose of the following analysis is to compare as much as possible the relative accuracies of the experimental latent fingerprint systems discussed in the previous sections. A manual classification system implemented on automatic search equipment will also be presented as a basis for comparison. From a comparative analysis of the automated systems with the manual system, potential benefits for completely automating the latent fingerprint classification and search procedures can be estimated.

It should be noted that while the accuracy results presented in this chapter represent actual experimental results conducted by the various research organizations, they are not comparable with each other because of the differences in data base and test sets. The specific differences will be pointed out later in this section. Actual accuracy performance of production models of systems which may be developed in the future may show significant improvements over those shown here.

ACCURACY ANALYSIS

The relative accuracies of several experimental systems are displayed graphically in Exhibit 3-1. (The NCIC system, corresponding to one of the curves, is explained below.) The exhibit contains graphs of reliability (the probability that the correct match will be identified in a list of candidates) versus selectivity (the fraction of the library which must be visually reviewed by a fingerprint technician). With the exception of the curve for DCJS (New York State Division of Criminal Justice Services), all the plots represent data for searching single rolled prints against a file of rolled prints. The curve for DCJS represents the searching of actual latent fingerprints against a file of rolled prints. The latents used include actual crime-scene prints, elimination prints (i.e., prints of persons with previous legitimate access to the crime scene), and fingerprints of division personnel lifted from desks and other objects within

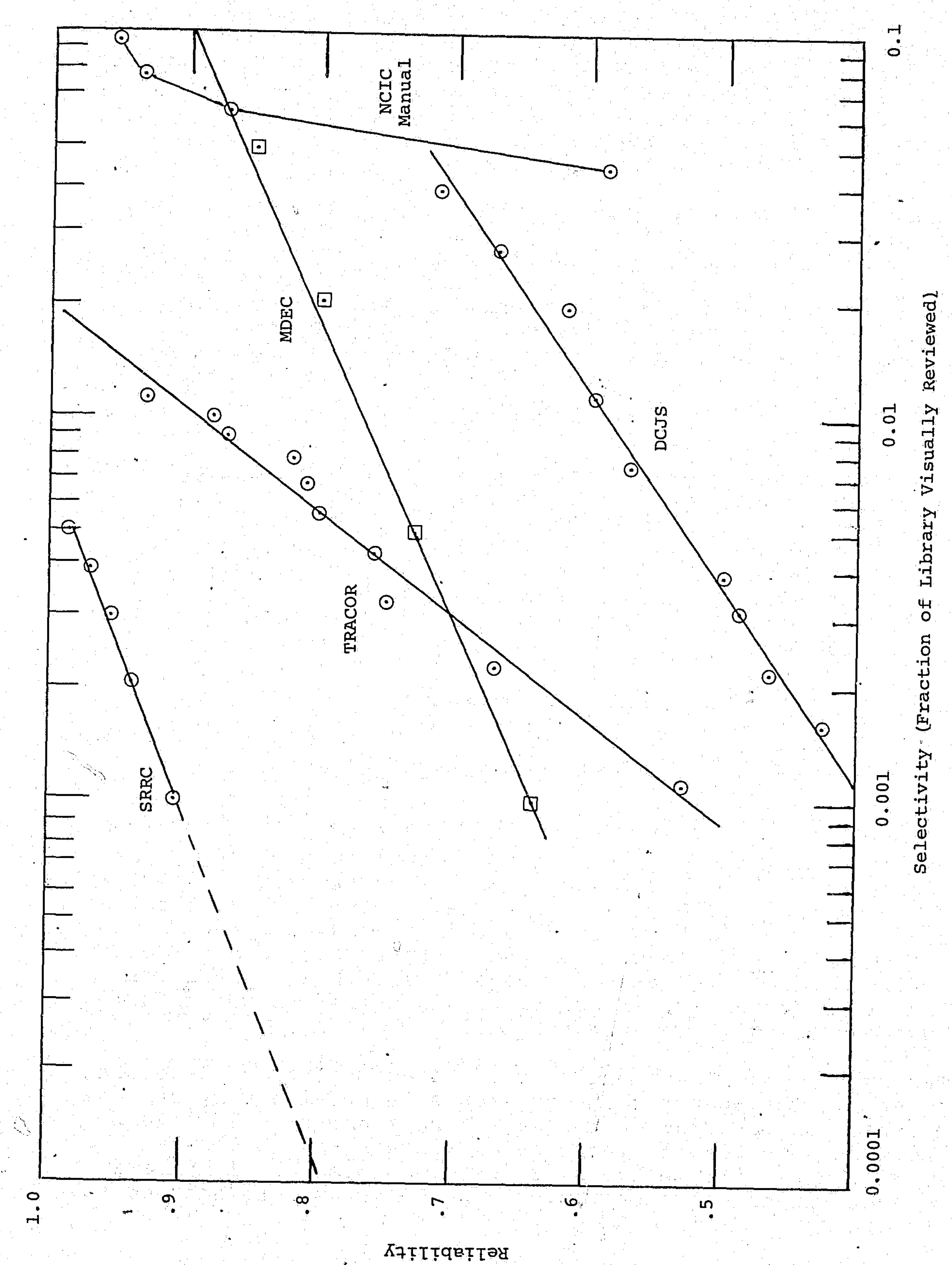


Exhibit 3-1. COMPARATIVE ACCURACIES OF SINGLE PRINT SYSTEMS

the department. The relatively poor performance by DCJS is accounted for largely by the difficulty in handling the poor quality of latent prints. No experimental results of searching single fingers against a file were available for the KMS Technology Center, the First Ann Arbor Corporation, or Argonne National Laboratory. Therefore, these agencies were not included in the comparison.

Exhibit 3-1 is constructed by plotting the fraction of the library which must be visually reviewed in order to obtain a given reliability. For example, in the TRACOR test reported in the previous section, 54% of the correct matches were in the first place on a candidate list taken from a file of 894 single prints. Therefore, if the proportion 1/894 (.11%) of the file is visually inspected, then 54% of the true matches will be located. If the first two candidates are inspected, then the reliability increases to 67% at a cost of viewing 2/894 (.22%) of the file.

From inspection of the exhibit it is clear that curves lying above and to the left of the others show superior performance. For example, if a reliability of .9 is desired and a file of 10,000 single prints must be searched, one would have to visually inspect 10% of the file or 1,000 cards using the MDEC (McDonnell Douglas Electronics Company) technique, 7% of the file or 700 cards for the NCIC system, 100 cards with the TRACOR system, and 10 cards with the Sperry system.

Sources and Limitations of Accuracy Data

Before forming conclusions concerning the data in Exhibit 3-1, it is important to consider their limitations:

Sperry Research Center

Data for the Sperry system were obtained directly from the Sperry Research Center and are described in Section 2-6. The data base and test set consisted of the 100 card test set for the Project SEARCH Holography Study, and represent an accurate cross-section of the contents of a state identification bureau. The test set consisted of both good and extremely poor quality fingerprints and therefore constituted an accurate basis for the results.

Two factors may have tended to overstate Sperry's performance, however. The Sperry technique tends to provide very strong matches for patterns of the same finger number. For example, index fingers tend to match index fingers and thumbs tend to match thumbs. Since the file was made up of equal numbers of each finger (all ten fingers on 100 cards were encoded to

comprise the 1000 finger data base) the Sperry results do not accurately reflect a situation where a finger number was known and a search was made only of the same corresponding finger. Another consideration is that approximately 5% of the inquiry cards were not processed due to low level of quality. If these cards were counted as misses, the entire Sperry curve would be lower by .05, which would still leave it the highest curve on the graph.

MDEC (McDonnell Douglas Electronics Company)

The data for MDEC was taken directly from Figure 13b, page 36, from their paper presented at the 1972 Carnahan Conference, (Reference 1). The data represents the reliability and selectivity of the MDEC approach within Henry Primary subpockets of the 10,000 card base file. The selectivity cannot be calculated on the basis of the entire file (Figure 13a of the paper) because the Henry Primary uses information on all ten fingers which is not available for a latent search. However, the results may understate MDEC's capability because within the Henry sub-file, similar pattern types are compared. That is, whorls are compared only with whorls and non-whorls with non-whorls. On the other hand, a factor which tends to overstate their performance is that they could select any one of the 10 fingers available on a fingerprint card and therefore, could select the best available quality prints.

TRACOR

The TRACOR test results were those reported in the final report submitted by TRACOR to the Texas Department of Public Safety (see Reference 14). According to Dr. Welch, whose review is attached to the TRACOR report, the fingerprint file of 894 single prints was selected to be generally of good quality and to be representative of the pattern types found in the Texas Identification Bureau. The test set which contained 83 known matches in the library, was also selected to be of good quality but contained a few unusual patterns such as an acid burn and a print where the ridges were not formed at birth. Also some inquiry cards contained smears or were lightly inked. The TRACOR results may be overstated relative to both Sperry and MDEC who used a representative library file containing both good and poor quality prints. The test set for the TRACOR experiment was also unusually low in loop patterns which are most difficult to search.

DCJS (New York State Division of Criminal Justice Services)

Data for DCJS results are taken from Appendix A of this report which was prepared by Frank Madrazo of DCJS. These data are undoubtedly an understatement of the capabilities of DCJS since actual latent fingerprints were used as search prints whereas in all other cases rolled ink prints were used as both the inquiry and library set. Even though some of the latents were of extremely poor quality all of them were coded and searched. It should be noted that the data for the experiment were collected on equipment which preceeded the present SAFES system. The old system lacked many of the improved features of the new system including a memory feature which prohibits the operator from encoding the same point twice. The test will be re-run in the near future with the new equipment resulting, hopefully, in improved results. Because of these many problems, lower reliabilities than those used for the other systems were used for DCJS in the cost analysis in this section.

NCIC Manual System

To provide a comparison against which the experimental systems could be measured, results of a system which uses manual encoding of fingerprints is included in Exhibit 3-1. Appropriate data for operational manually encoded latent systems such as Kodak Miracode were not available. However, reliability and selectivity data on the NCIC fingerprint system were available for the Project SEARCH State Identification Bureau project (Reference 6). The NCIC system uses codes for pattern type, ridge count on ulnar and radial loops, and tracings on whorls. The system thus closely approximates the common 3-digit Miracode coding system developed by the Atlanta, Georgia Police Department except for the coding of core type. Although the NCIC system is basically a 10-finger system, each finger has a separate code and, therefore, can be used as a single finger system.

The four points plotted on Exhibit 3-1 represent the reliabilities and selectivities associated with various tolerances on ridge counts. The lowest point corresponds to no tolerance on ridge count, the second point corresponds to a tolerance of ±1, the third to ±2, and the fourth to ±3. With a tolerance of ±3, 95.5% of the possible "hits" would be made. The remaining misses occur because of differences in pattern type, tracing, or a ridge count difference greater than ±3.

The selectivity of the NCIC system was based on the distribution of patterns and ridge counts on the right index finger, which is the most selective finger.

When using this NCIC manual system as a basis of comparison it should be kept in mind that it does not truly represent the full potential of manual latent systems. Another important limitation in this data is that the reliability measurements were done with high quality fingerprints and by having two separate technicians classify the same identical print. Therefore, differences in subsequent impressions of the same finger would not be accounted for.

CONCLUSIONS

Conclusions concerning the relative accuracy of the single finger systems are difficult to draw because of the substantial differences in test data and procedures which produced the test results. However, several of the automated systems demonstrate a superior performance over the manual NCIC system.

To obtain a complete comparison of the systems, a cost and timing analysis should be performed to derive the system operating costs for various workloads and file sizes anticipated in user agencies. Insufficient data were available to perform such an analysis for this report.

Section 4

SUMMARY OF SYSTEM ADVANTAGES AND DISADVANTAGES

In evaluating the progress of automated fingerprint searching and its application to latent fingerprints, it is instructive to consider the various advantages and disadvantages of alternative technical approaches.

The approaches described in the previous sections can be grouped into two major categories: optical comparison techniques, and scanning followed by digital data abstraction and comparison. The optical technique is represented by KMS Technology Center and McDonnell Douglas Electronics. The other five systems are all in the digital category.

The discussion of advantages and disadvantages of approaches, which follows below, will first center on the general differences between optical and digital techniques, then on differences among the approaches within each category.

OPTICAL VS. DIGITAL

Optical Comparison Technique

Advantages

- Optical systems have demonstrated a capability to handle the poor quality of latent prints, however, the better the quality of the latent, the better the system will perform. (See The New York City acceptance test for the MDEC system, Appendix B.)
- Since the library data base is maintained as individual records (aperture cards or slides), it is easy to maintain and purge.
- Visual comparison of potential match candidates can be accomplished rapidly because candidate records are physically segmented by the search process. No time is lost searching rolls of film or retrieving cards from files.

Disadvantage

- Because of the requirement of passing each library image through a laser light source, search times are long and require substantial operator labor. Improvements in search speed are limited by mechanical methods of card handling.

Scanning and Digital Encoding

Advantages

- The digital approach uses software processing, thereby taking advantage of rapid advances in mini-computer technology. In may cases the only specially built equipment is the fingerprint scanner. Commercially available scanners suitable for fingerprint work may even be on the market in the near future.
- Since software processing is used, improvements in speed and accuracy can be incorporated into the system at a later time with minimal additional cost.
- Hard wired processing modules could be added to systems in large agencies to improve processing and search speed.
- As evidenced by test results on single rolled prints presented in this report, digital processing may offer reliabilities and selectivities beyond those attainable with optical processing.
- Operational and acquisition costs of minimal systems are reasonable and well within the budgets of many state and municipal law enforcement agencies.
- Because latent prints are digitally encoded, computer files of latents for unsolved cases can be maintained. Incoming arrest cards can be searched against these latents when they arrive at the bureau. In optical systems, unsolved latents would have to be stored and only periodically searched against new file entries, since the systems are not designed to search incoming arrest cards against latents.

Disadvantage

- It is not known whether or not digital scanners can successfully deal with the poor quality of latent prints. The old model of the DCJS system is the only digital system tested with latents as opposed to single rolled prints; to date, their results are not impressive.

COMPARISON OF OPTICAL TECHNIQUES

KMS Technology Center

- The KMS system was designed as an identification system using all ten fingers at one time. The system as designed is probably not suited to latent fingerprint searching.

McDonnell Douglas Electronics Company

- The system used in the SEARCH Holography Study was designed specifically as a single print latent system.
- The system's capabilities in latent fingerprint searching have been sufficiently demonstrated to the New York Police Department to warrant full-scale operational use of the system. The experience in New York will provide invaluable data concerning the system's true operational cost and effectiveness.

COMPARISON OF DIGITAL TECHNIQUES

Sperry Research Center

Advantages

- To date, the Sperry system has demonstrated the best reliability and selectivity results based on single rolled fingerprints. Its capability to successfully encode and search latent prints is unknown.
- Ridge angle measurements as used by Sperry are relatively easy to make from fingerprint patterns, thereby minimizing the complexity of the print digitizer. The Sperry system would probably be able to process partial latent fingerprints as long as a core area of the print was available. The core area would be required by the system software for orientation of the print angles.
- The Sperry ten-finger print system could be used to digitize and search latent fingerprints. A special latent print data base may have to be built and maintained separately from the main identification files since the information in the latent system is considerably different from that stored in the ten print system. However, additional equipment would not have to be purchased.

Disadvantage

- As presently designed, the storage requirements are high. The 250 eight-bit angle measurements per finger total 2000 bits of information, which is comparable to the requirements of a minutiae-based system.

TRACOR

Advantages

- TRACOR shares some advantages with the Sperry system since the basic technique of angle comparison is the same.
- Angle measurements are much coarser than in the Sperry system (nearest 22.5° as opposed to 1.5%) resulting in the relatively small storage requirement of 216 bits per finger.

Disadvantages

- The coarse angle measurement, while reducing storage requirements, probably also caused the relatively poorer accuracy performance as compared to the Sperry system.
- The use of a delta in print alignment reduces the systems value as a latent system since many latents do not contain a delta. A different alignment procedure could overcome this problem, however.

First Ann Arbor Corporation

Advantages

- The system relies on data contained within a circular mask centered on the core and therefore, may have potential latent print capability since the core area is often available.
- The storage requirement for library prints is very low, 70 to 105 bits per finger depending on the desired number of classification cell categories.

Disadvantages

- The system has not been adequately proven. Test data bases were so small that assessments of reliability and selectivity were not possible.

- The system as presently designed requires manual centering of the mask, thereby increasing scanning time and cost. Manual centering also introduces a potential source of coding errors, which First Ann Arbor Corporation did not conclusively demonstrate could be adequately handled by their system.

New York State Division of Criminal Justice Services

Advantages

- Because it is semi-automated, the system will probably be able to handle poor quality latent prints typically found in crime scenes which are unprocessable by automatic methods.
- The SAFES equipment has an extremely clear, high resolution image of the fingerprint which enables the operators to work at maximum efficiency. The equipment also has a number of convenient operator aids in the encoding process.
- The data encoded on the SAFES system has a high potential of being compatible with that automatically encoded by the FBI FINDER system. These systems may, therefore, eventually complement each other in that the semi-automated approach would be used to encode prints unacceptable to the automatic system, whereas the automatic system would have the speed and economy to encode large data bases.

Disadvantages

- Because of the operator involvement, the encoding time is large, estimated to be between 8 and 10 minutes per fingerprint card. A technician would also require a rest period between every 2 or 3 prints to prevent fatigue. On the average, 35 fingerprints per day could be encoded by a single technician on a regular basis. This substantial drawback would apply only if the system were not compatible with the FINDER system which could automatically encode the data base. In that event, the time involved in encoding input latents would not be a problem.

Argonne National Laboratory

- ANL does not have a particular single print system or technique characteristics of the other systems described. They do have a general-purpose image processing system, ALICE, which is well suited to fingerprint research.
- The main distinguishing feature of the ALICE system is the combination of automated scanning with a man-machine interaction capability. The system may have potential in digitizing low quality latent prints with its manual interaction capability.
- Scanning for the TRACOR experiment was done using the ALICE system on a rental basis.

Section 5

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

From the preceding discussions of research and development activities by governmental agencies and private industry, and the results of an accuracy analysis, the following conclusions can be derived:

- The "Latent Value Study," (see Reference 4) conducted by NYSIIS establishes the value of an effective latent print searching system in identifying criminal offenders and clearing cases in which no other useful evidence is available.
- Useful fully-automated latent print search systems are commercially available or very close to being available for relatively low cost.
- No latent system which will retrieve one true match in a file with close to 100% reliability is near accomplishment. However, further research and development would undoubtedly improve the reliability and selectivity of present experimental latent systems. Many different technical approaches appear to have merit.
- Research and development programs primarily aimed at 10-finger identification have produced capabilities to search single fingers against a library file. However, the latent application is at least an order of magnitude more difficult than 10-finger identification since usually only one or a few latent prints are available for search and the prints themselves exhibit distortions, smearing, and lack of ridge information far worse than inked prints. Because of the special problems associated with latents, especially in attempting to automatically scan and digitize them, research programs should be structured to meet these specific problems.

- Accuracy results based on single rolled prints are not comparable among latent systems because of the lack of standardization in library data bases and test prints. Adequate testing using actual or simulated latent prints has not been accomplished for most systems discussed in this report.
- Semi-automated minutiae encoding appears feasible. Effectiveness in search system and compatibility with automated encoding remain to be tested.
- Most organizations surveyed, both governmental and private, have expressed interest in conducting further research and development on latent fingerprint searching. Private industry is willing to invest in such projects if national funding agencies (LEAA or NILECJ) indicate an interest in pursuing the problem.
- Although the FBI FINDER system was not directly studied in this report, the committee can see no reason why the existence of FINDER should limit fingerprint research or the purchase of fingerprint devices by state or local law enforcement agencies.

RECOMMENDATIONS

The following recommendations are presented for the consideration of the National Institute of Law Enforcement and Criminal Justice (NILECJ):

- Because of the recognized need for effective latent fingerprint searching systems and the encouraging results of experimental systems as described in this report, NILECJ should continue its support of latent fingerprint research.
- A coordinated program for supporting latent fingerprint research and development should be established and contain the following key features:

  1. NILECJ should sponsor an experiment to compare accuracies of prototype latent systems using a standard data base of fingerprint cards and a standard set of actual or simulated latent prints. The

latents should represent a cross-section of prints found at crime scenes which are of sufficient minimum quality to serve as evidence in court.

The experiment would accomplish the following;

a. Assess on an equitable basis the present capabilities of manual, semi-automated, or fully-automated systems.

b. Assess the operational costs of latent systems.

c. Encourage the investment of private capital in latent fingerprint research and development.

d. Establish a data base and test set for evaluating improvements in latent systems for years to come.

All types of latent systems including manual, semi-automated, and fully-automated systems should be included in the experiment. A special effort should be made to include the FBI FINDER system in the experiment.

2. In conjunction with Part 1, a study should be undertaken to determine the composition of a representative sample of latent prints. Based on the results of the study, the latent print test set should be constructed from actual crime-scene latents, elimination prints, or purposely produced and lifted latents as deemed appropriate by the study. A master fingerprint library representative of the patterns and varying quality of fingerprint cards found in state or municipal identification bureau files should also be selected.

3. NILECJ should financially support research and development projects which demonstrate promising results in the experiment.

4. Based on the evaluation of user groups (such as Project SEARCH), LEAA should encourage the construction of prototype equipment for installation and test in operational agencies.

5. NILECJ should selectively support research and development projects which may greatly improve latent print searching systems in the long term even though they have not demonstrated a capability at the time of the experiment. As soon as possible, these systems should be tested with the standard data base and test latents developed for the experiment.

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Appendix A

AN EVALUATION OF AN AUTOMATED FINGERPRINT MATCHER PROGRAM APPLIED TO LATENT FINGERPRINTS

By

Frank Madrazo

and

Richard Higgins

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AN EVALUATION

OF AN

AUTOMATED FINGERPRINT MATCHER PROGRAM

APPLIED TO LATENT FINGERPRINTS*

BY

FRANK MADRAZO

RICHARD HIGGINS

SUMMARY:

Data is presented resulting from an evaluation of an automated fingerprint matcher program as applied to a latent fingerprint system. Parameters evaluated are: minutiae location, ridge flow direction, minutiae types, and pattern types. Data is presented on the results of searches utilizing a test file of 94 latent fingerprints with the corresponding inked fingerprints. Data is also presented on the searching of latent fingerprints against a base file of 2,526 inked impressions.

INTRODUCTION:

An effective latent search program must make an "acceptable" percentage of hits with only a limited number of false retrievals. One procedure to pragmatically determine these statistics for any particular search program, is to code a sample file of known latent identifications and to search these against a file containing the corresponding inked (rolled) prints.

The main objective of the work described in this paper was to test a computerized search procedure for latent fingerprints. Secondary objectives included an evaluation of the use of the ridge flow direction angle and minutia type as search parameters.

The particular seach program chosen for evaluation in the latent fingerprint context was described by J.H. Wegstein in National Bureau of Standards Technical Note 538 "Automated Fingerprint Identification." Mr. Wegstein named the basic program "Statistical Matcher M-19."

For purposes of this study, we produced an Algol version of M-19 for use on the Division of Criminal Justice Services (DCJS) general purpose computer system.

*The work described in this paper was performed as part of New York State Division of Criminal Justice Services research into the feasibility of an automated latent fingerprint processing system.

PROCEDURE:

A sample file of 94 known idents were coded and searched against another file of 94 corresponding inked impressions. In addition, one phase of the test involved searching some of the latents against a larger sample file of 2,526 inked impressions.

Of the 94 latents coded for the sample:

32 were past DCJS idents
23 were elimination idents
29 were DCJS personnel idents.

Coding the Prints (Latents and Inked)

The inked prints and latents were microfilmed and then projected on the projection screen of a semi-automated digitizer at an approximate 8.4 magnification. First, the classifier entered a pattern type and finger number for each finger. A core point and a point to describe the orientation were then coded. The core point was the origin of the system and the orientation point, together with the core location, described the negative Y-axis. All minutiae found in a coding circle of 1.2 inch radius were then coded and oriented in this X-Y system. For each minutia point, a ridge flow direction point was also coded.

File Characteristics

Pattern Type

The pattern types of the 94 latents used in the sample were:

Right Slant Loop	32
Left Slant Loop	33
Whorls	28
Double Loop	1

Minutiae Point Counts

Table 1 illustrates the minutiae point count distribution of the 94 inked rolled prints, while Table 2 is the distribution found for the 94 latents.

The overall average point count of the 94 inked prints was 8.2 points. This average compares exactly with the 8.2 average point count previously calculated using data from a file of 17,767 inked prints.

TABLE 1

POINT COUNT DISTRIBUTION OF INKED PRINTS

No. of Points	Left Slant Loop	Right Slant Loop	Whorl	Double Loop	Total
0	1	0	0	0	1
3	3	2	0	0	5
4	4	2	3	0	9
5	5	3	3	0	11
6	3	3	2	0	8
7	4	3	4	1	12
8	4	6	1	0	11
9	1	4	2	0	7
10	3	1	2	0	6
11	1	3	2	0	6
12	0	1	1	0	2
13	2	4	3	0	9
14	1	0	0	0	1
15	0	1	3	0	4
16	0	0	1	0	1
22	0	0	1	0	1
TOTAL	32	33	28	1	94
AVERAGE	6.8	8.3	9.6	7.0	8.2

Overall Average Point Count 8.2

TABLE 2

POINT COUNT DISTRIBUTION OF LATENTS

NO. OF POINTS	RIGHT SLANT LOOP	LEFT SLANT LOOP	WHORLS	DOUBLE LOOPS	DCJS IDENTS	ROCH. IDENTS	PERSON-NEL IDENTS	TOTAL
1	1	0	0	0	1	0	0	1
2	1	0	0	0	1	0	0	1
3	3	5	2	0	4	4	2	10
4	5	3	2	1	4	2	5	11
5	3	2	4	0	2	4	3	9
6	3	6	3	0	3	1	8	12
7	5	2	4	0	3	3	5	11
8	3	5	2	0	2	3	5	10
9	5	4	2	0	5	4	2	11
10	0	1	1	0	1	0	1	2
11	2	3	2	0	5	0	2	7
12	0	0	3	0	0	0	3	3
13	0	0	0	0	0	0	0	0
14	0	0	1	0	1	0	0	1
15	0	0	1	0	0	0	1	1
16	1	0	1	0	0	0	2	2
17	0	1	0	0	0	1	0	1
18	0	0	0	0	0	0	0	0
19	0	1	0	0	0	1	0	1
TOTAL	32	33	28	1	32	23	39	94
AVER.	6.5	7.3	8.0	4.0	6.9	7.1	7.5	7.2

OVERALL AVERAGE POINT COUNT 7.2

The latent point count was also representative of latents found at crime scenes. Forty (40) latents coded and searched in a previous study had an average point count of 6.9, while the 94 latents in this study had an average point count of 7.2.

RESULTS OF PROGRAM EVALUATION:

Minutia Location (94 vs 94):

The test procedure required that if we were to evaluate the program's potential for latent searching, we would have to determine the most favorable value for the following two program defined tolerances:

1. The distance allowed between matched minutia points (TOL).

2. The area which defines a cluster or incremental tolerance (KR).

First we tried the original values (60 TOL and 10 KR) used in Wegstein's Technical Note. As Table 3 indicates, the results with these tolerances were not acceptable. For instance, only 14 latent prints out of a possible 94 were the top score when searched against the base file of 94 corresponding inked prints. This corresponds to roughly a 15 percent "hit" rate. Analysis of this data showed that this result was probably due to a difference in scale between Wegstein's data and ours. We next attempted a tolerance of 35 units (0.01 inch). This tolerance had been used in previous CRB search programs. Since this 35 produced favorable results, we continued with it and worked up and down to find an acceptable incremental (KR) tolerance. Table 3 illustrates that with tolerances of 35/25, 33 out of the 94 latents were the top score. In other words, there were no false retrievals for these prints. The second column for each combination of tolerances is a cumulative percent of the total 94 prints. For instance, with 5 false retrievals (Ranking Score - 1), we would expect a hit rate of 51.1% with tolerances of 35/25.

All possible tolerances were not exhausted. It is entirely possible that another TOL tolerance would produce improved results. For instance, our previous results would indicate that a TOL tolerance of 25 should also be tested. Hopefully, the matched scores would remain high but the false retrievals would be lowered substantially. However, a complete search involves considerable computer time, so we felt the results with 35 were encouraging enough to continue with it through the other stages of testing.

The data presented in Table 3 is based upon a search of the 94 latents against the corresponding 94 inked impressions. The ridge direction angles were not used as search parameters in these searches.

Minutia Location (94 Latents vs 2,526 Inked):

The results of searching 94 latents against 94 corresponding ink prints were encouraging, but another question had to be answered. How well would the matched scores obtained on the 94 vs 94 run compare with the scores obtained on a latent searched against a larger file? To test this, the latents were searched against a file of 2,526 coded inked prints. For these searches, the ridge direction angle was incorporated into the search procedure. Table 4 illustrates the results with and without pattern type as a search parameter.

Of the 47 latents which had the highest scores in the preliminary search, 17 still had the highest score when searched against a large file. Table 4 illustrates that using pattern type as a gross discriminator, approximately 50% of the latents were found in the top 10 retrievals. Table 4 also indicates that an approximate 3% false retrieval rate would be required to operate at a 65% hit rate if we use pattern type. Of the 26 latents not searched against the large file, 17 scored 0 with its matched print on the 94 vs 94 original search, and 9 were of too poor quality to expend additional computer time.

Minutia Angle (Ridge Flow Direction) Evaluation:

The ridge angle is defined as the general direction of the ridge at each minutia location. After the operator codes a minutia point, he follows the general ridge flow and using well defined rules, codes another point a short distance away from each minutia point. This point and the minutia point form an angle with either the X or Y axis. As mentioned previously, it was one of the sub-objectives of this study to evaluate the use of the angle in the Wegstein type matcher as a search parameter for latents.

The ridge flow angle is not a precise measurement, because of operator variability and possible problems in definitions for semi-automated encoding. Therefore, instead of using discrete angular designations as a search parameter, our circle around each minutia point was divided into 64 parts of 5 5/8° each. In this program test, if the difference between two points was less than TOL and the difference between two ridge angles was less than plus or minus a parameter ANG, the minutia points were considered matched.

TABLE 3

LATENT SEARCH COMPARISON BY TOLERANCES

FALSE RETRIEVAL DISTRIBUTION

RANKING OF MATCHED SCORES	TOL/KR 60/10		TOL/KR 35/15		TOL/KR 35/20		TOL/KR 35/25		TOL/KR 35/35	
	NO. OF PRINTS	HIT RATE*	NO. OF PRINTS	HIT RATE*	NO. OF PRINTS	HIT RATE*	NO. OF PRINTS	HIT RATE*	NO. OF PRINTS	HIT RATE*
1	14	14.9	27	28.7	32	34.0	33	35.1	2	28.7
2	5	20.2	10	39.4	5	39.4	6	41.5		35.1
3	4	24.5	4	43.6	5	44.7	4	45.7	6	41.5
4	1	25.5	2	45.7	2	46.8	2	47.9	5	46.8
5	1	26.6	0	45.7	2	48.9	1	48.9	1	47.9
6	1	27.7	1	46.8	1	50.0	2	51.1	1	48.9
7	1	28.7	2	48.9	2	52.1	1	52.1	1	50.0
8	3	31.9	2	51.1	1	53.2	1	53.2	3	53.2
9	2	34.0	2	53.2	1	54.3	1	54.3	4	57.4
10	2	36.2	0	53.2	0	54.3	2	56.4	1	58.5
11	-	36.2	2	55.3	1	55.3	2	58.5	3	61.7
12	6	42.6	3	58.5	3	58.5	1	59.6	0	61.7
13	1	43.6	0	58.5	3	61.7	1	60.6	1	62.8
14	1	44.7	0	58.5	0	61.7	1	61.7		62.8
15	-	44.7	2	60.6	1	62.8	0	61.7	0	62.8
16	2	46.8	0	60.6	0	62.8	1	62.8	0	62.8
17	2	48.9	2	62.8	2	64.9	1	63.8	0	62.8
18	1	50.0	0	62.8	1	66.0	1	64.9	0	62.8
19	1	51.1	1	63.8	0	66.0	2	67.0	1	63.8
20	2	53.2	1	64.9	0	66.0	2	69.1	0	63.8
21+	14	100.0	33	100.0	29	100.0	29	100.0	35	100.0

*hit rate: Percent of total possible (94) latents ranked as top score during a search. The results are based on 94 latents searched against the corresponding 94 inked prints.

TABLE 4

LARGE FILE SEARCH RESULTS[1]

DISTRIBUTION OF HITS BY RANKING

Ranking of Matched Prints	No. of Hits W/O Pattern Type	Cummulative % (Hit Rate)[2]	No. of Hits With Pattern Type	Cummulative % (Hit Rate)
1	17	18.1	25	26.6
2	8	26.6	6	33.0
3	1	27.7	6	39.4
4	2	29.8	3	42.6
5	5	35.1	2	44.7
6	1	36.2	2	46.8
7	1	37.2	1	47.9
8	2	39.4	1	48.9
9	-	39.4	1	50.0
10	1	40.4	1	51.1
11-19	6	46.8	2	57.4
20-29	2	48.9	2	59.6
30-39	2	51.1	2	61.7
40-49	1	53.2	-	61.7
50-59	4	56.4	4	66.0
60-69	-	56.4	1	67.0
70-79	-	56.4	3	70.2
80-89	3	59.6	1	71.3
90-99	2	61.7	-	71.3
100 +	8	70.2	8	80.9
2,529	17	100.0	17	100.0

[1] 2,526 coded inked fingerprints

[2] The cummulative percentage is based upon the sum of the number of hits at any point, divided by the total number of latents(94).

As with the distance tolerance, there is no formula to derive an angle tolerance nor is there any accepted magic number for an angle tolerance. From previous data, we started with ± 10 parts. Working up and down from 10, we found our best results at ± 6. Table 5 compares the searches of the 94 latents against 94 inked prints with and without angles.

The data in Table 5 provides a summary of the minutia and angle data. It is apparent from this data that the angle is an important search parameter. Using the angle, 14 more latents became the top score. This continued down the ranking and added approximately another 15% to the hit rate at each retrieval level.

Minutia Type Evaluation:

When the two files were coded, the fingerprint classifier coded the minutia by its type; i.e., bifurcation or ridge ending. The search program was then modified to include a matching of these two codes before any further distance and angle comparisons were made. Table 6 compares the results with and without the use of bifurcation and ridge ending codes.

The data indicates that using the minutia codes, the hit rates decrease. This is to be expected. From a systems point of view, however, a basic question must be answered. Does the hit rate decrease enough to outweigh some benefits which may result if minutiae types were used? For example, there is the possibility that the search time could be lowered considerably.

In analyzing Table 6, we have to consider two important factors which may have had an effect on the results:

1. The rules for bifurcations were vague. We've coded minutia type all along but have not placed much hope on really ever using it.

2. As implied above, when these sample files were coded, we did not stress coding the minutia as accurately as possible.

TABLE 5

ANGLE EVALUATION

RANKING DISTRIBUTION [1]

RANKING OF MATCHED SCORES	W/O ANGLES Tol=35 HITS	Kr=25 CUM %	WITH ANGLES Tol=35 HITS	Kr=25 Ang=6 CUM %
1	33	35.1	47	50.0
2	6	41.6	5	55.3
3	4	45.7	2	57.4
4	2	47.9	2	59.6
5	1	48.9	3	62.8
6	2	51.1	1	63.8
7	1	52.1	5	69.1
8	1	53.2	2	71.3
9	1	54.3	1	72.3
10	2	56.4	1	73.4
11	2	58.5	1	74.5
12	1	59.6	0	74.5
13	1	60.6	1	75.5
14	1	61.6	0	75.5
15	0	61.7	0	75.5
16	1	62.8	1	76.6
17	1	63.8	2	78.7
18	1	64.9	0	78.7
19	2	67.0	0	78.7
20	2	69.1	0	78.7
21+	29	100.0	20	100.0

[1] The results are based on 94 latents searched against the corresponding 94 inked prints.

TABLE 6

MINUTIA TYPE CODING EVALUATION [1]

RANKING DISTRIBUTION

RANKING OF MATCHED SCORES	NO MINUTIA TYPE TOL/KR/ANG 35/25/6		MINUTIA TYPE CODED TOL/KR/ANG 35/25/6	
	Hits	Cumm %	Hits	Cumm %
1	47	50.0	33	35.1
2	5	55.3	7	42.6
3	2	57.4	2	44.7
4	2	59.6	6	51.1
5	3	62.8	5	56.4
6	1	63.8	-	56.4
7	5	69.1	3	59.6
8	2	71.3	1	60.6
9	1	72.3	1	61.7
10	1	73.4	-	61.7
11	1	74.5	-	61.7
12	0	74.5	2	63.8
13	1	75.5	-	63.8
14	0	75.5	2	66.0
15	0	75.5	-	66.0
16	1	76.6	-	66.0
17	2	78.7	-	66.0
18	0	78.7	-	66.0
19	0	78.7	-	66.0
20	0	78.7	-	66.0
21+	20	100.0	32	100.0

[1] The results are based on 94 latents searched against the corresponding 94 inked prints. Minutia types coded were ridge endings and bifurcations.

Summary Data (Comparison of Score vs False Retrieval Rates):

The data in Table 7 represent summary score and false retrieval results for 68 of the 94 latents used during this study. These results were obtained by searching the latents against the large base file of 2,526 fingerprints.

In this table, an ideal case for any particular latent (Column 1) occurs when the top score (Column 2) equals the matched score (Column 3). This indicates that there were no false retrievals. Columns 4 and 5 describe the effect of using pattern type as a gross descriptor.

TABLE 7

LARGE FILE SEARCH RESULTS

LATENT NO.	TOP SCORE	MATCHED SCORE	TOTAL FALSE RETRIEVAL	FALSE RETRIEVAL W/ PATTERN TYPE
1	16.34	14.56	3	0
2	22.37	21.30	1	1
3	24.40	24.40	0	0
4	17.5	9.98	22	10
5	21.25	17.21	1	0
6	27.26	27.26	0	0
7	21.60	6.47	50	5
8	22.31	17.90	4	1
9	20.79	8.88	96	34
10	19.67	19.67	0	0
11	24.00	16.07	4	2
12	30.36	15.53	7	4
13	29.06	29.06	0	0
14	23.00	20.77	4	3
15	34.87	34.87	0	0
16	35.14	14.06	119	50
17	13.01	3.67	154	53
18	21.81	11.95	6	2
19	17.09	5.39	159	54
20	20.05	4.62	86	29
21	31.11	14.35	9	2
22	11.91	10.12	3	1
23	22.10	10.67	33	9
24	14.27	4.10	176	57
25	25.59	25.59	0	0
26	20.95	16.15	5	3
27	18.70	10.32	56	19
28	19.92	11.33	23	3
29	23.69	9.34	51	15
30	25.83	17.03	2	0

TABLE 7 - Continued

LATENT NO.	TOP SCORE	MATCHED SCORE	TOTAL FALSE RETRIEVAL	FALSE RETRIEVAL W/ PATTERN TYPE
31	22.11	22.11	0	0
32	19.15	8.40	86	32
33	37.95	37.95	0	0
34	18.26	7.84	83	29
35	11.84	.40	91	13
36	31.85	41.85	0	0
37	22.26	15.23	1	0
38	20.71	20.71	0	0
39	17.09	16.20	1	1
40	17.21	9.11	19	8
41	14.91	8.64	50	14
42	27.87	17.77	7	2
43	13.33	3.31	48	14
44	26.9	16.98	14	2
45	20.8	8.30	37	7
46	24.4	24.40	0	0
47	18.88	13.82	16	4
48	20.40	19.80	1	0
49	21.67	10.73	19	2
50	14.62	13.78	4	0
51	35.99	35.99	0	0
52	16.17	16.17	0	0
53	31.61	31.61	0	0
54	15.29	10.78	15	6
55	16.67	2.11	186	61
56	23.95	6.58	172	73
57	20.60	14.05	16	5
58	20.59	20.59	0	0
59	18.69	18.19	1	0
60	25.21	25.21	0	0
61	23.23	18.70	4	1
62	28.13	6.35	168	84
63	20.83	7.76	248	115

TABLE 7 - Continued

LATENT NO.	TOP SCORE	MATCHED SCORE	TOTAL FALSE RETRIEVAL	FALSE RETRIEVAL W/ PATTERN TYPE
64	19.43	5.40	198	79
65	17.34	1.38	214	70
66	25.61	21.41	1	1
67	29.77	24.00	1	0
68	20.51	20.51	0	0

DISCUSSION:

The foregoing has described an attempt at evaluating an automated method for searching latent fingerprints using minutia location, ridge direction angle and pattern type.

When analyzing the data, it is important to keep in mind that because of the constraints of computer storage and search time and available encoding equipment, the number of minutia points coded for individual latent and base file prints was small, 7.2 and 8.2 respectively. This most likely would have a negative effect on the performance of the cluster type Matcher M-19.

A second negative effect on the performance data derives from the nature of the encoding equipment used. The off-the-shelf digitizer used had no memory cues to tell an operator when a minutia point had been encoded.

This could lead to a duplication of encoded points, or more seriously, the neglect of coding validly occurring minutia.

A third parameter having an effect on the data is the orientation scheme. Performance of minutia matchers of the M-19 type is sensitive to orientation differences between the suspect and base file prints.

We anticipate that each of the foregoing problem areas will be diminished with the use of a semi-automated encoder currently being evaluated by DCJS. This encoder should allow us to encode a larger area of the fingerprint (including more minutiae) more accurately, since it contains provisions for memory cues and a more reliable orientation technique. We intend to repeat the experiments described above during our evaluation of the new encoder. We also will attempt to incorporate additional discriminators into the search argument such as core-delta distance.

Appendix B

RESULTS OF NEW YORK CITY'S ACCEPTANCE TEST

OF THE McDONNELL DOUGLAS LATENT COMPARISON SYSTEM

Printed by Permission of
The City of New York Police Department

June 15, 1973

From: Commanding Officer, Identification Section,

To: Deputy Commissioner - Administration.

Subject: VISIT TO ST. CHARLES MISSOURI - QUALIFICATION TEST MDEC AUTOMATED RECOGNITION SYSTEM.

1. On May 29, 1973, Lieutenant James A. Ghericich and Detective Vincent J. Scalice, #1721, Field Services Unit, Identification Section, conducted a test of the MDEC automated fingerprint recognition system at the vendors plant in St. Charles, Missouri. The purpose of this test was to qualify the equipment for acceptance under an LEAA Grant. The test consisted of an attempt to identify 100 latent fingerprints against a data base of 2,500 fingerprint charts gleaned from the files of this department.

2. In the original test, 30% of the file data base would necessarily be examined in order to attain 79% effective operation. The breakdown was:

TOP 10%	10-20%	20-30%	TOTAL
55	16	8	79

This figure was considered unacceptable.

3. Upon completion of this test 15 poor comparisons or outright rejects were examined at random in order to ascertain if any specific patterns for failure could be established. Of the 15, 9 were found to possess poor quality diazo copies. These diazos were reproduced to the quality deemed satisfactory and re-run. Each of the 9 were now in the top 25% of cards .

CONTINUED

1 OF 2

achieving correlation and some fell less than 5% from the top. It should be noted that additional match cards of poor diazo quality remain as time precluded a re-run in every case. However, it is logical to presume that similar improvement may be expected due to the consistency already demonstrated. It appears that with quality control in the photographic process (diazo) an accuracy rate of 90% or more could be achieved if the top 20% of the respondents were viewed.

4. The system does not distinguish various fingerprint pattern types which is to say that two fingerprints dissimilar to the eye may indicate a close correlation when subjected to machine analysis. This is a distinct advantage as many unnecessary and time consuming examinations may be eliminated by utilizing a simple key punch program for the aperture cards which has already been written. Thus close correlation would be affected only on those type fingerprints wherein an actual match could occur. This would in turn, further reduce the number of comparisons required on the part of a technician performing the search.

5. During the ten days of testing, machine failure occurred only once due to a burned out switch resulting in 30 minutes of down-time. However, a continuous problem was noted in the machanical card handling system. MDEC recognizes fully the problems with this support system and has indicated that it will be satisfactorily re-designed prior to the delivery of the equipment.

6. Both Lieutenant Ghericich and Detective Scalice concur that the employment of this system could favorably impact our department in the fingerprint identification field. Basing this judgment on expertise in latent fingerprints and photographic sciences it is felt this could prove to be a major breakthrough in latent fingerprint identification.

7. In conclusion, it is our recommendation that if the vendor can correct the card handling problem as stated and our department can assure a quality control microfilm operation, this department should acquire the MDEC Automated Fingerprint Recognition System with the utmost dispatch under the LEAA Funding Grant tentatively approved. It should be noted that the quality needed for the microfilm should be undertaken by a microfilm corporation capable of producing a product to military specifications.

8. For your information.

END