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Automated Identification and Analysis of Fingerprints by Interferometry

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ABSTRACT: The intricate line pattern of epidermal ridges in a fingerprint can be transformed into a characteristic interferogram of the moiré type by superimposing a centrosymmetric reference pattern. The interferogram is then dissected automatically into an array of cells whose optical densities are translated into a sequence of binary digits. By this procedure, fingerprints are easily read, filed, and transmitted as well as analyzed, identified, and matched by microcomputers.

KEYWORDS: criminalistics, fingerprints, interferometry, automated identification and analysis

The analysis of fingerprints has become the standard method for the positive identification of individuals because of the variety and invariance of epidermal ridge patterns. They do not change with age and will grow again as they were before even after an abrasion of the fingertips' epidermis.

Fingerprint pattern analysis is used principally in criminal investigations and forensic medicine but also in genetics and anthropology, in much the same way as it was introduced by Francis Galton and Edward Henry before the turn of the century. In the past 20 years, intense research efforts have centered on designing an apparatus capable of identifying and analyzing fingerprints automatically to cope with the ever increasing volume of information in police work and to reduce the bias associated with a subjective interpretation. One has come to realize also that the individuality of fingerprints could form the basis of access control systems [*1*] if an instrument or apparatus were devised that could give a go/no go decision automatically, within a very brief interval after an access request by presenting a fingerprint, and necessarily within very strict confidence limits of performance.

Fingerprints are classified by assigning a letter or number code to each characteristic element or pattern observed (for example, T for the tented arch, R for the radial loop, W for the whorl, and so forth). The topological constraints on continuous line pattterns containing loops or whorls require that triradii exist, that is, star-like forms where a ridge branches into two. An important element in establishing a fingerprint code is the number of ridges between a triradius and the center of the whorl or loop. The final identifying formula for an individual's set of fingerprints is given as a sequence of code letters and numbers for all ten fingers.

The conventional system of fingerprint analysis is expensive since it requires highly trained

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personnel; it is slow since it is performed in specialized centers only. The inevitable consequence is a delay in the decisions rendered on the basis of fingerprint comparisons. Still more time-consuming is a search to find a fingerprint on file matching the print of a single finger. However, situations in which a presumed criminal has to be identified on the basis of a single imprint arise very frequently.

The relatively slow process of compiling and emitting data has spurred the development of computers that could, (a) recognize fingerprints on the basis of a comparison with a register of patterns stored in a memory bank, (b) measure them with a high degree of precision, (c) produce the conventional code, and (d) search their files for a matching print. Computers performing these tasks are available; opto-electronic scanners look first for the location of the principal or determinant pattern in a print and, once found, proceed by measuring methodically the line slopes in these patterns as well as other features necessary to establish the code [*2*]. In another approach, a direct optical comparison and correlation was attempted [*3*]. Neither of the systems proved reliable in daily use; with both types a certain degree of data reduction is inevitable and might be the cause for the unacceptably high "false reject" and also "false accept" rates.

Pattern Recognition by Interferometry

The difficulties encountered with existing systems for the characterization of fingerprints probably derive from the fact that the analytical approach adopted tries to simulate too closely the integrating operations of the human eye and brain. We propose a method in which the line pattern in a fingerprint is translated into a field pattern of optical densities. Fingerprints as well as other complex patterns are then very easily expressed in digital form. None of the information contained in them is lost or falsified in the process. Furthermore, our method gives the correct topological description of a pattern and this extends its possible use to even the most onerous problems of line pattern recognition.

General Description of the Method

The automated analysis of fingerprints by interferometry is accomplished in the following way.

1. A transparent screen of circular centrosymmetric lines (that is, the reference pattern) is placed on the fingerprint or its image. The lines in the reference pattern have the same periodicity throughout and are of equal thickness. By the superposition, an interferometric pattern of the moiré type is generated [*4*]. The impressions from epidermal ridges running parallel to the overlaid circles are emphasized; those intercepting the lines at greater angles are far less conspicuous. Moiré interferograms produced in this way express the individual variations of the imprints without falsifying them since the superposition step is the equivalent of multiplying each element in the picture to be analyzed by a common factor.

2. The reference pattern is centered on the imprint's characteristic element (the arch, loop, whorl, and so forth) and is then gradually enlarged until its lines fill the space between adjacent ridges closest to the center in the fingerprint examined over the longest possible distance. Thus, the ridges and the reference lines running parallel to them add to form fields of equal density, distinct from areas where lines intercept at greater angles: with this, the pattern of lines is translated into a field pattern. The correct procedure for centering is demonstrated schematically in the examples of Fig. 1. The different types of epidermal ridge patterns in fingerprints give the moiré interferograms shown in Fig. 2.

3. An opto-electronic transducer scans the superimposed patterns and measures the optical density of every field in an electronically defined orthogonal grid containing as many unit cells as are required to characterize an individual fingerprint with a high degree of confidence. The grid is automatically enlarged with the reference pattern, and in the same proportion. The op-

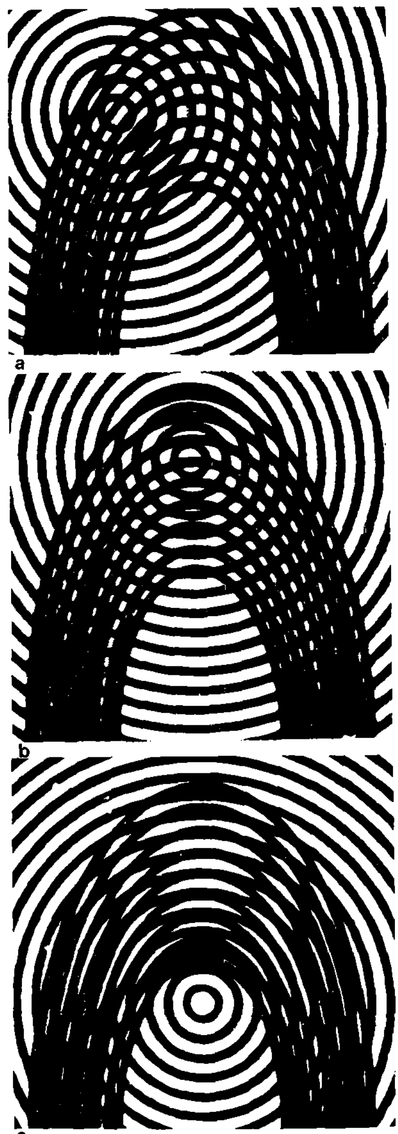


FIG. 1—*The centro-symmetric reference pattern superimposed on a set of arches representing the principal element in a fingerprint. The correct interferogram is obtained in* (c). (a) *Arbitrary position of the reference pattern.* (b) *Reference pattern correctly positioned on vertical axis of schematic print, off horizontal axis.* (c) *Correct center. Greatest optical density of interferogram extending over the longest inter-ridge distance possible as close to the centers of the line patterns as possible.*

tical density measured in each cell is digitized and the resulting values are stored in the sequence in which they were encountered by the scanner.

Discussion of the Method

By the method described, the intricate pattern of lines in a fingerprint is expressed as a field pattern of optical densities. All individual characteristics contained in the fingerprint are faithfully reproduced, if in a different form. Since no data reduction is involved, our method is better suited for the analysis of complex patterns than are computer programs that describe only the predominant element in an imprint while suppressing systematically all other features during the search. With the method given here, all elements characterizing the fingerprint are preserved in the actual topographic relation.

If the reference pattern is centered as prescribed and correctly enlarged it will always produce the interferogram characterizing an individual fingerprint. The geometric center of the imprint is found by rotating it or its image about an assumed axis which is to be relocated until

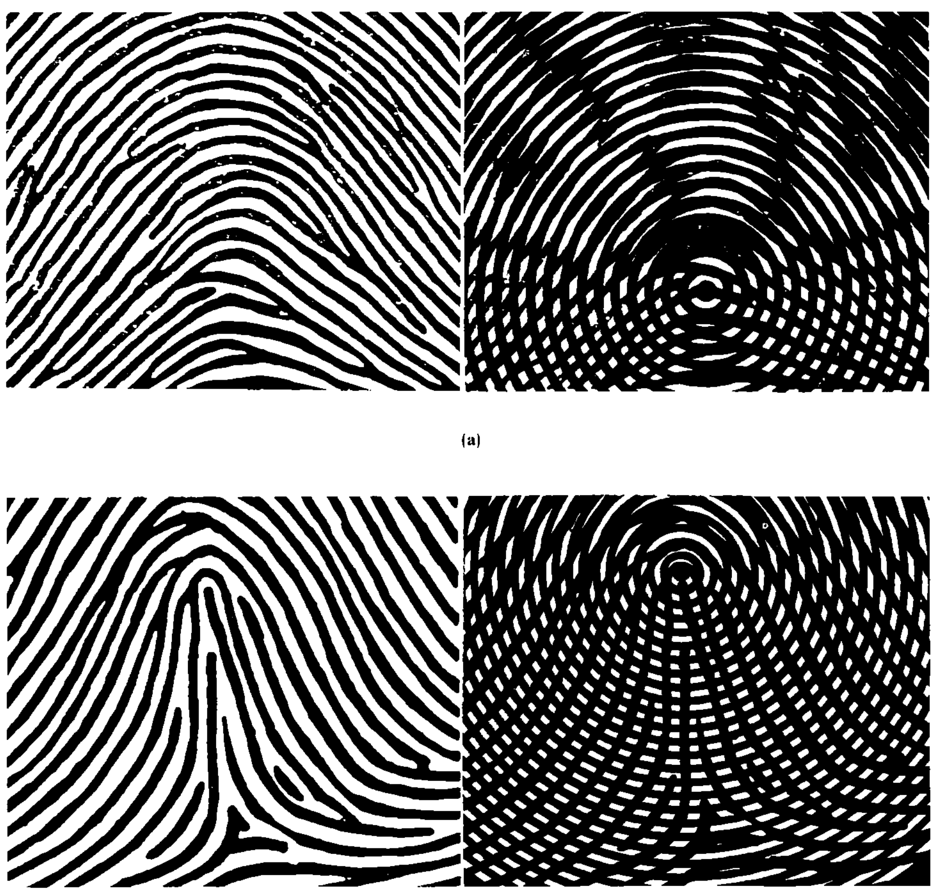
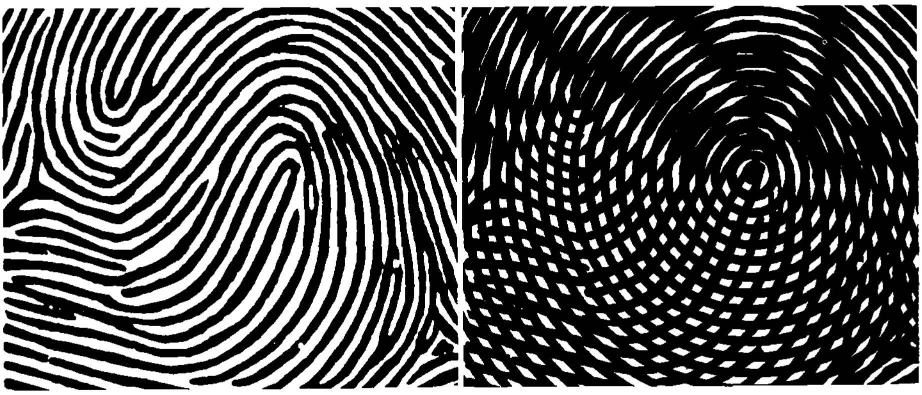
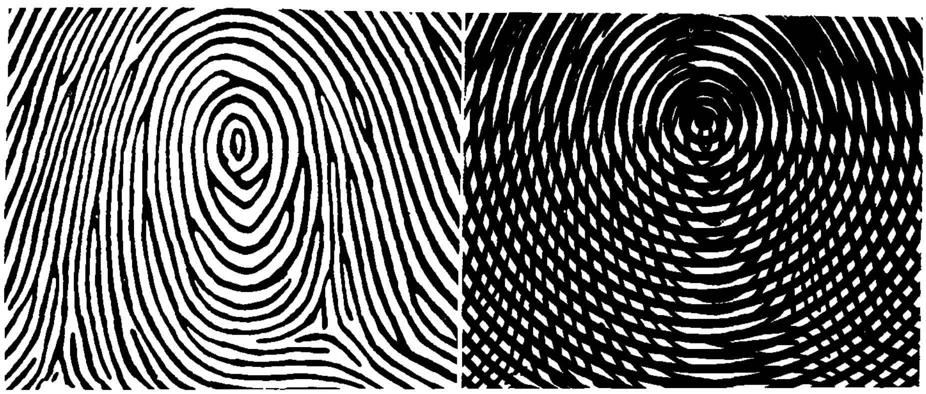


FIG. 2—*Moiré interferograms of the most frequently occuring epidermal ridge patterns. The lines in the reference pattern (left-side in* a, b, c, *and* d*) were made slightly thinner than is required to demonstrate the correct superposition.* (a) *The arch. The geometric center of this figure is found by the rotation step described in the text.* (b) *The tented arch.*



(c)



(d)

FIG. 2—(c) *The loop. Illustrated is a double loop. Whenever two figures of approximately equal prominence are present, the reference pattern is to be centered on the lower one or on the one pointing to the tip of the finger.* (d) *The whorl. Note that the center of the reference pattern does not coincide with the center of the fingerprint's most characteristic feature if the instructions are followed correctly.*

the frequency of optical densities measured at a fixed reference point close to the center is minimal. This procedure becomes clear with an example: if the axis of rotation is placed off center, for example, into a circle, a fixed point observed while the image is rotated will record a change in optical density until the correct center is found. Then, the reference point will be located either on the circle or inside it and record a minimal (in this case constant) change in the optical density with rotation. The reference pattern is centered on the imprint and enlarged as is described above. The characteristic interferogram is divided electronically into cells of equal size and the optical density of each is read by an opto-electronic scanner and expressed in binary code. The size of the cells has to change in correspondence to the degree of enlargement of the reference pattern. This is also done electronically with a coupling circuit.

The sequence of digits recorded is rapidly transmitted or processed by standard techniques. The probability of processing errors is small since human operators are involved only in the fitting of the reference pattern on the imprint and have to follow tight rules.

The analysis of a fingerprint gives a string or sequence of binary digits automatically. Any length of that can be compared by computer to any other sequence on file. Even partial prints are matched automatically, provided of course, that the central feature is available. The probability of finding a matching print grows in a direct proportion to the length of the string of digits used for comparison. For this reason, the device reading the moiré interferogram should scan it in both directions, that is, it should read the optical density in consecutive horizontal lines, end to end. Since the measuring field of the digitizer extends beyond the image to be analyzed, the computer is programmed such as to delete any sequence repeating "O" more than *n* (for example, four) times. The threshold at which the digitizer responds with "ON" or "1" is given by the proportion to which each of the individual cells seen is filled by the line patterns. No signal (or "OFF," or "O") will be recorded in cells traversed only by either (a) one line of the reference pattern, (b) the imprint of a single ridge, or (c) by a combination of the two which does not fill the cell to the desired degree. Faults in the imprint, for example, because of incomplete inking, are offset by adjusting the response level in such a way that "1" is signalled when the cell is filled to about 90%. With this, the dimensions of a cell are delineated: it should be square and one line of the reference pattern alone should fill it to between 50 and 60%. These conditions require, as mentioned, that the measuring cell grows in the same proportion as the reference cell is enlarged to fit the fingerprint.

The translation of a line pattern into a field pattern of optical densities follows the growth of a fingerprint and will always result in the same characteristic string of digits by which it is recognized. The proportional enlargement of the ridge pattern with growth is normalized by the enlargement of the reference pattern to fit the inter-ridge distances.

One of the most important advantages of the method described derives from the fact that the information is collected from single fingerprints. This will facilitate considerably the search for a match in a majority of criminal investigations, in all cases in which only one or a few prints are available for identification. Neither for the application of moiré interferometry nor for the subsequent analysis is it necessary to know if the print came from the left or the right hand, information required to arrive at the composite formula currently in use.

The Apparatus

All components of the apparatus required to implement the interferometric method described here are commercially available. In one of a number of possible configurations, the fingerprint is projected by a camera on an array of image sensors (Fig. 3) with a number of cells appropriate for the resolution needed. The image of the fingerprint is then displayed on the screen of a microcomputer. Complete recording systems of this type are produced at several levels of technical sophistication. An adequate low-cost system operating at a maximum scanning speed of 153 000 pixels per second (= bauds) can be purchased from Micron Technology (Boise, ID). Its image sensor is composed of an array of 256 cells horizontally and 125 cells vertically for a total of 32 000 pixels. The image recorded through the optical sensor is easily manipulated in any way desired, for example, such as to find the center of the fingerprint.

The reference pattern of centrosymmetric circles is permanently stored on a monochrome graphics display board as part of the microcomputer's hardware. The size adjustment of the reference pattern to fit the fingerprint is provided by the electronic equivalent of a zoom control. Integrated circuits comprising these functions with the appropriate resolution are made by a number of companies (for example, Scion, Reston, VA).

The line patterns superimposed on the screen are matched in intensity. The light levels in the displayed interferogram are then read from the screen memory as fast as the cursor scans the horizontal lines end to end. This is accomplished by program statements such as "peek" in the computer language BASIC that address a particular location in the screen memory and return the byte contained in it.

The logic circuit next in line of the block diagram of Fig. 3 stores the information to allow for the adjustment in size between lines of the reference pattern and that of the measuring cell. A final processing circuit averages the signals received over the number of pixels constituting one such cell. The performance characteristics of the electronic components mentioned permit the digitization of an interferogram in less than 1 s.

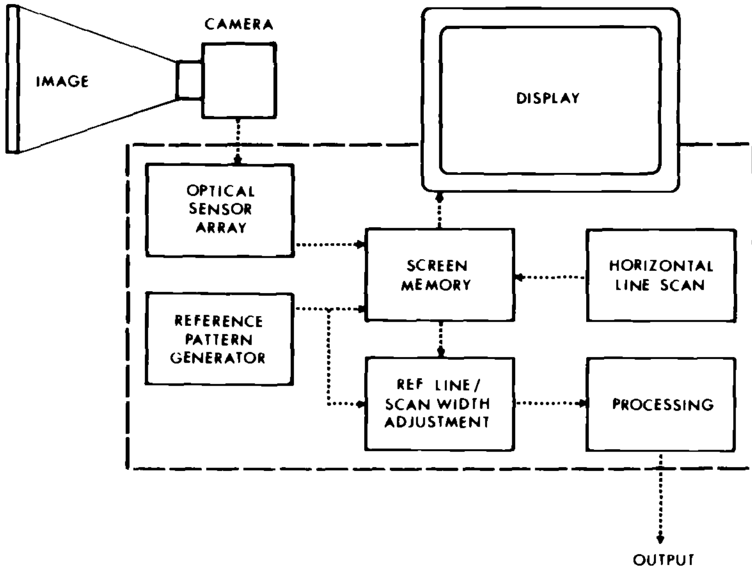


FIG. 3—*Block diagram of the opto-electronic apparatus implementing the method described.*

Conclusions

By the method we propose here, a fingerprint can be digitized nearly automatically. Once expressed in digital form it is transmitted easily, rapidly, and inexpensively. It can also be processed in a variety of ways and this brings out the additional advantage that it can be reconstructed at remote locations without the loss of information content. Reconstruction simply reverses the process of analysis by subtracting the defined reference pattern from the interferogram transmitted in digital form.

A sequence of bits coming from a matrix of only 100 by 100 cells (that is, from only one third of the 32 000 pixels seen with the commercial array of optical sensors we use) already expresses the individuality of a fingerprint in a most reliable fashion. The probability of finding an interferogram to match is given by the product of the probabilities of finding the correct match in each of the 10 000 cells ($= \frac{1}{2}_1 \times \frac{1}{2}_2 \times \cdots \times \frac{1}{2}_n$) and is, at 1 out of 2{exp 10 000}, extremely small. One could therefore tolerate a certain number of errors, for example, produced by incomplete inking, or one could reduce the length of the sequence of digits required for a positive identification without forfeiting the advantage of high fidelity.

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