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466

Matching Fingerprints by Computer

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Matching Fingerprints by Computer

by J.H. Wegstein, J.F. Rafferty, and W.J. Pencak

A procedure is described for determining whether two fingerprint impressions were made by the same finger. The procedure uses the X and Y coordinates and the individual directions of the minutiae (ridge endings and bifurcations). The identity of two impressions is established by matching a constellation or group of minutiae in one impression with a corresponding constellation in the other impression in terms of the relative distances and relative angles of the minutiae.

Key words: Computerized-fingerprint-identification, fingerprints, pattern-recognition.

1. Introduction

Several approaches have been made to automatic fingerprint identification including holographic techniques.[1,2] The techniques that use details of a fingerprint such as cores, deltas, ridge counts, ridge endings, and ridge bifurcations tend to be specialized according to the method by which the information is taken from the fingerprint. Thiebault[3] has described a technique using the directions of minutiae (ridge endings and bifurcations) where the data are obtained by a special camera that photographs the finger. Where a human operator identifies the core and delta as a reference axis, a matching technique has been developed that utilizes only the positions of minutiae.[4] The technique described in this paper is intended primarily for use with an automatic reader that reads minutiae directly from a fingerprint card without identifying cores and deltas.

This paper describes a procedure for matching fingerprint impressions by computer using only two types of minutiae: ridge endings and bifurcations. While it is anticipated that minutiae data may soon be read automatically by machine, the work reported in this paper utilizes data read manually. Each fingerprint impression used is photographed and enlarged by a factor of 10. The minutiae on each of these enlargements are then marked with a pencil on a piece of transparent plastic laid over the enlargement.

Since a ridge ending in one print may appear as a bifurcation in another print from the same finger, no distinction is made between ridge endings and bifurcations in recording data. For each of these minutiae, both a location and direction are defined as shown in Figure 1. If the areas marked B are considered as ridges, then point P is the location of a ridge ending and the line GP defines the direction of this minutia. If the areas marked A are considered as ridges, then point P is the location of a bifurcation, and the line GP defines the direction

associated with this minutia. Minutiae for two fingerprint impressions identified as IIP2 and IIP4 are shown in Figures 2 and 3.

The transparency is next taped to a drawing board so that all minutiae markings fall in the first quadrant of an X-Y coordinate system. The X axis is set parallel to the horizontal lines on the standard fingerprint card from which the print was photographed. The X and Y coordinates of each minutia, as shown in Figure 1, are then read in millimeters and recorded. The angle θ which the minutia direction makes with the X axis is recorded in degrees. The value of θ may range from 0 to 360 degrees. Each minutia is also given an identification number P. A table of data is thus prepared consisting of four columns of numbers P, X, Y, and θ for each fingerprint impression to be studied.

2. The Technique for Matching Fingerprints

This matching procedure is based on matching a constellation or group of minutiae formed about a particular minutia called the nucleus from one impression with a corresponding constellation from another impression. Figure 4 shows such a constellation using a minutia labeled a as a nucleus. Although a particular constellation flexes and stretches, it retains a certain pattern identity in impressions taken from the same finger over a period of years.[5] Matching just one constellation from one impression with a corresponding constellation from another impression appears to be sufficient for concluding that both impressions were made by the same finger.

Both relative distances and relative angles are used to match a constellation in one fingerprint impression with a similar constellation from another impression. The computer works with two minutiae at a time, such as a and b in Figure 4, from each of two different sets of impression data. As shown in Figure 5, it attempts to relate the pair of minutiae a and b from Impression 1 with a pair of minutiae e and f from Impression 2. Starting with minutiae a and b, the computer computes ΔS the distance between the minutiae, $\Delta\theta_1$ the difference between the angles of these minutiae, and $\Delta\gamma_1$ the angle between the direction of minutia a and the direction of the distance vector to minutia b. Similarly, values for ΔS_2, $\Delta\theta_2$, and $\Delta\gamma_2$ are computed with respect to minutiae e and f in Impression 2. Next, the differences

$$\Delta S = \Delta S_2 - \Delta S_1$$
$$\Delta\theta = \Delta\theta_2 - \Delta\theta_1$$
$$\Delta\gamma = \Delta\gamma_2 - \Delta\gamma_1$$

are computed. If ΔS is less than KS, $\Delta\theta$ is less than Kθ, and $\Delta\gamma$ is less than Kγ then a score S is set equal to one and pair ab is considered matched with ef. KS, Kθ, and Kγ are parameters that must be adjusted for optimum performance. The computer next relates minutia a to another minutia such as c in Figure 4. If the pair ac can be matched with e and some other minutia in the second impression, the score is increased by one. This process is repeated until the score S reaches a predetermined

value SM at which time Impression 1 is considered to be matched with Impression 2, and the computer prints "MAKE". If the score S fails to reach SM after S3 tries, the score S is reset to zero and the computer tries to find new pairs ab and ef that will establish a and e as nuclei for constellations that match. SM and S3 are also adjustable parameters.

3. Filing Minutia Data

Prior to attempting to match fingerprints the computer pre-processes each set of data by reading in the table of values of P, X, Y, and θ for each fingerprint impression. A typical impression will provide about 75 minutiae. For each minutia point, the computer computes an auxiliary variable φ where $\varphi = \theta$ if θ is less than or equal to 180° and $\varphi = \theta - 180$ if θ is greater than 180°. The minutia data are next sorted so that the corresponding values of φ are in ascending order. Thus a minutia whose θ is 1° or 181° will be near the beginning of the table and a minutia with a θ value of 179° or 359° will be near the end of the table. The table of values of P, X, Y, and θ ordered according to φ is next written on magnetic tape along with an identification number (Ident) for the impression and a number (IMX) which is the total number of points taken from the impression. Minutia data for numerous fingerprint impressions have thus been stored on magnetic tape for matching studies.

4. Sequencing the Search for a Match

The complete logical details of the computer program for matching fingerprint impression data are given in the flow diagrams in the Appendix. In the following text, numbers in parentheses refer to box numbers in the flow diagrams. Text in parentheses elaborates details of the flow diagrams and can be safely ignored by the non-programmer.

The operator first identifies two impressions that are know to be in the magnetic tape file (0), for example, Ident 1 = IIP2 and Ident 2 = IIP4. IIP2 and IIP4 are two impressions from the same finger taken about three years apart and the data from these will be used here in illustrating the procedure. Their minutiae tracings are shown in Figures 2 and 3.

The computer next reads from magnetic tape a table of data for each of the two impressions (1). The values of φ as explained earlier are re-computed and entered as a fifth column in each table (2-13). Figure 6 shows the middle portion of each table. The leftmost column in each table, I, is the line number and is not part of the table itself. (For convenience in programming, the numbers in these tables are identified as elements in a three dimensional array A_{INK}. Thus $A_{44\,3\,2}$ is the same as the 44th value of Y in IIP4 and is equal to 202.)

The search for a match begins by finding the first minutia in IIP2 with a φ greater than or equal to 90°. This minutia, P=8, becomes the a referred to in Figure 5 and the next minutia, P=42, would become the b. Similarly, in table IIP4, minutia 40 becomes e and minutia 44 would become f. (Boxes 2-13 locate the line numbers corresponding to a and e and also determine the center of gravity of the area covered by the minutiae from each of the impressions.)

Before attempting the match illustrated in Figure 5, the computer first checks to see if minutiae a and e are pointing in approximately the same direction by computing $\Gamma\theta = \theta$ (a) - θ (e). If $\Gamma\theta$ is less than $M\theta$, an adjustable parameter, the computer goes on to check whether minutiae a and e are in the same neighborhood in the fingerprint. This is accomplished by comparing differences in X andY with parameters KX and KY respectively (22-22.1). These measures of X and Y are referred to the center of gravity of the area covered by the minutiae of each impression to compensate for the arbitrary location of the minutiae tracings with respect to the X-Y coordinate axes.

In the illustrative data, minutiae 8 and 40 point in the same direction, but their values of X differ by an excessive amount. As referenced to the center of the pattern, the maximum difference allowed in this example is KX = 30 mm. Therefore minutia 40 is rejected (22.3) and the computer begins to step through the IIP4 data in a zig-zag pattern looking for an acceptable minutia e. (Subroutine "Zip-Zap" performs this index stepping.) The first steps of the path taken in searching for e are shown at the upper right of Figure 6. The computer will give up the search when $|\varphi(a) - \varphi(e)|$ becomes greater than $M\theta = 30°$ (40), or when the IIP4 data have been exhausted. In this example an e corresponding to minutia point 22 is found to be satisfactory. The computer therefore takes minutia 42 in IIP2 as b and begins a zig-zag search of the IIP4 data for a satisfactory f. This path is illustrated at the lower right of Figure 6.

When the possible values for f are exhausted, e is advanced another step along its zig-zag path and f begins a new zig-zag search. When the possible values for e are exhausted, b is advanced another step along its zig-zag path and both e and f are reset and restarted in their search. Similarly, when necessary, a also takes steps along a zig-zag path and each of the other points are restarted in succession.

In this example a score is achieved when a is 42 and b is 24 in IIP2 while e is 42 and f is 24 in IIP4. This changes the search pattern. a and e are now held stationary while b and f execute zig-zag search patterns (q = 2 in the flow charts). In the example, the score S quickly advances to SM = 4 and the computer prints "MAKE" followed by the table:

IIP2		IIP4	
a	b	e	f
42	24	42	24
42	41	42	41
42	22	42	22
42	79	42	79

The resulting matching constellations are shown in Figure 7.

5. Conclusion

The various parameters used in this procedure are listed below along with typical values and brief explanations of their functions.

$K\theta=8$
$KS=6$ Scoring parameters.
$K\gamma=6$

$K\theta$ also terminates the range of f if differences between certain φ values exceed $K\theta$.

$M\theta=35$ Skips steps of e by noting if a and e are not in the same direction. Skips steps of f by noting if b and f are not in the same direction. Sets stops on range of e if φ angle between a and e exceeds $M\theta$. Sets stops on range of f if φ angle between b and f exceeds $M\theta$.

SM=4 Score required to "MAKE".

K1=5 Maximum number of steps a can take.

K2=10 Maximum number of steps b can take for a given a.

K3=15 Maximum number of steps b can take while looking for another score after score accumulation has begun and a and c are held stationary.

KX=35 Maximum allowed difference in X values for a and e or b and f where each X is measured from the center of gravity of the rectangular area covered by minutiae.

KY=41 Maximum allowed difference in Y values for a and e or b and f where each Y is measured from the center of gravity of the rectangular area covered by minutiae.

Numerous computer runs must be made with fingerprint data from a given reader to determine optimum values for these parameters. Ideally, impressions from the same finger should always give a "MAKE" when compared and impressions from different fingers should always give a "NO" when compared. From experiments performed to date it appears feasible to find a set of parameters that will always give a "MAKE" when two impressions from the same finger are compared. However, these same parameters may on rare occasions also give a "MAKE" when two impressions from different fingers are compared. This flaw may be tolerated in a working system because human beings, who must always confirm identifications, can readily detect these false matches.

Computations to date indicate that this matching technique is much more reliable than a previously reported technique that emphasized compression of fingerprint data for filing.[6]

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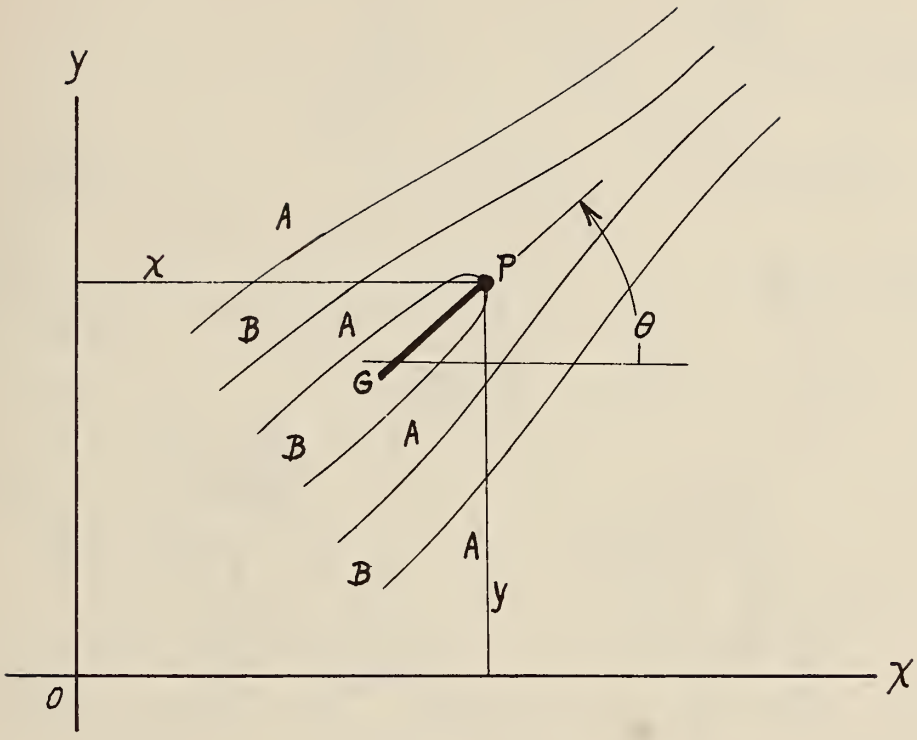


Location and Direction of a Minutia

Figure 1.

Figure 2
Impression IIP2

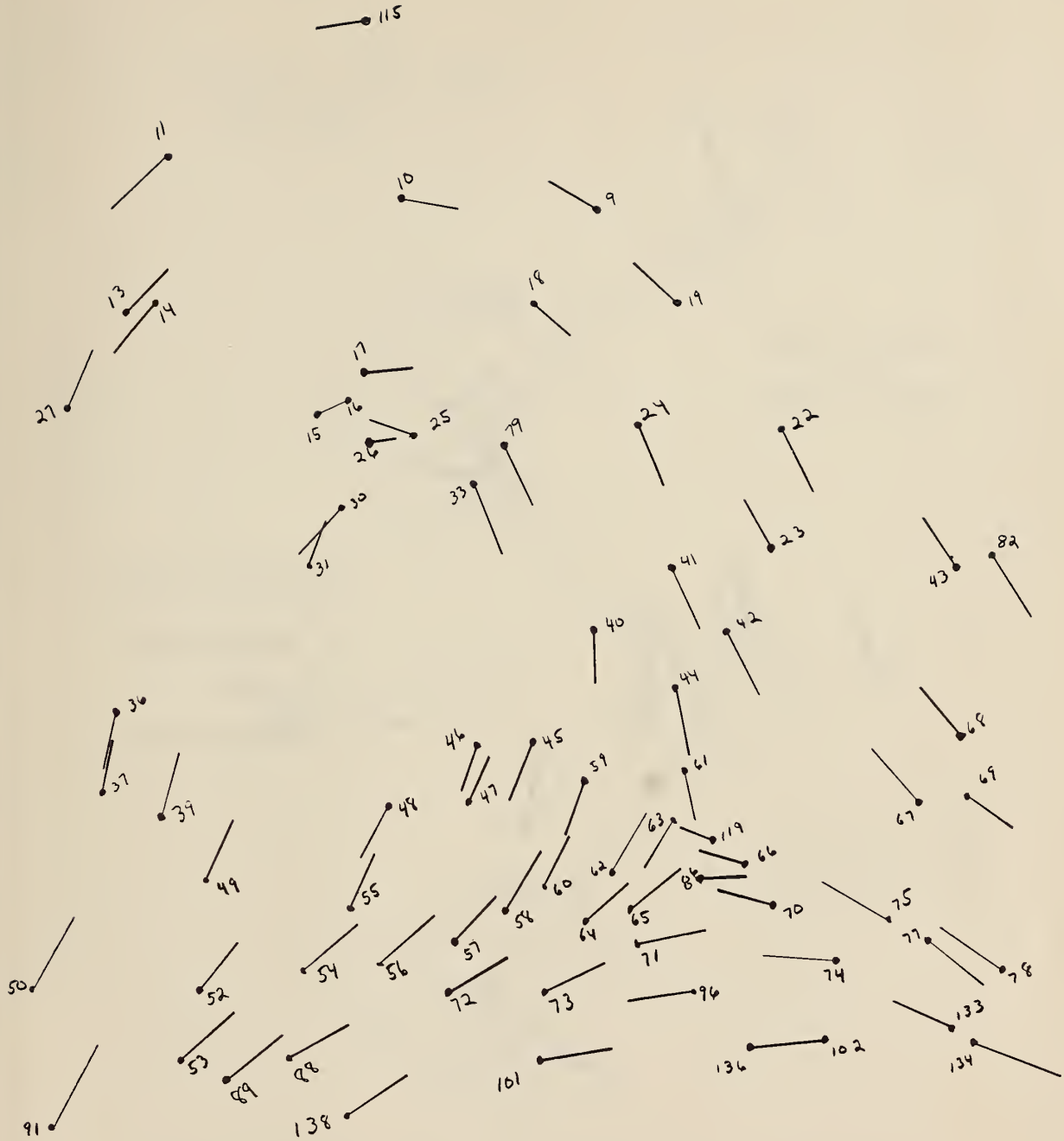
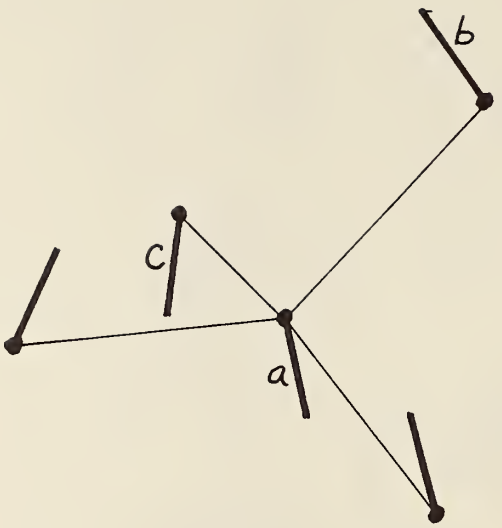


Figure 3

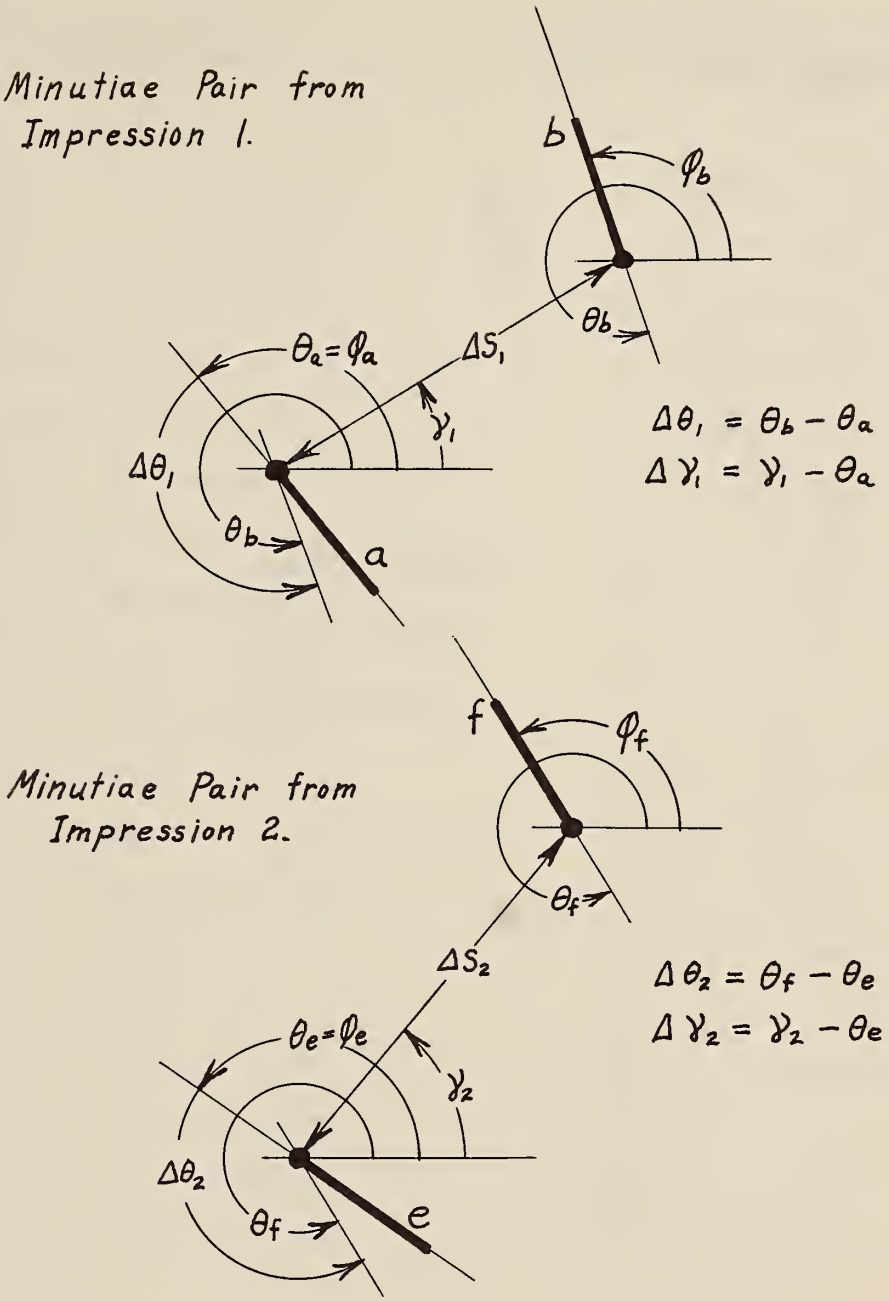
Impression IIP4

9.



Constellation of Minutiae

Figure 4.



Matching Pairs of Minutiae

$$\Delta\theta = \Delta\theta_2 - \Delta\theta_1$$

$$\Delta S = \Delta S_2 - \Delta S_1$$

$$\Delta\gamma = \Delta\gamma_2 - \Delta\gamma_1$$

Figure 5.

K=1

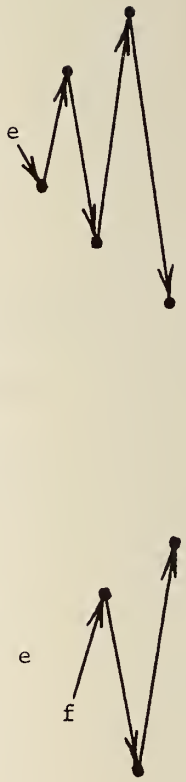
Impression IIP2
IMX = 91

I	P	X	Y	θ	φ	
40	29	208	222	233	53	
41	47	296	157	233	53	
42	38	223	178	235	55	
43	37	222	181	236	56	
44	36	230	193	58	58	
45	35	220	199	239	59	
46	40	328	181	75	75	
47	33	318	217	81	81	
48	61	333	153	83	83	
49	44	337	168	85	85	
50	79	328	224	87	87	
51	41	344	189	89	89	
52	8	385	245	90	90	a
53	42	348	174	91	91	b
54	7	397	229	91	91	
55	24	349	217	92	92	
56	22	372	201	93	93	
57	5	388	247	274	94	
58	107	441	242	274	94	

K=2

Impression IIP4
IMX = 74

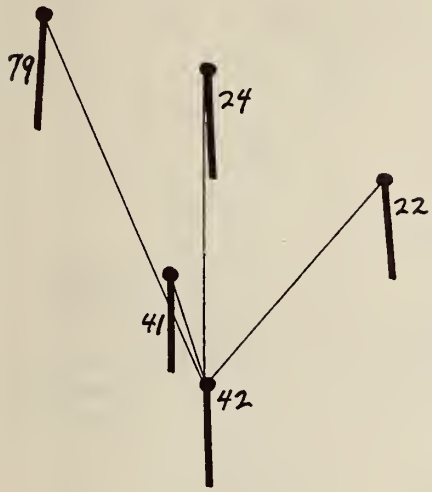
I	P	X	Y	θ	φ
40	31	225	229	249	69
41	46	258	193	70	70
42	39	195	181	254	74
43	37	183	186	256	76
44	36	186	202	77	77
45	40	281	215	90	90
46	44	297	204	100	100
47	61	298	188	100	100
48	33	258	244	110	110
49	24	291	255	111	111
50	138	230	122	111	111
51	41	297	227	114	114
52	79	264	252	114	114
53	42	307	215	116	116
54	22	319	254	116	116
55	23	316	230	300	120
56	82	360	228	121	121
57	43	353	226	303	123
58	67	344	180	305	125



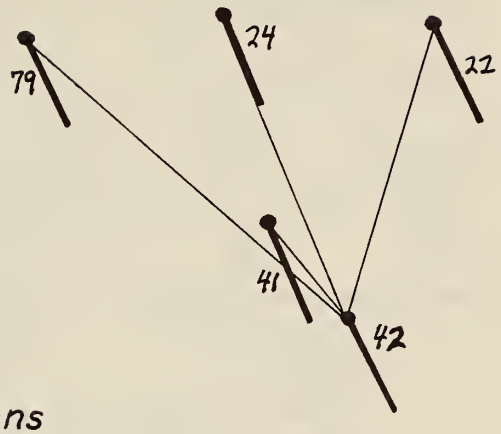
A Portion of the Minutia Data from Two Fingerprint Impressions

Figure 6.

Fingerprint
Impression II P2



Fingerprint
Impression II P4



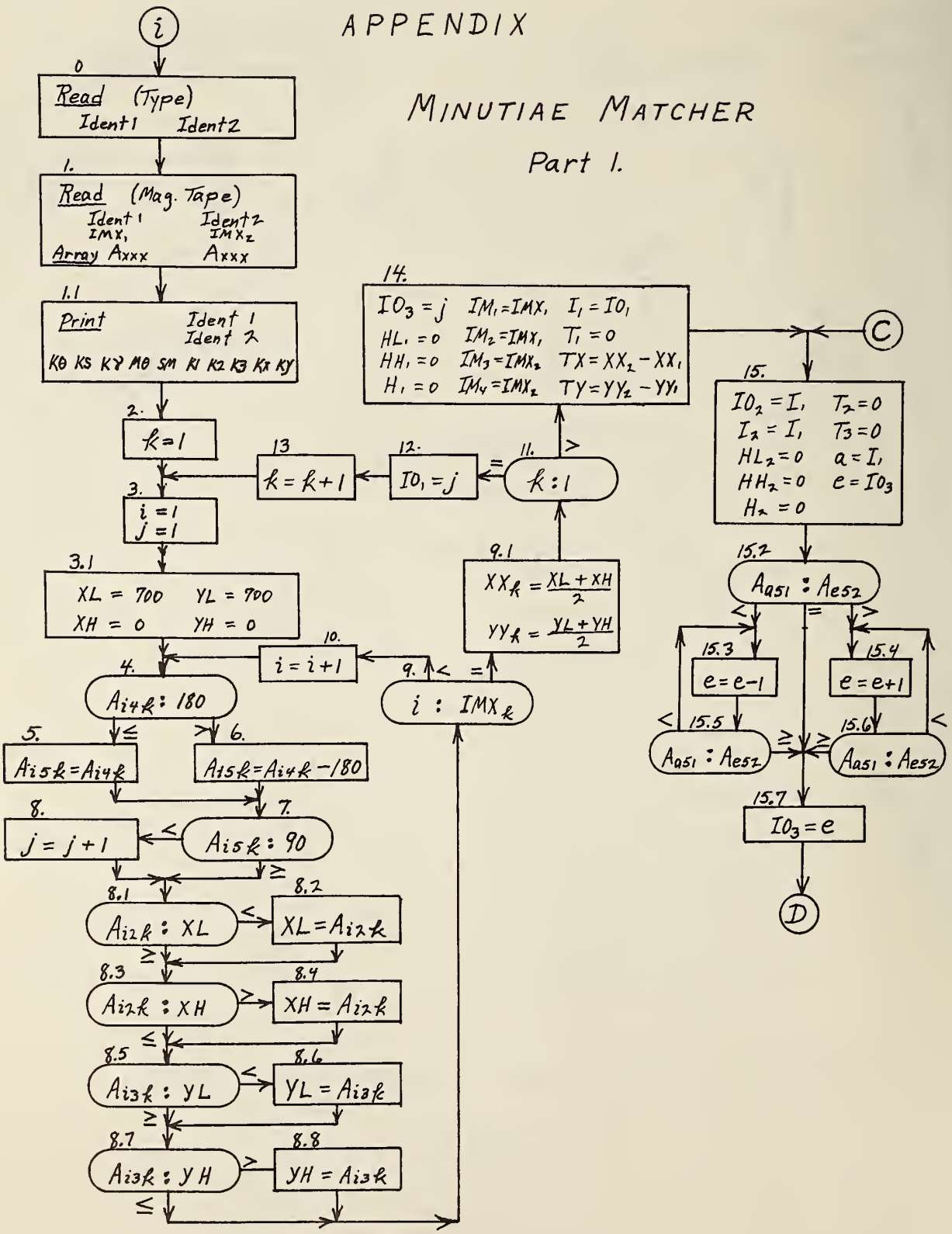
Constellations
of Minutiae

Figure 7.

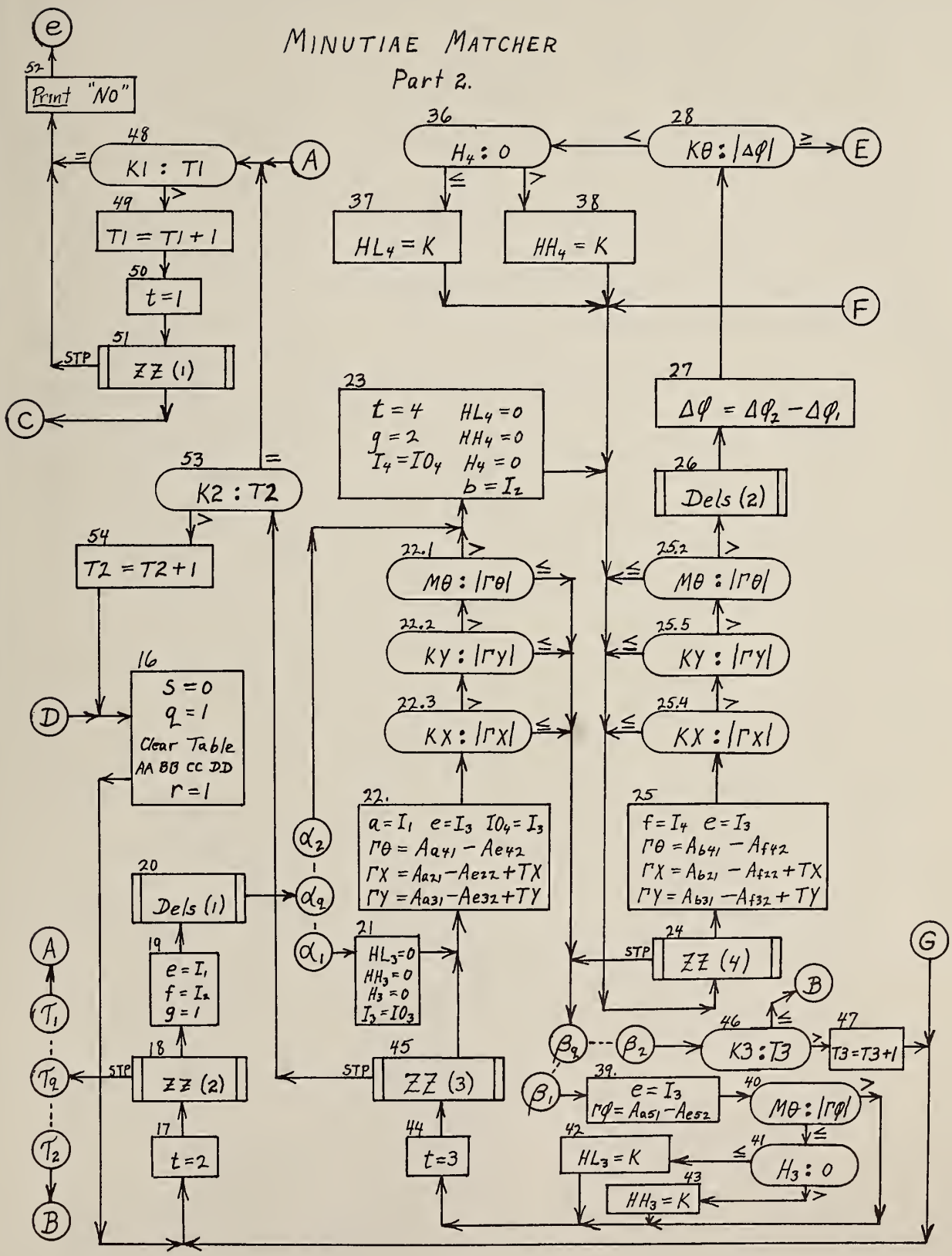
APPENDIX

MINUTIAE MATCHER

Part 1.



Minutiae Matcher
Part 2.



Minutiae Matcher
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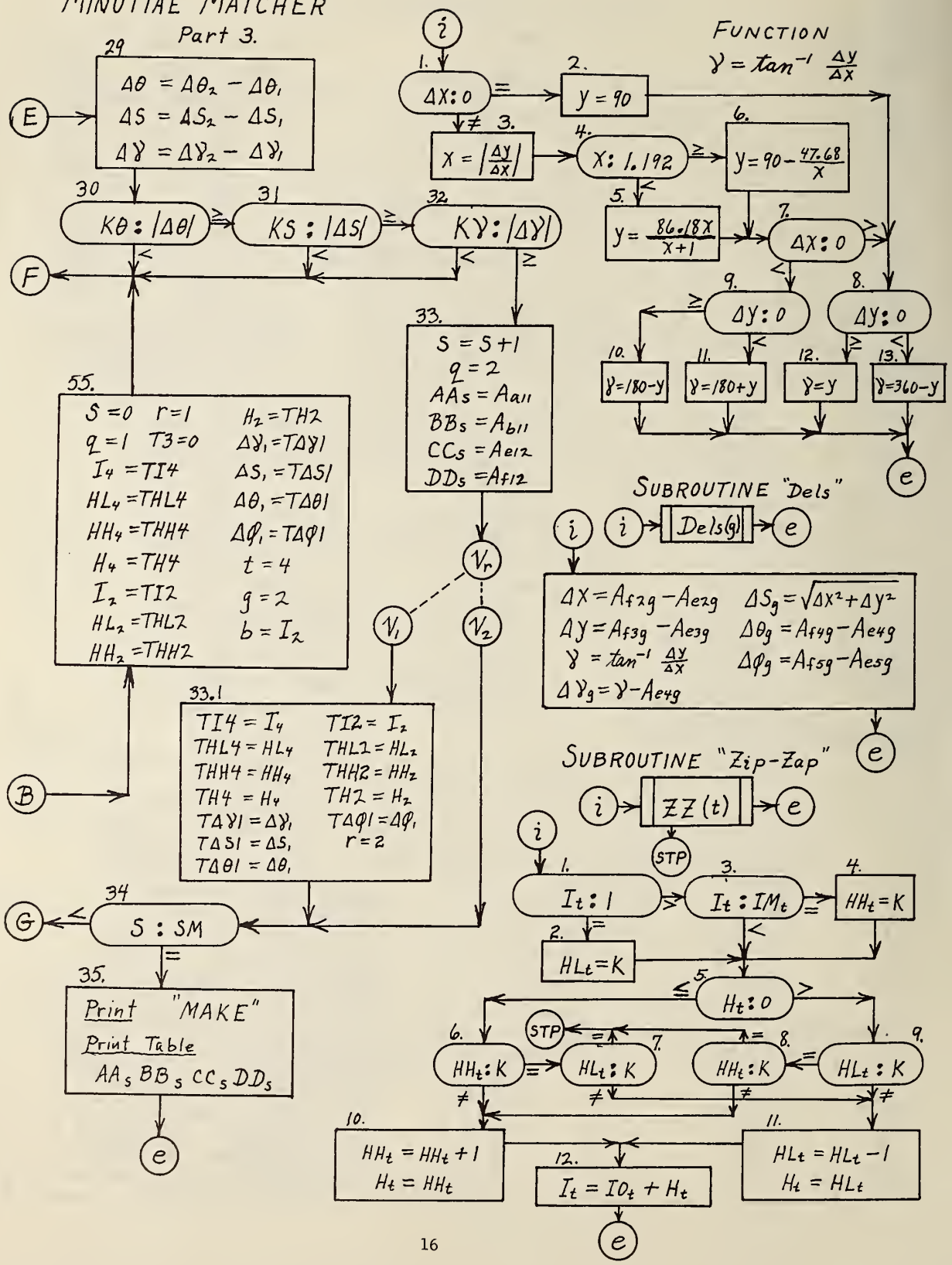

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