United States Patent [19]

Asai et al.

[11] **Patent Number: 4,646,352**

[45] **Date of Patent: Feb. 24, 1987**

[54] **METHOD AND DEVICE FOR MATCHING FINGERPRINTS WITH PRECISE MINUTIA PAIRS SELECTED FROM COARSE PAIRS**

[75] Inventors: **Koh Asai; Hiroyuki Izumisawa; Katsuaki Owada; Seiichiro Kinoshita; Shunji Matsuno,** all of Tokyo, Japan

[73] Assignee: **NEC Corporation,** Tokyo, Japan

[21] Appl. No.: **508,759**

[22] Filed: **Jun. 28, 1983**

[30] **Foreign Application Priority Data**

Jun. 28, 1982	[JP]	Japan	57-111114
Jun. 28, 1982	[JP]	Japan	57-111115
Jun. 28, 1982	[JP]	Japan	57-111116
Jun. 28, 1982	[JP]	Japan	57-111117
Jun. 28, 1982	[JP]	Japan	57-111118
Jun. 28, 1982	[JP]	Japan	57-111119
Jun. 29, 1982	[JP]	Japan	57-112216
Jun. 29, 1982	[JP]	Japan	57-112217
Jun. 29, 1982	[JP]	Japan	57-112218
Jun. 29, 1982	[JP]	Japan	57-112219

[51] **Int. Cl.**[4] **G06k 9/68**

[52] **U.S. Cl.** **382/5;** 382/37

[58] **Field of Search** 356/71; 382/5, 21, 30, 382/34

[56] **References Cited**

U.S. PATENT DOCUMENTS

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4,135,147	1/1979	Riganati et al.	382/5
4,185,270	1/1980	Fischer, II et al.	382/5
4,310,827	1/1982	Asai	382/21

Primary Examiner—Leo H. Boudreau

Attorney, Agent, or Firm—Sughrue, Mion, Zinn, Macpeak & Seas

[57] **ABSTRACT**

A pair candidate list (**73**) is formed by selecting minutia pairs with reference to a minutia list (**71**) showing original position and direction data given for minutiae by principal coordinate systems preliminarily selected on a search and a file fingerprint and those relation data of the minutiae which are substantially independent of the coordinate systems. It is very likely that the pair candidate list shows coarse pairs because the coordinate systems may not yet be optimally matched to each other. One of the coordinate systems is transformed by those optimum amounts to provide transformed position and direction data which are decided by the original position and direction data of the minutia pairs of the pair candidate list. A pair list (**86**) is formed by precisely selecting minutiae from the pair candidate list with reference to the transformed position and direction data and the original position and direction data given by the other principal coordinate system and to the relation data. On forming the pair list, an additional minutia list (**81**) is preferably formed which shows the transformed position and direction data and the last-mentioned original position and direction data together with the relation data.

10 Claims, 43 Drawing Figures

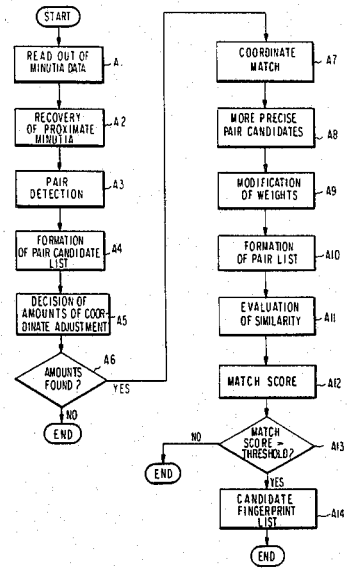


FIG. 1

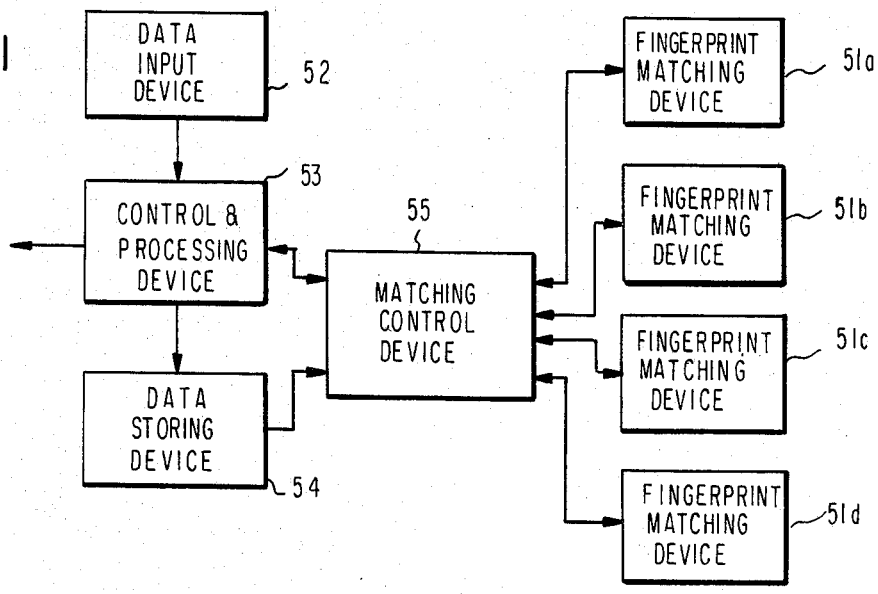


FIG. 2

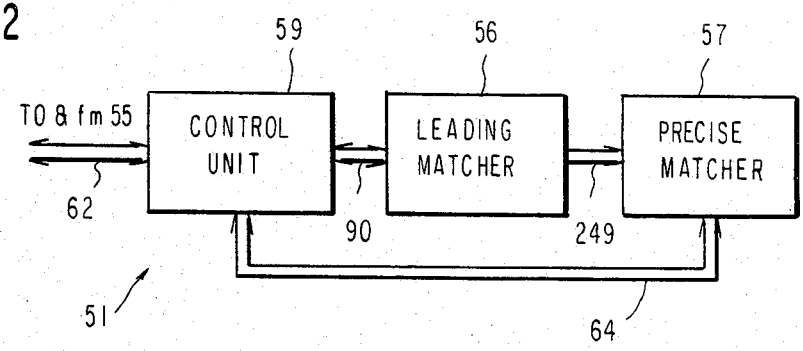


FIG. 3

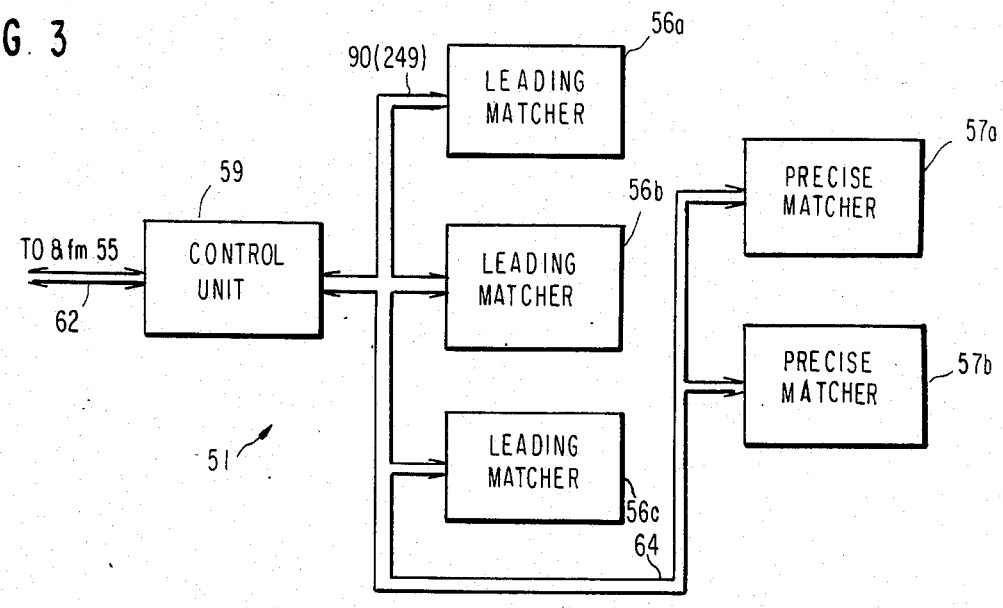


FIG. 4

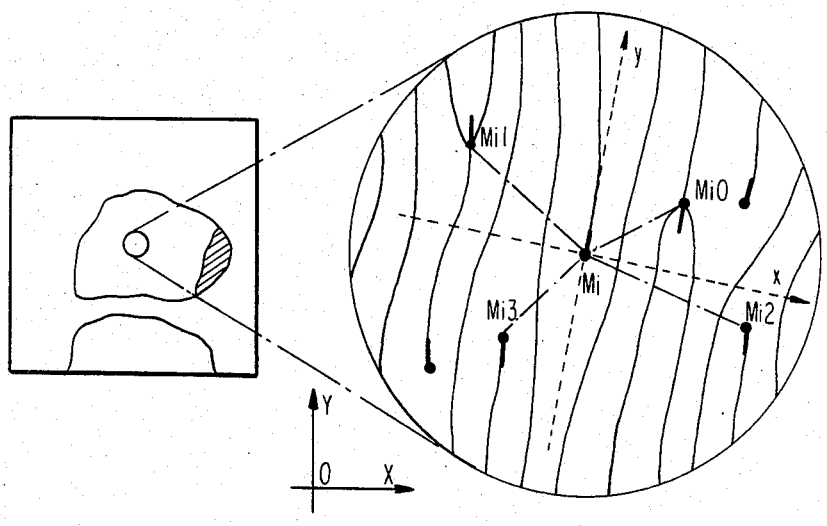


FIG. 5

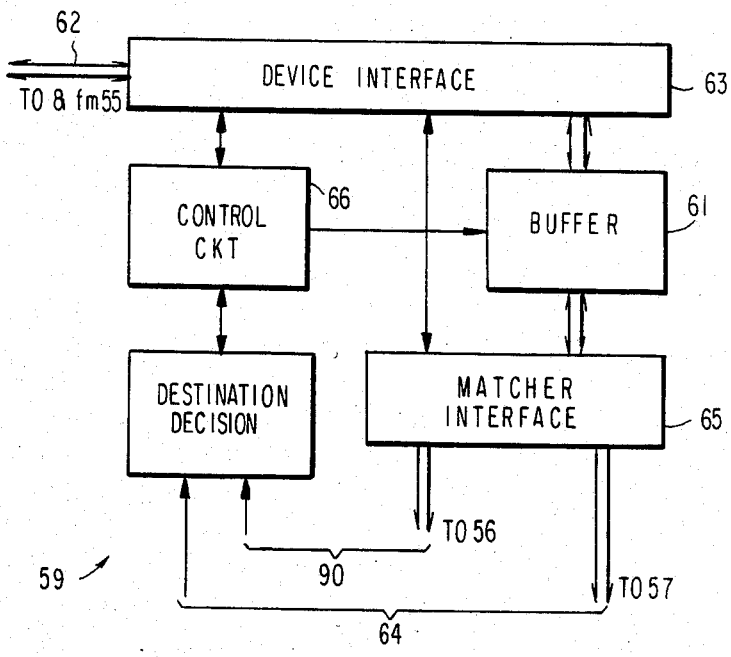


FIG. 8

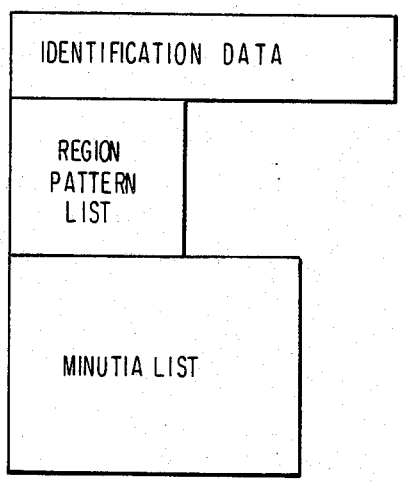


FIG. 6

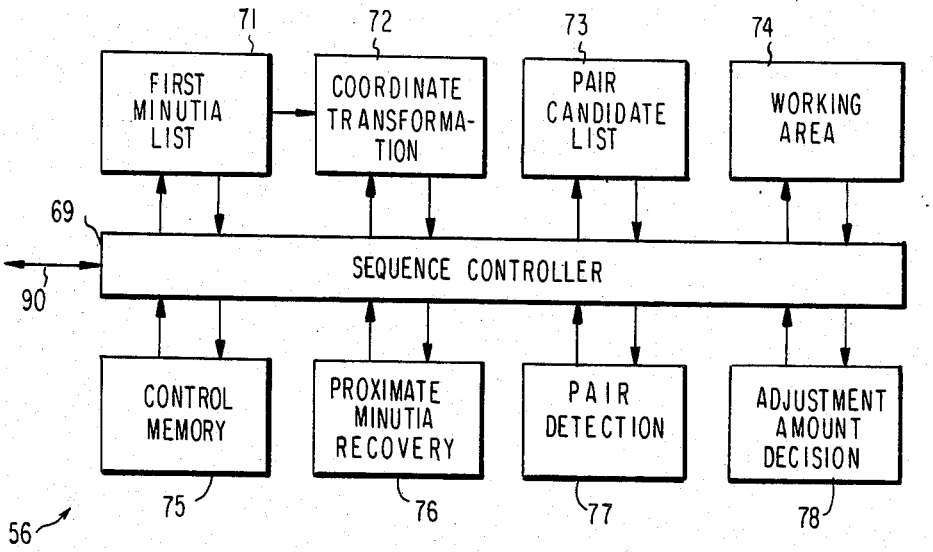

71
72
73
74
FIRST MINUTIA LIST
COORDINATE TRANSFORMATION
PAIR CANDIDATE LIST
WORKING AREA
69
SEQUENCE CONTROLLER
90
CONTROL MEMORY
PROXIMATE MINUTIA RECOVERY
PAIR DETECTION
ADJUSTMENT AMOUNT DECISION
75
76
77
78
56

FIG. 7

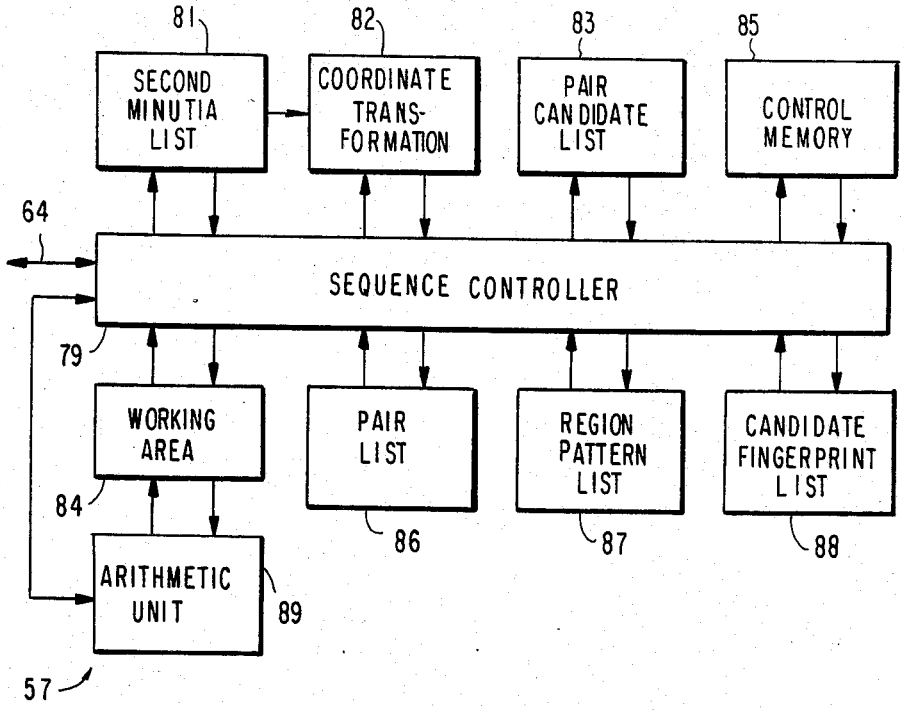

81
82
83
85
SECOND MINUTIA LIST
COORDINATE TRANS-FORMATION
PAIR CANDIDATE LIST
CONTROL MEMORY
64
SEQUENCE CONTROLLER
79
WORKING AREA
PAIR LIST
REGION PATTERN LIST
CANDIDATE FINGERPRINT LIST
84
86
87
88
ARITHMETIC UNIT
89
57

FIG. 9

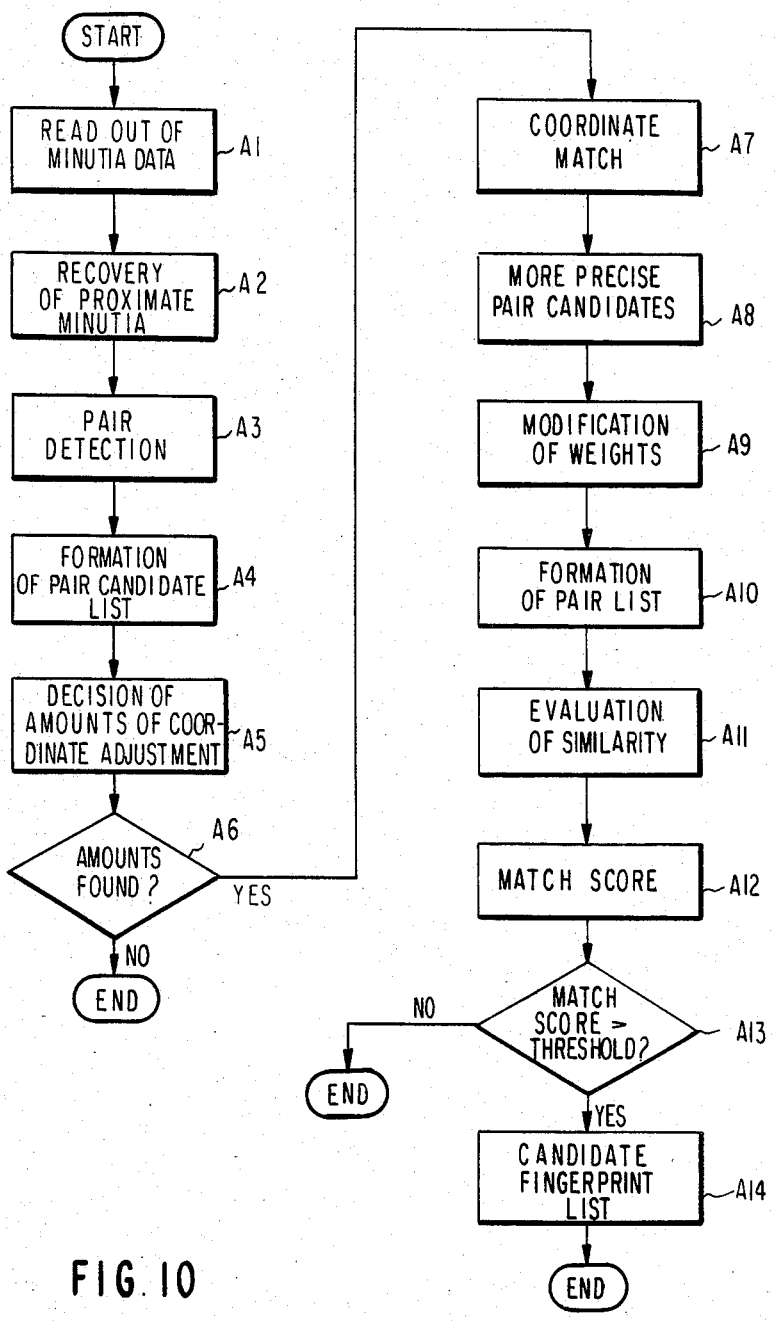

START
READ OUT OF MINUTIA DATA
A1
RECOVERY OF PROXIMATE MINUTIA
A2
PAIR DETECTION
A3
FORMATION OF PAIR CANDIDATE LIST
A4
DECISION OF AMOUNTS OF COORDINATE ADJUSTMENT
A5
AMOUNTS FOUND ?
A6
YES
NO
END
COORDINATE MATCH
A7
MORE PRECISE PAIR CANDIDATES
A8
MODIFICATION OF WEIGHTS
A9
FORMATION OF PAIR LIST
A10
EVALUATION OF SIMILARITY
A11
MATCH SCORE
A12
MATCH SCORE > THRESHOLD?
A13
NO
END
YES
CANDIDATE FINGERPRINT LIST
A14
END

FIG. 10

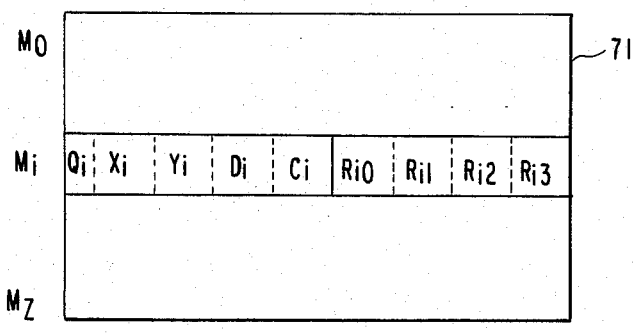

M0
71
Mi
Qi
Xi
Yi
Di
Ci
Ri0
Ril
Ri2
Ri3
MZ

FIG. 11

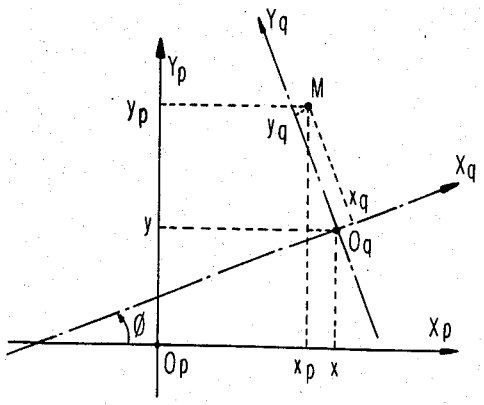

Yq
Yp
M
yp
yq
Xq
xq
y
Oq
Ø
Xp
Op
xp
x

FIG. 12

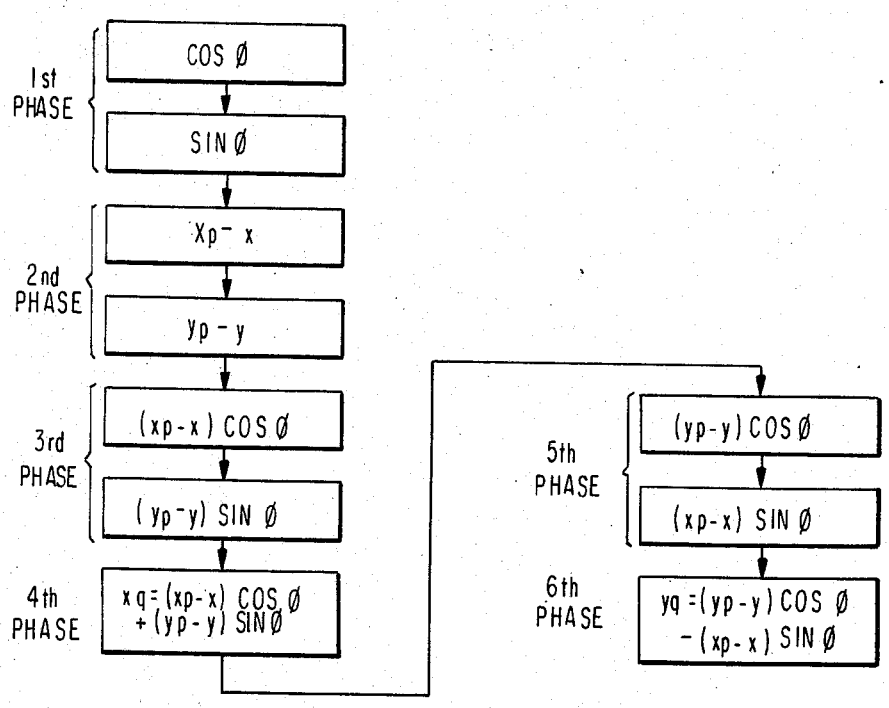

1st PHASE
COS Ø
SIN Ø
2nd PHASE
Xp - x
yp - y
3rd PHASE
(xp-x) COS Ø
(yp-y) SIN Ø
4th PHASE
xq=(xp-x) COS Ø +(yp-y) SIN Ø
5th PHASE
(yp-y) COS Ø
(xp-x) SIN Ø
6th PHASE
yq=(yp-y) COS Ø -(xp-x) SIN Ø

FIG. 13

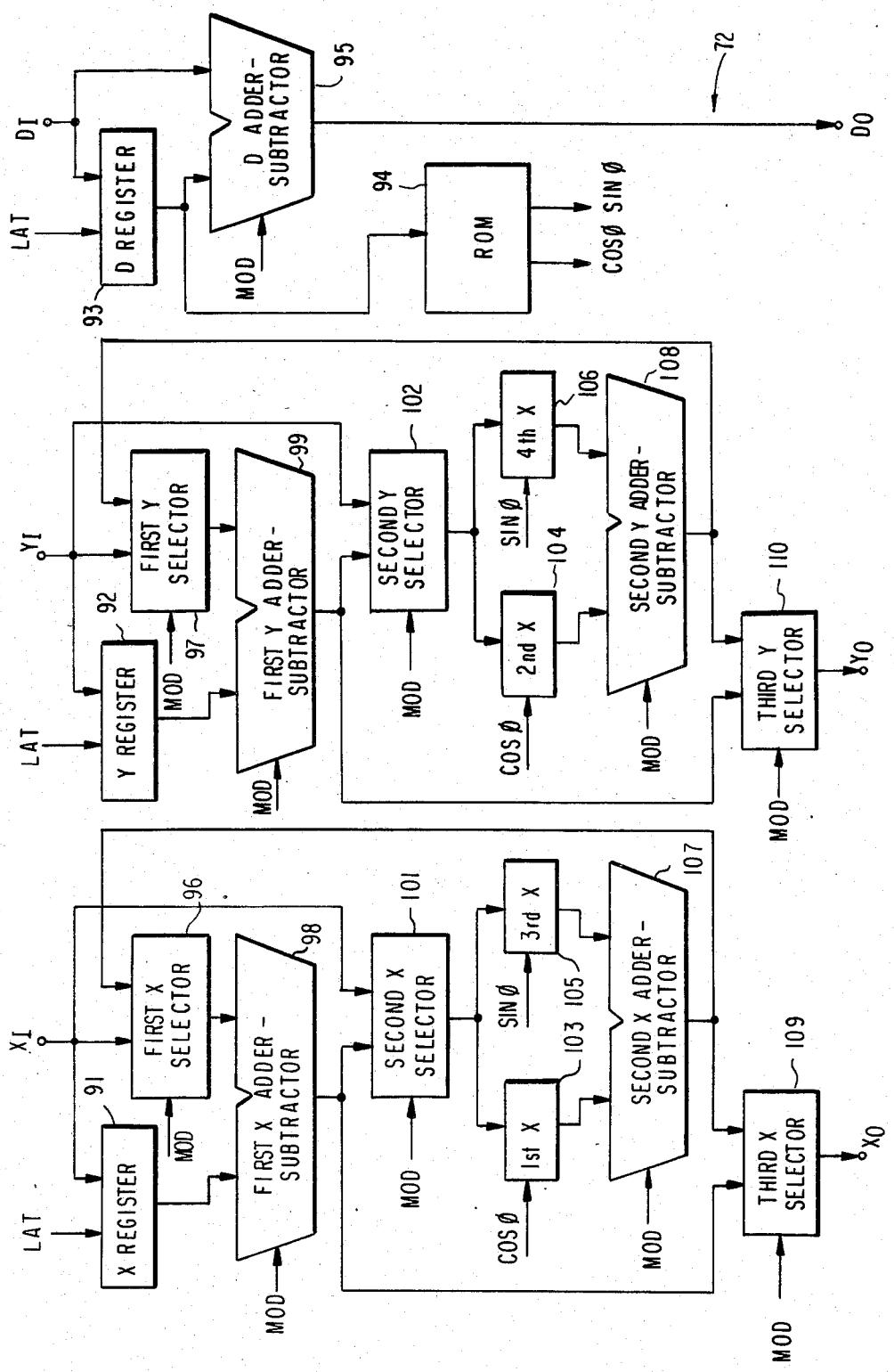

DI
LAT
D REGISTER
93
D ADDER-SUBTRACTOR
95
MOD
94
ROM
COSØ SINØ
72
DO
YI
92
Y REGISTER
FIRST Y SELECTOR
97
FIRST Y ADDER-SUBTRACTOR
99
SECOND Y SELECTOR
102
4th X
106
SINØ
2nd X
104
COSØ
SECOND Y ADDER-SUBTRACTOR
108
THIRD Y SELECTOR
110
YO
XI
91
X REGISTER
FIRST X SELECTOR
96
FIRST X ADDER-SUBTRACTOR
98
SECOND X SELECTOR
101
3rd X
103
105
1st X
SECOND X ADDER-SUBTRACTOR
107
THIRD X SELECTOR
109
XO

FIG. 14

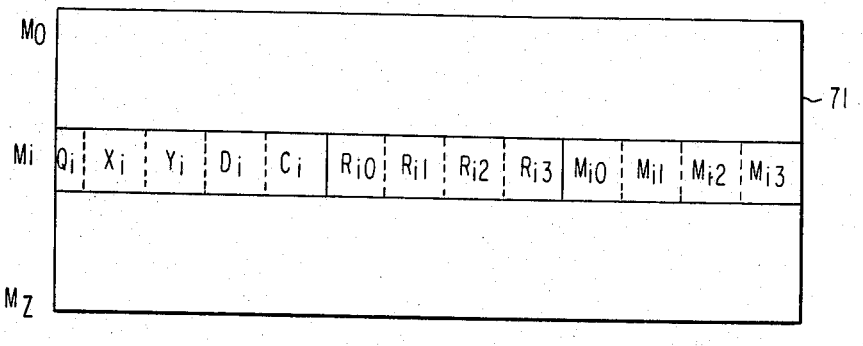


FIG. 16(a)

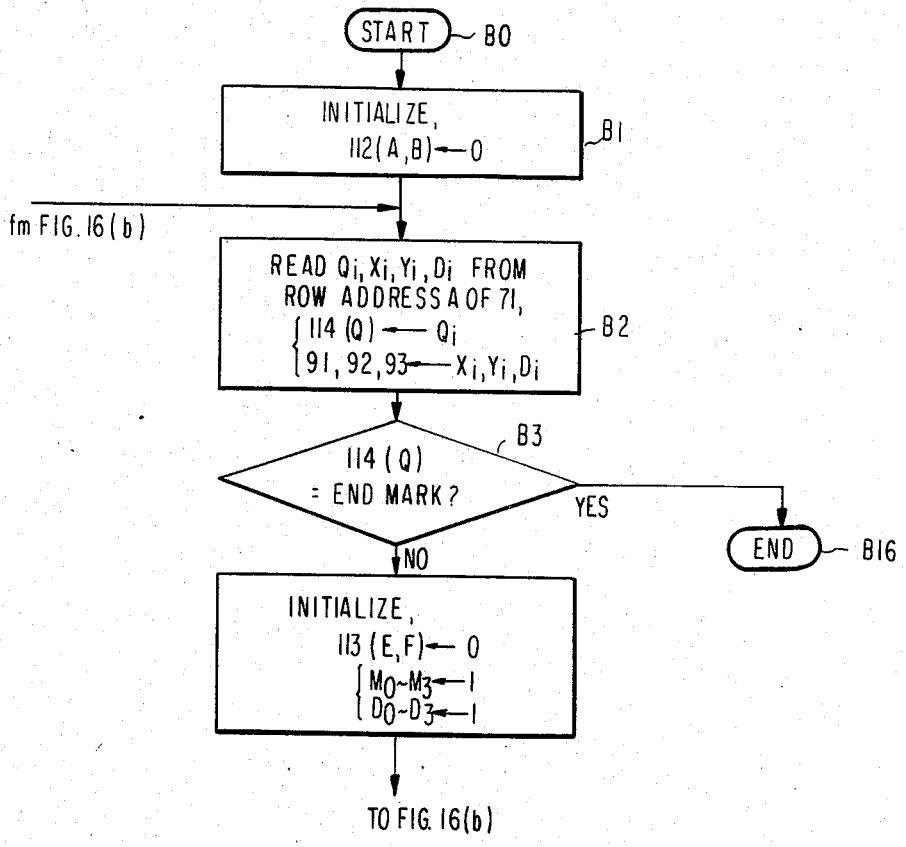


FIG. 15

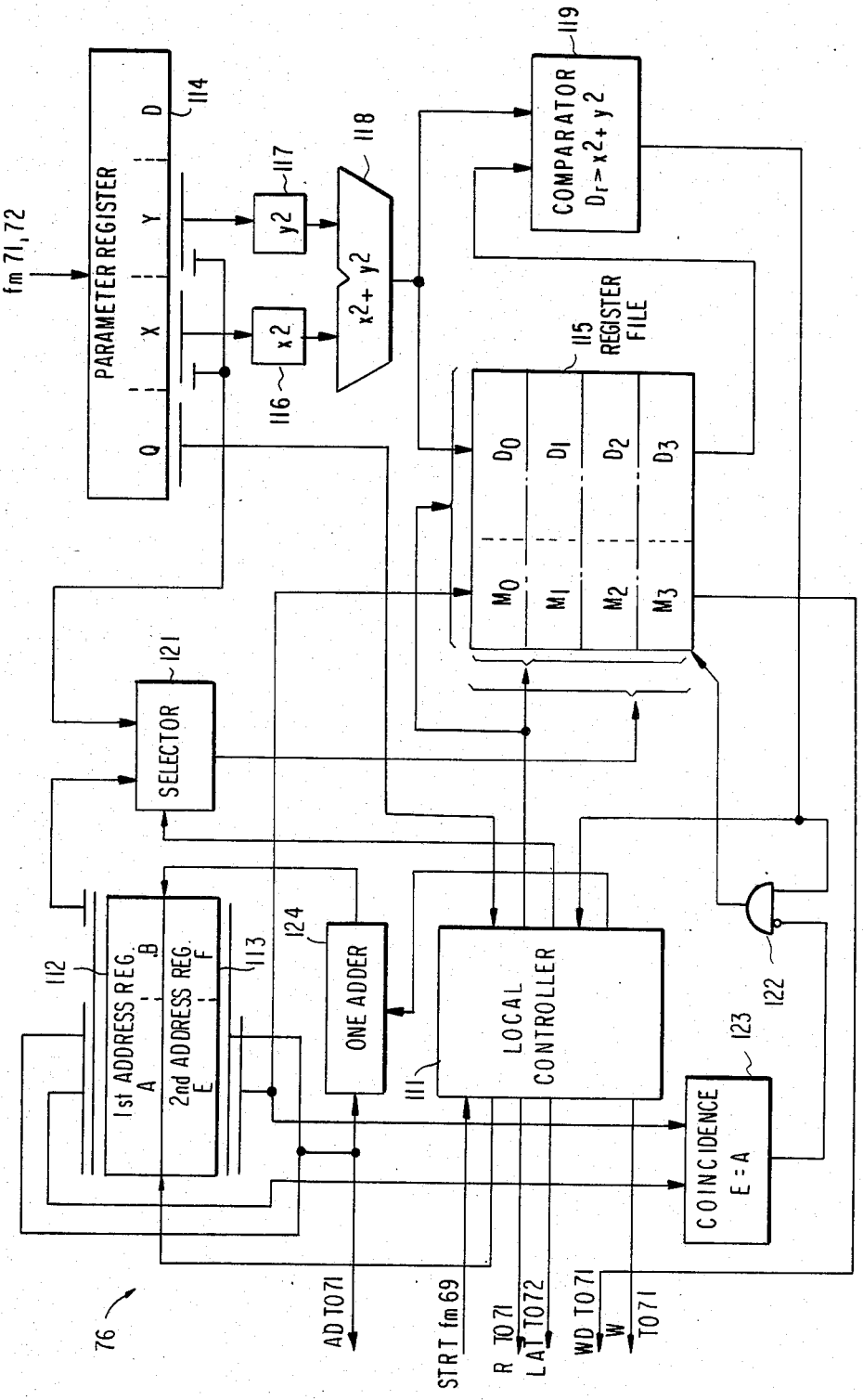

fm 71, 72
PARAMETER REGISTER
Q
X
Y
D
114
x2
116
y2
117
x2+ y2
118
COMPARATOR
$D_f > x^2 + y^2$
119
REGISTER FILE
115
D_0
D_1
D_2
D_3
M_0
M_1
M_2
M_3
SELECTOR
121
1st ADDRESS REG.
A
B
2nd ADDRESS REG.
E
F
112
113
ONE ADDER
124
LOCAL CONTROLLER
111
COINCIDENCE
E = A
123
122
76
AD TO 71
STRT fm 69
R TO 71
LAT TO 72
WD TO 71
W
TO 71

FIG. 16(b)

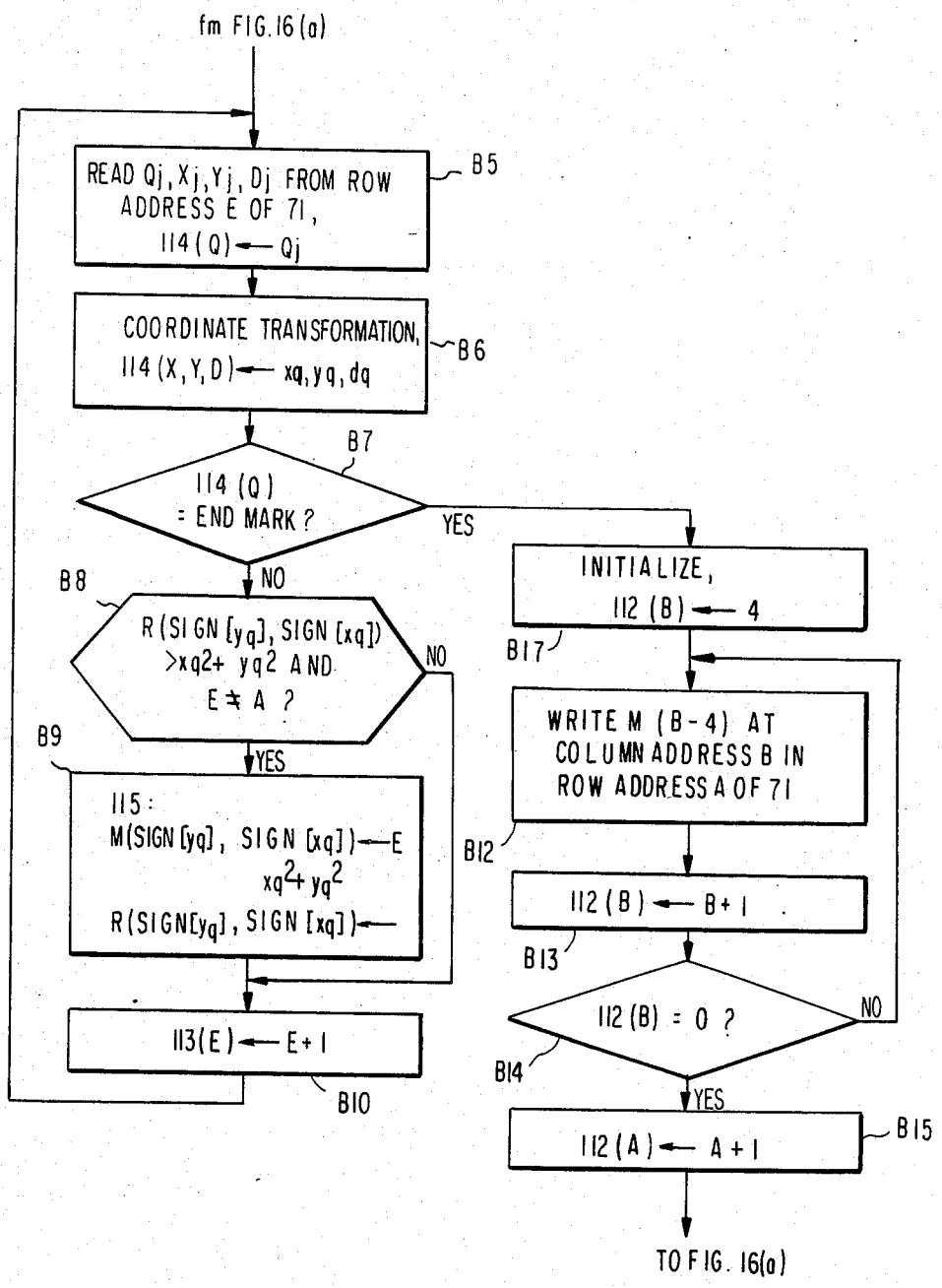

fm FIG. 16(a)
READ Qj, Xj, Yj, Dj FROM ROW ADDRESS E OF 71, 114(Q) ← Qj
B5
COORDINATE TRANSFORMATION, 114(X, Y, D) ← xq, yq, dq
B6
B7
114(Q) = END MARK ?
YES
NO
B8
R(SIGN[yq], SIGN[xq]) >xq2+ yq2 AND E ≠ A ?
NO
B9
YES
115: M(SIGN[yq], SIGN[xq]) ← E
xq2+ yq2
R(SIGN[yq], SIGN[xq]) ←
113(E) ← E+1
B10
INITIALIZE, 112(B) ← 4
B17
WRITE M(B-4) AT COLUMN ADDRESS B IN ROW ADDRESS A OF 71
B12
112(B) ← B+1
B13
112(B) = 0 ?
NO
B14
YES
112(A) ← A+1
B15
TO FIG. 16(a)

FIG. 17

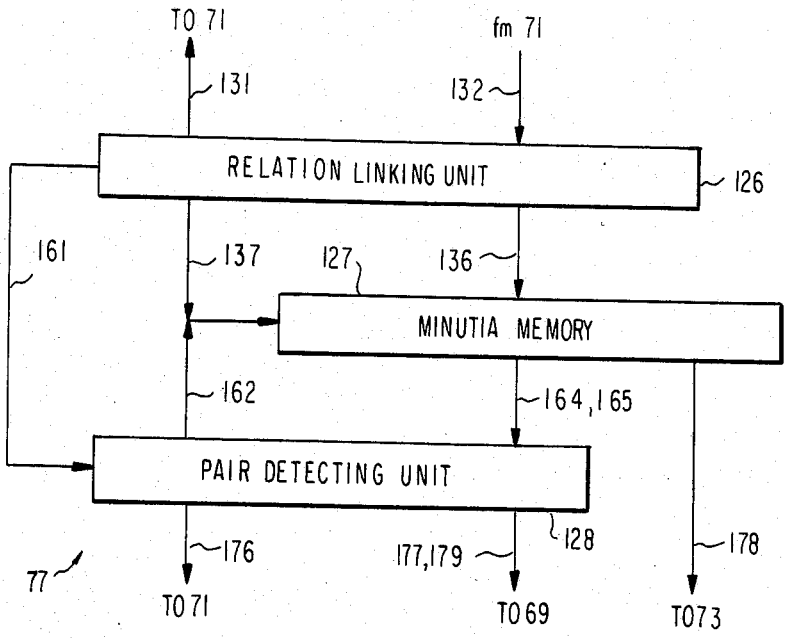

TO 71
fm 71
131
132
RELATION LINKING UNIT
126
161
137
127
136
MINUTIA MEMORY
162
164,165
PAIR DETECTING UNIT
128
176
177,179
178
77
TO 71
TO 69
TO 73

FIG. 18

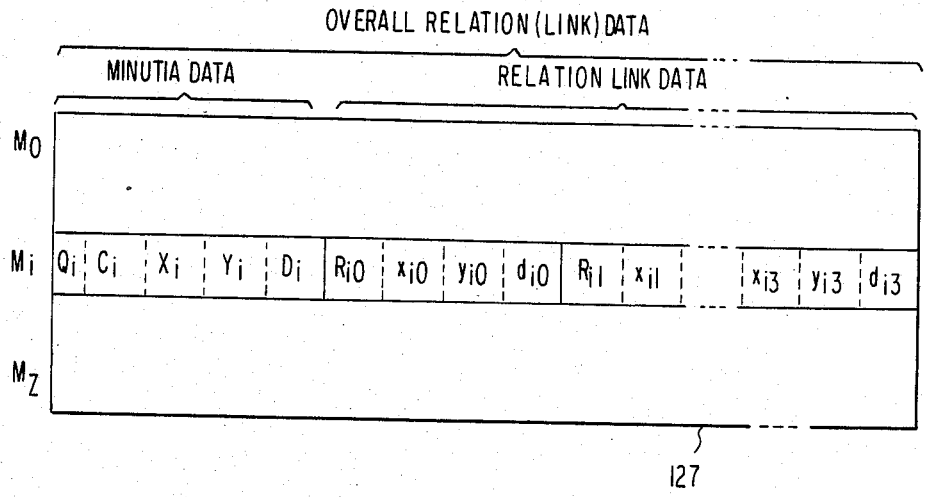

OVERALL RELATION (LINK) DATA
MINUTIA DATA
RELATION LINK DATA
M0
Mi
Qi Ci Xi Yi Di Ri0 xi0 yi0 di0 Ri1 xi1 xi3 yi3 di3
MZ
127

FIG. 19

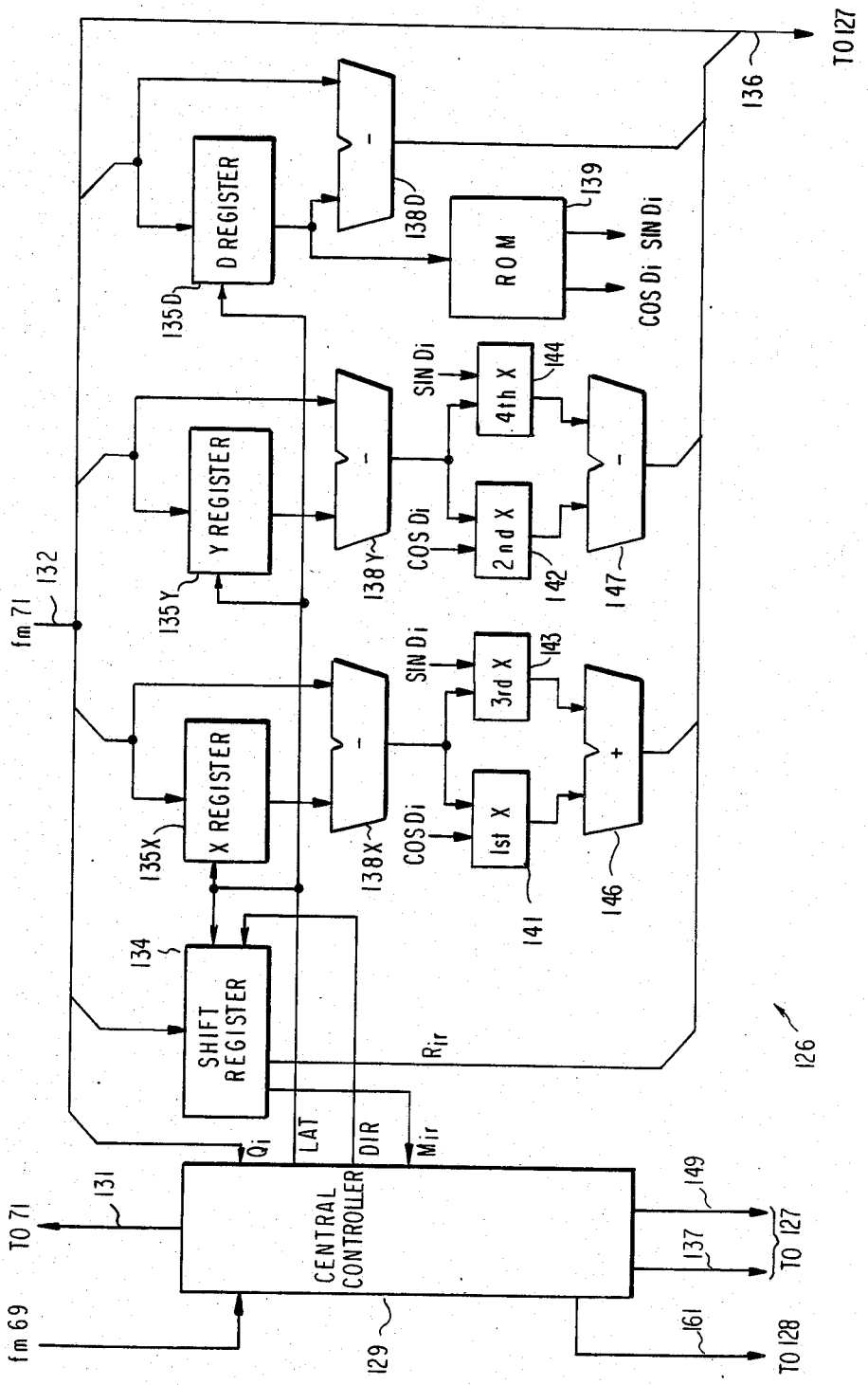

TO 127
136
D REGISTER
135D
138D
ROM
139
COS Di SIN Di
Y REGISTER
135Y
138Y
SIN Di
4th X
144
COS Di
2nd X
142
147
fm 71
132
X REGISTER
135X
138X
SIN Di
3rd X
143
COS Di
1st X
141
146
134
SHIFT REGISTER
Rir
Qi
LAT
DIR
Mir
126
131
TO 71
CENTRAL CONTROLLER
129
149
137
TO 127
fm 69
161
TO 128

FIG. 20

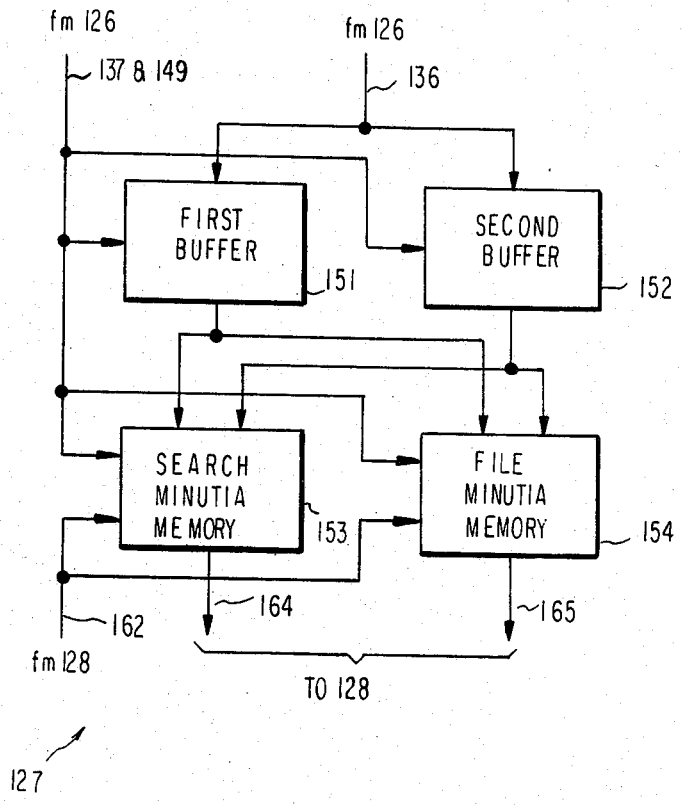

fm 126
137 & 149
fm 126
136
FIRST BUFFER
151
SECOND BUFFER
152
SEARCH MINUTIA MEMORY
153
FILE MINUTIA MEMORY
154
162
164
165
fm 128
TO 128
127

FIG. 39

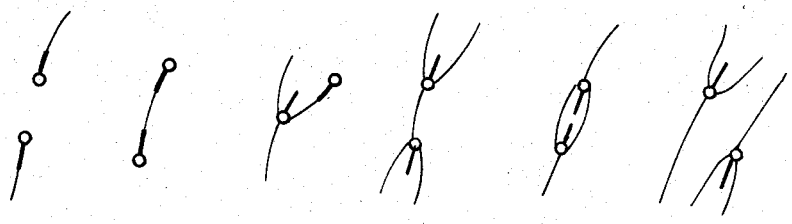


FIG. 21

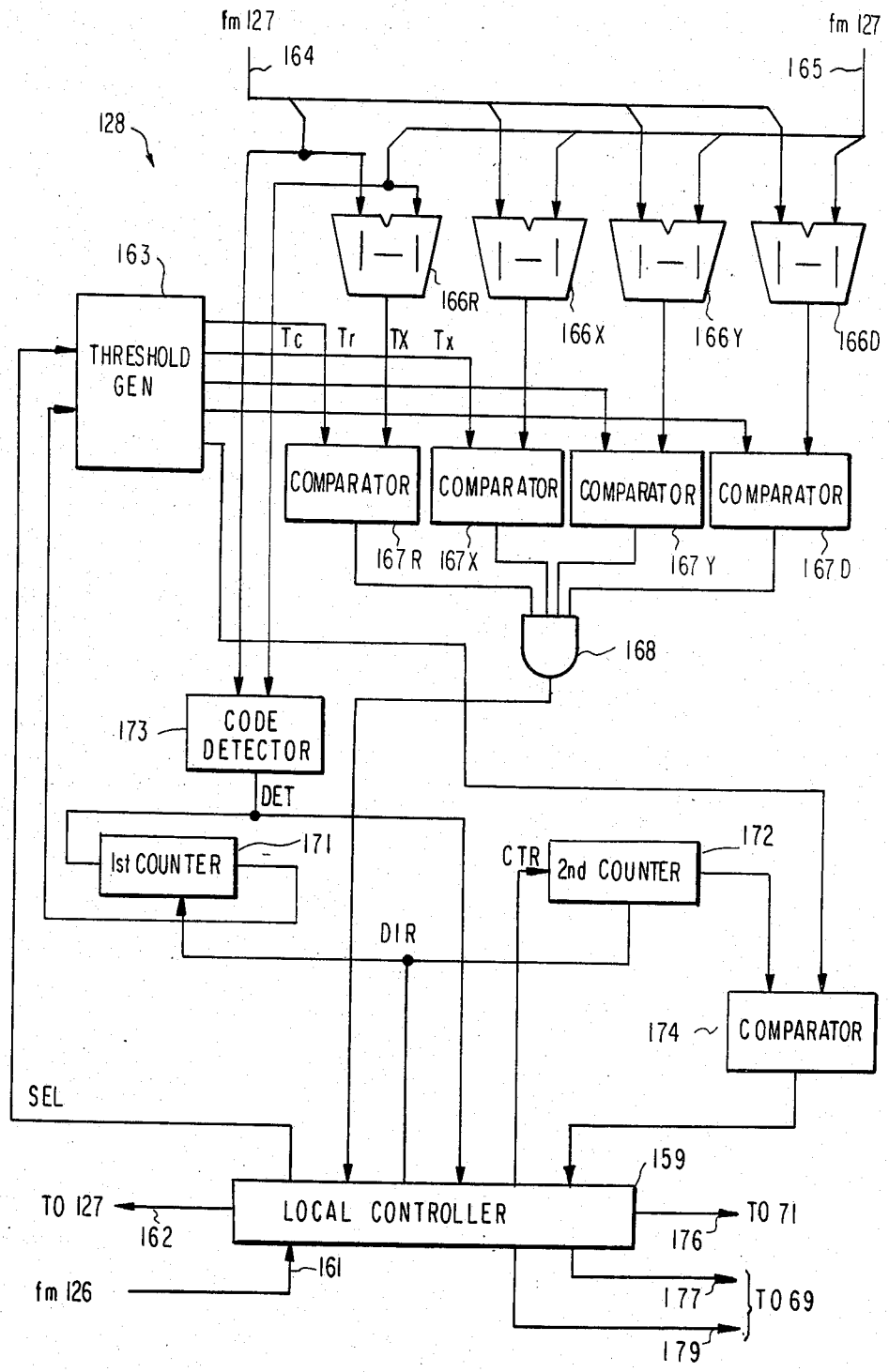

fm 127
164
fm 127
165
128
163
166R
166X
166Y
166D
THRESHOLD GEN
Tc
Tr
TX
Tx
COMPARATOR
COMPARATOR
COMPARATOR
COMPARATOR
167R
167X
167Y
167D
168
173
CODE DETECTOR
DET
171
1st COUNTER
CTR
172
2nd COUNTER
DIR
174
COMPARATOR
SEL
159
TO 127
162
LOCAL CONTROLLER
TO 71
176
fm 126
161
177
TO 69
179

FIG. 22

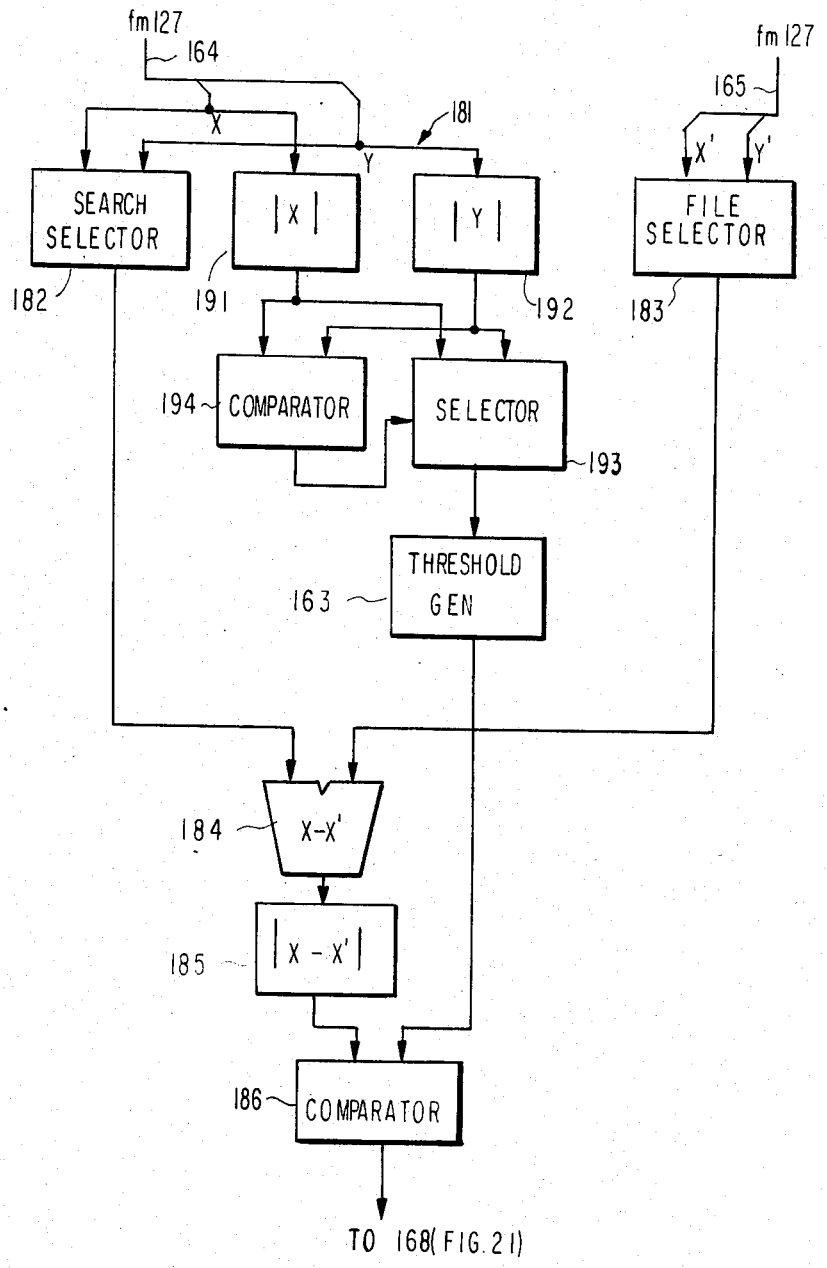

fm 127
164
X
Y
181
fm 127
165
X'
Y'
SEARCH SELECTOR
182
|X|
191
|Y|
192
FILE SELECTOR
183
194
COMPARATOR
SELECTOR
193
THRESHOLD GEN
163
184
X-X'
185
|X - X'|
186
COMPARATOR
TO 168(FIG. 21)

FIG. 23

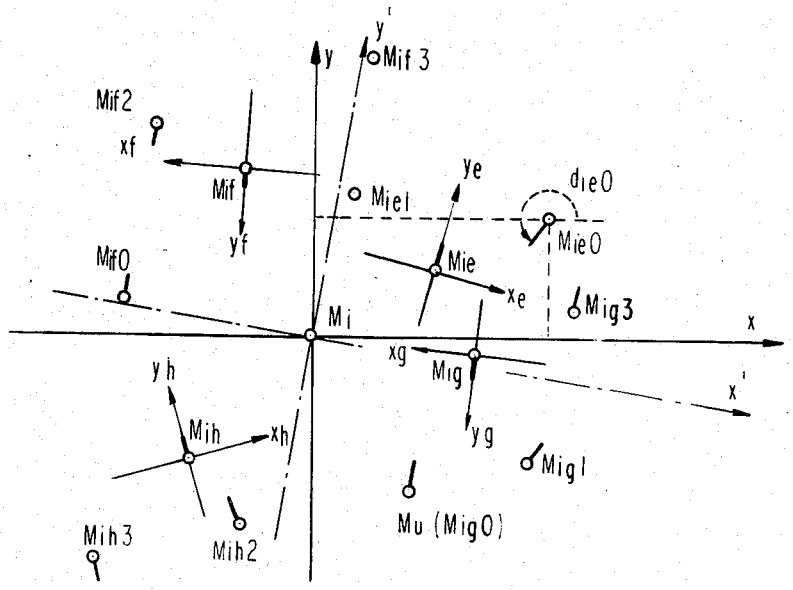

y'
y
Mif 3
Mif2
xf
Mif
yf
Miel
ye
dieO
MieO
MifO
Mie
xe
Mig3
x
Mi
xg
Mig
x'
yh
Mih
xh
yg
Mig1
Mu (MigO)
Mih3
Mih2

FIG. 24

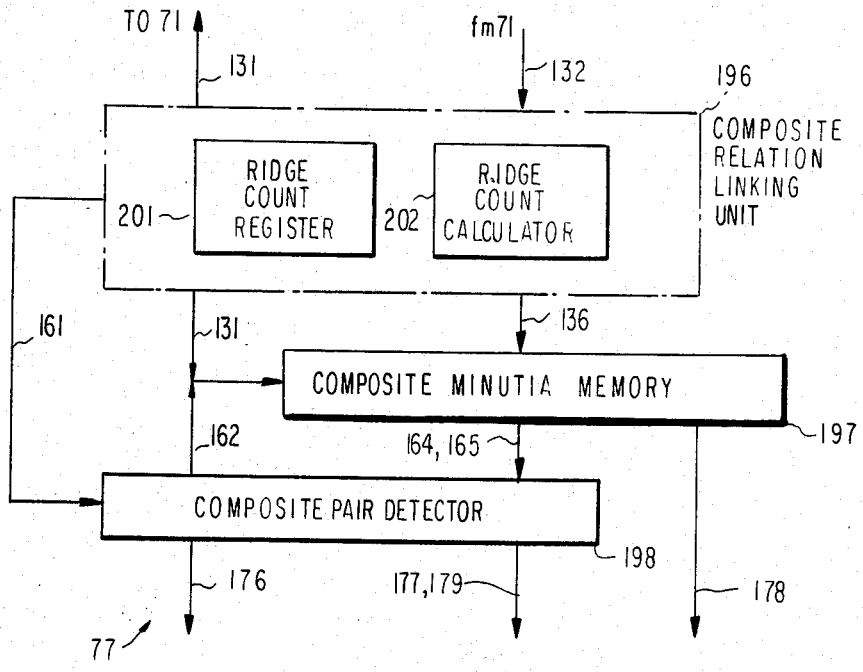

TO 71
131
fm71
132
196
COMPOSITE RELATION LINKING UNIT
RIDGE COUNT REGISTER
201
202
RIDGE COUNT CALCULATOR
161
131
136
COMPOSITE MINUTIA MEMORY
197
162
164, 165
COMPOSITE PAIR DETECTOR
198
176
177,179
178
77

FIG. 25

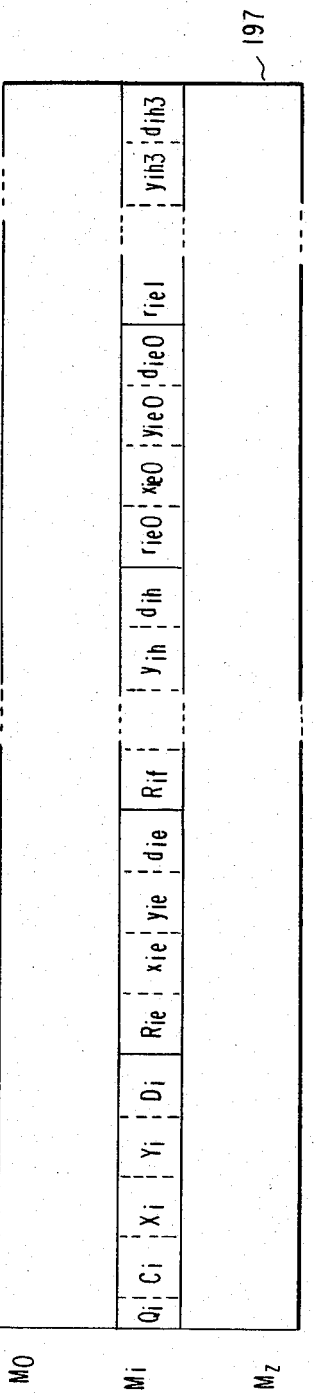

197
COMPOSITE RELATION DATA
MINUTIA DATA
PRIMARY RELATION DATA
SECONDARY RELATION DATA
Qi Ci Xi Yi Di Rie xie yie die Rif yih dih rieO xieO yieO dieO riel yih3 dih3
M0
Mi
Mz

FIG. 26

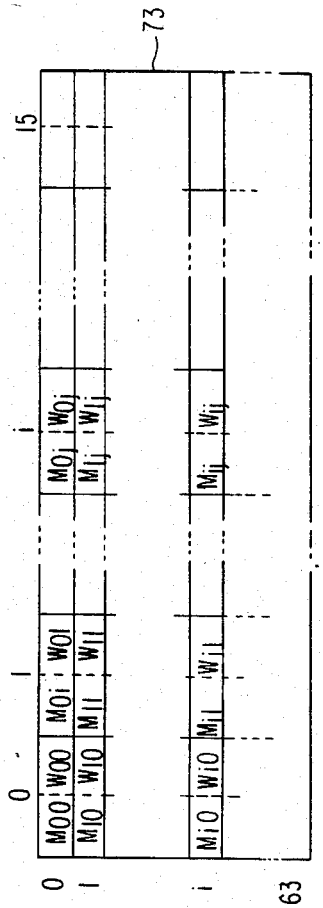

73
15
0
1
i
MOO WOO MOi WOI MOj WOj
MIO WIO MII WII Mij Wij
MiO WiO Mil Wil
0
1
i
63

FIG. 27

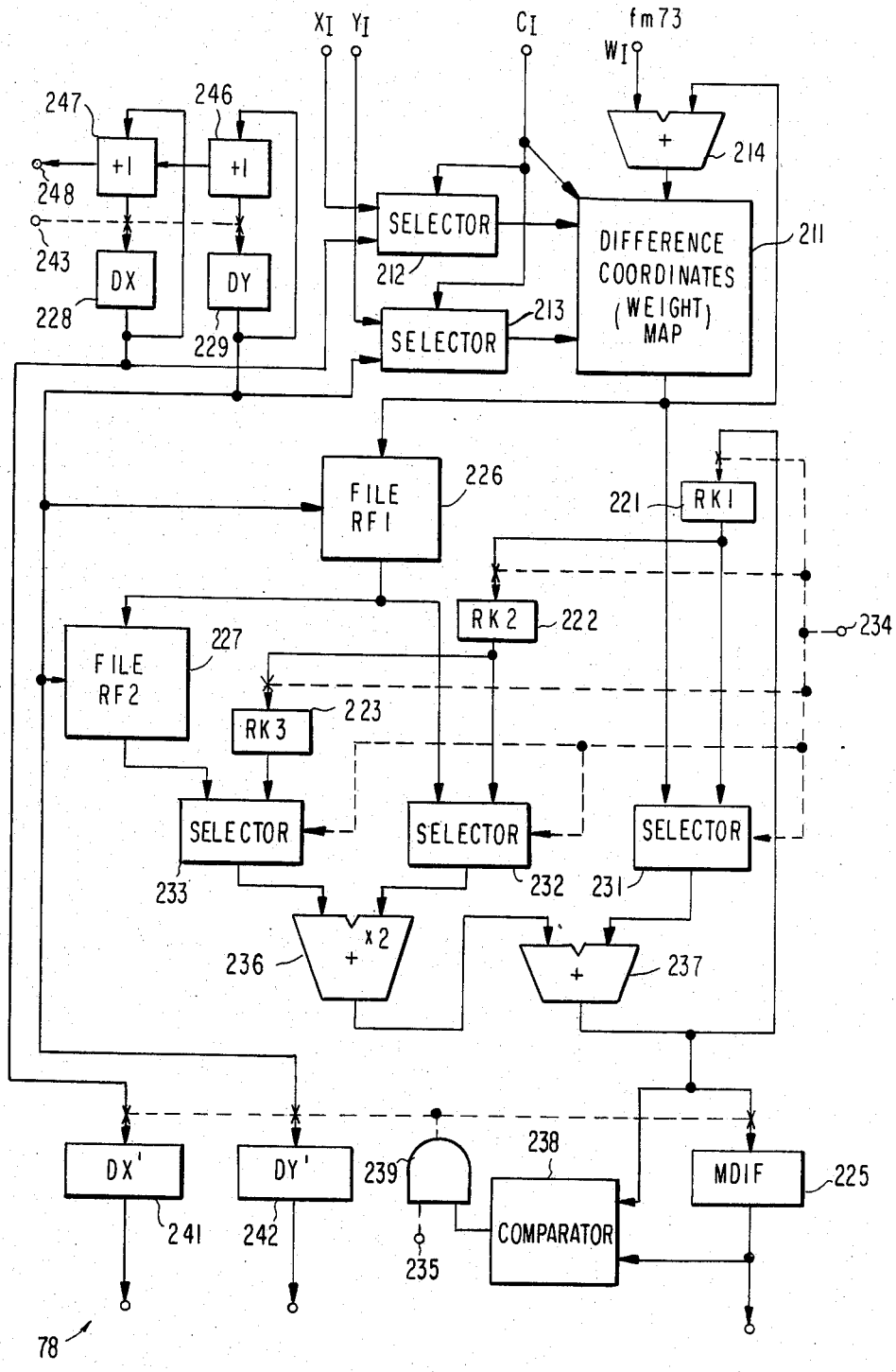

XI
YI
CI
fm73
WI
247
246
+1
+1
248
243
DX
DY
228
229
SELECTOR
212
SELECTOR
213
+
214
DIFFERENCE COORDINATES (WEIGHT) MAP
211
FILE RF1
226
221
RK1
RK2
222
234
FILE RF2
227
RK3
223
SELECTOR
SELECTOR
SELECTOR
233
232
231
x2
+
236
+
237
DX'
DY'
239
238
MDIF
225
241
242
COMPARATOR
235
78

FIG. 28

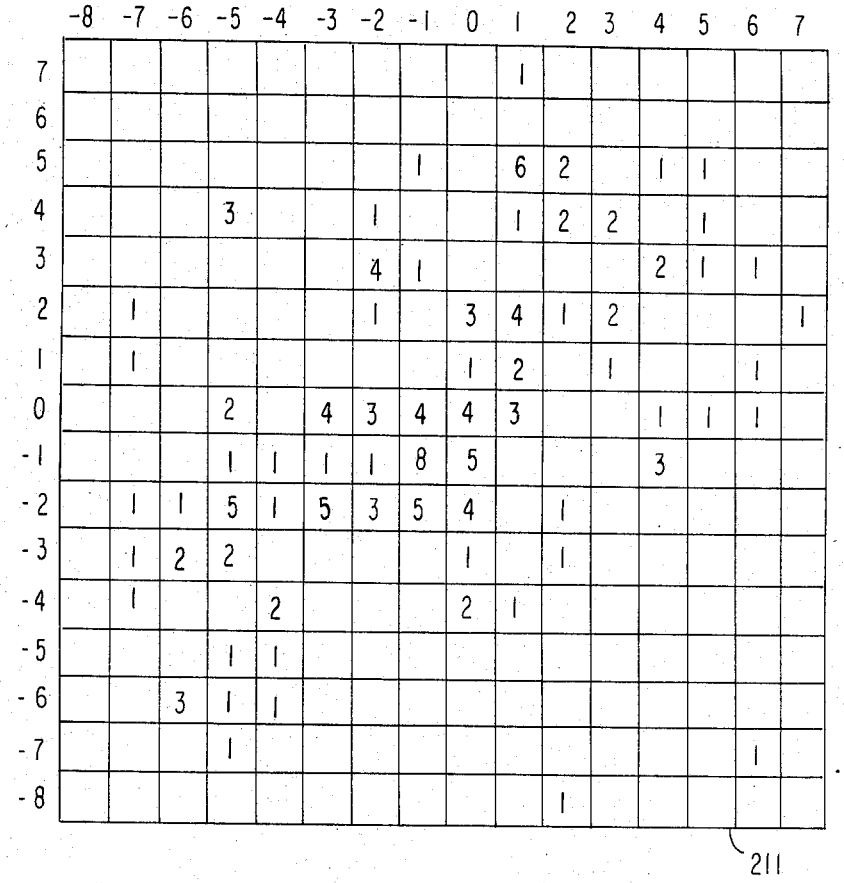

-8 -7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7
7 1
6
5 1 6 2 1 1
4 3 1 1 2 2 1
3 4 1 2 1 1
2 1 1 3 4 1 2 1
1 1 1 2 1 1
0 2 4 3 4 4 3 1 1 1
-1 1 1 1 8 5 3
-2 1 1 5 1 5 3 5 4 1
-3 1 2 2 1 1
-4 1 2 2 1
-5 1 1
-6 3 1 1
-7 1 1
-8 1
211

FIG. 30

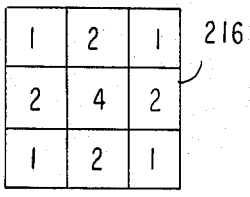

1 2 1
2 4 2
1 2 1
216

FIG. 29

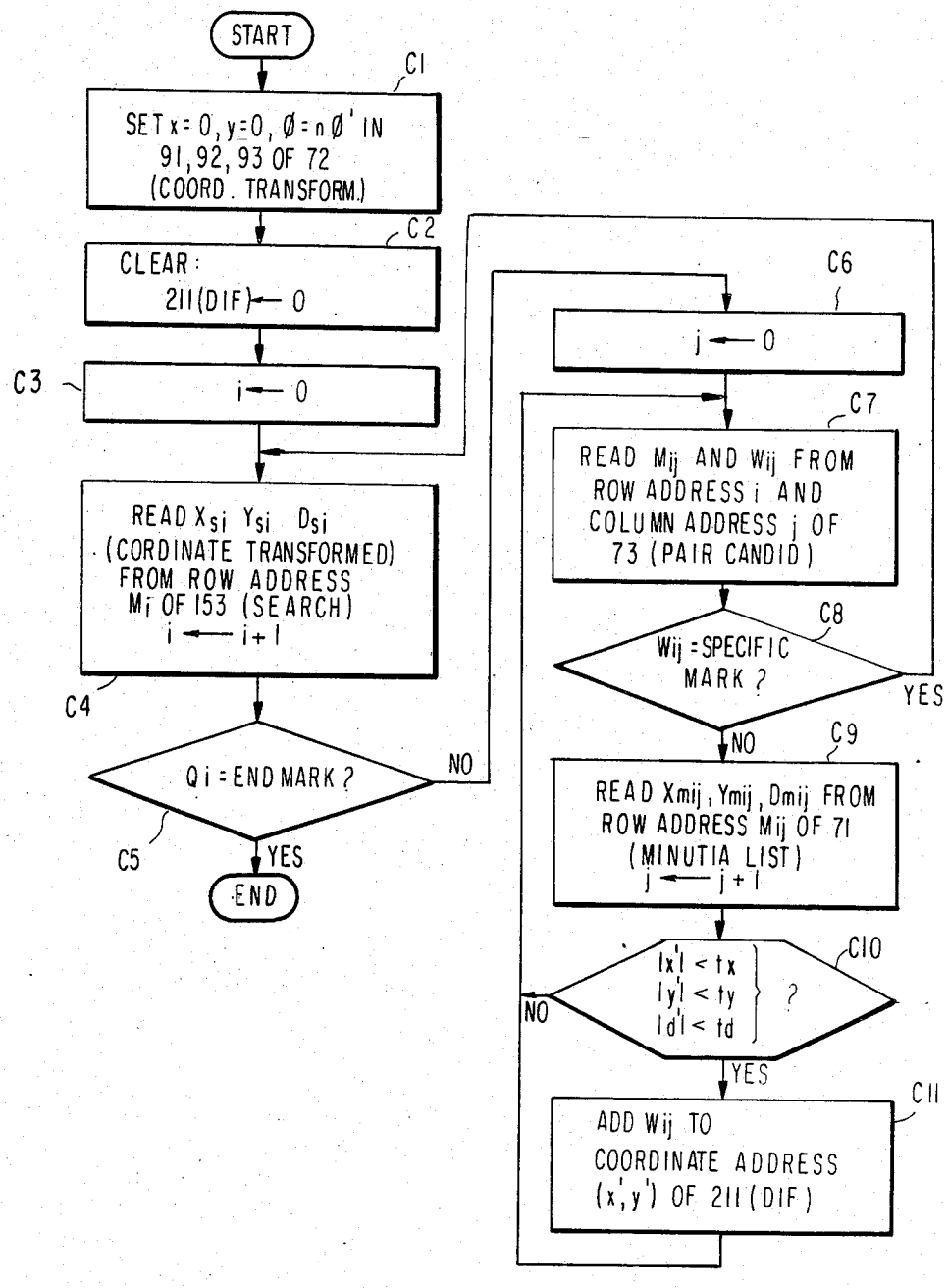

START
C1
SET x=0, y=0, Ø=nØ' IN 91, 92, 93 OF 72 (COORD. TRANSFORM.)
C2
CLEAR: 211(DIF)← 0
C3
i← 0
READ Xsi Ysi Dsi (CORDINATE TRANSFORMED) FROM ROW ADDRESS Mi OF 153 (SEARCH) i← i+1
C4
Qi = END MARK ?
NO
C5
YES
END
C6
j← 0
C7
READ Mij AND Wij FROM ROW ADDRESS i AND COLUMN ADDRESS j OF 73 (PAIR CANDID)
C8
Wij = SPECIFIC MARK ?
YES
NO
C9
READ Xmij, Ymij, Dmij FROM ROW ADDRESS Mij OF 71 (MINUTIA LIST) j← j+1
C10
|x'| < tx
|y'| < ty
|d'| < td
?
NO
YES
C11
ADD Wij TO COORDINATE ADDRESS (x', y') OF 211(DIF)

FIG. 31

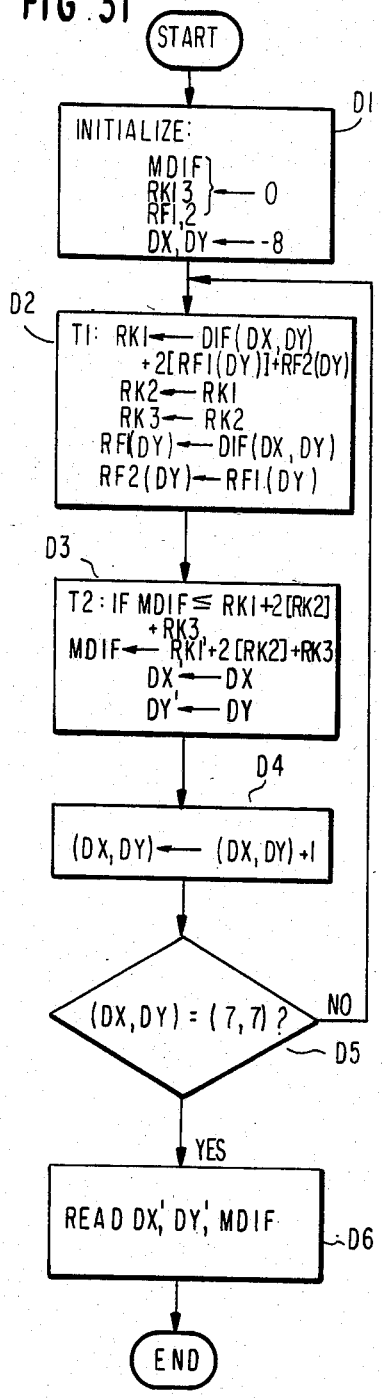

START
D1
INITIALIZE:
MDIF
RKI 3
RFI, 2
← 0
DX, DY ← -8
D2
T1: RKI ← DIF(DX, DY)
+2[RFI(DY)]1+RF2(DY)
RK2 ← RKI
RK3 ← RK2
RFI(DY) ← DIF(DX, DY)
RF2(DY) ← RFI(DY)
D3
T2: IF MDIF ≤ RKI+2[RK2]
+RK3
MDIF ← RKI+2[RK2]+RK3
DX' ← DX
DY' ← DY
D4
(DX, DY) ← (DX, DY)+1
(DX, DY) = (7, 7)?
NO
D5
YES
READ DX', DY', MDIF
D6
END

FIG. 32

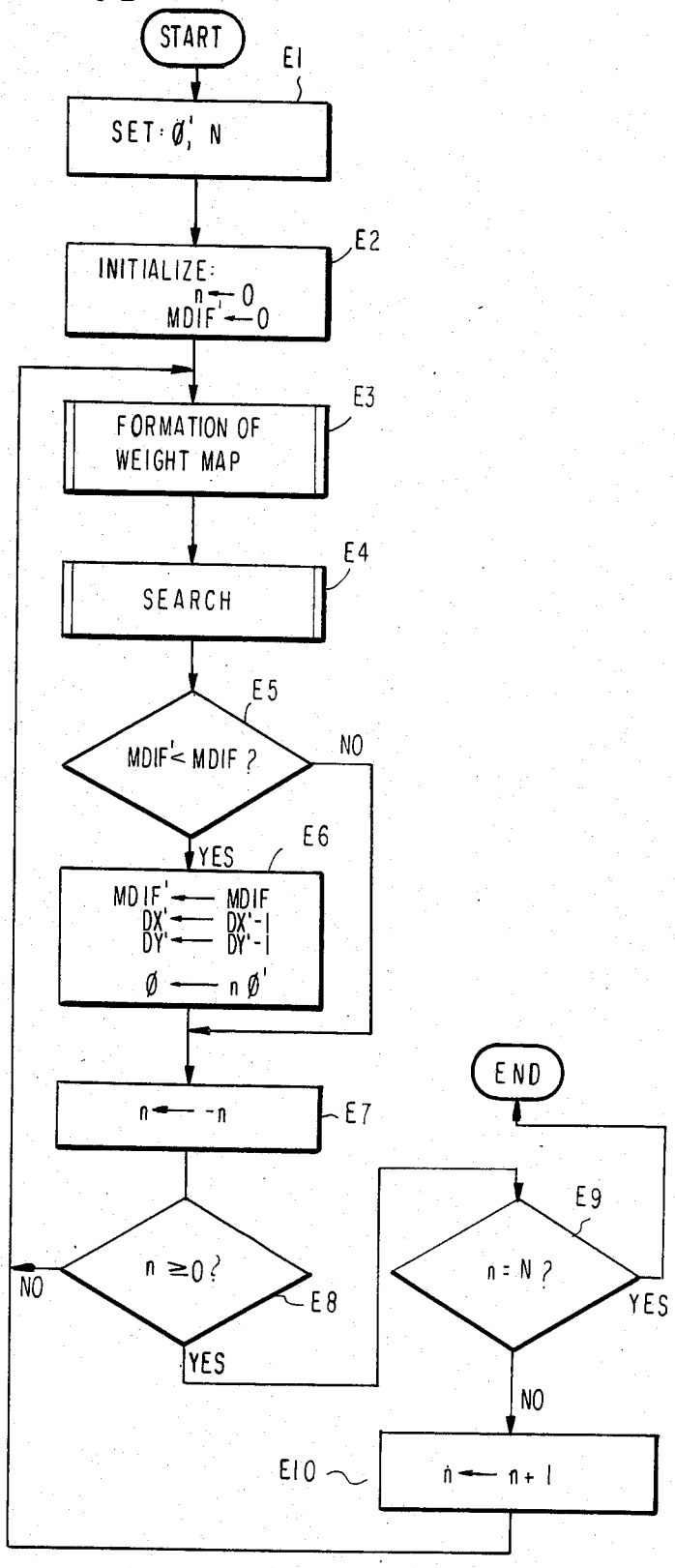

START
E1
SET: Ø', N
E2
INITIALIZE:
n ← 0
MDIF' ← 0
E3
FORMATION OF
WEIGHT MAP
E4
SEARCH
E5
MDIF' < MDIF ?
NO
YES
E6
MDIF' ← MDIF
DX' ← DX'-1
DY' ← DY'-1
Ø ← nØ'
n ← -n
E7
n ≥ 0?
NO
E8
YES
E9
n = N ?
YES
NO
E10
n ← n+1
END

FIG. 33

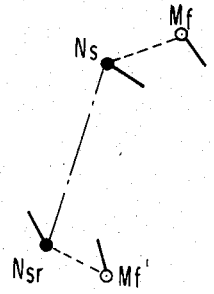


FIG. 34

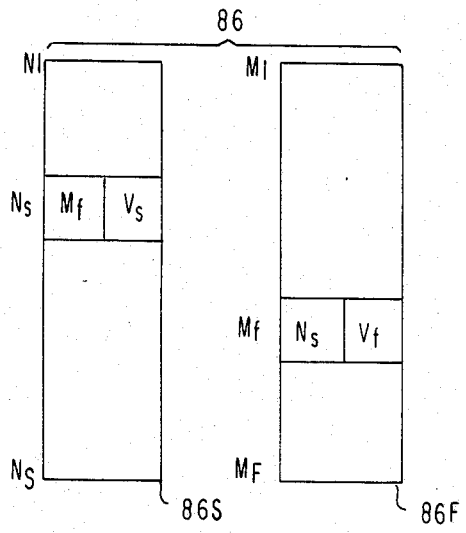


FIG. 35

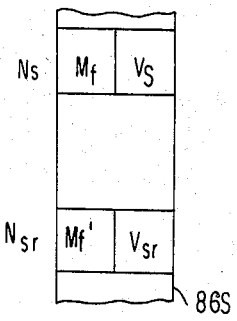


FIG. 36

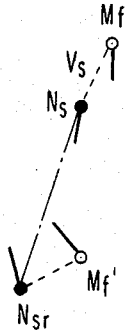


FIG. 37

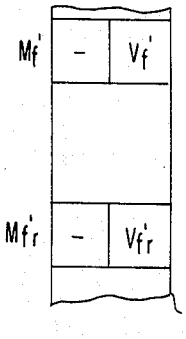


FIG. 38

FIG. 40

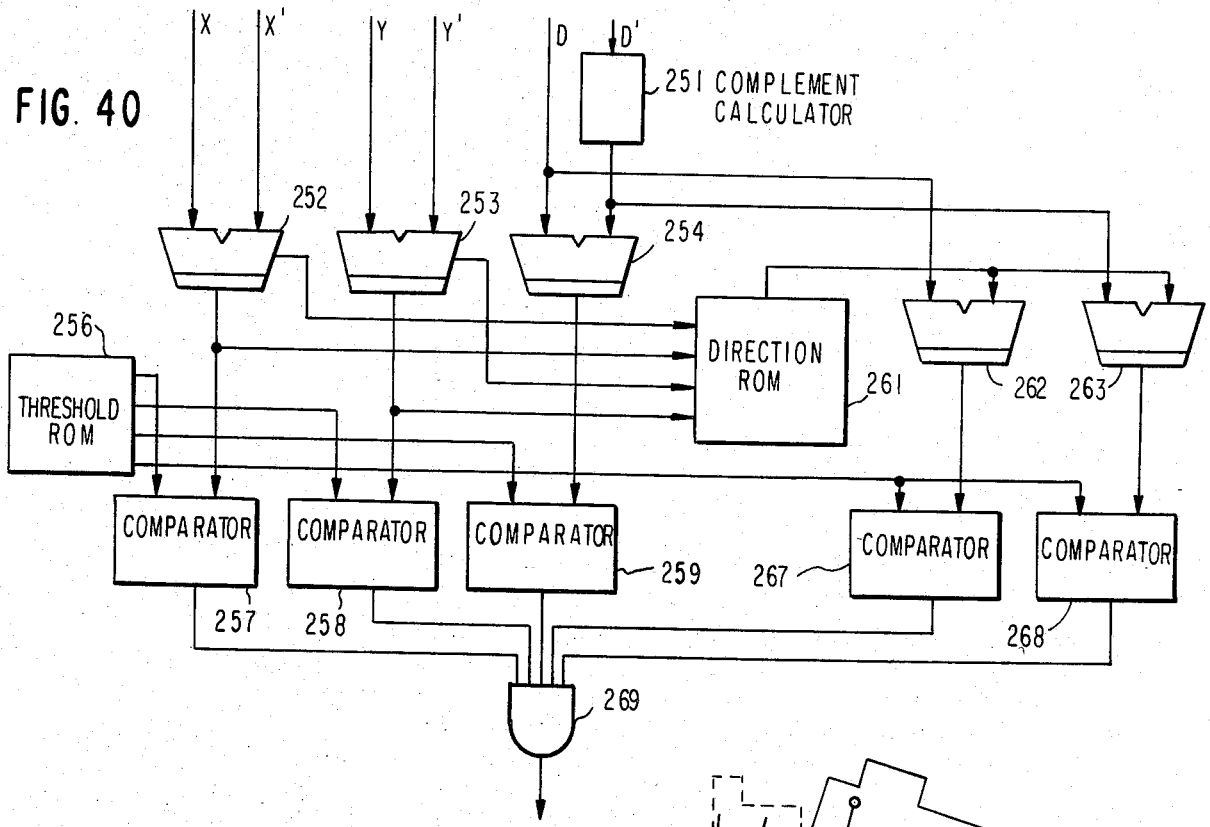


FIG. 41

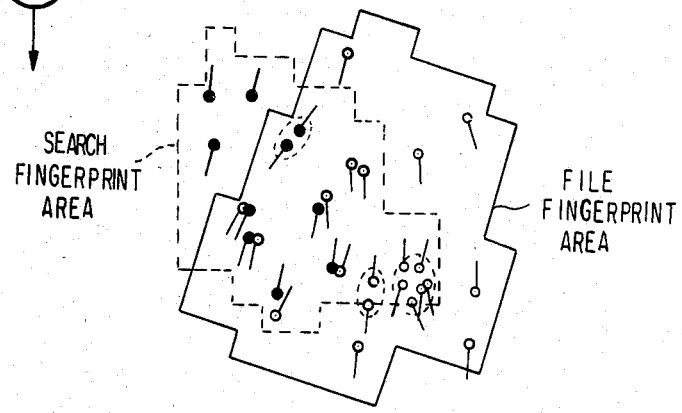
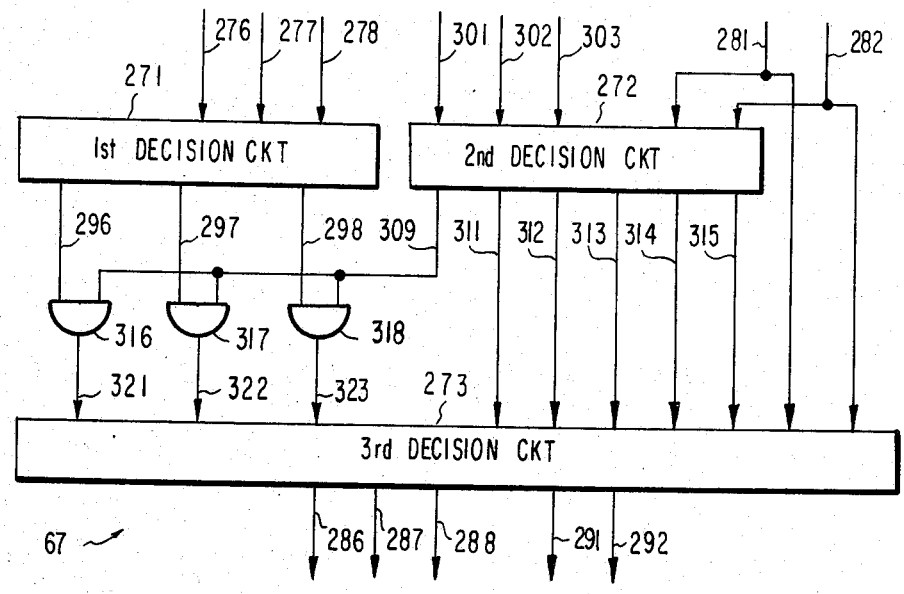


FIG. 42



METHOD AND DEVICE FOR MATCHING FINGERPRINTS WITH PRECISE MINUTIA PAIRS SELECTED FROM COARSE PAIRS

BACKGROUND OF THE INVENTION

This invention relates to a method and a device for matching fingerprints.

The word "fingerprint" is herein used as a representative of a fingerprint or a like pattern or figure. More particularly, the finerprint may be an actual finger, a palm print, a toe print, a soleprint, a squamous pattern, and a streaked pattern composed of streaks. The fingerprint may also be a diagram drawn by a skilled person to represent a faint fingerprint remain which is, for example, left at the scene of a crime.

The "matching" is for recognition of a fingerprint with reference to a plurality of known fingerprints. The matching may also be for discrimination, collation, and/or identification of the fingerprint.

A fingerprint to be matched with a known fingerprint, is usually called a search fingerprint. The known fingerprint is called a file fingerprint. Each fingerprint is featured by ridges and more specifically by minutiae.

It is conventional on carrying out the fingerprint matching to select a coordinate system on each fingerprint as will later be described with reference to a few of about forty figures of the accompanying drawing. The coordinate system is used to represent the position or location which each minutia has on the fingerprint. Furthermore, a direction is defined together with the sense in connection with each minutia with reference to the coordinate system. In addition to the position and direction data of each minutia, a local feature characteristic to each minutia is known which is independent of the coordinate system. An example of such a local feature is the difference between types of minutiae. Other examples are "relation data" which are representative of relationships between each minutia and adjacent minutiae. The relation data are substantially independent of the coordinate system as will become clear as the description proceeds with reference to the accompanying drawing. At any rate, the coordinate system will be called a principal coordinate system.

Fingerprint matching has been carried out by comparing the minutia position and direction data and relation data of a search fingerprint with those of each file fingerprint. Inasmuch as the coordinate systems are independently selected on the respective fingerprints, the position and direction data of a fingerprint must be transformed so as to be represented by a coordinate system which best matches with the coordinate system selected on the other fingerprint.

The best match has been attained only with time consuming procedures. Even with the best match, the fingerprint matching has been unreliable due to various circumstances under which the fingerprints are printed. This has resulted in unsatisfactory performance of a conventional method of fingerprint matching and of a conventional fingerprint matching device. Incidentally, the position and direction data given either by the principal coordinate systems or by a coordinate system into which at least one of the coordinate systems is transformed to provide a certain degree of match, will be called original position and direction data in contrast to transformed position and direction data which are obtained after specific coordinate transformation.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a method of reliably matching a search fingerprint with each file fingerprint.

It is another object of this invention to provide a method of the type described, which rapidly carries out the matching.

It is a further object of this invention to provide a fingerprint matching device for use in carrying out the method of the type described.

A method according to this invention is for deciding a degree of match between a search and a file fingerprint. As is well known in the art, such a method includes the steps of selecting principal coordinate systems for the respective fingerprints, selecting a search and a file fingerprint area where minutiae are clear, forming a minutia list showing those original position and direction data of the minutiae and those relation data of the minutiae which are given by the respective principal coordinate systems and which are substantially independent of the principal coordinate systems, respectively, and selecting pairs of minutiae from the minutiae of the respective fingerprints by comparing the original position and direction data given for the respective fingerprints and furthermore comparing the relation data given for the respective fingerprints.

The method according to this invention is characterized by the steps of forming a pair candidate list which shows the above-mentioned pairs of minutiae as candidate pairs, respectively, deciding those optimum amounts by referring to the original position and direction data of the minutiae of the pair candidates which are for matching the principal coordinate systems with each other, transforming the original position and direction data given by one of the principal coordinate systems for the minutiae of the pair condidates into transformed position and direction data given by a transformed coordinate system into which the above-mentioned one principal coordinate system is transformed by the optimum amounts, forming a pair list by referring to the minutia list, the pair candidate list, and the search and the file fingerprint areas, which pair list shows precise pairs of minutiae selected from those minutiae of the pair condidates which are present in an area common to the search and the file fingerprint areas wherein the minutiae of each precise pair have a precise local similarity between the transformed position and direction data and the original position and direction data given by the other principal coordinate system and between the relation data and which pair list furthermore shows evaluations, each representative of the local similarity, and deciding the degree of match by using the minutiae of the precise pairs and by referring to the evaluations.

A fingerprint matching device according to this invention is for deciding a degree of match between a search and a file fingerprint. A conventional fingerprint matching device includes minutia list memory means for memorizing a minutia list showing those original position and direction data of minutiae which are given by principal coordinate systems prelminarily selected on the search and the file fingerprints, respectively, and those relation data of the minutiae which are substantially independent of the principal coordinate systems, fingerprint area memory means for memorizing a search and a file fingerprint area where the minutiae are clear, and selecting means coupled to the minutia list memory

means for selecting pairs of minutiae from the minutiae of the respective fingerprints by comparing the original position and direction data given for the respective fingerprints and furthermore comparing the relation data given for the respective fingerprints.

The fingerprint matching device according to this invention is characterized by pair candidate list memory means coupled to the selecting means for memorizing a pair candidate list which shows the above-mentioned pairs of minutiae as pair candidates, respectively, optimum amount deciding means coupled to the minutia list memory means and the pair condidate list memory means for deciding those optimum amounts by referring to the original position and direction data of the minutiae of the pair candidates which are for matching the principal coordinate systems with each other, coordinate transforming means coupled to the minutia list memory means, the pair candidate list memory means, and the optimum amount deciding means for transforming one of the principal coordinate systems into a transformed coordinate system by the optimum amounts whereby the original position and direction data given by that one principal coordinate system are transformed into transformed position and direction data, pair list memory means coupled to the minutia list memory means, the pair candidate list memory means, and the fingerprint area memory means for memorizing a pair list which shows precise pairs of minutiae selected from those minutiae of the pair candidates which are present in an area common to the search and the file fingerprint areas wherein the minutiae of each precise pair have a precise local similarity between the transformed position and direction data and the original position and direction data given by the other principal coordinate system and between the relation data, which pair list furthermore shows evaluations, each representative of the local similarity, and deciding means coupled to the pair list memory means for deciding the degree of match by using the minutiae of the pair list and by referring to the evaluations.

BRIEF DESCRIPTION OF THE DRAWING

FIG. **1** is a block diagram of a fingerprint matching system;

FIG. **2** is a block diagram of a fingerprint matching device for use in the system depicted in FIG. **1** according to the instant invention;

FIG. **3** is a block diagram of another fingerprint matching device for use in the system of FIG. **1**, according to a more preferred embodiment of this invention;

FIG. **4** diagrammatically shows a fingerprint;

FIG. **5** is a block diagram of a control unit used in either of the devices illustrated in FIGS. **2** and **3**;

FIG. **6** is a block diagram of a leading matcher used in either of the devices shown in FIGS. **2** and **3**;

FIG. **7** is a block diagram of a precise matcher used in either of the devices depicted in FIGS. **2** and **3**;

FIG. **8**, drawn below FIG. **5** merely for convenience of illustration, shows minutia data which are generally used in fingerprint matching;

FIG. **9** shows a flow chart for use in describing a fingerprint matching method according to an embodiment of this invention;

FIG. **10** shows an example of a minutia list which is usually used in a fingerprint matching method or device;

FIG. **11** shows coordinate systems for use in describing coordinate transformation in general;

FIG. **12** shows a flow chart for use in describing general coordinate transformation;

FIG. **13** is a block diagram of a coordinate transforming circuit which is preferred for use in a fingerprint matching device according to an aspect of this invention;

FIG. **14** shows another example of the minutia list;

FIG. **15** is a block diagram of a proximate minutia recovery circuit for use in the leading matcher illustrated in FIG. **6**;

FIG. **16**(*a*), drawn below FIG. **14**, shows a leading part of a flow chart illustrative of operation of the proximate minutia recovery circuit depicted in FIG. **15**;

FIG. **16**(*b*) shows the remaining part of the flow chart;

FIG. **17** is a block diagram of a pair detection circuit for use in the leading matcher shown in FIG. **6**;

FIG. **18** shows an example of the content of a minutia list used in the pair detection circuit depicted in FIG. **17**;

FIG. **19** is a block diagram of a relation linking unit for use in the pair detection circuit of FIG. **17**;

FIG. **20** is a block diagram of a minutia memory for use in the pair detection circuit of FIG. **17**;

FIG. **21** is a block diagram of a pair detecting unit for use in the pair detection circuit of FIG. **17**;

FIG. **22** is a block diagram of a part of a modification of the pair detecting unit depicted in FIG. **21**;

FIG. **23** shows a coordinate plane for use in describing additional relation data;

FIG. **24** is a block diagram of a pair detection circuit in which the additional relation data are used;

FIG. **25** shows an example of the content of a composite minutia list used in the pair detection circuit illustrated in FIG. **24**;

FIG. **26** shows an example of a pair candidate list memory used in the leading matcher illustrated in FIG. **6**;

FIG. **27** is a block diagram of an adjustment amount deciding circuit for use in the leading matcher depicted in FIG. **6**;

FIG. **28** shows a weight map formed in the adjustment amount deciding circuit exemplified in FIG. **27**;

FIG. **29** shows a flow chart for use in describing operation of the adjustment amount deciding circuit of FIG. **27**;

FIG. **30**, drawn below FIG. **28**, shows a factor table which is automatically taken into consideration by the adjustment amount deciding circuit shown in FIG. **27**;

FIG. **31** shows another flow chart for use in describing the operation of the adjustment amount deciding circuit;

FIG. **32** shows still another flow chart for use in describing the operation of the adjustment amount deciding circuit;

FIG. **33** shows a set of several minutiae of a search and a file fingerprint;

FIG. **34** is a schematic diagram of a pair list memory for use in the precise matcher illustrated in FIG. **7**;

FIG. **35** shows an example of the content of the pair list memory depicted in FIG. **34**;

FIG. **36** shows another set of several minutiae;

FIG. **37** shows another example of the content of the pair list memory;

FIG. **38** shows two minutiae of a file fingerprint;

FIG. **39**, drawn below FIG. **20**, shows examples of minutia pairs;

FIG. 40 is a block diagram of a direction checking circuit for use in a precise matcher of the type exemplified in FIG. 7;

FIG. 41 exemplifies a search and a file fingerprint area together with minutiae thereof; and

FIG. 42 is a block diagram of a destination deciding circuit for use in the control unit depicted in FIG. 5.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

General Description

Referring to FIG. 1, a fingerprint matching system comprises four fingerprint matching devices **51***a*, **51***b*, **51***c*, and **51***d* which have a common structure according to the present invention. The number of the devices **51** (the subscripts being omitted) need not necessarily be four. Only one device **51** may be used in the system. The system further comprises a data input device **52**, a data control and processing device **53**, a data storing device **54**, and a matching control device **55**, all of which will later be described in detail.

Turning to FIG. 2, each fingerprint matching device **51** comprises a leading matcher **56**, a precise matcher **57**, and a control unit **59**, all of which will presently be described in outline and later in greater detail.

As exemplified in FIG. 3, the fingerprint matching device **51** may comprise a plurality of leading matchers **56***a*, **56***b*, and **56***c* and a lesser number of precise matchers **57***a* and **57***b*.

In either event, the fingerprint matching device **51** is for deciding a degree of match q between a search and a file fingerprint by comparing data of the search fingerprint with data of a great number of file fingerprints. One, if any, of the file fingerprint is selected, that gives a best match with the search finerprint as regards the degree of match q. When a plurality of search fingerprints are given for matching, the device **51** repeats the comparison. Merely for brevity of description, it will be assumed that the device **51** compares data of only one search fingerprint with data of the file fingerprints unless otherwise stated. The data of the search and the file fingerprints will be identified by subscripts S and F.

Referring to FIG. 4, each fingerprint is a pattern or figure composed of ridges exemplified by thin lines in an area depicted on an enlarged scale. Some of the ridges have abrupt endings. Ridges that have or have not abrupt endings, may have bifurcations or branches. Furthermore, the ridges may have a singular point at which the ridge is irregular as, for example, very thick. The fingerprint may have a cross point of two or more ridges. The abrupt endings, the bifurcations, and so forth are called minutiae. The difference between the abrupt endings, the bifurcations, and the like is referred to as a difference between types of minutiae or minutia types. The fingerprint generally includes an unclear area or region indicated by a hatched area in which at least the minutiae are not clear. It is possible to select, as by excluding such unclear area or areas from the fingerprint, a search and a file fingerprint area where the minutiae are clear.

In order to quantitatively deal with the minutiae, an X-Y coordinate system is selected so as to have an origin O at, for example, a lowest one of the abrupt endings of a leftmost ridge extending towards the palm. The Y axis has the positive sense or direction towards the finger tip. The coordinate system will herein be called a principal coordinate system. Incidentally, it is possible in general to judge the direction of the finger tip from the directions in which the ridges flow or trail.

The minutiae are consecutively numbered with reference to the coordinate system. The minutia numbers will be denoted by $M_0, M_1, M_2, \ldots, M_i, \ldots, M_j, \ldots$, and M_z, which denotation will be used also to represent the minutiae. It is to be noted in this connection that a natural number j need not always be greater than another natural number i but may either be equal to or less than the other natural number i. The last number z usually differs from a fingerprint to another. For example, a search fingerprint has less than sixty-four minutiae in general. A file fingerprint may have nearly one hundred and ninety-two minutiae.

The type of the i-th minutia M_i will be designated by Q_i. Each minutia M_i has a position or location given by coordinates (X_i, Y_i) of the principal coordinate system. It is known in the art to define a direction with sense D_i for each abrupt ending or bifurcation M_i with reference to the principal coordinate system. As indicated by a short thick line, the direction of an abrupt ending is defined by the direction in which the ridge extends from the abrupt ending. The direction of a bifurcation is precisely defined in U.S. Pat. No. 4,310,827 issued to Koh Asai, one of the present applicants and assignor to the instant assignee.

A concentration or density C, is defined for each minutia M_i by the number of other minutiae which are present in a prescribed area including the minutia M_i being taken into consideration. The prescribed area is conveniently a circle having the center at the minutia M_i under consideration and a predetermined radius. For the example depicted on the enlarged scale, the concentration C_i is seven for the minutia M_i.

An x-y local coordinate system will be selected for each minutia M_i. The local coordinate system has a local origin at the minutia M_i. The y axis has the positive sense in coincidence with the minutia direction D_i. The x-y coordinate plane is divided into a predetermined number of sectors having a common vertex at the minutia M_i. A proximate minutia, if any, is selected in each sector. For the example being illustrated, the sectors are the first through the fourth quadrants of the local coordinate system. Minutiae M_{i0}, M_{i1}, M_{i2}, and M_{i3} are representative of the proximate minutiae in the first, the second, the fourth, and the third quadrants, respectively. It should be noted that the double suffixes **i0** through **i3** are representative of pertinent one of 0 through the natural number z and that the suffix endings 0 through 3 are selected for the respective quadrants so as to simplify the circuitry of the fingerprint matching device **51** (FIGS. **1** through **3**) as will later become clear. The proximate minutiae M_{i0} through M_{i3} will either singly or collectively be designated by M_{ir}. As the case may be, the i-th minutia M_i used as the local origin, will be called a reference minutia in contrast to the proximate minutia or minutiae M_{ir}.

The number of ridges that lie between a reference minutia M_i and each proximate minutia M_{ir}, is herein named a ridge count and denoted by R_{ir}. The ridge count R_{ir} is what is called a relationship in the above-referenced Asai Patent and is different from the "ridge count" described in a reference cited in the Asai Patent. The illustrated minutia M_i has ridge counts R_{i0}, R_{i1}, R_{i2}, and R_{i3} which are equal to 1, 2, 4, and 1, respectively. In some cases, the ridge count R_{ir} may be zero.

Referring now to FIG. 5, the control unit **58** (FIGS. **2** and **3**) comprises a buffer memory **61** which is loaded,

as will become clear as the description proceeds, with data from the matching control unit **55** (FIG. **1**) through a bus **62** and a device interface circuit **63** and furthermore with data from the precise matcher **57** or matchers **57**'s through a bus **64** and a matcher interface circuit **65**. The buffer memory **61** is controlled by a control circuit **66**. A destination deciding circuit **67** is for deciding the destination of the data in the manner to be later described.

Turning to FIG. **6**, each leading matcher **56** (FIG. **2** or **3**) comprises a sequence controller **69** connected, as will later become clear, to a first minutia list memory **71** directly and also through a coordinate transforming circuit **72**, a pair candidate list memory **73**, a working area **74**, a control memory **75**, a proximate minutia recovery circuit or relation calculating circuit **76**, a pair detection circuit **77**, and a (coordinate) adjustment amount deciding circuit **78**. As will soon become clear, the minutia list memory **71** comprises search and file fingerprint memories **71S** and **71F**. The control memory **75** is preliminarily loaded with a microprogram (microcode) for use in controlling, among others, the adjustment amount deciding circuit **78** as will later be described in detail.

Further turning to FIG. **7**, each precise matcher **57** (FIG. **2** or **3**) comprises a sequence controller **79** connected, like in the leading matcher **56**, to a second minutia list memory **81** directly and through a coordinate transforming circuit **82**, a pair candidate list memory **83**, a working area **84**, a control memory **85**, a pair list memory **86**, a region pattern list memory **87**, a candidate fingerprint list memory **88**, and an arithmetic unit **89** which is connected also to the working area **84**. The control memory **85** is for controlling the arithmetic unit **89**.

A fingerprint matching device **51** according to preferred embodiments of this invention, will be described more in detail under the following subsections.

(1) Read out of Minutia Data,
(2) Coordinate Transformation,
(3) Recovery of Proximate Minutiae,
(4) Pair Detection,
(5) Modifications of Pair Detection,
(6) Pair Candidate List,
(7) Amounts of Coordinate Adjustment,
(8) Precise Matcher,
(9) Fingerprint Matching, and
(10) Destination Deciding Circuit.

A closing paragraph will be added to the description as an additional subsection (11).

Read out of Minutia Data

Referring to FIG. **8**, data for each fingerprint are composed of identification or descriptive data, a region pattern list, and a (first) minutia list. The identification data of each file fingerprint consist of an identification number given to the file fingerprint, the name of the person who printed the fingerprint, male or female, the date of birth, the name of finger, the date and the locality of print, and the like. The identification data of each search fingerprint may comprise some of these. The region pattern and the minutia lists of a search fingerprint may be formed by the data input device **52** (FIG. **1**) from the search fingerprint. The device revealed in the above-cited Asai Patent is effective for this purpose. The identification data and the region pattern and the minutia lists of a great number of file fingerprints may preliminarily be stored in the data input device **52**. At any rate, the region pattern list gives the search and the file fingerprint areas by the principal coordinate system. The minutia list will shortly be described in detail.

Referring back to FIG. **1**, data of the search fingerprint are transferred from the data input device **52** by the data control and processing device **53** to the data storing device **54** and stored therein. Also, data of the file fingerprints are successively stored in the data storing device **54** through the data control and processing device **53**. On so transferring the data, the data control and processing device **53** may or may not edit the data. For example, the data control and processing device **53** may keep the identification data except the identification numbers, which are sent to the data storing device **54** for storage therein.

After storage of the data of the search and the file fingerprints in the data storing device **54**, the data control and processing device **53** sends a command to the matching control device **55** through a bus to start the fingerprint matching. Before eventually supplied from the matching control device **55** through the bus with a result signal which represents the success or failure of the fingerprint matching, the data control and processing device **53** is free to deal with other jobs, such as transfer of the data of another search fingerprint from the data input device **52** to the data storing device **54**. Incidentally, the result signal represents the degree of match q upon success of the fingerprint matching and at least the identification number of the file fingerprint best matched with the search fingerprint.

Referring to FIG. **9** in addition to FIGS. **1** through **6** and **8**, a first step A_1 of the fingerprint matching is to read out the data of the search and the file fingerprints from the data storing device **54** by the matching control device **55** in response to the command. At the outset, the data of the search fingerprint are read out and delivered to the fingerprint matching devices **51**'s. In each fingerprint matching device **51**, the data of the search fingerprint are supplied to the leading matcher **54** (FIG. **2**) or matchers **56**'s (FIG. **3**) through the control unit **59** and a bus **90** (also in FIG. **5**) and stored in the search minutia list memory **71S** of every leading matcher **56** through the sequence controller **69**.

Subsequently, the matching control device **55** delivers the data of one of the file fingerprints to one of the free leading matchers **56** of the fingerprint matching devices **51** in the manner which will later be exemplified in connection with the destination deciding circuit **67** (FIG. **5**). In the free one of the leading matchers **56** the data are stored in the file minutia list memory **71F**. If there are other free leading matchers **56**, the matching control device **55** feeds the data of other file fingerprints thereto.

The fingerprint matching system comprising a plurality of fingerprint matching devices **51** as exemplified in FIG. **1**, is therefore capable of substantially concurrently matching the data of a search fingerprint with the data of a plurality of file fingerprints. Operation will, however, be described in the following as regards the data of only one file fingerprint unless otherwise stated.

Turning to FIG. **10**, the first minutia list memory **71** (FIG. **6**, **71S** or **71F**) comprises a plurality of memory sections having row addresses which can be specified by a row address signal indicative of a minutia number M_l at a time. Each memory sector has a plurality of memory fields having column addresses which can be indicated by a column address signal as will become clear as the description proceeds. Incidentally, the mi-

nutia memory **71** may temporarily store the identification numbers and the region pattern lists of the search and the file fingerprints.

According to one of the preferred embodiments of this invention, the memory fields of a memory sector accessible by the minutia number M_i, comprises a first field for the minutia type Q_i, a second field for the position and the direction data X_i, Y_i, and D_i, a third field for the concentration C_i, and a fourth field for the ridge counts R_{i0} through R_{i3} or R_{ir}. In the first field an end mark is stored in the memory sector which next follows the memory sector for the last-numbered minutia M_z.

Coordinate Transformation

Inasmuch as the search and the file fingerprints are printed under different circumstances, it is necessary on matching the search fingerprint with the file fingerprint to subject the minutia list of at least one of the search and the file fingerprints to a certain modification.

By way of example, different first and second principal coordinate systems are used in general on describing the minutia positions and directions of the search and the file fingerprints, respectively. The first (principal) coordinate system must be subjected to forward (coordinate) transformation to be a new principal coordinate system that gives a best match with the second coordinate system and will be referred to as a "central" coordinate system merely for convenience of discrimination. Incidentally, it is convenient to subject the first coordinate system to the coordinate transformation rather than the second coordinate system because of a generally much less number of the minutiae.

The region pattern list of the search fingerprint, however, need not be forwardly transformed as will later become clear. During comparison of the minutia lists between the search and the file fingerprints, the position data represented by the central coordinate system must therefore be subjected to back (coordinate) transformation for comparison with the region pattern list.

As will soon become clear, such coordinate transformation is necessary in a great number of cases.

Referring to FIG. **11**, the principal coordinate system has a principal origin O_p and principal X and Y axes X_p and Y_p. The central coordinate system has a central origin O_q and central X and Y axes X_q and Y_q. It will be presumed merely foor simplicity of description that each coordinate system is a right-hand orthogonal coordinate system.

The central origin O_q has coordinates (x, y) according to the principal coordinate system. The central X axis X_q is counterclockwise rotated by an angle of rotation ϕ from the principal X axis X_p. In other words, the forward transformation is to translate the principal origin O_p by translation components x and y and to rotate the principal coordinate plane by the angle of rotation ϕ.

Central coordinates (x_q, y_q) of a point M are related to principal coordinates (x_p, y_p) of the point M by:

$$x_q=(x_p-x)\cos\phi+(y_p-y)\sin\phi \quad (1)$$

and

$$y_q=(y_p-y)\cos\phi-(x_p-x)\sin\phi. \quad (2)$$

Turning to FIG. **12**, a first phase of the forward transformation is to calculate values $\cos\phi$ and $\sin\phi$ of the trigonometric or circular function. A second phase is to calculate first and second differences (x_p-x) and (y_p-y). A third phase is to calculate first and second products $(x_p-x)\cos\phi$ and $(y_p-y)\sin\phi$. A fourth phase is to calculate an ultimate sum according to Equation (1). A fifth phase is to calculate third and fourth products $(y_p-y)\cos\phi$ and $(x_p-x)\sin\phi$. A sixth phase is to calculate an ultimate difference in compliance with Equation (2). It is possible to simultaneously carry out the third and the fifth phases and also the fourth and the sixth phases.

Incidentally, the backward transformation is carried out in accordance with:

$$x_p=x_q\cos\phi-y_q\sin\phi+x \quad (3)$$

and

$$y_p=y_q\cos\phi+x_q\sin\phi+y. \quad (4)$$

The forward and backward transformation has been carried out by the use of software, which is not suited to rapid processing. In particular, a complicated electronic digital computer is indispensable on carrying out the first phase and the third and the fifth phases.

Referring now to FIG. **13**, an example of the coordinate transforming circuit **72** (FIG. **6**) is for rapidly carrying out the forward and the backward transformation with simple circuitry. As will later be described, a mode signal MOD is supplied from the sequence controller **69**. The mode signal MOD indicates the forward and the backward transformation by, for example, binary zero and one, respectively.

As will also be described in the following, X, Y, and D input terminals X_I, Y_I, and D_I are supplied at first with initial data consisting of the translation components x and y and the angle of rotation ϕ. When a latch pulse LAT is supplied from the sequence controller **69**, the initial data are stored in X, Y, and D registers **91**, **92**, and **93**. The latch pulse LAT is soon switched off.

The angle of rotation ϕ stored in the D register **93** is delivered to a ROM **94** as an address signal and to a D adder-subtractor **95** for the purpose which will shortly be described. Values of the trigonometric function are preliminarily stored in the ROM **94** for various values of the angle of rotation ϕ. Accessed by the address signal, the ROM **94** produces the values $\cos\phi$ and $\sin\phi$ to carry out the first phase (FIG. **12**). Incidentally, each angle ϕ may be given a binary number having up to eight bits. Each value $\cos\phi$ or $\sin\phi$ may be represented by a binary number of ten bits.

On carrying out the forward transformation, the input terminals X_I, Y_I, and D_I are supplied with the principal position data x_p and y_p and a principal direction datum d_p from the minutia list memory **71** (FIG. **6**) as will soon be described. Responsive to the mode signal MOD indicative of the forward transformation, first X and Y selectors **96** and **97** select the input data fed directly thereto from the input terminals X_I and Y_I to deliver the principal coordinates x_p and y_p to first X and Y adder-subtractors **98** and **99**. Controlled by the mode signal MOD, the adder-subtractors **98** and **99** calculate the first and the second differences to carry out the second phase. Controlled also by the mode signal MOD, second X and Y selectors **101** and **102** feed the differences to first and second multipliers **103** and **104**, which calculate the first and the second products to carry out the third phase. The second X and Y selectors **101** and **102** furthermore deliver the differences to third and fourth multipliers **105** and **106**, which calculate the

third and the fourth products according to the fifth phase.

Responsive to the mode signal MOD, second X and Y adder-subtractors **107** and **108** calculate the ultimate sum and difference to carry out the fourth and the sixth phases, respectively. Third X and Y selectors **109** and **110** are controlled by the mode signal MOD to feed the ultimate sum and difference to X and Y output terminals X_0 and Y_0 as the central coordinates x_q and y_q. The D adder-subtractor **95** calculates a difference $(d_p-\phi)$ and delivers the difference to a D output terminal D_0 as a central direction datum d_q.

For the backward transformation, the mode signal MOD is made to indicate the same. The input terminals X_I, Y_I, and D_I are supplied at first with the initial data, which are stored in the registers **91** through **93** by the latch pulse LAT. It is possible to make the registers **91** through **93** keep the initial data stored therein before beginning of the forward transformation.

At any rate, the input terminals X_I, Y_I, and D_I are now supplied with the central position and direction data x_q, y_q, and d_p. Responsive to the mode signal MOD indicative of the backward transformation, the second X and Y selectors **101** and **102** select the input data delivered thereto directly from the X and Y input terminals X_I and Y_I to feed the central coordinates x_q and y_q to the first and second multipliers **103** and **104**, respectively, and also to the third and the fourth multipliers **105** and **106**. The first and the second multipliers **103** and **104** calculate the products used in Equation (3) and the third and the fourth multipliers **105** and **106**, the products used in Equation (4).

Responsive to the mode signal MOD, the second X and Y adder-subtractors **107** and **108** calculate a difference and a sum of the products according to Equations (3) and (4), respectively. The first X and Y selectors **96** and **97** now select the input data fed thereto from the second X and Y adder-subtractors **107** and **108** to deliver the difference and the sum to the first X and Y adder-subtractors **98** and **99**, which calculate the right-hand side of Equations (3) and (4), respectively.

Controlled by the mode signal MOD, the third X and Y selectors **109** and **110** select the input data supplied thereto from the first X and Y adder-subtractors **98** and **99** to deliver the principal coordinates x_p and y_p to the X and the Y output terminals X_0 and Y_0. The D adder-subtractor **95** sums the central direction datum d_q and the angle of rotation ϕ to feed the principal direction datum d_q to the D output terminal D_0.

It may be helpful depending on the circumstances to refer to the central coordinate system again as a first principal coordinate system. Alternatively, the central coordinate system and the second principal coordinate system will be referred to as preliminarily matched coordinate systems when used in the pair detection which is already mentioned above as one of the subsections and will later be described in detail As will become clear as the description proceeds, the coordinate transforming circuit being illustrated, is capable of carrying out forward and backward transformation between the principal coordinate system and a local coordinate system. When used in the leading matcher **56** (FIG. **6**), the coordinate transforming circuit **72** need not carry out the backward transformation. On the other hand, the coordinate transformation circuit **82** (FIG. **7**) need not carry out the forward transformation. The coordinate transforming circuits **72** and **82** therefore need not comprise the selectors **96**, **97**, **101**, **102**, **109**, and **110**. The sequence controllers **69** and **79** need not produce the mode signal MOD. The circuitry illustrated with reference to FIG. **13** is useful when a single minutia list memory is used in place of the first and the second minutia memories **71** and **81** in storing the minutia list referred to hereinabove as the first minutia list. Use of the first and the second minutia list memories **71** and **81** is preferred because provision of the leading and the precise matchers **56** and **57** is thereby enabled and because the second minutia list memory **81** need not have a large memory capicity as will later become clear.

Recovery of Proximate Minutiae

Referring to FIG. **14**, a memory sector for the i-th minutia M_i in the search and the file minutia list memories **71S** and **71F** of the first minutia list memory **71** (FIG. **6**) may comprise first through eighth fields accessible by the column address signal. The fifth through the eighth fields are for storing the proximate minutia numbers M_{ir}, namely, the numbers given to the proximate minutiae M_{ir}. Recovery of the proximate minutiae M_{ir} is unnecessary in this event. The recovery is necessary as shown at a second step A_2 in FIG. **9** when the minutia list memory **71** is loaded with the minutia list in compliance with FIG. **10** in order to reduce the memory capacities of various memories used in the fingerprint matching system (FIG. **1**).

Speaking more in general, it is necessary on matching two fingerprints to compare a local feature of a minutia M_{iS} of the search fingerprint with a corresponding local feature of a minutia M_{jF} of the file fingerprint. The local features should preferably be independent of selection of the principal coordinate systems for the respective fingerprints. Examples of such local features are the minutia types Q_{iS} and Q_{jF} and the concentrations C_{iS} and C_{jF}. On defining the concentration, it is possible to use instead of a single prescribed area a plurality of prescribed areas for each reference minutia, such as the sectors described earlier in connection with the ridge counts R_{ir}.

The ridge counts R_{irS} and R_{jrF} are also useful as the local feature. Discussion will, however, later be given to the ridge counts R_{ir}.

It has now been confirmed that another local feature is effective on carrying out the comparison. The other local feature is a distance between the reference minutia M_i and each proximate minutia M_{ir}.

More specifically, the distance is conveniently calculated by the use of the local coordinate system described in conjunction with FIG. **4**. The distances for corresponding proximate minutiae, such as M_{i0S} and M_{j0F}, are used in evaluating a local similarity between the minutiae M_{iS} and M_{jF} under consideration. When a difference between such distances is less than a predetermined threshold, the local similarity between the minutiae M_{iS} and M_{jF} is given a mark 1. If the differences for the respective proximate minutiae M_{ir} in four quadrants are all less than the threshold, the local similarity is given a full mark 4.

As thus far been described, the ridge counts, the concentration or concentrations, the distances, and/or the like are calculated for each minutia with reference to a local coordinate system having a local origin at the minutia under consideration. These data will be referred to as relation data, which are substantially independent of the principal coordinate system and are helpful in founding a local similarity between a reference minutia

of the search fingerprint and a reference minutia in the file fingerprint.

Calculation or evaluation of the local similarity will be called relation evalution. The relation evalution must be carried out rapidly and yet with a high reliability because each search fingerprint must be compared with an enormous number of file fingerprints. The relation evaluation is also used in recovery of the proximate minutiae.

Referring to FIGS. **15** and **16**, an example of the proximate minutia recovery circuit **76** (FIG. **6**) comprises a local controller **111** operable according to a microprogram stored therein. Start of the distance calculation is indicated by a start signal STRT from the sequence controller **69** as shown at a zeroth step B_0 (FIG. **16**).

In compliance with the microprogram, the local controller **111** sets an initial value of zero in each of first and second fields A and B of a first address register **112** at a first step B_1. The address register **112** is for producing a composite address signal AD for specifying the row and the column addresses in one of the search and the file minutia list memories **71S** and **71F** at a time that may be selected by a read signal R according to the microprogram. Incidentally, a second address register **113** is for similarly accessing the same minutia list memory **71** (**71S** or **71F**) by a like address signal, designated also by AD, and has first and second fields which will be denoted by E and F. The first fields A and E are for producing the row address signals representative of the minutia numbers M_i and M_j. The second fields B and F are for likewise producing the column address signals for either the same field or different fields.

When zero is set in the second fields B and F and moreover when the i-th minutia M_i is concurrently specified by the row address signals produced from the first fields A and E, the minutia list memory **71** produces the minutia type Q_i from the first field. It will now be assumed that the address signals AD are for the search minutia list memory **71S** and that the zero column address signal accesses also the second field.

As indicated at a second step B_2, the controller **111** makes the first address register **112** produce the address signal AD. The minutia type Q_{0S} thereby read out, is set in a Q field of a parameter register **114**. The other data X_{0S}, Y_{0S}, and D_{0S} are delivered to the X, Y, and D registers **91** through **93** (FIG. **13**). Immediately thereafter, the sequence controller **69** is made to produce the latch pulse LAT (FIG. **13**) and the mode signal MOD indicative of the forward transformation. The position data X_0 and Y_0 (the suffix S being omitted for a short while) provide the translation components x and y described in connection with FIG. **13**. The direction datum D_0 provides the angle of rotation ϕ.

Inasmuch as the mode signal MOD in uncecessary for the coordinate transforming circuit **72** (FIG. **6**), the latch pulse LAT is produced by the local controller **111** rather than by the sequence controller **69** in the example being illustrated. It will now be surmised for brevity of description that the position and the direction data X_i, Y_i, and D_i are read from the search minutia list memory **71S**.

At a third step B_3, the controller **111** checks whether or not the minutia type Q_i stored in the Q field is the end mark. If not, the controller **111** sets the initial value of zero in each of the fields E and F of the second address register **113** and another initial value of one in each of address fields M_0, M_1, M_2, and M_3 and distance fields D_0, D_1, D_2, and D_3 of a register file **115** as shown at a fourth step B_4. The correspondingly numbered address and distance fields, such as M_0 and D_0, are two fields of a partial register of the register file **115**. As will presently become clear, the address fields M_r are eventually loaded with the proximate minutia numbers M_{ir} which are present in the first, the second, the fourth, and the third quadrants for the i-th minutia M_i being dealt with and used as the reference minutia. The initial value of one set in the address fields M_r and in the distance fields D_r indicate that there is no proximate minutiae in the respective quadrants and that the distance between the reference minutia M_i and a minutia in the corresponding quadrant is infinitely long.

As shown at a fifth step B_5, the controller **111** makes the second address register **113** produce the address signals AD representative of the contents of the fields E and F. The row address thereby specified, is for the zeroth minutia M_0. It will, however, be presumed like for the address signal AD produced from the first address register **112** that the row address for the j-th minutia M_j is indicated by the row address signal produced by the first field E of the second address register **113**.

The Q field of the parameter register **114** is rewritten into the minutia type Q_j. The other data X_j, Y_j, and D_j are supplied to the X, Y, and D adder-subtractors **98**, **99**, and **95** (FIG. **13**) as the principal data x_p, y_p, and d_p. At a sixth step B_6, the forward transformation is automatically carried out. The local (coordinate) data x_q, y_q, and d_q are stored in X, Y, and D fields of the parameter register **114** at a seventh step B_7.

The local position data x_q and y_q retained in the X and Y fields of the parameter register **114** are delivered to X and Y square calculators **116** and **117**, respectively. Squares thereby calculated, are fed to an adder **118**. The square of the distance between the i-th minutia M_i under consideration and the j-th minutia M_j being selected, is supplied to one of the two input ports of a comparator **119**.

In the meantime, a permutation of the sign bits of the local position data y_q and x_q stored in the Y and X fields of the parameter register **114**, is delivered towards a selector **121** to represent a two-digit binary number. The binary number indicates that the j-th minutia M_j is present in one of the quadrants that is decided as follows. If the binary number is 00 or decimal 0, the j-th minutia M_j is in the first quadrant. If the binary number is equal to 01, 11, and 10, namely, decimal 1, 3, and 2, the j-th minutia M_j is in the section through the fourth quadrants, respectively.

Unless the minutia type Q_j kept in the Q field of the parameter register **114** shows the end mark, the controller **111** sends a selection signal to the selector **121** to make the same supply the sign bit permunation to the register file **115** as an address signal for accessing the partial register having the address field M_r that is allotted to the quadrant indicated by the sign bit permutation. The content of the distance field D_r of the accessed partial register is supplied to the other input port of the comparator **119**.

As collectively shown at an eighth step B_8, the comparator **119** compares the sum $(x_q^2+y_q^2)$ with the distance $D(\text{sign}[y_q], \text{sign}[x_q])$ read out of the distance field D_r of the accessed partial register. If the former is less than the latter, the j-th minutae M_j is nearer to the i-th minutia M_i than another minutia which is previously dealt with to provide the distance being read out. The

comparator **119** informs the controller **111** of the fact by, for example, a binary one signal.

Meanwhile, contents of the first fields A and E of the address registers **112** and **113** are supplied to a coincidence detector **122**. When the contents are the same, the coincidence detector **112** produces a coincidence signal of logic one. That is, the logic one coincidence signal is produced when the j-th minutia M_j is not different from the i-th minutia M_i. The coincidence signal is fed to an inhibit port of an inhibit gate **123** to inhibit the binary one signal delivered thereto from the comparator **119**.

In the meanwhile, the content of the first field E of the second address register **113** is delivered to the address fields M_r of the register file **115**. Furthermore, the sum calculated by the adder **119** is supplied towards the distance fields D_r. When the coincidence signal is logic zero to indicate that the j-th minutia M_j is different from the i-th minutia M_i and consequently in one of the quadrants except the local origin M_i, the inhibit gate **123** supplies the binary one signal to the register file **115** as a write-in signal. At a ninth step B_9, the contents of the address and the distance fields M_r and D_r of one of the partial registers that is accessed by the sign bit permutation supplied thereto through the selector **121**, are renewed to the content of the first field E of the second address register **113** (the minutia number of the j-th minutia M_j) and to the sum (square of the distance between the minutiae M_i and M_j).

Either if the sum is not less than the previously calculated sum or if the j-th minutia M_j is in fact the i-th minutia M_i, the eighth step B_8 jumps to a tenth step B_{10} where the controller **111** makes a one-adder **124** add one to the content of the E field of the second address register **113**. When the sum is less than the previously calculated sum and furthermore when the j-th minutia M_j is different from the i-th minutia M_i, the above-described ninth step B_9 is followed by the tenth step B_{10}. The contents of the register file **115** are thus renewed whenever a nearer minutia is found in a certain one of the quadrants.

By so repeating either the steps B_5 and B_{10} or the steps B_5 through B_8 and B_{10} with the ninth step B_9 skipped, the controller **111** renews the contents of the register file **115**. Recovery of the proximate minutiae M_{ir} for the i-th minutia M_i ends when the end mark is eventually detected at the seventh step B_7. At this instant, the proximate minutia numbers M_{ir} are Kept in the respective address fields M_r. If no proximate minutia is found in a certain one of the quadrants, the initial value of one is held in the address field M_r allotted to that quadrant.

The process now proceeds to transfer of the proximate minutiae M_{ir} of the i-th minutia M_i. In the example being illustrated, the transfer is carried out to that one of the search and the file minutia list memories **71** (**71S** and **71F**) from which the i-th minutia M_i is read. As a result of the transfer, contents of the memory sector for the i-th minutia M_i are changed from those exemplified in FIG. **10** to those exemplified in FIG. **14**.

It will now be assumed merely for convenience of description that the column address of the fifth field (FIG. **14**) for the minutia number M_{i0} is decimal 4 or binary 100. At an eleventh step B_{11}, the local controller **111** initializes the content of the second field B of the first address register **112** to 4. Two consecutive less significant bits of the second field B are supplied to the selector **121**, which are now 00 out of the binary 100 and correspond to the address signal used in accessing the partial register (M_0 and D_0) assigned in the register file **115** to the first quadrant. As a part of the composite address signal AD, the second field B produces the column address signal for the fifth field. The row address signal produced from the first field A as another part of the address signal AD, still specifies the row address for the i-th minutia M_i in the minutia list memory **71** in question. Concurrently with the eleventh step B_{11}, the controller **111** makes the selector **121** select the two less significant bits.

The register file **115** produces the content of the accessed address field M_0 as a data signal WD, which is delivered towards the minutia list memory **71** under consideration. The controller **111** supplies a write-in signal W to the minutia list memory **71**. The minutia number M_{i0} is therefore pertinently written in the minutia list memory **71** at a twelfth step B_{12}.

At a thirteenth step B_{13}, the controller **111** makes the one-adder **124** add one to the content of the second field B. The content specifies the column address for the proximate minutia M_{i1}. The two less significant bits designates the second quadrant.

At a fourteenth step B_{14}, the controller **111** checks the content of the second field B whether or not overflow results from the addition of one to render the content equal to decimal **0**. If not, the process returns from the fourteenth step B_{14} to the twelfth step B_{12}.

Repeating the steps B_{12} through B_{14}, the controller **111** transfers the proximate minutia numbers M_{ir} to the minutia ist memory **71** being dealt with. When the overflow is detected at the fourteenth step B_{14}, the controller **111** makes the one-adder **124** add one to the content of the first field A at a fifteenth step B_{15}. The row address for the (i+1)-th minutia is now specified. The process returns from the fifteenth step B_{15} to the second step B_2.

In this manner, the proximate minutiae, if any, are recovered successively for the minutiae M_0, M_1, . . . , M_i, . . . , and M_z and stored in the minutia list memory **71** in question. After the proximate minutia number M_{z3} is eventually stored in the minutia list memory **71**, the content of the first field A of the first address register **112** becomes equal to (z+1) at the fifteenth step B_{15}. The end mark is now stored in the Q field of the parameter register **114**. When the controller **111** detects the end mark at the third step B_3, the recovery of the proximate minutiae comes to an end as shown at a sixteenth step B_{16}.

Pair Detection

For each minutia M_i, the minutia type Q_i, the position and the direction data X_i, Y_i, and D_i, and the like will now be called minutia data of the minutia M_i. The proximate minutia numbers M_{ir} and the ridge counts R_{ir} will be named fundamental relation data of the minutia M_i. The minutia data and the fundamental relation data will collectively be called overall minutia data of the minutia M_i. A link or combination of the position and the direction data x_{ir}, y_{ir}, and d_{ir} of the proximate minutiae M_{ir} as regards the local coordinate system for the minutia M_i used as the reference minutia, and the ridge counts R_{ir} will now be referred to as relation link data of the reference minutia M_i. The minutia data and the relation link data will collectively be called overall relation link data of the reference minutia M_i. For each fingerprint, a set of the overall minutia data or the overall relation link data of all minutiae will now be called fingerprint data of that fingerprint.

On matching a search fingerprint with each file fingerprint, it is important to find a pair of minutia of the search fingerprint and a minutia of the file fingerprint. On finding such pairs, it is already known to use the overall relation link data for each combination of a minutia of the search fingerprint and a minutia of the file fingerprint. The memory for storing the fingerprint data of the search and the file fingerprints, therefore must have a large memory capacity. This has rendered the conventional fingerprint matching device bulky and expensive.

It should be noted in this connection that a plurality of minutiae may be found at first in one of the search and the file fingerprints as pairs of a minutia of the other fingerprint at a third step A_3 depicted in FIG. 9. The pairs are later processed as regards the detail into a single pair. Such "pairs" will also be called a "pair" for the time being. At any rate, it is not mandatory according to this invention to care for such a plurality of pairs. Each of the position and the direction data X_i, Y_i, and D_i may therefore be given for the pair detection by a relatively coarse or wide quantization step as, for example, by only four consecutive more significant bits of each data X_i, Y_i, or D_i.

Referring to FIG. 17, an example of the pair detection circuit 77 (FIG. 6) is effective in rendering the fingerpint matching device 51 (FIG. 1) compact and inexpensive. The illustrated pair detection circuit 77 comprises a relation linking unit 126, a minutia memory 127, and a pair detecting unit 128 as will be described in the following.

Turning to FIG. 18, the minutia memory 127 may store, as will shortly be described in detail, the overall relation (link) data for the search fingerprint and one file fingerpint. In a memory section (to be later described) accessible by a row address signal indicative of a reference minutia M_i, the minutia data Q_i, C_i, X_i, Y_i, and D_i are stored in successive columns. Furthermore, the relation link data R_{i0}, x_{i0}, y_{i0}, d_{i0}, R_{i1}, x_{i1}, . . . , d_{i2}, R_{i3}, x_{i3}, y_{i3}, and d_{i3} are stored in successive columns. It will therefore be assumed that the minutia list memory 71 (FIG. 6, 71S or 71F) is for storing, for each minutia M_i, the minutia data and the fundamental relation data in the order of Q_i, C_i, X_i, Y_i, D_i, R_{i0}, M_{i0}, R_{i1}, M_{i1}, R_{i2}, . . . , R_{i3}, and M_{i3}, rather than in the order exemplified in FIG. 14. The local position and direction data x_{ir}, y_{ir}, and d_{ir} may, for storage in the minutia memory 127, be given by the coarse quantization step. When no proximate minutia is found in a quadrant r, a specific code is stored in place of the ridge count R_{ir} for the proximate minutia M_{ir}.

Referring to FIG. 19, the relation linking unit 126 (FIG. 17) comprises a central controller 129 put into operation by the sequence controller 69 (FIG. 6) after completion of recovery of proximate minutiae for the search fingerprint. The controller 129 sends a first address signal 131 (also in FIG. 17) to the search minutia list memory 71S of the minutia list memory 71. An input data signal 132 (also in FIG. 17) is sent back to the relation linking unit 126. When the address signal 131 indicates the i-th minutia M_{iS} as will presently be described, the data signal 132 represents the overall minutia data, namely, the minutia data Q_{iS}, C_{iS}, X_{iS}, Y_{iS}, and D_{iS} and the fundamental relation data R_{i0S}, M_{i0S}, R_{i1S}, . . . , R_{i3S}, and M_{i3S}. It is possible to make the address signal 131 give the position and the direction data X_{iS}, Y_{iS}, and D_{iS} by the coarse quantization step.

The fundamental relation data are fed towards a shift register 134. The position and the direction data X_{iS}, Y_{iS}, and D_{iS} are supplied towards X, Y, and D registers 135X, 135Y, and 135D. At least the minutia type Q_{iS} is supplied to the controller 129. The controller 129 produces a latch pulse LAT to store the fundamental relation data in the shift register 134 and the position and the direction data in the registers 135. An output data signal 136 (also in FIG. 17) supplied towards the minutia memory 127, represents the minutia data and then other data which will later be described.

The controller 129 checks whether or not the minutia type Q_i (the suffix S being omitted for a short while) represents in fact a minutia type. Having confirmed, the controller 129 supplies the minutia memory 127 with a second address signal 137 indicative of a row address for the i-th minutia M_i and a column address for the minutia data and sends a directive signal DIR to the shift register 134 to make the same supply the foremost proximate minutia number M_{i0} back to the controller 129, which makes the first address signal 131 indicate the proximate minutia number M_{i0} instead of the i-th minutia number M_i. The shift register 134 furthermore produces the ridge count R_{i0} as the output data signal 136.

The input data signal 132 now represents the overall minutia data for the i0-th minutia M_{i0}. The controller 129 makes the second address signal 137 indicate the row address for the i-th minutia M_i and the column address for the ridge count R_{i0} and the position and the direction data x_{i0}, y_{i0}, and d_{i0} which the proxmate minutia M_{i0} of the first quadrant has relative to the i-th minutia M_i used as the reference minutia.

Among the overall minutia data of the i0-th minutia M_{i0}, the position and the direction data X_{i0}, Y_{i0}, and D_{i0} are supplied directly to X, Y, and D subtractors 138X, 138Y, and 138D which are also supplied with the contents of the registers 135. The subtractors 138 calculate X, Y, and D differences $(X_{i0}-X_i)$, $(Y_{i0}-Y_i)$, and $(D_{i0}-D_i)$. The content of the D register 135D is supplied also to an ROM 139, similar to the ROM 94 (FIG. 13), for producing values cos D_i and sin D_1. The ROM 139 may, however, be simpler than the ROM 94 because each value cos D_i or sin D_i may have a lesser number of bits.

The X and the Y differences are supplied to first and second multipliers 141 and 142, respectively, to which the value cos D_i is supplied in common. The differences are supplied also to third and fourth multipliers 143 and 144, to which the value sin D_i is supplied in common. First and second products are delivered to an adder 146 and a subtractor 147, respectively. Third and fourth products are fed to the adder 146 and the subtractor 147, respectively. It is now understood that the elements 135, 138, 139, 141 through 144, 146, and 147 are for carrying out the forward transformation of the principal coordinate system for the search fingerprint to a local coordinate system for the i-th minutia M_i. The adder 146, the subtractor 147, and the D subtractor 138D are for making the output data signal 136 include the position and the direction data x_{i0}, y_{i0}, and d_{i0} which the proximate minutia M_{i0} has in the local coordinate system.

Thereafter, the controller 129 again produces the directive signal DIR to make the shift register 134 send the next following proximate minutia number M_{i1} back to the controller 129 and the ridge count R_{i1} as a part of the output data signal 136. The second address signal

137 is now made to represent the row address for the i-th minutia M_i and the column address for the ridge count R_{i1} and the position and the direction data x_{i1}, y_{i1}, and d_{i1}. The input data signal **132** supplies the position and the direction data X_{i1}, y_{i1}, and D_{i1} of the i**1**-th minutia M_{i1} to the subtractors **138**'s. The coordinate transformation is again carried out to make the output data signal **136** include the position and the direction data x_{i1}, y_{i1}, and d_{i1} as another part.

The processes described above in connection with the proximate minutiae M_{i0} and M_{i1} are repeated for the other proximate minutiae M_{i2} and M_{i3} to complete the relation linking operation for the i-th minutia M_i. When the processes are carried out for the last minutia M_z of the search fingerprint, the controller **129** supplies the minutia memory **127** (FIG. **17**) with a transfer signal **149** for the purpose which will shortly be described. The relation linking unit **126** subsequently repeats the relation linking operation as regards the minutiae M_0 through M_z of the file fingerprint (the suffix z used for the file fingerprint being generally greater than the suffix z for the search fingerprint as pointed out heretobefore).

Turning to FIG. **20**, the minutia memory **127** (FIG. **17**) comprises first and second buffer memories **151** and **152**, each having memory sectors accessible by the second address signal **137** indicative of the reference minutia numbers, such as M_i. Each memory sector has fields having column addresses accessed also by the second address signal **137**.

Each of search and file minutia memories **153** and **154** also has memory sectors accessible by the address signal **137** to store the overall relation data as exemplified in FIG. **18**.

As described heretofore, the output data signal **136** produced by the relation linking unit **126** for the i-th minutia M_i, represents at first the minutia data of the minutia M_i. Later, the data signal **146** repeatedly produced for each proximate minutia M_{ir} of the i-th minutia M_i, represents the ridge count R_{ir} between the i-th and the ir-th proximate minutiae M_i and M_{ir} and also the position and the direction data x_{ir}, y_{ir}, and d_{ir} of the proximate minutia M_{ir} as regerds the local coordinate system defined for the i-th minutia M_i.

The data represented by the output data signal **136** are successively stored by the second address signal **137** in the respective fields of the memory sector for the i-th minutia M_i in one of the first and the second buffer memories **151** and **152** that is rendered empty as will presently become clear. Merely for clarity of description, let the first buffer memory **151** be empty for the time being. The overall relation data obtained for the minutiae M_0 through M_z of the search fingerprint, are thus stored in the first buffer memory **151**. At this instant, the central controller **129** (FIG. **19**) produces the transfer signal **149** as described before. The transfer signal **149** is for moving the overall relation data from the first buffer memory **151** to the search minutia memory **153**. The first buffer memory **151** is thus rendered empty.

During transfer of the overall relation data for the search fingerprint by the transfer signal **149** and the second address signal **137**, the relation linking unit **126** successively produces the overall relation data for the file fingerprint. According to the assumption described above, the second buffer memory **52** is rendered empty already before beginning of the relation linking operation for the file fingerprint. The overall relation data are therefore stored in the second buffer memory **152**. The transfer signal **149** produced subsequent to completion of the relation linking operation for the file fingerprint, is for moving the overall relation data from the second buffer memory **152** to the file minutia memory **154** and for eventually rendering the second buffer memory **152** empty.

As described before, a great number of file fingerprints must be checked for each search fingerprint. While the overall relation data are moved from the second buffer memory **152** to the file minutia memory **154**, the relation linking operation is carried out for a second one of the file fingerprints. The overall relation data for the second file fingerprint are stored in the first buffer memory **151**.

As will later be described, the overall relation data previously stored in the file minutia memory **154** are successively supplied to the pair detecting unit **128** (FIG. **27**). The file minutia memory **154** is thereby rendered empty. The overall relation data for the second file fingerprint are therefore moved from the first buffer memory **151** to the file minutia memory **154** by the transfer signal **149**.

It is now understood that the transfer signal **149** is for the search minutia memory **153** at first and then repeatedly for the file minutia memory **154**. In this manner, the first and the second buffer memories **151** and **152** are alternatingly used in loading the file minutia memory **154** with the overall relation data of the successive ones of the file fingerprints. Meanwhile, the search minutia memory **153** keeps the overall relation data for each search fingerprint. After the overall relation data of all file fingerprints are used by the pair detecting unit **128**, it is possible to use the search minutia memory **153** for the overall relation data of another search fingerprint.

Referring to FIG. **21**, an examle of the pair detecting unit **128** (FIG. **17**) comprises a local controller **159**. Each time the file fingerprint data (overall relation data of one file fingerprint) are stored in the file minutia memory **153** (FIG. **20**) with the search fingerprint data kept in the search minutia memory **153**, the central controller **129** (FIG. **19**) produces a command signal **161** (also in FIG. **17**). Supplied with the command signal **161**, the local controller **159** delivers an address signal **162** (also in FIGS. **17** and **20**) to the search and the file minutia memories **153** and **154**. The controller **159** furthermore sends a selection signal SEL to a threshold generator **163**.

In each of the minutia memories **153** and **154**, the address signal **162** accesses at first the memory sector for the zeroth minutia M_0. In each memory sector, the address signal **162** specifies the column address for the minutia data at first and then successively the column addresses for the respective proximate minutiae. Thereafter, the address signal **162** similarly accesses the memory sectors for the successive file (fingerprint) minutiae while accessing the zeroth search minutia M_0. Subsequently, the address signal **162** likewise accesses the next search minutia and the successive file minutiae. Let it now be assumed that the address signal **162** accesses the i-th search minutia M_{iS} and the j-th file minutia M_{jF}. The minutia numbers M_{iS} and M_{jF} are retained in the controller **159** for the purpose which will later become clear.

While each column address for the minutia data is specified by the address signal **162**, the selection signal SEL makes the threshold generator **163** produce coarse thresholds T_C, T_X, T_Y, and T_D which will presently

become clear. While the column address for each proximate minutia is specified, the selection signal SEL makes the threshold generator **163** produce other coarse thresholds T_r, T_x, T_y, and T_d.

Responsive to the address signal **162**, the search and the file minutia memories **153** and **154** supply data signals **164** and **165** (also in FIGS. **17** and **20**) to R, X, Y, and D subtractors **166R**, **166X**, **166Y**, and **166D**, each being for calculating the absolute value of a difference between the data represented by the data signals **164** and **165**. The absolute values are delivered to R, X, Y, and D comparators **167R**, **167X**, **167Y**, and **167D** for comparing the absolute values with the respective (coarse) thresholds as will be described in the following.

At the outset, the R subtractor **166R** is for the concentrations C_{iS} and C_{jF}. The other subtractors **166** are for the position and the direction data of the search and the file minutiae. The comparators **167** supply an AND circuit **168** with logic one signals if:

$$\left.\begin{aligned} |C_{is} - C_{jF}| &\leqq T_C, \\ |X_{is} - X_{jF}| &\leqq T_X, \\ |Y_{is} - Y_{jF}| &\leqq T_Y, \\ \text{and } |D_{is} - D_{jF}| &\leqq T_D. \end{aligned}\right\} \quad (6)$$

The AND circuit **168** sends an output signal to the controller **159** only when the logic one signals are supplied thereto from all comparators **167**. Responsive to the output signal, the controller **159** sends a directive signal DIR to reset first and second counters **171** and **172** to zero. Furthermore, the controller **159** makes the address signal **162** specify the column address for the foremost proximate minutia in each memory sector as briefly described before.

The R subtractor **166R** is now for the ridge counts R_{irS} and R_{jrF}. As described hereinabove and will shortly become clearer, the ridge counts R_{irS} and R_{jrF} represented by the respective data signals **164** and **165** are supplied also to a code detector **173** for detecting if the specific code is present instead of the ridge count R_{irS} or R_{jrF}. The AND circuit **163** delivers the output signal to the controller **159** only if:

$$\left.\begin{aligned} |R_{irS} - R_{jrF}| &\leqq T_r, \\ |x_{irS} - x_{jrF}| &\leqq T_x, \\ |y_{irS} - y_{jrF}| &\leqq T_y, \\ \text{and } |d_{irS} - d_{jrF}| &\leqq T_d. \end{aligned}\right\} \quad (6)$$

Responsive to this output signal, the controller **159** sends a count signal CTR to the second counter **172** to add one to its content. If the specific code is detected instead of at least one of the ridge counts R_{irS} and R_{jrF}, the code detector **173** sends a detection signal DET to the first counter **171** and also to the controller **159**. The detection signal DET adds one to the content of the first counter **171** and prevents the controller **159** from producing the count signal CTR irrespective of the output signal of the AND circuit **168**.

The content of the first counter **171** is supplied to the threshold generator **163**, which produces a threshold corresponding to the number of specific codes. The threshold is delivered to a comparator **174** for comparison with the count of the second counter **172**. When the count of the second counter **172** is equal to or greater than the threshold, the comparator **174** supplies the controller **169** with a similarity signal indicative of a local similarity between the minutiae M_{iS} and M_{jF}.

Responsive to the similarity signal, the controller **159** supplies the sequence controller **69** (FIG. **6**) with an address signal **176** (also in FIG. **17**) representative of the search and the file minutia numbers M_{iS} and M_{jF} retained therein. The controller **159** furthermore supplies the sequence controller **169** with a data signal **177** representative of the local similarity represented by the similarity signal. Meanwhile the controller **159** may keep the address signal **162** indicative of the row addresses for the minutiae M_{iS} and M_{jF} to make the minutia memories **153** and **154** (FIG. **20**) produce the data signals **164** and **165** (collectively denoted by **178** in FIG. **17**). Moreover, the controller **159** delivers an instruction signal **179** (also in FIG. **17**) to the sequence controller **69**. Thereafter, the controller **159** makes the address signal **162** indicate a next one of the search minutiae and successively the zeroth through the z-th file minutiae.

It will now be understood that the order of the minutiae M_{iS} and M_{jF} designated by the address signal **162** need not be as described above. The minutia memory **127** may not be an independent unit but may be a part of the relation linking unit **126** or of the pair detecting unit **128**.

Modifications of Pair Detection

As will presently be described more in detail, a certain amount of error is unavoidable between the principal coordinate system selected for each file fingerprint and the central coordinate system into which the principal coordinate system for each search fingerprint is forwardly transformed. This is also the case even when the principal coordinate system for the file fingerprint is forwardly transformed to provide a match with the principal coordinate system for each search fingerprint.

The error between the origins of the principal and the central coordinate systems equally affects the position and the direction data of a minutia near to each origin and the data of a minutia remote therefrom. It is therefore possible to cover the error by the thresholds T_X, T_Y, and T_D and T_x, T_y, and T_d. The error resulting from the direction of the coordinate axis, however, grows greater for remoter minutiae. If the thresholds are selected to cover the greater error, the accuracy of the pair detection degrades for nearer minutiae.

Referring to FIG. **22**, a modification of the pair detecting unit **128** (FIGS. **17** and **21**) is for raising the accuracy. For use as a part of the pair detecting unit **128** illustrated with reference to FIG. **21**, a threshold selector **181** is supplied with the data signal **164** successively representative of combinations of the position data X_{iS} and Y_{iS} and the position data x_{irS} and y_{irS} (collectively denoted by X and Y). On the other hand, the position data X and Y and the position data X′ and Y′ (X_{jF} and Y_{jF} or x_{jrF} and y_{jrF}) are supplied to search and file selectors **182** and **183**. The local controller **159** (FIG. **21**) selects one of the combination X and X′ and the combination Y and Y′ at first and then the other. The selected combination X and X′ or Y and Y′ is supplied to a subtractor **184** and thence to an abosolute value circuit **185**, which supplies a comparator **186** with $|X-X'|$ or $|Y-Y'|$.

In the threshold selector **181**, the position data X and Y are delivered to X and Y absolute value circuits **191** and **192**. The absolute values produced by the absolute value circuits **191** and **192** are fed to a selector **193** and furthermore compared with each other by a compara-

tor **194**. Supplied with the greater absolute value, the threshold generator **163** (corresponding to that described in conjunction with FIG. **21**) produces the threshold T or t and T_D or T.

A combination of the subtractor **184** and the absolute value circuit **185** correspond to a combination of the subtractors **166X** and **166Y**. The comparator **186** corresponds to a combination of the comparators **167X** and **167Y**. The threshold T is for use as either of the thresholds T_X and T_Y and the threshold t, as either of T_x and T_y.

Referring now to FIG. **23**, the relation data are substantially independent of the principal coordinate system as pointed out hereinabove. The error between the principal coordinate systems, however, results in an error between the local coordinate systems which are defined for a search and a file minutia. An i-th minutia M_i of a file fingerprint of a certain finger will be taken into consideration as a reference minutia. According to an x-y local coordinate system based on the principal coordinate system, the reference minutia M_i has proximate minutiae M_{ir} as exemplified in FIG. **4**. The proximate minutiae will now be called primary proximate minutiae and represented by M_{ie}, M_{if}, M_{ig}, and M_{ih} as depicted in FIG. **23**. The primary proximate minutiae will either singly or collectively denoted by M_{ik}.

A search fingerprint of the finger under consideration is printed on different conditions as described heretobefore. It is very likely that a different principal coordinate system is selected for the search fingerprint. Even though transformed from the different principal coordinate system with best care, the central coordinate system may have a difference from the principal coordinate system selected for the file fingerprint.

Let the minutia in question in the search fingerprint be numbered also as the i-th minutia M_i for brevity of description. In the illustrated example, an x'-y' local coordinate system is based on the central coordinate system. The proximate minutia M_{ig} is remoter than the minutia M_{ie} in the first quadrant of the local x'-y' coordinate system and is therefore not found as a primary proximate minutia. Instead, another minutia M_u is found as a primary proximate minutia in the fourth quadrant. This again results in a reduction in the accuracy.

Referring to FIG. **24**, a modification of the pair detection circuit **77** (FIG. **6**) is effective in raising the accuracy. The circuit **77** comprises a composite relation linking unit **196**, a composite minutia memory **197**, and a composite pair detecting unit **198**, all similar to the corresponding units **126** through **128** described in conjunction with FIGS. **17** through **21**. Incidentally, it will be assumed that the minutia list memory **71** (FIG. **6**) is already loaded with the minutia data and the fundamental relation data of both a search fingerprint and one file fingerprint in the manner exemplified in FIG. **14**.

Turning back to FIG. **23**, the x-y coordinate system having the local origin at a reference minutia M_i will now be called a primary coordinate system. The relation link data R_{ik}, x_{ik}, y_{ik}, and d_{ik} calculated for the primary proximate minutia M_{ik} and shown in FIG. **18**, will be referred to as primary relation data of the reference minutia M_i.

In the manner described in connection with the primary coordinate system, secondary coordinate systems x_e-y_e, x_f-y_f, x_g-y_g, and x_h-y_h or x_k-y_k are defined to have the respective origins at the primary proximate minutiae M_{ik} and the coordinate axes coincident with the direction data d_{ik} of the primary proximate minutiae M_{ik}. Proximate minutiae M_{ikr} which are found in relation to the secondary coordinates system defined for each primary proximate minutia M_{ik}, will be called secondary proximate minutiae of the reference minutia M_i. If a specific minutia proximate to one of the primary proximate minutie M_{ik} is coincident with the reference minutia M_i or another primary proximate minutia, the specific minutia need not be included in the secondary proximate minutiae. If a secondary proximate minutia found as regards a primary proximate minutia M_{ik}, coincides with a secondary proximate minutia resulting from another primary proximate minutia, it is sufficient to use only one of the two as a secondary proximate minutia.

For the example being illustrated, the secondary proximate minutiae are minutiae M_{ie0}, M_{ie1}, M_{if0}, M_{if2}, M_{if3}, M_{ig0}, M_{ig1}, M_{ig3}, M_{ih2}, and M_{ih3}. A minutia which is proximate to the primary proximate minutia M_{ie} in the fourth quadrant of the secondary coordinate system x_e-y_e and which may be selected as a secondary proximate minutia M_{ie2}, is coincident with the primary proximate minutia M_{ig}. A minutia proximate to the primary proximate minutia M_{ie} in the third quadrant to be selected as a secondary proximate minutia M_{ie3}, is coincident with the reference minutia M_i. A minutia to be selected as a secondary proximate minutia M_{if1} in the secondary coordinate system x_f-y_f, is already selected as the secondary proximate minutia M_{ie1}. The secondary proximate minutiae selected in this manner, will either singly or collectively be denoted by M_{ikr}.

It is already described that the primary proximate minutiae M_{ik} have the primary relation data of the minutia M_i, namely, the ridge counts R_{ik} relative to the reference minutia M_i. The primary proximate minutiae M_{ik} furthermore have and the position and the direction data x_{ik}, y_{ik}, and d_{ik} as regards the primary coordinate system having the local origin at the minutia M_i. Likewise, each secondary proximate minutia M_{ikr} has position and direction data $x_{ikr}{}^k$, $y_{ikr}{}^k$, and $d_{ikr}{}^k$ as regards the secondary coordinate system x_k-y_k having the origin at each primary proximate minutia M_{ik} and a ridge count R_{ikr} between the secondary proximate minutia M_{ikr} and the primary proximate minutia M_{ik}.

Each primary proximate minutia M_{ik}, although so named, in an ik-th minutia. The ridge count and the position and the direction data which the secondary poroximate minutiae M_{ikr} have relative to the primary proximate minutia M_{ik}, are therefore readily obtained by the relation linking unit **126** illustrated with reference to FIG. **19** with reference to the minutia list memory **71** (FIG. **6**) loaded with the minutia and the fundamental relation data of the ik-th minutia M_{ik} as exemplified in FIG. **14**.

It is, however, desirable for use in the pair detection that the ridge count should be the number of ridges between the reference minutia M_i and each secondary proximate minutia M_{ikr}. Furthermore, the position and the direction data should be given in direct relation to the primary coordinate system having the local origin at the reference minutia M_i. The latter ridge counts and position and direction data for all secondary proximate minutiae of the reference minutia M_i will be called secondary relation data of the reference minutia M_i. The secondary relation data of either one or all of the secondary proximate minutiae M_{ikr} will now be denoted by r_{ikr}, x_{ikr}, y_{ikr}, and d_{ikr}.

Like the primary proximate minutia M_{ik}, each secondary proximate minutia M_{ikr} is an ikr-th minutia. It is

therefore possible to readily obtain the position and the direction data x_{ikr}, y_{ikr}, and d_{ikr} by using the relation linking unit **126** exemplified in FIG. **19** and by giving the translation components x and y and the angle of rotation ϕ the position and the direction data X_i, Y_i, and D_i of the reference minutia M_i rather than the position and the direction data X_{ik}, Y_{ik}, and D_{ik} of each primary proximate minutia M_{ik}.

As for the ridge count r_{ikr}, attention should be directed to the fact that each secondary proximate minutia M_{ikr} is remoter from the reference minutia M_i than the primary proximate minutia M_{ik} for the secondary proximate minutia M_{ikr} under consideration in that quadrant of the primary coordinate system in which the primary proximate minutia M_{ik} is present. The ridge count r_{ikr} is therefore readily calculated by using the ridge counts R_{ik} and $R_{ikr}{}^k$. The ridge count R_{ik} is given in the minutia list memory **71** (FIG. **6**) for the reference minutia M_i. The other ridge count $R_{ikr}{}^k$ is also given in the minutia list memory **71** for the ik-th minutia M_{ik}.

Turning to FIG. **25**, the composite minutia memory **197** is for storing a sequence of the minutia data of each minutia M_i and the primary and the secondary relation data thereof for the search fingerprint and one file fingerprint at a time. The sequence will be called composite relation link data.

Referring to FIG. **24** once again, the composite relation linking unit **196** is for calculating the composite relation link data of each minutia M_i of the search or the file fingerprint for storage in the composite minutia memory **197** as exemplified in FIG. **25**. An example of the composite relation linking unit **196** comprises a ridge count register **201** and a ridge count calculator **202** in addition to the circuitry illustrated with reference to FIG. **19**. The ridge count register and calculator **201** and **202** will presently be described more in detail. The signals used for and in the pair detection circuit **77** will be called as before and designated by like reference numerals although there are certain differences between the signals being used and the previously described signals as will shortly become clear.

Turning back to FIG. **19**, the illustrated relation linking unit **126** carries out the relation linking operation also in the composite relation linking unit **196** (FIG. **24**) as described heretobefore until the fundamental relation data R_{ik} and M_{ik} of the i-th minutia M_i are supplied as the input data signal **132** from the minutia list memory **71** (FIG. **6**, **71S** or **71F**) accessed by the first address signal **131** indicative of the minutia number M_i. The output data signal **136**, the second address signal **137**, and the transfer signal **149** are delivered towards the composite minutia memory **197** instead of the minutia memory **127** (FIGS. **17** and **20**).

Before delivery of the foremost primary proximate minutia M_{ie} back to the central controller **129** from the shift register **134**, the ridge count R_{ie} produced from the shift register **134** and included in the output data signal **136**, is fed also to the ridge count register **201** (FIG. **24**) and stored therein. When the ie-th minutia M_{ie} is indicated by the first address signal **131** instead of the i-th minutia M_i, the controller **129** retains the reference minutia number M_i. The fundamental relation data R_{ie0}, M_{ie0}, R_{ie1}, . . . , R_{ie3}, and M_{ie3} of the ie-th minutia M_{ie}, namely the primary proximate minutia M_{ie}, are included in the input data signal **132** and stored in the shift register **134** in the shift register stages next following the stage to which the last datum M_{ih} of the previously stored fundamental relation data of the i-th minutia M_i is shifted. The controller **129** retains also the primary proximate minutia number M_{ie}.

Having carried out the relation linking operation of the primary relation data as regards the primary proximate minutia M_{ie}, the controller **129** receives the next following primary proximate minutia number M_{if} from the shift register **134** to make the first address signal **131** specify the if-th minutia M_{if} as described hereinabove. The controller **129** retains the minutia number M_{if}.

In this manner, the controller **129** retains for each reference minutia M_i, the reference minutia number M_i and the primary proximate minutia numbers M_{ik}. The ridge count register **201** keeps the ridge counts R_{ik}. The registers **135**'s still keep the position and the direction data X_i, Y_i, and D_i of the reference minutia M_i.

After the primary relation data of the reference minutia M_i are stored in the composite minutia memory **197**, the controller **129** receives the foremost secondary proximade minutia number, such as M_{ie0}, from the shift register **134** and compares the same with the minutia numbers M_i and M_{ik} retained therein. If different, the controller **129** holds the minutia number M_{ie0} and makes the first address signal **131** specify the ie**0**-th minutia M_{ie0} and the second address signal **137** indicate the row address of the reference minutia M_i and the column address for the ridge count r_{ie0} and the position and the direction data x_{ie0}, y_{ie0}, and d_{ie0}.

In the meantime, the controller **129** makes the ridge count register **201** supply the ridge count R_{ik} to the ridge count calculator **202** and makes the shift register **134** deliver the ridge count R_{ie0} also to the ridge count calculator **202**. The ridge count calculator **202** produces the ridge count r_{ikr} as a part of the output data signal **136**.

The position and the direction data X_{ie0}, Y_{ie0}, and D_{ie0} comprised by the input data signal **132** are delivered directly to the subtractors **138**. The adder **146**, the subtractor **147**, and the D subtractor **138D** produce the position and direction data x_{ie0}, y_{ie0}, and d_{ie0} as another part of the output data signal **136**.

Subsequently, the controller **129** receives the next following secondary proximate minutia number, such as the ie**1**-th minutia number M_{ie1}. If the minutia number M_{ie1} is different from the reference minutia number M_i, the primary proximate minutia numbers M_{ik}, and the already retained secondary proximate minutia number or numbers, such as M_{ie0}, then the above-described processes are repeated. If the secondary proximate minutia number being supplied, is equal to one of the reference, the primary proximate, and the already stored secondary proximate minutia numbers, then the controller **129** at once receives the next following secondary proximate minutia number from the shift register **134**. In this manner, the secondary relation data of the reference minutia M_i are stored in the composite minutia memory **197**.

Thereafter, the controller **129** makes the first address signal **131** indicate the next following reference minutia number, clearing the ridge count register **201**. The shift register **134** is already rendered. After the composite relation data of the last reference minutia M_z are stored in the (buffer memory **151** or **152** of the) composite minutia memory **197**, the controller **129** produces the transfer signal **149**.

Referring to FIG. **21** again, the exemplified pair detecting unit **128** serves well as an example of the composite pair detecting unit **198** if the local controller **159** is slightly modified. More specifically, attention will be

directed to the instant at which comparison of Formulae (5) comes to an end for the foremost primary proximate minutie M_{ieS} and M_{jeF} in the search and the file fingerprints with the second counter **172** renewed to a certain count. The controller **159** does not thereafter makes the address signal **162** immediately indicate the next following primary proximate minutiae of the search and the file fingerprints but access, while keeping access to the data R_{ieS}, x_{ieS}, y_{ieS}, and d_{ieS}, successively to the secondary proximate minutia data r_{ierF}, x_{ierF}, y_{ierF}, and d_{ierF}.

If the specific code is detected by the code detector **173** in place of any one of the ridge counts r_{ierF}, the first counter **171** is counted up. The second counter **172** is counted up by the output signal which the AND circuit **168** produces when:

$$\left.\begin{aligned} |r_{ieS} - r_{jerF}| &\leqq T_r, \\ |x_{ieS} - x_{jerF}| &\leqq T_x, \\ |y_{ieS} - y_{jerF}| &\leqq T_y, \\ \text{and } |d_{ieS} - d_{jerF}| &\leqq T_d. \end{aligned}\right\} \quad (7)$$

The controller **159** thereafter makes the address signal **162** indicate each of the primary proximate minutiae M_{ierS} and successively the foremost primary proximate minutia M_{jeF} and the secondary proximate minutiae M_{jerF}. After access to the last combination of the secondary proximate minutiae M_{ierS} and M_{jerF}, the address signal **162** is made to access the next primary proximate minutiae M_{ifS} and M_{jfF}.

Pair Candidate List

Referring to FIG. **26**, an example of the pair candidate list memory **73** (FIG. **6**) has sixty-four row addresses accessible by the address signal **176** (FIGS. **17** and **21**) representative of the respective search minutiae M_0 through M_z (or M_{63}). The memory **73** has sixteen column addresses assigned to the file minutia numbers M_j (0 through 15) which are represented also by the address signal **176** and are selected from the file minutia numbers M_0 through M_z (for example, M_{191}) and rearranged as follows.

A pair candidate list is formed in the memory **73** at a fourth step A_4 shown in FIG. **9**. Each entry specified by a search minutia number M_i and one of rearranged file minutia numbers M_j has a pair candidate field M_{ij} and a weight field W_{ij}. The local similarities represented by the data signal **177** (FIGS. **17** and **21**) between each search minutia M_{iS} and the selected file minutiae (pairs in fact) M_{jF} indicated by the address signal **176** are compared with one another by the sequence controller **69** (FIG. **6**) or elsewhere. The file minutia numbers M_{jF} are thereby rearranged in the descending order of the local similarity. The column addresses are accessed in this descending order. For example, the zeroth column M_{i0} of the row address accessible by the search minutia number M_i, is for a file minutia having the highest local similarity with the search minutia M_{iS}.

The local similarity, now called a weight W_{ij}, is stored in the weight field W_{ij}. When only one file minutia is found for the search minutia M_i during the pair detection as a single pair, data are stored in only the zeroth column. As a consequence, each row address may be loaded with the data only to a certain column address depending on the threshold supplied to the comparator **174** (FIG. **21**). A specific mark is stored in the weight field W_{ij} of the next following empty column address. It is possible to understand that a minutia number of the file fingerprint is stored in the column address in which the specific mark is stored in place of the weight and consequently that each row address for a search minutia M_{iS} is loaded with a plurality of file minutiae which are found to be in pairs with the search minutia M_{iS}.

Amounts of Coordinate Adjustment

As described above, the pair candidate list memory **73** (FIGS. **6** and **26**) is formed by detecting the minutia pairs based on the relatively coarse quantization step. Each search minutia is related in the pair candidate list memory **73** to at least one file minutia in the descending order of the local similarity or weight W_{ij}. The pair candidate list memory **73** is useful in more precisely matching the principal coordinate system selected for the search fingerprint with the principal coordinate system of each file fingerprint by deciding a set of optimum amounts of coordinate adjustment or coordinate match for the principal coordinate systems. It will be assumed that the principal coordinate system of the search fingerprint should be more precisely matched to the principal coordinate system of a file fingerprint.

Referring to FIG. **27**, an example of the (coordinate) adjustment amount deciding circuit **78** (FIG. **6**) is for rapidly and reliably deciding the optimum amounts as shown at a fifth step A_5 in FIG. **9**. Decision of the optimum adjustment amounts is carried out by referring to the exemplified pair candidate list memory **73** (FIG. **26**) and to either the minutia memory **127** (FIGS. **17** and **20**) or more preferably back to the minutia list memory **71** which may be loaded with the precise data as exemplified in FIG. **10**.

Each set of adjustment amounts consists of a pair of translation components and an angle of rotation, which will now be denoted again by x and y and afresh by $n\phi'$. It is to be noted that the angle ϕ' represents a preselected unit angle and that the letter n, an integer.

At the outset, the principal coordinate plane of the search fingerprint is rotated by an angle $n\phi'$ into a coordinate system, which will be called a search coordinate system. Let the position data X_i and Y_i of a search minutia M_i be forward transformed by the rotation of the principal coordinate plane to a temporary set of position data X_{si} and Y_{si}. Let one of the file minutiae that is given in the pair candidate list memory **73**, be the j-th minutia M_{jF}. The position data of the minutia M_{jF} will be designated by X_{mij} and Y_{mij}, which may be read from the file minutia memory **71F** of the minutia list memory **71**. A pair of differences x' and y' are calculated by:

$$\left.\begin{aligned} x' &= X_{mij} - X_{si} \\ y' &= Y_{mij} - Y_{si}. \end{aligned}\right\} \quad (8)$$

The exemplified adjustment amount deciding circuit **78** comprises a difference coordinate plane memory **211** representative of a difference coordinate plane (denoted also by the reference numeral **211**) which will shortly be described more in detail. The circuit **78** forms a weight map on the difference coordinate plane **211** as will be described in the following.

Turning to FIG. **28**, an example of the difference coordinate plane memory **211** has abscissa address accessible by the difference x' and ordinate address accessibly by the difference y'. An address specified by a combination of the differences x' and y' will be called a

coordinate address. It is assumed that each difference x' or y' is from minus 8 up to plus 7, both inclusive.

Referring to FIG. **29** in addition to FIG. **27**, the control memory **75** (FIG. **6**) specifies a search minutia M_i to read the precise positon and direction data X_i, Y_i, and D_i directly from the minutia list memory **71**. As will later become clear, let the amounts of adjustment x', y', and $n\phi'$ be provisionally selected and stored by the control memory **75** in the registers **91** through **93** (FIG. **13**) of the exemplified coordinate transforming circuit **72**. For the time being, zero is used at a first step C_1 as x' and y' which are provisionally selected as the translation components x and y. The (precise) position and direction data read out of the minutia list memory **71** are transformed by the coordinate transforming circuit **72** into the search position and direction data X_{si}, Y_{si}, and D_{si}. Incidentally, the ROM **94** produces the values cos ($n\phi'$) and sin ($n\phi'$).

Subsequently, the control memory **75** accesses the row address allotted in the pair candidate list memory **73** to the search minutia M_{iS} and a certain column address to find a file minutia M_{jF} which provides a pair with the search minutia M_{iS}. The (precise) position and direction data of the file minutia M_{jF} are read directly from the minutia list memory **71** as X_{mij}, Y_{mij}, and D_{mij}. Differences x', y', and d' are calculated according to Equations (8) and to:

$$d' = D_{mij} - D_{si}. \tag{9}$$

The control memory **75** supplies the differences x' and y' to X and Y input terminals X_I and Y_I and also a control signal to a control input terminal C_I. When the control signal takes a binary one value, X and Y selectors **212** and **213** supply the differences x' and y' to the difference coordinate plane memory **211**. The contents of a coordinate address specified by the differences x' and y' in the memory **211**, is supplied to one of two input ports of an adder **214**. The other input port is supplied with the weight W_{ij} from the pair candidate list memory **73** through a weight input terminal W_I. The sum calculated by the adder **214** is stored in the coordinate address being accessed.

In this manner, the weights W_{ij} are accumulated on the difference coordinate plane **211** according to the differences x' and y' to provide the weight map. The weights W_{ij} accumulated on the respective coordinate addresses are dependent on the angle of rotation $n\phi'$. Incidentally, the exemplified abscissa and ordinate addresses are relatively coarsely quantized although the position and the direction data X_{si}, X_{mij}, and so forth are precise. The access to a coordinate address is therefore carried out by using only four consecutive more significant bits of each of the row and the column address signals.

More particularly, the control memory **75** initializes the contents of the respective coordinate addresses to zero at a second step C_2. At this instant, the address signal **162** is made to indicate the zeroth search minutia M_0 as shown at a third step C_3. The search position and direction data X_{si}, Y_{si}, and D_{si} are calculated at a fourth step C_4, with the search minutiae successively specified. At a fifth step C_5, the minutia type Q_i is checked. If the end mark is detected, the weight map is complete.

If the end mark is not detected at the fifth step C_5, the column address is initialized to zero at a sixth step C_6. The pair candidate list memory **73** is accessed by the row and the column addresses at a seventh step C_7. The accessed weight field W_{ij} is checked at an eighth step C_8 whether or not the specific mark is present. If the specific mark is detected, the eighth step C_8 returns to the fourth step C_4.

If the specific mark is not detected at the eighth step C_8, the minutia list memory **71** is accessed at a ninth step C_9. The position and the direction data X_{Mij}, Y_{mij}, and D_{mij} are read out and used to calculate the differences x', y', and d' according to Equations (8) and (9). The file minutia number is increased by one.

At a tenth step C_{10}, the differences x', y', and d' are checked against preselected thresholds t_x, t_y, and t_d. If at least one of the differences exceeds the threshold, the tenth step C_{10} returns to the seventh step C_7. If all differences are equal to or less than the respective thresholds, the weight W_{ij} is added to the content of the coordinate address at an eleventh step C_{11}. The steps C_7 through C_{11} or the steps C_7 through C_9 and C_{11} are repeated. In the weight map exemplified in FIG. **28**, the accumulated weights are exemplified by numbers selected from 1 through 8.

Turning to FIG. **30**, a factor table **216** is exemplified for use in searching a specific coordinate address at which the accumulated weight is maximum. The table **216** is preferred in order to exclude a coordinate address at which the accumulated weight shows an unduly high value. The table **216** is used as will presently be described for each coordinate address of search and gives factors to be multiplied by the weights accumulated on nine coordinate addresses which form a matrix of three rows and three columns with the coordinate address of search at the center.

Referring to FIG. **31** besides FIG. **27**, an initial value of zero is set at a first step D_1 in first through third registers **221**, **222**, and **223**, a maximum register **225**, and first and second register files **226** and **227**. Another initial value of minus 8 is set in X and Y registers **228** and **229** to indicate a start point of search (the leftmost and lowest coordinate address of the difference coordinate plane **211**). A binary zero value is given to the control signal (C_I), responsive to which the selectors **212** and **213** make the contents of the X and Y registers **228** and **229** access the weight map and responsive to which the difference coordinate plane memory **211** is adapted to read out.

The first register file **226** is fed directly from the difference coordinate plane memory **211**. The second register file **227** is fed from the first register file **226**. The register files **226** and **227** are accessed by the Y register **229**.

The adjustment amount deciding circuit **78** comprises first through third selectors **231**, **232**, and **233**. A timing signal input terminal, depicted separately at **234** and **235**, is supplied with a timing signal from the control memory **75**. The timing signal specifies first and second timings T_1 and T_2 by, for example, logic zero and one values, respectively.

A first adder **236** is for adding twice the data selected by the second selector **232** and the data selected by the third selector **233**. A second adder **237** is for adding the data supplied from the first adder **236** and the data selected by the first selector **231** to supply the sum to the first register **221** and also to a comparator **238**. The sum is furthermore directed towards the maximum register **225**.

During the first timing T_1, the registers **221** through **223** are enabled. Furthermore, the selectors **231** through **233** are made to select the data supplied directly from

the difference coordinate plane memory **211** and the data supplied from the register files **226** and **227**, respectively. The following processes are therefore carried out concurrently at a second step D_2.

$$\left.\begin{aligned} RK1 &\leftarrow DIF(DX, DY) + 2[RFI(DY)] \\ &\quad + RF2(DY), \\ RK2 &\leftarrow RK1, \\ RK3 &\leftarrow RK2, \\ RF1(DY) &\leftarrow DIF(DX, DY), \\ \text{and } RF2(DY) &\leftarrow RF1(DY), \end{aligned}\right\} \quad (10)$$

where DX and DY, DIF, RK1 through RK3, and RF1 and RF2 represent contents of the X and Y registers **228** and **229**, of the difference coordinate plane memory **211**, of the registers **221** through **223**, and of the register files **226** and **227**, respectively. The data on the right-hand sides represent the contents before renewal and those on the left-hand sides, renewed data.

During the second timing T_2, the registers **221** through **223** are disabled. The selectors **231** through **233** are made to select the data fed from the registers **221** through **223**, respectively. As a result, the second adder **237** produces a sum (RK1+2[RK2]+RK3). The comparator **238** compares the sum with the content (MDIF) of the maximum register **225**. If the sum is less than the content, the comparator **238** enables an AND circuit **239** for the logic one timing signal. An input port of the maximum register **225** is therefore enabled. The following processes are simultaneously carried out at a third step D_3.

$$\left.\begin{aligned} MDIF &\leftarrow RK1 + 2[RK2] + RK3, \\ DX' &\leftarrow DX, \\ \text{and } DY' &\leftarrow DY, \end{aligned}\right\} \quad (11)$$

where DX' and DY' represent the contents of X' and Y' registers **241** and **242**.

Thereafter, the control memory **75** sends another timing signal to an input terminal **243** to enable inputs to the X and Y registers **228** and **229**. At a fourth step D_4, a first one-adder **246** adds one in general to the content DY of the Y register **229**. Only when the content DY represents seven, the one-adder **246** supplies a carry to a second one-adder **247**, which adds one to the content DX of the X register **228**. When the content DX becomes equal to seven, the second one-adder **247** delivers a carry to an end output terminal **248**. The latter carry is detected by the control memory **75** as an end of the search at a fifth step D_5. Before detection of the latter carry, the processes return from the fifth step D_5 to the second step D_2. When the latter carry is detected, the contents DX' and DY' are read out of the X' and Y' registers **241** and **242** as the translation components x and y at a sixth step D_6.

In order to facilitate an understanding of the search, let it be assumed that the contents DX and DY of the X and Y registers **228** and **229** are for the abscissa address x' of 3 and the ordinate address y' of 5 of the difference coordinate plane **211** exemplified in FIG. **28**. During the first timing T_1, Formulae (10) shows that the contents RF1(5), RF2(5), and RK1 through RK3 are equal to DIF(2, 5), DIF(1, 5), (DIF(3, 5)+2[DIF(2, 5)]+DIF(1, 5)), (DIF(3, 4)+2[DIF(2, 4)]+DIF(1, 4)) or the content RK1 which the first register **221** had at the previous instant when DY was equal to 4, and (DIF(3, 5)+2[DIF(2, 3)]+DIF(1, 3)) or the content RK1 which the first register **221** had at the next previous instant when DY was equal to 3, respectively.

In the course of the second timing T_2, processes are carried out according to Formulae (11). The second adder **237** gives a sum which is equal to:

$$\begin{aligned} &DIF(3, 5) + 2[DIF(2, 5)] + DIF(1, 5) + \\ &\quad 2[DIF(3, 4) + 4[DIF(2, 4)] + 2[DIF(1, 4)] + \\ &\quad\quad DIF(3, 3) + 2[DIF(2, 3)] + DIF(1, 3), \end{aligned} \quad (12)$$

which shows that the above-described search is carried out by multiplying nine accumulated weights by the factors of the factor table **216** (FIG. **30**) and by summing up the products. It is to be noted in connection with Equation (12) that the greatest factor of 4 is multiplied to DIF(2, 4), namely, the weight accumulated on the coordinate address (2, 4) rather than the coordinate address (3, 5) being checked. The coordinate address on which the maximum weight is accumulated, is therefore given by (X'−1, Y'−1). The optimum amounts of coordinate adjustment are obtained by alternatingly repeating the above-described accumulation and search.

Referring afresh to FIG. **32** and again to FIG. **27**, the working area **74** (FIG. **6**) is for storing the unit angle of rotation ϕ', the integers n, the maximum value of the integer N, an angle of rotation ϕ as will shortly be described, (X'−1) and (Y'−1) previously obtained from the contents X' and Y' of the X' and Y' registers **241** and **242**, and that content read out of the maximum register **225** which will now be called a previous maximum and denoted by MDIF'.

At the outset, the control memory **75** sets the unit angle ϕ' and the maximum integer N in the working area **74** at a first step E_1. The memory **75** gives an initial value of zero to the integer n and also to the previous maximum MDIF' at a second step E_2.

The control memory **75** makes the exemplified adjusting amount deciding circuit **78** (FIG. **27**) form a weight map at a third step E_3 and then the search at a fourth step E_4. Responsive to the end of search signal, the memory **75** reads the maximum register **225** and compares the maximum MDIF with the previous maximum MDIF' at a fifth step E_5. When the read-out maximum MDIF is greater than the previous maximum MDIF', the control memory **75** substitutes the former for the latter at a sixth step E_6. Furthermore, the memory **75** reads the X' and Y' registers **241** and **242** and substitutes (X'−1) and (Y'−1) for the previously read-out values in the working areas **75** and rewrites the angle of rotation ϕ by the angle of rotation $n\phi'$ by which the new maximum is obtained.

The control memory **75** changes the sign of the integer n at a seventh step E_7. If the read-out maximum MDIF is equal to or less than the previous maximum MDIF', the step E_5 jumps to the step E_7. As an eighth step E_8, the memory **75** checks whether or not the new integer is equal to or greater than zero. If not, the step E_8 returns to the step E_3. If the new integer is equal to or greater than zero, the memory **75** checks whether or not the new integer is equal to the maximum integer N at a ninth step E_9. If not, the memory **75** adds one to the new integer at a tenth step E_{10} and makes the process return to the second step E_2. If the maximum integer N is reached, the optimum amounts are obtained.

It may be that the maximum MDIF eventually obtained as a result of the above-described steps, is found

at a sixth step A_6 of FIG. 9 to be less than a preselected threshold. In this event, the control memory 75 judges that the file fingerprint being matched, is different from the search fingerprint. In other words, the matching is unsuccesful. The memory 75 suspends the matching and informs the matching control device 55 (FIG. 1) of the fact. Only when the eventually obtained maximum MDIF exceeds the threshold, the memory 75 transfers the precise position and direction data and so forth from the minutia list memory 71 (FIG. 6) to the precise matcher 57 (FIG. 2 or 3) through a bus 249 (FIG. 2) or the buses 64 and 90 (FIG. 3) at a seventh step A_7 of FIG. 9. The transfer of the position and direction data and the like is preferably carried out with reference to the pair candidate list memory 73 and through the coordinate transforming circuit 72 in which the optimum amounts of adjustment are set for the forward transformation.

Precise Matcher

Referring back to FIG. 7, the first minutia list is transferred as a second minutia list in the second minutia list memory 81. As will presently become clear, the minutiae used in the precise matcher 57 are those listed in the pair candidate list memory 73 and the (primary) proximate minutiae of the search and the file minutiae given in the pair candidate list. It will be assumed for convenience of description that the minutia list memory 81 is loaded with the second minutia list in the form shown in FIG. 18 together with the identification numbers of the search and the file fingerprints being dealt with. The pair candidate list memory 73 is rendered empty by transfer of the pair candidate list preliminarily to the pair candidate list memory 83. The region pattern list is transferred either from the first minutia list memory 71 or directly from the data storing device 54 (FIG. 1) to the region pattern list memory 87.

At an eighth step A_8 depicted in FIG. 9, the sequence controller 79 (FIG. 7) reads the position and the direction data of the pair candidates from the minutia list memory 81 with reference to the pair candidate list memory 83. The read out is carried out directly without the use of the coordinate transforming circuit 82. This is because the data are stored in the minutia list memory 81 with the coordinates optimally matched at the seventh step A_7. The read-out data are checked against thresholds which are stricter than those used in Formulae (5). Comparison defined by Formulae (6) and (7) is no more necessary. The sequence controller 79 selects those of the pair candidates together with the weights, which are within the stricter thresholds.

Referring now to FIG. 33, the selected search minutiae will be denoted by N_s. The file minutia which is in a stricter pair (the stricter pair being possibly still "pairs") with each selected search minutia N_s, will be designated by M_f where f represents a strictly selected one of 0 through z for the file fingerprint. The weights which are preliminarily moved to the pair candidate list memory 83, remain only for the stricter pairs after the eighth step A_8 (FIG. 9).

At a ninth step A_9 of FIG. 9, the pair candidate list memory 83 (FIG. 7) is modified as regards the remaining weights. As described above, the proximate minutiae N_{sr} and M_{fr} are stored in the minutia list memory 81.

The sequence controller 79 (FIG. 7) successively accesses the minutia list memory 81 by the minutia numbers N_s and M_f to read the proximate minutia numbers N_{sr} and M_{fr}. The controller 79 searches the pair candidate list memory 83 for the proximate minutiae M_{fr} in the row address assigned to each proximate minutia N_{sr}. If one is found as depicted at M_f (FIG. 33), the file minutia M_f is in stricter pair with the proximate search minutia N_{sr} being dealt with. The weight for the pair N_{sr} and M_f is added to the weight for the pair N_s and M_f to provide a modified weight for the pair N_s and M_f.

In each row address of the pair candidate list memory 83, the pairs are rearranged in the descending order of the modified weights. The modified weights so rearranged, will be denoted by W_{st} where t represents 0, 1, ...

Referring to FIG. 34, the pair list memory 86 (FIG. 7) comprises search and file pair list memories 86S and 86F. The search pair list memory 86S has row addresses assigned to (strictly selected) search minutiae N_1 through N_S as will presently be described. Each row address N_s has a pair field M_f and an evaluation field V_s. The file pair list memory 86F likewise has row addresses allotted to (strictly selected) file minutiae M_1 through M_F. Each row address M_f has a pair field N_s and an evaluation field V_f.

At a tenth step A_{10} of FIG. 9, the pair list memory 86 is formed as follows. At the outset, the evaluation fields V_s and V_f are initialized to a negative value. The pair candidate list memory 83 is repeatedly scanned from the row address N_1 to the row address N_S. From the pair (N_s, M_{s0}) having the maximum modified weight and consequently stored in the zeroth column, the modified weight W_{s0} is read out. A difference between the maximum modified weight W_{s0} and the next following modified weight W_{s1} is calculated.

Reliability of the pair is decided for each pair (N_s, M_{s0}) in consideration of the modified weight W_{s0} and the difference. The pairs of each row address are rearranged in the descending order of the reliability. The pairs (N_s, M_{s0}) are renumbered into pairs (N_s, M_f) or (N_1, M_1), . . . , (N_s, M_s), . . . , (N_f, M_f), . . . (the suffix s being not necessarily less than the other suffix f). The modified weight, now called evaluations V_1, . . . , V_s, . . . , V_f, . . . , are substituted for the negative value in the respective evaluation fields V_1, . . . , V_s, . . . , V_f, ... The pairs remaining in the pair candidate list memory 83 are erased.

Turning to FIGS. 35 and 36, one of proximate minutiae of a search minutia N_s (renumbered) is depicted at N_{sr} together with a file minutia M_f (also renumbered) in a pair for the search minutia N_s in the manner depicted in FIG. 33. Like the modification of the pair candidate list memory 83, the pair list memory 86 is modified in a former half of an eleventh step A_{11} illustrative of decision of the evaluation in FIG. 9.

At first, the row address N_s is checked in the search pair list memory 86S. If the evaluation V_s is positive (not the initial value), the file minutia number M_f of the pair is read out. The search minutia N_s is used to access the minutia list memory 81 (FIG. 7) to read the proximate minutia numbers N_{sr}. Each proximate minutia N_{sr} is used to check the search pair list memory 86S whether or not the evaluation field V_{sr} is positive. If positive, the evaluation V_{sr} is added to the evaluation V_s. The evaluation V_s is rewritten by the sum, which will be called a modified evaluation and again denoted by V_s. The other new address of the pair list memory 86 are similarly dealt with.

Further turning to FIGS. 37 and 38, a file minutia M_f is depicted together with a proximate minutia M_{fr}. The

proximate minutiae M_{fr} are read from the minutia list memory **81** as before.

The modification of the pair list memory **86** is followed by relaxation of the evaluation in the latter half of the eleventh step A_{11} of FIG. **9**. During modification of the pair list memory **86**, the negative initial value may be read from the evaluation field V_f of the row address for the minutia M_f. The position data of the minutia M_f are read directly from the minutia list memory **81** and used to access the region pattern list memory **87**. If the region pattern list memory **87** indicates that the minutia M_f is in the unclear area (FIG. **4**), the negative initial value is rewritten in the evaluation field V_f to zero which is indicative of "don't care." If the minutia M_f is in the file fingerprint area, the negative initial value is left as it stands.

The relaxation of the evaluation is carried out also for the search minutiae N_s. In this connection, attention should be directed to the facts that the position and the direction data of the search minutiae are given by a coordinate system into which the principal coordinate system for the search fingerprint is forwardly transformed on loading the minutia list memory **81** by the use of the optimum amounts of coordinate adjustment and that the pattern region list of the search fingerprint is given in the pattern region list memory **87** by the principal coordinate system. The coordinate transforming circuit **82** should therefore be used on reading the position data from the minutia list memory **81** to access the region pattern list memory **87**. For this purpose, the registers which correspond to the registers **91** through **93** in the circuit **82**, should preliminarily be loaded with the optimum amounts when the fingerprint matching is transferred from the leading matcher **56** to the precise matcher **57**. A search minutia for which the negative initial value is left untouched in the evaluation field, will be denoted by $N_{s'}$.

The relaxation of the evaluation is continued. The ridge count R_{fr} (FIG. **36**) which the file minutia M_f has relative to each proximate minutia M_{fr}, is read from the minutia list memory **81**. If the ridge count R_{fr} is equal to zero, the minutiae M_f and M_{fr} are very closely positioned on the file fingerprint and will be called close minutiae. The direction data D_f and D_{fr} are checked as will shortly be described, whether or not the directions D_f and D_{fr} are opposite to each other. If the negative initial value is left also in the evaluation field V_{fr}, the negative initial values are changed in the evaluation fields V_f and V_{fr} to zero indicative of "don't care" as before. The process is carried out also for the search minutiae $N_{s'}$. The direction data are checked in the exemplified precise matcher **57** by the arithmetic unit **89** under the control of the control memory **85** and in cooperation with the working area **84**.

FIG. **39** exemplifies several combinations of close minutiae having opposite directions. It is to be noted that the direction of a bifurcation is depicted opposite to that defined in the above-referenced Asai Patent.

Referring to FIG. **40**, a direction checking circuit is for use in place of the arithmetic unit **89** in solely checking the directions. The position and the direction data of the close minutiae M_f and M_{fr} or $N_{s'}$ and $N_{s'r}$ will be denoted merely by X, Y, and D and X', Y', and D'. A complement calculator **251** is supplied with the direction datum D' to produce a direction datum D_0 opposite to the direction D', namely, a sum of D' and π. The absolute values of differences between X and X', between Y and Y', and between D and D_0 are calculated by absolute difference calculators **252**, **253**, and **254**. A threshold ROM **256** is for supplying comparators **257**, **258**, and **259** with thresholds for comparison with the respective absolute values of differences.

Attention should be directed to the direction data D and D_0 so that the angle of π radians may be given by the most significant bit. This is in order to insure the difference $(D-D_0)$ as regards the periodicity of angle.

A direction ROM **261** is accessed by the differences $(X-X')$ and $(Y-Y')$ or by the absolute values of the differences and the sign bits of the respective differences. The ROM **261** is preliminarily loaded with angles ϕ (the same symbol being again used) given by:

$$\phi = \arctan\,[(Y'-Y)/(X'-X)].$$

The absolute values of differences between the direction datum D and the angle ϕ and between the direction datum D_0 and the angle ϕ are calculated by additional absolute difference calculators **262** and **263**. The threshold ROM **256** supplies additional comparators **267** and **268** with an additional threshold for comparison with the absolute values calculated by the calculators **262** and **263**. Attention should be directed to the facts that each difference is nearly equal to zero and that the most significant bit of the difference would correspond to $\pi/2$.

An AND gate **269** is supplied with the results of comparison from the comparators **257** through **259**, **267**, and **268**. Only when all results show that the absolute values of the differences are not greater that the thresholds, the AND gate **269** supplies the sequence controller **79** (FIG. **7**) with an output signal indicative of the fact that the close minutiae have opposite directions.

Referring to FIG. **41**, small circles show file minutiae M_f and $M_{f'}$. Dots show search minutiae N_s and $N_{s'}$. It may be found that close minutiae do not have opposite directions. In this event, the minutia list memory **81** is accessed by the minutia numbers M_f and M_{fr} to read the concentrations C_f and C_{fr}. If the concentrations C_f and C_{fr} have a great value as compared with a threshold, the evaluation field V_f and V_{fr} are rewritten to zero indicative of "don't care." Summarizing, the relaxation of the pair list memory **86** is carried out as regards the minutiae which are not in an area common to the search and the file fingerprint areas. The relaxation is furthermore carried out in connection with those of the close minutiae which either have opposite directions or are densely positioned. Such close minutiae are enclosed in FIG. **41** with dashed-line curves.

Fingerprint Matching

The precise matcher **57** carried out precise matching between a search fingerprint and one of the file fingerprints at a time by eventually calculating a match score (degree of match) q as indicated at a twelfth step A_{12} in FIG. **9**. More particularly, the sequence controller **79** (FIG. **7**) reads the pair list memory **86** and makes the control memory **85** control the arithmetic unit **89**. Using the working area **84**, the arithmetic unit **89** calculates the match score q in accordance with:

$$q = \left(\sum_{s}^{S} V_s \times \sum_{f}^{F} V_f\right) / (S \times F),$$

where S and F are representative of the numbers of search and file minutiae which are present in the com-

mon area described in conjunction with FIG. **41**. The sequence controller **69** compares the match score q with a threshold at a thirteenth step A_{13} of FIG. **9**.

If the match score q is less than the threshold, the precise matching is at once suspended. The precise matcher **57** under consideration is ready for precise matching for another file fingerprint.

If the match score q is not less than the threshold, the identification number of the file fingerprint is stored in the candidate fingerprint list memory **88** (FIG. 7) at a fourteenth step A_{14} of FIG. **9** together with the match score q. In a fingerprint matching system depicted in FIG. **1** and comprising leading and precise matchers, the match scores q obtained for a search fingerprint are compared with one another. The matching control device **55** is informed of the identification number of the file fingerprint that has the maximum of the match scores q. The matching control device **55** sends the identification number to the data control and processing device **53**, which produces a result signal indicative of the identification data of the file fingerprint. Meanwhile, the data of another search fingerprint are transferred to the fingerprint matching devices **51**'s.

Destination Deciding Circuit

Referring to FIG. **42**, an example of the destination deciding circuit **67** (FIG. **5**) is specifically useful in the fingerprint matching device **51** exemplified in FIG. **3** and comprises first through third decision circuits **271**, **272**, and **273**. The first decision circuit **271** is supplied with first through third primary busy signals **276**, **277**, and **278** which indicate that the first through the third leading matchers **56***a*, **56***b*, and **56***c* are busy. First and second secondary busy signals **281** and **282** indicative of the facts that the first and the second precise matchers **57***a* and **57***b* are busy, are delivered to the second and the third decision circuits **272** and **273**. The third decision circuit **273** produces first through third primary allowance signals **286**, **287**, and **288** and first and second secondary allowance signals **291** and **292** which allow transfer of data to the first through the third leading matchers **56***a*, **56***b*, and **56***c* and to the first and the second precise matchers **57***a* and **57***b*, respectively. The primary busy and allowance signals **276** through **278** and **286** through **288** are transmitted through the bus **90** (FIGS. **2** and **3**). The secondary busy and allowance signals **281**, **282**, **291**, and **292** are transmitted through the bus **64**.

When a command indicative of transfer of data from the data storing device **54** (FIG. **1**) to the leading or the precise matchers **56**'s or **57**'s, is supplied through the bus **62**, the device interface circuit **63**, and the control circuit **66**, the first decision circuit **271** produces first through third primary decision signals **296**, **297**, and **298**. According to logic operation, the signals **296** through **298** are produced when the first through the third primary busy signals **276** through **288** are absent, respectively.

When supplied with first through third transfer request signals **301**, **302**, and **303** from the first through the third leading matchers **56**'s through the bus **90**, the second decision circuit **272** produces an inhibit signal **309** and first through fifth secondary decision signals **311**, **312**, **313**, **314**, and **315**. The inhibit signal **309** is produced either (1) when at least one of the transfer request signals **301** through **303** is present and furthermore when the secondary busy signals **281** and **282** are both present or (2) when all transfer request signals **301** through **303** are absent. The first secondary decision signal **311** is produced in the presence of the first transfer request signal **301**. The second secondary decision signal **312** is produced when the second transfer request signal **302** is present in the absence of the first transfer request signal **301**. The third secondary decision signal **313** is produced when the third transfer request signal **303** is present in the absence of the first and the second transfer request signals **301** and **302**. The fourth and the fifth secondary decision signals **314** and **315** are produced when at least one of the transfer request signals **301** through **303** is present in the absence of the first and the second secondary busy signals **281** and **282**, respectively.

First through third AND circuits **316**, **317**, and **318** are supplied with the inhibit signal **309** in common. Responsive to the first through the third primary decision signals **296** through **298**, the first through the third AND circuits **316** through **318** produce first through third ternary dceision signals **321**, **322**, and **323**, respectively. The third decision circuit **273** includes a flip-flop (not shown) for selecting either of the first and the second precise matchers **57** when both are idle. It will be assumed that the flip-flop produces first and second quaternary decision signals **326** and **327** (not shown) to select the first and the second precise matchers **57**, respectively.

The first primary allowance signal **281** is produced when at least one of the first secondary and ternary decision signals **311** and **321** is present. The second primary allowance signal **287** is produced when at least one of the second secondary and ternary decision signals **312** and **322** is present. The third primary allowance signal **288** is produced when at least one of the third secondary and ternary decision signals **313** and **323** is present.

The first secondary allowance signal **291** is produced when the fourth secondary decision signal **314** is present and moreover either when the first secondary busy signal **281** is absent or when the first quaternary decision signal **316** is present in the absence of the second secondary busy signal **282**. The second secondary allowance signal **292** is produced when the fifth secondary decision signal **315** is present and furthermore either when the second secondary busy signal **282** is absent or when the second quaternary decision signal **327** is present in the absence of the first secondary busy signal **281**.

Closing Paragraph

While the preferred embodiments of this invention and modifications thereof have so far been described with reference to the accompanying drawing, it will now readily be possible for one skilled in the art to carry this invention into effect in various other manners. For example, modification of the pair candidate list memory **83** and of the pair list memory **86** should preferably be carried out for all combinations of the proximate minutiae. The memories, such as the minutia memories **153** and **154**, may be loaded with the data in other ways. Attention should finally be directed to the fact that it is possible to implement the sequence controllers **69** and **79**, the pair detecting unit **128** or **198**, and the like by microcomputers as will readily be understood from the description of operation.

What is claimed is:

1. A method of deciding a degree of match between a search and a file fingerprint, comprising the steps of:

selecting preliminarily matched coordinate systems on the respective fingerprints;

selecting a search and a file fingerprint area where minutiae are clear;

forming a minutia list showing those original position and direction data of the minutiae which are given by the respective preliminarily matched coordinate systems, said minutia list furthermore showing those relation data of the minutiae which are substantially independent of said preliminarily matched coordinate systems;

selecting pairs of minutiae from the minutiae of the respective fingerprints by comparing the original position and direction data given for the respective fingerprints and furthermore comparing the relation data given for the respective fingerprints;

forming a pair candidate list which shows said pairs of minutiae as pair candidates, respectively;

deciding optimum amounts of coordinate match by referring to the original position and direction data of the minutiae of said pair candidates, said optimum amounts being for precisely matching said preliminarily matched coordinate systems with each other;

transforming the original position and direction data given by a predetermined one of said preliminarily matched coordinate systems for the minutiae of said pair candidates into transformed position and direction data given by a transformed coordinate system into which said predetermined one of the preliminarily matched coordinate systems is transformed by said optimum amounts;

forming a pair list by referring to said minutia list, said pair candidate list, and said search and said file fingerprint areas, said pair list showing precise pairs of minutiae selected from those minutiae of said pair candidates which are present in an area common to said search and said file fingerprint areas, the minutiae of each precise pair having a precise local similarity between the transformed position and direction data and the original position and direction data given by a different one of said preliminarily matched coordinate systems and between the relation data, said different one of the preliminarily matched coordinate systems being different from said predetermined one of the preliminarily matched coordinate systems, said pair list furthermore showing evaluations, each evaluation being representative of said local similarity; and

deciding said degree of match using the minutiae of said pair list and by referring to said evaluations.

2. A method as claimed in claim **1**, wherein said minutia list forming step comprises the steps of:

selecting primary local coordinate systems which having primary local origins at the respective minutiae;

selecting primary proximate minutiae with reference to the respective primary local coordinate systems, said primary proximate minutiae being proximate to the respective local origins;

deciding primary data of said primary proximate minutiae with reference to the respective primary coordinate systems;

selecting secondary local coordinate systems which have secondary local origins at the respective primary proximate minutiae;

selecting secondary proximate minutiae with reference to the respective secondary local coordinate systems, said secondary proximate minutiae being proximate to the respective secondary local origins;

deciding secondary data of said secondary proximate minutiae with reference to the respective primary local coordinate systems; and

listing said primary and said secondary data as said relation data.

3. A method as claimed in claim **1**, wherein said pair list forming step comprises the steps of:

forming an additional minutia list which shows said transformed position and direction data, the original position and direction data given by said different one of the preliminarily matched coordinate systems for the minutiae of said pairs of candidates, and the relation data of the minutiae of said pair candidates; and

forming said pair list by referring to said additional minutia list, said pair candidate list, and said search and said file fingerprint areas, the transformed position and direction data given in said additional minutia list being used in evaluating said precise local similarity.

4. A fingerprint matching device for deciding a degree of match between a search and a file fingerprint, comprising:

minutia list producing means (**71, 72, 81**) for producing a minutia list showing those original position and direction data of minutiae which are given by preliminarily matched coordinate systems selected on said search and said file fingerprints, respectively, said minutia list furthermore showing those relation data of said minutiae which are substantially independent of said preliminarily matched coordinate systems;

fingerprint area memory means (**87**) for memorizing a search and a file fingerprint area where the minutiae are clear;

selecting means (**77**) coupled to said minutia list producing means for selecting pairs of minutiae from the minutiae of the respective fingerprints, said pairs of minutiae having similar original position and direction data given for the respective fingerprints and furthermore similar relation data given for the respective fingerprints;

pair candidate list memory means (**73**) coupled to said selecting means for memorizing a pair candidate list which shows said pairs of minutiae as pair candidates, respectively;

optimum amount deciding means (**78, 75**) coupled to said minutia list producing means and said pair candidate list memory means for deciding optimum amounts of coordinate match by referring to the original position and direction data of the minutiae of said pair candidates, said optimum amounts being for precisely matching said preliminarily matched coordinate systems with each other;

coordinate transforming means (**72**) coupled to said minutia list producing means, said pair candidate list memory means, and said optimum amount deciding means for transforming a predetermined one of said preliminarily matched coordinate systems into a transformed coordinate system by said optimum amounts, said coordinate transforming means thereby transforming the original position and direction data given by said predetermined one of the

preliminarily matched coordinate systems for the minutiae of said pair candidates into transformed position and direction data;

pair list memory means (**86, 83**) coupled to said minutia list producing means, said pair candidate list memory means, and said fingerprint area memory means for memorizing a pair list showing precise pairs of minutiae selected from those minutiae of said pair candidates which are present in an area common to said search and said file fingerprint areas, the minutiae of each precise pair having a precise local similarity between the transformed position and direction data and the original position and direction data given by a different one of said preliminarily matched coordinate systems and between the relation data, said different one of the preliminarily matched coordinate systems being different from said predetermined one of the preliminarily matched coordinate systems, said pair list furthermore showing evaluations, each evaluation being representative of said local similarity; and

deciding means (**89**) coupled to said pair list memory means for deciding said degree of match by using the minutiae of said pair list and by referring to said evaluations.

5. A fingerprint matching device as claimed in claim **4**, wherein said minutia list producing means comprises:

first means (in **197**) for producing a remaining part of said minutia list, said part showing the original position and direction data given by the respective preliminarily matched coordinate systems and furthermore showing that part of said relation data which gives primary data represented by primary local coordinate systems selected to have primary local origins at the respective minutiae, said primary data being given to primary proximate minutiae with reference to the respective primary local coordinate systems, said primary proximate minutiae being selected proximate to the respective primary local origins with reference to the respective primary local coordinate systems; and

second means (in **197**) for producing a remaining part of said minutia list, said remaining part showing that remaining part of said relation data which gives secondary data represented by the respective primary local coordinate systems, said secondary data being given to secondary proximate minutiae which are selected proximate to the respective primary proximate minutiae with reference to the respective ones of secondary local coordinate systems selected to have secondary local origins at the respective primary proximate minutiae.

6. A fingerprint matching device as claimed in claim **5**, wherein:

said primary proximate minutiae are selected proximate to each primary local origin in a predetermined number of sectors which have a common vertex at said each primary local origin and into which the primary local coordinate system having said each primary local origin is divided;

said secondary proximate minutiae being selected proximate to each of the secondary local origins located at the respective primary proximate minutiae selected for said each primary local origin in a prescribed number of sectors which have a common vertex at said each of the secondary local origins and into which the secondary local coordinate system having said each of the secondary local origins is divided;

said secondary data comprising ridge counts between said each primary local origin and the respective secondary proximate minutiae which are selected for the secondary local origins located at the respective primary proximate minutiae selected for said each primary local origin.

7. A fingerprint matching device as claimed in claim **4**, wherein:

said minutia list producing means comprises:

first minutia list producing means (**71, 72**) for producing a first minutia list which shows the original position and direction data given by the respective preliminarily matched coordinate systems and the relation data of the respective minutiae; and

second minutia list producing means (**81**) coupled to said coordinate transforming means and said pair candidate list memory for producing a second minutia list which shows said transformed position and direction data, the original position and direction data given by said different one of the preliminarily matched coordinate systems for the minutiae of said pair candidates, and the relation data for the minutiae of said pair candidates;

said selecting means being coupled to said first minutia list producing means;

said optimum amount deciding means being coupled to said first minutia list producing means and said pair candidate list memory means;

said coordinate transforming means being coupled to said first minutia list producing means, said pair candidate list memory means, and said optimum amount deciding means;

said pair list memory means being coupled to said second minutia list producing means, said pair candidate list memory means, and said fingerprint area memory means, the transformed position and direction data used in giving said precise local similarity being those given by said second minutia list producing means.

8. A fingerprint matching device as claimed in claim **4**, wherein said relation data comprise a ridge count between each minutia of said search and said file fingerprint and a minutia which is proximate to said each minutia in said search and said file fingerprints.

9. A fingerprint matching device as claimed in claim **4**, wherein:

said pair candidate list memory means is for memorizing the pair candidate list which furthermore shows a local similarity measure for each pair candidate;

said optimum amount deciding means uses the local similarity measures for the respective pair candidates on deciding said optimum amount;

said pair list memory means determines said precise local similarity by using the local similarity measures selected for the respective precise pairs.

10. A fingerprint matching device as claimed in claim **9**, the pair candidate consisting of a first and a second minutia, wherein said optimum amount deciding means comprises:

a two-dimensional memory (**211**) supplied with the local similarity measures for the respective pair candidates from said pair candidate list memory means;

means (**212–214**) for accumulating the local similarity measures in said two-dimensional memory accord-

ing to coordinate increment sets and angular increments, each coordinate increment set representing differences between the original position data of the first minutia of each pair candidate and the transformed position data into which the original position data of the second minutia of said each pair candidate are transformed when each angular increment is given to the preliminarily matched coordinate system selected for the fingerprint including the second minutia of said each pair candidate; and

means (75) for giving said optimum amounts by the coordinate increment set and the angular increment for which the local similarity measures are most accumulated in said two-dmensional memory.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 4,646,352

DATED : February 24, 1987

INVENTOR(S) : Koh ASAI; Hiroyuki IZUMISAWA; Katsuaki OWADA; Seiichiro KINOSHITA; & Shunji MATSUNO, all of Tokyo Japan

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 1, line 11, change "finerprint" to --fingerprint--.

Column 2, line 37, change "condidates" to --candidates--.

Column 5, line 36, change "finerprint" to --fingerprint--.

Column 6, line 67, change "58" to --59--.

Column 8, line 39, change "54" to --56--.

Column 9, line 45, change "foor" to --for--.

Column 11, line 22, change "d_p" to --d_q--;

line 49, change "d_q to --d_p--.

Column 12, line 11, change "capicity" to --capacity--.

Column 14, line 50, change "section" to --second--;

line 55, change "permunation" to --permutation--.

Column 15, line 41, change "and" to --through--.

Column 16, line 30, change "ist" to --list--.

Column 19, line 43, change "regerds" to --regards--.

Column 21, line 23, change equation no. "(6)" to --(5)--.

Column 23, line 4, change "T" (second occurrence) to --T_d--.

Column 24, line 35, delete "and" (first occurrence)

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It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 26, line 19, change "proximade" to --proximate--;
line 60, after "rendered" insert --empty--.
Column 32, line 57, change "As" to --At--.
Column 36, line 42, change "field" to --fields--;
line 53, change "carried" to --carries--.
Column 38, line 20, change "dceision" to --decision--.

Signed and Sealed this

Tenth Day of May, 1988

Attest:

Attesting Officer

DONALD J. QUIGG

Commissioner of Patents and Trademarks