EXHIBIT 4.06

region, said outer region extending inward from outer edges of said sensing plane and said outer region having a first portion in an X plane and a second portion in a Y plane;

simultaneously developing a first set of signals proportional to the value of said capacitance for each of said row conductive lines when no object is located proximate to said sensing plane;

simultaneously developing a second set of signals proportional to the value of said capacitance for each of said column conductive lines when no object is located proximate to said sensing plane;

simultaneously developing a third set of signals proportional to the value of said capacitance for each of said row conductive lines when an object is located proximate to said sensing plane;

simultaneously developing a fourth set of signals proportional to the value of said capacitance for each of said column conductive lines when said object is located proximate to said sensing plane;

computing a first weighted average of the difference between said first set of signals and said third set of signals to generate a present-position signal in the X direction of said sensing plane; and

computing a second weighted average of the difference between said second set of signals and said fourth set of signals generate a present-position signal in the Y direction of said sensing plane;

generating first relative position X and Y signals representing the difference between said present-position signals in both X and Y directions and a previous set of present-position signals in both X and Y directions, and sending said first relative position X and Y signals to said computer if said object is not in said outer region of said sensing plane, and;

generating a second relative position X signal representing the difference between said X coordinate of said present position of said object and an X coordinate of a fixed position on said sensing plane if said object is in said second portion of said outer region of said sensing plane, and sending said second relative position X signal to said computer so long as said object is in said second portion of said outer region of said sensing plane;

generating a second relative position Y signal representing the difference between said X coordinate of said present position of said object and a Y coordinate of a fixed position on said sensing plane if said object is in said first portion of said outer region of said sensing plane, and sending said second relative position Y signal to said computer so long as said object is in said first portion of said outer region of said sensing plane.

15. The method of claim 14 wherein said fixed position on said sensing plane is the geometric center of said sensing plane.

16. The method of claim 14, wherein the steps of simultaneously developing said first, second, third, and fourth sets of signals includes the steps of:

placing a first known voltage on said row conductive lines;

discharging said row conductive lines for a fixed time at a fixed current;

measuring and storing a first set of row conductive line resultant voltages across said row conductive lines;

placing a second known voltage on said row conductive lines;

charging said row conductive lines for said fixed time at said fixed current;

measuring and storing a second set of row conductive line resultant voltages across said row conductive lines;

averaging corresponding ones of said first and second sets of row conductive line resultant voltages;

placing a first known voltage on said column conductive lines;

discharging said column conductive lines for a fixed time at a fixed current;

measuring and storing a first set of column conductive line resultant voltages across said column conductive lines;

placing a second known voltage on said column conductive lines;

charging said column conductive lines for said fixed time at said fixed current;

measuring and storing a second set of column conductive line resultant voltages across said column conductive lines; and

averaging corresponding ones of said first and second sets of column conductive line resultant voltages.

17. The method of claim 14 wherein the steps of computing said first and second weighted averages comprises the steps of:

computing a sum and a weighted sum of said first set of signals;

computing a sum and a weighted sum of said second set of signals;

computing a sum and a weighted sum of said third set of signals;

computing a sum and a weighted sum of said fourth set of signals;

computing a row numerator by subtracting said weighted sum of said first set of signals from said weighted sum of said third set of signals;

computing a row denominator by subtracting said sum of said second set of signals from said sum of said fourth set of signals;

dividing said row numerator by said row denominator to derive a row position signal representing the position of said object in a row dimension;

computing a column numerator by subtracting said weighted sum of said second set of signals from said weighted sum of said second set of signals;

computing a column denominator by subtracting said sum of said second set of signals from said sum of said second set of signals; and

dividing said column numerator by said column denominator to derive a column position signal representing the position of said object in a column dimension.

18. The method of claim 17 including the further steps of:

storing said sum and said weighted sum of said first and third set of signals as a stored sum and a stored weighted sum of said second and fourth sets of signals; and

using said stored sum and said stored weighted sum in computing subsequent ones of said row numerators and denominators and said column numerators and denominators

using said stored sum and a stored weighted sum for providing an electrical signal representative of a subsequent position of said object in said two dimensional plane.

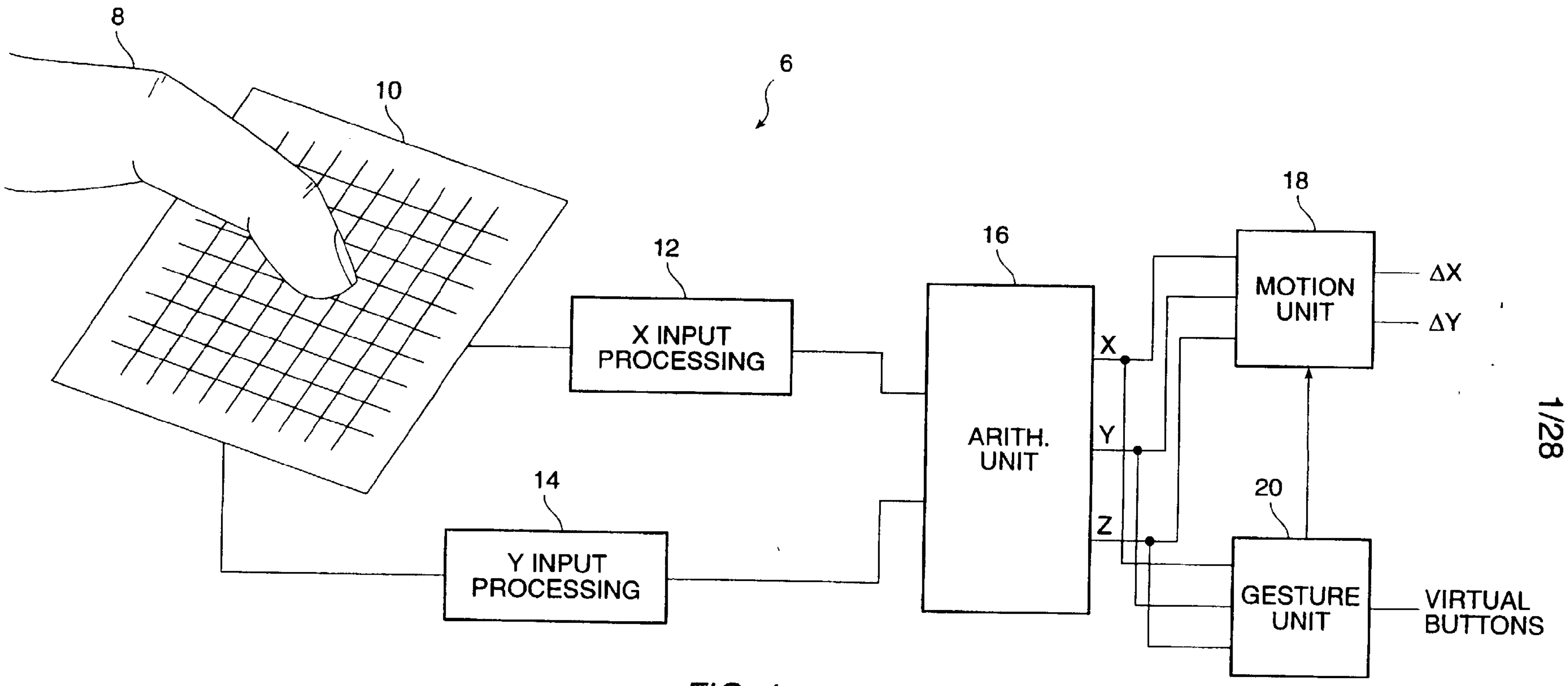
8
6
10
12
X INPUT PROCESSING
14
Y INPUT PROCESSING
16
ARITH. UNIT
X
Y
Z
18
MOTION UNIT
ΔX
ΔY
20
GESTURE UNIT
VIRTUAL BUTTONS

FIG. 1

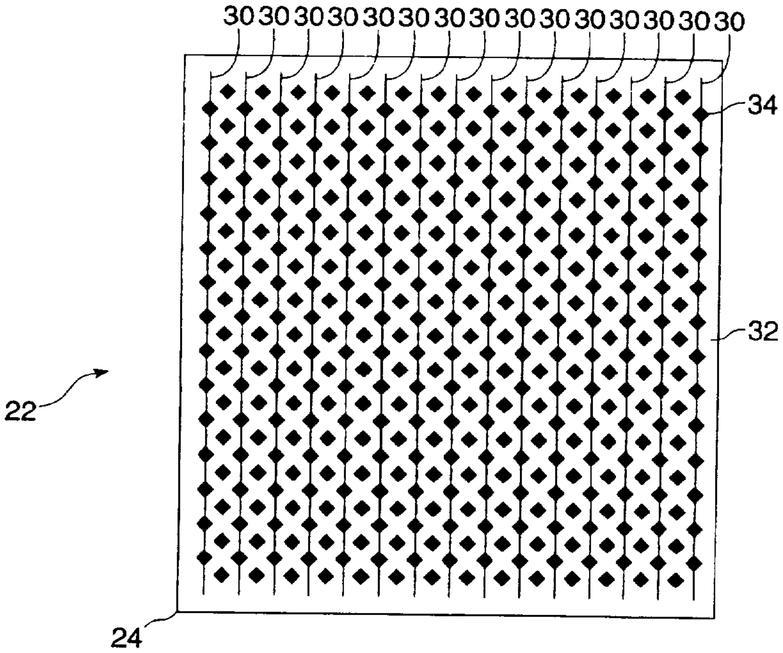
30
30
30
30
30
30
30
30
30
30
30
30
30
30
30
34
32
22
24

FIG. 2A

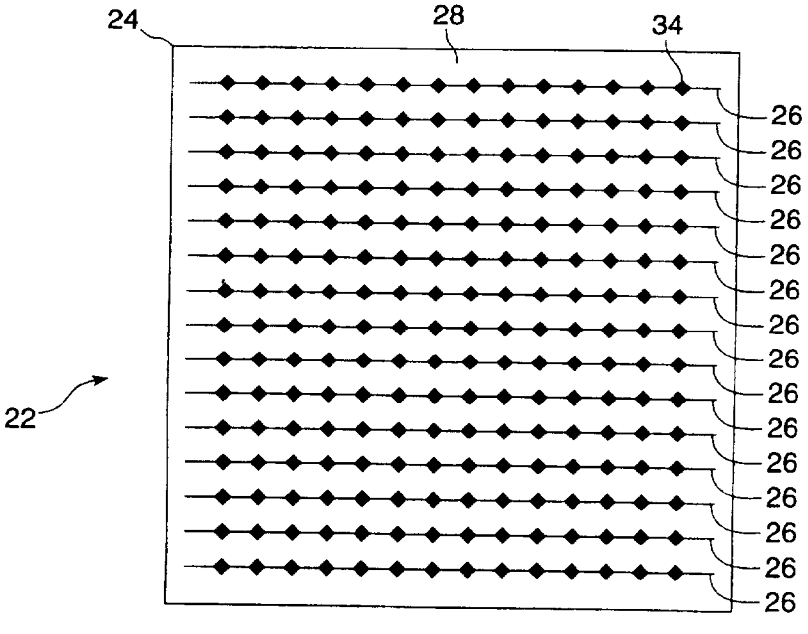
24
28
34
26
26
26
26
26
26
26
26
26
26
26
26
26
26
26
26
22

FIG. 2B

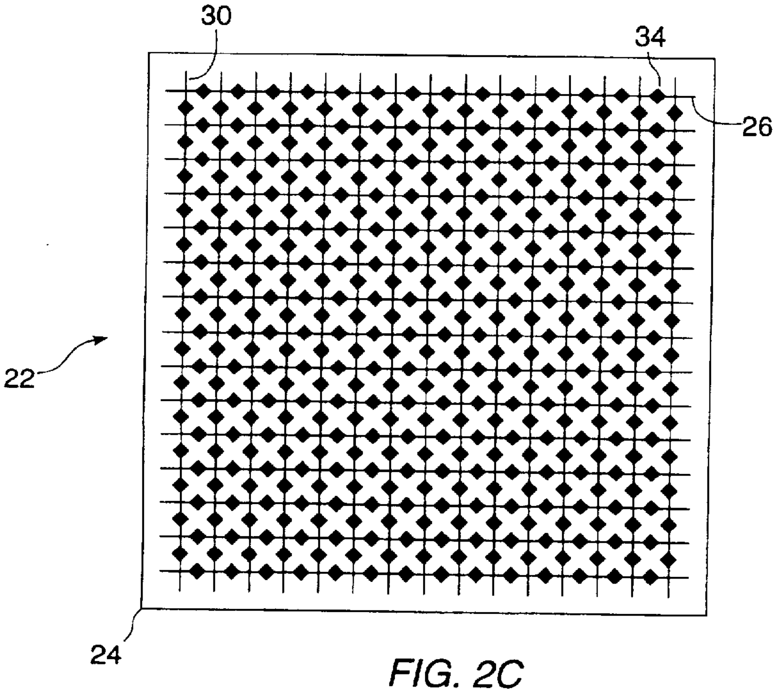

FIG. 2C

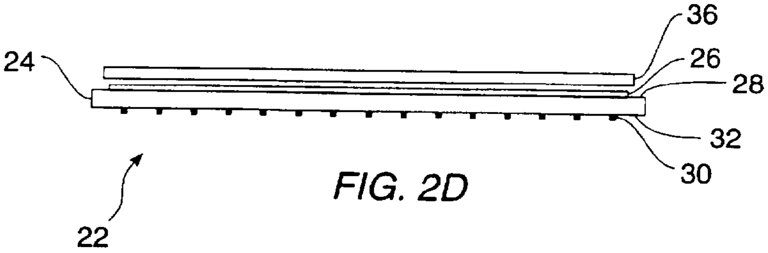

FIG. 2D

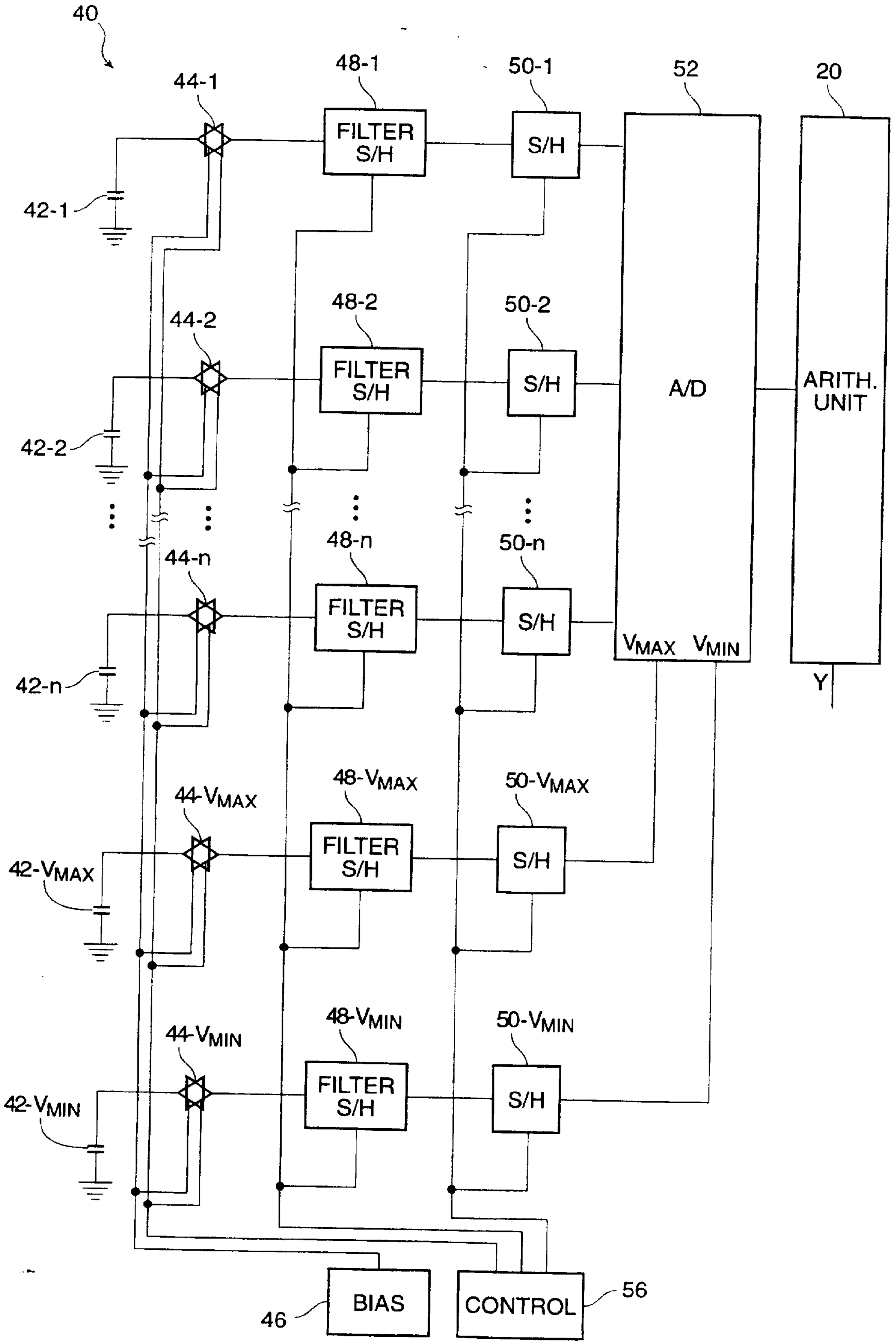
40
44-1
48-1
FILTER S/H
50-1
S/H
52
20
42-1
44-2
48-2
FILTER S/H
50-2
S/H
A/D
ARITH. UNIT
42-2
44-n
48-n
FILTER S/H
50-n
S/H
42-n
VMAX
VMIN
Y
44-VMAX
48-VMAX
FILTER S/H
50-VMAX
S/H
42-VMAX
44-VMIN
48-VMIN
FILTER S/H
50-VMIN
S/H
42-VMIN
BIAS
46
CONTROL
56

FIG. 3

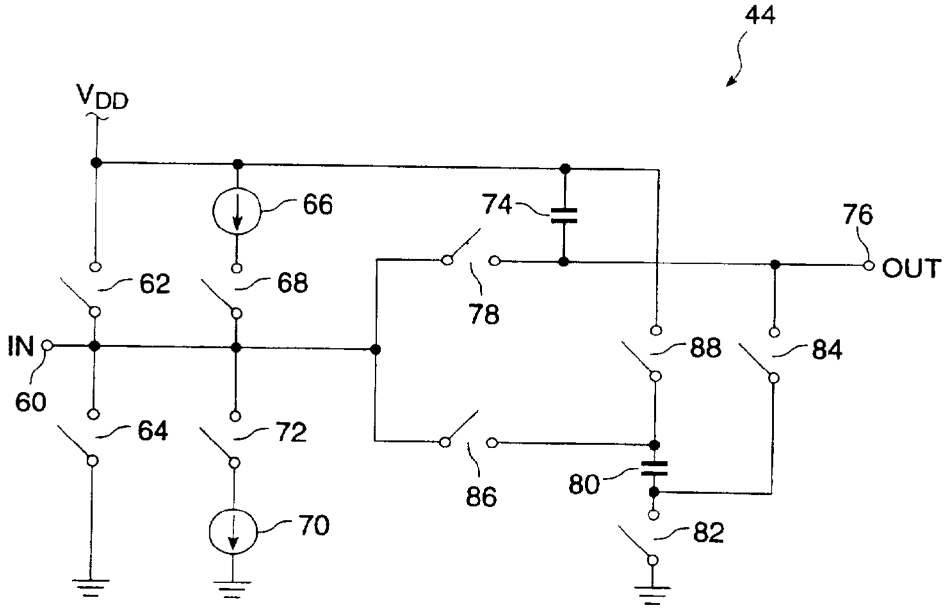
44
VDD
66
74
76
OUT
62
68
78
IN
88
84
60
64
72
86
80
70
82

FIG. 4A

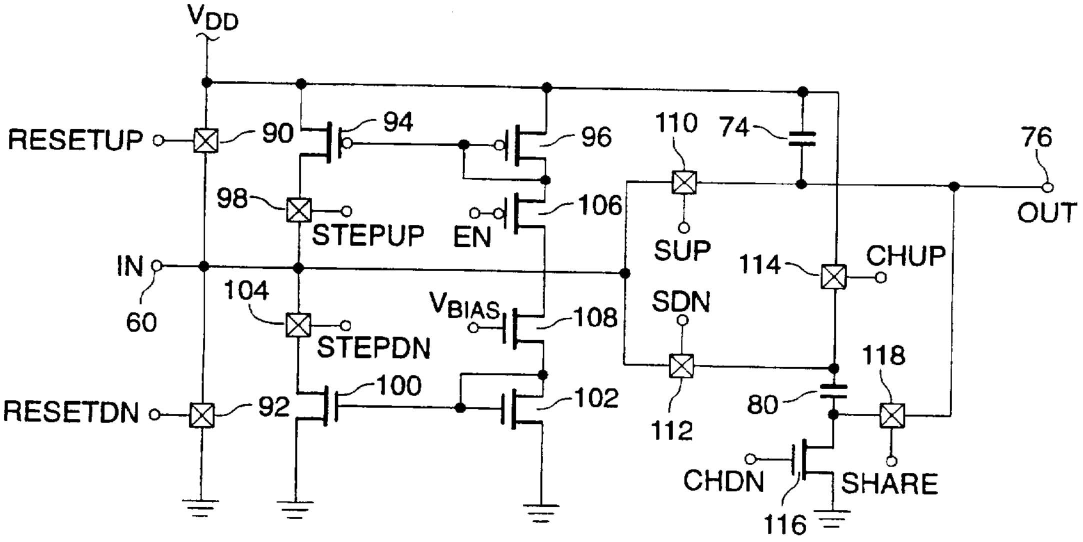
VDD
RESETUP
90
94
96
110
74
76
98
STEPUP
106
EN
SUP
OUT
IN
114
CHUP
60
104
VBIAS
108
SDN
STEPDN
118
100
RESETDN
92
102
112
80
CHDN
SHARE
116

FIG. 4B

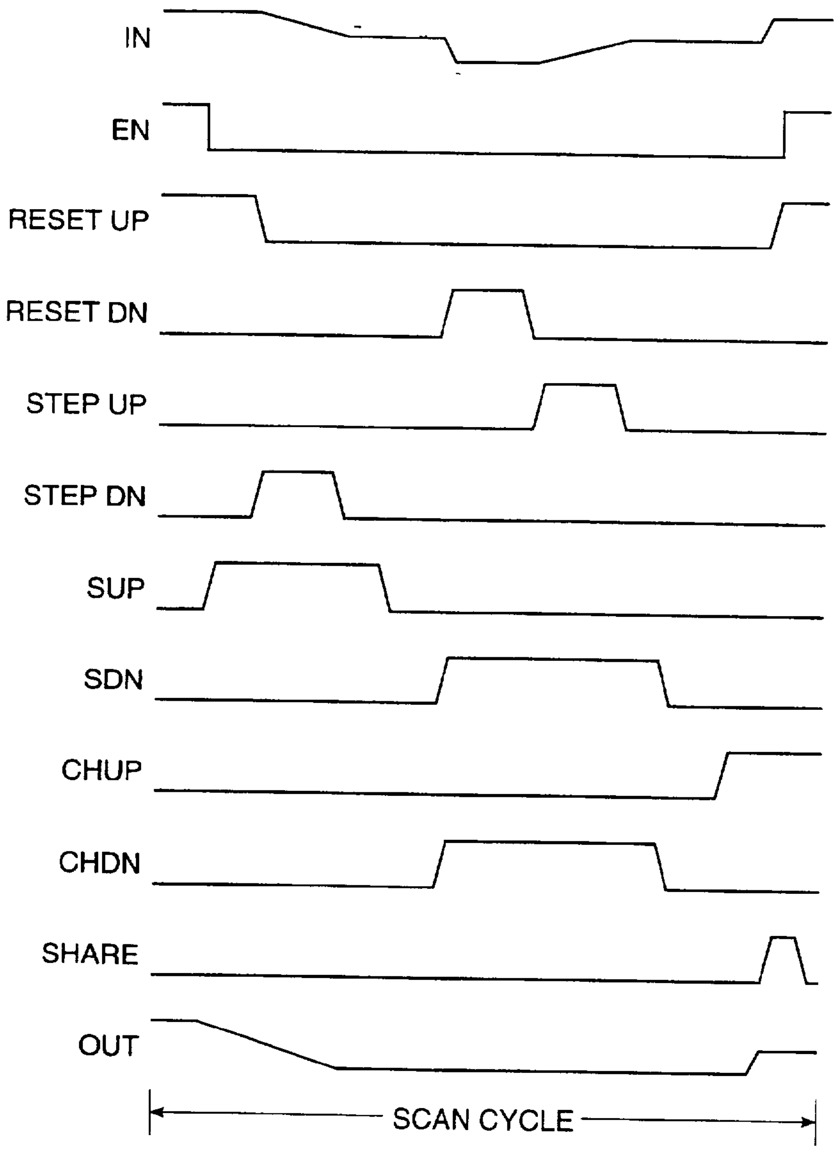
IN
EN
RESET UP
RESET DN
STEP UP
STEP DN
SUP
SDN
CHUP
CHDN
SHARE
OUT
SCAN CYCLE

FIG. 5

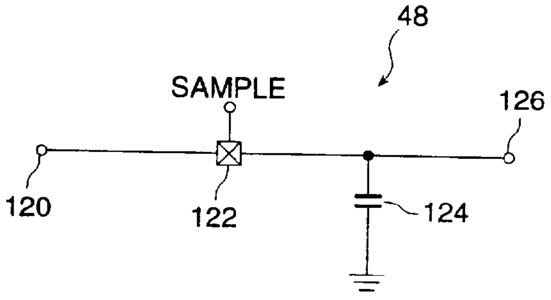
48
SAMPLE
126
120
122
124

FIG. 6

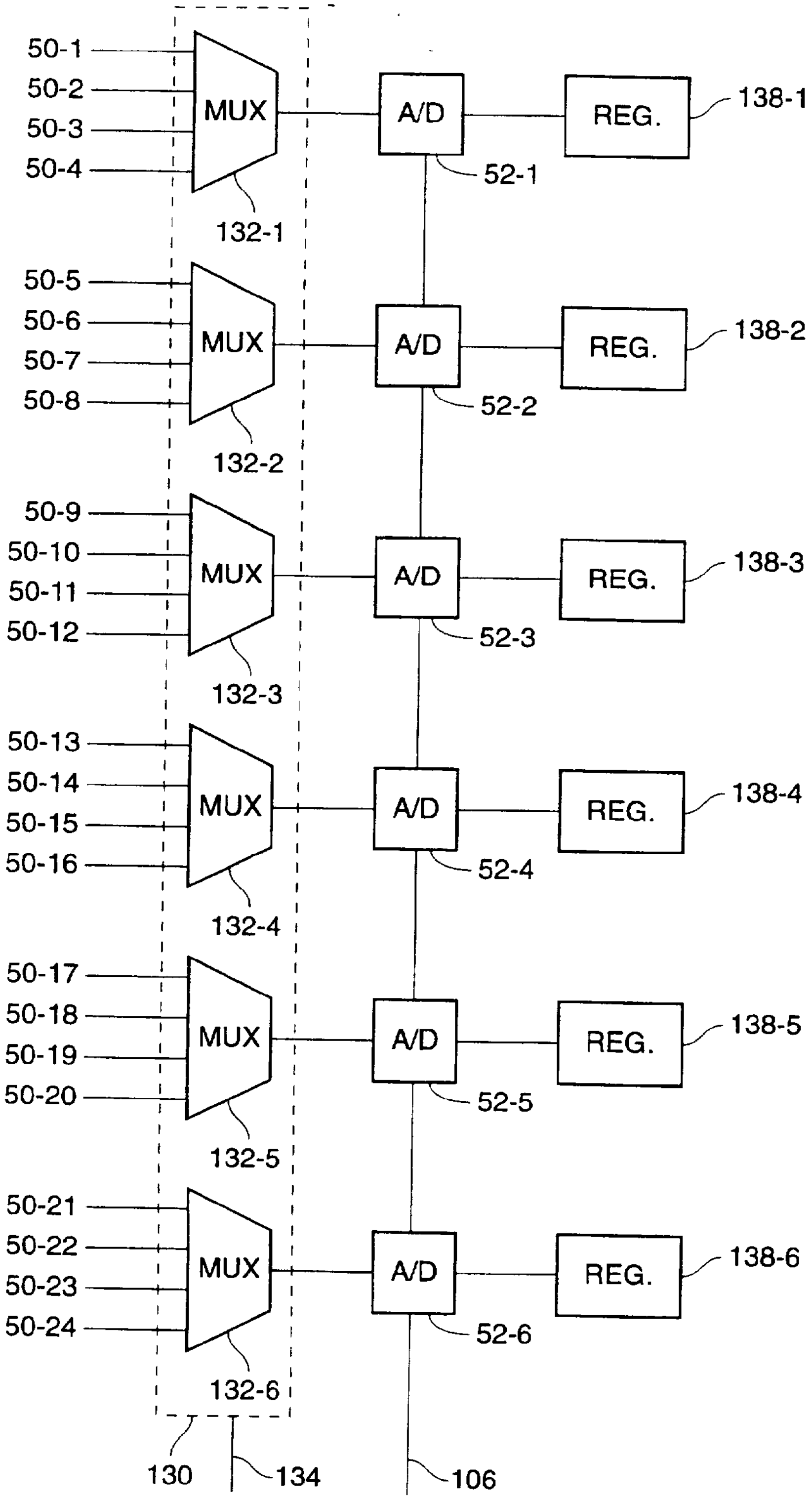
50-1
50-2
50-3
50-4
MUX
132-1
A/D
52-1
REG.
138-1
50-5
50-6
50-7
50-8
MUX
132-2
A/D
52-2
REG.
138-2
50-9
50-10
50-11
50-12
MUX
132-3
A/D
52-3
REG.
138-3
50-13
50-14
50-15
50-16
MUX
132-4
A/D
52-4
REG.
138-4
50-17
50-18
50-19
50-20
MUX
132-5
A/D
52-5
REG.
138-5
50-21
50-22
50-23
50-24
MUX
132-6
A/D
52-6
REG.
138-6
130
134
106

FIG. 7

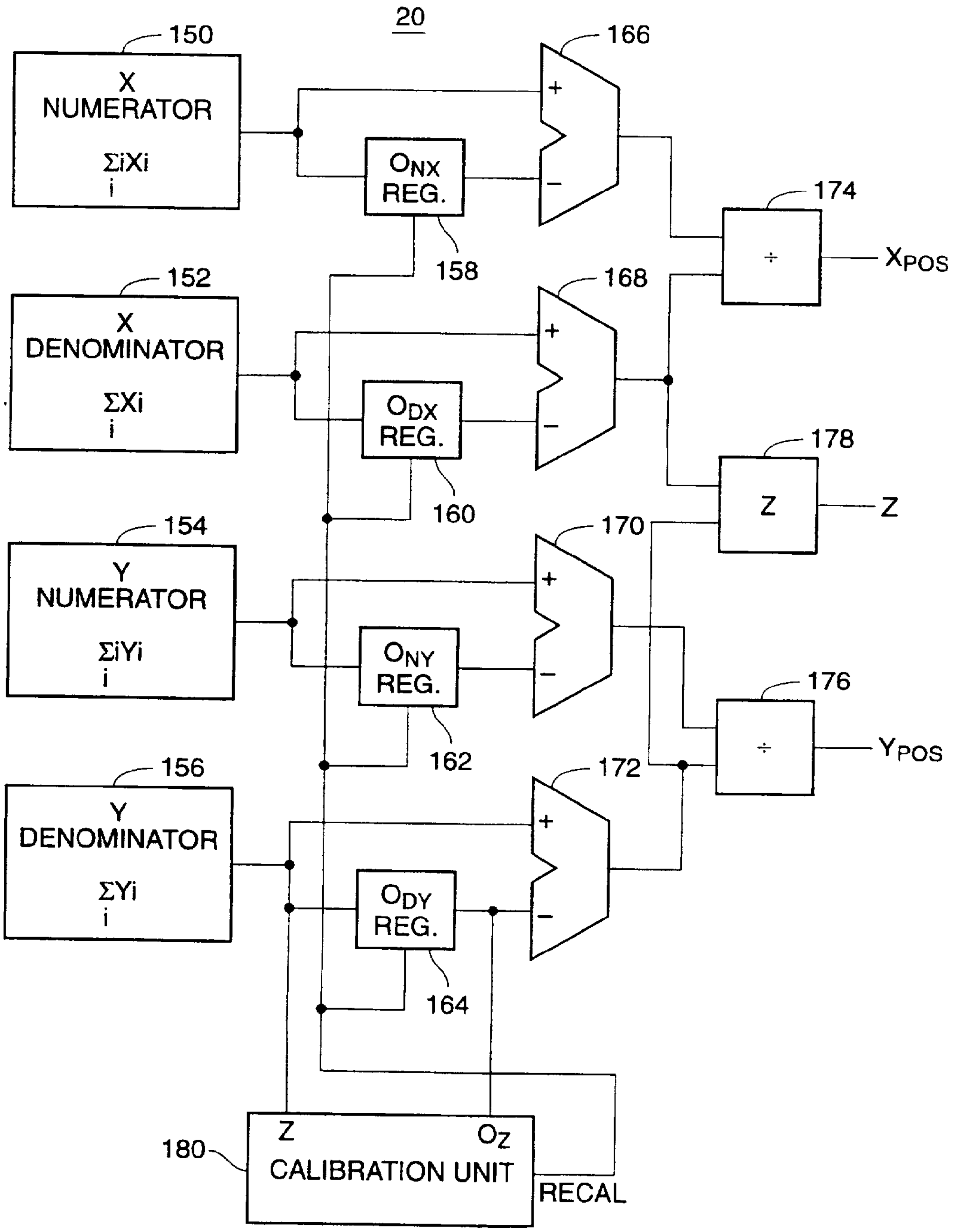
20
150
X NUMERATOR
$\sum_i iX_i$
152
X DENOMINATOR
$\sum_i X_i$
154
Y NUMERATOR
$\sum_i iY_i$
156
Y DENOMINATOR
$\sum_i Y_i$
$O_{NX}$ REG.
158
$O_{DX}$ REG.
160
$O_{NY}$ REG.
162
$O_{DY}$ REG.
164
166
168
170
172
+
−
174
÷
$X_{POS}$
178
Z
Z
176
÷
$Y_{POS}$
180
Z
$O_Z$
CALIBRATION UNIT
RECAL

FIG. 8

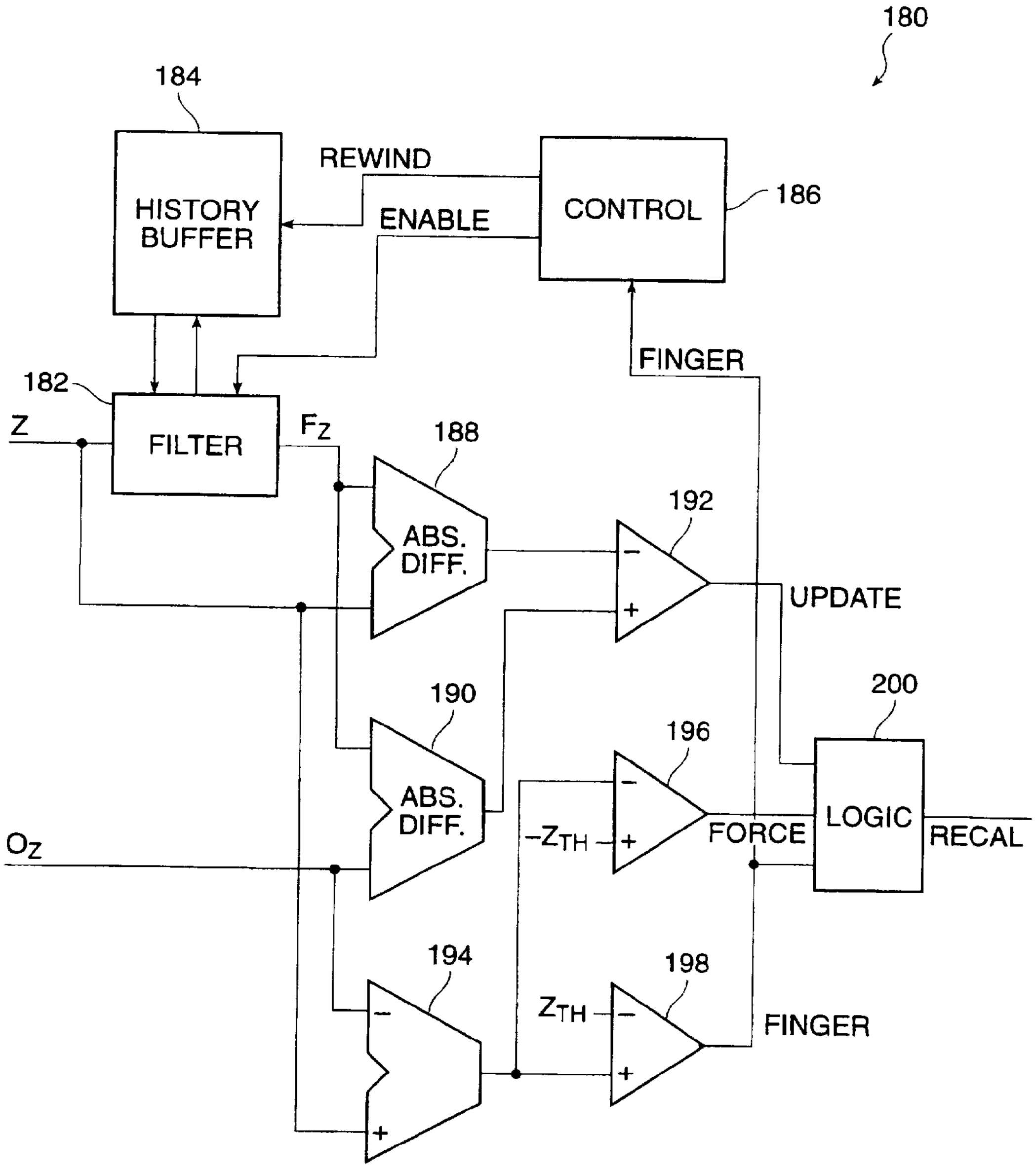
180
184
HISTORY BUFFER
REWIND
ENABLE
CONTROL
186
FINGER
182
Z
FILTER
$F_Z$
188
ABS. DIFF.
192
UPDATE
190
ABS. DIFF.
196
$O_Z$
$-Z_{TH}$
FORCE
200
LOGIC
RECAL
194
198
$Z_{TH}$
FINGER

FIG. 9

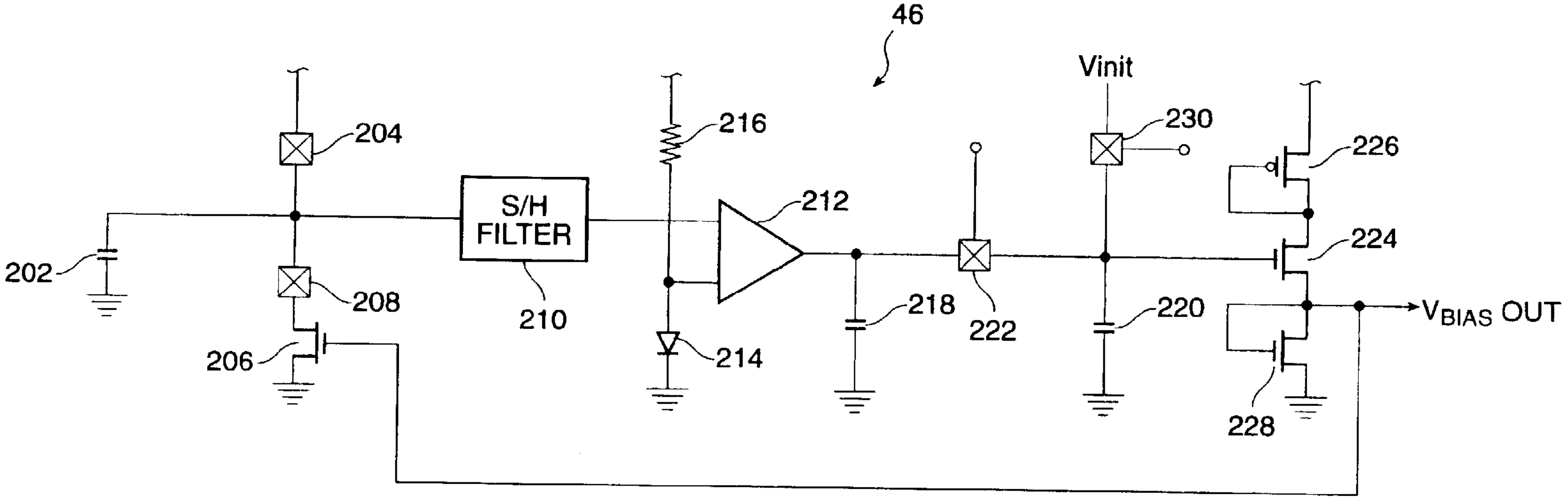
46
Vinit
204
216
230
226
212
224
S/H
FILTER
202
208
210
218
222
220
V_BIAS OUT
214
206
228

FIG. 10

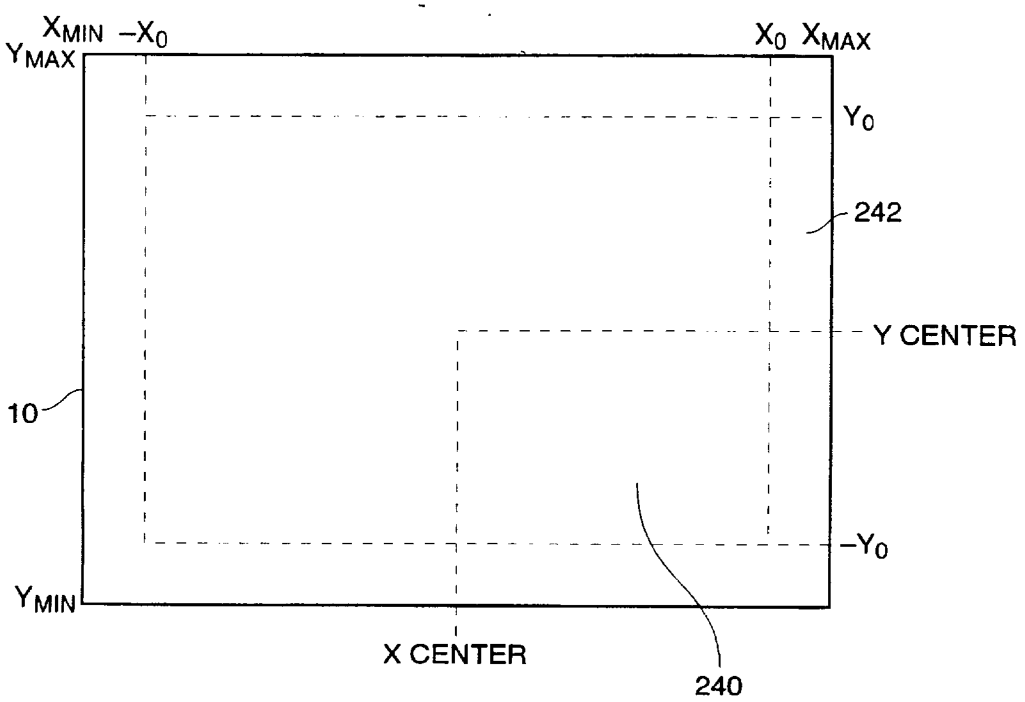

*FIG. 11*

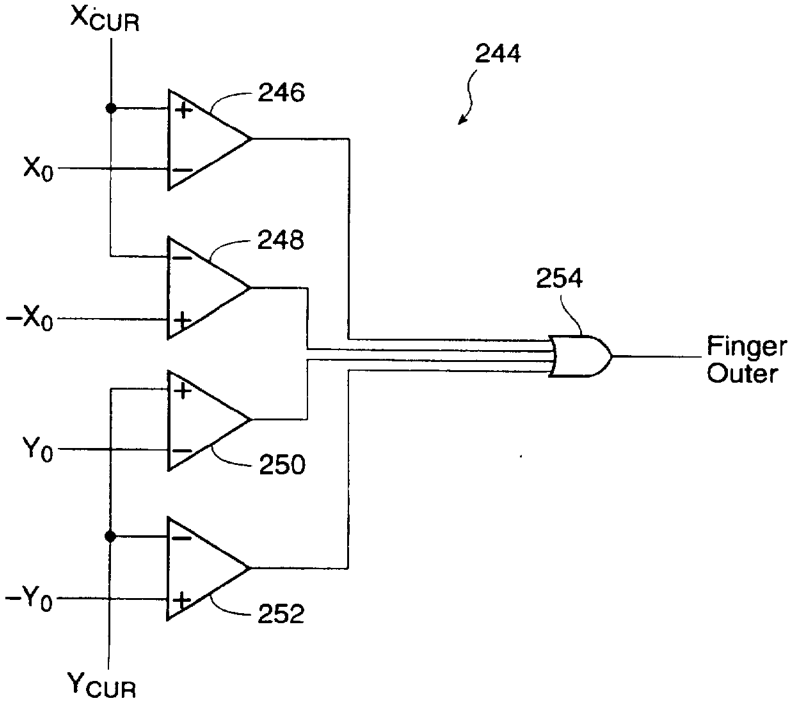

*FIG. 12A*

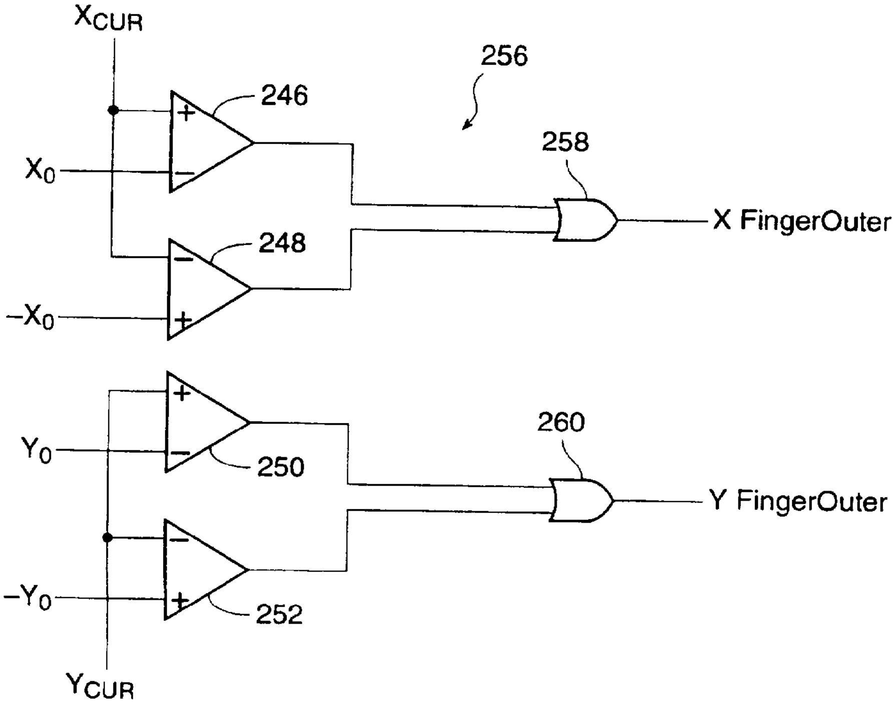
$X_{CUR}$
256
246
258
$X_0$
X FingerOuter
248
$-X_0$
260
$Y_0$
250
Y FingerOuter
$-Y_0$
252
$Y_{CUR}$

FIG. 12B

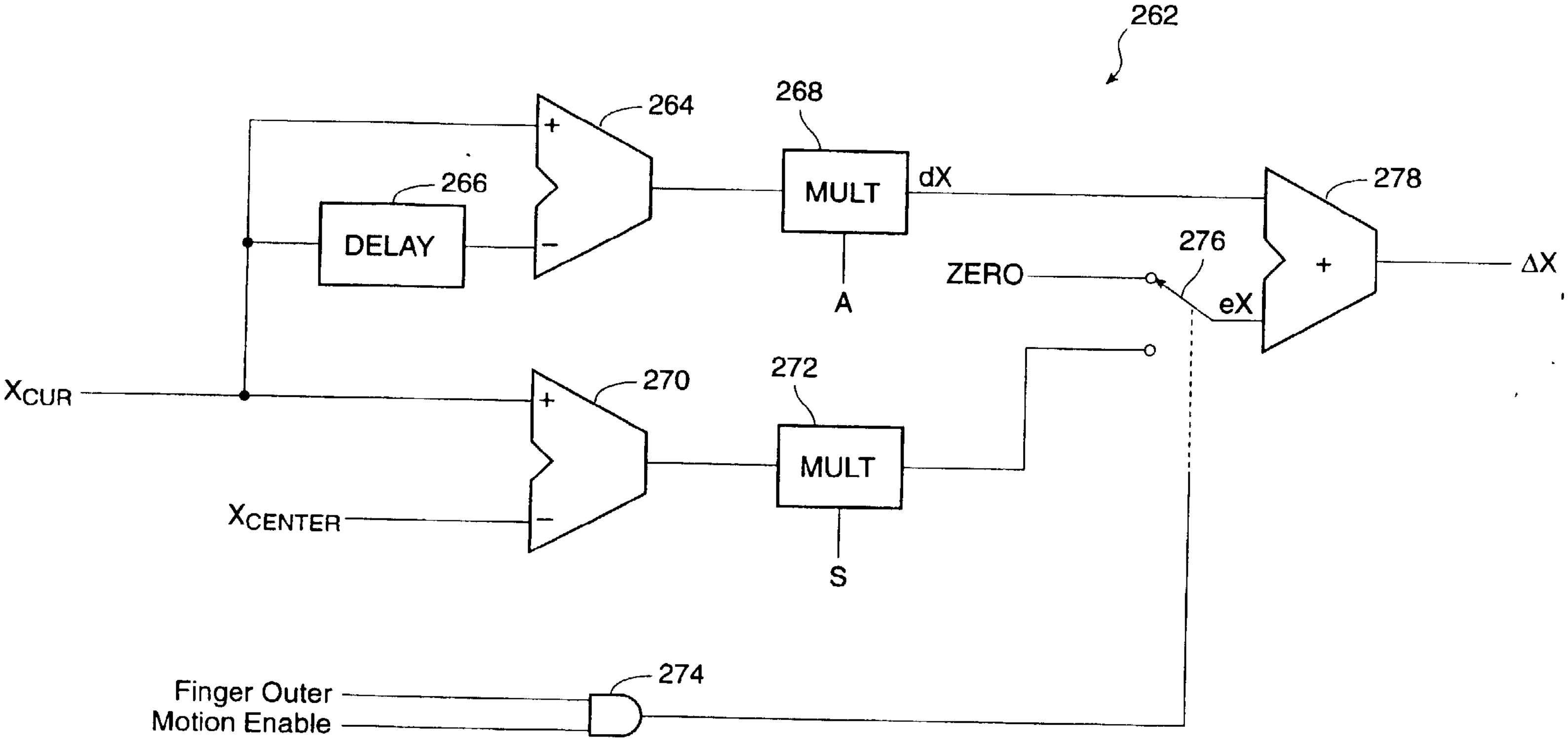
262
264
268
266
DELAY
MULT
dX
278
A
276
ZERO
eX
+
ΔX
+
−
$X_{CUR}$
270
272
+
MULT
$X_{CENTER}$
−
S
274
Finger Outer
Motion Enable

FIG. 13

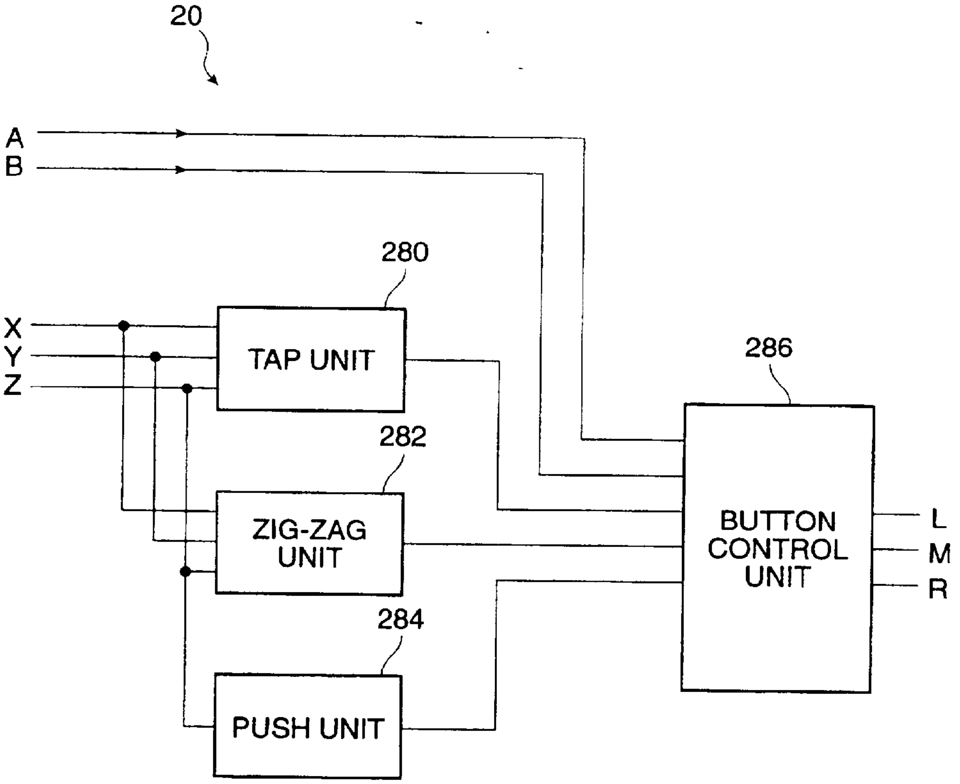

FIG. 14

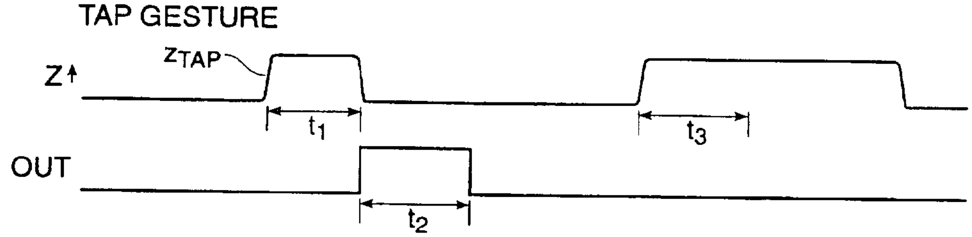

FIG. 15A

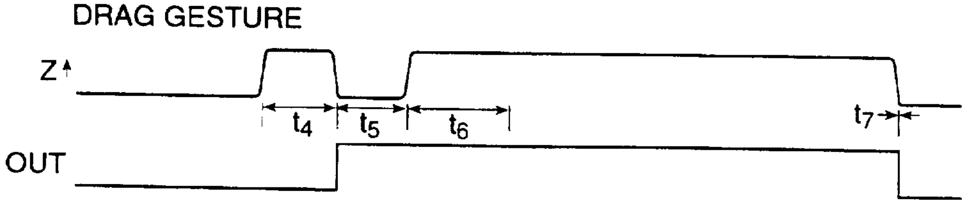

FIG. 15B

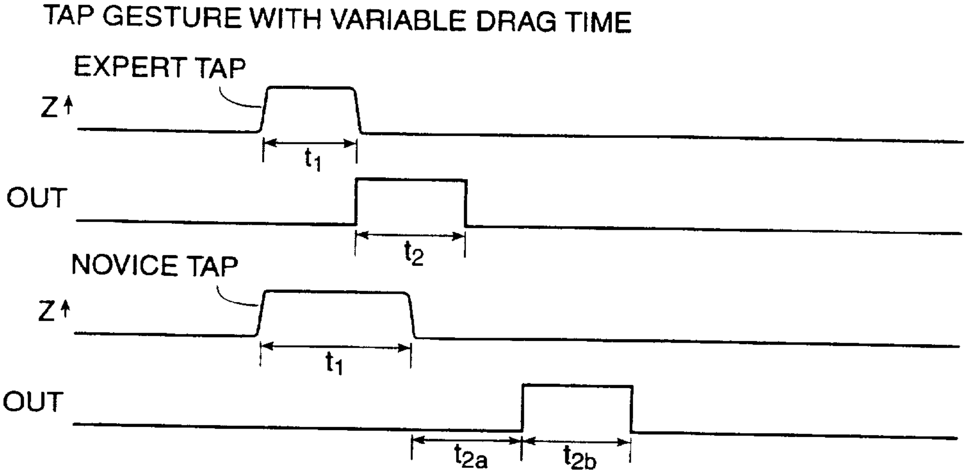

FIG. 15C

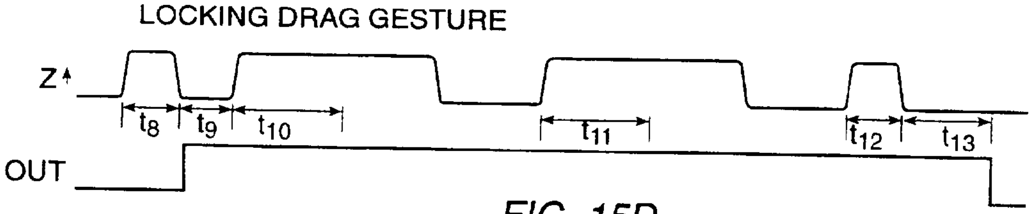

FIG. 15D

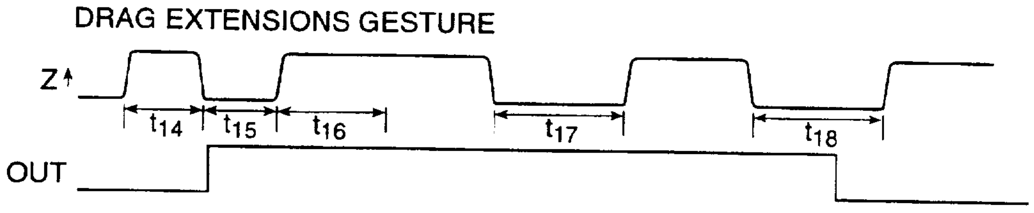

FIG. 15E

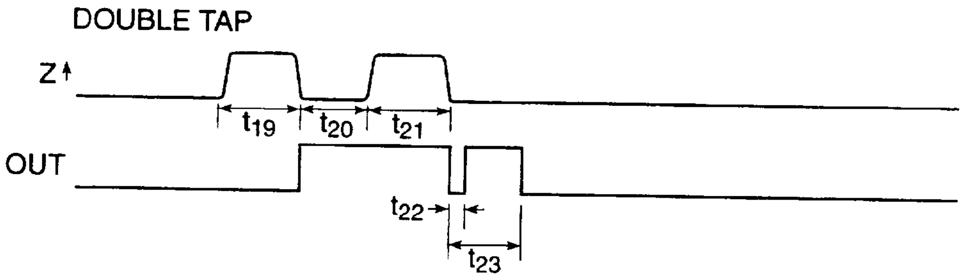

FIG. 15F

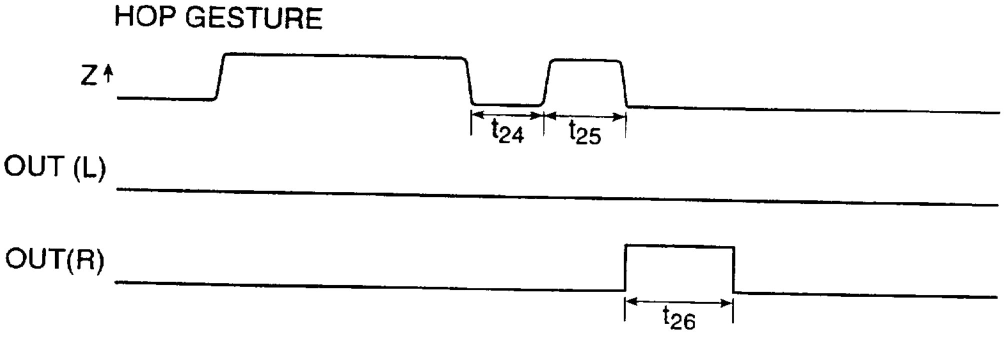

FIG. 15G

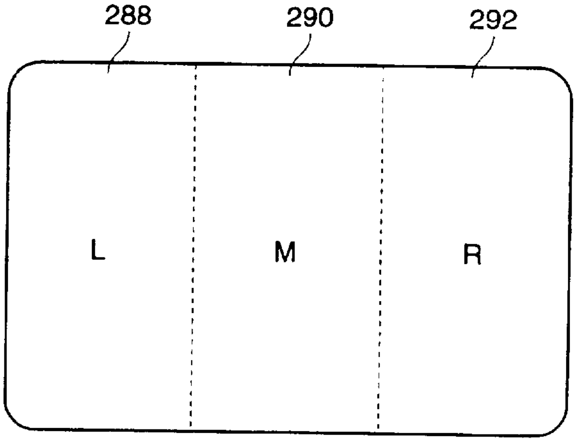

FIG. 16A

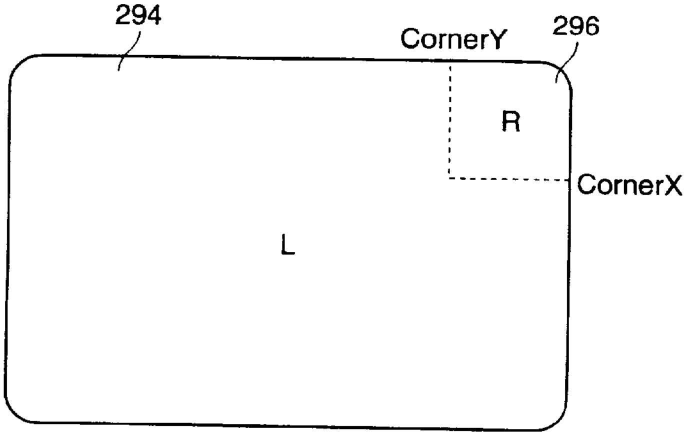

FIG. 16B

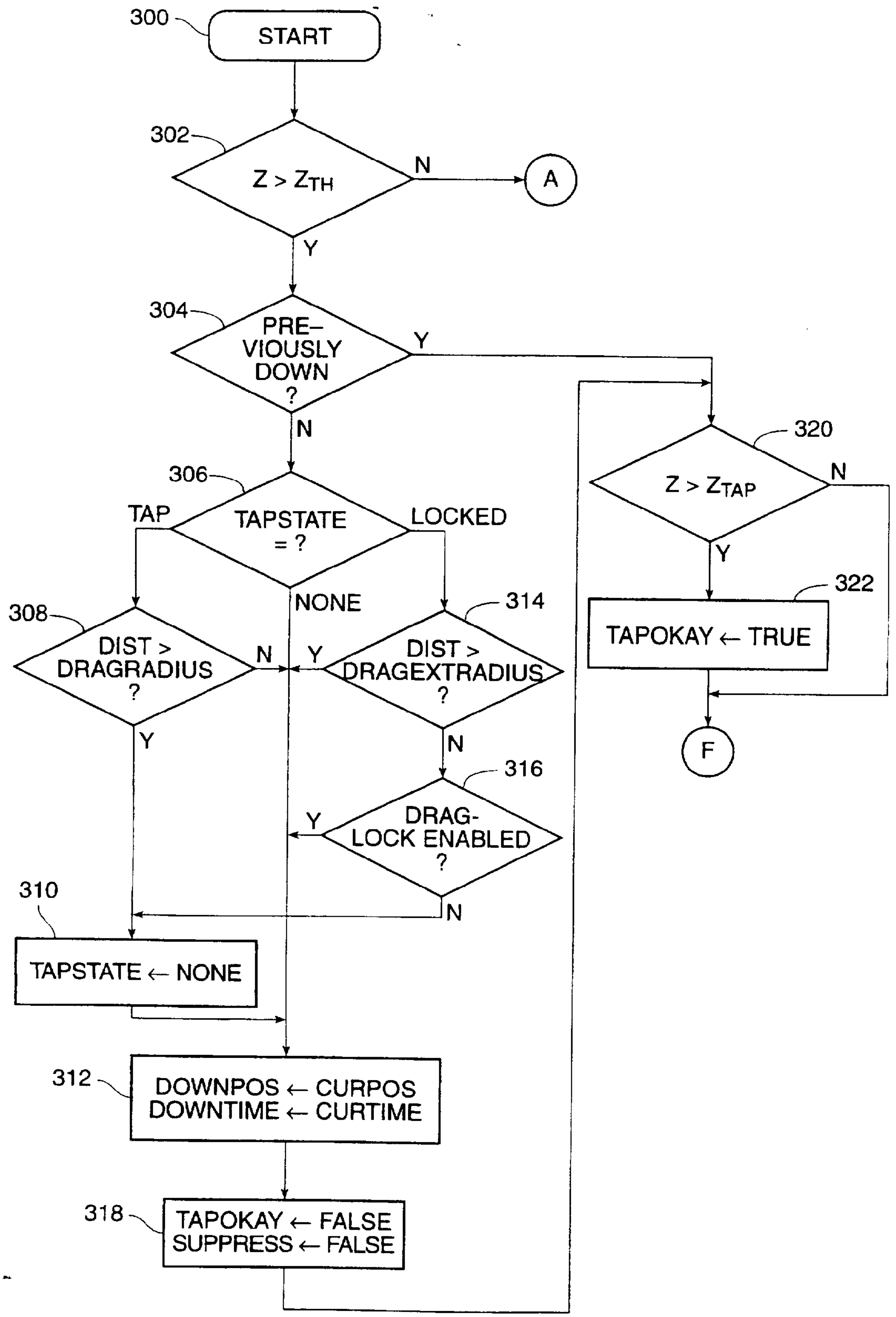
300
START
302
Z > ZTH
N
A
Y
304
PRE-VIOUSLY DOWN ?
Y
N
306
TAPSTATE = ?
TAP
LOCKED
NONE
308
DIST > DRAGRADIUS ?
N
Y
314
DIST > DRAGEXTRADIUS ?
Y
N
316
DRAG-LOCK ENABLED ?
Y
N
310
TAPSTATE ← NONE
312
DOWNPOS ← CURPOS
DOWNTIME ← CURTIME
318
TAPOKAY ← FALSE
SUPPRESS ← FALSE
320
Z > ZTAP
N
Y
322
TAPOKAY ← TRUE
F

*FIG. 17A*

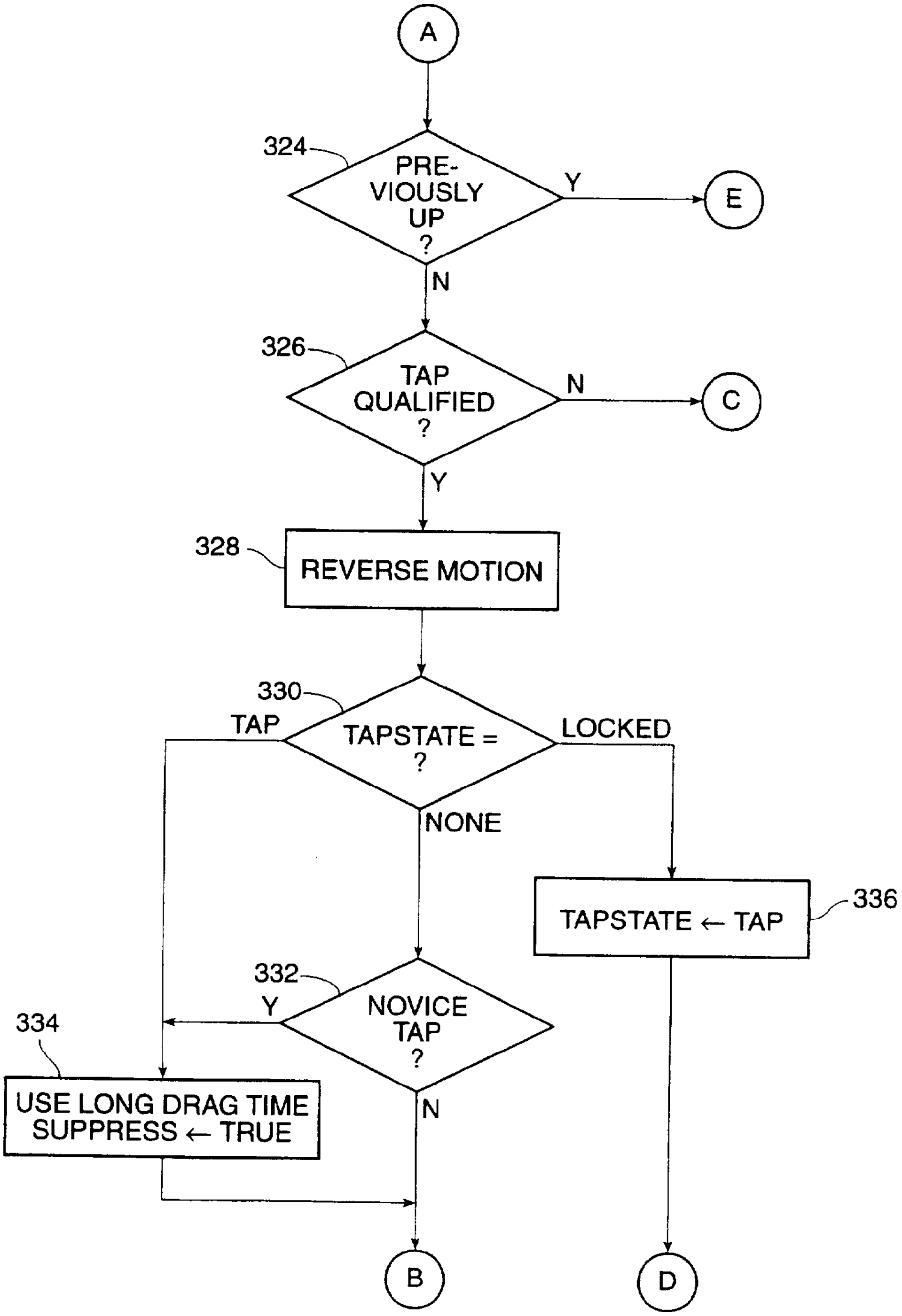
A
324
PRE-VIOUSLY UP ?
Y
E
N
326
TAP QUALIFIED ?
N
C
Y
328
REVERSE MOTION
330
TAP
TAPSTATE = ?
LOCKED
NONE
TAPSTATE ← TAP
336
332
Y
NOVICE TAP ?
334
USE LONG DRAG TIME
SUPPRESS ← TRUE
N
B
D

*FIG. 17B*

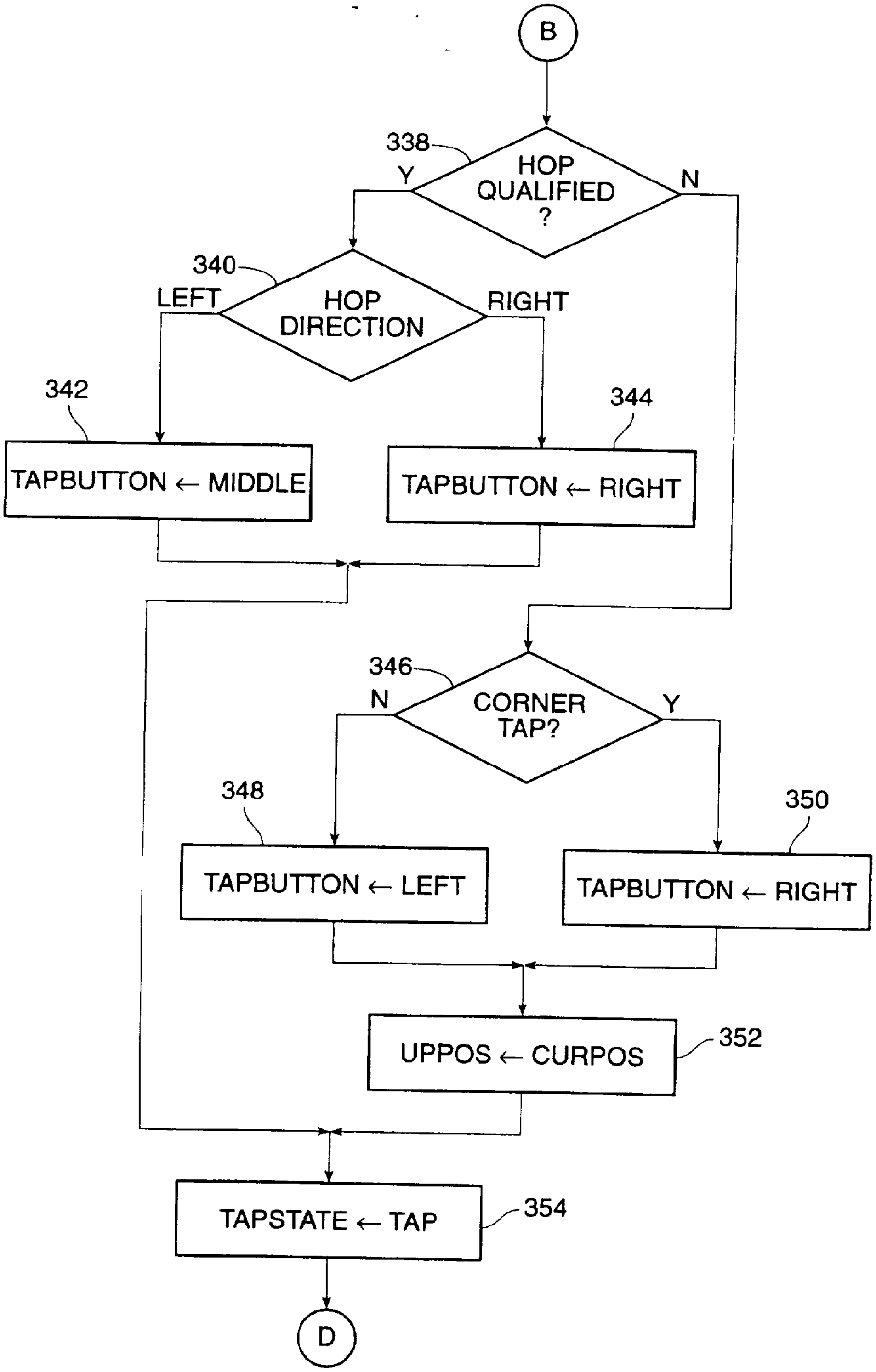
B
338
HOP QUALIFIED ?
Y
N
340
HOP DIRECTION
LEFT
RIGHT
342
TAPBUTTON ← MIDDLE
344
TAPBUTTON ← RIGHT
346
CORNER TAP?
N
Y
348
TAPBUTTON ← LEFT
350
TAPBUTTON ← RIGHT
UPPOS ← CURPOS
352
TAPSTATE ← TAP
354
D

*FIG. 17C*

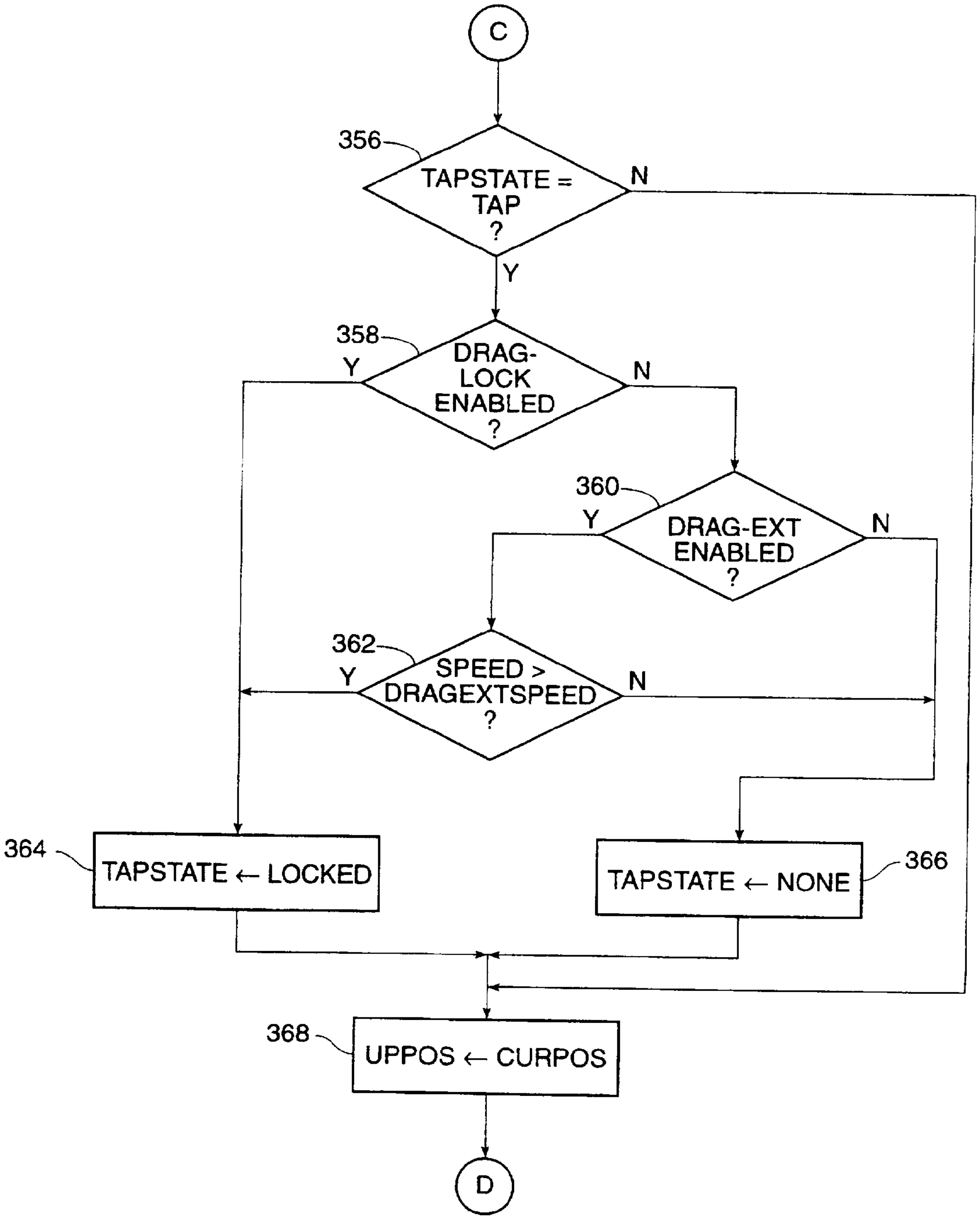
C
356
TAPSTATE = TAP ?
N
Y
358
DRAG-LOCK ENABLED ?
Y
N
360
DRAG-EXT ENABLED ?
Y
N
362
SPEED > DRAGEXTSPEED ?
Y
N
364
TAPSTATE ← LOCKED
366
TAPSTATE ← NONE
368
UPPOS ← CURPOS
D

FIG. 17D

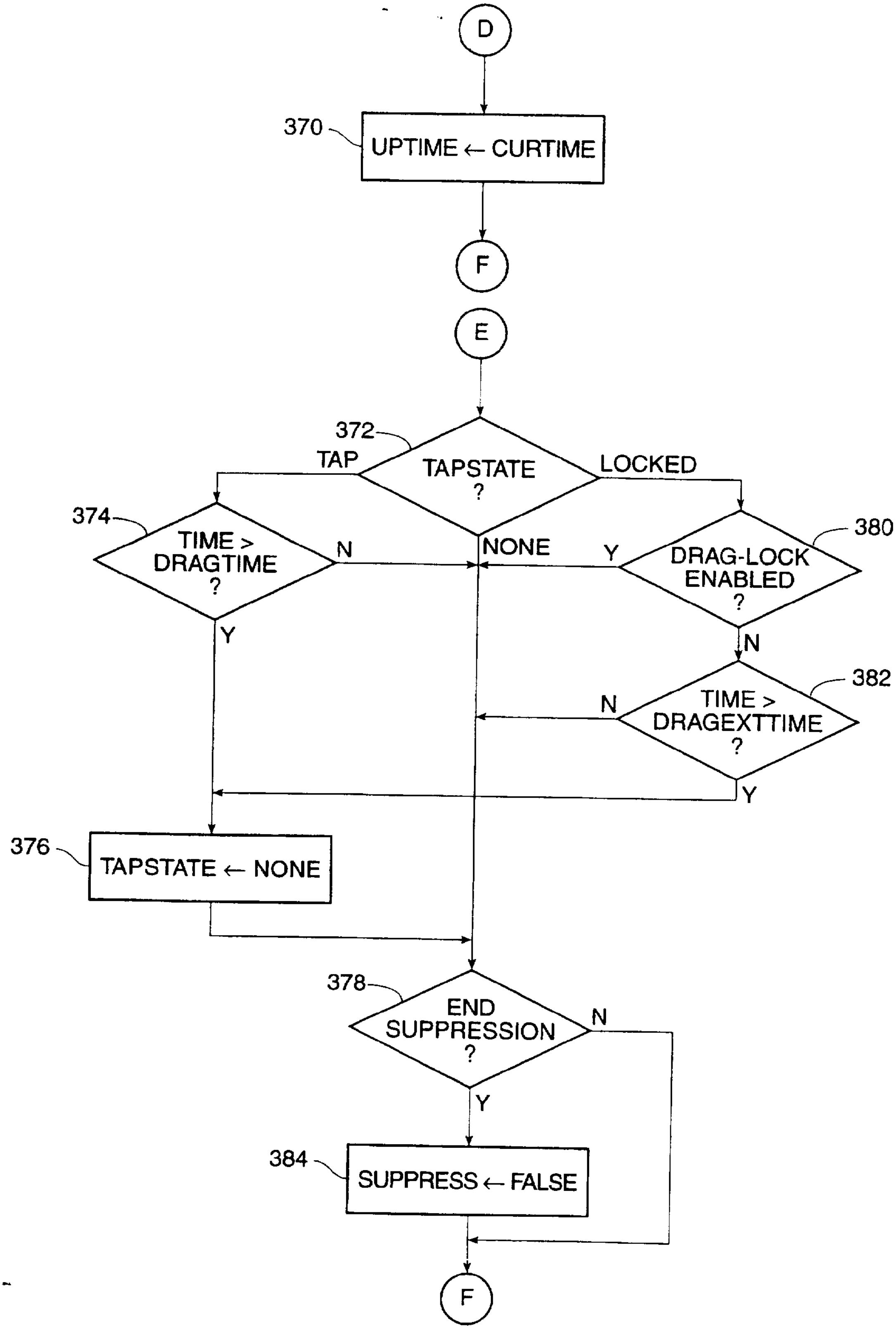
D
370
UPTIME ← CURTIME
F
E
372
TAPSTATE ?
TAP
LOCKED
NONE
374
TIME > DRAGTIME ?
N
Y
380
DRAG-LOCK ENABLED ?
Y
N
382
TIME > DRAGEXTTIME ?
N
Y
376
TAPSTATE ← NONE
378
END SUPPRESSION ?
N
Y
384
SUPPRESS ← FALSE
F

FIG. 17E

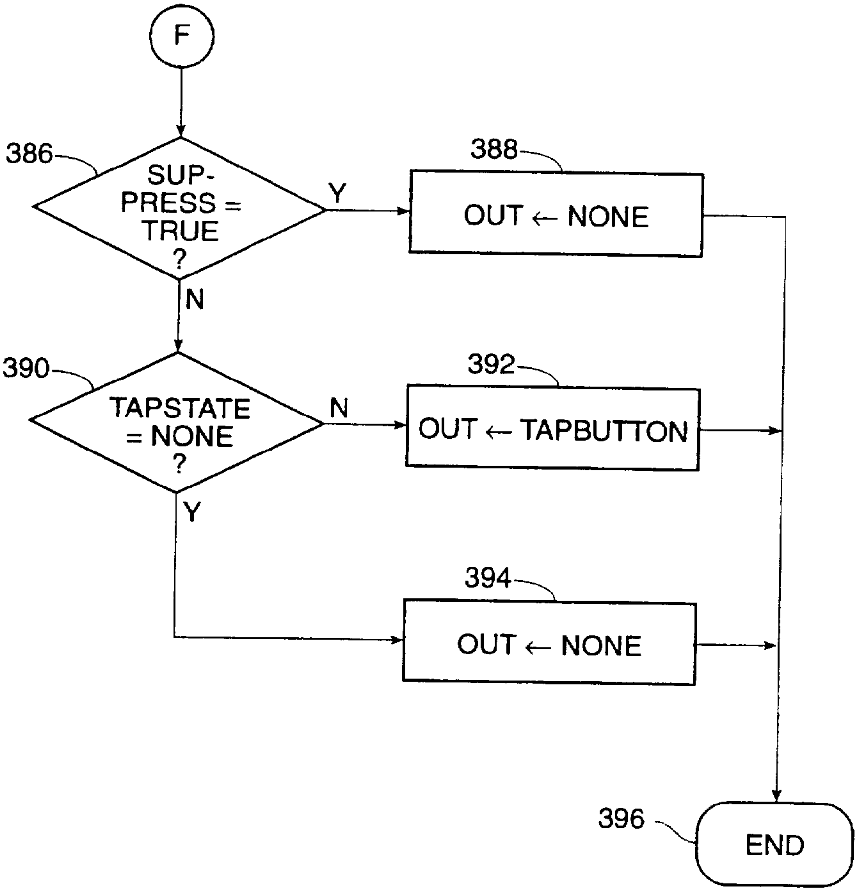
F
386
SUP-
PRESS =
TRUE
?
Y
N
388
OUT ← NONE
390
TAPSTATE
= NONE
?
N
Y
392
OUT ← TAPBUTTON
394
OUT ← NONE
396
END

FIG. 17F

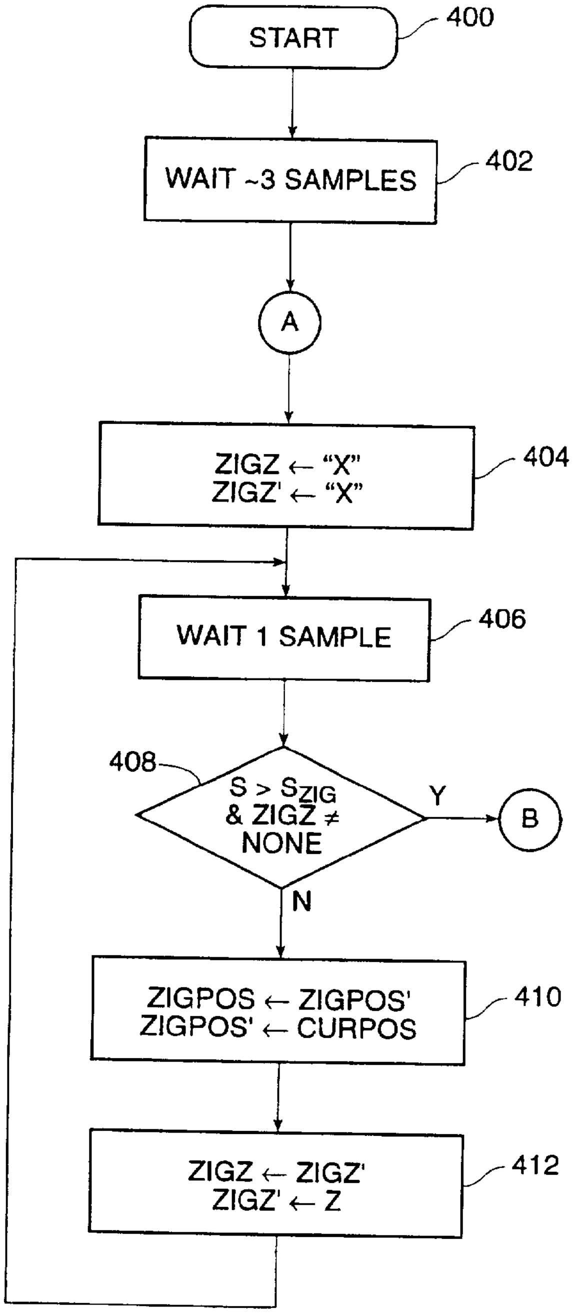
START
400
WAIT ~3 SAMPLES
402
A
ZIGZ ← "X"
ZIGZ' ← "X"
404
WAIT 1 SAMPLE
406
408
S > S_ZIG & ZIGZ ≠ NONE
Y
B
N
ZIGPOS ← ZIGPOS'
ZIGPOS' ← CURPOS
410
ZIGZ ← ZIGZ'
ZIGZ' ← Z
412

FIG. 18A

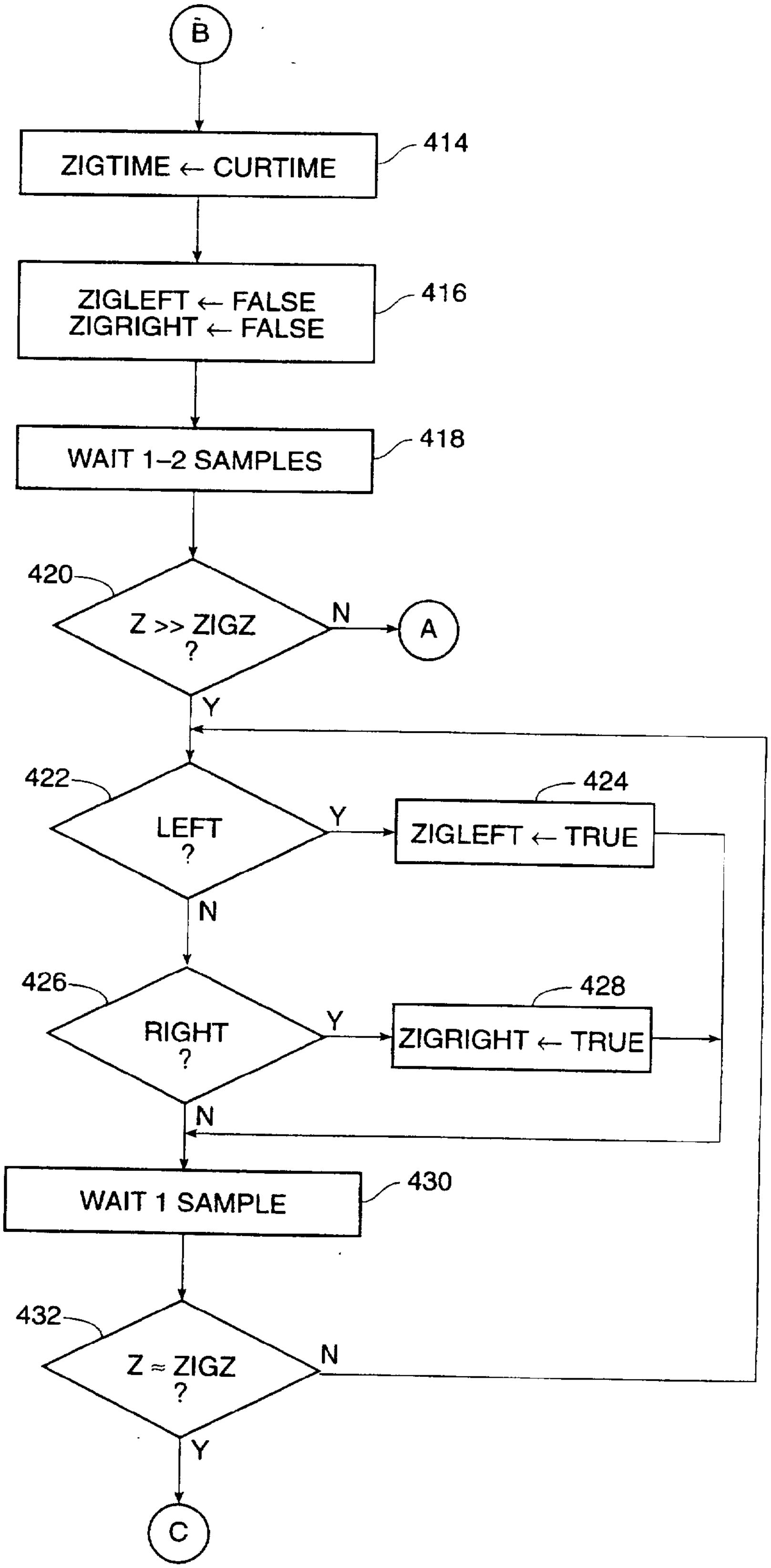
B
ZIGTIME ← CURTIME
414
ZIGLEFT ← FALSE
ZIGRIGHT ← FALSE
416
WAIT 1–2 SAMPLES
418
420
Z >> ZIGZ ?
N
A
Y
422
LEFT ?
Y
ZIGLEFT ← TRUE
424
N
426
RIGHT ?
Y
ZIGRIGHT ← TRUE
428
N
WAIT 1 SAMPLE
430
432
Z ≈ ZIGZ ?
N
Y
C

FIG. 18B

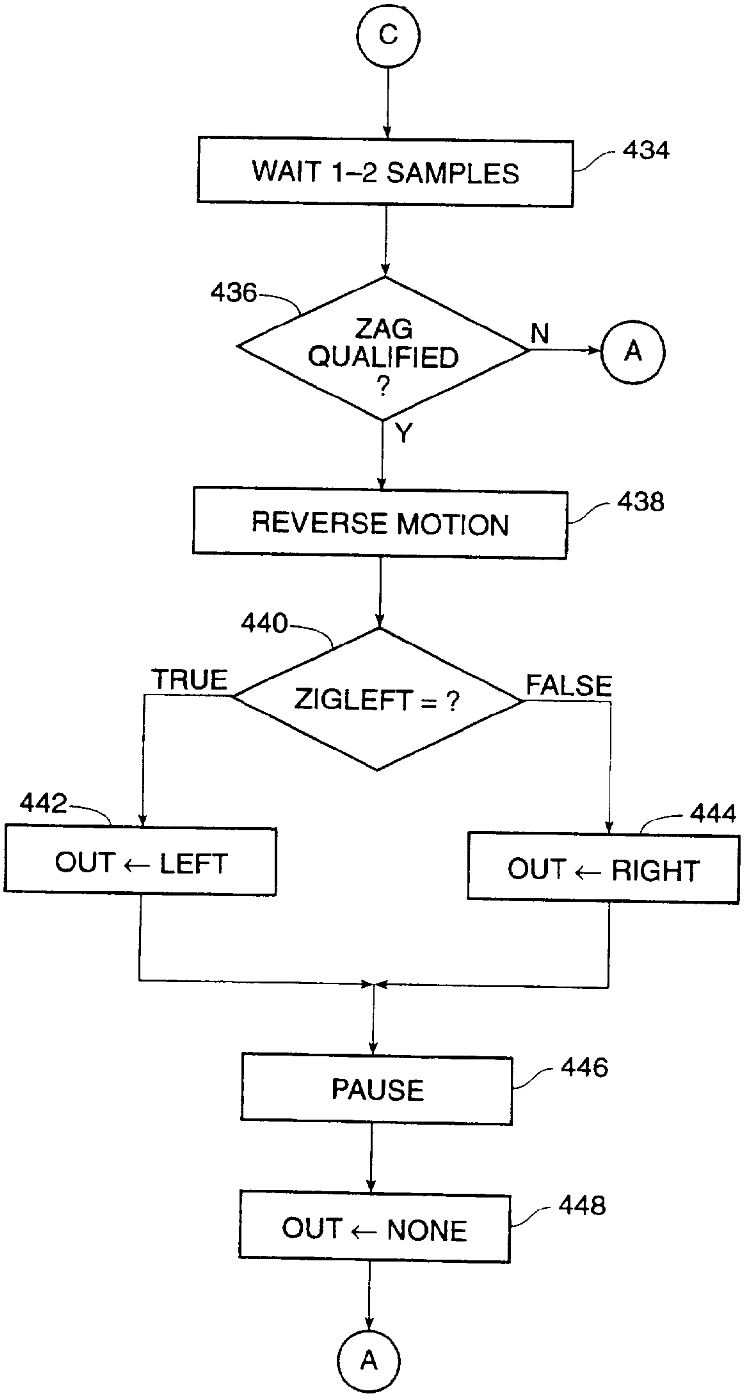
C
WAIT 1–2 SAMPLES
434
436
ZAG QUALIFIED ?
N
A
Y
REVERSE MOTION
438
440
ZIGLEFT = ?
TRUE
FALSE
442
OUT ← LEFT
444
OUT ← RIGHT
PAUSE
446
OUT ← NONE
448
A

FIG. 18C

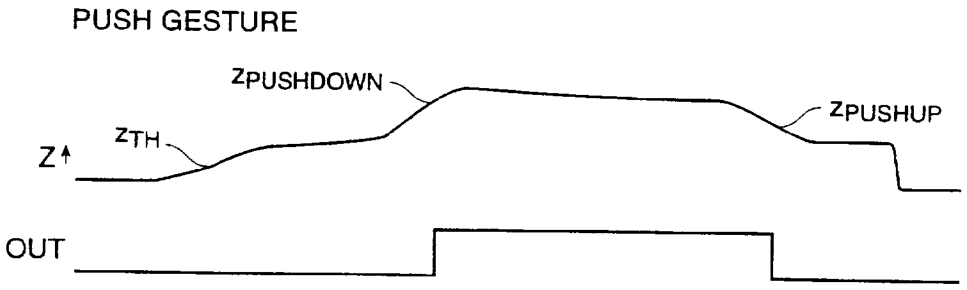
PUSH GESTURE
ZPUSHDOWN
ZTH
Z
ZPUSHUP
OUT

FIG. 19

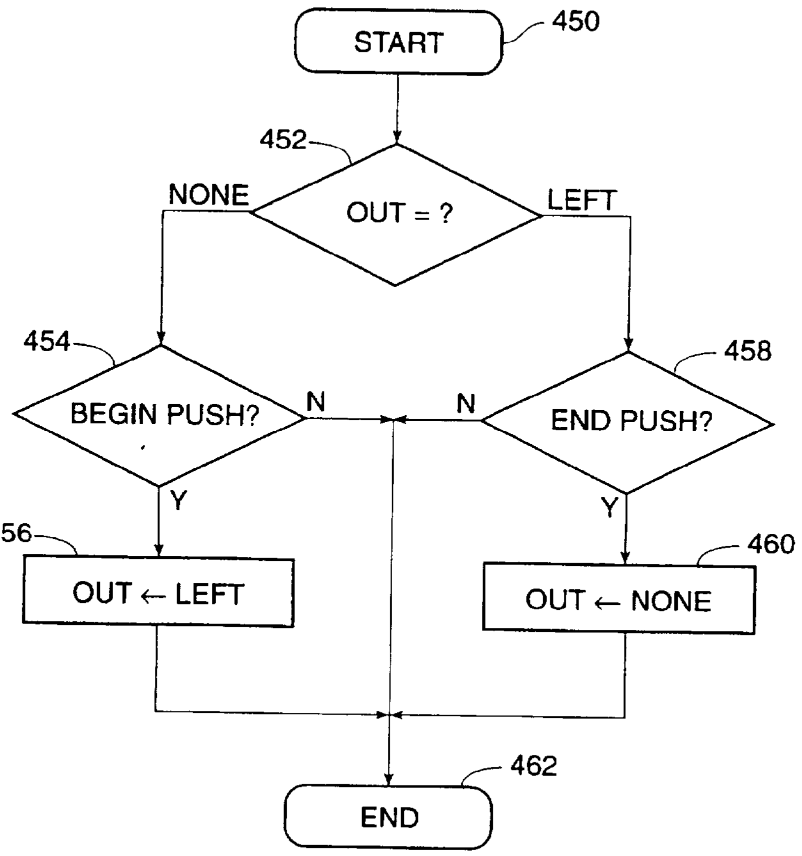
START
450
452
OUT = ?
NONE
LEFT
454
BEGIN PUSH?
N
Y
456
OUT ← LEFT
458
END PUSH?
N
Y
460
OUT ← NONE
462
END

FIG. 20

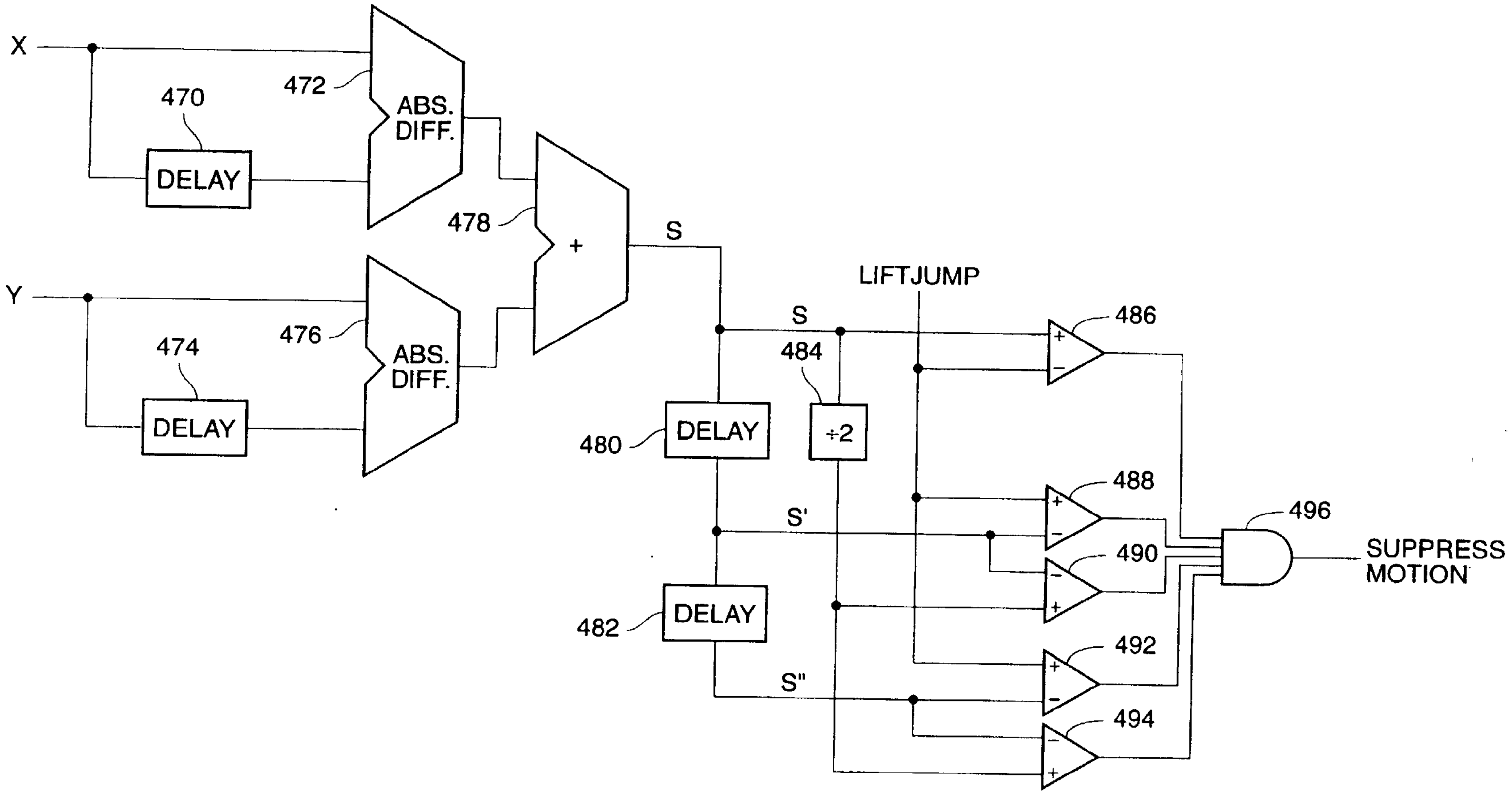
X
470
DELAY
472
ABS. DIFF.
Y
474
DELAY
476
ABS. DIFF.
478
+
S
LIFTJUMP
S
484
÷2
480
DELAY
S'
482
DELAY
S"
486
488
490
492
494
496
SUPPRESS MOTION

FIG. 21

# INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 97/05333

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 G06F3/033 G06K11/16

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 G06F G06K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category * | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| Y | WO 96 07966 A (SYNAPTICS INC ;GILLESPIE DAVID (US); ALLEN TIMOTHY P (US); MILLER) 14 March 1996<br>see the whole document | 6-18 |
| Y | PATENT ABSTRACTS OF JAPAN<br>vol. 095, no. 006, 31 July 1995<br>& JP 07 072976 A (KYOCERA CORP), 17 March 1995,<br>see abstract | 6-18 |
| P,X | WO 96 11435 A (SYNAPTICS INC ;GILLESPIE DAVID (US); ALLEN TIMOTHY P (US); WOLF RA) 18 April 1996<br>see the whole document | 1 |
| P,A | | 6-18 |

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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1

| | |
|---|---|
| Date of the actual completion of the international search<br>21 July 1997 | Date of mailing of the international search report<br>28. 07. 97 |
| Name and mailing address of the ISA<br>European Patent Office, P.B. 5818 Patentlaan 2<br>NL - 2280 HV Rijswijk<br>Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,<br>Fax (+31-70) 340-3016 | Authorized officer<br>Bailas, A |

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Information on patent family members

International Application No
PCT/US 97/05333

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|---|---|---|---|
| WO 9607966 A | 14-03-96 | US 5543590 A<br>AU 3544395 A<br>EP 0777875 A<br>US 5488204 A | 06-08-96<br>27-03-96<br>11-06-97<br>30-01-96 |
| WO 9611435 A | 18-04-96 | US 5543591 A<br>AU 4001995 A | 06-08-96<br>02-05-96 |

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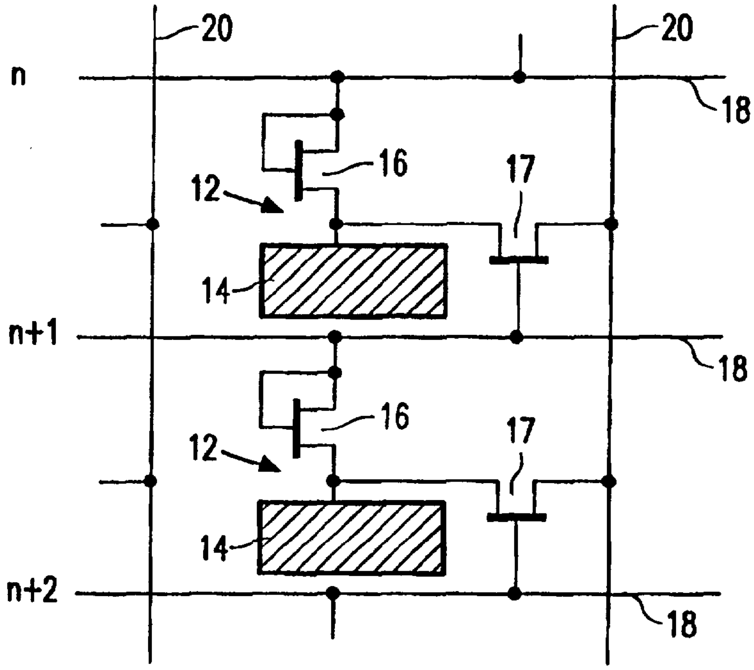
**(54) Title:** FINGERPRINT SENSING DEVICES AND SYSTEMS INCORPORATING SUCH

**(57) Abstract**

A fingerprint sensing device comprises an array of sense elements (12) each of which includes a sense electrode (14) which together with an overlying fingerprint portion forms a capacitor (35). The capacitor is charged by operation of a first switching device (16) via a first address conductor (18). A second switching device (17) is then operated to transfer the charge on the sense electrode to a second address conductor (20) where it is sensed (24) and an output indicative of capacitance provided accordingly. Fast, reliable, scanning is achieved. A row and column array of sense elements is conveniently addressed using sets of row and column conductors (18, 20) and the device can readily be implemented using thin film devices, e.g. TFTs, as the switching devices on an insulating support and with integrated drive circuits.



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DESCRIPTION

# FINGERPRINT SENSING DEVICES AND SYSTEMS INCORPORATING SUCH

The present invention relates to a fingerprint sensing device comprising an array of sense elements which each comprise a sense electrode and a first switching device connected to the sense electrode and a first address conductor that is operable by a control signal supplied to the first address conductor by a drive circuit to apply charge to the sense electrode, the sense electrode of the sense element being spaced from a sensing surface over which a finger whose print is to be sensed is placed, and providing in combination with an individual portion of an overlying finger a capacitance, and sense means connected to each sense element via a second address conductor for providing an output indicative of the capacitances of the sense elements. The invention relates also to a fingerprint recognition system incorporating such a device.

A fingerprint sensing device of the above kind is described in US-A-5 325 442. In this device, the sense elements are arranged in a row and column array and the switching devices of the sense elements comprise thin film transistors, TFTs, connected to a drive circuit via sets of row and column address conductors. The gates of the TFTs of the sense elements in one row are connected to a respective, common, row conductor while the sources of the TFTs of all sense elements in one column are connected to a respective, common, column address conductor. The drain electrode of each TFT is connected to the sense electrode of the sense element. The sense electrodes together with overlying dielectric material and individual fingerprint portions when placed over the dielectric material constitute capacitors. The row address conductors are connected to a scan circuit which applies a gating (selection) signal to each row conductor in a respective row address period to turn on the TFTs of the sense elements of each row in sequence. Simultaneously with a gating signal a predetermined potential is applied to the column address conductors to charge the capacitors. The individual capacitances of these capacitors depend on the spacing of the fingerprint portions from the sense electrodes, as determined by the presence of a ridge of a trough of the fingerprint, and are measured by sensing the charging current flowing in the column conductors during charging of the capacitors, using current or charge sensing amplifier circuits incorporated in the drive circuit. At the end of the row address period, the TFTs are turned off and a gating signal applied to the next row conductor to turn on the TFTs of the next row of sense elements. Each row of sense elements is addressed in this manner in turn and the variation in sensed capacitances produced over the array of sense elements by a fingerprint ridge pattern provides an electronic image or representation of the three dimensional form of the fingerprint surface.

In order to allow consecutive readings of the capacitance image of a fingerprint, or readings of different fingerprints, in successive field scan operations, the charge on the sense electrodes is removed, or at least reduced, before the sense elements are addressed again. This is achieved either by incorporating a resistor in each sense element which is connected between the sense electrode and ground, by changing the predetermined voltage applied to column conductors in successive read cycles, or by arranging the drive circuit to include an intermediate reset cycle between successive read cycles. The provision of a resistor, for example using a doped semiconductor material, is difficult and complicates the fabrication of the sense element array, while the other two discharge schemes cause complications to the drive circuit. Moreover, it is important in this device for minimising cross-talk problems that there is highly controlled, or low, leakage in the TFTs and that the leakage characteristics of the TFTs across the array are substantially uniform. This can be difficult to achieve, particularly if the TFTs are formed on a polymer substrate. The speed at which successive read-outs could be achieved would also be compromised by the need for these discharge schemes.

It is an object of the present invention to provide an improved fingerprint sensing device.

According to one aspect of the present invention, a fingerprint sensing device of the kind described in the opening paragraph is characterised in that each sense element includes a second switching device which is connected between the sense electrode and the second address conductor and which is operable by the drive circuit following operation of the first switching device to transfer the charge on the sense electrode to the second address conductor.

By virtue of the two switching devices being arranged to be operated by the drive circuit in succession so as to apply charge to the capacitor formed by the sense electrode and an overlying fingerprint portion and then to transfer the charge, the amount of which depends on the capacitance, to an address conductor of the second set where it is sensed, fast and reliable read-outs from the array are possible and, importantly, the need to discharge the capacitances of the individual sense elements as in the known arrangement by using resistances, which limits the scan speed, by introducing reset cycles or by changing drive signals, which complicate the drive circuit as well as affecting scan speed, is removed. With the invention, the control signals needed for operating the sense elements can be of very simple form, and an uncomplicated drive circuit, capable of fast operation, can be used.

The sense elements are preferably arranged in rows and columns and connected to sets of first and second address conductors extending in the row and column directions with the first switching devices of each sense element in a row being connected to a common address conductor of the first set and with the second switching device of each sense element in a column being connected to a common address conductor of the second set. In this case, the drive circuit may conveniently be arranged to supply a control signal to each of the address conductors of the first set in sequence so as to operate the first switching devices of the sensing elements on a row by row basis.

Preferably the second switching devices of the sense elements in a row are coupled to an address conductor of the first set which is different to that to which the first switching devices of the row of sense elements are connected and are operable by a control signal applied to that different address conductor. Conveniently, the address conductor of the first set to which the second switching devices of a row of sense elements are coupled comprises an address conductor to which the first switching devices of the adjacent row of sense elements are connected.

The first and second switching devices of the sense elements may comprise transistors. With regard to the first switching devices, a first main terminal of the transistor is preferably coupled to the address conductor of the first set to which its control electrode is connected, the second main terminal being connected to the sense electrode of the sense element. In this way, the potential applied to the sense electrode upon operation of the first switching device conveniently is provided by the control signal used to operate the switching device. Alternatively, the first main terminals of the first switching devices in a row may be connected to a separate supply line. In a preferred embodiment, the transistors of the array of sense elements comprise thin film transistors (TFTs) which, together with the sets of address conductors and the sense electrodes, are provided on an insulating support, for example of polymer material or glass. Because of the nature of the sense elements, the low or controlled leakage and uniformity requirements for the TFTs is much less critical than with the known arrangement. The removal of the need for controlled or low leakage in the TFTs means that the TFT fabrication requirements can be much less stringent which greatly facilitates the use of TFTs on polymer substrates rather than glass. The first switching devices could alternatively be two terminal non-linear switching devices connected between the associated address conductor of the first set and the sense electrodes, for example comprising thin film diodes, although from an ease of fabrication point of view when using thin film technology it is preferred that the first and second switching devices are of the same kind. The TFTs may comprise amorphous silicon devices. In a preferred embodiment, however, the TFTs comprise polysilicon TFTs. For convenience, the drive circuit is preferably integrated on the support and fabricated simultaneously with the sense element TFTs and the sets of address conductors and this is readily possible using polysilicon technology. Inexpensive and compact sensing devices are then obtained which are ideally suited to, for example, integration in smart cards and the like.

According to another aspect of the present invention there is provided a fingerprint recognition system comprising a sensing device in accordance with the one aspect of the invention, means responsive to the output from the sense means of the device to provide characteristical data of a sensed fingerprint, and means for comparing said characteristical data with stored characteristical data for one or more fingerprints.

Embodiments of fingerprint sensing devices, and a fingerprint recognition system incorporating such, in accordance with the invention will now be described, by way of example, with reference to the accompanying drawings, in which:-

Figure 1 is a simplified schematic diagram of an embodiment of the sensing device showing an array of sense elements together with associated addressing circuitry;

Figure 2 shows schematically the equivalent circuit of two typical sense elements in the array of the device of Figure 1;

Figure 3 is a schematic cross-sectional view through a part of the sensing device illustrating the manner of its operation;

Figure 4 illustrates typical drive waveforms used in operation of the device;

Figure 5a and 5b illustrate alternative forms of sense circuits for use in the device; and

Figure 6 illustrates in simple block diagram form a fingerprint recognition system using the sensing device.

It is to be understood that the Figures are merely schematic and are not drawn to scale. Certain dimensions may have been exaggerated while others have been reduced. The same reference numbers are used throughout the Figures to indicate the same, or similar, parts.

Referring to Figure 1, the fingerprint sensing device comprises an active matrix addressed sensing pad 10 having an X-Y array of regularly-spaced sense elements 12 consisting of r rows (l to r) each with c sense elements, which are operable to scan a fingerprint. Only a few rows and columns are shown for simplicity. In practice there may be around 512 rows and 512 columns of sense elements occupying an area of approximately 2.5 cms by 2.5cms.

Referring also to Figure 2, each sense element of the array comprises a sense electrode 14 connected to a first switching device, which in this embodiment comprises a three terminal switching device 16 in the form of an n-type field effect transistor (FET) and a second switching device 17 also in the form of an n-type FET. The X-Y array of sense elements is addressed via a set of regularly-spaced row (selection) address conductors 18 and a set of regularly - spaced column (sensing) address conductors 20 with individual sense elements being located at respective intersections of the two sets of conductors. All sense elements in the same row are connected to an adjacent pair of row conductors 18 and all sense elements in the same column are connected to a respective, common, column conductor 20. The row conductors 18 are connected at their one ends to a row driver circuit 22, comprising a digital shift register circuit, and the column conductors 20 are connected at their one ends to a sense circuit, 24.

As can be seen in Figure 2, each row conductor 18, apart from the first and the last, is associated with, and shared by, the sense elements in two adjacent rows. The gate electrode and source terminal of the first FET 16 of each sense element in one row are interconnected, and thus connected to the same row conductor 18, e.g. the $n^{th}$ conductor, while its drain is connected to the sense electrode 14. The gate electrode of the second FET 17 of each sense element in the row is connected to the other associated row conductor 18, i.e. the succeeding (n+1)th row conductor, and the source and drain terminals of this second FET 17 are connected respectively to the sense electrode 14 and the associated column conductor 20. The gates of the first and second FETS 16 and 17 of each of the sense elements in the next row are connected respectively to the (n+1)th and (n+2)th row conductors 18, and so on. The sense elements 12 and address conductors 18 and 20 of the pad 10 are fabricated using standard thin film technology as used in active matrix addressed display devices for example, and as such it is not thought necessary to describe here the manner of fabrication in detail. Briefly, it involves the deposition and definition by photolithographic processes of a number of layers on an insulating substrate. The electrodes 14 and sets of address conductors 18 and 20 can be formed of metal and the FETs 16 can be formed as amorphous silicon or polycrystalline silicon thin film transistors (TFTs) using an appropriate insulating substrate e.g. of glass, polymer, or quartz. The first switching devices need not comprise FETs but could instead be diode structures, for example thin film p-i-n devices or other two terminal non-linear switching devices connected between the row conductor and the sense electrode. While it is preferred to use thin film device technology, it will be appreciated that the sensing pad 10 could alternatively be fabricated using a semiconductor wafer and integrated circuit technology.

An example of one form of array construction is shown schematically and simplified in Figure 3 which is a cross-section through a representative part of the pad 10 comprising three complete sense electrodes 14. The TFT devices 16 and 17, which are not visible in this section, are formed on an insulating substrate 30 from a deposited layer of amorphous or polycrystalline silicon material, constituting the TFTs' channels, with a deposited layer of dielectric material, for example silicon nitride, constituting the gate insulator layers of the TFTs. The sense electrodes 14, comprising regularly spaced and equally sized rectangular conductive pads, and the set of address conductors

20 extending therebetween are defined from a deposited metal layer. Integral extensions of the electrodes 14 respectively form the drain contacts and source contacts of the TFTs 16 and 17 and integral extensions of the conductors 20 form the drain contacts of the TFTs 17. Insulating material is provided between the conductors 18 and 20 at the regions where they intersect. The set of row conductors 18, not visible in Figure 3, is formed from a deposited metal layer with each row conductor extending between adjacent rows of sense electrodes 14 and having integral extensions spaced along its length, for example as indicated at 21 in Figure 3, which serve as gate electrodes of the TFTs 16 and 17.

To complete the structure of the sensing device, a dielectric film 32, for example of silicon nitride or polyimide, is deposited completely over the structure on the substrate 30 to provide a continuous sensing surface 34 spaced from, and substantially parallel to, the substrate surface.

The physical dimensions of the sense electrodes 14 are chosen in accordance with the desired resolution characteristics in fingerprint sensing. By way of example, the sense electrodes may have a pitch of around 50 to 100 micrometres in both the row and column directions. The thickness of the insulating film 32 is selected taking into account the value of the relative permittivity of the material used for this film. For example, for a relative permittivity of approximately 4, a film thickness of around 0.5 micrometres may be used.

In operation of this sensing device, a finger whose print is to be scanned is placed on the sensing surface 34. Actual, or close, physical contact with the surface 34 then occurs at the ridges of the fingerprint, as illustrated in Figure 3 where one ridge of 36 of part of the finger surface 37 is depicted. Troughs in the fingerprint profile are spaced from the surface 34 by a considerably greater distance. The ridged finger surface is therefore spaced from the array of electrodes 14 by a minimum distance determined by the thickness of the thin insulating film 32. Each sense electrode 14 and the respective overlying portion of the finger surface form opposing plates of a capacitor 35, as depicted by dotted lines in Figure 3, with the upper plate, constituted by the finger surface portion, being effectively at ground potential. The intervening insulating film 32, and any air gap present between the finger surface portion and the sensing surface 34, provide the capacitor dielectric. The capacitances of these individual capacitors varies as a function of the spacing, d,between the finger surface and the sensing surface 34, with larger capacitances occurring where the fingerprint ridges are in contact with surface 34 and smaller capacitances occurring where the troughs in the fingerprint overlie the sense electrodes 14. The variation in capacitances produced over the array of sensing elements 12 of the pad 10 by a fingerprint ridge pattern thus constitutes in effect an electronic "image" of the three dimensional form of the fingerprint surface. These capacitances are sensed within the sensing device and an output provided indicative of the variation, and hence the three-dimensional profile of the fingerprint.

Sensing the capacitance variation between the individual sense elements 12 in the array is accomplished as follows. Each sense element is addressed through its associated row, selection, and column, sensing, conductors 18 and 20. The row driver circuit 22 is arranged to provide a control signal comprising a selection (gating) signal in the form of a voltage pulse to each row address conductor 18, one at a time in turn, and so each row conductor, starting at row 1, receives a selection signal in sequence. An example of drive waveforms applied to three successive row conductors is shown in Figure 4. A selection pulse signal, Vs, applied to a row conductor 18, e.g. the nth row conductor, turns on the TFTs 16 of all sense elements 12 in the row causing the associated capacitors 35 of the row of sense elements to be charged to approximately the level of the pulse signal, i.e. Vs. Upon termination of this selection signal Vs, the TFTs 16 turn off and charge is held on each of the capacitors 35 of the row, the amount of charge, q, stored in each capacitor being dependent on its capacitance, C, and approximately equal to C.Vs. Almost immediately thereafter a selection pulse signal is applied to the succeeding, $(n+1)^{th}$, row conductor 18 which similarly turns on the TFTs 16 of the sense elements in the next row and charges up their associated capacitances 35. At the same time, this subsequent selection signal also turns on the TFTs 17 of the previous row of sense elements, effectively connecting each of the sense electrodes 14 of the sense elements in that row to its respective associated column conductor 20. The column conductor is at virtual earth and the charge held on the electrode 14 flows in the column conductor where it is detected by a charge sense amplifier in the circuit 24. The charges stored in the capacitors of each of the sense elements in the row are simultaneously read-out and detected in this way via their respective column conductors 20 and respective charge sense amplifiers in the circuit 24. The amount of charge from each capacitor depends on the size of the capacitor and thus is determined according to whether a ridge or a trough of a fingerprint overlies the sense electrode 14 concerned. If a ridge overlies an electrode 14, a certain amount of charge will be read out whereas if a trough overlies the electrode the amount of charge read out will be substantially zero.

In this way, therefore, a single selection pulse applied to a row conductor is effective to charge up the capacitors of the sense elements in one row and read out the capacitors of the sense elements of the immediately preceding row. Each row of sense elements is addressed in this manner in a row address period, corresponding to the duration of two successive selection signals, by the sequential application of a selection signal to the row conductors 18 so as to scan the fingerprint and a complete "image" of the capacitor characteristics is built up following the addressing of all rows in the array in one complete field period. Typically, the selection signal Vs can be of around 20 microseconds in duration, Ts, enabling around seventy frames per second.

Figure 5a illustrates the charge sense amplifier configuration of the circuit 24, the part shown serving two adjacent column conductors 20. In this circuit, the column conductors 20 are connected to charge amplifiers 50 with capacitive feedback whose analogue outputs are similarly switched in succession by means of a shift register 45 operating switches 46 to provide on output line 47 a serial train of pulses whose magnitude is indicative of the charge flow in each column conductor. The charge amplifiers 50, which set the virtual earth level for the column conductors, are reset in the period between addressing successive rows of sense elements by a reset pulse applied to a reset line 51 which operates switches 52 to discharge the shunt capacitors of the amplifiers.

In Figure 5b part of an alternative sensing circuit, for three adjacent column conductors, using current sensing amplifiers is shown. The column conductors 20 are connected to respective current amplifiers 40 with resistive feedback whose outputs are supplied to sample and hold circuits 41. The bias condition of the amplifiers sets the aforementioned virtual earth level on the column conductors 20. These circuits 41 are operated simultaneously, and in synchronism with the gating pulse applied to a row conductor 18, by means of a sampling pulse supplied along a common line 42. The analogue outputs of the circuits 41 are switched in succession by means of a shift register 45 operating switches 46 in sequence to provide a serial output of pulses along line 47 whose magnitudes are indicative of the instantaneous current values in each of the conductors 20.

Other suitable types of sense means, for example comprising digital latch type circuits, could be utilised.

As the capacitor 35 of each sense element in a row is charged and then immediately discharged for read-out in one row address period there is no need for an integration period or for the sense elements to be reset prior to a subsequent address period. The sense elements in a row are effectively discharged at the end of the row address period. Several readings of the capacitance image of a fingerprint can be taken in rapid succession over consecutive field periods, or readings of different fingerprints in consecutive operations can be performed easily if desired. Fast scanning with read-out of the sense elements of the array is possible, the charge/discharge cycle of a row of sense elements taking only a few microseconds. The leakage requirements for the TFTs 16 and 17 is less critical than with the known device of US-A-5325442 and the need for a high uniformity of this characteristic in the

TFTs across the array is less important. The source terminals of the TFTs 16 are at zero volts except for the relatively short period of a selection signal on the row conductor. It can be expected that the TFTs 16 and 17 will exhibit some gate/source capacitance. During read-out of a sense element the capacitor 35 discharges to OV (the column conductor potential). The falling edge of the selection signal Vs applied to the TFT 17 may couple a voltage to the junction between the sense electrode 14 and the TFT 16. If a ridge overlies this sense electrode 14, the capacitance of the capacitor 35 is large compared to the gate/source capacitance of the TFTs 16 and 17. If a trough overlies the sense electrode 14, however, the capacitance is small and comparable to, or less than, the gate/source capacitance. Consequently a small voltage could exist at this junction after termination of the row address period but this can be reduced if necessary by using a self-aligned process when fabricating the TFTs and/or by appropriately scaling the TFTs 16 relative to the TFTs 17. The generally low steady state voltage across the source - drain terminals of the TFTs 17 implies negligible vertical crosstalk currents in the column conductors. The device has the further advantages of requiring a very simple drive scheme, entailing the provision of simple voltage pulse signals to the row conductors in succession, which allows a simple form of row driver circuit to be utilised, and offers a very good signal to noise ratio.

While in the above embodiment each row conductor 18 is shared by two adjacent sense element rows, each row of sense elements could instead be connected to its own respective pair of row conductors but this would require the provision of two separate row conductors between each adjacent rows of sense elements. Also, the voltage supplied to the sense electrodes of a row of sense elements could be provided by an auxiliary conductor extending in the row direction and between the two row conductors 18 associated with the row of sense elements to which the source terminals of the TFTs 16 are connected. The auxiliary conductors for all the rows of sense elements would be interconnected at one side of the array, preferably the side opposite the row driver circuit 22, and coupled to a potential source at an appropriate level. The capacitors of the sense elements would then be charged to this voltage level rather than a level slightly less than Vs due to a voltage drop across the TFTs 16.

The drive circuit of the device, comprising the row driver circuit 22 and the sensing circuit 24, may be integrated on the same substrate as that carrying the array of sense elements and fabricated simultaneously with the components of the sense elements thereby providing an inexpensive and compact sensing device. Such integration is conveniently achieved using polysilicon thin film technology. If low temperature polysilicon process technology is employed, the substrate can be of plastics material, and particularly a flexible polymer material. Such a sensing device can readily be incorporated in a smart card.

Strips of conductive material may be provided directly on the upper surface of the insulating 32 of the device which extend over the spaces between adjacent rows or adjacent columns, or both, of the sense electrodes 14, for example as lines or in a grid pattern, and which are grounded electrically.

A matrix of discrete, electrically conductive pad electrodes may be provided on the surface of the insulating layer, each overlying and similar in size and shape to a sense electrode 14, to form the opposite plates of the capacitors 35. Ridges of a fingerprint ground particular ones of these pad electrodes where they are in contact and the capacitance of the capacitors 35 is then determined by the area of the sense electrodes 14 and their opposing pad electrodes and the thickness of the intervening insulating layer 32 so that substantially identical, and more distinctive, capacitances are obtained at all ridge contact locations. Elsewhere, surface portions of the finger are spaced from their underlying pad electrodes and the capacitance values are dependent on this spacing as before.

Figure 6 shows in schematic block form a fingerprint recognition system incorporating the sensing device, here represented by the block 60. The system includes means responsive to an output from the sensing circuit of the device to provide characteristical data of a sensed fingerprint, and means for comparing said characteristical data with stored characterisical data for one or more fingerprints. The output obtained from the sensing device is provided in a form comparable to the video output provided by an image sensor in known optical fingerprint sensing devices. Accordingly, and as will be apparent to skilled persons, components of the system, other than the sensing device, can be generally of the kind employed in systems using optical sensing devices. The characteristical data, in accordance with standard practice, may take the form of information regarding the orientation of ridge lines and relative positions of minutiae, that is, the endings and bifurcations of the lines. The processing of information obtained from the sensing device to produce and compare characteristical data can follow known schemes and techniques. Because the sensing device of the invention is capable of providing information of the three dimensional profile of a fingerprint improved accuracy of identification or verification can be obtained by making use of topological features in addition to the spatial positions of minutiae, although of course use may be made only of information in respect of the two-dimensional ridge patterns to simplify the processing necessary if less accuracy is acceptable. Briefly, the output from the device 60, suitably conditioned, is fed to an analysis circuit 61 which is programmed to detect characterising features of the fingerprint sensed such as the position of minutiae. Data from the circuit 61 is supplied to a computer 62 which through standard algorithms compares the data with characteristical data of a plurality of fingerprints, or a single fingerprint depending on whether the system is used for identification or merely verification purposes, held in a storage device 63 and which provides an output in accordance with whether or not a match has been found.

The circuit 61 can be programmed either to utilise the three dimensional information provided by the sensing device for high accuracy of recognition, or alternatively, with appropriate discrimination to select particular output signal values from the device 60, utilising specific information representative of the two dimensional ridge pattern in the nature of a binary image similar to that obtained from known optical sensing devices.

In summary, therefore, a fingerprint sensing device has been disclosed which comprises an array of sense elements each of which includes a sense electrode which together with an overlying fingerprint portion forms a capacitor. The capacitor is charged by operation of a first switching device via a first address conductor. A second switching device is then operated to transfer the charge in the sense electrode to a second address conductor where it is sensed and an output indicative of capacitance provided accordingly. Fast, reliable, scanning is achieved. A row and column array of sense elements is conveniently addressed using sets of row and column conductors and the device can readily be implemented using thin film devices, e.g. TFTs, as the switching devices on an insulating support and with integrated drive circuits.

From reading the present disclosure, other modifications will be apparent to persons skilled in the art. Such modifications may involve other features which are already known in the field of fingerprint sensing and component parts thereof and which may be used instead of or in addition to features already described herein.

## CLAIMS

1. A fingerprint sensing device comprising an array of sense elements which each comprise a sense electrode and a first switching device connected to the sense electrode and a first address conductor that is operable by a control signal supplied to the first address conductor by a drive circuit to apply a charge to the sense electrode, the sense electrode of the sense element being spaced from a sensing surface over which a finger whose print is to be sensed is placed and providing in combination with an individual portion of an overlying finger a capacitance, and sense means connected to each sense element via a second address conductor for providing an output indicative of the capacitance of the sense elements, characterised in that each sense element includes a second switching device which is connected between the sense electrode and the second address conductor and which is operable by the drive circuit following operation of the first switching device to transfer the charge on the sense electrode to the second address conductor.

2. A fingerprint sensing device according to Claim 1, characterised in that the sense elements are arranged in rows and columns and connected to sets of first and second address conductors extending in the row and column directions, the first switching devices of each sense element in a row being connected to a common address conductor of the first set and the second switching devices of each sense element in a column being connected to a common address conductor of the second set.

3. A fingerprint sensing device according to Claim 2, characterised in that the drive circuit is arranged to supply a control signal to each of the address conductors of the first set in sequence so as to operate the first switching devices of the sense elements on a row by row basis.

4. A fingerprint sensing device according to Claim 3, characterised in that

the second switching devices of the sense elements in a row are coupled to an address conductor of the first set which is different to that to which the first switching devices of the row of sense elements are connected and are operable by a control signal applied to that different address conductor.

5. A fingerprint sensing device according to Claim 4, characterised in that the address conductor of the first set to which the second switching devices of a row of sense elements are coupled comprises an address conductor to which the first switching devices of the adjacent row of sense elements are connected.

6. A fingerprint sensing device according to any one of the preceding claims, characterised in that the first and second switching devices of the sense elements comprise transistors.

7. A fingerprint sensing device according to Claim 6, characterised in that a first main terminal and the control electrode of each of the first switching devices in a row of sense elements are connected to the same address conductor.

8. A fingerprint sensing device according to any one of Claim 6 or claim 7, characterised in that the transistors comprise thin film transistors which together with the sets of first and second address conductors and the sense electrodes of the sense elements are carried on an insulating substrate.

9. A fingerprint sensing device according to Claim 6 or Claim 7, characterised in that the sense elements and sets of first and second address conductors comprise an integrated circuit on a semiconductor wafer substrate.

10. A fingerprint sensing device according to Claim 8 or Claim 9, characterised in that the drive circuit and sense means are integrated on the

same substrate as that of the array of sense elements.

11. A fingerprint sensing device according to any one of the preceding claims, characterised in that the sense electrodes of the array of sense elements are covered by a dielectric whose surface provides said sensing surface.

12. A fingerprint recognition system comprising a fingerprint sensing device according to any one of Claims 1 to 11, means responsive to the output from the sense means to provide characteristical data of a sensed fingerprint, and means for comparing said characteristical data with stored characteristical data for one or more fingerprints.

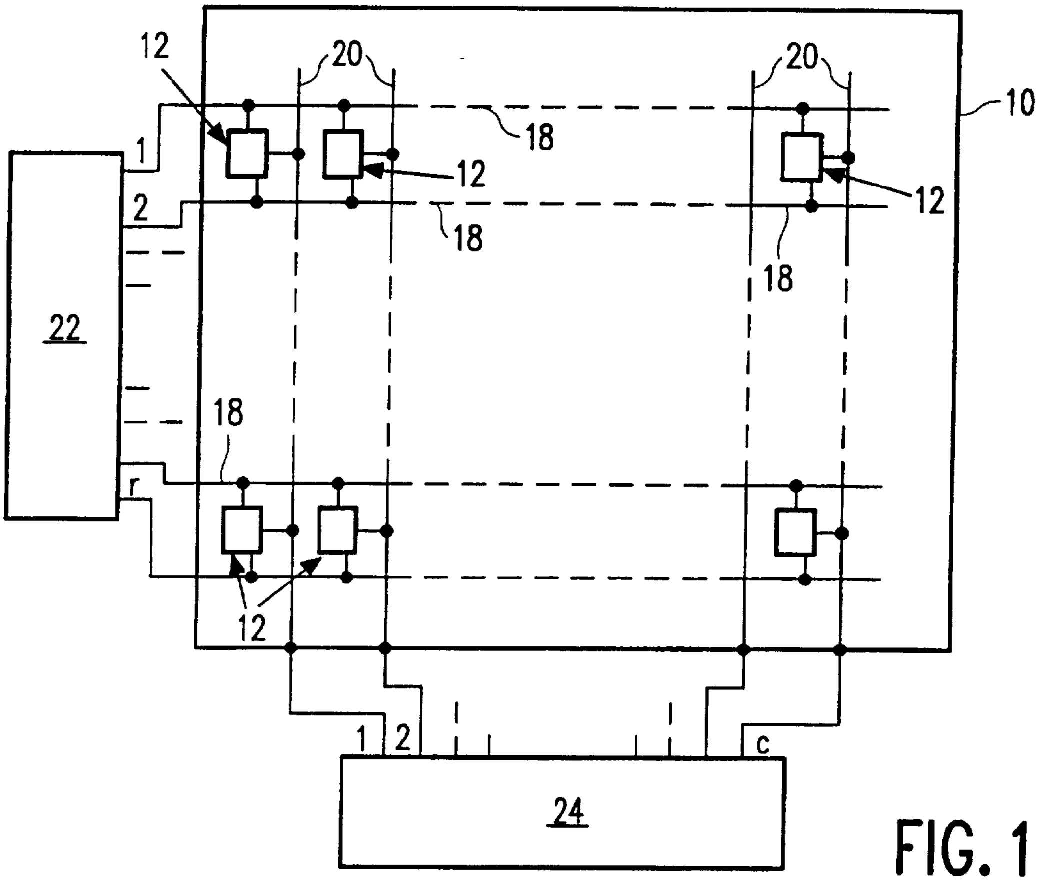
12
20
20
10
18
12
12
1
2
18
18
22
18
r
12
1
2
c
24

FIG. 1

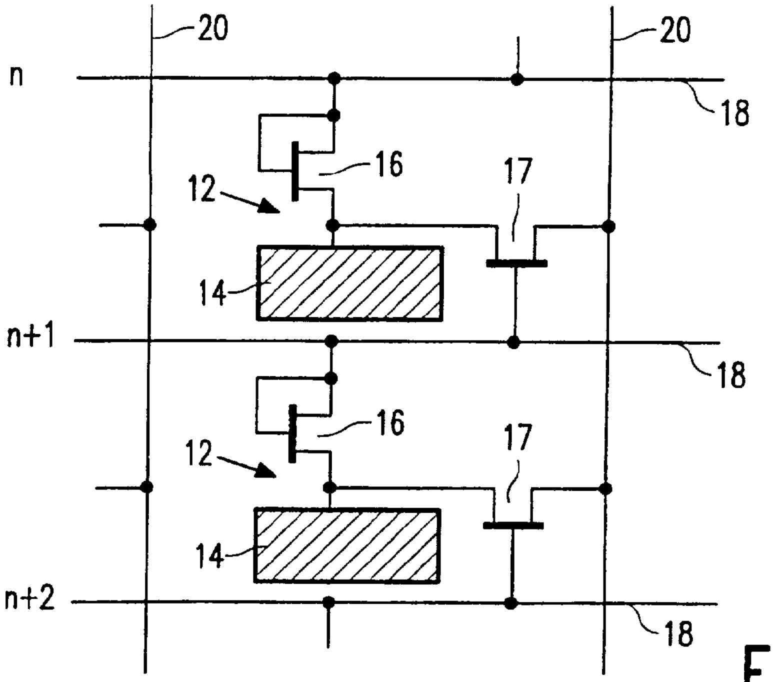
20
20
n
18
16
17
12
14
n+1
18
16
17
12
14
n+2
18

FIG. 2

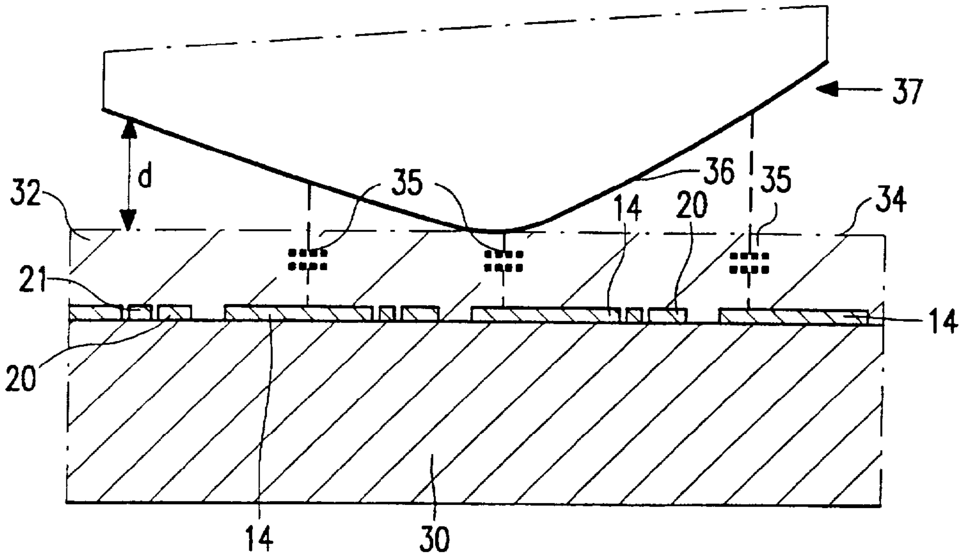

FIG. 3

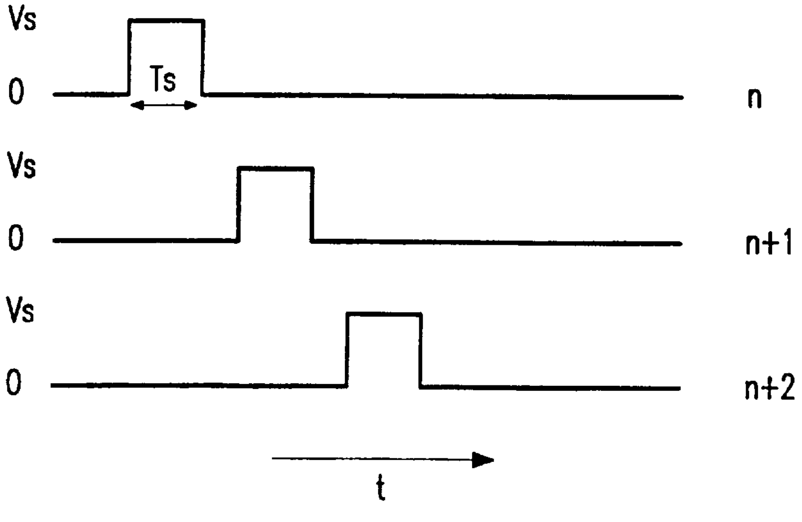

FIG. 4

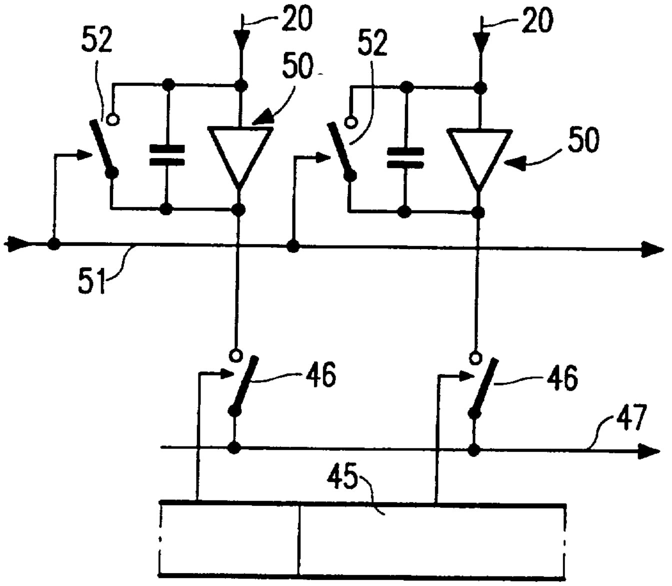

FIG. 5a

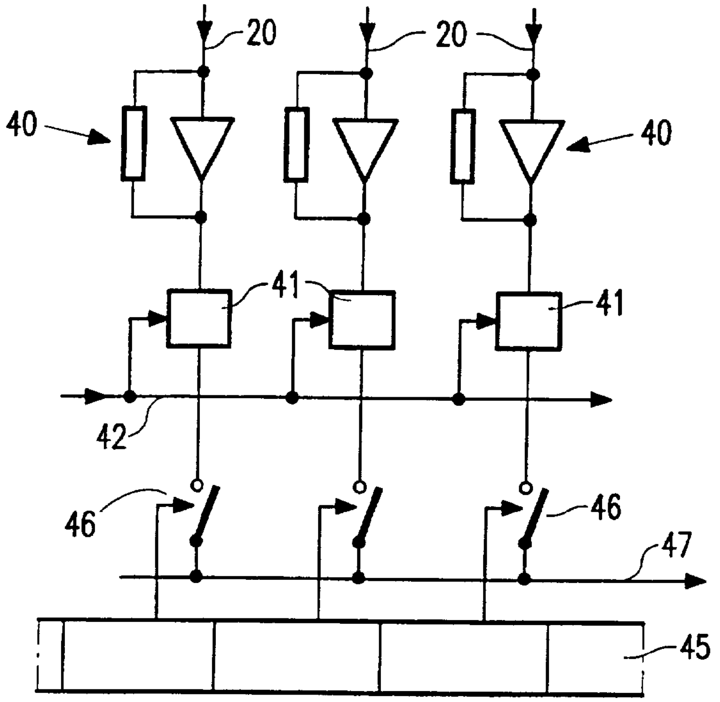

FIG. 5b

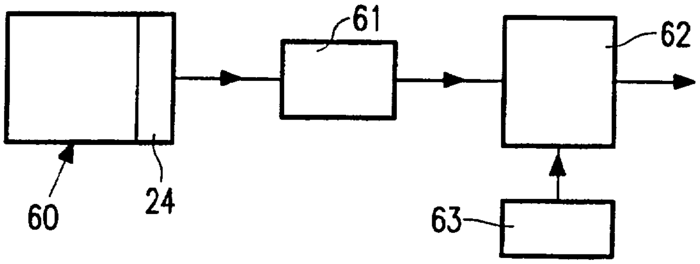

FIG. 6

# INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB 97/00302

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: A61B 5/117, G06K 9/00, G01B 7/287
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: A61B, G01B, G06K, G07C, G11C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPI

C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| A | US 5325442 A (ALAN KNAPP), 28 June 1994 (28.06.94), abstract<br>-- | 1-12 |
| A | US 4353056 A (C.TSIKOS), 5 October 1982 (05.10.82), abstract<br>--<br>-------- | 1-12 |

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" erlier document but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

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|---|---|
| Date of the actual completion of the international search<br>15 Sept 1997 | Date of mailing of the international search report<br>16 -09- 1997 |
| Name and mailing address of the ISA/<br>Swedish Patent Office<br>Box 5055, S-102 42 STOCKHOLM<br>Facsimile No. +46 8 666 02 86 | Authorized officer<br>Malin Keijser<br>Telephone No. +46 8 782 25 00 |

Form PCT/ISA/210 (second sheet) (July 1992)

# INTERNATIONAL SEARCH REPORT

Information on patent family members

01/09/97

International application No.

PCT/IB 97/00302

| Patent document cited in search report | Publication date | Patent family member(s) | Publication date |
|---|---|---|---|
| US 5325442 A | 28/06/94 | DE 69115558 D,T | 01/08/96 |
| | | EP 0457398 A,B | 21/11/91 |
| | | GB 2244164 A | 20/11/91 |
| | | JP 4231803 A | 20/08/92 |
| US 4353056 A | 05/10/82 | EP 0041693 A,B | 16/12/81 |

Form PCT/ISA/210 (patent family annex) (July 1992)

XP-002363467

# Issues and Techniques in Touch-Sensitive Tablet Input

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## Abstract

Touch-sensitive tablets and their use in human-computer interaction are discussed. It is shown that such devices have some important properties that differentiate them from other input devices (such as mice and joysticks). The analysis serves two purposes: (1) it sheds light on touch tablets, and (2) it demonstrates how other devices might be approached. Three specific distinctions between touch tablets and one button mice are drawn. These concern the *signaling of events*, *multiple point sensing* and the *use of templates*. These distinctions are reinforced, and possible uses of touch tablets are illustrated, in an example application. Potential enhancements to touch tablets and other input devices are discussed, as are some inherent problems. The paper concludes with recommendations for future work.

CR Categories and Subject Descriptors: I.3.1 [**Computer Graphics**]: Hardware Architecture: Input Devices. I.3.6 [**Computer Graphics**]: Methodology and Techniques: Device Independence, Ergonomics, Interaction Techniques.

General Terms: Design, Human Factors.

Additional Keywords and Phrases: touch sensitive input devices.

## 1. Introduction

Increasingly, research in human-computer interaction is focusing on problems of input [Foley, Wallace & Chan 1984; Buxton 1983; Buxton 1985]. Much of this attention is directed towards input technologies. The ubiquitous Sholes keyboard is being replaced and/or complemented by alternative technologies. For example, a major focus of the marketing strategy for two recent personal computers, the Apple Macintosh and Hewlett-Packard 150, has been on the input devices that they employ (the mouse and touch-screen, respectively).

Now that the range of available devices is expanding, how does one select the best technology for a particular application? And once a technology is chosen, how can it be used most effectively? These questions are important, for as Buxton [1983] has argued, the ways in which the user *physically* interacts with an input device have a marked effect on the type of user interface that can be effectively supported.

In the general sense, the objective of this paper is to help in the selection process and assist in effective use of a specific class of devices. Our approach is to investigate a specific class of devices: touch-sensitive tablets. We will identify touch tablets, enumerate their important properties, and compare them to a more common input device, the mouse. We then go on to give examples of transactions where touch tablets can be used effectively. There are two intended benefits for this approach. First, the reader will acquire an understanding of touch tablet issues. Second, the reader will have a concrete example of how the technology can be investigated, and can utilize the approach as a model for investigating other classes of devices.

## 2. Touch-Sensitive Tablets

A touch-sensitive tablet (touch tablet for short) is a flat surface, usually mounted horizontally or nearly horizontally, that can sense the location of a finger pressing on it. That is, it is a tablet that can sense that it is being touched, and where it is being touched. Touch tablets can vary greatly in size, from a few inches on a side to several feet on a side. The most critical requirement is that the user is not required point with some manually held device such as a stylus or puck.

What we have described in the previous paragraph is a *simple* touch tablet. Only one point of contact is sensed, and then only in a binary, touch/no touch, mode. One way to extend the potential of a simple touch tablet is to sense the degree, or pressure, of contact. Another is to sense multiple points of contact. In this case, the location (and possibly pressure) of several points of contact would be reported. Most tablets currently on the market are of the "simple" variety. However, Lee, Buxton and Smith [1985], and Nakatani (private communication) have developed prototypes of multi-touch, multi-pressure sensing tablets.

We wish to stress that we will restrict our discussion of touch technologies to touch tablets, which can and should be used in ways that are different from touch screens. Readers interested in touch-screen technology are referred to Herot & Weinsapfel [1978], Nakatani & Rohrlich [1983] and Minsky [1984]. We acknowledge that a flat touch screen mounted horizontally is a touch tablet as defined above. This is not a contradiction, as a touch screen has exactly the properties of touch tablets we describe below, as long as there is no attempt to mount a display below (or behind) it or to make it the center of the user's visual focus.

Some sources of touch tablets are listed in Appendix A.

## 3. Properties of Touch-Sensitive Tablets

Asking "Which input device is best?" is much like asking "How long should a piece of string be?" The answer to both is: it depends on what you want to use it for. With input devices, however, we are limited in our understanding of the relationship between device properties and the demands of a specific application. We will investigate touch tablets from the perspective of improving our understanding of this relationship. Our claim is that other technologies warrant similar, or even more detailed, investigation.

Touch tablets have a number of properties that distinguish them from other devices:

- They have no mechanical intermediate device (such as stylus or puck). Hence they are useful in hostile environments (e.g., classrooms, public access terminals) where such intermediate devices can get lost, stolen, or damaged.
- Having no puck to slide or get bumped, the tracking symbol "stays put" once placed, thus making them well suited for pointing tasks in environments subject to vibration or motion (e.g., factories, cockpits).
- They present no mechanical or kinesthetic restrictions on our ability to indicate more than one point at a time. That is, we can use two hands or more than one finger simultaneously on a single tablet. (Remember, we can manually control at most two mice at a time: one in each hand. Given that we have ten fingers, it is conceivable that we may wish to indicate more than two points simultaneously. An example of such an application appears below).
- Unlike joysticks and trackballs, they have a very low profile and can be integrated into other equipment such as desks and low-profile keyboards (e.g., the Key Tronic Touch Pad, see Appendix A). This has potential benefits in portable systems, and, according to the Keystroke model of Card, Newell and Moran [1980], reduces homing time from the keyboard to the pointing device.
- They can be molded into one-piece constructions thus eliminating cracks and grooves where dirt can collect. This makes them well suited for very clean environments (eg. hospitals) or very dirty ones (eg., factories).
- Their simple construction, with no moving parts, leads to reliable and long-lived operation, making them suitable for environments where they will be subjected to intense use or where reliability is critical.

They do, of course, have some inherent disadvantages, which will be discussed at the close of the paper.

In the next section we will make three important distinctions between touch tablets and mice. These are:

- Mice and touch tablets vary in the number and types of events that they can transmit. The difference is especially pronounced when comparing to simple touch tablets.
- Touch tablets can be made that can sense multiple points of contact. There is no analogous property for mice.
- The surface of a tablet can be partitioned into regions representing a collection of independent "virtual" devices. This is analogous to the partitioning of a screen into "windows" or virtual displays. Mice, and other devices that transmit "relative change" information, do not lend themselves to this mode of interaction without consuming display real estate for visual feedback. With conventional tablets and touch tablets, graphical, physical or virtual templates can be placed over the input device to delimit regions. This allows valuable screen real estate to be preserved. Physical templates, when combined with touch sensing, permit the operator to sense the regions without diverting the eyes from the primary display during visually demanding tasks.

After these properties are discussed, a simple finger painting program is used to illustrate them in the context of a concrete example. We wish to stress that we do not pretend that the program represents a viable paint program or an optimal interface. It is simply a vehicle to illustrate a variety of transactions in an easily understandable context.

Finally, we discuss improvements that must be made to current touch tablet technology, many of which we have demonstrated in prototype form. Also, we suggest potential improvements to other devices, motivated by our experience with touch technology.

## 4. Three Distinctions Between Touch Tablets and Mice[1]

The distinctions we make in this section have to do with suitability of devices for certain tasks or use in certain configurations. We are only interested in showing that there are some uses for which touch tablets are not suitable, but other devices are, and vice versa. We make no quantitative claims or comparisons regarding performance.

### Signaling

Consider a rubber-band line drawing task with a one button mouse. The user would first position the tracking symbol at the desired starting point of the line by moving the mouse with the button released. The button would then be depressed, to signal the start of the line, and the user would manipulate the line by moving the mouse until the desired length and orientation was achieved. The completion of the line could then be signaled by releasing the button.[2]

Figure 1 is a state diagram that represents this interface. Notice that the button press and release are used to signal the beginning and end of the rubber-band drawing task. Also note that in states 1 and 2 both motion and signaling (by pressing or releasing the button, as appropriate) are possible.

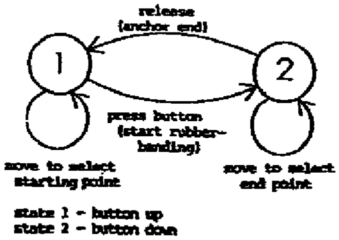

Figure 1. State diagram for rubber-banding with a one-button mouse.

Now consider a simple touch tablet. It can be used to position the tracking symbol at the starting point of the line, but it cannot generate the signal needed to initiate rubber-banding. Figure 2 is a state diagram representation of the capabilities of a simple touch tablet. In state 0, there is no contact with the tablet.[3] In this state only one action is possible: the user may touch the tablet. This causes a change to state 1. In state 1, the user is pressing on the tablet, and as a consequence position reports are sent to the host. There is no way to signal a change to some other state, other than to release (assuming the exclusion of temporal or spatial cues, which tend to be clumsy and difficult to learn). This returns the system to state 0. This signal could not be used to initiate rubber-banding, as it could also mean that the user is pausing to think, or wishes to initiate some other activity.

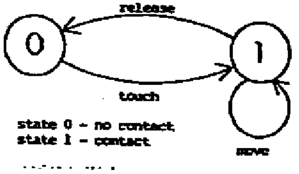

Figure 2. Diagram for showing states of simple touch-tablet.

This inability to signal while pointing is a severe limitation with current touch tablets, that is, tablets that do not report pressure in addition to location. (It is also a property of trackballs, and joysticks without "fire" buttons). It renders them unsuitable for use in many common interaction techniques for which mice are well adapted (e.g., selecting and dragging objects into position, rubber-band line drawing, and pop-up menu selection); techniques that are especially characteristic of interfaces based on *Direct Manipulation* [Shneiderman 1983].

One solution to the problem is to use a separate function button on the keyboard. However, this usually means two-handed input where one could do, or, awkward co-ordination in controlling the button and pointing device with a single hand. An alternative solution when using a touch tablet is to provide some level of pressure sensing. For example, if the tablet could report two levels of contact pressure (i.e., hard and soft), then the transition from soft to hard pressure, and vice versa, could be used for signaling. In effect, pressing hard is equivalent to pressing the button on the mouse. The state diagram showing the rubber-band line drawing task with this form of touch tablet is shown in Figure 3.[4]

As an aside, using this pressure sensing scheme would permit us to select options from a menu, or

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[1] Although we are comparing touch tablets to one button mice throughout this section, most of the comments apply equally to tablets with one-button pucks or (with some caveats) tablets with styli.

[2] This assumes that the interface is designed so that the button is held down during drawing. Alternatively, the button can be released during drawing, and pressed again, to signal the completion of the line.

[3] We use state 0 to represent a state in which no location information is transmitted. There no analogous state for mice, and hence no state 0 in the diagrams for mice. With conventional tablets, this corresponds to "out of range" state.

At this point the alert reader will wonder about difficulty in distinguishing between hard and soft pressure, and friction (especially when pressing hard). Taking the last first, hard is a relative term. In practice friction need not be a problem (see Inherent Problems, below).

[4] One would conjecture that in the absence of button clicks or other feedback, pressure would be difficult to regulate accurately. We have found two levels of pressure to be easily distinguished, but this is a ripe area for research. For example, Stu Card [private communication] has suggested that the threshold between soft and hard should be reduced (become "softer") while hard pressure is being maintained. This suggestion, and others, warrant formal experimentation.

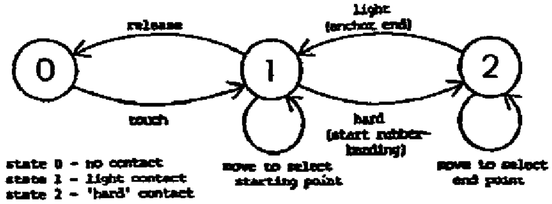

Figure 3. State diagram for rubber-banding with pressure sensing touch tablet.

activate light buttons by positioning the tracking symbol over the item and "pushing". This is consistent with the gesture used with a mouse, and the model of "pushing" buttons. With current simple touch tablets, one does just the opposite: position over the item and then lift off, or "pull" the button.

From the perspective of the signals sent to the host computer, this touch tablet is capable of duplicating the behaviour of a one-button mouse. This is not to say that these devices are equivalent or interchangeable. They are not. They are physically and kinesthetically very different, and should be used in ways that make use of the unique properties of each. Furthermore, such a touch tablet can generate one pair of signals that the one-button mouse cannot — specifically, press and release (transition to and from state 0 in the above diagrams). These signals (which are also available with many conventional tablets) are very useful in implementing certain types of transactions, such as those based on character recognition.

An obvious extension of the pressure sensing concept is to allow continuous pressure sensing. That is, pressure sensing where some large number of different levels of pressure may be reported. This extends the capability of the touch tablet beyond that of a traditional one button mouse. An example of the use of this feature is presented below.

### Multiple Position Sensing

With a traditional mouse or tablet, only one position can be reported per device. One can imagine using two mice or possibly two transducers on a tablet, but this increases costs, and two is the practical limit on the number of mice or tablets that can be operated by a single user (without using feet). However, while we have only two hands, we have ten fingers. As playing the piano illustrates, there are some contexts where we might want to use several, or even all of them, at once.

Touch tablets need not restrict us in this regard. Given a large enough surface of the appropriate technology, one could use all fingers of both hands simultaneously, thus providing ten separate units of input. Clearly, this is well beyond the demands of many applications and the capacity of many people, however, there are exceptions. Examples include chording on buttons or switches, operating a set of slide potentiometers, and simple key roll-over when touch typing. One example (using a set of slide potentiometers) will be illustrated below.

### Multiple Virtual Devices and Templates

The power of modern graphics displays has been enhanced by partitioning one physical display into a number of virtual displays. To support this, display window managers have been developed. We claim (see Brown, Buxton and Murtagh [1985]) that similar benefits can be gained by developing an input window manager that permits a single physical input device to be partitioned into a number of virtual input devices. Furthermore, we claim that multi-touch tablets are well suited to supporting this approach.

Figure 4a shows a thick cardboard sheet that has holes cut in specific places. When it is placed over a touch tablet as shown in Figure 4b, the user is restricted to touching only certain parts of the tablet. More importantly, the user can *feel* the parts that are touchable, and their shape. Each of the "touchable" regions represents a separate virtual device. The distinction between this template and traditional tablet mounted menus (such as seen in many CAD systems) is important.

Traditionally, the options have been:

a) Save display real estate by mounting the menu on the tablet surface. The cost of this option is eye diversion from the display to the tablet, the inability to "touch type", and time consuming menu changes.

b) Avoid eye diversion by placing the menus on the display. This also make it easier to change menus, but still does not allow "touch typing", and consumes display space.

Touch tablets allow a new option:

c) Save display space and avoid eye diversion by using templates that can be felt, and hence, allow "touch typing" on a variety of virtual input devices. The cost of this option is time consuming menu (template) changes.

It must be remembered that for each of these options, there is an application for which it is best. We have contributed a new option, which makes possible new interfaces. The new possibilities include more elaborate virtual devices because the improved kinesthetic feedback allows the user to concentrate on providing input, instead of staying in the assigned region. We will also show (below) that its main cost (time consuming menu changes) can be reduced in some applications by eliminating the templates.

## 5. Examples of Transactions Where Touch Tablets Can Be Used Effectively

In order to reinforce the distinctions discussed in the previous section, and to demonstrate the use of touch tablets, we will now work through some examples based on a toy paint system. We wish to stress again that we make no claims about the quality of the example as a paint system. A paint system is a common and easily understood application, and thus, we have chosen to use it simply as a vehicle for discussing interaction techniques that use touch tablets.

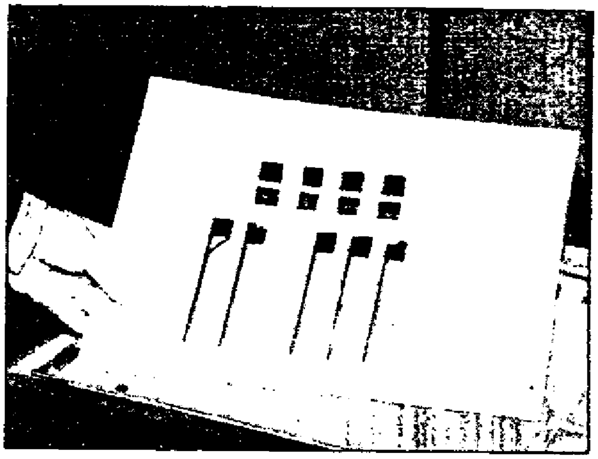

Figure 4a. Sample template.

Figure 5. Main display for paint program.

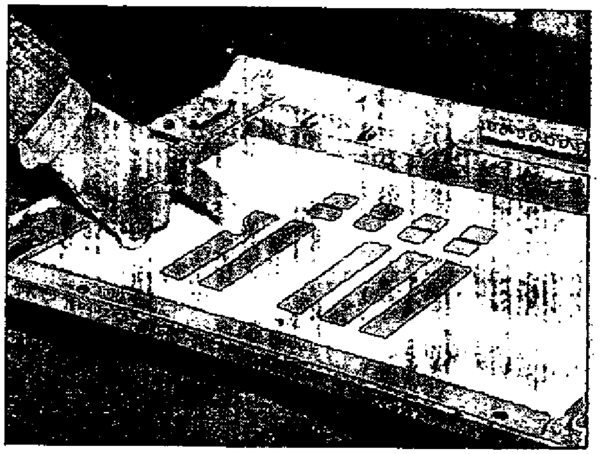

Figure 4b. Sample template in use.

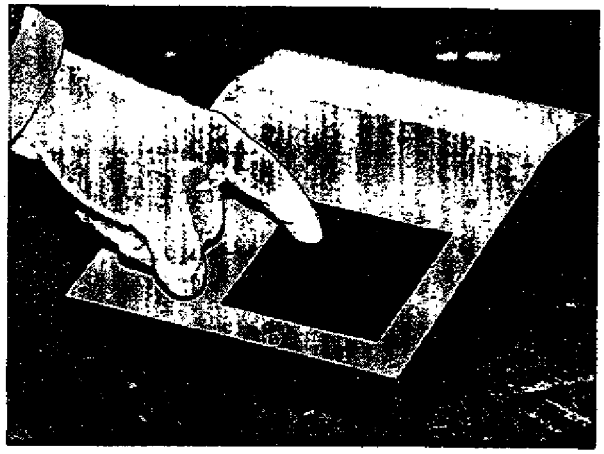

Figure 6. Touch tablet used in demonstrations.

The example paint program allows the creation of simple finger paintings. The layout of the main display for the program is shown in Figure 5. On the left is a large drawing area where the user can draw simple free-hand figures. On the right is a set of menu items. When the lowest item is selected, the user enters a colour mixing mode. In switching to this mode, the user is presented with a different display that is discussed below. The remaining menu items are "paint pots". They are used to select the colour that the user will be painting with.

In each of the following versions of the program, the input requirements are slightly different. In all cases an 8 cm x 8 cm touch tablet is used (Figure 6), but the pressure sensing requirements vary. These are noted in each demonstration.

### 5.1. Painting Without Pressure Sensing

This version of the paint program illustrates the limitation of having no pressure sensing. Consider the paint program described above, where the only input device is a touch tablet without pressure sensing. Menu selections could be made by pressing down somewhere in the menu area, moving the tracking symbol to the desired menu item and then selecting by releasing. To paint, the user would simply press down in the drawing area and move (see Figure 7 for a representation of the signals used for painting with this program).

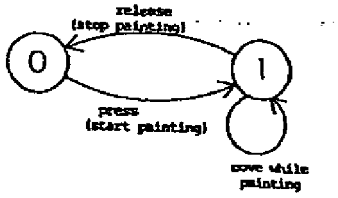

Figure 7. State diagram for drawing portion of simple paint program.

There are several problems with this program. The most obvious is in trying to do detailed drawings. The user does not know where the paint will appear until it appears. This is likely to be too late. Some form of feedback, that shows the user where the brush is, without painting, is needed. Unfortunately, this cannot be done with this input device, as it is not possible to signal the change from tracking to painting and vice versa.

The simplest solution to this problem is to use a button (e.g., a function key on the keyboard) to signal state changes. The problem with this solution is the need to use two hands on two different devices to do one task. This is awkward and requires practice to develop the co-ordination needed to make small rapid strokes in the painting. It is also inefficient in its use of two hands where one could (and normally should) do.

Alternatively, approaches using multiple taps or timing cues for signalling could be tried, however, we have found that these invariably lead to other problems. It is better to find a direct solution using the properties of the device itself.

### 5.2. Painting with Two Levels of Pressure

This version of the program uses a tablet that reports two levels of contact pressure to provide a satisfactory solution to the signaling problem. A low pressure level (a light touch by the user) is used for general tracking. A heavier touch is used to make menu selections, or to enable painting (see Figure 8 for the tablet states used to control painting with this program). The two levels of contact pressure allow us to make a simple but practical one finger paint program.

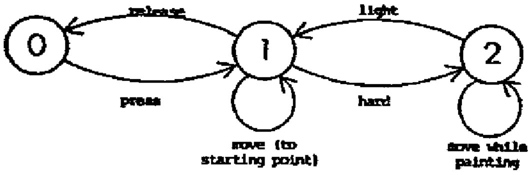

Figure 8. State diagram for painting portion of simple paint program using pressure sensing touch tablet.

This version is very much like using the one button mouse on the Apple Macintosh with MacPaint [Williams, 1984]. Thus, a simple touch tablet is not very useful, but one that reports two levels of pressure is similar in power (but not feel or applicability) to a one button mouse.[5]

### 5.3. Painting with Continuous Pressure Sensing

In the previous demonstrations, we have only implemented interaction techniques that are common using existing technology. We now introduce a technique that provides functionality beyond that obtainable using most conventional input technologies.

In this technique, we utilize a tablet capable of sensing a continuous range of touch pressure. With this additional signal, the user can control both the width of the paint trail and its path, using only one finger. The new signal, pressure, is used to control width. This is a technique that cannot be used with any mouse that we are aware of, and to our knowledge, is available on only one conventional tablet (the GTCO Digipad with pressure pen [GTCO 1982]).

We have found that using current pressure sensing tablets, the user can accurately supply two to three bits of pressure information, after about 15 minutes practice. This is sufficient for simple doodling and many other applications, but improved pressure resolution is required for high quality painting.

### 5.4. "Windows" on the Tablet: Colour Selection

We now demonstrate how the surface of the touch tablet can be *dynamically* partitioned into "windows" onto virtual input devices. We use the same basic techniques as discussed under templates (above), but show how to use them without templates. We do this in the context of a colour selection module for our paint program. This module introduces a new display, shown in Figure 9.

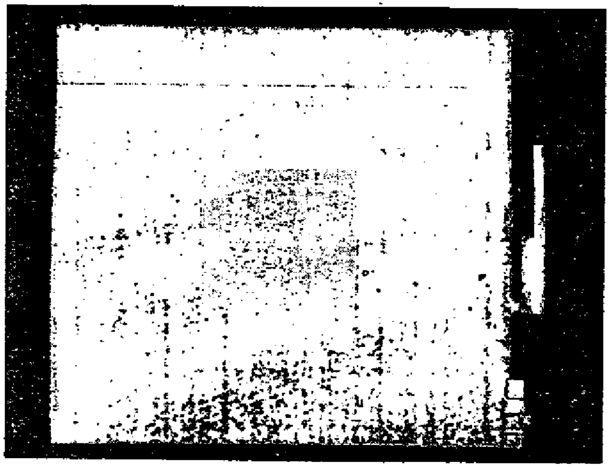

Figure 9. Colour mixing display.

In this display, the large left side consists of a colour patch surrounded by a neutral grey border. This is the patch of colour the user is working on. The right side of the display contains three bar graphs with two light buttons underneath. The primary function of the bar graphs is to provide feedback, representing relative proportions of red, green and blue in the colour patch. Along with the light buttons below, they also serve to remind the user of the current layout of the touch tablet.

In this module, the touch tablet is used as a "virtual operating console". Its layout is shown (to scale) in Figure 10. There are 3 valuators (corresponding to the bar graphs on the screen) used to control

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[5] Also, there is the problem of friction, to be discussed below under "Inherent Problems".

colour, and two buttons: one, on the right, to bring up a pop-up menu used to select the colour to be modified, and another, on the left, to exit.

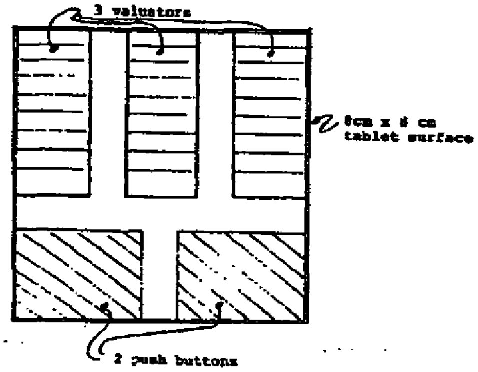

Figure 10. Layout of virtual devices on touch tablet.

The single most important point to be made in this example is that a single *physical* device is being used to implement 5 *virtual* devices (3 valuators and 2 buttons). This is analogous to the use of a display window system, in its goals, and its implementation.

The second main point is that there is nothing on the tablet to delimit the regions. This differs from the use of physical templates as previously discussed, and shows how, in the absence of the need for a physical template, we can instantly change the "windows" on the tablet, without sacrificing the ability to touch type.

We have found that when the tablet surface is small, and the partioning of the surfaces is not too complex, the users very quickly (typically in one or two minutes) learn the positions of the virtual devices relative to the edges of the tablet. More importantly, they can use the virtual devices, practically error free, without diverting attention from the display. (We have repeatedly observed this behaviour in the use of an application that uses a 10 cm square tablet that is divided into 3 sliders with a single button across the top).

Because no template is needed, there is no need for the user to pause to change a template when entering the colour mixing module. Also, at no point is the user's attention diverted from the display. These advantages cannot be achieved with any other device we know of, without consuming display real estate.

The colour of the colour patch is manipulated by *dragging* the red, green and blue values up and down with the valuators on the touch tablet. The valuators are implemented in relative mode (i.e., they are sensitive to changes in position, not absolute position), and are manipulated like one dimensional mice. For example, to make the patch more red, the user presses near the left side of the tablet, about half way to the top, and slides the finger up (see Figure 11). For larger changes, the device can be repeatedly stroked (much like stroking a mouse). Feedback is provided by changing the level in the bar graph on the screen and the colour of the patch.

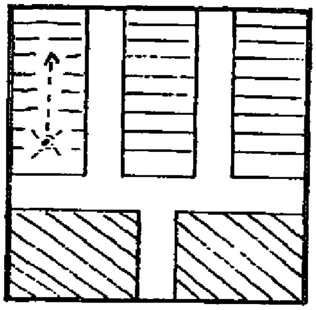

Figure 11. Increasing red content, by pressing on red valuator and sliding up.

Using a mouse, the above interaction could be approximated by placing the tracking symbol over the bars of colour, and dragging them up or down. However, if the bars are narrow, this takes acuity and concentration that distracts attention from the primary task — monitoring the colour of the patch. Furthermore, note that the touch tablet implementation does not need the bars to be displayed at all, they are only a convenience to the user. There are interfaces where, in the interests of maximizing available display area, there will be no items on the display analogous to these bars. That is, there would be nothing on the display to support an interaction technique that allows values to be manipulated by a mouse.

Finally, we can take the example one step further by introducing the use of a touch tablet that can sense multiple points of contact (e.g., [Lee, et al. 1985]). With this technology, all three colour values could be changed at the same time (for example, fading to black by drawing all three sliders down together with three fingers of one hand). This simultaneous adjustment of colours could *not* be supported by a mouse, nor any single commercially available input device we know of. Controlling several valuators with one hand is common in many operating consoles, for example: studio light control, audio mixers, and throttles for multi-engine vehicles (e.g., aircraft and boats). Hence, this example demonstrates a cost effective method for providing functionality that is currently unavailable (or available only at great cost, in the form of a custom fabricated console), but has wide applicability.

### 5.5. Summary of Examples

Through these simple examples, we have demonstrated several things:

- The ability to sense at least two levels of pressure is a virtual necessity for touch tablets, as without it, auxiliary devices must be used for signaling, and "direct manipulation" interfaces cannot be effectively supported.
- The extension to continuous pressure sensing opens up new possibilities in human-computer interaction.

- Touch tablets are superior to mice and tablets when many simple devices are to be simulated. This is because: (a) there is no need for a mechanical intermediary between the fingers and the tablet surface, (b) they allow the use of templates (including the edges of the tablet, which is a trivial but useful template), and (c) there is no need for positional feedback that would consume valuable display space.
- The ability to sense multiple points of contact radically changes the way in which users may interact with the system. The concept of multiple points of contact does not exist for, nor is it applicable to, current commercially available mice and tablets.

### 6. Inherent Problems with Touch Tablets

A problem with touch tablets that is annoying in the long term is friction between the user's finger and the tablet surface. This can be a particularly severe problem if a pressure sensitive tablet is used, and the user must make long motions at high pressure. This problem can be alleviated by careful selection of materials and care in the fabrication and calibration of the tablet.[6] Also, the user interface can be designed to avoid extended periods of high pressure.

Perhaps the most difficult problem is providing good feedback to the user when using touch tablets. For example, if a set of push-on/push-off buttons are being simulated, the traditional forms of feedback (illuminated buttons or different button heights) cannot be used. Also, buttons and other controls implemented on touch tablets lack the kinesthetic feel associated with real switches and knobs. As a result, users must be more attentive to visual and audio feedback, and interface designers must be freer in providing this feedback. (As an example of how this might be encouraged, the input "window manager" could automatically provide audible clicks as feedback for button presses).

### 7. Potential Enhancements to Touch Tablets (and other devices)

The first problem that one notices when using touch tablets is "jitter" when the finger is removed from the tablet. That is, the last few locations reported by the tablet, before it senses loss of contact, tend to be very unreliable.

This problem can be eliminated by modifying the firmware of the touch tablet controller so that it keeps a short FIFO queue of the samples that have most recently be sent to the host. When the user releases pressure, the oldest sample is retransmitted, and the queue is emptied. The length of the queue depends on the properties of the touch tablet (e.g., sensitivity, sampling rate). We have found that determining a suitable value requires only a few minutes of experimentation.

A related problem with most current tablet controllers (not just touch tablets) is that they do not inform the host computer when the user has ceased pressing on the tablet (or moved the puck out of range). This information is essential to the development of certain types of interfaces. (As already mentioned, this signal is not available from mice). Currently, one is reduced to deducing this event by timing the interval between samples sent by the tablet. Since the tablet controller can easily determine when pressure is removed (and must if it is to apply a de-jittering algorithm as above), it should share this information with the host.

Clearly, pressure sensing is an area open to development. Two pressure sensitive tablets have been developed at the University of Toronto [Sasaki, et al. 1981; Lee, et al. 1985]. One has been used to develop several experimental interfaces and was found to be a very powerful tool. They have recently become available from Elographics and Big Briar (see Appendix A). Pressure sensing is not only for touch tablets. Mice, tablet pucks and styli could all benefit by augmenting switches with strain gauges, or other pressure sensing instruments. GTCO, for example, manufactures a stylus with a pressure sensing tip [GTCO 1982], and this, like our pressure sensing touch tablets, has proven very useful.

### 8. Conclusions

We have shown that there are environments for which some devices are better adapted than others. In particular, touch tablets have advantages in many hostile environments. For this reason, we suggest that there are environments and applications where touch tablets may be the most appropriate input technology.

This being the case, we have enumerated three major distinctions between touch tablets and one button mice (although similar distinctions exist for multi-button mice and conventional tablets). These assist in identifying environments and applications where touch tablets would be most appropriate. These distinctions concern:

- limitation in the ability to signal events,
- suitability for multiple point sensing, and
- the applicability of tactile templates.

These distinctions have been reinforced, and some suggestions on how touch tablets may be used have been given, by discussing a simple user interface. From this example, and the discussion of the distinctions, we have identified some enhancements that can be made to touch tablets and other input devices. The most important of these are pressure sensing and the ability to sense multiple points of contact.

We hope that this paper motivates interface designers to consider the use of touch tablets and shows some ways to use them effectively. Also, we hope it encourages designers and manufacturers of input devices to develop and market input devices with the enhancements that we have discussed.

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[6] As a bad example, one commercial "touch" tablet requires so much pressure for reliable sensing that the finger cannot be smoothly dragged across the surface. Instead, a wooden or plastic stylus must be used, thus loosing many of the advantages of touch sensing.

The challenge for the future is to develop touch tablets that sense continuous pressure at multiple points of contact and incorporate them in practical interfaces. We believe that we have shown that this is worthwhile and have shown some practical ways to use touch tablets. However, interface designers must still do a great deal of work to determine where a mouse is better than a touch tablet and vice versa.

Finally, we have illustrated, by example, an approach to the study of input devices, summarized by the credo: "Know the interactions a device is intended to participate in, and the strengths and weaknesses of the device." This approach stresses that there is no such thing as a "good input device," only good interaction task/device combinations.

## 9. Acknowledgements

The support of this research by the Natural Sciences and Engineering Research Council of Canada is gratefully acknowledged. We are indebted to Kevin Murtagh and Ed Brown for their work on virtual input devices and windowing on input. Also, we are indebted to Elographics Corporation for having supplied us with the hardware on which some of the underlying studies are based.

We would like to thank the referees who provided many useful comments that have helped us with the presentation.

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| | |
|---|---|
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### Appendix A: Touch Tablet Sources

Big Briar: 3 by 3 inch continuous pressure sensing touch tablet

Big Briar, Inc.
Leicester, NC
28748

Chalk Board Inc.: "Power Pad", large touch table for micro-computers

Chalk Board Inc.
3772 Pleasantdale Rd.,
Atlanta, GA 30340

Elographics: various sizes of touch tablets, including pressure sensing

Elographics, Inc.
105 Randolph Toad
Oak Ridge, Tennessee
37830
(615)-482-4100

Key Tronic: Keyboard with touch pad.

Keytronic
P.O. Box 14687
Spokane, WA 99214
(509)-928-8000

KoalaPad Technologies: Approx. 5 by 7 inch touch tablet for micro-computers

Koala Technologies
3100 Patrick Henry Drive
Santa Clara, California
95050

Spiral Systems: Trazor Touch Panel, 3 by 3 inch touch tablet

Spiral System Instruments, Inc.
4853 Cordell Avenue, Suite A-10
Bethesda, Maryland
20814

TASA: 4 by 4 inch touch tablet (relative sensing only)

Touch Activated Switch Arrays Inc.
1270 Lawrence Stn. Road, Suite G
Sunnyvale, California
94089

PTO/SB/21 (11-08)
Approved for use through 12/31/2008. OMB 0651-0031
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# TRANSMITTAL FORM

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| Application Number | 11/677,958 |
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| First Named Inventor | Wayne C. WESTERMAN |
| Art Unit | 2629 |
| Examiner Name | R. Hjerpe |
| Attorney Docket Number | 106842508604 |
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## ENCLOSURES (*Check all that apply*)

☐ Fee Transmittal Form
  ☐ Fee Attached
☐ Amendment/Reply
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  ☐ Affidavits/declaration(s)
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☐ Proprietary Information
☐ Status Letter
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copies of four (4) foreign patent publications
copies of sixteen (16) non patent literature documents

Remarks

## SIGNATURE OF APPLICANT, ATTORNEY, OR AGENT

| | | | |
|---|---|---|---|
| Firm Name | MORRISON & FOERSTER LLP (Customer No. 69753) | | |
| Signature | | | |
| Printed name | Kenneth Xie | | |
| Date | December 12, 2008 | Reg. No. | 60,350 |

Via EFS Web

Client Ref. No.: P3960USC13

la-1008935

Via EFS Web
Patent
Docket No. 106842508604
Client Ref. No.: P3960USC13

# IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Patent Application of:
Wayne C. WESTERMAN et al.

Serial No.: 11/677,958

Filing Date: February 22, 2007

For: ELLIPSE FITTING FOR MULTI-TOUCH SURFACES

Examiner: R. Hjerpe

Group Art Unit: 2629

Confirmation No.: 1844

# INFORMATION DISCLOSURE STATEMENT UNDER 37 C.F.R. § 1.97 & 1.98

MS Amendment
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Dear Madam:

Pursuant to 37 C.F.R. § 1.97 and § 1.98, Applicants submit for consideration in the above-identified application the documents listed on the attached Form PTO/SB/08a/b. Copies of four (4) of the foreign documents and sixteen (16) of the non-patent literature documents (all of which shows a check mark in the translation box) are submitted herewith. However, copies of the remaining documents cited in the attached Form PTO/SB/08a/b were previously submitted in an Information Disclosure Statement and/or Office Action, directed to the related application Serial Number 11/015,434 (now U.S. Patent No. 7,339,580), filed December 17, 2004, and, accordingly, copies are not included herewith. This protocol conforms with 37 C.F.R. §1.98(d) and M.P.E.P. 609.02(A)(2). The Examiner is requested to make these documents of record in the application.

This Information Disclosure Statement is submitted:

☐ With the application; accordingly, no fee or separate requirements are required.

☒ Within three months of the application filing date or before mailing of a first Office Action on the merits; accordingly, no fee or separate requirements are required. However, if applicable, a certification under 37 C.F.R. § 1.97 (e)(1) has been provided.

Applicants would appreciate the Examiner initialing and returning the Form PTO/SB/08a/b, indicating that the information has been considered and made of record herein.

The information contained in this Information Disclosure Statement under 37 C.F.R. § 1.97 and § 1.98 is not to be construed as a representation that: (i) a complete search has been made; (ii) additional information material to the examination of this application does not exist; (iii) the information, protocols, results and the like reported by third parties are accurate or enabling; or (iv) the above information constitutes prior art to the subject invention.

In the unlikely event that the transmittal form is separated from this document and the Patent and Trademark Office determines that an extension and/or other relief (such as payment of a fee under 37 C.F.R. § 1.17 (p)) is required, Applicants petition for any required relief including extensions of time and authorize the Director to charge the cost of such petition and/or other fees due in connection with the filing of this document to **Deposit Account No. 03-1952** referencing 106842508604.

Dated: December 12, 2008

Respectfully submitted,

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Patent
Docket No. 106842508604
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## IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

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| In re Patent Application of:<br>Wayne C. WESTERMAN et al. | Examiner: R. Hjerpe |
| Serial No.: 11/677,958 | Group Art Unit: 2629 |
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| For: ELLIPSE FITTING FOR MULTI-TOUCH SURFACES | |

## SUPPLEMENTAL INFORMATION DISCLOSURE STATEMENT UNDER 37 C.F.R. § 1.97 & 1.98

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Dear Madam:

Pursuant to 37 C.F.R. §1.97 and § 1.98, Applicants submit for consideration in the above-identified application the documents listed on the attached Form PTO/SB/08a/b. A copy of U.S. Patent Application No. 11/332,861 (document number 48) on the attached Form PTO/SB/08a/b is not included herewith. This protocol conforms with the waiver of the requirement under 37 C.F.R. §1.98 to provide copies of pending U.S. Patent Applications. Copies of foreign documents and non-patent literature are submitted herewith. The Examiner is requested to make these documents of record.

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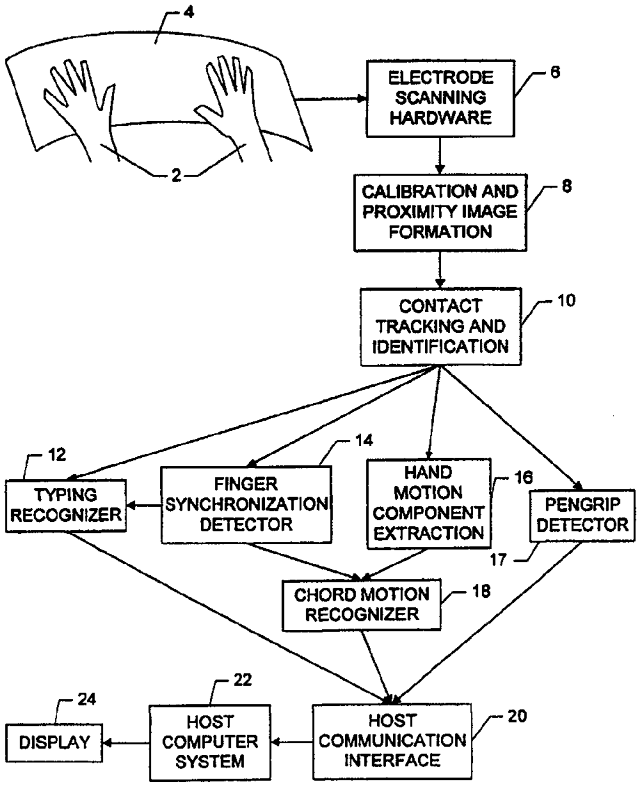
**(54) Title:** METHOD AND APPARATUS FOR INTEGRATING MANUAL INPUT

**(57) Abstract**

Apparatus and methods are disclosed for simultaneously tracking multiple finger (202–204) and palm (206, 207) contacts as hands approach, touch, and slide across a proximity–sensing, compliant, and flexible multi–touch surface (2). The surface consists of compressible cushion (32), dielectric electrode (33), and circuitry layers. A simple proximity transduction circuit is placed under each electrode to maximize the signal–to–noise ratio and to reduce wiring complexity. Scanning and signal offset removal on electrode array produces low–noise proximity images. Segmentation processing of each proximity image constructs a group of electrodes corresponding to each distinguishable contacts and extracts shape, position and surface proximity features for each group. Groups in successive images which correspond to the same hand contact are linked by a persistent path tracker (245) which also detects individual contact touchdown and liftoff. Classification of intuitive hand configurations and motions enables unprecedented integration of typing, resting, pointing, scrolling, 3D manipulation, and handwriting into a versatile, ergonomic computer input device.



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# METHOD AND APPARATUS FOR INTEGRATING MANUAL INPUT

## BACKGROUND OF THE INVENTION

The present application is based upon U.S. provisional patent application Serial No. 60/072,509, filed January 26, 1998, and the U.S. utility application Serial No. 09,236,513, filed January 25, 1999.

### A. Field of the Invention

The present invention relates generally to methods and apparatus for data input, and, more particularly, to a method and apparatus for integrating manual input.

### B. Description of the Related Art

Many methods for manual input of data and commands to computers are in use today, but each is most efficient and easy to use for particular types of data input. For example, drawing tablets with pens or pucks excel at drafting, sketching, and quick command gestures. Handwriting with a stylus is convenient for filling out forms which require signatures, special symbols, or small amounts of text, but handwriting is slow compared to typing and voice input for long documents. Mice, finger-sticks and touchpads excel at cursor pointing and graphical object manipulations such as drag and drop. Rollers, thumbwheels and trackballs excel at panning and scrolling. The diversity of tasks that many computer users encounter in a single day call for all of these techniques, but few users will pay for a multitude of input devices, and the separate devices are often incompatible in a usability and an ergonomic sense. For instance, drawing tablets are a must for graphics professionals, but switching between drawing and typing is inconvenient because the pen must be put down or held awkwardly between the fingers while typing. Thus, there is a long-felt need in the art for a manual input device which is cheap yet offers convenient integration of common manual input techniques.

Speech recognition is an exciting new technology which promises to relieve some of the input burden on user hands. However, voice is not appropriate for inputting all types of data either. Currently, voice input is best-suited for dictation of long text documents. Until natural language recognition matures sufficiently that very high level voice commands can be understood by the computer, voice will have little advantage over keyboard hot-keys and mouse menus for command and control. Furthermore, precise pointing, drawing, and manipulation of graphical objects is difficult with voice commands, no matter how well speech is understood. Thus, there will always be a need in the art for multi-function manual input devices which supplement voice input.

A generic manual input device which combines the typing, pointing, scrolling, and handwriting capabilities of the standard input device collection must have ergonomic, economic, and productivity advantages which outweigh the unavoidable sacrifices of abandoning device specialization. The generic device must tightly integrate yet clearly distinguish the different types of input. It should therefore appear modeless to the user in the sense that the user should not need to provide explicit mode switch signals such as buttonpresses, arm relocations, or stylus pickups before switching from one input activity to another. Epidemiological studies suggest that repetition and force multiply in causing repetitive strain injuries. Awkward postures, device activation force, wasted motion, and repetition should be minimized to improve ergonomics. Furthermore, the workload should be spread evenly over all available muscle groups to avoid repetitive strain.

Repetition can be minimized by allocating to several graphical manipulation channels those tasks which require complex mouse pointer motion sequences. Common graphical user interface operations such as finding and manipulating a scroll bar or slider control are much less efficient than specialized finger motions which cause scrolling directly, without the step of repositioning the cursor over an on-screen control. Preferably the graphical manipulation channels should be distributed amongst many finger and hand motion combinations to spread the workload. Touchpads and mice with auxilliary scrolling controls such as the Cirque® Smartcat touchpad with edge scrolling, the IBM® ScrollPoint™ mouse with embedded pointing stick, and the Roller Mouse described in U.S. Patent No. 5,530,455 to Gillick et al. represent small improvements in this area, but still do not provide enough direct manipulation channels to eliminate many often-used cursor motion sequences. Furthermore, as S. Zhai et al. found in "Dual Stream Input for Pointing and Scrolling," Proceedings of CHI '97 Extended Abstracts (1997), manipulation of more than two degrees of freedom at a time is very difficult with these devices, preventing simultaneous panning, zooming and rotating.

Another common method for reducing excess motion and repetition is to automatically continue pointing or scrolling movement signals once the user has stopped moving or lifts the finger. Related art methods can be distinguished by the conditions under which such motion continuation is enabled. In U.S. Patent No. 4,734,685, Watanabe continues image panning when the distance and velocity of pointing device movement exceed thresholds. Automatic panning is stopped by moving the pointing device back in the opposite direction, so stopping requires additional precise movements. In U.S. Patent No. 5,543,591 to Gillespie et al., motion continuation occurs when the finger enters an edge border region around a small touchpad. Continued motion speed is fixed and the direction corresponds to the direction from the center of the touchpad to the finger at the edge. Continuation mode ends when the finger leaves the border region or lifts off the pad. Disadvantageously, users sometimes pause at the edge of the pad without intending for cursor motion to continue, and the unexpected motion continuation becomes annoying. U.S. Patent No. 5,327,161 to Logan et al. describes motion continuation when the finger enters a border area as well, but in an alternative trackball emulation mode, motion continuation can be a function solely of lateral finger velocity and direction at liftoff. Motion continuation decays due to a friction factor or can be stopped by a subsequent touchdown on the surface. Disadvantageously, touch velocity at liftoff is not a reliable indicator of the user's desire for motion continuation since when approaching a large target on a display at high speeds the user may not stop the pointer completely before liftoff. Thus it would be an advance in the art to provide a motion continuation method which does not become activated unexpectedly when the user really intended to stop pointer movement at a target but happens to be on a border or happens to be moving at significant speed during liftoff.

Many attempts have been made to embed pointing devices in a keyboard so the hands don't have to leave typing position to access the pointing device. These include the integrated pointing key described in U.S. Patent No. 5,189,403 to Franz et al., the integrated pointing stick disclosed by J. Rutledge and T. Selker in "Force-to-Motion Functions for Pointing," Human-Computer Interaction - INTERACT '90, pp. 701-06 (1990), and the position sensing keys described in U.S. Patent No. 5,675,361 to Santilli. Nevertheless, the limited movement range and resolution of these devices leads to poorer pointing speed and accuracy than a mouse , and they add mechanical complexity to keyboard construction. Thus there exists a need in the art for pointing methods with higher resolution, larger movement range, and more degrees of freedom yet which are easily accessible from typing hand positions.

Touch screens and touchpads often distinguish pointing motions from emulated button clicks or keypresses by assuming very little lateral fingertip motion will occur during taps on the touch surface which are intended as clicks. Inherent in these methods is the assumption that tapping will usually be straight down from the suspended finger position, minimizing those components of finger motion tangential to the surface. This is a valid assumption if the surface is not finely divided into distinct key areas or if the user does a slow, "hunt and peck" visual search for each key before striking. For example, in U.S. No. Patent 5,543,591 to Gillespie et al., a touchpad sends all lateral motions to the host computer as cursor movements. However, if the finger is lifted soon enough after touchdown to count as a tap and if the accumulated lateral motions are not excessive, any sent motions are undone and a mouse button click is sent instead. This method only works for mouse commands such as pointing which can safely be undone, not for dragging or other manipulations. In U.S. Patent No. 5,666,113 to Logan, taps with less than about 1/16" lateral motion activate keys on a small keypad while lateral motion in excess of 1/16" activates cursor control mode. In both patents cursor mode is invoked by default when a finger stays on the surface a long time.

However, fast touch typing on a surface divided into a large array of key regions tends to produce more tangential motions along the surface than related art filtering techniques can tolerate. Such an array contains keys in multiple rows and columns which may not be directly under the fingers, so the user must reach with the hand or flex or extend fingers to touch many of the key regions. Quick reaching and extending imparts significant lateral finger motion while the finger is in the air which may still be present when the finger contacts the surface. Glancing taps with as much as 1/4" lateral motion measured at the surface can easily result. Attempting to filter or suppress this much motion would make the cursor seem sluggish and unresponsive. Furthermore, it may be desirable to enter a typematic or automatic key repeat mode instead of pointing mode when the finger is held in one place on the surface. Any lateral shifting by the fingertip during a prolonged finger press would also be picked up as cursor jitter without heavy filtering. Thus, there is a need in the art for a method to distinguish keying from pointing on the same surface via more robust hand configuration cues than lateral motion of a single finger.

An ergonomic typing system should require minimal key tapping force, easily distinguish finger taps from resting hands, and cushion the fingers from the jarring force of surface impact. Mechanical and membrane keyboards rely on the spring force in the keyswitches to prevent activation when the hands are resting on the keys. This causes an irreconcilable tradeoff between the ergonomic desires to reduce the fatigue from key activating force and to relax the full weight of the hands onto the keys during rest periods. Force minimization on touch surfaces is possible with capacitive or active optical sensing, which do not rely on finger pressure, rather than resistive-membrane or surface-acoustic-wave sensing techniques. The related art touch devices discussed below will become confused if a whole hand, including its four fingertips, a thumb and possibly palm heels, rests on the surface. Thus, there exists a long felt need in the art for a multi-touch surface typing system based on zero-force capacitive sensing which can tolerate resting hands and a surface cushion.

An ergonomic typing system should also adapt to individual hand sizes, tolerate variations in typing style, and support a range of healthy hand postures. Though many ergonomic keyboards have been proposed, mechanical keyswitches can only be repositioned at great cost. For example, the keyboard with concave keywells described by Hargreaves et al. in U.S. Patent No. 5,689,253 fits most hands well but also tends to lock the arms in a single position. A touch surface key layout could easily be morphed, translated, or arbitrarily reconfigured as long as the changes didn't confuse the user. However, touch surfaces may not provide as much laterally orienting tactile feedback as the edges of mechanical keyswitches. Thus, there exists a need in the art for a surface typing recognizer which can adapt a key layout to fit individual hand postures and which can sustain typing accuracy if the hands drift due to limited tactile feedback.

Handwriting on smooth touch surfaces using a stylus is well-known in the art, but it typically doesn't integrate well with typing and pointing because the stylus must be put down somewhere or held awkwardly during other input activities. Also, it may be difficult to distinguish the handwriting activity of the stylus from pointing motions of a fingertip. Thus there exists a need in the art for a method to capture coarse handwriting gestures without a stylus and without confusing them with pointing motions.

Many of the input differentiation needs cited above could be met with a touch sensing technology which distinguishes a variety of hand configurations and motions such as sliding finger chords and grips. Many mechanical chord keyboards have been designed to detect simultaneous downward activity from multiple fingers, but they do not detect lateral finger motion over a large range. Related art shows several examples of capacitive touchpads which emulate a mouse or keyboard by tracking a single finger. These typically measure the capacitance of or between elongated wires which are laid out in rows and columns. A thin dielectric is interposed between the row and column layers. Presence of a finger perturbs the self or mutual capacitance for nearby electrodes. Since most of these technologies use projective row and column sensors which integrate on one electrode the proximity of all objects in a particular row or column, they cannot uniquely determine the positions of two or more objects, as discussed in S. Lee, "A Fast Multiple-Touch-Sensitive Input Device," University of Toronto Masters Thesis (1984). The best they can do is count fingertips which happen to lie in a straight row, and even that will fail if a thumb or palm is introduced in the same column as a fingertip.

In U.S. Patent Nos. 5,565,658 and 5,305,017, Gerpheide et al. measure the mutual capacitance between row and column electrodes by driving one set of electrodes at some clock frequency and sensing how much of that frequency is coupled onto a second electrode set. Such synchronous measurements are very prone to noise at the driving frequency, so to increase signal-to-noise ratio they form virtual electrodes comprised of multiple rows or multiple columns, instead of a single row and column, and scan through electrode combinations until the various mutual capacitances are nulled or balanced. The coupled signal increases with the product of the rows and columns in each virtual electrodes, but the noise only increases with the sum, giving a net gain in signal-to-noise ratio for virtual electrodes consisting of more than two rows and two columns. However, to uniquely distinguish multiple objects, virtual electrode sizes would have to be reduced so the intersection of the row and column virtual electrodes would be no larger than a finger tip, i.e. about two rows and two columns, which will degrade the signal-to-noise ratio. Also, the signal-to-noise ratio drops as row and column lengths increase to cover a large area.

In U.S. Patent Nos. 5,543,591, 5,543,590, and 5,495,077, Gillespie et al measure the electrode-finger self-capacitance for row and column electrodes independently. Total electrode capacitance is estimated by measuring the electrode voltage change caused by injecting or removing a known amount of charge in a known time. All electrodes can be measured simultaneously if each electrode has its own drive/sense circuit. The centroid calculated from all row and column electrode signals establishes an interpolated vertical and horizontal position for a single object. This method may in general have higher signal-to-noise ratio than synchronous methods, but the signal-to-noise ratio is still degraded as row and column lengths increase. Signal-to-noise ratio is especially important for accurately locating objects which are floating a few millimeters above the pad. Though this method can detect such objects, it tends to report their position as being near the middle of the pad, or simply does not detect floating objects near the edges.

Thus there exists a need in the art for a capacitance-sensing apparatus which does not suffer from poor signal-to-noise ratio and the multiple finger indistinguishability problems of touchpads with long row and column electrodes.

U.S. Patent No. 5,463,388 to Boie et al. has a capacitive sensing system applicable to either keyboard or mouse input, but does not consider the problem of integrating both types of input simultaneously. Though they mention independent detection of arrayed unit-cell electrodes, their capacitance transduction circuitry appears too complex to be economically reproduced at each electrode. Thus the long lead wires connecting electrodes to remote signal conditioning circuitry can pickup noise and will have significant capacitance compared to the finger-electrode self-capacitance, again limiting signal-to-noise ratio. Also, they do not recognize the importance of independent electrodes for multiple finger tracking, or mention how to track multiple fingers on an independent electrode array.

Lee built an early multi-touch electrode array with 7 mm by 4 mm metal electrodes arranged in 32 rows and 64 columns. The "Fast Multiple-Touch-Sensitive Input Device (FMTSID)" total active area measured 12" by 16", with a .075 mm Mylar dielectric to insulate fingers from electrodes. Each electrode had one diode connected to a row charging line and a second diode connected to a column discharging line. Electrode capacitance changes were measured singly or in rectangular groups by raising the voltage on one or more row lines, selectively charging the electrodes in those rows, and then timing the discharge of selected columns to ground through a discharge resistor. Lee's design required only two diodes per electrode, but the principal disadvantage of Lee's design is that the column diode reverse bias capacitances allowed interference between electrodes in the same column.

All of the related capacitance sensing art cited above utilize interpolation between electrodes to achieve high pointing resolution with economical electrode density. Both Boie et al. and Gillespie et al. discuss computation of a centroid from all row and column electrode readings. However, for multiple finger detection, centroid calculation must be carefully limited around local maxima to include only one finger at a time. Lee utilizes a bisective search technique to find local maxima and then interpolates only on the eight nearest neighbor electrodes of each local maximum electrode. This may work fine for small fingertips, but thumb and palm contacts may cover more than nine electrodes. Thus there exists a need in the art for improved means to group exactly those electrodes which are covered by each distinguishable hand contact and to compute a centroid from such potentially irregular groups.

To take maximum advantage of multi-touch surface sensing, complex proximity image processing is necessary to track and identify the parts of the hand contacting the surface at any one time. Compared to passive optical images, proximity images provide clear indications of where the body contacts the surface, uncluttered by luminosity variation and extraneous objects in the background. Thus proximity image filtering and segmentation stages can be simpler and more reliable than in computer vision approaches to free-space hand tracking such as S. Ahmad, "A Usable Real-Time 3D Hand Tracker", Proceedings of the 28th Asilomar Conference on Signals, Systems, and Computers - Part 2, vol. 2, *IEEE* (1994) or Y. Cui and J. Wang, "Hand Segmentation Using Learning-Based Prediction and Verification for Hand Sign Recognition," Proceedings of the 1996 IEEE Computer Society Conference on Computer Vision and Pattern Recognition, pp. 88-93 (1996). However, parts of the hand such as intermediate finger joints and the center of the palms do not show up in capacitive proximity images at all if the hand is not flattened on the surface. Without these intermediate linkages between fingertips and palms the overall hand structure can only be guessed at, making hand contact identification very difficult. Hence the optical flow and contour tracking techniques which have been applied to free-space hand sign language recognition as in F. Quek, "Unencumbered Gestural Interaction," IEEE Multimedia, vol. 3, pp. 36-47 (1996), do not address the special challenges of proximity image tracking.

Synaptics Corp. has successfully fabricated their electrode array on flexible mylar film rather than stiff circuit board. This is suitable for conforming to the contours of special products, but does not provide significant finger cushioning for large surfaces. Even if a cushion was placed under the film, the lack of stretchability in the film, leads, and electrodes would limit the compliance afforded by the compressible material. Boie et al suggests that placing compressible insulators on top of the electrode array cushions finger impact. However, an insulator more than about one millimeter thick would seriously attenuate the measured finger-electrode capacitances. Thus there exists a need in the art for a method to transfer finger capacitance influences through an arbitrarily thick cushion.

## SUMMARY OF THE INVENTION

It is a primary object of the present invention to provide a system and method for integrating different types of manual input such as typing, multiple degree-of-freedom manipulation, and handwriting on a multi-touch surface.

It is also an object of the present invention to provide a system and method for distinguishing different types of manual input such as typing, multiple degree-of-freedom manipulation, and handwriting on a multi-touch surface, via different hand configurations which are easy for the user to learn and easy for the system to recognize.

It is a further object of the present invention to provide an improved capacitance-transducing apparatus that is cheaply implemented near each electrode so that two-dimensional sensor arrays of arbitrary size and resolution can be built without degradation in signal to noise.

It is a further object of the present invention to provide an electronic system which minimizes the number of sensing electrodes necessary to obtain proximity images with such resolution that a variety of hand configurations can be distinguished.

Yet another object of the present invention is to provide a multi-touch surface apparatus which is compliant and contoured to be comfortable and ergonomic under extended use.

Yet another object of the present invention is to provide tactile key or hand position feedback without impeding hand resting on the surface or smooth, accurate sliding across the surface.

It is a further object of the present invention to provide an electronic system which can provide images of flesh proximity to an array of sensors with such resolution that a variety of hand configurations can be distinguished.

It is another object of the present invention to provide an improved method for invoking cursor motion continuation only when the user wants it by not invoking it when significant deceleration is detected.

Another object of the present invention is to identify different hand parts as they contact the surface so that a variety of hand configurations can be recognized and used to distinguish different kinds of input activity.

Yet another object of the present invention is to reliably extract rotation and scaling as well as translation degrees of freedom from the motion of two or more hand contacts to aid in navigation and manipulation of two-dimensional electronic documents.

It is a further object of the present invention to reliably extract tilt and roll degrees of freedom from hand pressure differences to aid in navigation and manipulation of three-dimensional environments.

Additional objects and advantages of the invention will be set forth in part in the description which follows, and in part will be obvious from the description, or may be learned by practice of the invention. The objects and advantages of the invention will be realized and attained by means of the elements and combinations particularly pointed out in the appended claims.

To achieve the objects and in accordance with the purpose of the invention, as embodied and broadly described herein, the invention comprises a sensing device that is sensitive to changes in self-capacitance brought about by changes in proximity of a touch device to the sensing device, the sensing device comprising: two electrical switching means connected together in series having a common node, an input node, and an output node; a dielectric-covered sensing electrode connected to the common node between the two switching means; a power supply providing an approximately constant voltage connected to the input node of the series-connected switching means; an integrating capacitor to accumulate charge transferred during multiple consecutive switchings of the series connected switching means; another switching means connected in parallel across the integrating capacitor to deplete its residual charge; and a voltage-to-voltage translation device connected to the output node of the series-connected switching means which produces a voltage representing the magnitude of the self-capacitance of the sensing device. Alternatively, the sensing device comprises: two electrical switching means connected together in series having a common node, an input node, and an output node; a dielectric-covered sensing electrode connected to the common node between the two switching means; a power supply providing an approximately constant voltage connected to the input node of the series-connected switching means; and an integrating current-to-voltage translation device connected to the output node of the series connected switching means, the current-to-voltage translation device producing a voltage representing the magnitude of the self-capacitance of the sensing device.

To further achieve the objects, the present invention comprises a multi-touch surface apparatus for detecting a spatial arrangement of multiple touch devices on or near the surface of the multi-touch apparatus, comprising: one of a rigid or flexible surface; a plurality of two-dimensional arrays of one of the sensing devices (recited in the previous paragraph) arranged on the surface in groups wherein the sensing devices within a group have their output nodes connected together and share the same integrating capacitor, charge depletion switch, and voltage-to-voltage translation circuitry; control circuitry for enabling a single sensor device from each two-dimensional array; means for selecting the sensor voltage data from each two-dimensional array; voltage measurement circuitry to convert sensor voltage data to a digital code; and circuitry for communicating the digital code to another electronic device. The sensor voltage data selecting means comprises one of a multiplexing circuitry and a plurality of voltage measurement circuits.

To still further achieve the objects, the present invention comprises a multi-touch surface apparatus for sensing diverse configurations and activities of touch devices and generating integrated manual input to one of an electronic or electro- mechanical device, the apparatus comprising: an array of one of the proximity sensing devices described above; a dielectric cover having symbols printed thereon that represent action-to-be-taken when engaged by the touch devices; scanning means for forming digital proximity images from the array of sensing devices; calibrating means for removing background offsets from the proximity images; recognition means for interpreting the configurations and activities of the touch devices that make up the proximity images; processing means for generating input signals in response to particular touch device configurations and motions; and communication means for sending the input signals to the electronic or electro-mechanical device.

To even further achieve the objects, the present invention comprises a multi-touch surface apparatus for sensing diverse configurations and activities of fingers and palms of one or more hands near the surface and generating integrated manual input to one of an electronic or electro-mechanical device, the apparatus comprising: an array of proximity sensing means embedded in the surface; scanning means for forming digital proximity images from the proximities measured by the sensing means; image segmentation means for collecting into groups those proximity image pixels intensified by contact of the same distinguishable part of a hand; contact tracking means for parameterizing hand contact features and trajectories as the contacts move across successive proximity images; contact identification means for determining which hand and which part of the hand is causing each surface contact; synchronization detection means for identifying subsets of identified contacts which touchdown or liftoff the surface at approximately the same time, and for generating command signals in response to synchronous taps of multiple fingers on the surface; typing recognition means for generating intended key symbols from asynchronous finger taps; motion component extraction means for compressing multiple degrees of freedom of multiple fingers into degrees of freedom common in two and three dimensional graphical manipulation; chord motion recognition means for generating one of command and cursor manipulation signals in response to motion in one or more extracted degrees of freedom by a selected combination of fingers; pen grip detection means for recognizing contact arrangements which resemble the configuration of the hand when gripping a pen, generating inking signals from motions of the inner fingers, and generating cursor manipulation signals from motions of the palms while the inner fingers are lifted; and communication means for sending the sensed configurations and activities of finger and palms to one of the electronic and electro-mechanical device.

To further achieve the objects, the present invention comprises a method for tracking and identifying hand contacts in a sequence of proximity images in order to support interpretation of hand configurations and activities related to typing, multiple degree-of-freedom manipulation via chords, and handwriting, the method comprising the steps of: segmenting each proximity image into groups of electrodes which indicate significant proximity, each group representing proximity of a distinguishable hand part or other touch device; extracting total proximity, position, shape, size, and orientation parameters from each group of electrodes; tracking group paths through successive proximity images including detection of path endpoints at contact touchdown and liftoff; computing velocity and filtered position vectors along each path; assigning a hand and finger identity to each contact path by incorporating relative path positions and velocities, individual contact features, and previous estimates of hand and finger positions; and maintaining estimates of hand and finger positions from trajectories of paths currently assigned to the fingers, wherein the estimates provide high level feedback to bias segmentations and identifications in future images.

To still further achieve the objects, the present invention comprises a method for integrally extracting multiple degrees of freedom of hand motion from sliding motions of two or more fingers of a hand across a multi-touch surface, one of the fingers preferably being the opposable thumb, the method comprising the steps of: tracking across successive scans of the proximity sensor array the trajectories of individual hand parts on the surface; finding an innermost and an outermost finger contact from contacts identified as fingers on the given hand; computing a scaling velocity component from a change in a distance between the innermost and outermost finger contacts; computing a rotational velocity component from a change in a vector angle between the innermost and outermost finger contacts; computing a translation weighting for each contacting finger; computing translational velocity components in two dimensions from a translation weighted average of the finger velocities tangential to surface; suppressively filtering components whose speeds are consistently lower than the fastest components; transmitting the filtered velocity components as control signals to an electronic or electro-mechanical device.

To even further achieve the objects, the present invention comprises a manual input integration method for supporting diverse hand input activities such as resting the hands, typing, multiple degree-of-freedom manipulation, command gesturing and handwriting on a multi-touch surface, the method enabling users to instantaneously switch between the input activities by placing their hands in different configurations comprising distinguishable combinations of relative hand contact timing, proximity, shape, size, position, motion and/or identity across a succession of surface proximity images, the method comprising the steps of: tracking each touching hand part across successive proximity images; measuring the times when each hand part touches down and lifts off the surface; detecting when hand parts touch down or lift off simultaneously; producing discrete key symbols when the user asynchronously taps, holds, or slides a finger on keyregions defined on the surface; producing discrete mouse button click commands, key commands, or no signals when the user synchronously taps two or more fingers from the same hand on the surface; producing gesture commands or multiple degree-of-freedom manipulation signals when the user slides two or more fingers across the surface; and sending the produced symbols, commands and manipulation signals as input to an electronic or an electro-mechanical device.

To still even further achieve the objects, the present invention comprises a method for choosing what kinds of input signals will be generated and sent to an electronic or electro-mechanical device in response to tapping or sliding of fingers on a multi-touch surface, the method comprising the following steps: identifying each contact on the surface as either a thumb, fingertip or palm; measuring the times when each hand part touches down and lifts off the surface; forming a set of those fingers which touch down from the all finger floating state before any one of the fingers lifts back off the surface; choosing the kinds of input signals to be generated by further distinctive motion of the fingers from the combination of finger identities in the set; generating input signals of this kind when further distinctive motions of the fingers occur; forming a subset any two or more fingers which touch down synchronously after at least one finger has lifted back off the surface; choosing a new kinds of input signals to be generated by further distinctive motion of the fingers from the combination of finger identities in the subset; generating input signals of this new kind when further distinctive motions of the fingers occur; and continuing to form new subsets, choose and generate new kinds of input signals in response to liftoff and synchronous touchdowns until all fingers lift off the surface.

To further achieve the objects, the present invention comprises a method for continuing generation of cursor movement or scrolling signals from a tangential motion of a touch device over a touch-sensitive input device surface after touch device liftoff from the surface if the touch device operator indicates that cursor movement continuation is desired by accelerating or failing to decelerate the tangential motion of the touch device before the touch device is lifted, the method comprising the following steps: measuring, storing and transmitting to a computing device two or more representative tangential velocities during touch device manipulation; computing and storing a liftoff velocity from touch device positions immediately prior to the touch device liftoff; comparing the liftoff velocity with the representative tangential velocities, and entering a mode for continuously moving the cursor if a tangential liftoff direction approximately equals the representative tangential directions and a tangential liftoff speed is greater than a predetermined fractional multiple of representative tangential speeds; continuously transmitting cursor movement signals after liftoff to a computing device such that the cursor movement velocity corresponds to one of the representative tangential velocities; and ceasing transmission of the cursor movement signals when the touch device engages the surface again, if comparing means detects significant deceleration before liftoff, or if the computing device replies that the cursor can move no farther or a window can scroll no farther.

It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory only and are not restrictive of the invention, as claimed.

## BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate several embodiments of the invention and together with the description, serve to explain the principles of the invention. In the drawings:

FIG. **1** is a block diagram of the integrated manual input apparatus;

FIG. **2** is a schematic drawing of the proximity sensor with voltage amplifier;

FIG. **3** is a schematic drawing of the proximity sensor with integrating current amplifier;

FIG. **4** is a schematic drawing of the proximity sensor implemented with field effect transistors;

FIG. **5** is a schematic drawing of the proximity sensor as used to implement 2D arrays of proximity sensors;

FIG. **6** is a block diagram showing a typical architecture for a 2D array of proximity sensors where all sensors share the same amplifier;

FIG. **7** is a block diagram of circuitry used to convert proximity sensor output to a digital code;

FIG. **8** is a block diagram showing a typical architecture for a 2D array of proximity sensors where sensors within a row share the same amplifier;

FIG. **9** is a schematic of a circuit useful for enabling the output gates of all proximity sensors within a group (arranged in columns);

FIG. **10** is a side view of a 2D proximity sensor array that is sensitive to the pressure exerted by non-conducting touch objects;

FIG. **11** is a side view of a 2D proximity sensor array that provides a compliant surface without loss of spatial sensitivity;

FIG. **12** is a side view of a 2D proximity sensor array that is sensitive to both the proximity of conducting touch objects and to the pressure exerted by non-conducting touch objects;

FIG. **13** is an example proximity image of a hand flattened onto the surface with fingers outstretched;

FIG. **14** is an example proximity image of a hand partially closed with fingertips normal to surface;

FIG. **15** is an example proximity image of a hand in the pen grip configuration with thumb and index fingers pinched;

FIG. **16** is a data flow diagram of the hand tracking and contact identification system;

FIG. **17** is a flow chart of hand position estimation;

FIG. **18** is a data flow diagram of proximity image segmentation;

FIG. **19** is a diagram of the boundary search pattern during construction of an electrode group;

FIG. **20**A is a diagram of the segmentation strictness regions with both hands in their neutral, default position on surface;

FIG. **20**B is a diagram of the segmentation strictness regions when the hands are in asymmetric positions on surface;

FIG. **20**C is a diagram of the segmentation strictness regions when the right hand crosses to the left half of the surface and the left hand is off the surface;

FIG. **21** is a flow chart of segmentation edge testing;

FIG. **22** is a flow chart of persistent path tracking;

FIG. **23** is a flow chart of the hand part identification algorithm;

FIG. **24** is a Voronoi cell diagram constructed around hand part attractor points;

FIG. **25**A is a plot of orientation weighting factor for right thumb, right inner palm, and left outer palm versus contact orientation;

FIG. **25**B is a plot of thumb size factor versus contact size;

FIG. **25**C is a plot of palm size factor versus ratio of total contact proximity to contact eccentricity;

FIG. **25**D is a plot of palm separation factor versus distance between a contact and its nearest neighbor contact;

FIG. **26** is a flow chart of the thumb presence verification algorithm;

FIG. **27** is a flow chart of an alternative hand part identification algorithm;

FIG. **28** is a flow chart of the pen grip detection process;

FIG. **29** is a flow chart of the hand identification algorithm;

FIGS. **30**A-C show three different hand partition hypotheses for a fixed arrangement of surface contacts;

FIG. **31**A is a plot of the hand clutching direction factor versus horizontal hand velocity;

FIG. **31**B is a plot of the handedness factor versus vertical position of outermost finger relative to next outermost;

FIG. **31**C is a plot of the palm cohesion factor versus maximum horizontal separation between palm contacts within a hand;

FIG. **32** is a plot of the inner finger angle factor versus the angle between the innermost and next innermost finger contacts;

FIG. **33** is a plot of the inter-hand separation factor versus the estimated distance between the right thumb and left thumb;

FIG. **34** is a flow chart of hand motion component extraction;

FIG. **35** is a diagram of typical finger trajectories when hand is contracting;

FIG. **36** is a flow chart of radial and angular hand velocity extraction;

FIG. **37** is a flow chart showing extraction of translational hand velocity components;

FIG. **38** is a flow chart of differential hand pressure extraction;

FIG. **39**A is a flow chart of the finger synchronization detection loop;

FIG. **39**B is a flow chart of chord tap detection;

FIG. **40**A is a flow chart of the chord motion recognition loop;

FIG. **40**B is a flow chart of chord motion event generation;

FIG. **41** is a flow chart of key layout morphing;

FIG. **42** is a flow chart of the keypress detection loop;

FIG. **43**A is a flow chart of the keypress acceptance and transmission loop; and

FIG. **43**B is a flow chart of typematic emulation.

## DESCRIPTION OF THE PREFERRED EMBODIMENTS

Reference will now be made in detail to the present preferred embodiments of the invention, examples of which are illustrated in the accompanying drawings. Wherever possible, the same reference numbers will be used throughout the drawings to refer to the same or like parts.

FIG. **1** is a system block diagram of the entire integrated manual input apparatus. Sensors embedded in the multi-touch surface **2** detect proximity of entire flattened hands **4**, fingertips, thumbs, palms, and other conductive touch devices to the surface **2**. In a preferred embodiment, the surface is large enough to comfortably accommodate both hands **4** and is arched to reduce forearm pronation.

In alternative embodiments the multi-touch surface **2** may be large enough to accommodate motion of one hand, but may be flexible so it can be fitted to an armrest or clothing.

Electronic scanning hardware **6** controls and reads from each proximity sensor of a sensor array. A calibration module **8** constructs a raw proximity image from a complete scan of the sensor array and subtracts off any background sensor offsets. The background sensor offsets can simply be a proximity image taken when nothing is touching the surface.

The offset-corrected proximity image is then passed on to the contact tracking and identification module **10**, which segments the image into distinguishable hand-surface contacts, tracks and identifies them as they move through successive images.

The paths of identified contacts are passed on to a typing recognizer module **12**, finger synchronization detection module **14**, motion component extraction module **16**, and pen grip detection module **17**, which contain software algorithms to distinguish hand configurations and respond to detected hand motions.

The typing recognizer module **12** responds to quick presses and releases of fingers which are largely asynchronous with respect to the activity of other fingers on the same hand. It attempts to find the key region nearest to the location of each finger tap and forwards the key symbols or commands associated with the nearest key region to the communication interface module **20**.

The finger synchronization detector **14** checks the finger activity within a hand for simultaneous presses or releases of a subset of fingers. When such simultaneous activity is detected, it signals the typing recognizer to ignore or cancel keystroke processing for fingers contained in the synchronous subset. It also passes on the combination of finger identities in the synchronous subset to the chord motion recognizer **18**.

The motion component extraction module **16** computes multiple degrees of freedom of control from individual finger motions during easily performable hand manipulations on the surface **2**, such as hand translations, hand rotation about the wrist, hand scaling by grasping with the fingers, and differential hand tilting.

The chord motion recognizer produces chord tap or motion events dependent upon both the synchronized finger subset identified by the synchronization detector **14** and on the direction and speed of motion extracted in **16**. These events are then posted to the host communication interface **20**.

The pen grip detection module **17** checks for specific arrangements of identified hand contacts which indicate the hand is configured as if gripping a pen. If such an arrangement is detected, it forwards the movements of the gripping fingers as inking events to the host communication interface **20**. These inking events can either lay digital ink on the host computer display for drawing or signature capture purposes, or they can be further interpreted by handwriting recognition software which is well known in the art. The detailed steps within each of the above modules will be further described later.

The host communication interface keeps events from both the typing recognizer **12** and chord motion recognizer **18** in a single temporally ordered queue and dispatches them to the host computer system **22**. The method of communication between the interface **20** and host computer system **22** can vary widely depending on the function and processing power of the host computer. In a preferred embodiment, the communication would take place over computer cables via industry standard protocols such as Apple Desktop Bus, PS/2 keyboard and mouse protocol for PCs, or Universal Serial Bus (USB). In alternative embodiments the software processing of modules **10-18** would be performed within the host computer **22**. The multi-touch surface apparatus would only contain enough hardware to scan the proximity sensor array **6**, form proximity images **8**, and compress and send them to the host computer over a wireless network. The host communication interface **20** would then play the role of device driver on the host computer, conveying results of the proximity image recognition process as input to other applications residing on the host computer system **22**.

In a preferred embodiment the host computer system outputs to a visual display device **24** so that the hands and fingers **4** can manipulate graphical objects on the display screen. However, in alternative embodiments the host computer might output to an audio display or control a machine such as a robot.

The term "proximity" will only be used in reference to the distance or pressure between a touch device such as a finger and the surface **2**, not in reference to the distance between adjacent fingers. "Horizontal" and "vertical" refer to x and y directional axes within the surface plane. Proximity measurements are then interpreted as pressure in a z axis normal to the surface. The direction "inner" means toward the thumb of a given hand, and the direction "outer" means towards the pinky finger of a given hand. For the purposes of this description, the thumb is considered a finger unless otherwise noted, but it does not count as a fingertip. "Contact" is used as a general term for a hand part when it touches the surface and appears in the current proximity image, and for the group and path data structures which represent it.

FIG. **2** is a schematic diagram of a device that outputs a voltage **58** dependent on the proximity of a touch device **38** to a conductive sense electrode **33.** The proximity sensing device includes two electrical switching means **30** and **31** connected together in series having a common node **48**, an input node **46**, and an output node **45.** A thin dielectric material **32** covers the sensing electrode **33** that is electrically connected to the common node **48.** A power supply **34** providing an approximately constant voltage is connected between reference ground and the input node **46.** The two electrical switches **30** and **31** gate the flow of charge from the power supply **34** to an integrating capacitor **37**. The voltage across the integrating capacitor **37** is translated to another voltage **58** by a high-impedance voltage amplifier **35**. The plates of the integrating capacitor **37** can be discharged by closing electrical switch **36** until the voltage across the integrating capacitor **37** is near zero. The electrical switches **30** and **31** are opened and closed in sequence but are never closed at the same time, although they may be opened at the same time as shown in FIG. **2**. Electrical switch **30** is referred to as the input switch; electrical switch **31** is referred to as the output switch; and, electrical switch **36** is referred to as the shorting switch.

The proximity sensing device shown in FIG. **2** is operated by closing and opening the electrical switches **30**, **31**, and **36** in a particular sequence after which the voltage output from the amplifier **58**, which is dependent on the proximity of a touch device **38**, is recorded. Sensor operation begins with all switches in the open state as shown in FIG. **2**. The shorting switch **36** is then closed for a sufficiently long time to reduce the charge residing on the integrating capacitor **37** to a low level. The shorting switch **37** is then opened. The input switch **30** is then closed thus allowing charge to flow between the power supply and the common node **48** until the voltage across the input switch **30** becomes zero. Charge Q will accumulate on the sensing electrode **33** according to

$$Q = V\,(e*A)/D \qquad (1)$$

where V is the voltage of the power supply **34**, e is the permittivity of the dielectric sensing electrode cover **32** and the air gap between the cover and the touch device **38**, D is the thickness of this dielectric region, and A is the overlap area of the touch device **38** and the sensing electrode **33**. Therefore, the amount of charge accumulating on the sensing electrode **33** will depend, among other things, on the area of overlap of the touch device **38** and the sensing electrode **33** and the distance between the touch device **38** and the sensing electrode **33**. The input switch **30** is opened after the voltage across it has become zero, or nearly so. Soon after input switch **30** is opened the output switch **31** is closed until the voltage across it is nearly zero. Closing the output switch **31** allows charge to flow between the sensing electrode **33** and the integrating capacitor **37** resulting in a voltage change across the integrating capacitor **37** according to:

$$\text{delta } V = (V - Vc)/(1 + C*D/e*A) \qquad (2)$$

where Vc is the voltage across the integrating capacitor **37** before the output switch **31** was closed, C is the capacitance of the integrating capacitor **37**, and A and D are equal to their values when input switch **30** was closed as shown in Equation 1. Multiple switchings of the input **30** and output **31** switches as described above produce a voltage on the integrating capacitor **37** that reflects the proximity of a touch device **38** to the sensing electrode **33**.

FIG. **3A** is a schematic diagram of the proximity sensor in which the shorting transistor **36** and the voltage-to-voltage translation device **35** are replaced by a resistor **40** and a current-to-voltage translation device **41**, respectively. The integrating function of capacitor **37** shown in FIG. **2** is, in this variation of the proximity sensor, carried out by the capacitor **39** shown in FIG. **3A**. Those skilled in the art will see that this variation of the proximity sensor produces a more linear output **58** from multiple switchings of the input and output switches, depending on the relative value of the resistor **40**. Alternatively, the resistor **40** can be replaced by a shorting switch **69** (cf. FIG. **3B**) to improve linearity. Although, the circuits shown in FIG. **3** provide a more linear output than the circuit shown in FIG. **2** the circuits of FIG. **3** generally require dual power supplies while the circuit of FIG. **2** requires only one.

The electrical switches shown in FIG. **2** can be implemented with various transistor technologies: discrete, integrated, thin film, thick film, polymer, optical, etc. One such implementation is shown in FIG. **4A** where field effect transistors (FETs) are used as the input **30**, output **31**, and shorting **36** switches. The FETs are switched on and off by voltages applied to their gate terminals (**43**, **44**, and **55**). For the purpose of this description we will assume the FET is switched on when its gate voltage is logic 1 and switched off when its gate voltage is logic 0. A controller **42** is used to apply gate voltages as a function of time as shown in FIG. **4B**. In this example, a sequence of three pairs of pulses (**43** and **44**) are applied to the input and output transistor gates. Each pair of pulses **43** and **44** produces a voltage change across the integrating capacitor **37** as shown in Equation 2. The number of pulse pairs applied to input **43** and output **44** gates depends on the desired voltage across integrating capacitor **37**. In typical applications the number is between one and several hundred pulse-pairs.

FIG. **5** shows the proximity sensor circuitry appropriate for use in a system comprising an array of proximity sensors **47** as in a multi-touch surface system. The proximity sensor **47** consists of the input transistor **30**, the output transistor **31**, the sensing electrode **33**, the dielectric cover **32** for the sensing electrode **33**, and conductive traces **43**, **44**, **45**, and **46**. The conductive traces are arranged so as to allow the proximity sensors **47** comprising a 2D array to be closely packed and to share the same conductive traces, thus reducing the number of wires needed in a system. FIG. **6** shows an example of such a system where the input nodes **46** of all proximity sensors are connected together and connected to a power supply **34**. The output nodes **45** of all proximity sensors are connected together and connected to a single integrating capacitor **37**, a single shorting transistor **36**, and a single voltage-to-voltage amplifier **35**. In this implementation, a single proximity sensor **47** is enabled at a time by applying a logic 1 signal first to its input gate **43** and then to its output gate **44**. This gating of a single proximity sensor **47** one at a time is done by input gate controller **50** and output gate controller **51**. For example, to enable the proximity sensor **47** in the lower right corner the input gate controller **50** would output a logic one pulse on conductive trace **43a**. This is followed by a logic one pulse on conductive trace **44h** produced by output gate controller **51**. Repetition of this pulse as shown in FIG. **4B** would cause charge to build up on integrating capacitor **37** and a corresponding voltage to appear at the output of the amplifier **58**. The entire array of proximity sensors **47** is thus scanned by enabling a single sensor at a time and recording its output.

FIG. **7A** is a schematic of typical circuitry useful for converting the proximity sensor output **58** to a digital code appropriate for processing by computer. The proximity sensor output **58** is typically non-zero even when there is no touch device (e.g., ref. no. **38** in FIG. **2**) nearby. This non-zero signal is due to parasitic or stray capacitance present at the common node **48** of the proximity sensor and is of relatively constant value. It is desirable to remove this non-zero background signal before converting the sensor output **58** to a digital code. This is done by using a differential amplifier **64** to subtract a stored record of the background signal **68** from the sensor output **58**. The resulting difference signal **65** is then converted to a digital code by an ADC (analog to digital converter) **60** producing a K-bit code **66**. The stored background signal is first recorded by sampling the array of proximity sensors **47** (FIG. **6**) with no touch devices nearby and storing a digital code specific for each proximity sensor **47** in a memory device **63**. The particular code corresponding to the background signal of each proximity sensor is selected by an M-bit address input **70** to the memory device **63** and applied **69** to a DAC (digital to analog converter) **61**.

The 2D array of proximity sensors **47** shown in FIG. **6** can be connected in groups so as to improve the rate at which the entire array is scanned. This is illustrated in FIG. **8** where the groups are arranged as columns of proximity sensors. In this approach, the input nodes of the proximity sensors are connected together and connected to a power supply **34**, as in FIG. **6**. The output gates **44** are also connected in the same way. However, the input gates **43** are now all connected together and the output nodes **45** are connected to only those proximity sensors **47** within a row and to a dedicated voltage amplifier **35**. With this connection method, all of the proximity sensors in a column are enabled at a time, thus reducing the time to scan the array by a factor N, where N is the number of proximity sensors in a group. The outputs **58a-h** could connect to dedicated converter circuitry as shown in FIG. **7A** or alternatively each output **58a-h** could be converted one at a time using the circuitry shown in FIG. **7B**. In this figure, the output signals from each group **58a-h** are selected one at a time by multiplexer **62** and applied to the positive input of the differential amplifier **64**. With this later approach, it is assumed that the ADC **60** conversion time is much faster than the sensor enable time, thus providing the suggested speed up in sensor array scanning.

FIG. **9** shows a typical circuit useful for the control of the proximity sensor's output gate **44**. It consists of three input signals **75**, **76**, **78** and two output signals **44**, **77**. The output gate signal **44** is logic 1 when both inputs to AND gate **79** are logic 1. The AND input signal **77** becomes logic 1 if input signal **76** is logic 1 when input signal **78** transitions from logic 0 to logic 1, otherwise it remains logic 0. A linear array of these circuits **81** can be connected end-to-end to enable the output gates of a single group of proximity sensors at a time as shown in FIG. **8**.

FIG. **10** shows a cover for the multi-touch surface **89** that permits the system to be sensitive to pressure exerted by non-conducting touch objects (e.g., gloved fingers) contacting the multi-touch surface. This cover comprises a deformable dielectric touch layer **85**, a deformable conducting layer **86**, and a compliant dielectric layer **87**. The touch surface **85** would have a symbol set printed on it appropriate for a specific application, and this surface could be removed and replaced with another one having a different symbol set. The conducting layer **86** is electrically connected **88** to the reference ground of the proximity sensor's power supply **34**. When a touch object presses on the top surface **85** it causes the conducting surface **86** under the touch device to move closer to the sensing electrode **33** of the proximity sensor. This results in a change in the amount of charge stored on the sensing electrode **33** and thus the presence of the touch object can be detected. The amount of charge stored will depend on the pressure exerted by the touch object. More pressure results in more charge stored as indicated in Equation 1.

To obtain a softer touch surface on the multi-touch device a thicker and more compliant dielectric cover could be used. However, as the dielectric thickness increases the effect of the touch device on the sensing electrodes **33** spreads out thus lowering spatial resolution. A compliant anisotropically-conducting material can be used to counter this negative effect while also providing a soft touch surface. FIG. **11** shows a cover in which a compliant anisotropically-conducting material **90** is set between a thin dielectric cover **85** and the sensing electrodes **33**. If the conductivity of the compliant material **90** is oriented mostly in the vertical direction, the image formed by a touch device on the surface **85** will be translated without significant spreading to the sensing electrodes **33**, thus preserving spatial resolution while providing a compliant touch surface.

FIG. **12** shows a cross section of a multi-touch surface that senses both the proximity and pressure of a touch device. The touch layer **85** is a thin dielectric that separates touch devices from the sensing electrodes **33**. Proximity sensing is relative to this surface. The electrodes **33** and associated switches and conductors are fabricated on a compliant material **89** which is attached to a rigid metal base **92**. The metal base **92** is electrically connected **88** to the reference ground of the proximity sensor's power supply **34**. When a touch device presses on the touch surface **85** it causes the sensing electrodes **33** directly below to move closer to the rigid metal base **92**. The distance moved depends on the pressure applied and thus the pressure exerted by a touch device can be detected as described before.

To illustrate typical properties of hand contacts as they appear in proximity images, FIGS. **13-15** contain sample images captured by a prototype array of parallelogram-shaped electrodes. Shading of each electrode darkens to indicate heightened proximity signals as flesh gets closer to