EXHIBIT 3.15

initiated by a touch on the surface. The time intervals between the arrival of the echo and the beginning of the transmission of the source signal, measured in two directions as shown Fig. 2.3 give the information on the position of the object. The touch sensor shown Fig. 2.3, developed by T.S.D Limited [ref 2.4], actually provides outputs of x+y and 2y enabling the derivation of x and y where x and y are the distance horizontally from a vertical edge and vertically from a horizontal edge respectively.

Video Technique:

The video approach to the touch input device uses a T.V camera to scan a translucent plate on which the finger tip is placed. The signal from the TV camera is then processed to obtain one bit of information per pixel. Using a programmable threshold voltage, one bit per pixel is obtained to determine the shape of a 2-D projection of an object on the plate. The data resulting from this process are stored in a memory to which access by a dedicated processor is allowed. This processor implements further processes such as determining non-zero locations in the memory (that is, the position of the object) and identifying shapes (grouping the pixels for an object). Nimish Metha presented such a system [ref 2.5] whose basic configuration is shown in Fig. 2.4.

Capacitive:

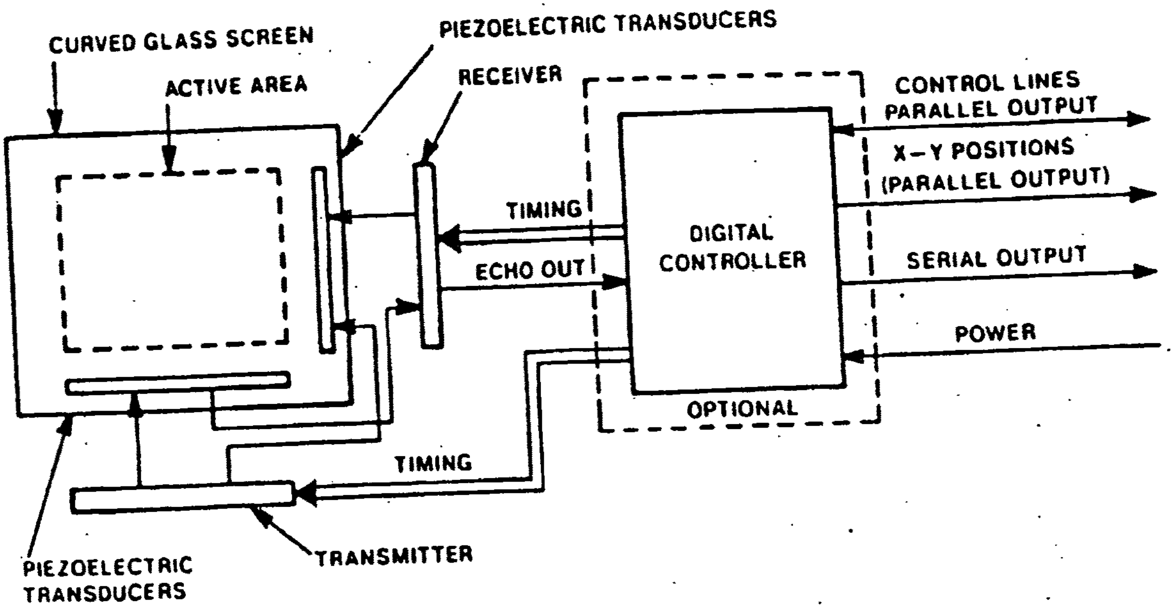


Fig. 2.3 Block Diagram of Touch Screen Digitizer

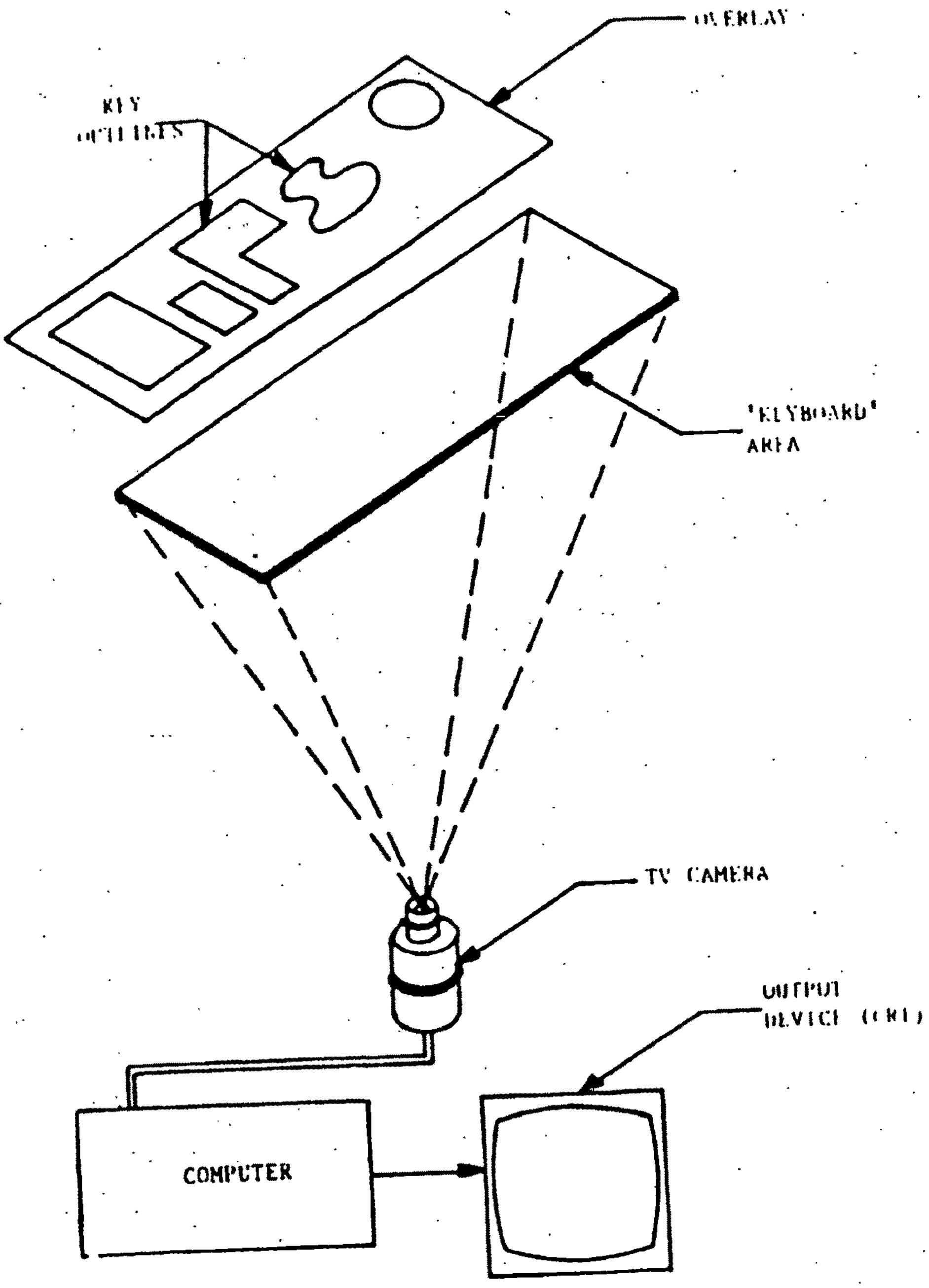


Fig. 2.4 Video System for Touch Tablet

Capacitive sensors are used in various applications such as single touch switches and touch tablets. Two kinds of touch tablet using capacitive sensors will be examined here. The one developed by TASA [ref 2.6] shown in Fig 2.5 measures the capacitance between the plate and the area covered by the touch. This measured datum is then compared with a previous reading stored in a shift register. In order to reduce the size of the shift register, a tablet is divided into many sub-regions in which the position of the touch is uniquely located. One such sub-region is much larger than the maximum size of a single touch so as to avoid an overflow. TASA utilizes the sensor to detect relative movements of a finger rather than its absolute position.

Another capacitance tablet developed by Sasaki, Fedorkow and others at the University of Toronto [ref 2.8] uses sensors for the rows and columns which are interleaved as shown in Fig 2.6. It uses analog multiplexors to select a row or a column sensor. In order to find the capacitance of a row or a column, it counts the time to charge up the capacitive sensor. Because the capacitance of the sensors on the tablet without a touch is not constant, and the capacitance change produced by a touch is relatively small compared to the capacitance of the surroundings, the system uses a measure of the initial capacitances of the sensors (without touch) whose values are stored in the memory for reference. The couch point is determined by finding a set of the maximum difference values (current value less the reference value) for the rows and columns.

2.3 SHORTCOMINGS OF EXISTING DEVICES

The scanning properties of the devices described in the previous section can be distinguished depending on their position, pressure and multiple touch sensing capabilities. All the devices or transducers referenced are capable of locating the position of a touch, with a resolution which is characteristic of each device. Only capacitive sensors and the MIT resistive sensor provide pressure of touch whereas the video system and the MIT resistive sensor give a multiple touch capability.

Projective sensors, that is, all of the sensors introduced in the previous section except the video system and the MIT high resolution resistive sensor, cannot detect multiple touches without ambiguity since the detection of touch by two horizontal and two vertical sensors can be interpreted in seven possible ways as shown in Fig. 2.7.

In general, the missing data may be retrieved by introducing more axes, as is done in a tomographic imaging system. Using this scheme, if the upper limit of the number of touch points is two, the introduction of one more axis

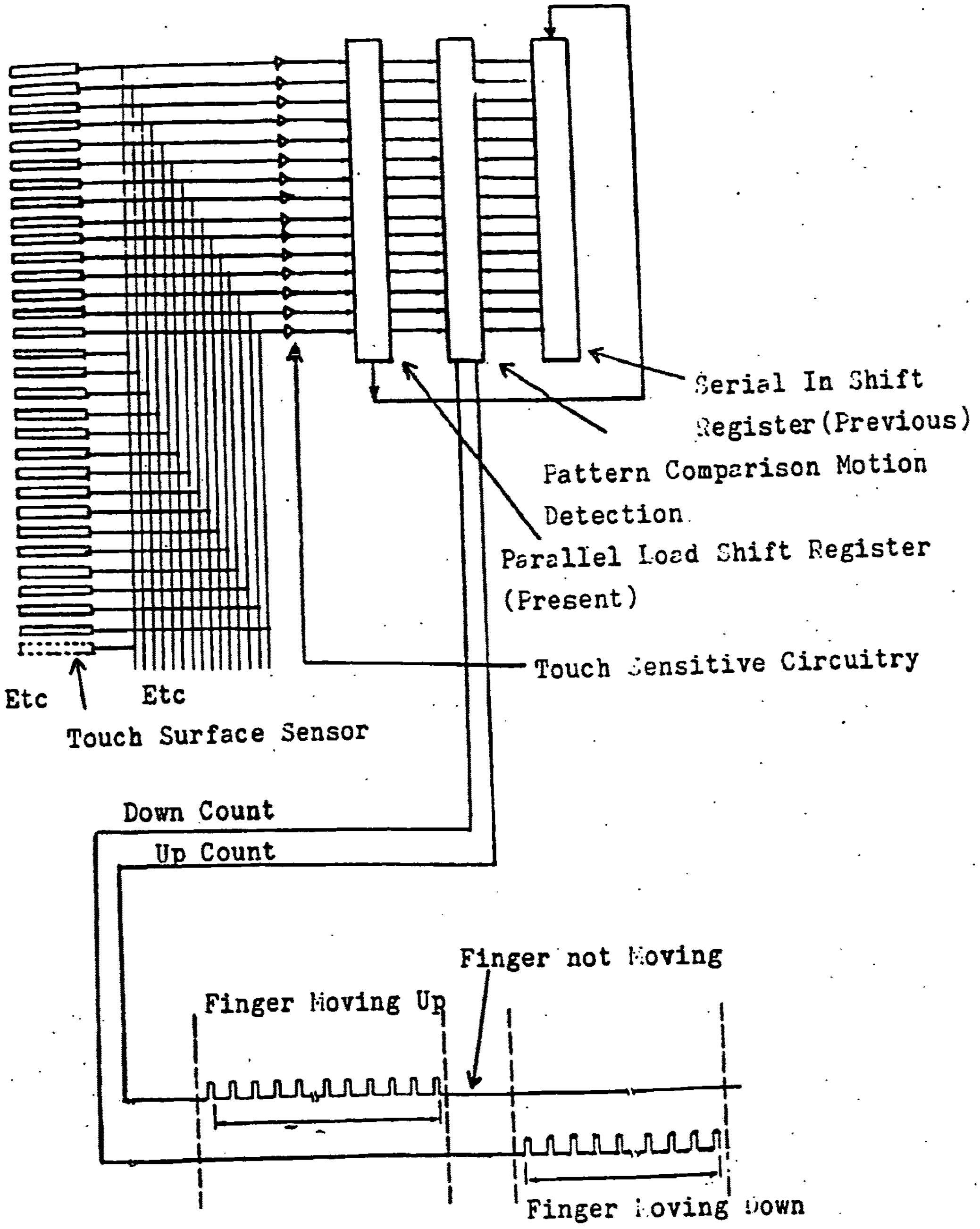


Fig. 2.5 Block and Time Diagram of TASA Touch Tablet

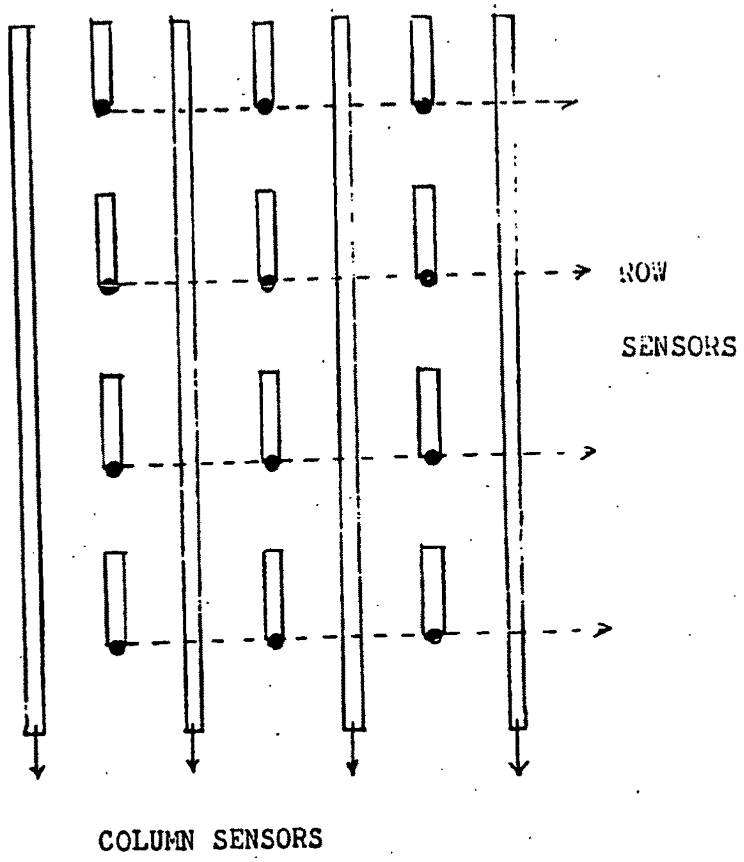
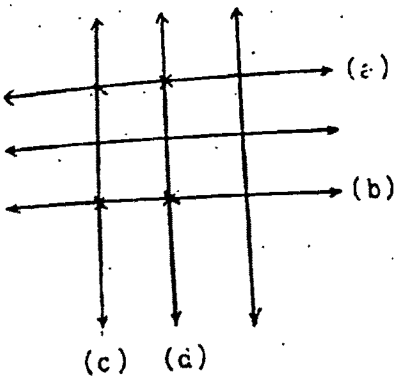


Fig. 2.6 Capacitive Sensor Configuration of the U of T Touch Tablet

clearly distinguishes at least two points as shown (a) and (b) in Fig 2.7. At least two additional axes are required to distinguish two points without ambiguity if an upper limit to the number of touches is not assumed. Cases in which the number of touches is more than two are shown in (c) to (g) in Fig. 2.7. But as soon as the number of axes is increased, the attraction of any scheme of 2-d projection diminishes because the cost of implementation rises greatly. For example the capacitive tablet may require an unimplementable number of wire layers whereas introduction of sensors and sources for IR and Ultrasound schemes may be extremely difficult. Moreover as the number of the touch points increase, additional axes do not help in resolving a basic shortcoming of the sensor from which only on and off information is available. This is the existence of a region for which identification of points inside is not possible as shown Fig. 2.8.

The video technique seems to solve all the problems embedded in all of the "projective sensor" systems including pressure if "area of touch" by a compressible finger corresponds to the pressure. But a video system is quite bulky due to the optical enclosure and it is slow because it has to access the data stored in memory by the camera processing unit. The maximum speed is limited by the scan rate of the camera(30 per second) even though this maximum can be achieved only by pipelining all the processes required.



Detection of touch by row sensors (a), (b) and column sensors (c), (d) can be interpreted in 7 possible ways as shown below.

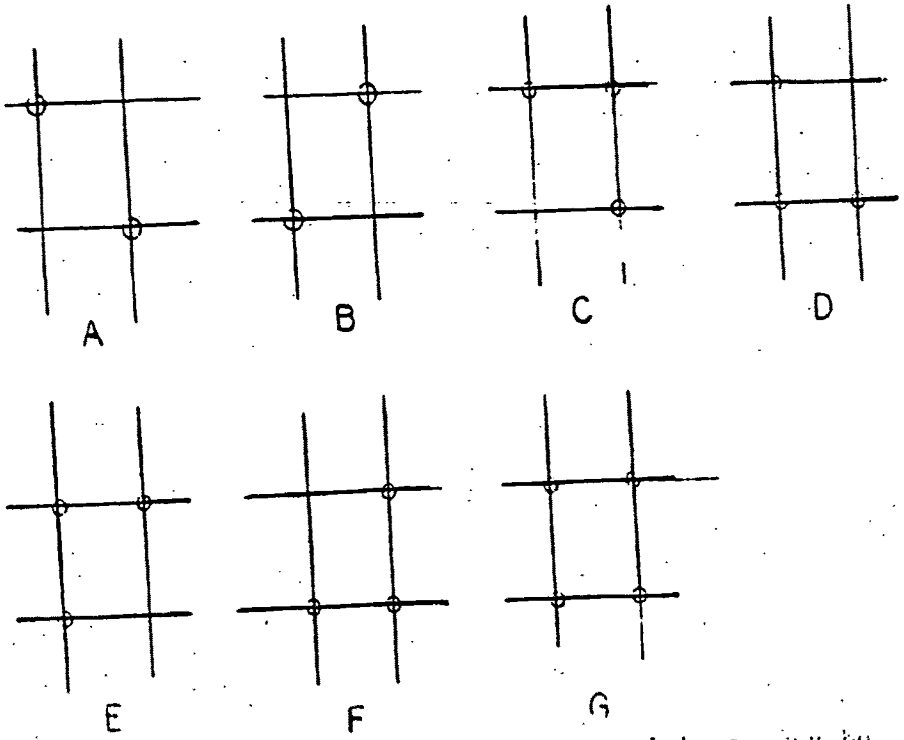


Fig. 2.7 Possible sets of points whose existence may be implied by two sensors on both row and column.

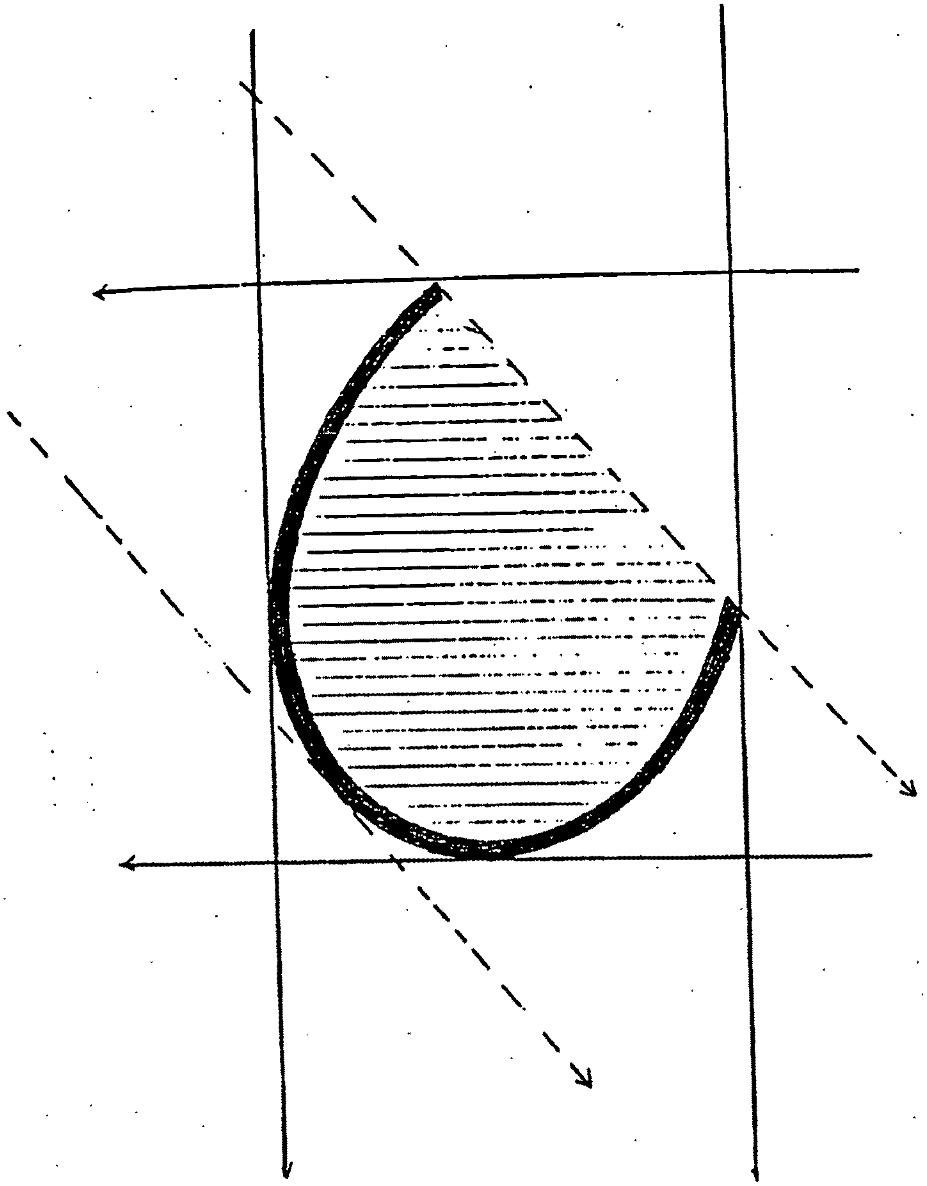


Fig. 2.8 Concave touch points that block the points inside. Any point or group of points within the shaded region cannot be identified by any number of projections.

2.4 APPROACHES TO THE PROBLEMS

One concludes from the previous discussion that existing systems and devices do not provide an appropriate means to reach our goal. The major problem of the projective sensor is generally the ambiguity on multiple points. As a solution to this problem, multiple axes are required. This however, increases the cost as well as the number of points to be scanned. Furthermore it cannot eliminate the ambiguity within regions of "concave touch points" using any reasonable number of axis. On this basis, all projective methods must be discarded.

One idea of some significance that can be introduced is to avoid scanning all the pixels in the tablet which contain no information. For example, scanning all 2048 points of a tablet having a resolution 64 by 32 for fewer than 10 points is really quite a ridiculous approach. In fact, if the number of the points to be searched is comparably small, then an improved algorithm, here called binary scanning, can be used. It is described as follows.

Consider a plane of a tablet with resolution 8 by 8 to be searched for a touch point as shown in the Fig. 2.9. First, check the tablet for touch as a whole region as shown by the area ABCD in the figure. If touch is detected, divide the tablet into two equal regions shown by the line EF and check each of the two regions ABEF and EFCD for touchedness.

select the touched region, region EFCD in this case, and divide this into two equal regions as shown by the division line GH, selecting the touched region. Continue this process until no further division is possible, that is, until a unit sensor, designated as the region PKMO in Fig. 2.9, is reached. The figure also shows the sequence of subdivision in the binary scanning operation. More details of this algorithm are given in chapter 4.

Using this algorithm, a search for one point on a tablet having a resolution 64 by 32, requires twenty two scanning times:

$$2*\log_2(64*32)=22$$

If there is no overhead in binary scanning and scanning begins at the "top of the tree" (that is, with a region in which all pixels are grouped together), then using binary scanning, the number of touched points that can be identified in the time that it would take to detect one touch if all pixels are scanned one by one linearly is

$$N=\frac{64*32}{22}=186.$$

This shows immediately that the binary scanning method is much superior to linear scanning if the number of points to be scanned is fewer than 186.

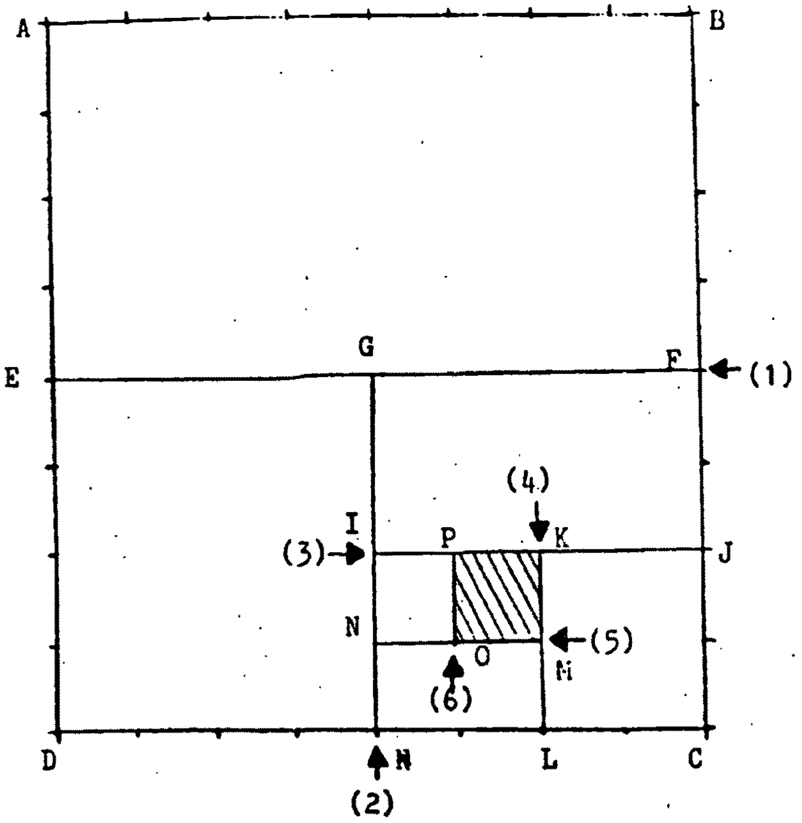


Fig. 2.9 Binary scanning operation.
(n)-Sequence of subdivision in binary operation.

For example the speed gain over linear scanning when the number of points is ten is

$$\frac{64*32}{22*10}=9.3$$

That is, for 10 points binary scanning is about 9.3 times faster than linear scanning.

Now compare such a 64*32 binary scanning tablet with a 2-d projective touch tablet such as used in the HP Personal Computer Input Screen, or with the capacitive single touch tablet with 64 by 32 resolution. In each case the speed gain for detection of a single touch is

$$\frac{64+32}{22}=4.36$$

or about 4.3. That is, the binary scanning tablet is potentially 4.3 times faster than one for which only sequential scan is possible.

Even if the binary scanning algorithm is applied to the projective tablet, the speed for the projective tablet will not exceed the speed of the 2-d image tablet. The scanning time for a projective tablet having the same resolution is found as follows; Since there are 64 + 32 sensors only, and the binary scanning algorithm is applied to the row and the column sensors separately, the scanning time is

$*\log_2(64)+2*\log_2(32)=22$

Thus the binary scanning algorithm seems to be a very attractive one for application to the FMTSID. However it necessitates two special hardware features:

— 1. Unlike the projective sensor system which allows to address only a group of positions in a column or a row, all individual positions of m by n tablet should be addressable.

— 2. It should be able to group a number of adjacent sensors as one larger sensor region.

The first requirement is to permit sensing of multiple touches, the second allows for the binary scanning algorithm. In addition to these necessary features, a measure of the intensity of touch should be considered as a third requirement to increase the capability of the FMTSID.

The sensors that can possibly accommodate these requirements are many. However the degree of difficulty in implementation varies one to another. In the following, various sensor types are examined in view of the requirements identified above.

A resistive image sensor can be used with a slight modification of the multiplexor as shown in the Fig. 2.1, however far too much time is required to evaluate the resistance using two port parameter calculations. Besides, the basic approach requires that all the row resistances have to be evaluated once using linear scanning; that is, binary scanning is not applicable to rowwise scanning.

For the video system, the row and the column scanning registers are not accessible and with the video data stored in memory, it is not possible to satisfy the second requirement. However the third requirement may be met by the addition of a little more hardware. In general, therefore, it is not a good choice.

None of the other devices presented in the previous section satisfy the requirements. Thus it is necessary to identify further sensor types.

A resistive polymer (J.S.R) was examined [ref 2.7]. The polymer changes resistivity with applied pressure. One of the applications shown by J.S.R has two closely-placed, but separated, metal coated plates on the PC board on which the rubber sheet lies such that if the rubber is pressed down, the two plates are connected. This unit may be used with a lot of multiplexors to select one of all sensors on the board. However a problem with this sensor is that it takes a very long time for the material to recover electrically to the original state after the finger is released (about 100 msec).

piezoelectric material was also examined. One possible approach is to apply the same hardware technique used in keyboard applications. However this approach does not eliminate the multiplexing problem. Unfortunately during the time required for multiplexing, the charge developed by the impact of the touch can be lost.

Finally, it seemed that the capacitive sensor offered the greatest potential of all available approaches for the following reasons:

— 1. Capacitive sensors do not need additional equipment, that is, the basic insulating sheet and touch plate are sufficient.

— 2. Multiplexors for individual sensors can be avoided or are degenerately simple using row and column addressing methods described in chapter 3

— 3. Capacitive sensors can accommodate all three features identified above. In particular, a measure of intensity is available since the area of finger contact and corresponding capacitance increases with finger pressure.

— 4. Capacitive sensors are very durable since no additional elements are needed and there is no recovery time phenomenon involved as exists with resistive rubber.

However there are some drawbacks to capacitive sensors. First they require time to charge and discharge. However these times can be reasonably well controlled. The second drawback is that a capacitive sensor generates radio frequency noise when the tablet is touched. The third drawback is low resolution. However the low resolution can be compensated by software technique as discussed in chapter 4. Noise in the radio frequency spectrum, which is potentially a problem in some environments, does not deteriorate the operation of the tablet. Since level of the noise could not be known at the time of design, it was not considered as a factor in the choice of sensor.

2.5 CONCLUSION

In this chapter, several kinds of touch sensitive input device have been examined as a part of the process of developing a flexible multi-purpose input device. Many devices and sensor types have been analyzed from different points of view in order to achieve the desired goals.

With respect to the initial goals of developing a flexible multi-purpose input device, it seems that the touch tablet as conventionally defined, does not fulfill the requirements of flexibility and adaptability, but rather that a fast multiple touch sensitive input device (FMTSID) must be pursued to meet the real requirements.

In order to reach this goal, capacitive sensor based hardware with a binary scanning algorithm was chosen for development.

CHAPTER 3

HARDWARE DESIGN AND IMPLEMENTATION

3.1 INTRODUCTION

This chapter describes the details of the hardware implementation of a fast multiple-touch-sensitive input device (FMTSID). The design of the hardware is based on the hardware requirements identified in the previous chapter and on tradeoffs between software and hardware. The hardware basically consists of a sensor matrix board, row and column selection registers, A/D converting circuits and a dedicated CPU.

The design of the sensor matrix is based on the technique of capacitance measurement between a finger tip and a metal plate. Row selection registers select one or more rows by setting the corresponding bits to a high state in order to charge up the sensors while the column selection registers select one or more columns by turning on corresponding analog switches to discharge the sensors through timing resistors. The intersecting region of the selected rows and the selected columns represents the selected sensors as a unit. A/D converting circuits ure the discharging time interval of the selected sensors. A University of Toronto 6809 board was used as dedicated CPU.

The details of the sensor matrix design are given in section 3.2, with the rest of the hardware described in section 3.3. Section 3.4 describes the scanning sequence used in conjunction with the hardware development process while section 3.5 concludes with a description of the hardware implementation.

3.2 THE SENSOR MATRIX

The design and construction of the sensor matrix board is straightforward. The touch surface of the sensor board consists of number of small metal-coated rectangular-shaped areas serving as sensor plate capacitors. The design of the metal plate area of a unit sensor depends on the measurable capacitance change that results when the area is covered by a finger tip, and on the resolution that can be implemented.

A 12" by 16" sensor matrix area with a resolution of 32 by 64 was chosen, resulting in 7 mm by 4 mm area for each sensor. The estimated capacitance between the sensor plate and a touching finger separated by 3 mil (0.075 mm) Mylar insulating coversheet is

$$Cs=e\frac{A}{d}=3*8.85*10^{-12}[F/m]\frac{7mm*4mm}{0.075mm}=10pF$$

where e is the dielectric constant of the insulating coversheet, A is the area of the unit sensor and d the thickness of the insulating sheet.

The charge associated with the touch capacitance is stored between the sensor plate and the touching finger acting as ground. For this purpose human beings can be considered to be a large charge reservoir. For the static charge case, a suitable model of a human being is an approximate 100 pF capacitor with one plate connected to ground. [ref 3.1] Therefore, it is safe to assume a touch as ground reference for measurement of relatively small capacitances.

The 10 pF of sensor capacitance change is relatively small but measurable. For a timing resistor of 100 k, the time change due to the sensor capacitance change is about 1 micro-second. The tradeoff between the time taken for the measurement of the capacitance and the ease of measurement seems to be obvious. If the capacitance is high, it is "easy" to measure but it takes longer, slowing down the scanning procedure. The clock cycle used to count the discharging time is also limited by noise in the analog circuits as well as by timing limitations of the TTL circuits used. With these limitations in mind, the period of the counter clock was chosen to be 100 nano-seconds.

In order to select a sensor by row and column access, two diodes were used for each sensor. One diode, connected to the row line, is used to charge up the sensors in the row. It is referred to as the Charging Diode (CD) as shown in Fig. 3.2. The CD also serves to block the charge flowing back to the row line when the row line voltage is dropped to zero. The other diode called the Discharging Diode(DD), connected to the column line, enables discharging of the selected row sensors to a virtual ground. Also the DD blocks charge flow from the sensors in the selected row to the sensors in the unselected row during the discharging period. The selection of rows, by the row selection procedure, causes the sensors to be charged. The sensors in the column are then discharged through associated timing resistors connected to the column selection switches.

Fig 3.1 (a) shows the components associated with a selected sensor. There are two related time periods: One for the selection of rows (that is, the charging period) and the other for the selection of columns (that is, the discharging period). The capacitance is measured while the sensor discharges. The signal output during discharging is shown in Fig. 3.1 (b).

Analytic equations can be derived for the model assuming that the reverse diode resistance is much higher than the discharge resistor R and the forward resistance is much

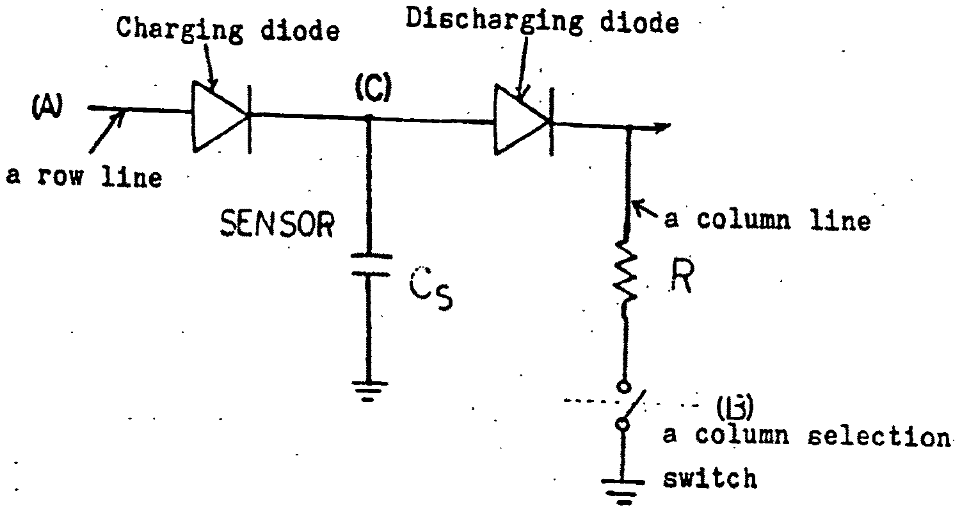


Fig. 3.1 a. A model of a selected sensor in the sensor matrix

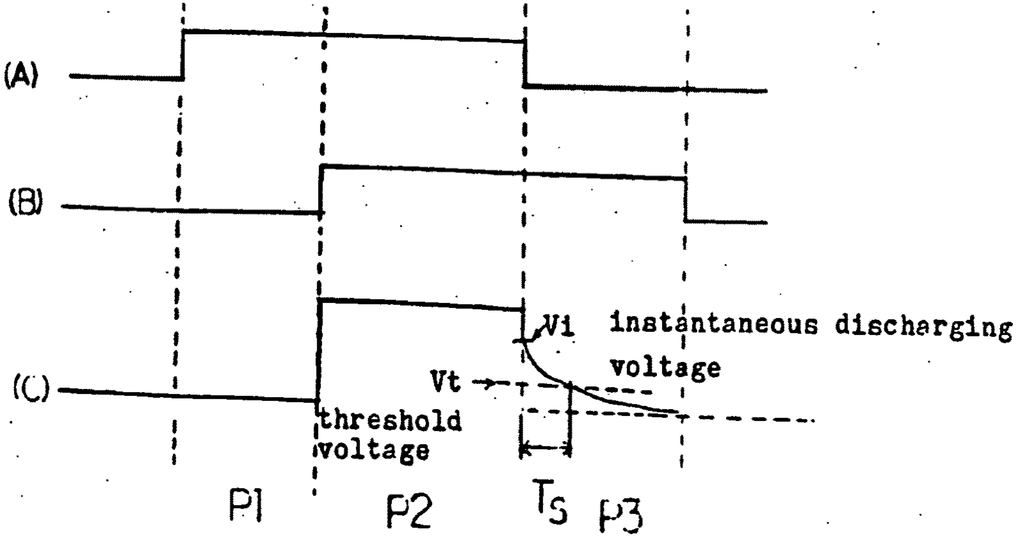


Fig. 3.1 b. The timing diagram for discharging time measurement of a selected sensor as shown above.

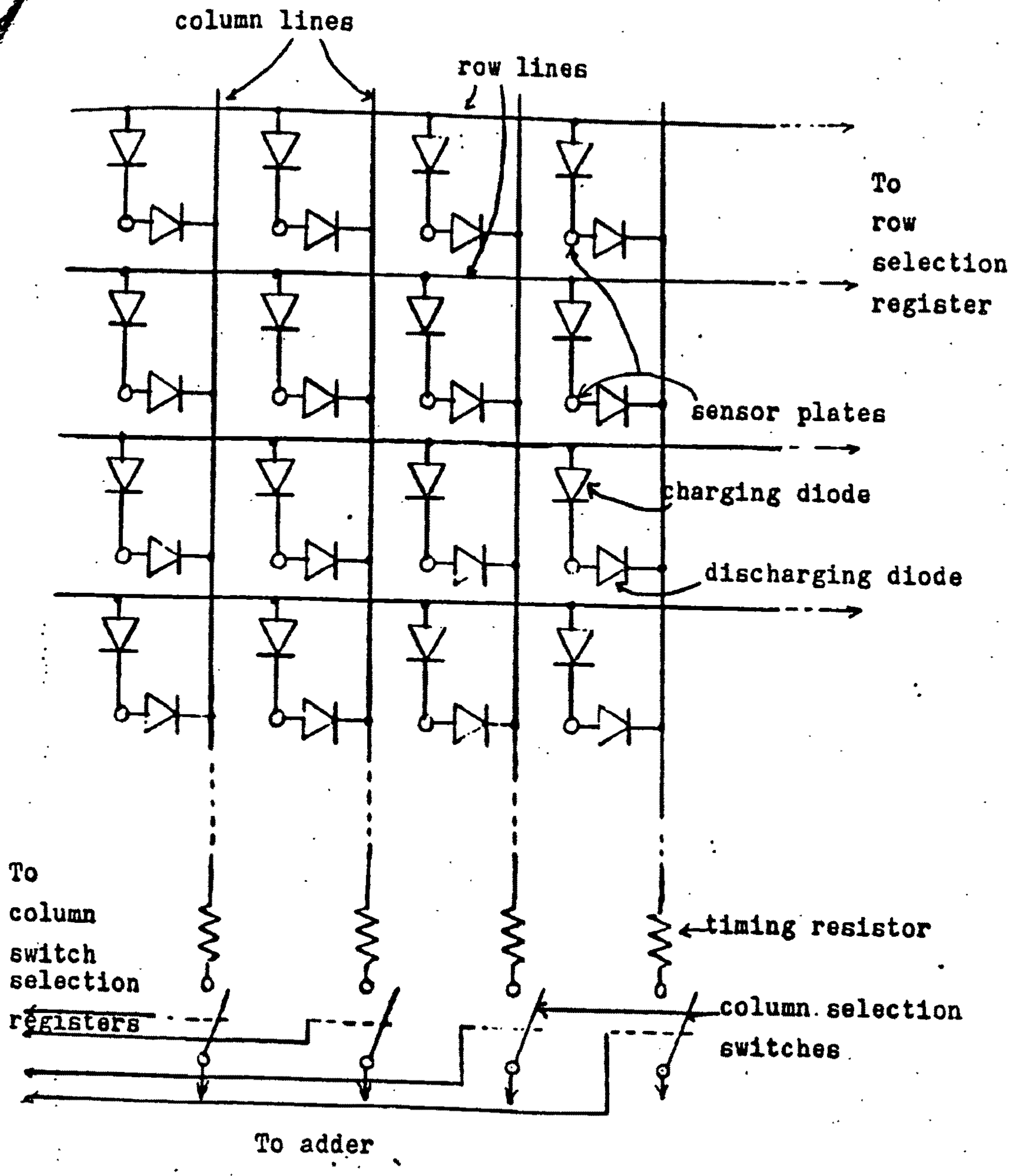


Fig. 3.2 A small section of sensor matrix.

aller than the discharge resistor R. The derivation is as follows.

The discharging voltage (V) is given by

$$V=Vi*\exp(\frac{-t}{T})$$

where Vi is the instantaneous initial voltage of the discharging period and T is the time constant.

T is given by

$$T=R(Cs+Cr)$$

where Cs is the sensor capacitance and Cr is the reverse bias capacitance of the diode.

The voltage Vi can be found from

$$Vi=(\frac{Cs}{Cs+Cr})(\frac{Qs-Qf}{Qs})(Vcc-Vd)$$

where Qs and Qf are respectively the charges stored in the sensor and the forward biased diode just before the discharging period begins, and Vcc and Vd are respectively the high state voltage for CMOS and the diode voltage drop. In the equation for Vi, the first factor is associated with charging up a reverse biased diode while the second factor results from the charge in the forward biased diode stored ring the charging period.

The discharge time is measured by the comparison with a threshold voltage (Vt) and it is given by

$$Ts=-T\ln\left(\frac{Vt}{Vi}\right)$$

From these analytic equations, the following conclusions relating to the selection of appropriate voltage levels and the diode type can be made.

1. The higher the Vcc, the less sensitive is the measurement to the threshold voltage at $V = Vt$ where the $Vt = aVcc$ and the sensitivity, that is the derivative of V with respect to t, is $-aVcc/T$.

2. The smaller the reverse bias diode capacitance, the higher the resulting Vi and the less time it takes to measure the same sensor capacitance.

3. The smaller Qf can be made, the higher Vi will be.

The first implication is the choice of CMOS logic to interface the sensor matrix using high logic voltages with Vcc equal to 15 volts. To use CMOS logic directly connected to the sensor board which is prone to high static voltage from touch, the circuitry must be protected. High negative voltage bypass diodes are connected to each row line(charging source) for this reason.

The second implication is the use of diodes with small reverse capacitance. The diode 1N 4148 was chosen for low capacitance, low cost, and availability. The reverse bias capacitance of this diode is specified as 4 pF.

The third implication relates directly to the forward current of the diode since Qf = Cf * Vd = k * Id * Vd, where Cf is the forward capacitance, Vd is the diode voltage drop, Id is the diode forward current and k is some constant. Furthermore, since Id = (Vcc - 2*Vd)/R, the Id selected is then interrelated with the timing resistor chosen.

Further analysis of the sensor matrix is of interest: there are 2048 such unit sensors implemented on the P.C board. Accordingly the analysis is rather complicated because the rows and columns are electrically not completely separated. A small section of the sensor matrix configuration is shown in Fig. 3.2 for illustration. The reverse bias capacitance couples the sensors in a column. Moreover there exist capacitances between columns due to the physical configuration of the sensor plates and wires and due to the parasitic capacitances in the circuit, and these couple the sensors in a row. The first of these coupling is seen to be unavoidable while effort was taken to reduce the second.

A simple column sensor array has been analyzed as shown in appendix A. Only the results will be discussed here. The analysis is based on an effort to obtain Vi, the instant initial voltage in the discharge period, r, the ratio of the sensor capacitance over the surrounding capacitance, and m, the separation parameter in the rows.

The instantaneous discharging voltage Vi for a case when a selected sensor is touched, is given by

$$Vi=\frac{st*a+0.5*(n-1)-f*b}{st+0.5*(n+3)}(Vcc-2*Vd)$$

where a = (Vcc-Vd)/(Vcc-2*Vd), b=Vd/(Vcc-2*Vd), f=Cf/Cr, and st=Cs||Ct/Cr.

The ratio of the sensor capacitance to the intrinsic capacitance of the surroundings, r, is

$$r=\frac{st}{\frac{n+1}{2}+st}$$

The separation parameter m is the number of non-selected sensors which must be touched, to cause a non-touched, but selected, sensor to report as "touched". Appendix A shows equations for derivation of this parameter and its evaluation by computer iteration in terms of variables such as the ratio of Cs/Cr and Cf/Cr. When Cs/Cr = 2.5 and Cf/Cr = 12.5, the separation parameter m is about 8, and when Cs/Cr

5.0 and Cf/Cr = 12.5 the m is about 25. The first result implies that if more than 8 sensors are touched in a column, then the result will be a wrong report that all the sensors in the column have been touched. The second result implies that if more than 25 sensors are touched in a column, the result will be a report that all the sensors in the column have been touched. Nevertheless, all of the analysis for the single selected sensor model is still valid with some complication.

The analysis becomes more complicated when the parameters for rows and column are included in the equations. Since the operational amplifier adds currents from selected columns and consequently the discharging time increases by 1+ln(2)/a, where a = ln(Vi/Vt), when the number of columns increases by factor of two, the reference values are expected to be increased by the factor of 1.57 for a = ln(10/3) = 1.2 correspondingly. However, an increase in the number of rows in a group is not expected to increase the reference values because the charge stored in the non-selected reverse bias diodes becomes smaller whereas the charge stored in the selected forward bias diodes remain constant during charging period and consequently Vi becomes smaller.

Efforts have been made to separate the columns as much as possible. However there still will be some coupling capaances between columns due to physical adjacency; but their effects are considered to be minimal.

3.3 INTERFACE CIRCUIT DESIGN AND IMPLEMENTATION

Interfacing between the sensor matrix and the dedicated CPU requires three main circuit blocks: row selection registers, column switch selection registers and A/D converting circuits. The CPU selects the row or rows of a sensor group, initiating charging of all the associated sensors. After a charging interval, the CPU discharges the selected column or columns corresponding to a sensor group by connecting a group of discharge resistors whose current is summed via a high slew rate operational amplifier.

There is tradeoff between the scheme using a single bit for each row and one using decoding circuits to implement binary addressing suited to the binary scanning algorithm. The bit per row scheme requires 32 bits of register while binary coding needs 6 bits of register since only 32 * 2 -1 patterns of sensor grouping exit according to the binary scanning algorithm. However, the first scheme was chosen because it is ultimately flexible, that is, it allows one to implement "all" scanning nodes by means of software. Thus changes can be easily made in the case of difficulty with implementation of a particular software algorithm. The

We could have individually controlled switches instead of a mux to sum rows in a column?

lemented prototype uses four 8 bit registers with a common reset signal for row selection.

For the same reasons sufficient column switch selection registers are provided so that one can generate any group pattern through software. However, to reduce the number of chips on the board, four switches are controlled by each bit resulting in four simultaneous analog signals and necessitating four counters. However as a result only 2 8-bit latches are needed to control 64 switches. The four sets of data are provided to the CPU after each scan. These data are manipulated by software in correspondence with the selected resolution mode. This implies the hardware itself acts as an array of 32 by 16 bits while the software emulates 32 by 64 bits of scanning resolution. The scanning algorithm is explained in chapter 4.

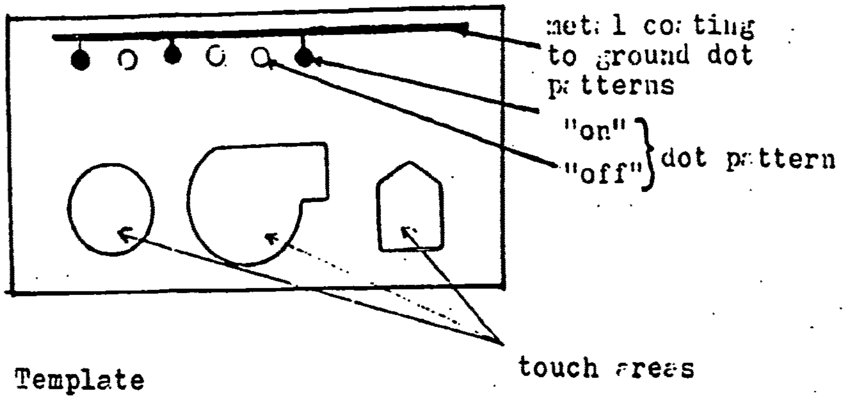
The charges stored in the selected row(s) flow down through the selected switches to the virtual ground of the fast operational amplifier. All the discharging currents are correspondingly added to produce a signal from which the discharging time of all the selected sensors can be found by comparison with a threshold voltage. The output of the negative voltage comparator is fed to the enable signal of the counter and to the data bus as a status bit for the counter readiness. All the counters are reset when the row selection registers are deselected in order to initiate the counting process.

The clock rate (10 MHz) allows about 10 counts to correspond to the sensor capacitance change due to a touch. But, of course, the capacitance of all the circuitry attached to the column line during the discharging period is much larger than the sensor capacitance. Before scanning the tablet for a touch, the dedicated CPU scans it completely in all possible resolution modes when not touched. The values so obtained are stored as references. Touches are identified by the differences between the reference values and the values measured during use.

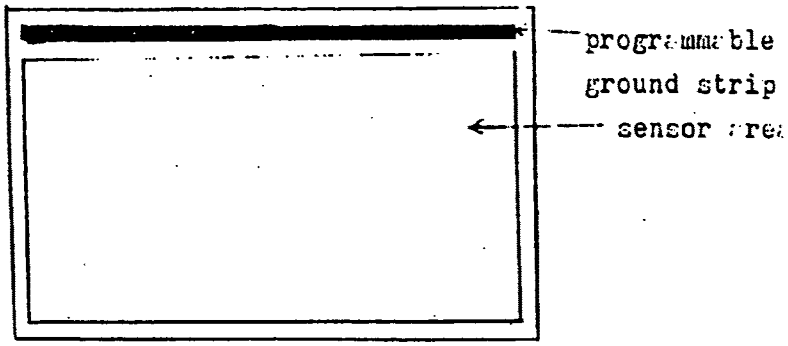
The capacitance change corresponding to the touch by more than one finger when the resolution is very small, that is, when the area of the sensors selected is large, is also very large. Thus the number of bits in the counter should be enough to measure the maximum capacitance. However it is unnecessary either to have enough number of bits to measure the entire capacitance including the surrounding capacitances, or to store the corresponding "complete" counter values as references. It is necessary to have only one more bit than the number of bits required to count the value of change in the capacitance rather than complete counter values in order to measure difference of the capacitance due to touch. Thus only an 8 bit counter was implemented with space allowed for an extra 4 bit counter in case that a greater number of bits is found to be necessary. The 8 bit counter enables the measurement of a 7 bit capacitance change regardless of the degree of overflow in the counter. This means that if the difference, touched to non-touched, does not exceed 127, the difference can be obtained without ambiguity. For example, a counter value 4 is larger than f8 if the difference is less than 7f in hexadecimal; in other words, an unsigned 8 bit comparison would not be appropriate. Therefore the counter does not need to accommodate the entire discharging time including the time due to the surrounding capacitance, which may require more than 8 bits. Some manipulation is done in software to utilize the facts above. A complete analysis is given in appendix B.

The remaining circuits are for shifting CMOS levels to TTL level and for decoding addresses. Eight addresses are decoded with a R/W signal. One write address is used for a single register whose output controls the discharge of all the sensor matrix at once, the grounding of the ground strip on the board for template recognition applications as described below, and as well as controls three LED outputs.

A metal strip is located on one side of the touch surface of the board. This strip is a programmable ground strip which can be grounded to allow a metal-coated pattern on the back side of the template shown in Fig.3.3 to be scanned. It can be ungrounded for normal binary scanning so



Template



Touch sensitive tablet

Fig. 3.3 Template and touch sensitive tablet.
The template pattern lies on the sensor area.
Its metal coating touches the ground strip
which is grounded to initiate recognition of
the template.

that the "touch" by the pattern can be ignored. Otherwise it increases the time to scan all the points on the touch surface including the unneeded points from the template because the binary scanning time is directly proportional to the number of points on the tablet.

3.4 THE HARDWARE SCANNING SEQUENCE

This section describes the reading sequence for data from the sensor matrix board. A block diagram of the hardware circuit is shown in Fig. 3.4 to assist the reader. The sequence is as follows.

— 1. Reset the row selection registers. That is, ground the inputs to the sensor matrix.

— 2. Discharge all the sensors directly to ground (but not through R) for about 2 microseconds.

— 3. Select the row selection registers with an appropriate bit pattern.

— 4. Select column switches by turning on the appropriate bit pattern in the column switch selection registers about 4 micro-seconds to stabilize the sensor charge.

— 5. Reset the row selection registers and the the output counters together to initiate counting of the discharg-

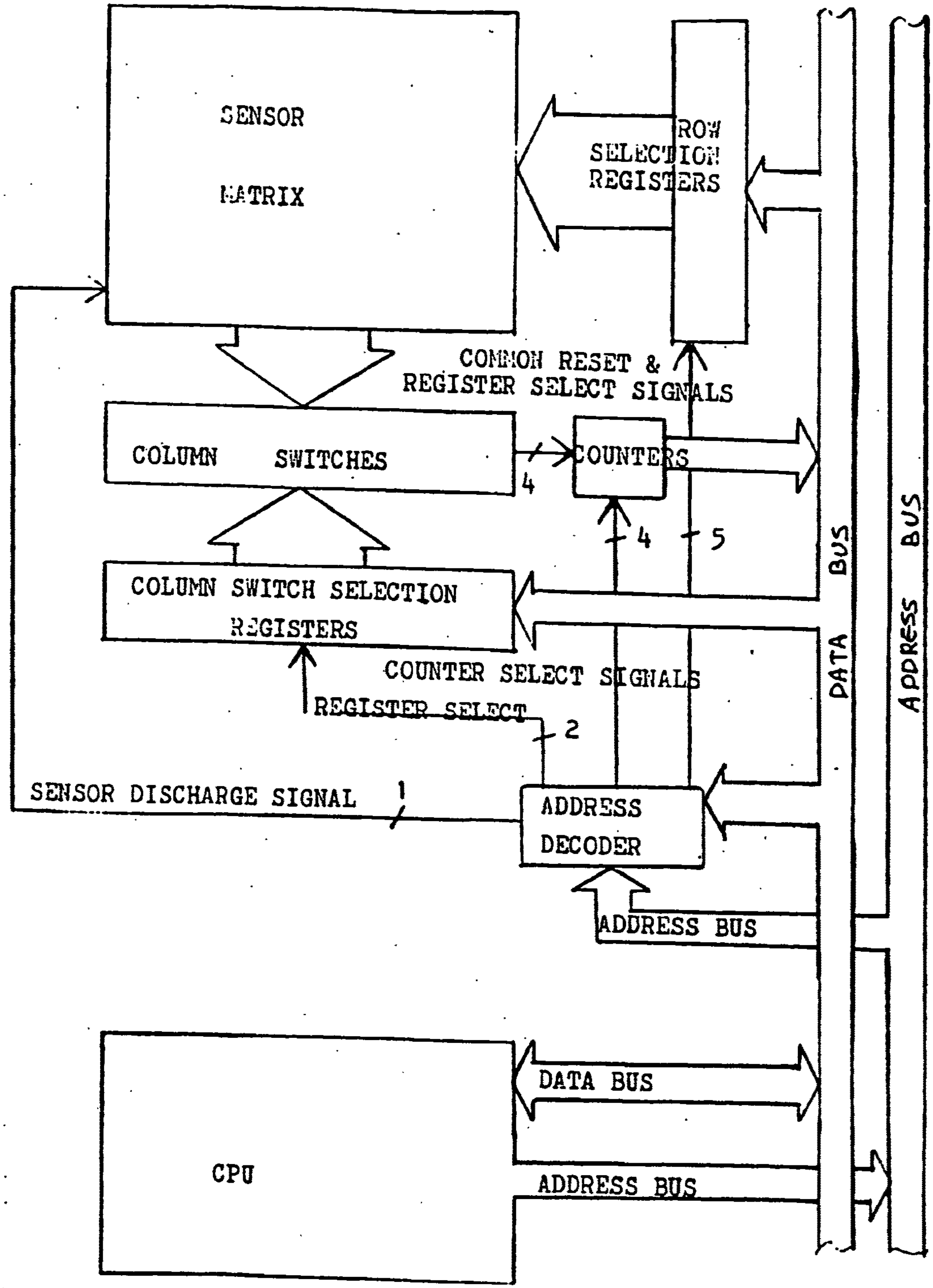


Fig. 3.4 Block diagram of the hardware.

ing time.

— 6. Wait until the counters are ready by reading the status bits.

— 7. Read the counters.

The bit patterns in the row selection register and in the column switch selection register represent the row and column addresses respectively. These, however, have to be converted to a convenient form corresponding to physical placement which is understandable to the user or to the interfacing routine. This process is described in the next chapter.

3.5 CONCLUSIONS

In this chapter, tradeoffs between software and hardware have been discussed while introducing the design of the sensor board and its interfacing circuits. A prototype tablet has been implemented and tested. There were difficulties but all have been surmounted. The detailed results of performance testing are described in the chapter 5.

```
    for(i=0; i<3; i++)
    switch(i) {
     case 0: bs(coladr+1,rowadr,levelr,levelc);
             break;
     case 1: bs(coladr,rowadr+1,levelr,levelc);
             break;
     case 2: bs(coladr+1,rowadr+1,levelr,levelc);
             break;
     default: break;
     }
   }
 }
```

The binary scanning algorithm is actually implemented in assembler in a non-recursive way; however the structure and the algorithm have not been changed from the representation above. This algorithm and the modified linear scanning algorithm are very sensitive to the values of the thresholds for each level. Thus detecting very small contact areas over a large sensor group area is rather difficult. Accordingly if the threshold for the top level is high then a small intensity of touch may not be detected; whereas if it is low, then the search may not be successful. Consequently this would slow down the scanning procedure since a large number of unsuccessful trys at the bottom level (caused by low threshold in the higher levels) delays the scan of the actual touch points.

4.6 COMPENSATION FOR LOW RESOLUTION HARDWARE

It may seem that the resolution of the hardware is too low for use in graphics applications. However touch intensity and multi-touch sensitivity can be used to enhance resolution. This is possible because the center of a touch can be most accurately estimated by an interpolation utilizing the values of the adjacent sensor intensities. For a simple example, consider the estimation of the center of the touch by an interpolation method as follows:

Suppose the touched point is (i,j) and its intensity value is z(i,j). Let the dx and dy be the relative position of the interpolation to the integer position (i,j). Then the dx, and dy can be obtained from the values of the adjacent intensities as follows.

$$dx=\frac{\sum_{k}(-1,+1)(z(i+k,j+1)-z(i+k,j-1)}{\sum_{k}(-1,+1)\sum_{\ell}(-1,+1)(z(i+k,j+\ell))}$$

$$dy=\frac{\sum_{k}(-1,+1)(z(i+1,j+k)-z(i-1,j+k))}{\sum_{k}(-1,+1)\ \sum_{\ell}(-1,+1)(z(i+k,j+\ell))}$$

Thus the estimated center of touch is (i+dx, j+dy).

A simple case is shown in Fig 4.5 where possible interpolation points are shown when 1, 2, 3, 4, or 5 bits of intensity are provided from two adjacent sensors. The picture shows that interpolation points are not evenly populated and that the scheme does not give good resolution even if a fairly high number of intensity bits are provided. Therefore it may be good idea to map each interpolation point to another domain which gives evenly populated points

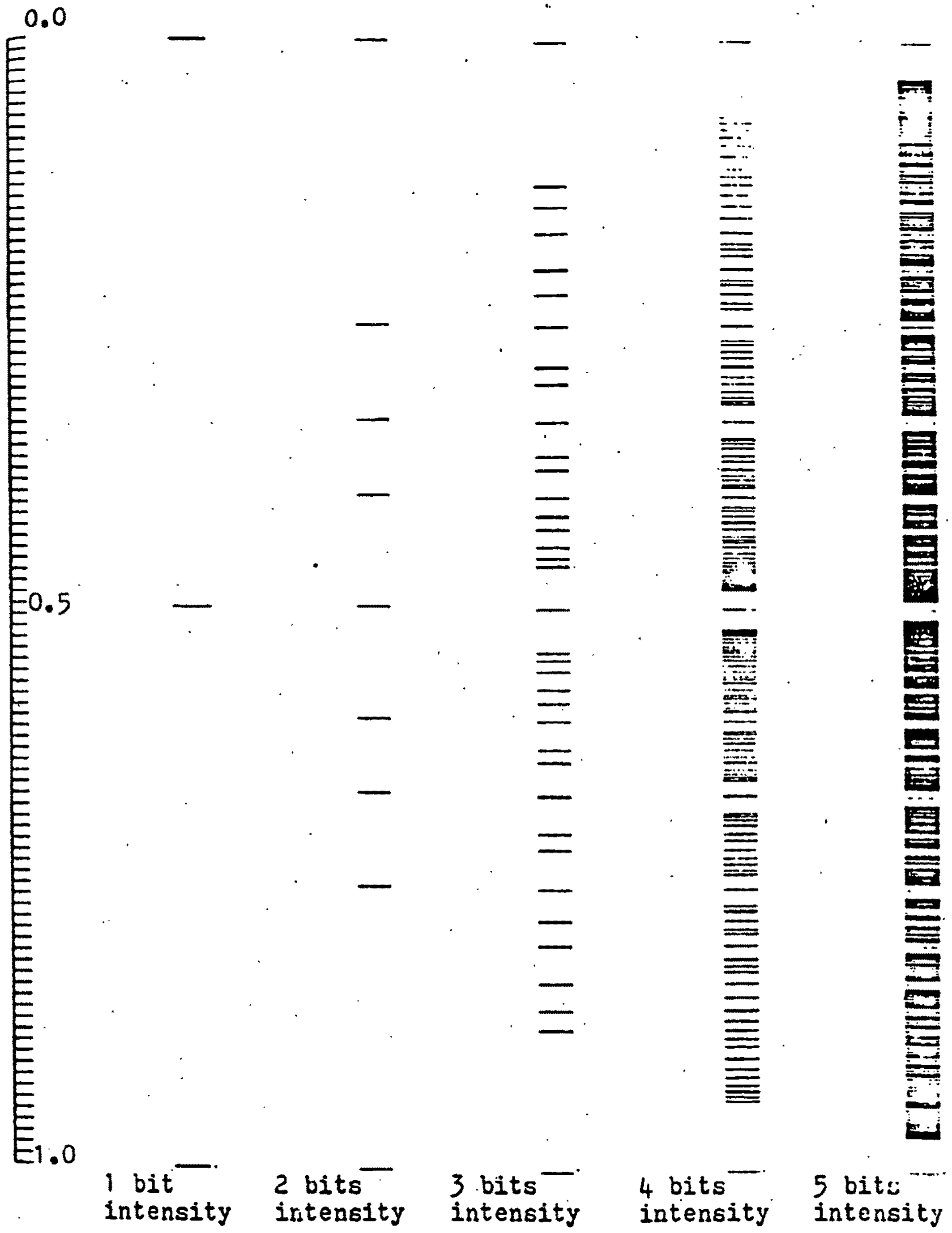


Fig. 4.5 Centers of pressure interpolated from two sensors with the number of available bits for pressure being 1, 2, 3, 4, and 5 from left to right.

Each line represents a possible interpolation point.

for possible combinations of the intensities from two adjacent sensors. However such an interpolation mapping scheme has not been implemented due to complications involved for more than two sensors.

However the interpolation should be performed in terms of the physical center of the touch shape. Since the intensity given by the capacitance measurement is dependent of the area of touch on the cover of sensor plate, the accurate center of a touch is more dependent of the size of the touch relative to the size of the sensor area as well as the shape of sensor plate.

For the implementation, however, it uses direct interpolation scheme for a few cases. One of interest is interpolating 3 by 3 sensors with a touched point in the center and the other is interpolation of all points on the tablet. The later one obviously gives highest resolution but it simply emulates a single touch tablet with a high resolution.

The software in the dedicated CPU utilizes the communication with the host computer to accommodate the interpolation scheme in the host computer.

4.7 SEQUENCE OF OPERATIONS

The programs in the dedicated processor are sequenced

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APPLICATION
FOR
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TITLE: Force Imaging Input Device and System

INVENTORS: Steve Hotelling and Brian Q. Huppi

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FORCE IMAGING INPUT DEVICE AND SYSTEM

Background

[0001] The invention relates generally to electronic system input devices and, more particularly, to force imaging and location-and-force imaging mutual capacitance systems.

[0002] Numerous touch sensing devices are available for use in computer systems, personal digital assistants, mobile phones, game systems, music systems and the like (*i.e.*, electronic systems). Perhaps the best known are resistive-membrane position sensors which have been used as keyboards and position indicators for a number of years. Other types of touch sensing devices include resistive tablets, surface acoustic wave devices, touch sensors based on resistance, capacitance, strain gages, electromagnetic sensors or pressure sensors, and optical sensors. Pressure sensitive position sensors have historically offered little benefit for use as a pointing device (as opposed to a data entry or writing device) because the pressure needed to make them operate inherently creates stiction between the finger and the sensor surface. Such stiction has, in large measure, prevented such devices from becoming popular.

[0003] Owing to the growing popularity of portable devices and the attendant need to integrate all input functions into a single form factor, the touch pad is now one of the most popular and widely used types of input device. Operationally, touch pads may be categorized as either "resistive" or "capacitive." In resistive touch pads, the pad is coated with a thin metallic electrically conductive layer and resistive layer. When the pad is touched, the conductive layers come into contact through the resistive layer causing a change in resistance (typically measured as a change in current) that is used to identify where on the pad the touch event occurred. In capacitive touch pads, a first set of conductive traces run in a first direction and are insulated by a dielectric insulator from a second set of conductive traces running in a second direction (generally orthogonal to the first direction). The grid formed by the overlapping conductive traces create an array of capacitors that can store electrical charge. When an object is brought into proximity or contact with the touch pad, the capacitance of the capacitors at that location change. This change can be used to identify the location of the touch event.

[0004] One drawback to using touch pads as input devices is that they do not generally provide pressure or force information. Force information may be used to obtain a more robust indication of how a user is manipulating a device. That is, force information may be used as another input dimension for purposes of providing command and control signals to an associated electronic device. Thus, it would be beneficial to provide a force measurement system as part of a touch pad input device.

Summary

[0005] In one embodiment the invention provides a force sensitive touch pad that includes first and second sets of conductive traces separated by a spring membrane. When a force is applied, the spring membrane deforms moving the two sets of traces closer together. The resulting change in mutual capacitance is used to generate an image indicative of the location (relative to the surface of the touch pad) and strength or intensity of an applied force. In another embodiment, the invention provides a combined location and force sensitive touch pad that includes two sets of drive traces, one set of sense traces and a spring membrane. In operation, one of the drive traces is used in combination with the set of sense traces to generate an image of where one or more objects touch the touch pad. The second set of drive traces is used in combination with the sense traces and spring membrane to generate an image of the applied force's strength or intensity and its location relative to the touch pad's surface. Force touch pads and location and force touch pads in accordance with the invention may be incorporated in a variety of electronic devices to facilitate recognition of an increased array of user manipulation.

[0006] In yet another embodiment, the described force sensing architectures may be used to implement a display capable of detecting the amount of force a user applies to a display (e.g., a liquid crystal display unit). Display units in accordance with this embodiment of the invention may be used to facilitate recognition of an increased array of user input.

Brief Description of the Drawings

[0007] Figure 1 shows, in exploded perspective view, a force detector in accordance with one embodiment of the invention.

[0008] Figures 2A and 2B show, in cross-section, an unloaded (A) and loaded (B) force detector in accordance with FIG. 1.

[0009] Figure 3 shows, in block diagram form, a force detection system in accordance with one embodiment of the invention.

[0010] Figure 4 shows, in block diagram form, a more detailed view of the force detection system in accordance with FIG. 3.

[0011] Figure 5 shows, in cross-section, a location and force detection device in accordance with one embodiment of the invention.

[0012] Figure 6 shows, in cross section, a location and force detection device in accordance with another embodiment of the invention.

[0013] Figure 7 shows an exploded view of drive and sense traces in accordance with FIG. 6.

[0014] Figures 8A-8C show various views of a location and force detection device in accordance with still another embodiment of the invention.

[0015] Figures 9A-9C show various views of a location and force detection device in accordance with yet another embodiment of the invention.

[0016] Figures 10A and 10B show, in cross section, a location and force detection device in accordance with another embodiment of the invention.

[0017] Figures 11A-11C show various views of a spring membrane in accordance with another embodiment of the invention.

[0018] Figures 12A and 12B show, in block diagram form, a force detection display system in accordance with one embodiment of the invention.

Detailed Description

[0019] The following description is presented to enable any person skilled in the art to make and use the invention as claimed and is provided in the context of the particular examples discussed below (touch pad input devices for personal computer systems), variations of which will be readily apparent to those skilled in the art. Accordingly, the claims appended hereto are not intended to be limited by the disclosed embodiments, but are to be accorded their widest scope consistent with the principles and features disclosed herein. By way of example only, force imaging systems in accordance with the invention are equally applicable to electronic devices other than personal computer systems such as computer workstations, mobile phones, hand-held digital assistants and digital control panels for various machinery and systems (mechanical, electrical and electronic).

[0020] Referring to FIG. 1, the general concept of a force detector in accordance with the invention is illustrated as it may be embodied in touch pad device **100**. As illustrated, force detector **100** comprises cosmetic layer **105**, sense layer **110** (including conductive paths **115** and electrical connector **120**), dielectric spring layer **125** (including spatially offset raised structures **130**), drive layer **135** (including conductive paths **140** and electrical connector **145**) and base or support **150**. (It will be understood by those of ordinary skill in the art that connectors **120** and **145** provide unique connections for each conductive trace on layers **110** and **135** respectively.)

[0021] Cosmetic layer **105** acts to protect other elements of the system from ambient conditions (*e.g.*, dust and moisture) and, further, provides a surface through which users interact with detector **100**. Conductive paths **115** on sense layer **110** are arranged so that they overlap conductive paths **140** on drive layer **135**, thereby forming capacitors whose plates (conductive paths **115** and **140**) are separated by sense layer substrate **110**, dielectric spring layer **125** and raised structures **130**. Dielectric spring layer **125** and raised structures **130** together create a mechanism by which sense layer **110**'s conductive paths **115** are brought into closer proximity to drive layer **135**'s conductive paths **140** when a force is applied to cosmetic layer **105**. It will be recognized that this change in separation causes the mutual capacitance between sense layer and drive layer conductive paths (**115** and **140**) to change (increase) – a change indicative of the amount, intensity or strength of the force applied to cosmetic layer **105**. Base or support layer **150** provides structural integrity for force detector **100**.

[0022] Referring to FIG. 2A, a cross-sectional view of force detector **100** is shown in its unloaded or "no force" state. In this state, the mutual capacitance between sense layer **110** and drive layer **135** conductive paths (**115** and **140**) results in a steady-state or quiescent capacitance signal (as measured via connectors **120** and **145** in FIG. 1). Referring to FIG. 2B, when external force **200** is applied to cosmetic layer **105**, dielectric spring layer **125** is deformed so that sense layer **110** moves closer to drive layer **135**. This, in turn, results in a change (increase) in the mutual capacitance between the sense and drive layers – a change that is approximately monotonically related to the distance between the two and, therefore, to the intensity or strength of applied force **200**. More specifically, during operation traces **140** (on drive layer **135**) are electrically stimulated one at a time and the mutual capacitance associated with the stimulated trace and each of traces **115** (on sense layer **110**) is measured. In this way an image of the strength or intensity of force **200** applied to cosmetic layer **105** is obtained. As previously noted, this change in mutual capacitance may be determined though appropriate circuitry.

[0023] Referring to FIG. 3, a block diagram of force imaging system **300** utilizing force detector touch pad **100** is shown. As illustrated, force imaging system **300** comprises force detector **100** coupled to touch pad controller **305** through connectors **120** (for sense signals **310**) and **145** (for drive signals **315**). Touch pad controller **305**, in turn, periodically sends signals to host processor **320** that represent the (spatial) distribution of force applied to detector **100**. Host processor **320** may interpret the force information to perform specified command and control actions (*e.g.*, select an object displayed on display unit **325**).

[0024] Referring to FIG. 4, during operation drive circuit **400** in touch pad controller **305** sends ("drives") a current through drive signals **315** and connector **145** to each of the plurality of drive layer conductive paths **140** (see FIG. 1) in turn. Because of capacitive coupling, some of this current is carried through to each of the plurality of sense layer conductive paths **115** (see FIG. 1). Sensing circuits **405** (*e.g.*, charge amplifiers) detect the analog signal from sense signals **310** (via connector **120**) and send them to analysis circuit **410**. One function of analysis circuit **410** is to convert the detected analog capacitance values to digital form (*e.g.*, through A-to-D converters). Another function of analysis circuit is to queue up a plurality of digitized capacitance values for transmission to host processor **320** (see FIG. 3). Yet another function of analysis circuit is to control drive circuit **400** and, perhaps, to dynamically adjust operation of sense circuits **405** (*e.g.*, such as by changing the threshold value at which a "change" in capacitance is detected). One embodiment of controller **305** suitable for use in the present invention is described in US patent application entitled "Multipoint Touch Screen Controller," serial number 10/999,999 by Steve Hotelling, Christoph Krah and Brian Huppi, filed 15 March 2006 and which is hereby incorporated in its entirety.

[0025] In another embodiment, a force detector in accordance with the invention is combined with a capacitive location detector to create a touch pad device that provides both location and force detection. Referring to FIG. 5, combined location and force detector **500** comprises cosmetic layer **505**, circuit board or substrate **510** (including a first plurality of conductive drive paths **515** on a first surface and a plurality of sense paths **520** on a second surface), dielectric spring layer **525** (including alternating, or spatially offset, raised structures **530**), drive layer **535** (including a second plurality of conductive drive paths) and base or support **540**. In one embodiment, conductive drive paths **515** and **535** are laid down on substrate **510** and support **540** respectively to form rows and sense conductive paths are laid down on substrate **510** to form columns. Accordingly, during operation first drive paths **515** are driven (one at a time) during a first time period and, during this same time, sense paths

520 are interrogated to obtain an image representing the location of one or more cosmetic layer touches. Similarly, second drive paths **535** are driven (one at a time) during a second time period and, during this same time, sense paths **520** are again interrogated to obtain an image representing, this time, the strength or intensity of the force applied to cosmetic layer **505**. The operation of computer input devices (*e.g.*, touch pads) for touch detection based on the principle of mutual capacitance is described in US patent application entitled "Multipoint Touchscreen" by Steve Hotelling, Joshua A. Strickon and Brian Q. Huppi, serial number 10/840,862 and which is hereby incorporated in its entirety.

[0026] Referring to FIG. 6, location and force touch pad **600** in accordance with another embodiment of the invention is shown in cross section. In this embodiment, cosmetic layer **605** comprises a polyester or polycarbonate film. Layer **610** comprises an acrylic-based pressure sensitive or ultraviolet light cured adhesive. Layer **615** functions as a two-sided circuit board that has a first plurality of conductive drive traces **620** oriented in a first direction on a "top" surface (*i.e.*, toward cosmetic layer **605**) and a plurality of conductive sense traces **625** oriented in a second direction on a "bottom" surface. In one embodiment, circuit substrate layer **615** comprises a low temperature plastic or thermoplastic resin such as polyethylene terephthalate ("PET"). In this embodiment, drive traces **620** and sense traces **625** may comprise printed silver ink. In another embodiment, circuit substrate layer **615** comprises a flexible circuit board, or fiberglass or glass and drive and sense traces (**620** and **625**) comprise Indium tin oxide ("ITO") or copper. Layer **630**, in one embodiment, comprises a layered combination consisting of adhesive-PET-adhesive, where the adhesive components are as described above with respect to layer **610**. Layers **635**, **640** and **645** comprise PET of varying thicknesses. As shown, the "bottom" surface of layer **640** has affixed thereon a second plurality of conductive drive traces **650** oriented in substantially the same orientation as first conductive drive traces **620**. Raised and spatially offset support structures **655** and layer **660** also comprise a layered combination consisting of adhesive-PET-adhesive (similar to layer **630**, see above). Layers **605**-**660** are affixed to and supported by base or stiffener plate **665**. For example, in a portable or notebook computer system, base **665** could be formed from a rigid material such as a metal stamping that is part of the computer system's frame. Similarly, base **665** could be the internal framing within a personal digital assist and or mobile telephone. Table 1 identifies the thickness for each of layers **600**-**660** for one embodiment of touch pad **600**.

Table 1: Dimensions for Illustrative Touch Pad **600**

Layer	Material	Thickness (mm)
605	Polyester, polycarbonate film, glass or ceramic	0.3
610	Pressure sensitive adhesive ("PSA") or ultraviolet ("UV") light cured adhesive	0.05
615	PET	0.075 ± 0.02
620	Silver ink, copper, Indium tin oxide	0.006
625	Silver ink, copper, Indium tin oxide	0.006
630	Layered PSA-PET-PET	0.03 ± 0.01

Table 1: Dimensions for Illustrative Touch Pad **600**

Layer	Material	Thickness (mm)
635	PET	0.075 ± 0.02
640	PET	0.1 ± 0.02
645	PET	0.125 ± 0.02
650	Silver ink, copper, Indium tin oxide	0.006
655	Layered: PSA	0.025 ± 0.01
	PET	0.1 ± 0.02
	PSA	0.025 ± 0.01

Active touch pad surface: 271 mm × 69 mm
No of drive traces (**620** and **650**): 13
Number of sense traces (**625**): 54
Pixel separation: 5 mm

[0027] In operation touch pad **600** measures the change (*e.g.*, decrease) in capacitance due to cosmetic layer **605** being touched at one or more locations through the mutual capacitance between drive traces **620** and sense traces **625**. In a manner as described above, touch pad **600** also measures forces applied to cosmetic layer as sense traces **625** and drive traces **650** are brought into closer proximity through the measured change (*e.g.*, increase) in mutual capacitance between them. In this embodiment, raised structures **655** are used on both sides of the second layer of drive traces (**650**) to provide additional movement detection capability.

[0028] During measurement operations, each of drive traces **620** are stimulated in turn and, simultaneously, the change in mutual capacitance between drive traces

620 and sense traces **625** is measured. Once each of drive traces **620** have been stimulated (and the corresponding change in capacitance measured via sense traces **625**), each of drive traces **650** are driven in turn and sense traces **625** are used to determine the change in mutual capacitance related to force (that is, the mutual capacitance change between traces **625** and **650** due to an applied force). In this manner, images of both the "touch" input and "force" input to cosmetic layer **605** can be obtained.

[0029] One of ordinary skill in the art will recognize that the above-described "scanning" sequence is not required. For example, drive traces **620** and **650** could be stimulated in overlapping fashion such that a first trace in drive traces **620** is stimulated, followed by a first trace in drive traces **650**, followed by a second trace in drive traces **620** and so on. Alternatively, groups of traces in drive traces **620** could be stimulated first, followed by a group of traces in drive traces **650**, and so on.

[0030] In one embodiment drive traces **620** (associated with touch location measurement operations) use a different geometry from drive traces **650** (associated with force measurement operations) and sense traces **625** (used during both location and force measurement operations). Referring to FIG. 7, it can be seen that drive traces **620** utilize conductive traces that employ internal floating plate structures **700** and, in addition, are physically larger than either the conductive traces used in sense **625** and drive traces **650** (both of which, in the illustrated embodiment, have the same physical size/structure). It has been found that this configuration provides increased sensitivity for determining where one or more objects (*e.g.*, a finger of stylus) touch, or come into close proximity to, cosmetic surface **605**.

[0031] Referring to FIG. 8A, in another embodiment of a combined touch and force sensitive touch pad in accordance with the invention (touch pad **800**), raised structures **655** may be replaced by beads or polymer dots **805** (also referred to as rubber or elastomer dots). In this embodiment, beads **805** operate in a manner similar to that of raised structures **655** (see FIG. 6). As shown, beads **805** rest on a thin adhesive layer **810** and are sized to keep layers **630** and **640** at a specified distance when no applied force is present. One illustrative layout and spacing of beads **805** is shown in FIGS. 8B (lop view) and 8C (cross-section). Table 2 identifies the approximate dimensions for each component of touch pad **800** that is different from prior illustrated touch pad **600**.

Table 2: Dimensions for Illustrative Touch Pad **800**

Layer	Material	Thickness (mm)
805	Rubber or polymer (*e.g.*, elastomer)	
810	Pressure sensitive adhesive ("PSA") or ultraviolet ("UV") light cured adhesive	0.015
a	Column bead separation	1.0
b	Row bead separation	5.0
c	Bead offset	2.5 ± 0.15
d	Bead height	0.15
Active touch pad surface: 271 mm × 69 mm		

Table 2: Dimensions for Illustrative Touch Pad **800**

Layer	Material	Thickness (mm)
No of drive traces (**620** and **650**): 13		
Number of sense traces (**625**): 54		
Pixel separation: 5 mm		

[0032] Referring to FIG. 9A, in yet another embodiment of a combined touch and force sensitive touch pad in accordance with the invention (touch pad **900**), a single layer of deformable beads or elastomer dots **905** are used. In touch pad **900**, thin adhesive layers **910** are used to mechanically couple the beads to the rest of the touch pad structure and the structure itself to base **665**. One illustrative layout and spacing of deformable beads **905** is shown in FIGS. 9B (lop view) and 9C (cross-section). Table 3 identifies the approximate dimensions for each component of touch pad **900** that is different from prior illustrated touch pad **600**.

Table 3: Dimensions for Illustrative Touch Pad **900**

Layer	Material	Thickness (mm)
905	Rubber or polymer (*e.g.*, elastomer)	
910	Pressure sensitive adhesive ("PSA") or ultraviolet ("UV") light cured adhesive	0.015
a	Column bead separation	1.0
b	Row bead separation	1.0
c	Bead offset	0.5
d	Bead width	0.5

Table 3: Dimensions for Illustrative Touch Pad **900**

Layer	Material	Thickness (mm)
e	Bead height	0.15

Active touch pad surface: 271 mm × 69 mm

No of drive traces (**620** and **650**): 13

Number of sense traces (**625**): 54

Pixel separation: 5 mm

[0033] Referring to FIG. 10A, in another embodiment of a combined touch and force sensitive touch pad in accordance with the invention (touch pad **1000**), spring membrane **1005** is used instead of raised structures (*e.g.*, **530** and **655**) or deformable beads (*e.g.*, **805** and **905**). In touch pad **1000**, thin adhesive layers **1010** are used to mechanically couple PET spring **1005** to layers **635** and **640** as well as to mechanically couple layer **645** to base **665**. Referring to FIG. 10B, in one embodiment spring membrane comprises a single rippled sheet of PET whose run-to-rise ratio (*i.e.*, a/b) is typically in the range of approximately 10:1 to 50:1. One of ordinary skill in the art will recognize that the exact value used in any given embodiment may change due to a variety of factors such as, for example, the physical size of the touch pad surface, the amount of weight specified for full deflection (*e.g.*, 200 grams) and the desired sense of "stiffness" presented to the user. Table 4 identifies the approximate dimensions for each component of touch pad **1000** that is different from prior illustrated touch pad **600**.

Table 4: Dimensions for Illustrative Touch Pad **1000**

Layer	Material	Thickness (mm)
1005	PET	0.75
1010	Pressure sensitive adhesive ("PSA") or ultraviolet ("UV") light cured adhesive	0.025
a/b	Spring run-to-rise ratio	10:1 → 50:1

Active touch pad surface: 271 mm × 69 mm

No of drive traces (**620** and **650**): 13

Number of sense traces (**625**): 54

Pixel separation: 5 mm

[0034] Referring to FIG. 11A, in another embodiment rippled spring membrane **1005** may be replaced by dimpled spring membrane **1105**. In this implementation, spring membrane **1105** is a single sheet of deformable material (*e.g.*, PET) that has dimples formed in it by, for example, thermal or vacuum forming techniques. Figures 11B and 11C show top views of two possible dimple arrangements. Two illustrative layouts (lop view) for dimpled membrane **1105** are shown in FIGS. 11B and 11C. As used in FIGS. 11A-11C, the "+" symbol represents a raised region and a "-" symbol represents a depressed region. Table 5 identifies the approximate dimensions "a" through "e" specified in FIG. 11A.

Table 5: Dimensions for Illustrative Spring Membrane **1100**

Layer	Material	Thickness (mm)
1105	PET	0.075
a	Dimple top length	1.0
b	Dimple width	1.25
c	Dimple separation	2.5
d	Dimple rise and fall length	0.075

[0035] Various changes in the materials, components and circuit elements are possible without departing from the scope of the following claims. For example, drive traces and sense traces in accordance with FIGS. 1-10 have been described as being orthogonal. The manner in which drive traces and cut across or intersect with sense traces, however, generally depends on the coordinate system used. In a Cartesian coordinate system, for example, sense traces are orthogonal to the driving traces thereby forming nodes with distinct x and y coordinates. Alternatively, in a polar coordinate system, sense traces may be concentric circles while drive traces may be radially extending lines (or vice versa).

[0036] In addition, in the embodiments of FIGS. 1 and 2, drive layer **135** and drive traces **140** (and, therefore, connector **145**) may be incorporated within and on spring membrane **125**. That is, drive traces **140** could be laid down or etched on a surface of flexible membrane **125**. Similarly, drive traces 535 could be incorporated into and as part of flexible membrane **525** (see FIG. 5).

[0037] One of ordinary skill in the art will also recognize that beads in accordance with FIGS. 8 and 9 (see FIGS. 8 and 9) could also be used in place of raised structures **130, 530** and **655** (see FIGS. 1, 2A, 2B, 5 and 6). Similarly, spring mechanisms **1005** (see FIG. 10) and **1105** (see FIG. 11) could be used in place of beads **805** (see FIG. 8), deformable beads **805** and **905** (see FIGS. 8 and 9) or raised structures **130, 530** and **655** (see FIGS. 1, 5 and 6).

[0038] Referring to FIG. 12A, in another embodiment force detection in accordance with the invention may be incorporated within a display unit rather than a touchpad. For example, system **1200** includes processor **1205**, standard input-output ("I/O") devices **1210** (*e.g.*, keyboard, mouse, touch pad, joy stick and voice input) and display **1215** incorporating force detection capability in accordance with the invention. Referring to FIG. 12B, in this embodiment, display **1215** includes display element **1220**, display element electronics **1225**, force element **1230** and force electronics **1235**. In this manner, user **1240** views display element **1220** of display **1200** through force element **1230**. By way of example, display element **1220** and electronics **125** may comprise a conventional liquid crystal display ("LCD") display. Force element **1230** may comprise a force-only sensor (*e.g.*, similar to the embodiments of FIGS. 1 and 2) or a force and location sensor (*e.g.*, similar to the embodiments of FIGS. 5-11). Force electronics **1235** may comprise processing circuitry as described in FIG. 4. That is, force electronics **1235** is capable of driving and sensing mutual capacitance signals as described in connection with a touch pad in accordance with the invention.

[0039] It will be recognized by those of ordinary skill in the art that use of the described force detection technology should, when applied to display **1215**, utilize transparent or substantially transparent drive and sense traces such as that provided by ITO (*i.e.*, rather than copper which is opaque). Similarly, the gap between the first layer of traces (*e.g.*, drive traces) and a second layer of traces (*e.g.*, sense traces) used to detect an applied force (see discussion above) should be transparent or substantially transparent. For example, compressible transparent spacers could be used to embody offset raised structures **130**, support structures **655**, deformable beads **805**, **905** or spring membranes **1005**, **1105**.

Claims

1. A force imaging touch pad, comprising:

a first layer having a first plurality of conductive traces oriented in a first direction on a first surface thereof;

a second layer having a second plurality of conductive traces oriented in a second direction on a first surface thereof; and

a deformable dielectric membrane juxtaposed between the first and second layers,

wherein the first and second plurality of conductive traces are adapted to create a capacitance image when a force is applied to the first layer, the capacitance image indicative of an intensity of the applied force.

2. The force imaging touch pad of claim 1, wherein the first plurality of conductive traces and the second plurality of conductive traces are substantially orthogonal.

3. The force imaging touch pad of claim 1, wherein the deformable dielectric membrane comprises:

a substantially flat membrane having a first surface oriented toward the first layer and a second surface oriented toward the second layer;

a first plurality of raised structures coupled to the first surface of the substantially flat membrane; and

a second plurality of raised structures coupled to the second surface of the substantially flat membrane, wherein the second plurality of raised structures are substantially offset from the first plurality of raised structures.

4. The force imaging touch pad of claim 1, wherein the deformable dielectric membrane comprises:

a substantially flat membrane; and

a plurality of deformable beads affixed to one surface of the substantially flat membrane, wherein the deformable beads are adapted to compress when a force is applied to the first layer toward the second layer.

5. The force imaging touch pad of claim 1, wherein the deformable dielectric membrane comprises one or more thermoplastic springs.

6. The force imaging touch pad of claim 1, wherein the deformable dielectric membrane comprises a dimpled deformable membrane.

7. The force imaging touch pad of claim 5, wherein the thermoplastic springs comprise Polyethylene terephthalate.

8. The force imaging touch pad of claim 1, further comprising a mutual capacitance measurement circuit electrically coupled to the first and second plurality of conductive traces.

9. A force and location imaging touch pad, comprising:

a first layer having a first plurality of conductive traces oriented in a first direction on a first surface thereof and a second plurality of conductive traces oriented in a second direction on a second surface thereof;

a second layer having a third plurality of conductive traces oriented in substantially the first direction;

a base layer;

a first deformable membrane juxtaposed between the first and second layers; and

a second deformable membrane juxtaposed between the second layer and the base layer,

wherein the first and second plurality of conductive traces are adapted to create a first capacitance image when one or more objects come into close proximity to the first surface, the first capacitance image indicative of where the one or more objects are located relative to the first surface,

wherein the second and third plurality of conductive traces are adapted to create a second capacitance image when a force is applied to the first layer, the second capacitance image indicative of an intensity of the applied force.

10. The force and location imaging touch pad of claim 9, wherein the first layer comprises a flexible circuit board.

11. The force and location imaging touch pad of claim 9, wherein the first layer comprises one or more layers of thermoplastic resin.

12. The force and location imaging touch pad of claim 9, wherein the first plurality of conductive traces and the second plurality of conductive traces are substantially orthogonal.

13. The force and location imaging touch pad of claim 9, wherein the second layer comprises a flexible circuit board.

14. The force and location imaging touch pad of claim 9, wherein the second layer comprises one or more layers of thermoplastic resin.

15. The force and location imaging touch pad of claim 9, wherein the first deformable membrane comprises a first plurality of raised structures, the second deformable membrane comprises a second plurality of raised structures and the first and second raised structures are substantially spatially offset from one another.

16. The force and location imaging touch pad of claim 15, wherein the first and second plurality of raised structures comprise thermoplastic resin.

17. The force and location imaging touch pad of claim 9, wherein the first deformable membrane comprises a first plurality deformable beads, the second deformable membrane comprises a second plurality of deformable beads and the first and second plurality of deformable beads are substantially spatially offset from one another.

18. The force and location imaging touch pad of claim 17, wherein the deformable beads comprise elastomer beads.

19. The force and location imaging touch pad of claim 9, wherein each of the first and second plurality of raised structures comprise one or more thermoplastic springs.

20. The force and location imaging touch pad of claim 19, wherein the thermoplastic springs comprise Polyethylene terephthalate.

21. The force and location imaging touch pad of claim 9, further comprising a mutual capacitance measurement circuit electrically coupled to the first, second and third plurality of conductive traces.

22. A force and location imaging touch pad, comprising:

a first surface having a first plurality of conductive traces oriented in a first direction;

a second surface having a second plurality of conductive traces oriented in a second direction, the first and second surfaces juxtaposed to and electrically isolated from one another;

a third surface having a third plurality of conductive traces oriented in substantially the first direction; and

a deformable membrane between the second and third layers,

wherein the first and second plurality of conductive traces are adapted to create a first capacitance image when one or more objects come into close proximity to the first surface, the first capacitance image indicative of where the one or more objects are located relative to the first surface,

wherein the second and third plurality of conductive traces are adapted to create a second capacitance image when a force is applied to the first surface, the second capacitance image indicative of an intensity of the applied force.

23. The force and location imaging touch pad of claim 22, wherein the first and second surfaces are surfaces of a common layer.

24. The force and location imaging touch pad of claim 23, wherein the common layer comprises a flexible circuit board.

25. The force and location imaging touch pad of claim 23, wherein the common layer comprises one or more layers of thermoplastic resin.

26. The force and location imaging touch pad of claim 22, wherein the first plurality of conductive traces and the second plurality of conductive traces are substantially orthogonal.

27. The force and location imaging touch pad of claim 22, wherein the third surface comprises thermoplastic resin.

28. The force and location imaging touch pad of claim 22, wherein the deformable membrane comprises:

a substantially flat membrane having a first surface oriented toward the first plurality of conductive traces and a second surface oriented toward the third plurality of conductive traces;

a first plurality of raised structures coupled to the first surface of the substantially flat membrane; and

a second plurality of raised structures coupled to the second surface of the substantially flat membrane, wherein the second plurality of raised structures are substantially spatially offset from the first plurality of raised structures.

29. The force and location imaging touch pad of claim 22, wherein the deformable membrane comprises:

a substantially flat membrane; and

a plurality of deformable beads affixed to one surface of the substantially flat membrane, wherein the deformable beads are adapted to compress when a force is applied to the first layer toward the second layer.

30. The force and location imaging touch pad of claim 22, wherein the deformable membrane comprises a dimpled deformable membrane.

31. The force and location imaging touch pad of claim 29, wherein the deformable beads comprise polymer.

32. The force and location imaging touch pad of claim 22, wherein the deformable membrane comprises one or more thermoplastic springs.

33. The force and location imaging touch pad of claim 32, wherein the thermoplastic springs comprise Polyethylene terephthalate.

34. The force and location imaging touch pad of claim 22, further comprising a mutual capacitance measurement circuit electrically coupled to the first, second and third plurality of conductive traces.

35. An electronic device, comprising:

a processing unit;

a display unit operatively coupled to the processing unit;

a mutual capacitance measurement circuit operatively coupled to the processing unit; and

a force and location imaging touch pad in accordance with one of claims 9 and 22 and operatively coupled to the mutual capacitance measurement circuit.

36. The electronic device of claim 35, wherein the electronic device comprises a computer system.

37. The electronic device of claim 35, wherein the electronic device comprises a mobile telephone.

38. The electronic device of claim 35, wherein the electronic device comprises a personal digital assistant.