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(71) Applicant : **SYNAPTICS, INCORPORATED**
2698 Orchard Parkway
San Jose, California 95134 (US)

(72) Inventor : **Miller, Robert J.**
1021, Washo Drive,
Fremont, California 94539 (US)
Inventor : **Bisset, Stephen J.**
1426 Arbor Avenue
Los Altos, California 94024 (US)

(74) Representative : **Williams, Trevor John**
J.A. KEMP & CO. 14 South Square Gray's Inn
London WC1R 5LX (GB)

(54) Object position detector.

(57) A proximity sensor system includes a sensor matrix array having a characteristic capacitance between horizontal and vertical conductors connected to sensor pads. The capacitance changes as a function of the proximity of an object or objects to the sensor matrix. The change in capacitance of each node in both the X and Y directions of the matrix due to the approach of an object is converted to a set of voltages in the X and Y directions. These voltages are processed by analog circuitry to develop electrical signals representative of the centroid of the profile of the object, i.e., its position in the X and Y dimensions. The profile of position may also be integrated to provide Z-axis (pressure) information.

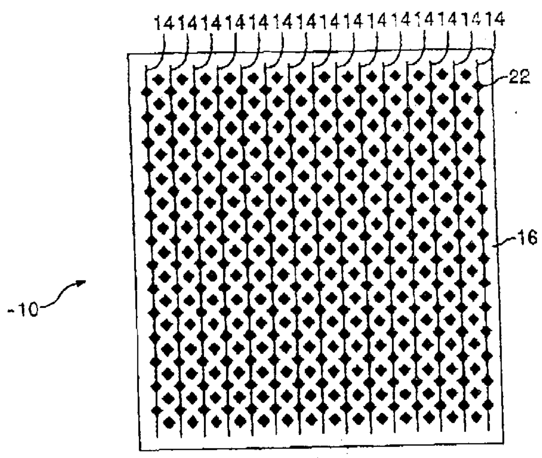

FIG. 1a

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BACKGROUND OF THE INVENTION

1. Field Of The Invention

The present invention relates to object position sensing transducers and systems. More particularly, the present invention relates to object position sensors useful in applications such as cursor movement for computing devices and other applications.

2. The Prior Art

Numerous devices are available or have been proposed for use as object position detectors for use in computer systems and other applications. The most familiar of such devices is the computer "mouse". While extremely popular as a position indicating device, a mouse has mechanical parts and requires a surface upon which to roll its position ball. Furthermore, a mouse usually needs to be moved over long distances for reasonable resolution. Finally, a mouse requires the user to lift a hand from the keyboard to make the cursor movement, thereby upsetting the prime purpose, which is usually typing on the computer.

Trackball devices are similar to mouse devices. A major difference, however is that, unlike a mouse device, a trackball device does not require a surface across which it must be rolled. Trackball devices are still expensive, have moving parts, and require a relatively heavy touch as do the mouse devices. They are also large in size and doe not fit well in a volume sensitive application like a laptop computer.

There are several available touch-sense technologies which may be employed for use as a position indicator. Resistive-membrane position sensors are known and used in several applications. However, they generally suffer from poor resolution, the sensor surface is exposed to the user and is thus subject to wear. In addition, resistive-membrane touch sensors are relatively expensive. A one-surface approach requires a user to be grounded to the sensor for reliable operation. This cannot be guaranteed in portable computers. An example of a one-surface approach is the UnMouse product by MicroTouch, of Wilmington, MAAtwo-surface approach has poorer resolution and potentially will wear out very quickly in time.

Surface Acoustic Wave (SAW) devices have potential use as position indicators. However, this sensor technology is expensive and is not sensitive to light touch. In addition, SAW devices are sensitive to residue buildup on the touch surfaces and generally have poor resolution.

Strain gauge or pressure plate approaches are an interesting position sensing technology, but suffer from several drawbacks. This approach may employ piezo-electric transducers. One drawback is that the piezo phenomena is an AC phenomena and may be sensitive to the user's rate of movement. In addition, strain gauge or pressure plate approaches are a somewhat expensive because special sensors are required.

Optical approaches are also possible but are somewhat limited for several reasons. All would require light generation which will require external components and increase cost and power drain. For example, a "finger-breaking" infra-red matrix position detector consumes high power and suffers from relatively poor resolution.

BRIEF DESCRIPTION OF THE INVENTION

The present invention comprises a position-sensing technology particularly useful for applications where finger position information is needed, such as in computer "mouse" or trackball environments. However the position-sensing technology of the present invention has much more general application than a computer mouse, because its sensor can detect and report if one or more points are being touched. In addition, the detector can sensa the pressure of the touch.

There are at least two distinct embodiments of the present invention. Both embodiments of the present invention include a sensor comprising a plurality of spaced apart generally parallel conductive lines disposed on a first surface.

According to a first embodiment of the present invention, referred to herein as a "finger pointer" embodiment, a position sensing system Includes a position sensing transducer comprising a touch-sensitive surface disposed on a substrate, such as a printed circuit board, including a matrix of conductive lines. A first set of conductive lines runs in a first direction and is insulated from a second set of conductive lines running in a second direction generally perpendicular to the first direction. An insulating layer is disposed over the first and second sets of conductive lines. The insulating layer is thin enough to promote significant capacitive coupling between a finger placed on its surface and the first and second sets of conductive lines.

Sensing eledronics respond to the proximity of a finger to translate the capacitance changes between the conductors caused by finger proximity into position and touch pressure Information. Its output is a simple X, Y and pressure value of the one object on Its surface. The matrix of conductive lines are successively scanned, one at a time, with the capacltive information from that scan indicating how close a finger is to that node. That information provides a profile of the proximity of the finger to the sensor in each dimension. The centroid of the profile is computed with that value being the position of the finger in that dimension. The profile of position is also integrated with that result providing the Z (pressure) information. The position sensor of the first embodiment of the invention can only detect the position of one object on its sensor surface. If more than one object is present, the position sensor of this embodiment tries to compute the centroid position of the combined set of objects.

According to a second embodiment of the present invention, a position sensing system includes a position sensing transducer as described herein. Sensing electronics respond to the.proximity of a finger to translate the capacitance changes between the conductors running in one direction and those running in the other direction caused by finger proximity into position and touch pressure information. The sensing electronics of the second embodiment of the invention saves information for every node in its sensor matrix and can thereby give the full X/Y dimension picture of what it is sensing. It thus has much broader application for richer multi-dimensional sensing than does the first "finger pointer' embodiment. In this embodiment, referred to herein as the "position matrix" approach, the x,y coordinate information can be used as input to a on-chip neural network processor. This allows an operator to use multiple fingers, coordinated gestures, etc. for even more complex interactions.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1a is a top view of an object position sensor transducer according to a presently preferred embodiment of the invention showing the object position sensor surface layer Including a top conductive trace layer and conductive pads connected to a bottom trace layer.

FIG. 1b is a bottom view of the object position sensor transducer of FIG. 1a showing the bottom conductive trace layer.

FIG. 1c is a composite view of the object position sensor transducer of FIGS. 1a and 1b showing both the top and bottom conductive trace layers.

FIG. 1d is a cross-sectional view of the object position sensor transducer of FIGS. 1a-1c.

FIG. 2 is a block diagram of sensor decoding electronics which may be used with the sensor transducer in accordance with a first embodiment of the present invention.

FIGS. 3a and 3b are graphs of output voltage versus matrix conductor position which illustrate the effect of the minimum detector.

FIG. 4 is a simplified schematic diagram of an integrating charge amplifier circuit suitable for use in the present invention.

FIG. 5 is a timing diagram showing the relative timing of control signals used to operate the object position sensor system of the present invention with an integrating charge amplifier as shown in FIG. 4.

FIG. 6a is a schematic diagram of a first alternate embodiment of an integrating charge amplifier circuit suitable for use in the present invention including additional components to bring the circuit to equilibrium prior to integration measurement.

FIG. 6b is a timing diagram showing the control and timing signals used to drive the integrating charge amplifier of FIG. 6a and the response of various nodes in the amplifier to those signals.

FIG. 7a is a schematic diagram of a second alternate embodiment of an integrating charge amplifier circuit suitable for use in the present invention including additional components to bring the circuit to equilibrium prior to integration measurement.

FIG. 7b is a timing diagram showing the control and timing signals used to drive the integrating charge amplifier of FIG. 7a and the response of various nodes in the amplifier to those signals.

FIG. 8 is a schematic diagram of a minimum detector circuit according to a presently preferred embodiment of the invention.

FIG. 9 is a schematic diagram of a maximum detector circuit according to a presently preferred embodiment of the invention.

FIG. 10 is a schematic diagram of a linear voltage-to-current converter circuit according to a presently preferred embodiment of the invention.

FIG. 11 is a schematic diagram of a position encoder centroid computing circuit according to a presently preferred embodiment of the invention.

FIG. 12 is a schematic diagram of a Z Sum circuit according to a presently preferred embodiment of the invention.

FIG. 13 is a schematic diagram of a multiplier circuit according to a presently preferred embodiment of the invention.

FIG. 14 is a schematic diagram of a combination driving-point impedance circuit and receiving-point impedance circuit according to a presently preferred position matrix embodiment of the invention.

FIG. 15 is a block diagram of a the structure of a portion of a sample/hold array suitable for use in the present invention.

FIG. 16a is a block diagram of a simple version of a position matrix embodiment of the present invention in which the matrix of voltage information is sent to a computer which processes the data.

FIG. 16b is a block diagram of a second version of a position matrix embodiment of the present invention employing a sample/hold array such as that depicted in FIG. 15.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT

Those of ordinary skill in the art will realize that the following description of the present invention is illustrative only and not in any way limiting. Other embodiments of the invention will readily suggest themselves to such skilled persons.

The present invention brings together in combination a number of unique features which allow for new applications not before possible. Because the object position sensor of the present invention has very low power requirements, it is beneficial for use in battery operated or low power applications such as lap top or portable computers. It is also a very low cost solution, has no moving parts (and is therefore virtually maintenance free), and uses the existing printed circuit board traces for sensors. The sensing technology of the present invention can be integrated into a computer motherboard to even further lower its cost in computer applications. Similarly, in other applications the sensor can be part of an already existent circuit board.

Because of its small size and low profile, the sensor technology of the present invention is useful in lap top or portable applications where volume is important consideration. The sensor technology of the present invention requires circuit board space for only a single sensor interface chip that can interface directly to a microprocessor, plus the area needed on the printed circuit board for sensing.

The sensor material can be anything that allows creation of a conductive X/Y matrix of pads. This includes not only standard PC board, but also flexible PC board, conductive elastomer materials, and piezoelectric Kynar plastic materials. This renders it useful as well in any portable equipment application or in human interface where the sensor needs to be molded to fit within the hand.

The sensor can be conformed to any three dimensional surface. Copper can be plated in two layers on most any surface contour producing the sensor. This will allow the sensor to be adapted to the best ergonomic form needed for a application. This coupled with the "light-touch" feature will make it effortless to use in many applications. The sensor can also be used in an indirect manner, i.e it can have a conductive foam over the surface and be used to detect any object (not just conductive) that presses against it's surface.

Small sensor areas are practical, i.e., a presently conceived embodiment takes about 1.5"x 1.5" of area, however those of ordinary skill in the art will recognize that the area is scalable for different applications. The matrix area is scaleable by either varying the matrix trace spacing or by varying the number of traces. Large sensor areas are practical where more information is needed.

Besides simple X and Y position information, the sensor technology of the present invention also provides finger pressure information. This additional dimension of information may be used by programs to control special features such as "brush-width" modes in Paint programs, special menu accesses, etc., allowing provision of a more natural sensory input to computers.

The user will not even have to touch the surface to generate the minimum reaction. This feature can greatly minimize user strain and allow for more flexible use.

The sense system of the present invention depends on a transducer device capable of providing position and pressure information regarding the object contacting the transducer. Referring first to FIGS. 1a-1d, top, bottom, composite, and cross-sectional views, respectively, are shown of a presently-preferred touch sensor array for use in the present invention. Since capacitance is exploited by this embodiment of the present invention, the sensor surface is designed to maximize the capacitive coupling between top (X) trace pads to the bottom (Y) trace pads in a way that can be maximally perturbed and coupled to a finger or other object placed above the surface.

A presently preferred sensor array 10 according to the present invention comprises a substrate 12 Including a set of first conductive traces 14 disposed on a top surface 16 thereof and run in a first direction to comprise rows of the array. A second set of conductive traces 18 are disposed on a bottom surface 20 thereof and run In a second direction preferably orthogonal to the first direction to form the columns of the array. The top and bottom conductive traces 14 and 18 are alternately in contact with periodic sense pads 22 comprising enlarged areas, shown as diamonds in FIGS. 1a-1c. While sense pads 22 are shown as diamonds in FIGS. 1a-1c, any shape, such as circles, which allows close packing of the sense pads, is equivalent for purposes of this invention.

The number and spacing of these sense pads 22 depends upon the resolution desired. For example, in an actual embodiment constructed according to the principles of the present invention, a 0.10 inch center-to-center diamond-shaped pattern of conductive pads disposed along a matrix of 15 rows and 15 columns of conductors is employed. Every other sense pad 22 in each direction in the pad pattern is connected to conductive traces on the top and bottom surfaces 16 and 20, respectively of substrate 12.

Substrate 12 may be a printed circuit board, a flexible circuit board or any of a number of available circuit interconnect technology structures. Its thickness is unimportant as long as contact may be made therethrough from the bottom conductive traces 18 to their sense pads 22 on the top surface 16. The printed circuit board comprising substrate 12 can be constructed using standard Industry techniques. Board thickness is not important. Pad-to-pad spacing should preferably be minimized to something in the range of about 15 mils or less. Connections from the conductive pads 22 to the bottom traces 18 may be made employing standard plated-through hole techniques well known in the printed circuit board art.

An insulating layer 24 is disposed over the sense pads 22 on top surface 16 to insulate a human finger or other object therefrom. Insulating layer 24 is preferably a thin layer (i.e., approximately 5 mils) to keep capacitive coupling large and may comprise a material, such as mylar, chosen for its protective and ergonomic characteristics.

There are two different capacitive effects taking place when a finger approaches the sensor array 10. The first capacitive effect is trans-capacitance, or coupling between sense pads 22, and the second capacitive effect is self-capacitance (ground capacitance), or coupling to earth-ground. Sensing circuitry is coupled to the sensor array 10 of the present invention and responds to changes in either or both of these capacltances, This is important because the relative sizes of the two capacitances change greatly depending on the user environment. The ability of the present invention to detect changes in both self capacitance and trans-capacitance results in a very versatile system having a wide range of applications.

According to a first embodiment of the invention, a position sensor system including sensor array 10 and associated touch detector circuitry will detect a finger position on a matrix of printed circuit board traces via the capacitive effect of finger proximity to the sensor array 10. The position sensor system will report the X, Y position of a finger placed near the sensor array 10 to much finer resolution than the spacing between the row and column traces 14 and 18. The position sensor according to this embodiment of the invention will also report a Z value proportional to the outline of that finger and hence Indicative of the pressure with which the finger contacts the surface of insulating layer 22 over the sensing array 10.

According to a presently preferred embodiment of the invention, a very sensitive, light-touch detector circuit may be provided using adaptive analog VLSI techniques. The circuit of the present invention is very robust and calibrates out process and systematic errors. The detector circuit of the present invention will process the capacitive input information and provide digital information to a microprocessor.

According to this embodiment of the invention, sensing circuitry is contained on a single sensor processor integrated circuit chip. The sensor processor chip can have any number of X and Y "matrix" inputs. The number of X and Y inputs does not have to be equal. The Integrated circuit has a digital bus as output. In the illustrative example disclosed in FIGS. 1a-1d herein, the sensor array has 15 traces in both the Y and Y directions. The sensor processor chip thus has 15 X inputs and 15 Y inputs.

The X and Y matrix nodes are successively scanned, one at a time, with the capacitive information from that scan indicating how close a finger is to that node. The scanned information provides a profile of the finger proximity in each dimension. According to this aspect of the present invention, the profile centroid is derived in both the X and Y directions and is the position in that dimension. The profile curve of proximity is also integrated to provide the Z information.

Referring now to FIG. 2, a block diagram of presently preferred sensing circuitry 30 for use according to the present invention is shown. The sensing circuitry of this embodiment employs a driving-point impedance measurement for each X and Y line in the sensing matrix 10. The block diagram of FIG. 2 illustrates the portion of the sensing circuitry for developing signals from one direction (shown as X in the matrix). The circuitry for developing signals from the other direction in the matrix is identical and Its interconnection to the circuitry shown in FIG. 2 will be disclosed herein. The circuitry of FIG. 2 illustratively discloses an embodiment in which information from six X matrix lines X1 . . . X6 are processed. Those of ordinary skill in the art will recognize that this embodiment is illustrative only, and that actual embodiments fabricated according to the present invention may employ an arbitrarily sized matrix, limited only by technology constraints.

The driving-point capacitance measurement for each of X lines X1 ... X6 is derived from an integrating charge amplifier circuit. These circuits are shown in block form at reference numerals 32-1 through 32-6. The function of each of integrating charge amplifier circuits 32-1 through 32-6 is to develop an output voltage proportional to the capacitance sensed on its corresponding X matrix line.

The driving-point capacitance measurement is made for all X (row) conductors 14 and all Y (column) conductors 18 in the sensor matrix array 10. A profile of the finger proximity mapped into the X and Y dimension is generated from the driving-point capacitance measurement data. This profile is then used to determine a centrold in both dimensions, thereby determining the X and Y position of the finger.

The output voltages of integrating charge amplifier circuits 32-1 through 32-6 are utilized by several other circuit elements and are shown for convenience in FIG. 2 as distributed by bus 34. Bus 34 is a six conductor bus, and those of ordinary skill in the art will recognize that each of its conductors comprises the output of one of integrating charge amplifiers 32-1 through 32-6.

The first of circuit elements driven by the outputs of integrating charge amplifier circuits 32-1 through 32-6 Is linear voltage-to-current converter 36. The function of linear voltage-to-current converter 36 is to convert the output voltages of integrating charge amplifiers 32-1 through 32-6 to currents for subsequent processing.

The current outputs from linear voltage-to-current converter 36 are presented as inputs to X position encode circuit 38. The function of X position encode circuit 38 is to convert the input information into a signal representing object proximity in the X dimension of the sensor array matrix. According to a pre-

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