the lines from the spaces therebetween, i.e., the patterned ITO can become quite visible thereby producing a touch screen with undesirable optical properties. To further exacerbate this problem, the ITO material is typically applied in a manner that produces a relatively low resistance, and unfortunately low resistance ITO tends to be less transparent than high resistance ITO.

In order to prevent the aforementioned problem, the dead areas between the ITO may be filled with indexing matching materials. In another embodiment, rather than simply etching away all of the ITO, the dead areas (the uncovered spaces) may be subdivided into unconnected electrically floating ITO pads, i.e., the dead areas may be patterned with spatially separated pads. The pads are typically separated with a minimum trace width. Furthermore, the pads are typically made small to reduce their impact on the capacitive measurements. This technique attempts to minimize the appearance of the ITO by creating a uniform optical retarder. That is, by seeking to create a uniform sheet of ITO, it is believed that the panel will function closer to a uniform optical retarder and therefore non-uniformities in the visual appearance will be minimized. In yet another embodiment, a combination of index matching materials and unconnected floating pads may be used.

FIG. 10 is a partial front elevation view, in cross section of a display arrangement 170, in accordance with one embodiment of the present invention. The display arrangement 170 includes an LCD display 172 and a touch screen 174 positioned over the LCD display 170. The touch screen may for example correspond to the touch screen shown in FIG. 9. The LCD display 172 may correspond to any conventional LCD display known in the art. Although not shown, the LCD display 172 typically includes various layers including a fluorescent panel, polarizing filters, a layer of liquid crystal cells, a color filter and the like.

The touch screen 174 includes a transparent sensing layer 176 that is positioned over a first glass member 178. The sensing layer 176 includes a plurality of sensor lines 177 positioned in columns (extend in and out of the page). The first glass member 178 may be a portion of the LCD display 172 or it may be a portion of the touch screen 174. For example, it may be the front glass of the LCD display 172 or it may be the bottom glass of the touch screen 174. The sensor layer 176 is typically disposed on the glass member 178 using suitable transparent conductive materials and patterning techniques. In some cases, it may be necessary to coat the sensor layer 176 with material of similar refractive index to improve the visual appearance, i.e., make more uniform.

The touch screen 174 also includes a transparent driving layer 180 that is positioned over a second glass member 182. The second glass member 182 is positioned over the first glass member 178. The sensing layer 176 is therefore sandwiched between the first and second glass members 178 and 182. The second glass member 182 provides an insulating layer between the driving and sensing layers 176 and 180. The driving layer 180 includes a plurality of driving lines 181 positioned in rows (extend to the right and left of the page). The driving lines 181 are configured to intersect or cross the sensing lines 177 positioned in columns in order to form a plurality of capacitive coupling nodes 182. Like the sensing layer 176, the driving layer 180 is disposed on the glass member using suitable materials and patterning techniques. Furthermore, in some cases, it may be necessary to coat the driving layer 180 with material of similar refractive index to improve the visual appearance. Although the sensing layer is typically patterned on the first glass member, it should be noted that in some cases it may be alternatively or additionally patterned on the second glass member.

The touch screen 174 also includes a protective cover sheet 190 disposed over the driving layer 180. The driving layer 180 is therefore sandwiched between the second glass member 182 and the protective cover sheet 190. The protective cover sheet 190 serves to protect the under layers and provide a surface for allowing an object to slide thereon. The protective cover sheet 190 also provides an insulating layer between the object and the driving layer 180. The protective cover sheet is suitably thin to allow for sufficient coupling. The protective cover sheet 190 may be formed from any suitable clear material such as glass and plastic. In addition, the protective cover sheet 190 may be treated with coatings to reduce stiction when touching and reduce glare when viewing the underlying LCD display 172. By way of example, a low stiction/anti reflective coating may be applied over the cover sheet 190. Although the line layer is typically patterned on a glass member, it should be noted that in some cases it may be alternatively or additionally patterned on the protective cover sheet.

The touch screen 174 also includes various bonding layers 192. The bonding layers 192 bond the glass members 178 and 182 as well as the protective cover sheet 190 together to form the laminated structure and to provide rigidity and stiffness to the laminated structure. In essence, the bonding layers 192 help to produce a monolithic sheet that is stronger than each of the individual layers taken alone. In most cases, the first and second glass members 178 and 182 as well as the second glass member and the protective sheet 182 and 190 are laminated together using a bonding agent such as glue. The compliant nature of the glue may be used to absorb geometric variations so as to form a singular composite structure with an overall geometry that is desirable. In some cases, the bonding agent includes an index matching material to improve the visual appearance of the touch screen 170.

With regards to configuration, each of the various layers may be formed with various sizes, shapes, and the like. For example, each of the layers may have the same thickness or a different thickness than the other layers in the structure. In the illustrated embodiment, the first glass member 178 has a thickness of about 1.1 mm, the second glass member 182 has a thickness of about 0.4 mm and the protective sheet has a thickness of about 0.55 mm. The thickness of the bonding layers 192 typically varies in order to produce a laminated structure with a desired height. Furthermore, each of the layers may be formed with various materials. By way of example, each particular type of layer may be formed from the same or different material. For example, any suitable glass or plastic material may be used for the glass members. In a similar manner, any suitable bonding agent may be used for the bonding layers 192.

FIGS. 11A and 11B are partial top view diagrams of a driving layer 200 and a sensing layer 202, in accordance with one embodiment. In this embodiment, each of the layers 200 and 202 includes dummy features 204 disposed between the driving lines 206 and the sensing lines 208. The dummy features 204 are configured to optically improve the visual appearance of the touch screen by more closely matching the optical index of the lines. While index matching materials may improve the visual appearance, it has been found that there still may exist some non-uniformities. The dummy features 204 provide the touch screen with a more uniform appearance. The dummy features 204 are electrically isolated and positioned in the gaps between each of the lines 206 and 208. Although they may be patterned separately, the dummy features 204 are typically patterned along with the lines 206 and 208. Furthermore, although they may be formed from different materials, the dummy features 204 are typically formed with the same transparent conductive material as the

lines as for example ITO to provide the best possible index matching. As should be appreciated, the dummy features will more than likely still produce some gaps, but these gaps are much smaller than the gaps found between the lines (many orders of magnitude smaller). These gaps, therefore have minimal impact on the visual appearance. While this may be the case, index matching materials may be additionally applied to the gaps between the dummy features to further improve the visual appearance of the touch screen. The distribution, size, number, dimension, and shape of the dummy features may be widely varied.

FIG. 12 is a simplified diagram of a mutual capacitance circuit 220, in accordance with one embodiment of the present invention. The mutual capacitance circuit 220 includes a driving line 222 and a sensing line 224 that are spatially separated thereby forming a capacitive coupling node 226. The driving line 222 is electrically coupled to a voltage source 228, and the sensing line 224 is electrically coupled to a capacitive sensing circuit 230. The driving line 222 is configured to carry a current to the capacitive coupling node 226, and the sensing line 224 is configured to carry a current to the capacitive sensing circuit 230. When no object is present, the capacitive coupling at the node 226 stays fairly constant. When an object 232 such as a finger is placed proximate the node 226, the capacitive coupling changes through the node 226 changes. The object 232 effectively shunts some of the field away so that the charge projected across the node 226 is less. The change in capacitive coupling changes the current that is carried by the sensing lines 224. The capacitive sensing circuit 230 notes the current change and the position of the node 226 where the current change occurred and reports this information in a raw or in some processed form to a host controller. The capacitive sensing circuit does this for each node 226 at about the same time (as viewed by a user) so as to provide multipoint sensing.

The sensing line 224 may contain a filter 236 for eliminating parasitic capacitance 237, which may for example be created by the large surface area of the row and column lines relative to the other lines and the system enclosure at ground potential. Generally speaking, the filter rejects stray capacitance effects so that a clean representation of the charge transferred across the node 226 is outputted (and not anything in addition to that). That is, the filter 236 produces an output that is not dependent on the parasitic capacitance, but rather on the capacitance at the node 226. As a result, a more accurate output is produced.

FIG. 13 is a diagram of an inverting amplifier 240, in accordance with one embodiment of the present invention. The inverting amplifier 240 may generally correspond to the filter 236 shown in FIG. 12. As shown, the inverting amplifier includes a non inverting input that is held at a constant voltage (in this case ground), an inverting input that is coupled to the node and an output that is coupled to the capacitive sensing circuit 230. The output is coupled back to the inverting input through a capacitor. During operation, the input from the node may be disturbed by stray capacitance effects, i.e., parasitic capacitance. If so, the inverting amplifier is configured to drive the input back to the same voltage that it had been previously before the stimulus. As such, the value of the parasitic capacitance doesn't matter.

FIG. 14 is a block diagram of a capacitive sensing circuit 260, in accordance with one embodiment of the present invention. The capacitive sensing circuit 260 may for example correspond to the capacitive sensing circuits described in the previous figures. The capacitive sensing circuit 260 is configured to receive input data from a plurality of

sensing points 262 (electrode, nodes, etc.), to process the data and to output processed data to a host controller.

The sensing circuit 260 includes a multiplexer 264 (MUX). The multiplexer 264 is a switch configured to perform time multiplexing. As shown, the MUX 264 includes a plurality of independent input channels 266 for receiving signals from each of the sensing points 262 at the same time. The MUX 264 stores all of the incoming signals at the same time, but sequentially releases them one at a time through an output channel 268.

The sensing circuit 260 also includes an analog to digital converter 270 (ADC) operatively coupled to the MUX 264 through the output channel 268. The ADC 270 is configured to digitize the incoming analog signals sequentially one at a time. That is, the ADC 270 converts each of the incoming analog signals into outgoing digital signals. The input to the ADC 270 generally corresponds to a voltage having a theoretically infinite number of values. The voltage varies according to the amount of capacitive coupling at each of the sensing points 262. The output to the ADC 270, on the other hand, has a defined number of states. The states generally have predictable exact voltages or currents.

The sensing circuit 260 also includes a digital signal processor 272 (DSP) operatively coupled to the ADC 270 through another channel 274. The DSP 272 is a programmable computer processing unit that works to clarify or standardize the digital signals via high speed mathematical processing. The DSP 274 is capable of differentiating between human made signals, which have order, and noise, which is inherently chaotic. In most cases, the DSP performs filtering and conversion algorithms using the raw data. By way of example, the DSP may filter noise events from the raw data, calculate the touch boundaries for each touch that occurs on the touch screen at the same time, and thereafter determine the coordinates for each touch event. The coordinates of the touch events may then be reported to a host controller where they can be compared to previous coordinates of the touch events to determine what action to perform in the host device.

FIG. 15 is a flow diagram 280, in accordance with one embodiment of the present invention. The method generally begins at block 282 where a plurality of sensing points are driven. For example, a voltage is applied to the electrodes in self capacitance touch screens or through driving lines in mutual capacitance touch screens. In the later, each driving line is driven separately. That is, the driving lines are driven one at a time thereby building up charge on all the intersecting sensing lines. Following block 282, the process flow proceeds to block 284 where the outputs (voltage) from all the sensing points are read. This block may include multiplexing and digitizing the outputs. For example, in mutual capacitance touch screens, all the sensing points on one row are multiplexed and digitized and this is repeated until all the rows have been sampled. Following block 284, the process flow proceeds to block 286 where an image or other form of data (signal or signals) of the touch screen plane at one moment in time can be produced and thereafter analyzed to determine where the objects are touching the touch screen. By way of example, the boundaries for each unique touch can be calculated, and thereafter the coordinates thereof can be found. Following block 286, the process flow proceeds to block 288 where the current image or signal is compared to a past image or signal in order to determine a change in pressure, location, direction, speed and acceleration for each object on the plane of the touch screen. This information can be subsequently used to perform an action as for example moving a pointer or cursor or making a selection as indicated in block 290.

FIG. 16 is a flow diagram of a digital signal processing method 300, in accordance with one embodiment of the present invention. By way of example, the method may generally correspond to block 286 shown and described in FIG. 15. The method 300 generally begins at block 302 where the raw data is received. The raw data is typically in a digitized form, and includes values for each node of the touch screen. The values may be between 0 and 256 where 0 equates to the highest capacitive coupling (no touch pressure) and 256 equates to the least capacitive coupling (full touch pressure). An example of raw data at one point in time is shown in FIG. 17A. As shown in FIG. 17A, the values for each point are provided in gray scale where points with the least capacitive coupling are shown in white and the points with the highest capacitive coupling are shown in black and the points found between the least and the highest capacitive coupling are shown in gray.

Following block 302, the process flow proceeds to block 304 where the raw data is filtered. As should be appreciated, the raw data typically includes some noise. The filtering process is configured to reduce the noise. By way of example, a noise algorithm may be run that removes points that aren't connected to other points. Single or unconnected points generally indicate noise while multiple connected points generally indicate one or more touch regions, which are regions of the touch screen that are touched by objects. An example of a filtered data is shown in FIG. 17B. As shown, the single scattered points have been removed thereby leaving several concentrated areas.

Following block 304, the process flow proceeds to block 306 where gradient data is generated. The gradient data indicates the topology of each group of connected points. The topology is typically based on the capacitive values for each point. Points with the lowest values are steep while points with the highest values are shallow. As should be appreciated, steep points indicate touch points that occurred with greater pressure while shallow points indicate touch points that occurred with lower pressure. An example of gradient data is shown in FIG. 17C.

Following block 306, the process flow proceeds to block 308 where the boundaries for touch regions are calculated based on the gradient data. In general, a determination is made as to which points are grouped together to form each touch region. An example of the touch regions is shown in FIG. 17D.

In one embodiment, the boundaries are determined using a watershed algorithm. Generally speaking, the algorithm performs image segmentation, which is the partitioning of an image into distinct regions as for example the touch regions of multiple objects in contact with the touchscreen. The concept of watershed initially comes from the area of geography and more particularly topography where a drop of water falling on a relief follows a descending path and eventually reaches a minimum, and where the watersheds are the divide lines of the domains of attracting drops of water. Herein, the watershed lines represent the location of pixels, which best separate different objects touching the touch screen. Watershed algorithms can be widely varied. In one particular implementation, the watershed algorithm includes forming paths from low points to a peak (based on the magnitude of each point), classifying the peak as an ID label for a particular touch region, associating each point (pixel) on the path with the peak. These steps are performed over the entire image map thus carving out the touch regions associated with each object in contact with the touchscreen.

Following block 308, the process flow proceeds to block 310 where the coordinates for each of the touch regions are

calculated. This may be accomplished by performing a centroid calculation with the raw data associated with each touch region. For example, once the touch regions are determined, the raw data associated therewith may be used to calculate the centroid of the touch region. The centroid may indicate the central coordinate of the touch region. By way of example, the X and Y centroids may be found using the following equations:

$$X_c = \Sigma Z * x / \Sigma Z; \text{ and}$$

$$Y_c = \Sigma Z * y / \Sigma Z,$$

where

X_c represents the x centroid of the touch region

Y_c represents the y centroid of the touch region

x represents the x coordinate of each pixel or point in the touch region

y represents the y coordinate of each pixel or point in the touch region

Z represents the magnitude (capacitance value) at each pixel or point

An example of a centroid calculation for the touch regions is shown in FIG. 17E. As shown, each touch region represents a distinct x and y coordinate. These coordinates may be used to perform multipoint tracking as indicated in block 312. For example, the coordinates for each of the touch regions may be compared with previous coordinates of the touch regions to determine positioning changes of the objects touching the touch screen or whether or not touching objects have been added or subtracted or whether a particular object is being tapped.

FIGS. 18 and 19 are side elevation views of an electronic device 350, in accordance with multiple embodiments of the present invention. The electronic device 350 includes an LCD display 352 and a transparent touch screen 354 positioned over the LCD display 352. The touch screen 354 includes a protective sheet 356, one or more sensing layers 358, and a bottom glass member 360. In this embodiment, the bottom glass member 360 is the front glass of the LCD display 352. Further, the sensing layers 358 may be configured for either self or mutual capacitance as described above. The sensing layers 358 generally include a plurality of interconnects at the edge of the touch screen for coupling the sensing layer 358 to a sensing circuit (not shown). By way of example, the sensing layer 358 may be electrically coupled to the sensing circuit through one or more flex circuits 362, which are attached to the sides of the touch screen 354.

As shown, the LCD display 352 and touch screen 354 are disposed within a housing 364. The housing 364 serves to cover and support these components in their assembled position within the electronic device 350. The housing 364 provides a space for placing the LCD display 352 and touch screen 354 as well as an opening 366 so that the display screen can be seen through the housing 364. In one embodiment, as shown in FIG. 18, the housing 364 includes a facade 370 for covering the sides the LCD display 352 and touch screen 354. Although not shown in great detail, the facade 370 is positioned around the entire perimeter of the LCD display 352 and touch screen 354. The facade 370 serves to hide the interconnects leaving only the active area of the LCD display 352 and touch screen 354 in view.

In another embodiment, as shown in FIG. 19, the housing 364 does not include a facade 370, but rather a mask 372 that is printed on interior portion of the top glass 374 of the touch screen 354 that extends between the sides of the housing 364. This particular arrangement makes the mask 372 look submerged in the top glass 356. The mask 372 serves the same

function as the facade **370**, but is a more elegant solution. In one implementation, the mask **372** is a formed from high temperature black polymer. In the illustrated embodiment of FIG. **19**, the touch screen **354** is based on mutual capacitance sensing and thus the sensing layer **358** includes driving lines **376** and sensing lines **378**. The driving lines **376** are disposed on the top glass **356** and the mask **372**, and the sensing lines **378** are disposed on the bottom glass **360**. The driving lines and sensing lines **376** and **378** are insulated from one another via a spacer **380**. The spacer **380** may for example be a clear piece of plastic with optical matching materials retained therein or applied thereto.

In one embodiment and referring to both FIGS. **18** and **19**, the electronic device **350** corresponds to a tablet computer. In this embodiment, the housing **364** also encloses various integrated circuit chips and other circuitry **382** that provide computing operations for the tablet computer. By way of example, the integrated circuit chips and other circuitry may include a microprocessor, motherboard, Read-Only Memory (ROM), Random-Access Memory (RAM), a hard drive, a disk drive, a battery, and various input/output support devices.

While this invention has been described in terms of several preferred embodiments, there are alterations, permutations, and equivalents, which fall within the scope of this invention. For example, although the touch screen was primarily directed at capacitive sensing, it should be noted that some or all of the features described herein may be applied to other sensing methodologies. It should also be noted that there are many alternative ways of implementing the methods and apparatuses of the present invention. It is therefore intended that the following appended claims be interpreted as including all such alterations, permutations, and equivalents as fall within the true spirit and scope of the present invention.

What is claimed is:

1. A touch panel comprising a transparent capacitive sensing medium configured to detect multiple touches or near touches that occur at a same time and at distinct locations in a plane of the touch panel and to produce distinct signals representative of a location of the touches on the plane of the touch panel for each of the multiple touches, wherein the transparent capacitive sensing medium comprises:

a first layer having a plurality of transparent first conductive lines that are electrically isolated from one another; and

a second layer spatially separated from the first layer and having a plurality of transparent second conductive lines that are electrically isolated from one another, the second conductive lines being positioned transverse to the first conductive lines, the intersection of transverse lines being positioned at different locations in the plane of the touch panel, each of the second conductive lines being operatively coupled to capacitive monitoring circuitry;

wherein the capacitive monitoring circuitry is configured to detect changes in charge coupling between the first conductive lines and the second conductive lines.

2. The touch panel as recited in claim **1** wherein the conductive lines on each of the layers are substantially parallel to one another.

3. The touch panel as recited in claim **2** wherein the conductive lines on different layers are substantially perpendicular to one another.

4. The touch panel as recited in claim **1** wherein the transparent first conductive lines of the first layer are disposed on a first glass member, and wherein the transparent second conductive lines of the second layer are disposed on a second glass member, the first glass member being disposed over the second glass member.

5. The touch panel as recited in claim **4** further including a third glass member disposed over the first glass member, the first and second glass members being attached to one another via an adhesive layer, the third glass member being attached to the first glass member via another adhesive layer.

6. The touch panel as recited in claim **1** wherein the conductive lines are formed from indium tin oxide (ITO).

7. The touch panel as recited in claim **1**, wherein the capacitive sensing medium is a mutual capacitance sensing medium.

8. The touch panel as recited in claim **7**, further comprising a virtual ground charge amplifier coupled to the touch panel for detecting the touches on the touch panel.

9. The touch panel as recited in claim **1**, the transparent capacitive sensing medium formed on both sides of a single substrate.

10. A display arrangement comprising:

a display having a screen for displaying a graphical user interface; and

a transparent touch panel allowing the screen to be viewed therethrough and capable of recognizing multiple touch events that occur at different locations on the touch panel at a same time and to output this information to a host device to form a pixilated image;

wherein the touch panel includes a multipoint sensing arrangement configured to simultaneously detect and monitor the touch events and a change in capacitive coupling associated with those touch events at distinct points across the touch panel; and

wherein the touch panel comprises:

a first glass member disposed over the screen of the display;

a first transparent conductive layer disposed over the first glass member, the first transparent conductive layer comprising a plurality of spaced apart parallel lines having the same pitch and linewidths;

a second glass member disposed over the first transparent conductive layer;

a second transparent conductive layer disposed over the second glass member, the second transparent conductive layer comprising a plurality of spaced apart parallel lines having the same pitch and linewidths, the parallel lines of the second transparent conductive layer being substantially perpendicular to the parallel lines of the first transparent conductive layer;

a third glass member disposed over the second transparent conductive layer; and

one or more sensor integrated circuits operatively coupled to the lines.

11. The display arrangement as recited in claim **10** further including dummy features disposed in the space between the parallel lines, the dummy features optically improving the visual appearance of the touch screen by more closely matching the optical index of the lines.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO.   : 7,663,607 B2   Page 1 of 1
APPLICATION NO. : 10/840862
DATED   : February 16, 2010
INVENTOR(S)   : Hotelling et al.

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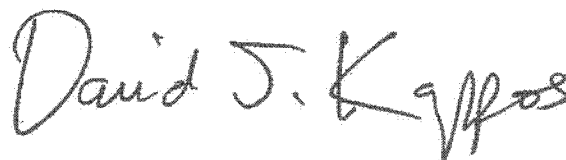
On the Title Page:

The first or sole Notice should read --

Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 1423 days.

Signed and Sealed this

Twenty-eighth Day of December, 2010

David J. Kappos
Director of the United States Patent and Trademark Office