ABSTRACT

In one embodiment, a change in capacitance at one or more capacitive nodes of a touch sensor of a device is detected. The change in capacitance is detected in response to a stylus being in proximity with but not touching the touch sensor. The stylus includes one or more computer-readable media embodying logic and one or more electrodes for effecting charge transfer wirelessly in the device through the touch sensor of the device. The change in capacitance is analyzed to determine a distance between the stylus and the device.
Figure 1

TOUCH SENSOR

CONTROLLER

CONNECTION

10
14
16
18
12
600 DETECT CHANGE IN CAPACITANCE IN CAPACITIVE NODES OF TOUCH-SENSOR OF DEVICE IN RESPONSE TO HOVERING STYLUS

610 ANALYZING CHANGE IN CAPACITANCE TO DETERMINE DISTANCE BETWEEN STYLUS AND DEVICE
DETERMINING HOVER DISTANCE OF AN ACTIVE STYLUS

RELATED APPLICATION


TECHNICAL FIELD

[0002] This disclosure generally relates to active styluses.

BACKGROUND

[0003] A touch sensor may detect the presence and location of a touch or the proximity of an object (such as a user’s finger or a stylus) within a touch-sensitive area of the touch sensor overlaid on a display screen, for example. In a touch-sensitive display application, the touch sensor may enable a user to interact directly with what is displayed on the screen, rather than indirectly with a mouse or touch pad. A touch sensor may be attached to or provided as part of a desktop computer, laptop computer, tablet computer, personal digital assistant (PDA), smartphone, satellite navigation device, portable media player, portable game console, kiosk computer, point-of-sale device, or other suitable device. A control panel on a household or other appliance may include a touch sensor.

[0004] There are a number of different types of touch sensors, such as, for example, resistive touch screens, surface acoustic wave touch screens, and capacitive touch screens. Herein, reference to a touch sensor may encompass a touch screen, and vice versa, where appropriate. When an object touches or comes within proximity of the surface of the capacitive touch screen, a change in capacitance may occur within the touch screen at the location of the touch or proximity. A touch-sensor controller may process the change in capacitance to determine its position on the touch screen.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] FIG. 1 illustrates an example touch sensor with an example touch-sensor controller.
[0006] FIG. 2 illustrates an example active stylus exterior.
[0007] FIG. 3 illustrates an example active stylus interior.
[0008] FIG. 4 illustrates an example active stylus with touch sensor device.
[0009] FIGS. 5A and 5B illustrate one or more electrodes in a tip of an active stylus, the electrodes transmitting voltage signals that communicate the stylus’s relative location or movement to a touch-sensitive device.
[0010] FIG. 6 illustrates a method for determining the hover distance of an active stylus.

DESCRIPTION OF EXAMPLE EMBODIMENTS

[0011] FIG. 1 illustrates an example touch sensor 10 with an example touch-sensor controller 12. Touch sensor 10 and touch-sensor controller 12 may detect the presence and location of a touch or the proximity of an object within a touch-sensitive area of touch sensor 10. Herein, reference to a touch sensor may encompass both the touch sensor and its touch-sensor controller, where appropriate. Similarly, reference to a touch-sensor controller may encompass both the touch-sensor controller and its touch sensor, where appropriate. Touch sensor 10 may include one or more touch-sensitive areas, where appropriate. Touch sensor 10 may include an array of drive and sense electrodes (or an array of electrodes of a single type) disposed on one or more substrates, which may be made of a dielectric material. Herein, reference to a touch sensor may encompass both the electrodes of the touch sensor and the substrate(s) that they are disposed on, where appropriate. Alternatively, where appropriate, reference to a touch sensor may encompass the electrodes of the touch sensor, but not the substrate(s) that they are disposed on.

[0012] An electrode (whether a ground electrode, guard electrode, drive electrode, or sense electrode) may be an area of conductive material forming a shape, such as for example a disc, square, rectangle, thin line, other suitable shape, or suitable combination of these. One or more cuts in one or more layers of conductive material may (at least in part) create the shape of an electrode, and the area of the shape may (at least in part) be bounded by those cuts. In particular embodiments, the conductive material of an electrode may occupy approximately 100% of the area of its shape. As an example and not by way of limitation, an electrode may be made of indium tin oxide (ITO) and the ITO of the electrode may occupy approximately 100% of the area of its shape (sometimes referred to as a 100% fill), where appropriate. In particular embodiments, the conductive material of an electrode may occupy substantially less than 100% of the area of its shape. As an example and not by way of limitation, an electrode may be made of fine lines of metal or other conductive material (FLM), such as for example copper, silver, or a copper- or silver-based material, and the fine lines of conductive material may occupy approximately 5% of the area of its shape in a hatched, mesh, or other suitable pattern. Herein, reference to FLM encompasses such material, where appropriate. Although this disclosure describes or illustrates particular electrodes made of particular conductive material forming particular shapes with particular fill percentages having particular patterns, this disclosure contemplates any suitable electrodes made of any suitable conductive material forming any suitable shapes having any suitable patterns.

[0013] Where appropriate, the shapes of the electrodes (or other elements) of a touch sensor may constitute in whole or in part one or more macro-features of the touch sensor. One or more characteristics of the implementation of those shapes (such as, for example, the conductive materials, fills, or patterns within the shapes) may constitute in whole or in part one or more micro-features of the touch sensor. One or more macro-features of a touch sensor may determine one or more characteristics of its functionality, and one or more micro-features of the touch sensor may determine one or more optical features of the touch sensor, such as transmittance, refraction, or reflection.

[0014] A mechanical stack may contain the substrate (or multiple substrates) and the conductive material forming the drive or sense electrodes of touch sensor 10. As an example and not by way of limitation, the mechanical stack may include a first layer of optically clear adhesive (OCA) beneath a cover panel. The cover panel may be clear and made of a resilient material suitable for repeated touching, such as for example glass, polycarbonate, or poly(methyl methacrylate) (PMMA). This disclosure contemplates any suitable cover panel made of any suitable material. The first layer of OCA may be disposed between the cover panel and the substrate with the conductive material forming the drive or sense electrodes. The mechanical stack may also include a second layer...
of OCA and a dielectric layer (which may be made of polyethylene terephthalate (PET) or another suitable material, similar to the substrate with the conductive material forming the drive or sense electrodes). As an alternative, where appropriate, a thin coating of a dielectric material may be applied instead of the second layer of OCA and the dielectric layer. The second layer of OCA may be disposed between the substrate with the conductive material making up the drive or sense electrodes and the dielectric layer, and the dielectric layer may be disposed between the second layer of OCA and an air gap to a display of a device including touch sensor 10 and touch-sensor controller 12. As an example only and not by way of limitation, the cover panel may have a thickness of approximately 1 mm; the first layer of OCA may have a thickness of approximately 0.05 mm; the substrate with the conductive material forming the drive or sense electrodes may have a thickness of approximately 0.05 mm; the second layer of OCA may have a thickness of approximately 0.05 mm; and the dielectric layer may have a thickness of approximately 0.05 mm. Although this disclosure describes a particular mechanical stack with a particular number of particular layers made of particular materials and having particular thicknesses, this disclosure contemplates any suitable mechanical stack with any suitable number of any suitable layers made of any suitable materials and having any suitable thicknesses. As an example and not by way of limitation, in particular embodiments, a layer of adhesive or dielectric may replace the dielectric layer, second layer of OCA, and air gap described above, with there being no air gap to the display.

[0015] One or more portions of the substrate of touch sensor 10 may be made of polyethylene terephthalate (PET) or another suitable material. This disclosure contemplates any suitable substrate with any suitable portions made of any suitable material. In particular embodiments, the drive or sense electrodes in touch sensor 10 may be made of ITO in whole or in part. In particular embodiments, the drive or sense electrodes in touch sensor 10 may be made of fine lines of metal or other conductive material. As an example and not by way of limitation, one or more portions of the conductive material may be copper or copper-based and have a thickness of approximately 5 μm or less and a width of approximately 10 μm or less. As another example, one or more portions of the conductive material may be silver or silver-based and similarly have a thickness of approximately 5 μm or less and a width of approximately 10 μm or less. This disclosure contemplates any suitable electrodes made of any suitable material.

[0016] Touch sensor 10 may implement a capacitive form of touch sensing. In a mutual-capacitance implementation, touch sensor 10 may include an array of drive and sense electrodes forming an array of capacitive nodes. A drive electrode and a sense electrode may form a capacitive node. The drive and sense electrodes forming the capacitive node may come near each other, but not make electrical contact with each other. Instead, the drive and sense electrodes may be capacitively coupled to each other across a space between them. A pulsed or alternating voltage applied to the drive electrode (by touch-sensor controller 12) may induce a charge on the sense electrode, and the amount of charge induced may be susceptible to external influence (such as a touch or the proximity of an object). When an object touches or comes within proximity of the capacitive node, a change in capacitance may occur at the capacitive node and touch-sensor controller 12 may measure the change in capacitance. By measuring changes in capacitance throughout the array, touch-sensor controller 12 may determine the position of the touch or proximity within the touch-sensitive area(s) of touch sensor 10.

[0017] In a self-capacitance implementation, touch sensor 10 may include an array of electrodes of a single type that may each form a capacitive node. When an object touches or comes within proximity of the capacitive node, a change in self-capacitance may occur at the capacitive node and controller 12 may measure the change in capacitance, for example, as a change in the amount of charge needed to raise the voltage at the capacitive node by a pre-determined amount. As with a mutual-capacitance implementation, by measuring changes in capacitance throughout the array, controller 12 may determine the position of the touch or proximity within the touch-sensitive area(s) of touch sensor 10. This disclosure contemplates any suitable form of capacitive touch sensing, where appropriate.

[0018] In particular embodiments, one or more drive electrodes may together form a drive line running horizontally or vertically or in any suitable orientation. Similarly, one or more sense electrodes may together form a sense line running horizontally or vertically or in any suitable orientation. In particular embodiments, drive lines may run substantially perpendicular to sense lines. Herein, reference to a drive line may encompass one or more drive electrodes making up the drive line, and vice versa, where appropriate. Similarly, reference to a sense line may encompass one or more sense electrodes making up the sense line, and vice versa, where appropriate.

[0019] Touch sensor 10 may have drive and sense electrodes disposed in a pattern on one side of a single substrate. In such a configuration, a pair of drive and sense electrodes capacitively coupled to each other across a space between them may form a capacitive node. For a self-capacitance implementation, electrodes of only a single type may be disposed in a pattern on a single substrate. In addition or as an alternative to having drive and sense electrodes disposed in a pattern on one side of a single substrate, touch sensor 10 may have drive electrodes disposed in a pattern on one side of a substrate and sense electrodes disposed in a pattern on another side of the substrate. Moreover, touch sensor 10 may have drive electrodes disposed in a pattern on one side of a substrate and sense electrodes disposed in a pattern on one side of another substrate. In such configurations, an intersection of a drive electrode and a sense electrode may form a capacitive node. Such an intersection may be a location where the drive electrode and the sense electrode “cross” or come nearest each other in their respective planes. The drive and sense electrodes do not make electrical contact with each other—instead they are capacitively coupled to each other across a dielectric at the intersection. Although this disclosure describes particular configurations of particular electrodes forming particular nodes, this disclosure contemplates any suitable configuration of any suitable electrodes forming any suitable nodes. Moreover, this disclosure contemplates any suitable electrodes disposed on any suitable number of any suitable substrates in any suitable patterns.

[0020] As described above, a change in capacitance at a capacitive node of touch sensor 10 may indicate a touch or proximity input at the position of the capacitive node. Touch-sensor controller 12 may detect and process the change in capacitance to determine the presence and location of the touch or proximity input. Touch-sensor controller 12 may
then communicate information about the touch or proximity input to one or more other components (such one or more central processing units (CPUs)) of a device that includes touch sensor 10 and touch-sensor controller 12, which may respond to the touch or proximity input by initiating a function of the device (or an application running on the device). Although this disclosure describes a particular touch-sensor controller having particular functionality with respect to a particular device and a particular touch sensor, this disclosure contemplates any suitable touch-sensor controller having any suitable functionality with respect to any suitable device and any suitable touch sensor.

[0021] Touch-sensor controller 12 may be one or more integrated circuits (ICs), such as for example general-purpose microprocessors, microcontrollers, programmable logic devices (PLDs) or programmable logic arrays (PLAs), fuse-programmable arrays (FPGAs), or application-specific ICs (ASICs). In particular embodiments, touch-sensor controller 12 comprises analog circuitry, digital logic, and digital non-volatile memory. In particular embodiments, touch-sensor controller 12 is disposed on a flexible printed circuit (FPC) bonded to the substrate of touch sensor 10, as described below. The FPC may be active or passive, where appropriate. In particular embodiments multiple touch-sensor controllers 12 are disposed on the FPC. Touch-sensor controller 12 may include a processor unit, a drive unit, a sense unit, and a memory unit. The drive unit may supply drive signals to the drive electrodes of touch sensor 10. The sense unit may sense charge at the capacitive nodes of touch sensor 10 and provide measurement signals to the processor unit representing capacitances at the capacitive nodes. The processor unit may control the supply and timing of drive signals to the drive electrodes by the drive unit and process measurement signals from the sense unit to detect and process the presence and location of a touch or proximity input within the touch-sensitive area(s) of touch sensor 10. The processor unit may also track changes in the position of a touch or proximity input within the touch-sensitive area(s) of touch sensor 10. The memory unit may store programming for execution by the processor unit, including programming for controlling the drive unit to supply drive signals to the drive electrodes, programming for processing measurement signals from the sense unit, and other suitable programming, where appropriate. Although this disclosure describes a particular touch-sensor controller having a particular implementation with particular components, this disclosure contemplates any suitable touch-sensor controller having any suitable implementation with any suitable components.

[0022] Tracks 14 of conductive material disposed on the substrate of touch sensor 10 may couple the drive or sense electrodes of touch sensor 10 to connection pads 16, also disposed on the substrate of touch sensor 10. As described below, connection pads 16 facilitate coupling of tracks 14 to touch-sensor controller 12. Tracks 14 may extend into or around (e.g. at the edges of) the touch-sensitive area(s) of touch sensor 10. Particular tracks 14 may provide drive connections for coupling touch-sensor controller 12 to drive electrodes of touch sensor 10, through which the drive unit of touch-sensor controller 12 may supply drive signals to the drive electrodes. Other tracks 14 may provide sense connections for coupling touch-sensor controller 12 to sense electrodes of touch sensor 10, through which the sense unit of touch-sensor controller 12 may sense charge at the capacitive nodes of touch sensor 10. Tracks 14 may be made of fine lines of metal or other conductive material. As an example and not by way of limitation, the conductive material of tracks 14 may be copper or copper-based and have a width of approximately 100 μm or less. As another example, the conductive material of tracks 14 may be silver or silver-based and have a width of approximately 100 μm or less. In particular embodiments, tracks 14 may be made of ITO in whole or in part in addition or as an alternative to fine lines of metal or other conductive material. Although this disclosure describes particular tracks made of particular materials with particular widths, this disclosure contemplates any suitable tracks made of any suitable materials with any suitable widths. In addition to tracks 14, touch sensor 10 may include one or more ground lines terminating at a ground connector (which may be a connection pad 16) at an edge of the substrate of touch sensor 10 (similar to tracks 14).

[0023] Connection pads 16 may be located along one or more edges of the substrate, outside the touch-sensitive area(s) of touch sensor 10. As described above, touch-sensor controller 12 may be on an FPC. Connection pads 16 may be made of the same material as tracks 14 and may be bonded to the FPC using an anisotropic conductive film (ACF). Connection pads 16 may include conductive lines on the FPC coupling touch-sensor controller 12 to connection pads 16, in turn coupling touch-sensor controller 12 to tracks 14 and to the drive or sense electrodes of touch sensor 10. In another embodiment, connection pads 16 may be connected to an electro-mechanical connector (such as a zero insertion force wire-to-board connector); in this embodiment, connection pads 16 may not include an FPC. This disclosure contemplates any suitable connection 18 between touch-sensor controller 12 and touch sensor 10.

[0024] FIG. 2 illustrates an example exterior of an example active stylus 20. Active stylus 20 may include one or more components, such as buttons 30 or sliders 32 and 34 integrated with an outer body 22. These external components may provide for interaction between active stylus 20 and a user or between a device and a user. As an example and not by way of limitation, interactions may include communication between active stylus 20 and a device, enabling or altering functionality of active stylus 20 or a device, or providing feedback to or accepting input from one or more users. The device may be any suitable device, such as, for example and without limitation, a desktop computer, laptop computer, tablet computer, personal digital assistant (PDA), smartphone, satellite navigation device, portable media player, portable game console, kiosk computer, point-of-sale device, or other suitable device. Although this disclosure provides specific examples of particular components configured to provide particular interactions, this disclosure contemplates any suitable component configured to provide any suitable interaction. Active stylus 20 may have any suitable dimensions with outer body 22 made of any suitable material or combination of materials, such as, for example and without limitation, plastic or metal. In particular embodiments, exterior components (e.g. 30 or 32) of active stylus 20 may interact with internal components or programming of active stylus 20 or may initiate one or more interactions with one or more devices or other active styluses 20.

[0025] As described above, actuating one or more particular components may initiate an interaction between active stylus 20 and a user or between the device and the user. Components of active stylus 20 may include one or more buttons 30 or one or more sliders 32 and 34. As an example
and not by way of limitation, buttons 30 or sliders 32 and 34 may be mechanical or capacitive and may function as a roller, trackball, or wheel. As another example, one or more sliders 32 or 34 may function as a vertical slider 34 aligned along a longitudinal axis, while one or more wheel sliders 32 may be aligned along the circumference of active stylus 20. In particular embodiments, capacitive sliders 32 and 34 or buttons 30 may be implemented using one or more touch-sensitive areas. Touch-sensitive areas may have any suitable shape, dimensions, location, or be made from any suitable material. As an example and not by way of limitation, sliders 32 and 34 or buttons 30 may be implemented using areas of flexible mesh formed using lines of conductive material. As another example, sliders 32 and 34 or buttons 30 may be implemented using a FPC.

[0026] Active stylus 20 may have one or more components configured to provide feedback to or accepting feedback from a user, such as, for example and without limitation, tactile, visual, or audio feedback. Active stylus 20 may include one or more ridges or grooves 24 on its outer body 22. Ridges or grooves 24 may have any suitable dimensions, have any suitable spacing between ridges or grooves, or be located at any suitable area on outer body 22 of active stylus 20. As an example and not by way of limitation, ridges 24 may enhance a user’s grip on outer body 22 of active stylus 20 or provide tactile feedback to or accept tactile input from a user. Active stylus 20 may include one or more audio components 38 capable of transmitting and receiving audio signals. As an example and not by way of limitation, audio component 38 may contain a microphone capable of recording or transmitting one or more users’ voices. As another example, audio component 38 may provide an auditory indication of a power status of active stylus 20. Active stylus 20 may include one or more visual feedback components 36, such as a light-emitting diode (LED) indicator. As an example and not by way of limitation, visual feedback component 36 may indicate a power status of active stylus 20 to the user.

[0027] One or more modified surface areas 40 may form one or more components on outer body 22 of active stylus 20. Properties of modified surface areas 40 may be different than properties of the remaining surface of outer body 22. As an example and not by way of limitation, modified surface area 40 may be modified to have a different texture, temperature, or electromagnetic characteristic relative to the surface properties of the remainder of outer body 22. Modified surface area 40 may be capable of dynamically altering its properties, for example by using haptic interfaces or rendering techniques. A user may interact with modified surface area 40 to provide any suitable functionally. For example and not by way of limitation, dragging a finger across modified surface area 40 may initiate an interaction, such as data transfer, between active stylus 20 and a device.

[0028] One or more components of active stylus 20 may be configured to communicate data between active stylus 20 and the device. For example, active stylus 20 may include one or more tips 26 or nibs. Tip 26 may include one or more electrodes configured to communicate data between active stylus 20 and one or more devices or other active styli. Tip 26 may be made of any suitable material, such as a conductive material, and have any suitable dimensions, such as, for example, a diameter of 1 mm or less at its terminal end. Active stylus 20 may include one or more ports 28 located at any suitable location on outer body 22 of active stylus 20. Port 28 may be configured to transfer signals or information between active stylus 20 and one or more devices or power sources. Port 28 may transfer signals or information by any suitable technology, such as, for example, by universal serial bus (USB) or Ethernet connections. Port 28 may transmit or receive signals wirelessly, for example using BlueTooth or wireless fidelity (WiFi) technologies. Although this disclosure describes and illustrates a particular configuration of particular components with particular locations, dimensions, composition and functionality, this disclosure contemplates any suitable configuration of suitable components with any suitable locations, dimensions, composition, and functionality with respect to active stylus 20.

[0029] FIG. 3 illustrates an example internal components of active example stylus 20. Active stylus 20 may include one or more internal components, such as a controller 50, sensors 42, memory 44, or power source 48. In particular embodiments, one or more internal components may be configured to provide for interaction between active stylus 20 and a user or between a device and a user. In other particular embodiments, one or more internal components, in conjunction with one or more external components described above, may be configured to provide interaction between active stylus 20 and a user or between a device and a user. As an example and not by way of limitation, interactions may include communication between active stylus 20 and a device, enabling or altering functionality of active stylus 20 or a device, or providing feedback to or accepting input from one or more users.

[0030] Controller 50 may be a microcontroller or any other type of processor suitable for controlling the operation of active stylus 20. Controller 50 may be one or more ICs—such as, for example, general-purpose microprocessors, microcontrollers, PLDs, PLAs, or ASICs. Controller 50 may include a processor unit, a drive unit, a sense unit, and a storage unit. The drive unit may supply signals to electrodes of tip 26 through center shaft 41. The drive unit may also supply signals to control or drive sensors 42 or one or more external components of active stylus 20. The sense unit may sense signals received by electrodes of tip 26 through center shaft 41 and provide measurement signals to the processor unit representing input from a device. The sense unit may also sense signals generated by sensors 42 or one or more external components and provide measurement signals to the processor unit representing input from a user. The processor unit may control the supply and timing of signals to the electrodes of tip 26 and process measurement signals from the sense unit to detect and process input from the device. The processor unit may also process measurement signals from sensors 42 or one or more external components. The storage unit may store programming for execution by the processor unit, including programming for controlling the drive unit to supply signals to the electrodes of tip 26, programming for processing measurement signals from the sense unit corresponding to input from the device, programming for processing measurement signals from sensors 42 or external components to initiate a pre-determined function or gesture to be performed by active stylus 20 or the device, and other suitable programming, where appropriate. As an example and not by way of limitation, programming executed by controller 50 may electronically filter signals received from the sense unit. Although this disclosure describes a particular controller 50 having a particular implementation with particular components, this disclosure contemplates any suitable controller having any suitable implementation with any suitable components.
In particular embodiments, active stylus 20 may include one or more sensors 42, such as touch sensors, gyroscopes, accelerometers, contact sensors, or any other type of sensor that detect or measure data about the environment in which active stylus 20 operates. Sensors 42 may detect and measure one or more characteristic of active stylus 20, such as acceleration or movement, orientation, contact, pressure on outer body 22, force on tip 26, vibration, or any other suitable characteristic of active stylus 20. As an example and not by way of limitation, sensors 42 may be implemented mechanically, electronically, or capacitively. As described above, data detected or measured by sensors 42 communicated to controller 50 may initiate a pre-determined function or gesture to be performed by active stylus 20 or the device. In particular embodiments, data detected or received by sensors 42 may be stored in memory 44. Memory 44 may be any form of memory suitable for storing data in active stylus 20. In other particular embodiments, controller 50 may access data stored in memory 44. As an example and not by way of limitation, memory 44 may store programming for execution by the processor unit of controller 50. As another example, data measured by sensors 42 may be processed by controller 50 and stored in memory 44.

Power source 48 may be any type of stored-energy source, including electrical or chemical-energy sources, suitable for powering the operation of active stylus 20. In particular embodiments, power source 48 may be charged by energy from a user or device. As an example and not by way of limitation, power source 48 may be a rechargeable battery that may be charged by motion induced on active stylus 20. In other particular embodiments, power source 48 of active stylus 20 may provide power to or receive power from the device. As an example and not by way of limitation, power may be inductively transferred between power source 48 and a power source of the device.

FIG. 4 illustrates an example active stylus 20 with an example device 52. Device 52 may have a display (not shown) and a touch sensor with a touch-sensitive area 54. Device 52 display may be a liquid crystal display (LCD), a LED display, a LED-backlight LCD, or other suitable display and may be visible through a cover panel and substrate (and the drive and sense electrodes of the touch sensor disposed on it) of device 52. Although this disclosure describes a particular device display and particular display types, this disclosure contemplates any suitable device display and any suitable display types.

Device 52 electronics may provide the functionality of device 52. As example and not by way of limitation, device 52 electronics may include circuitry or other electronics for wireless communication to or from device 52, execute programming on device 20, generating graphical or other user interfaces (UIs) for device 20 display to display to a user, managing power to device 52 from a battery or other power source, taking still pictures, recording video, other suitable functionality, or any suitable combination of these. Although this disclosure describes particular device electronics providing particular functionality of a particular device, this disclosure contemplates any suitable device electronics providing any suitable functionality of any suitable device.

In particular embodiments, active stylus 20 and device 52 may be synchronized prior to communication of data between active stylus 20 and device 52. As an example and not by way of limitation, active stylus 20 may be synchronized to device through a pre-determined bit sequence transmitted by the touch sensor of device 52. As another example, active stylus 20 may be synchronized to device by processing the drive signal transmitted by drive electrodes of the touch sensor of device 52. Active stylus 20 may interact or communicate with device 52 when active stylus 20 is brought in contact with or in proximity to touch-sensitive area 54 of the touch sensor of device 52. In particular embodiments, interaction between active stylus 20 and device 52 may be capacitive or inductive. As an example and not by way of limitation, when active stylus 20 is brought in contact with or in the proximity of touch-sensitive area 54 of device 52, signals generated by active stylus 20 may influence capacitive nodes of touch-sensitive area of device 52 or vice versa. As another example, a power source of active stylus 20 may be inductively charged through the touch sensor of device 52, or vice versa. Although this disclosure describes particular interactions and communications between active stylus 20 and device 52, this disclosure contemplates any suitable interactions and communications through any suitable means, such as mechanical forces, current, voltage, or electromagnetic fields.

In particular embodiments, measurement signal from the sensors of active stylus 20 may initiate, provide for, or terminate interactions between active stylus 20 and one or more devices 52 or one or more users, as described above. Interaction between active stylus 20 and device 52 may occur when active stylus 20 is contacting or in proximity to device 52. As an example and not by way of limitation, a user may perform a gesture or sequence of gestures, such as shaking or inverting active stylus 20, whilst active stylus 20 is hovering above touch-sensitive area 54 of device 52. Active stylus may interact with device 52 based on the gesture performed with active stylus 20 to initiate a pre-determined function, such as authenticating a user associated with active stylus 20 or device 52. Although this disclosure describes particular movements providing particular types of interactions between active stylus 20 and device 52, this disclosure contemplates any suitable movement influencing any suitable interaction, in any suitable way.

In particular embodiments, active stylus 20 may be used in a hover configuration or mode. In hover mode, active stylus 20 is in proximity to but is not touching device 52 (e.g., touch sensor 10 of device 52). One potential benefit of using a stylus in a hover mode is that a physical imprint (e.g., a fingerprint, grease print, or vibration from touch) is not left on device 52; this may allow for increased security in the use of device 52. As an example, a gesture used while hovering may be used to unlock device 52 without leaving any physical imprint (e.g., a pattern of fingerprints on device 52) that may be detected. The distance that active stylus 20 hovers above or in proximity to device 52 may be determined either by active stylus 20 or by device 52, including, for example, by controller 12 or controller 50. As an example, active stylus 20 may function well when it hovers in proximity to device 52 in distances ranging between approximately (e.g., plus or minus 2 millimeters) 0 and 25 millimeters. In particular embodiments, the distance between active stylus 20 and device 52 may be calculated between a particular location on the body of active stylus 20 (e.g., the point of active stylus tip 26) and a particular location on device 52 (e.g., a particular point on touch sensor 10).

In particular embodiments, the distance that active stylus 20 hovers in proximity to device 52 may be measured by laser infrareds, ultrasound, or sensors, any of which
may be on active stylus 20, on device 52, or on both active stylus 20 and device 52. In particular embodiments, the hover distance may be determined using touch sensor 10, without the need for additional sensors on device 52. As discussed above, touch sensor 10 may include an array of drive and sense electrodes forming an array of capacitive nodes. As an example, the change in mutual capacitance of each capacitive node in the array on touch sensor 10 may be measured to determine stylus location, as the mutual capacitance measured at each capacitive node will vary with stylus position in the x-, y-, and z- (hover) directions with respect to device 52. In particular, the measured change in mutual capacitance experienced by each capacitive node in the array on touch sensor 10 will be larger the closer that active stylus 20 is to the capacitive node in any (x-, y-, or z-) direction. By examining the pattern of changes in measured mutual capacitance values for the capacitive nodes in the array on touch sensor 10 (either for the array as a whole or, in certain embodiments, within subgroups of capacitive nodes in the array), the hover distance of active stylus 20 may be determined. As an example, by analyzing the pattern of capacitive nodes that experienced a measured change in mutual capacitance (and those capacitive nodes that did not, or that experienced a measured change to a lesser extent), the location of active stylus 20 (e.g., the location of the active stylus tip 26) may be determined in the x-y plane with respect to device 52.

By analyzing the amount of the measured change in mutual capacitance for the array of capacitive nodes on touch sensor 10, however, the location of active stylus 20 may be determined in the z-direction with respect to device 52. That is, when the measured change in mutual capacitance for the array of capacitive nodes on touch sensor 10 is relatively large (an amount which may vary between different products), then active stylus 20 may be calculated to be closer in the z-direction (have a smaller hover distance) to device 52. As another example, when the change in mutual capacitance for the array of capacitive nodes on touch sensor 10 is relatively small (an amount which may vary between different products), then active stylus 20 may be calculated to be farther in the z-direction (have a larger hover distance) to device 52. In other embodiments, the shape of the profile of those capacitive nodes that experience a change in mutual capacitance may also be analyzed to determine the location of active stylus 20 in the z-direction. In particular embodiments, the hover distance may be determined by controller 12. In other embodiments, the hover distance may be determined by another processor using the response from controller 12. In other embodiments, the hover distance may be determined by controller 50 in stylus 20, based on signals or capacitance changes measured at active stylus 20 via electrodes in active stylus tip 26. In yet other embodiments, the hover distance of a finger or a passive stylus may be determined in the same or similar manner in which it is determined for active stylus 20, because any suitable mutual-capacitance system will experience a change in capacitance depending on the location of either a stylus (whether active or passive) or a finger.

In particular embodiments, by analyzing the number of capacitive nodes in the array on touch sensor 10 that experienced a measured change in mutual capacitance, as well as the degree of change of mutual capacitance, it may be possible to determine if a stylus (whether active or passive) or finger is in proximity to device 52, and if so, whether it is hovering or touching device 52. In particular embodiments, one or more pre-determined thresholds for measured changes in mutual capacitance may be set in controller 12, and these pre-determined thresholds may be associated with distances (e.g., hover distances) from device 52. These pre-determined thresholds may be set during a tuning or testing period where a user is asked to bring a stylus (whether active or passive) or a finger in a hover above device 52 and in contact with device 52. Controller 12 may then analyze the measured changes in mutual capacitance that occur during this testing or tuning period to set thresholds that may assist in determining whether a stylus or finger is in proximity to device 52, and if so, whether it is hovering above or in contact with device 52. For example, controller 12 may determine that a particular measured change in mutual capacitance (determined, e.g., during a testing period with an active stylus) corresponds to the active stylus being a distance of 10 mm above device 52.

In particular embodiments, pre-determined thresholds (e.g., set during a tuning or testing period) may be used to determine whether a stylus or finger is present, whether it is hovering above device 52, or whether it is touching device 52. In yet other embodiments, analyzing the number of capacitive nodes in the array on touch sensor 10 that experienced a measured change in mutual capacitance, as well as the degree of change of mutual capacitance may be used to determine whether a stylus or finger is present, whether it is hovering above device 52, or whether it is touching device 52. As an example, if a relatively large change in mutual capacitance is measured, but the change is limited to a relatively small number of nodes of the array on touch sensor 10, the controller 12 may determine that an active stylus is not touching device 52. As another example, if a relatively large change in mutual capacitance is measured, and the change is measured over a relatively large number of nodes of the array on touch sensor 10, the controller 12 may determine that a finger is touching device 52, as a finger generally has a larger profile than, for example, a stylus. As yet another example, if a relatively medium or small change in mutual capacitance is measured, and the change is limited to a relatively small number of nodes of the array on touch sensor 10, the controller 12 may determine that a passive stylus is touching device 52. Finally, if a relatively small change in mutual capacitance is measured, but the change is measured over a relatively large number of nodes of the array on touch sensor 10, the controller 12 may determine that a finger is hovering over device 52. In particular embodiments, both a stylus and a finger may be used at the same time with device 52, and separate (but potentially overlapping) portions of touch sensor 10 may provide data to controller 12 to make determinations about whether a stylus or finger (or both) is present, if it is hovering above device 52, or whether it is in contact with device 52.

By measuring hover distance, a user may hover (with active stylus 20 or a finger) and use device 52 without contacting device 52. As an example, a user can use device 52 (e.g., touch sensor 10) as a piano. As another example, a user may use active stylus 20 (or a finger) to make a gesture (e.g., a signature) while hovering that may be used to unlock or authenticate active stylus 20. By unlocking or authenticating device 52 using a three-dimensional gesture as opposed to a two-dimensional gesture (done by contacting device 52, perhaps leaving an imprint), more security can be provided to the user of device 52 and active stylus 20. That is, a three-dimensional gesture (using the x-, y-, and z-directions with respect to device 52) may be harder to copy than a two-dimensional gesture (using only the x- and y-directions), and, additionally, a gesture completed while hovering will not leave an imprint.
The determination of hover distance (e.g., the location of active stylus 20 or a finger in the z-direction with respect to device 52) may be used for a variety of purposes. By way of example, the determination of hover distance may be used to determine whether a user is making a gesture (and if so, which gesture) or whether there has been a change in orientation in active stylus 20 with respect to device 52 (e.g., allowing active stylus 20 to be used as a joystick). The determination of the hover distance of active stylus 20 may be used to decide whether to employ high voltage signals for signal transmission (on either device 52 or active stylus 20) to provide for better signal-to-noise ratios. As another example, the hover distance may be used in conjunction with algorithms for dynamic configuration of electrodes in active stylus tip 26 so that when it is determined that active stylus 20 is hovering beyond a particular distance from device 52, electrodes in active stylus tip 26 should be reconfigured in a particular manner. Similarly, the hover distance may be used to dynamically adjust signal thresholds used by active stylus 20 or device 52 to reduce the effects of noise.

In FIG. 5A, active stylus 20 is near touch-sensitive display 54 of touch-sensitive device 52. Tip 26 of active stylus 20 is located a distance D1 away from touch-sensitive display 54. As an example, D1 may be between approximately 0 and 25 millimeters. One or more electrodes in tip 26 may, in particular embodiments, receive voltage signals from active stylus 20 and output voltage signals to touch-sensitive device 52. Conductive material, such as drive and sense lines near touch-sensitive display 54, and associated electronics in touch-sensitive device 52 may sense these voltage signals. As an example, voltage signals produced by electrodes in tip 26 alter the net charge present on sense lines in the proximity of tip 26, communicating information about the location of active stylus 20 in directions parallel to touch-sensitive display 52. The net charge present on sense lines also depends on the distance D1 that active stylus tip 26 is from touch-sensitive display 54, communicating information to touch-sensitive device 52 about the location of active stylus 20 in directions perpendicular to touch-sensitive display 54. In particular embodiments, motion of tip 26 relative to touch-sensitive display 54 is detected by touch-sensitive device 52 through changes in the net charge on sense lines as active stylus 20 moves. In particular embodiments, motion of tip 26 relative to touch-sensitive display 54 is determined by correlating information about the location of active stylus 20 with the point in time active stylus 20 had been at that location. In particular embodiments, active stylus 20 may be oriented at any suitable angle with respect to touch-sensitive display 52.

As an example, FIG. 5B illustrates the body of active stylus 20 contacting touch-sensitive display 54 and tip 26 separated from touch-sensitive display 54 by a distance D2.

FIG. 6 illustrates an example method for determining the hover distance of an active stylus (e.g., active stylus 20). The method begins at step 600, when a change in capacitance in one or more capacitive nodes of a touch-sensor (e.g., touch sensor 10) of a device (e.g., device 52) is detected in response to a stylus being in proximity to (but not touching) the device. It should be noted that in particular embodiments, a signal need not be actively transmitted for hover distance to be calculated, as a change in capacitance may still be detected even with a passive object such as a finger. The change in capacitance may be detected in the mutual capacitance outputs of one or more of the capacitive nodes in an array on a touch-sensitive area (e.g., touch sensor 10) of device 52. At step 610, this change in capacitance is analyzed to determine the hover distance of the stylus. As discussed above, it may be possible to analyze the magnitude of the pattern of change in mutual capacitance across the array of capacitive nodes to determine whether active stylus 20 is closer or farther from device 52. In particular embodiments, the steps illustrated in FIG. 6 may be repeated any number of times. Although this disclosure describes and illustrates particular steps of the method of FIG. 6 as occurring in a particular order, this disclosure contemplates any suitable steps of the method of FIG. 6 occurring in any suitable order. Furthermore, although this disclosure describes and illustrates particular components, devices, or systems carrying out particular steps of the method of FIG. 6, this disclosure contemplates any suitable combination of any suitable components, devices, or systems carrying out any suitable steps of the method of FIG. 6.

Herein, reference to a computer-readable non-transitory storage medium or media may include one or more semiconductor-based or other integrated circuits (ICs) (such as, for example, field-programmable gate arrays (FPGAs) or application-specific ICs (ASICs)), hard disk drives (HDDs), hybrid hard drives (HHDs), optical discs, optical disc drives (ODDs), magneto-optical discs, magneto-optical drives, floppy disks, floppy disk drives (FDDs), magnetic tapes, holographic storage media, solid-state drives (SSDs), RAM-drives, SECURE DIGITAL cards, SECURE DIGITAL drives, any another suitable computer-readable non-transitory storage media, or a suitable combination of these, where appropriate. A computer-readable non-transitory storage medium may be volatile, non-volatile, or a combination of volatile and non-volatile, where appropriate.

Herein, “or” is inclusive and not exclusive, unless expressly indicated otherwise or indicated otherwise by context. Therefore, herein, “A or B” means “A, B, or both,” unless expressly indicated otherwise or indicated otherwise by context. Moreover, “and” is both joint and several, unless expressly indicated otherwise or indicated otherwise by context. Therefore, herein, “A and B” means “A and B, jointly or severally,” unless expressly indicated otherwise or indicated otherwise by context.

This disclosure encompasses all changes, substitutions, variations, alterations, and modifications to the example embodiments herein that a person having ordinary skill in the art would comprehend. Moreover, reference in the appended claims to an apparatus or system or a component of an apparatus or system being adapted to, arranged to, capable of, configured to, enabled to, operable to, or operative to perform a particular function encompasses that apparatus, system, component, whether or not it or that particular function is activated, turned on, or unlocked, as long as that apparatus, system, or component is so adapted, arranged, capable, configured, enabled, operable, or operative.

What is claimed is:

1. A method comprising:
   - detecting a change in capacitance at one or more capacitive nodes of a touch sensor of a device in response to a stylus being in proximity with but not touching the touch sensor, the stylus comprising one or more computer-readable media embodying logic and one or more electrodes for effecting charge transfer wirelessly in the device through the touch sensor of the device; and
analyzing the change in capacitance to determine a distance between the stylus and the device.

2. The method of claim 1, wherein the electrodes are located in a tip of the stylus.

3. The method of claim 1, wherein the device detects the change in capacitance at the one or more capacitive nodes of the touch sensor and analyzes the change in capacitance to determine the distance between the stylus and the device.

4. The method of claim 2, wherein the stylus detects the change in capacitance at the stylus electrodes and analyzes the change in capacitance to determine the distance between the stylus and the device.

5. The method of claim 1, wherein analyzing the change in capacitance comprises analyzing a magnitude of the change in capacitance.

6. The method of claim 1, wherein analyzing the change in capacitance comprises analyzing the change in capacitance in each of the one or more capacitive nodes of the touch sensor.

7. The method of claim 1, wherein the distance between the stylus and the device is measured between one or more of the electrodes of the stylus and the touch sensor.

8. One or more computer-readable non-transitory storage media embodying logic that is operable when executed to: detect a change in capacitance at one or more capacitive nodes of a touch sensor of a device in response to a stylus being in proximity with but not touching the touch sensor, the stylus comprising one or more electrodes for effecting charge transfer wirelessly in the device through the touch sensor of the device; and analyze the change in capacitance to determine a distance between the stylus and the device.

9. The media of claim 8, wherein the electrodes are located in a tip of the stylus.

10. The media of claim 8, wherein the logic is located at the device.

11. The media of claim 9, wherein the stylus further comprises one or more computer-readable non-transitory storage media embodying logic that is operable when executed to detect a change in capacitance at the stylus electrodes and analyze the change in capacitance to determine the distance between the stylus and the device.

12. The media of claim 8, wherein analyzing the change in capacitance comprises analyzing a magnitude of the change in capacitance.

13. The media of claim 8, wherein analyzing the change in capacitance comprises analyzing the change in capacitance in each of the one or more capacitive nodes of the touch sensor.

14. The media of claim 8, wherein the distance between the stylus and the device is measured between one or more of the electrodes of the stylus and the touch sensor.

15. A device comprising: a touch sensor comprising one or more capacitive nodes; and

one or more computer-readable non-transitory storage media embodying logic that is operable when executed to:

- detect a change in capacitance at a capacitive node in response to a stylus being in proximity with but not touching the touch sensor, the stylus comprising one or more electrodes for effecting charge transfer wirelessly in the device through the touch sensor of the device; and

- analyze the change in capacitance to determine a distance between the stylus and the device.

16. The device of claim 15, wherein the electrodes are located in a tip of the stylus.

17. The device of claim 16, wherein the stylus further comprises one or more computer-readable non-transitory storage media embodying logic that is operable when executed to detect a change in capacitance at the stylus electrodes and analyze the change in capacitance to determine the distance between the stylus and the device.

18. The device of claim 15, wherein analyzing the change in capacitance comprises analyzing a magnitude of the change in capacitance.

19. The device of claim 15, wherein analyzing the change in capacitance comprises analyzing the change in capacitance in each of the one or more capacitive nodes of the touch sensor.

20. The device of claim 15, wherein the distance between the stylus and the device is measured between one or more of the electrodes of the stylus and the touch sensor.

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