OPTICAL ELEMENTS WITH ALTERNATING REFLECTIVE LENS FACETS

FIELD OF THE INVENTION

[0001] The field of the present invention is light-based touch screens.

BACKGROUND OF THE INVENTION

[0002] Many consumer electronic devices are now being built with touch sensitive screens, for use with finger or stylus touch user inputs. These devices range from small screen devices such as mobile phones and car entertainment systems, to mid-size screen devices such as notebook computers, to large screen devices such as check-in stations at airports.

[0003] Most conventional touch screen systems are based on resistive or capacitive layers. Such systems are not versatile enough to offer an all-encompassing solution, as they are not easily scalable.

[0004] Reference is made to **FIG. 1**, which is a prior art illustration of a conventional touch screen system. Such systems include an LCD display surface **606**, a resistive or capacitive overlay **801** that is placed over the LCD surface, and a controller integrated circuit (IC) **701** that connects to the overlay and converts inputs from the overlay to meaningful signals. A host device (not shown), such as a computer, receives the signals from controller IC **701**, and a device driver or such other program interprets the signals to detect a touch-based input such as a key press or scroll movement.

[0005] Reference is made to **FIG. 2**, which is a prior art illustration of a conventional resistive touch screen. Shown in **FIG. 2** are conductive and resistive layers **802** separated by thin spaces. A PET film **803** overlays a top circuit layer **804**, which overlays a conductive coating **806**. Similarly, a conductive coating **807** with spacer dots **808** overlays a bottom circuit layer **805**, which overlays a glass layer **607**. When a pointer **900**, such

[0048] **FIG. 33** is a simplified diagram of a wide beam touch screen, with emitter and receiver lenses that have micro-lens patterns, in accordance with an embodiment of the present invention;

[0049] **FIG. 34** is a simplified diagram of two emitters with lenses that have micro-lens patterns integrated therein, in accordance with an embodiment of the present invention;

[0050] **FIG. 35** is a simplified diagram of two receivers with lenses that have micro-lens patterns integrated therein, in accordance with an embodiment of the present invention;

[0051] **FIG. 36** is a simplified diagram of a side view of a single-unit light guide, in the context of an electronic device with a display and an outer casing, in accordance with an embodiment of the present invention;

[0052] **FIG. 37** is a simplified diagram of side views, from two different angles, of a lens with applied feather patterns on a surface, in accordance with an embodiment of the present invention;

[0053] **FIG. 38** is a simplified diagram of a portion of a wide-beam touch screen, in accordance with an embodiment of the present invention;

[0054] **FIG. 39** is a top view of a simplified diagram of light beams entering and exiting micro-lenses etched on a lens, in accordance with an embodiment of the present invention;

[0055] **FIG. 40** is a simplified diagram of a side view of a dual-unit light guide, in the context of a device having a display and an outer casing, in accordance with an embodiment of the present invention;

[0056] **FIG. 41** is a picture of light guide units, within the content of a device having a PCB and an outer casing, in accordance with an embodiment of the present invention;

[0057] **FIG. 42** is a top view of the light guide units of **FIG. 41**, in accordance with an embodiment of the present invention;

[0095] **FIGS. 89** and **90** are simplified illustrations of a lens for refracting light in three directions, having a lens surface with a repetitive pattern of substantially planar two-sided and three-sided recessed cavities, respectively, in accordance with embodiments of the present invention;

[0096] **FIGS. 91** - **93** are simplified illustrations of a touch screen surrounded with alternating emitters and receivers and diagonal wide beams crossing the screen, in accordance with an embodiment of the present invention;

[0097] **FIG. 94** is a simplified graph of light distribution across a diagonal wide beam in a touch screen, in accordance with an embodiment of the present invention;

[0098] **FIG. 95** is a simplified graph of light distribution across three overlapping diagonal wide beams in a touch screen, in accordance with an embodiment of the present invention;

[0099] **FIG. 96** is a simplified graph of touch detection as a finger glides across three overlapping diagonal wide beams in a touch screen, in accordance with an embodiment of the present invention;

[00100] **FIG. 97** is a simplified graph of detection signals from a diagonal wide beam as a fingertip moves across the screen at three different locations, in accordance with an embodiment of the present invention;

[00101] **FIG. 98** is a simplified illustration of a first embodiment for a touch screen surrounded with alternating emitters and receivers, whereby diagonal and orthogonal wide beams crossing the screen are detected by one receiver, in accordance with an embodiment of the present invention;

[00102] **FIG. 99** is a simplified illustration of a second embodiment for a touch screen surrounded with alternating emitters and reciters, whereby diagonal and orthogonal wide beams crossing the screen are detected by one receiver, in accordance with an embodiment of the present invention;

[00129] **FIG. 131** is a simplified diagram showing a stylus and a mirror image of the stylus, moved closer to the bottom of a touch area vis-à-vis **FIG. 129**, in accordance with an embodiment of the present invention;

[00130] **FIG. 132** is a simplified diagram showing a stylus and a mirror image of the stylus, separated apart from one another, in accordance with an embodiment of the present invention;

[00131] **FIG. 133** is a simplified flowchart of a method for determining a three-dimensional pointed location, in accordance with an embodiment of the present invention;

[00132] **FIG. 134** is a simplified diagram of a touch area that displays six touch icons, used for determining a camera orientation, in accordance with an embodiment of the present invention;

[00133] **FIGS. 135** and **136** are illustrations of opposing rows of emitter and receiver lenses in a touch screen system, in accordance with an embodiment of the present invention;

[00134] **FIG. 137** is a simplified illustration of a technique for determining a touch location, by a plurality of emitter-receiver pairs in a touch screen system, in accordance with an embodiment of the present invention;

[00135] **FIG. 138** is an illustration of a light guide frame for the configuration of **FIGS. 135** and **136**, in accordance with an embodiment of the present invention;

[00136] **FIG. 139** is a simplified flowchart of a method for touch detection for a light-based touch screen, in accordance with an embodiment of the present invention;

[00137] **FIGS. 140 – 142** are illustrations of a rotation gesture, whereby a user places two fingers on the screen and rotates them around an axis;

[00212] Shown in **FIG. 26** is a graph of detected light intensity. Total detected light corresponds to a shaded area under the graph. An object touching the screen blocks a portion of this light. If the object touching the screen moves across the wide beam, from left to right, the amount of blocked light increases, and correspondingly the total detected light decreases, as the object progresses from the left edge of the beam to the center of the beam. Similarly, the amount of blocked light decreases, and correspondingly the total detected light increases, as the object progresses from the center of the beam to the right edge of the beam.

[00213] It is noted that the detected light intensities at the edges of the light beam are strictly positive, thus ensuring that a touch at these edges is detected.

[00214] Reference is made to **FIG. 27**, which is a simplified diagram of a wide-beam touch screen, showing intensity distributions of overlapping light signals from two emitters, in accordance with an embodiment of the present invention. **FIG. 27** shows light detected from emitters **201** and **202**. A touch point **980** on display **636** blocks light from these emitters differently. Area **973** indicates attenuation of light from emitter **201** by touch point **980**, and the union of areas **973** and **974** corresponds to the attenuation of light from emitter **202** by point **980**. By comparing the light attenuation the two emitter-receiver pairs, **201**-**302** and **202**-**302**, a precise touch coordinate is determined.

[00215] Reference is made to **FIG. 28**, which is a simplified diagram of a wide-beam touch screen, showing intensity distributions of two sets of overlapping light signals from one emitter, in accordance with an embodiment of the present invention. As shown in **FIG. 28**, touch point **980** is inside the area detected by emitter-receiver pair **201**-**301** and emitter-receiver pair **201**-**302**. The attenuation of the light signal at receiver **302**, depicted as area **976**, is greater than the attenuation at

an upper portion **463** and a lower portion **464**. The micro-lenses are located at an upper surface **466** of lower portion **464**. As such, the micro-lenses are not embedded in the collimating lens portion of light guide **464**.

[00238] In configuration no. 2, the curved shape of the collimating lens necessitated a fan/feather pattern for the micro-lenses etched thereon. In distinction, in configuration no. 3 the micro-lenses are etched on rectangular surface **466**, and are arranged as parallel rows. Such a parallel arrangement, referred to herein as a "tubular arrangement", is shown in **FIG. 42**. Specifically, a parallel series of micro-lenses **467** are shown along an upper surface of light guide **464** in **FIG. 42**.

[00239] An advantage of configuration no. 3 is that the flat upper surface of the light guide may be molded as nearly parallel with the screen surface as possible, since the mold is one flat surface that lifts off the top of light guide **464**. Furthermore, in configuration no. 3, only portion **464** of the light guide has a low tolerance requirement for positioning. Portion **463** has a higher tolerance, since its surfaces are not placed at a focal point of an element.

[00240] As shown in **FIG. 40**, light beams **100** emitted by emitter **200** enter light guide unit **464** at surface **465**, are reflected by reflective surface **451** through surface **466**, and into light guide unit **463**. Inside light guide unit **463**, light beams **100** are reflected by surface **452**, and exit through surface **453** over display **637**.

[00241] **FIG. 40** indicates that the height, **H3**, added by the light guide over display **637** comprises the sum of the height, **H1**, of internal reflective surface **452**, and the height, **H2**, of the thickness of outer casing **827**.

[00242] Reference is made to **FIG. 41**, which is a picture of light guide units **463** and **464**, within the content of a device having a PCB **700** and

[00261] It is noted that placement of emitters and receivers underneath a device screen, and placement of a collimating reflective element opposite each emitter or receiver, imposes restrictions on the thickness of the device. A first restriction is that the thickness of the device be at least the sum of the screen thickness and the emitter or receiver thickness. A second restriction is that in order to properly collimate light that is reflected upward above the screen, the reflective element opposite the emitter or receiver be curved into a convex "smile" shape, as shown inter alia in **FIGS. 37** and **38**. The convex shape adds to the total thickness of the device.

[00262] Designers of tablets and e-book readers strive to achieve as slim a form factor as possible. As such, according to an embodiment of the present invention, the receivers and collimating lenses are placed inside a border surrounding the screen, instead of being placed underneath the screen. This is particularly feasible for tablets and e-book readers that provide a non-screen border area for holding the device.

[00263] Reference is made to **FIG. 49**, which is a simplified diagram of a touch screen device held by a user, in accordance with an embodiment of the present invention. Shown in **FIG. 49** is a device **826** with a touch screen **800** surrounded by a frame **840** held by hands **930**.

[00264] Reference is made to **FIG. 50**, which is a simplified diagram of a touch screen with wide light beams covering the screen, in accordance with an embodiment of the present invention. **FIG. 50** shows a top view and a side view of a touch system with a touch screen **800**, in the context of an electronic device such as a tablet or an e-book reader. **FIG. 50** also shows emitters **200** and receivers **300**, each coupled with a pair of lenses **550** and **551**, separated by an air gap **555**, for collimating light. The side view shows a device casing **827** and a frame **849** surrounding touch screen **800**. Frame **849** provides a grip for a user to

in the upper portion of **FIG. 67** shows three detection signals of a fingertip as it traverses the three paths **925** – **927**, labeled in the graph legend as LED edge, Midscreen and PD edge, respectively. The three detection signals in the graph are substantially overlapping. As such, the signal is uniformly detected along its depth, and the signal varies as a function of the touch along only one axis of the screen. Thus determining a touch location along a first axis is independent of the detection signal along a second axis. Moreover, the intensity of the signal is uniform along the second axis, making the signal robust.

Supporting Various Screen Sizes

[00296] Some embodiments of Configuration no. 5 includes optical elements with alternating facets that are focused on two neighboring light emitting or receiving elements. When such an optical element is separate from the light emitters or receivers, the emitters or receivers are generally spaced at a particular pitch. When such an optical element is formed as a rigid module together with an emitter or a receiver, the embedded emitter or receiver is precisely positioned with respect to the reflective facets. The facets aimed at a neighboring module, are aimed in accordance with the embedded emitter or receiver in the neighboring module that is similarly situated in its module. Such positioning potentially restricts the size of a screen to integral multiples of the pitch. E.g., with a pitch of 10 mm between emitters, the screen dimensions must be integral multiples of 10 mm. Embodiments of the present invention are able to overcome this restriction, as described in what follows.

[00297] Reference is made to **FIG. 68**, which is a simplified diagram of four optical elements and four neighboring emitters, in accordance with an embodiment of the present invention. Shown in **FIG. 68** are four

overlapping wide beams on the second axis set, such that touch detection on the second axis set is also precise.

[00307] A dual-unit light guide is described hereinabove with reference to **FIGS. 41** and **42**. As described there, the lower portion **464** of the light guide contains reflective facets or lenses that are focused on the emitters and receivers, and the upper portion **463** includes reflective surface and lenses that do not require precision placement vis-à-vis the emitters and receivers. In Configuration No. 5, the alternating reflective or refractive facets form part of the lower portion. A three-sided refractive cavity for distributing light beams in three directions is formed as part of the upper portion. In Configuration No. 5, use of micro-lenses **467** is not required. Alternatively, the alternating facets are formed in transparent plastic modules that include an emitter or receiver, as described hereinbelow with reference to **FIG. 105**. An arrangement of these modules replaces lower portion **464**, and upper portion **463** remains.

[00308] Reference is made to **FIG. 82**, which is a simplified illustration of a touch screen with light beams directed along four axes, in accordance with an embodiment of the present invention. Shown in **FIG. 82** is a row of light emitters **200** along the top edge of a screen **800**, and a row of light receivers **300** along the bottom edge of screen **800**. The left and right edges of screen **800** include opposing rows of combined emitter-receiver elements **230**. Elements **230** act as emitters and as receivers. In an embodiment of the present invention, an emitter and a receiver are combined in a single unit, such as the reflective and transmissive sensor manufactured by Vishay Corporation of Malvern, PA. In another embodiment of the present invention, an LED is used for both light emission and detection. An integrated circuit that both emits and detects light using an LED and a current limiting resistor, is described in Dietz, P.H., Yerazunis, W.S. and Leigh, D.L., "Very low cost sensing and

communication using bidirectional LEDs", International conference on Ubiquitous Computing (UbiComp), October, 2003.

[00309] Reference is made to **FIG. 83**, which is a simplified illustration of an alternate configuration of light emitters and light receivers with two grid orientations, in accordance with an embodiment of the present invention. Shown in **FIG. 83** are light emitters **200** in an alternating pattern with light receivers **300** around a screen perimeter. Light emitted by each emitter is detected by two receivers at an opposite screen edge, the two receivers being separate by an emitter therebetween.

[00310] In order that the light from an emitter arrive at the outer edges of two opposite receivers, the wide beams emitted from each emitter must span a distance of three optical lenses. This is in contrast to the configuration described above with shift-aligned emitters and receivers, where the two receivers that detect light from a common emitter are positioned adjacent one another, and thus the wide beams emitted from each emitter need only span a distance of two optical lenses.

[00311] Reference is made to **FIG. 84**, which is a simplified illustration of a configuration of alternating light emitters and light receivers, in accordance with an embodiment of the present invention. As shown in **FIG. 84**, emitter **201** is situated between receivers **303** and **304** along the bottom screen edge, and emitter **202** is situated between receivers **301** and **302** along the top screen edge. Light from emitter **201** is detected by receivers **301** and **302**, and light from emitter **202** is detected by receivers **303** and **304**.

[00312] Reference is made to **FIG. 85**, which is a simplified illustration of two wide light beams from an emitter being detected by two receivers, in accordance with an embodiment of the present invention. Shown in **FIG. 85** are two wide beams from emitter **201** that exit lens **440** and arrive at

screen, and a second pair of light beams emitted from emitter **200** to receivers **302** and **303** along the adjacent left edge of the display screen. A third pair of light beams (not shown) is emitted from emitter **200** to receivers at the adjacent right edge of the display screen. The second and third pairs of light beams are each oriented at an angle of approximately 45° relative to the first pair of light beams.

[00317] Also shown in **FIG. 88** is a lens **439**, used to refract light from emitter **200** to lenses **442** and **443**, which are oriented at approximately 45° to the left of lens **439**. In an embodiment of the present invention, lens **439** is made of a plastic material, which has an index of refraction on the order of 1.4 – 1.6. As such, an angle of incidence of approximately 84° is required in order for the light to be refracted at an angle of 45°. However, for such a large angle of incidence, the amount of light lost due to internal reflection is large. In order to improve throughput, two air/plastic interfaces are used to achieve an angle of refraction of approximately 45°, as described hereinabove.

Tri-Directional Micro-Lenses

[00318] Reference is made to **FIGS. 89** and **90**, which are simplified illustrations of a lens for refracting light in three directions, having a lens surface with a repetitive pattern of substantially planar two-sided and three-sided recessed cavities, respectively, in accordance with embodiments of the present invention. The flat surface opposite the emitter or receiver is distal to the emitter or receiver in **FIG. 89** forming a three-sided cavity, and is proximal thereto in **FIG. 90** separating two two-sided cavities.

[00319] Such three-sided lenses are used in several embodiments. In a first embodiment, the lens is used without an additional optical component with alternating facets for interleaving neighboring beams. In

this embodiment, wide beams cover the screen but do not necessarily overlap to provide two or more detection signals for interpolation. A typical use case for this embodiment is finger input, but not stylus input. The tri-directional lens enables detection on four different axes, to eliminate ambiguity and ghosting in multi-touch cases. The tri-directional lens also provides additional touch location information; namely, four axes instead of two, and the additional information increases the precision of the touch location, even for a single touch.

[00320] In a second embodiment, the lens is used with an additional optical component with alternating facets for interleaving neighboring beams, or with an alternative arrangement providing overlapping detection signals. In this embodiment, overlapping wide beams provide two or more detection signals for interpolation. Typical use cases for this embodiment are finger and stylus input. The tri-directional lenses and the interleaving facets may be formed in two distinct components. The interleaving facets component is positioned closer to its emitter or receiver than the tri-directional component, since the tolerance for imprecise placement of the interleaving facets component is low, whereas the tolerance for imprecise placement of the tri-directional lens component is high. Alternatively, the tri-directional lenses and the interweaving facets may be formed in a single rigid component. For example, a diffractive grating interleaves signals from two sources and also splits the beams in three directions.

[00321] Shown in **FIG. 89** is a lens **527** with a pattern of micro-lenses **528** on its bottom surface. The micro-lens pattern shown in **FIG. 89** has three substantially planar sides, each side refracting light in a different direction. The pattern of micro-lenses **528** form a saw-tooth repetitive pattern along the bottom edge of the upper section of the lens. The three

emitters and reciters, whereby diagonal and orthogonal wide beams crossing the screen are detected by one receiver, in accordance with an embodiment of the present invention. **FIG. 99** shows an embodiment with different numbers of elements positioned along adjacent screen edges. Three beams **167** – **169** are shown for one receiver **300**; namely, one directed to an opposite emitter **200**, and the other two directed at substantially 45° angles to emitters **201** and **202**, one of which is on an opposite edge and another of which is positioned on an adjacent edge. These diagonal beams generate two axes that are perpendicular to one another.

Palm Rejection

[00333] When a user rests his hypothenar muscles, located on the side of his palm beneath his little finger, on a touch screen when writing with a stylus, ghosting generally occurs. This part of the palm blocks a large area of the touch screen, and often blocks a series of light beams along the screen's vertical axis, thereby hiding the stylus' touch position along the vertical axis.

[00334] Reference is made to **FIG. 100**, which is a simplified illustration of a user writing on a prior art touch screen with a stylus. Shown in **FIG. 100** is a hand **930** holding a stylus **931**, and drawing a line **932** on a touch screen **800**. The user's palm is resting on screen **800**, blocking two series of light beams depicted as dotted lines; namely, a series **113** along the screen's horizontal axis, and a series **114** along the screen's vertical axis. The location of the stylus tip on the vertical axis is within series **114**. Beam **115** does detect the tip of the stylus, but it only provides a horizontal axis location.

[00335] Embodiments of the present invention overcome the drawback illustrated in **FIG. 100**. Reference is made to **FIG. 101**, which is a

simplified illustration of light beams detecting location of a stylus when a user's palm rests on a touch screen, in accordance with an embodiment of the present invention. By providing two sets of detection axes; namely, an orthogonal set and a diagonal set, a two-dimensional location of a stylus is determined. **FIG. 101** shows that beams **115** and **116** uniquely detect a stylus. Since each detection comprises overlapping wide beams whose signals are interpolated, as described hereinabove, the stylus position is determined with high precision, despite beams **115** and **116** not being perpendicular to one another. When the bottom of the user's palm does not block diagonal beam **117**, then beam **117** also detects the stylus location separately from the palm. In such case, beams **116** and **117** are used to detect the stylus location. Alternatively, all three detecting beams **115** – **117** may be used.

[00336] Another challenge that arises with touch screens that support both stylus and finger input arises when a user places his palm on the screen in order to write with a stylus, is misinterpretation of the initial contact between palm and screen as being a tap on an icon, in response to which the device launches an unintended application whose icon was tapped. Once the palm is resting on the screen, an area of contact is used to reject the palm touch as a screen tap. Nevertheless, the initial contact may cover a small surface area of the screen and thus be misinterpreted as a screen tap.

[00337] According to embodiments of the present invention, light beams above the screen are used to detect a palm as it approaches the screen. In one embodiment this is accomplished by projecting light from each emitter at several heights above the screen, as illustrated in **FIG. 14** showing an approaching finger **900** blocking beam **101** but not beam **102**. In another embodiment, multiple layers of emitters and receivers are arranged around the screen, and used to detect objects at different

heights above the screen, as described hereinabove with reference to a user input gesture cavity and, in particular, with the cavity frame folded on top of the screen.

[00338] Reference is made to **FIG. 102**, which is a simplified illustration of a frame surrounding a touch screen, in accordance with an embodiment of the present invention. **FIG. 102** shows a frame **849** surrounding a touch screen, similar to frame **849** of **FIG. 49**. Two stacked rows of emitters **200** and receivers **300** are provided in the frame. When assembled together with a display in an electronic device, the stacked rows of emitters and receivers are raised above the display surface and provide object detection at two heights, namely, on the screen by the lower row of emitters and receivers, and above the screen by the upper row of emitters and receivers. When a user's palm begins to touch the screen, a large palm area is detected hovering above the screen. This enables the device to determine that a palm is approaching the screen, and that any screen tap is inadvertent.

[00339] In another embodiment of the present invention, only one row of emitters and receivers is provided for detecting a palm hovering above the screen, and touches on the screen are detected by conventional detection systems imposed on the display including inter alia capacitive or resistive touch sensors.

[00340] According to an embodiment of the present invention, a user interface disables screen taps for activating functions when a palm is detected. When the palm is detected, the user interface is configured to launch applications in response to a user touching an icon and gliding his finger away from the touched location along the touch screen. I.e., two sets of user interface gestures are provided. When no palm is detected, the first set of gestures is used. With the first set of gestures, a tap on an icon activates an application or function associated with the icon.

placing an emitter or receiver in exactly the correct position vis-à-vis the reflective or refractive facets, are handled during manufacture of the modular blocks, thus removing the burden of high precision assembly from a device manufacturer.

[00346] Simplified manufacturing is achieved by integrating optical elements and electronic components into a single unit. As such, complex surfaces may be gathered into one component, thereby reducing the need for high assembly tolerances.

[00347] Reference is made to **FIG. 105**, which is an illustration of optical components made of plastic material that is transparent to infrared light, in accordance with an embodiment of the present invention. Shown in **FIG. 105** is an optical component **488** that includes a forward-facing LED **236**, and electronics to handle the LED signal. Optical component **488** is connected to electrical pads **760** and **761**. Optical component **488** is used to transmit collimated light beams from two emitters; namely, emitter **235** and emitter **236**. Emitter **235** is included in a neighboring optical component **489**. In the alternating emitter-receiver embodiment described hereinabove, optical component **488** is used to transmit collimate light beams for one emitter and one receiver. E.g., neighboring module **489** includes a receiver instead of emitter **235**.

[00348] Light beams from emitter **235** exit optical component **489** through a tight-fitting surface **491**, and enter optical component **488** through a tight-fitting surface **490**. **FIG. 105** shows non-parallel light beams from emitters **235** and **236** hitting alternating facets on a wave-like multi-faceted reflective surface **493**. Components **488** and **489** are substantially identical, and fit together. A device manufacturer can thus use these components as building blocks to create a touch screen, by arranging a series of these building blocks in a row along each edge of the display. Typical arrangements are (a) two adjacent display edges are

before exiting optical element **497**. Another portion of the non-parallel beams are collimated by a neighboring module, not shown in **FIG. 105**. The beams **100** that exit optical element **497** are directed upwards and are reflected over display **642** by a light guide **498**. In an embodiment of the present invention, three-way refracting cavities are etched, or otherwise formed, on the lower surface of optical element **498** to refract the light beams in three directions in order to provide two coordinate systems for determining a touch location. The light beams **100** enter a light guide **499** on the opposite side of screen **642**, and are reflected below display **642** into optical element **496**. In embodiments supporting the two coordinate systems, the three-way refracting cavities are present on the underside of optical element **499** as well. As described hereinabove, optical element **496** and its neighboring optical element, not shown, focus the incoming light beams on photo diode **394**. In one embodiment of the present invention, the light guides **498** and **499** are constructed as a frame that surrounds display **642**.

[00353] In the touch screen of **FIG. 106**, two types of light beam redirection occur. A first redirection requires multiple facets directed at a single focus point. A second redirection uniformly redirects incoming beams at a 90º angle, or folds incoming light beams into a narrow waist or focus, as described hereinabove with reference to configuration no. 4. In some embodiments, the collimated beams are refracted in three directions, in between the first and second redirections, by refracting cavities.

[00354] The first type of redirection requires that the emitter or receiver be positioned at a specific location relative to the focal point of many facets. As such, the positioning of the emitter or receiver and its reflective surfaces, is sensitive to variations in placement. Thus the assembly of the emitter or receiver, together with its corresponding

pressure is released, the resilient member returns the screen to its original position within the light guide frame.

[00365] Reference is made to **FIGS. 112 – 115**, which are illustrations of a touch screen **800** that detects occurrence of a hard press, in accordance with an embodiment of the present invention. **FIG. 112** shows touch screen **800** in rest position, screen **800** being supported by resilient supporting members **841** and **842** that create a flex air gap **843**, which are mounted on a printed circuit board **700**. **FIG. 112** shows two light guides, **518** and **519**, one on either side of screen **800**, for directing light **100** from an emitter **200** over screen **800** to a receiver **300**. Only a small upper portion of each light guide **518** and **519** extends above screen **800**. Receiver **300** communicates detected light intensities to a calculating unit (not shown).

[00366] **FIG. 113** shows a finger **900** pressing down on the screen, causing members **841** and **842** to compress and to narrow flex air gap **843**. As a result, a larger portion of light guides **518** and **519** are exposed above screen **800**, thus allowing (a) more light **100** from emitter **200** to traverse screen **800** and be detected by receiver **300**, and (b) more ambient light **101** to reach receiver **300**. In various embodiments, either or both of these increases in detected light are used to indicate a hard press. In other embodiments, the amount of downward pressure applied is determined based on the amount of additional detected light, thus enabling discrimination between more hard and less hard touches.

[00367] In some embodiments, the light guide frame includes protruding lips **520** and **521**, shown in **FIG. 114**, that extend over the edges of screen **800**, to counter balance the upward force of resilient members **841** and **842** when no downward pressure is applied to screen **800**. Resilient members **841** and **842** may comprise inter alia a flexible

screen surface and of a pointer, or a plurality of pointers, touching the screen surface. In some embodiments of the present invention, the screen pixels include light sensors, each of which generates a pixel of an image of the underside of the screen glass, the image being referred to herein as the "screen glass image".

[00371] As described hereinbelow, methods according to embodiments of the present invention determine precise touch coordinates using spatial and temporal filters. Application of these methods to configuration no. 8 yields sub-pixel precision for touch coordinates.

[00372] Pixels in the screen glass image at the center of a touch location are generally completely blocked; i.e., the level of light detected at each such pixel is below a designated threshold, indicating that the pixel is occluded by a touch object. Pixels in the screen glass image along the edges of a touch location are generally only partially blocked; i.e., the level of light detected at each such pixel is above the designated threshold, indicating that the pixel is only partially occluded by the touch object.

[00373] A calculating unit that receives the screen glass image data assigns a relative weight to each pixel coordinate, based on a touch detection intensity associated with that pixel, as indicated by the pixel's value. The calculating unit further interpolates the pixel coordinates, based on their associated weights, to determine a touch coordinate. In some embodiments, the calculating unit calculates a touch area having a perimeter, wherein the edges of the touch area are calculated on a sub-pixel level based on the above interpolations. The temporal filters described hereinbelow are applied inter alia when a series of connected touches are concatenated into a glide movement over a time duration.

[00374] Reference is made to **FIG. 118**, which is a simplified diagram of an image sensor **844** positioned beneath a screen glass display **635**, to

methods are of advantage for pen and stylus support, which have fine touch points, and provide highly accurate touch location determination for single-finger and multi-finger touches as well.

[00395] Reference is made to **FIGS. 135** and **136**, which are illustrations of opposing rows of emitter lenses and receiver lenses in a touch screen system, in accordance with an embodiment of the present invention. Positioned behind each emitter and receiver lens is a corresponding respective light emitter **200** or light receiver **300**. As shown in **FIG. 135**, each emitter **200** is positioned opposite two receivers **300** that detect light beams emitted by the emitter. Similarly, each receiver **300** is positioned opposite two emitters **200**, and receives light beams emitted from both emitters.

[00396] **FIG. 135** shows **(A)** a single, full beam **173** from an emitter **200** that spans two receivers **300**; **(B)** the portion of the full beam, designated **174**, detected by the left one of the two receivers **300**; **(C)** the portion of the full beam, designated **175**, detected by the right one of the two receivers **300**; **(D)** multiple beams **176**, for multiple emitters **200**, covering the touch screen, and **(E)** multiple beams **177**, for multiple emitters **200**, covering the touch screen. Generally, each emitter **200** is activated alone. Precision touch detection is described hereinbelow, wherein a touch point is detected by multiple beams. It will be appreciated from **(D)** and **(E)** that points on the screen are detected by at least one beam **176** and one beam **177**.

[00397] To conserve power, when the touch screen is idle only one set of beams, namely, beams **176** or beams **177**, are scanned in a scanning sweep, and only for the axis with the smallest number of emitters **200**. The scanning toggles between beams **176** and beams **177**, and thus two scanning sweeps along the axis activate every emitter-receiver pair along the axis. The other axis, with the larger number of emitters, is only

[00437] In embodiments with optical elements with three-way lenses that create light beams along two sets of axes, similar calculations are performed on the diagonal detection beams to determine locations on the second axis system. As described hereinabove, touch objects typically block a larger portion of the diagonal signals that of the orthogonal signals.

[00438] The spatial and temporal filters described hereinabove with reference to shift-aligned emitter-receiver arrangements are applied in aligned emitter-receiver arrangements as well.

Calibration of Touch Screen Components

[00439] Reference is made to **FIG. 153**, which is a simplified flowchart of a method of calibration and touch detection for a light-based touch screen, in accordance with an embodiment of the present invention. In general, each emitter/receiver pair signal differs significantly from signals of other pairs, due to mechanical and component tolerances. Calibration of individual emitters and receivers is performed to ensure that all signal levels are within a pre-designated range that has an acceptable signal-to-noise ratio.

[00440] In accordance with an embodiment of the present invention, calibration is performed by individually setting (i) pulse durations, and (ii) pulse strengths, namely, emitter currents. For reasons of power consumption, a large current and a short pulse duration is preferred. When a signal is below the pre-designated range, pulse duration and/or pulse strength is increased. When a signal is above the pre-designated range, pulse duration and/or pulse strength is decreased.

[00441] As shown in **FIG. 153**, calibration (operation **1051**) is performed at boot up (operation **1050**), and is performed when a signal is detected outside the pre-designated range (operation **1055**).

expected noise level, a new measurement is performed, and both results are compared to the previous result, to get a best match. If the final value is within the expected noise level, a counter is incremented. Otherwise, the counter is cleared. The counter is subsequently used to determine if a signal is stable or unstable, when updating reference values and when recalibrating.

[00445] After each complete scan, signals are normalized with their respective reference values. If the normalized signals are not below a touch threshold, then a check is made if a recalibration or an update of reference values is necessary. If a normalized signal is below the touch threshold, then a touch is detected (operation **1053**).

[00446] To reduce risk of a false alarm touch detection, due to a sudden disturbance, the threshold for detecting an initial point of contact with the screen, such as when a finger first touches the screen, is stricter than the threshold for detecting movement of a point of contact, such as gliding of a finger along the screen while touching the screen. I.e., a higher signal difference is required to detect an initial touch, vis-à-vis the difference required to detect movement of an object along the screen surface. Furthermore, an initial contact is processed as pending until a rescan verifies that the touch is valid and that the location of the touch remains at approximately the same position.

[00447] To determine the size of a touch object (operation **1057**), the range of blocked signals and their amplitudes are measured. For large objects, there is a wait for detecting an initial point of contact with the screen, until the touch has settled, since the touch of a large object is generally detected when the object is near the screen before it has actually touched the screen. Additionally, when a large object approaches the screen in a direction not perpendicular to the touch area, the subsequent location moves slightly from a first contact location.

application U.S. Serial No. 12/371,609 entitled LIGHT-BASED TOUCH SCREEN filed on February 15, 2009, the contents of which are hereby incorporated by reference. Inter alia, reference is made to paragraphs [0073], paragraphs [0087] – [0091] and FIG. 11 of this application as published in U.S. Publication No. 2009/0189878 A1 on July 30, 2009.

[00467] Emitter driver circuitry **740** includes circuitry **742** for configuring individual photoemitter pulse durations and pulse currents for each emitter-detector pair via a programmable current source. Circuitry **742** is described in applicants' co-pending patent application U.S. Serial No. 13/052,511 entitled LIGHT-BASED TOUCH SCREEN WITH SHIFT-ALIGNED EMITTER AND RECEIVER LENSES filed on March 21, 2011, the contents of which are hereby incorporated by reference. Inter alia, reference is made to paragraphs [0343] – [0358] and FIGS. 99 – 101 of this application as published in U.S. Publication No. 2011/0163998 on July 7, 2011.

[00468] Chip package **731** includes detector driver circuitry **750** for selectively activating a plurality of photo detectors **300** that are outside of the chip package, and signal conducting pins **733** for connecting photo detectors **300** to detector driver circuitry **750**. Detector driver circuitry **750** includes circuitry **755** for filtering current received from photo detectors **300** by performing a continuous feedback bandpass filter, and circuitry **756** for digitizing the bandpass filtered current. Circuitry **755** is described inter alia at paragraphs [0076], paragraphs [107] – [0163] and FIGS. 14 – 23B of the above-referenced U.S. Publication No. 2009/0189878 A1. Chip package **731** also includes detector signal processing circuitry **753** for generating detection signals representing measured amounts of light detected on photo detectors **300**.

[00469] Chip package **731** further includes I/O pins **736** for communicating with a host processor **772**. Chip package **731** further includes controller circuitry **759** for controlling emitter driver circuitry

TABLE IV: LED multiplex mapping to LED_ROW and LED_COL pins

LED	LED_ROW pin enabled	LED_COL pin enabled
1	1	1
2	2	1
3	3	1
4	4	1
5	5	1
6	6	1
7	1	2
8	2	2
9	3	2
10	4	2
11	5	2
12	6	2
13	1	3
14	2	3
15	3	3
16	4	3
17	5	3
18	6	3
19	1	4
20	2	4
21	3	4
22	4	4
23	5	4
24	6	4
25	1	5
26	2	5

[00474] Advantages of having a dedicated controller for emitters and receivers in a light-based touch screen are power savings and performance. In conventional systems, a conventional chip, such as the MSP430 chip manufactured by Texas Instruments of Dallas, TX, controls emitters and receivers. Regarding power savings, conventional chips do not provide access to all of the power consuming chip elements. Moreover, with conventional chips it is not possible to power on and off external elements in sync with the emitters. For example, with a conventional chip the amplifier unit connected to the receivers and the analog-to-digital convertor (ADC) for digitizing receiver light detection current, cannot be turned on and off in sync with activation of the emitters. In conventional systems, these elements are left powered on throughout an entire scan sequence. In distinction, the dedicated

9. When placing two fingers on the screen, there is an inherent delay between the first and second touches. Completing multiple scan sequences in a very short time allows the system to determine the first touch, which is unambiguous. Then, assuming that the first touch is maintained when the second touch is detected, the second touch location is easily resolved. E.g., if it is determined that one touch is in the upper left corner and the touch detection pattern is as shown in **FIGS. 8** and **9**, then the second touch location must be at the lower right corner of the screen.

[00485] Thus it will be appreciated by those skilled in the art that a dedicated controller in accordance with the present invention is power-efficient, highly accurate and enables highs sampling rates. The host configures the controller for low power, corresponding to 100 Hz or less, or for high frequency scanning, such as 500 Hz – 1000 Hz.

[00486] Determination of which configuration is appropriate is based inter alia on the area of the touch screen covered by a touch pointer, since jitter and lag are less prominent for a touch covering a relative large area, such as a finger touch, than for a touch covering a relatively small area, such as a stylus touch. Based on the area covered by the pointer, as determined by the size of the shadowed area of light-based touch screen signals, the host determines whether a finger or a stylus is being used, and configures an appropriate scan rate based on the trade-off between power and accuracy.

[00487] In accordance with an embodiment of the present invention, the dedicated controller includes scan range registers for selectively activating LEDs, and current control and pulse duration registers for specifying an amount of current and a duration, for each activation. The scan range registers designate a first LED and a first PD to be activated along each screen edge, the number of LEDs to be activated along each

CLAIMS

What is claimed is:

1. An optical element for a light based touch surface comprising a concatenated plurality of segments, wherein each segment is paired with a respective light emitter, each segment comprising an undulating series of pairs of reflective or refractive facets, wherein a first facet in each pair is oriented so as to collimate light emitted from a first light emitter associated with the segment and a second facet in each pair is oriented so as to collimate light emitted from a second light emitter associated with the segment, and wherein the first light emitter associated with the segment is the light emitter paired with the segment and the second light emitter associated with the segment is the light emitter paired with a neighboring segment.

2. The optical element of claim **1**, wherein, for each of said plurality of segments, light emitted from the first light emitter associated with the segment is directed by the segment to generate a first local spatial light intensity distribution of collimated light beams across an area of the touch surface, and light emitted from the second light emitter associated with the segment is directed by the segment to generate a second local spatial light intensity distribution of collimated light beams across the area of the touch surface, and wherein the first and second local spatial light intensity distributions are different distributions.

3. The optical element of claim **2** wherein, for each of said plurality of segments, a first plurality of the first facets of its series of facet pairs, near the first light emitter associated with the segment, comprise sizes that decrease as a function of the first facet's distance

from the first light emitter, and a second plurality of the first facets, further from the first light emitter, comprise sizes that increase as a function of the first facet's distance from the first light emitter, such that the first local spatial light intensity distribution is substantially linear as a function of spatial position.

4. A modular component for a light based touch surface assembly, comprising:

at least one of said plurality of segments of the optical element of claim **1** and the light emitters paired therewith in a single unit; and

two oppositely contoured outer edges, to facilitate inter-fitting the modular component with a similar neighboring modular component that contains a segment adjacent to one of the segments comprised in the modular component, by positioning one of the contoured outer edges of the modular component alongside the oppositely contoured outer edge of the neighboring modular component.

5. An optical touch detection system, comprising:

a housing;

a surface mounted in said housing;

a set of first optical elements in accordance with claim **1** positioned along one edge of said surface;

the light emitters paired with the segments of said set of first optical elements, mounted in said housing;

a set of second optical elements positioned along an edge of said surface opposite the one edge, comprising a concatenated plurality of like segments, wherein each segment is paired with a respective light receiver, each segment comprising an undulating series of

pairs of reflective or refractive facets, wherein a first facet in each pair directs collimated light to a first light receiver associated with the segment and a second facet in each pair directs collimated light to a second light receiver associated with the segment, and wherein the first light receiver associated with the segment is the light receiver paired with the segment and the second light receiver associated with the segment is the light receiver paired with a neighboring segment;

the light receivers paired with the segments of said set of second optical elements, mounted in said housing; and

a calculating unit, mounted in said housing and connected to said light receivers, for determining a location of a pointer touching said surface, based on amounts of light emitted from said light emitters that is blocked by the pointer, as determined by outputs of said light receivers.

6. The optical touch screen of claim **5** wherein, for each of said plurality of segments of said set of first optical elements, the collimated light directed by the first facets of each of the series of facet pairs of the segment at least partially overlap with the collimated light directed by the second facets, and wherein said calculating unit determines the location of the pointer touching the surface based on outputs of at least three light receivers that receive light emitted by three neighboring light emitters.

7. The optical touch screen of claim **5**, wherein the segments of said set of first optical elements do not all have the same length, and the segments of said set of second optical elements do not all have the same length.

8. The optical touch screen of claim **5**, further comprising a set of third optical elements in accordance with claim **1**, arranged along an edge of said surface adjacent to said one edge, wherein one of the segments of one of said set of first optical elements and one of the segments of one of said set of third optical elements are paired with the same emitter.

9. An optical element for a light based touch surface, comprising a concatenated plurality of segments, wherein alternating ones of said segments are respectively paired with alternating light emitters and light receivers, each segment comprising an undulating series of pairs of reflective or refractive facets, wherein a first facet in each pair is oriented so as to collimate light emitted from a light emitter associated with the segment, and a second facet in each pair is oriented so as to direct collimated light onto a light receiver associated with the segment, and wherein the light receiver associated with the segment is one of the light receivers that neighbor the light emitter associated with the segment.

10. The optical element of claim **9** wherein, for each of said plurality of segments, light emitted from the light emitter associated with the segment is directed by the segment to generate a local spatial light intensity distribution of collimated light beams across an area of the touch surface, wherein a first plurality of the first facets of its series of facet pairs, near the light emitter associated with the segment, comprise sizes that decrease as a function of the first facet's distance from the light emitter, and a second plurality of the first facets, further from the light emitter, comprise sizes that increase as a function of the first facet's distance from the light emitter, and wherein the local spatial light

intensity distribution is substantially linear as a function of spatial position.

11. A modular component for a light based touch surface assembly, comprising:

at least one of said plurality of segments of the optical element of claim **9** and the light emitters and receivers paired therewith in a single unit; and

two oppositely contoured outer edges, to facilitate inter-fitting the modular component with a similar neighboring modular component that contains a segment adjacent to one of the segments comprised in the modular component, by positioning one of the contoured outer edges of the modular component alongside the oppositely contoured outer edge of the neighboring modular component.

12. An optical touch detection system, comprising:

a housing;

a surface mounted in said housing;

a frame of optical elements in accordance with claim **9**, surrounding said surface;

the alternating plurality of light emitters and light receivers paired with the segments in the optical elements of said frame, mounted in said housing; and

a calculating unit mounted in said housing and connected to said light receivers to determine the location of an object on said surface based on amounts of light emitted from said emitters that is blocked by the pointer, as determined from outputs of said light receivers.

13. The optical touch detection system of claim **12**, further comprising a frame of lenses inside said frame of optical elements, each of said lenses comprising a pattern of recessed cavities formed by a repetitive pattern of three substantially planar facets, for refracting collimated light emitted by said emitters in three directions and for directing collimated beams from three directions onto said receivers.

14. The optical touch detection system of claim **13**, wherein said calculating unit determines the locations of at least two objects that are on said surface simultaneously.

15. The optical touch detection system of claim **13**, wherein said calculating unit determines the locations of at least three non-aligned objects that are on said surface simultaneously.

16. The optical touch detection system of claim **13**, wherein said calculating unit determines the locations of at least four non-aligned objects that are on said surface simultaneously.

17. The optical touch detection system of claim **13**, wherein said calculating unit determines the location of a stylus on said surface, the stylus being held by a user, when the user's palm blocks some of the light emitted from said emitters from reaching the stylus.

18. A lens for refracting light in three directions, comprising a lens surface having a repetitive pattern of recessed cavities formed by a repetitive pattern of three substantially planar facets.

19. An optical arrangement for a touch screen comprising:

an emitter or a receiver;

a collimating optical element in cooperation with said emitter or receiver; and

the lens of claim **18** in cooperation with said collimating optical element.

20. The optical arrangement of claim **19**, wherein said collimating optical element comprises a reflector.

21. The optical arrangement of claim **19**, wherein said collimating optical element comprises a refracting lens.

22. The optical arrangement of claim **19**, wherein said collimating optical element comprises a series of alternating facets that collimate light for two foci.

23. The optical arrangement of claim **22**, wherein the pitch of the cavities is less than half of the pitch of the alternating facets.

24. The lens of claim **18** wherein the cavities are three-sided, and wherein left and right planes of each cavity flank the middle plane of the cavity at dihedral angles of approximately 122°.

25. The lens of claim **24**, comprising plastic surfaces having an index of refraction of approximately 1.6.

26. The lens of claim **18** wherein the cavities are two-sided, and wherein the left and right planes of each cavity form a dihedral angle of approximately 64°.

27. An optical touch screen, comprising:

a housing;

a display mounted in said housing;

a plurality of lenses according to claim **1**, mounted in said housing along edges of said display;

a plurality of light emitters mounted in said housing, for transmitting light pulses through at least one of said lenses, the light pulses being refracted over said display in three directions;

a plurality of light receivers mounted in said housing, for receiving the refracted light pulses through at least one of said lenses; and

a calculating unit, mounted in said housing and connected to said receivers, for determining a location of a pointer on said display that partially blocks the light pulses emitted by said emitters, based on outputs of said receivers,

wherein said emitters and said receivers are arranged in an alternating fashion along edges of said display.

28. The optical touch screen of claim **27**, wherein the pointer is aligned with part of a user's hand that blocks a plurality of the light pulses.

29. The optical touch screen of claim **27**, wherein said calculating unit determines locations of two pointers on said display that partially block the light pulses emitted by said emitters, based on outputs of said receivers.

30. The optical touch screen of claim **27**, wherein said calculating unit determines locations of three pointers on said display that

partially block the light pulses emitted by said emitters, based on outputs of said receivers.

31. The optical touch screen of claim **27**, wherein said emitters and said receivers are situated at a fixed pitch along edges of said display, and wherein the refracted light pulses form two grids of orthogonal light pulses.

32. The optical touch screen of claim **27**, wherein said emitters and said receivers are situated at a first pitch along shorter screen edges and at a second pitch along longer screen edges, and wherein the refracted light pulses form a grid of orthogonal light pulses and another grid of non-orthogonal light pulses.

33. A method of identifying the locations of two or more pointers simultaneously touching a display screen, comprising:

controlling a plurality of light emitters to emit light over the display screen in directions parallel to two axes, wherein a portion of the emitted light is blocked by two or more pointers that are simultaneously touching the display screen;

measuring amounts of light detected by a plurality of light receivers;

further controlling the plurality of light emitters to emit light over the display screen in directions parallel to two different axes, wherein a portion of the emitted light is blocked by the two or more pointers that are simultaneously touching the display screen;

further measuring amounts of light detected by the plurality of light receivers; and

processing the results of said measuring and said further measuring to infer the locations of the two or more pointers on the display screen.

34. The method of claim **33** wherein said further controlling and said further measuring are only performed if the locations of the two or more pointers on the display screen cannot be inferred unambiguously by the results of said measuring alone.

35. A controller for a light-based touch screen comprising:

a chip package coupled with a light-based touch screen;

emitter driver circuitry inside said chip package for selectively activating a plurality of photoemitters that are outside of said chip package;

detector driver circuitry inside said chip package for selectively activating a plurality of photo detectors that are outside of said chip package;

detector signal processing circuitry for generating detection signals representing measured amounts of light detected on the plurality of photo detectors;

a first plurality of signal conducting pins for connecting the plurality of photoemitters outside the chip package to said emitter driver circuitry inside the chip package;

a second plurality of signal conducting pins for connecting the plurality of photo detectors outside the chip package to said detector driver circuitry and to said detector signal processing circuitry inside the chip package;

controller circuitry inside said chip package for controlling said emitter driver circuitry and said detector driver circuitry; and

at least one input/output pin for communicating with a host processor and for outputting the detection signals generated by said detector signal processing circuitry to the host processor, for the host processor to identify one or more locations on the touch screen that are being touched.

36. The controller of claim **35**, wherein said controller circuitry comprises programmable registers for configuring a scan pattern whereby each of said plurality of photoemitters is paired with one or more of said plurality of photo detectors, and each of said plurality of photo detectors is paired with one or more of said plurality of photoemitters.

37. The controller of claim **36**, wherein said plurality of photoemitters and photo detectors are arranged to respectively emit and detect two sets of overlapping wide light beams, and wherein said controller circuitry is configurable to generate a scan sequence of one set of the wide light beams to detect an initial touch, and to generate a scan sequence of both sets of the wide light beams after detecting the initial touch.

38. The controller of claim **37**, wherein the photoemitters and photo detectors are activated so as to respectively emit and detect the two sets of overlapping wide light beams in 1 millisecond or less, to provide substantially concurrent detections along horizontal and vertical touch screen axes.

39. The controller of claim **38**, wherein the photoemitters and photo detectors are activated so as to respectively emit and detect the two sets of overlapping wide light beams at a rate of at least 50 Hz, to detect an

initial touch location of a first of two fingers when a user places two fingers on the touch screen, and wherein the host processor identifies the second touch location of the two fingers based on the initial touch location.

40. The controller of claim **38** further comprising:

an analog-to-digital controller (ADC);

an amplifier; and

a digital controller core,

wherein the photoemitters and photo detectors are activated so as to respectively emit and detect the two sets of overlapping wide light beams at a rate of at least 100 Hz, and wherein the controller consumes less than 2 milliwatts of power by selectively activating said ADC, said amplifier, and said digital controller core only when needed.

41. The controller of claim **38**, wherein the photoemitters and photo detectors are activated so as to respectively emit and detect the two sets of overlapping wide light beams at a rate of at least 500 Hz, wherein the host processor updates the identified touch locations at a rate of 100 Hz or less, and wherein the host enhances the signal-to-noise ratio based on statistics of multiple activations for each identified touch location.

42. The controller of claim **41**, wherein the controller consumes less than 20 milliwatts of power.

43. The controller of claim **36**, wherein said plurality of photoemitters and photo detectors are arranged to respectively emit and detect two sets of overlapping wide light beams, and wherein said

controller circuitry is configurable to generate an alternating scan sequence of both sets of the wide light beams to detect an initial touch.

44. The controller of claim **36**, wherein said plurality of photoemitters and photo detectors are arranged to respectively emit and detect two sets of overlapping wide light beams along each of four axes, and wherein said controller circuitry is configurable to generate a scan sequence of both sets of wide light beams on the four axes.

45. The controller of claim **36**, wherein said emitter driver circuitry comprises:

a plurality of registers for storing individual photoemitter pulse duration values for a corresponding plurality of emitter-detector pairs; and

circuitry for generating the photoemitter pulses in accordance with the stored pulse duration values.

46. The controller of claim **36**, wherein said emitter driver circuitry comprises:

a plurality of registers for storing individual photoemitter pulse current values for a corresponding plurality of emitter-detector pairs; and

circuitry for generating the photoemitter pulses in accordance with the stored pulse current values.

47. The controller of claim **46**, wherein said circuitry for generating the photoemitter pulses comprises a programmable current source, for driving the photoemitters.

48. The controller of claim **35**, wherein said detector signal processing circuitry comprises circuitry for filtering current received from the photo detectors.

49. The controller of claim **48**, wherein said circuitry for filtering current comprises circuitry to perform a continuous feedback bandpass filter.

50. The controller of claim **49**, wherein said detector signal processing circuitry comprises circuitry to digitize the bandpass filtered current.

51. The controller of claim **50**, wherein said controller circuitry subtracts a first digitized current value representing an ambient light value from a second digitized current value representing light detected during activation of a photoemitter.

52. The controller of claim **35**, wherein said controller circuitry comprises circuitry for activating the photoemitters and the photo detectors in order according to a user-defined sequence.

53. The controller of claim **35**, wherein said controller circuitry comprises circuitry for selecting a user-defined subset of the plurality of photoemitters and a user-defined subset of the plurality of photo detectors and for activating the selected photoemitters and the selected photo detectors in order according to a user-defined sequence.

54. A touch screen system, comprising:

a housing;

a surface mounted on said housing;

a host processor mounted in said housing, for determining touch locations on said surface;

a plurality of light emitters for emitting light that is transmitted over said surface;

a plurality of light receivers for producing output values based on detected light emitted by said emitters; and

first and second controllers according to claim **35** connected to said host processor, to said emitters and to said receivers, for receiving scan configuration settings from said host processor, for activating said emitters in a substantially uninterrupted scan sequence in accordance with the scan configuration settings, and for storing output values from said receivers,

wherein the numbers of said light emitters and said light receivers are greater than the respective numbers of light emitters and light receivers supported by the signal conducting pins of each of said first and second controllers.

55. The touch screen system of claim **54** wherein a first emitter is connected to said first controller and a second emitter is connected to said second controller, wherein light from the first emitter and light from the second emitter is detected by a receiver that is connected to both of said controllers, and wherein the receiver output values for detected light emitted by the first emitter are stored by said first controller and the receiver output values for detected light emitted by the second emitter are stored by said second controller.

Optical Touch Detection System

FIELD OF THE INVENTION

[0001] The field of the present invention is light-based touch screens.

BACKGROUND OF THE INVENTION

[0002] Many consumer electronic devices are now being built with touch sensitive screens, for use with finger or stylus touch user inputs. These devices range from small screen devices such as mobile phones and car entertainment systems, to mid-size screen devices such as notebook computers, to large screen devices such as check-in stations at airports.

[0003] Most conventional touch screen systems are based on resistive or capacitive layers. Such systems are not versatile enough to offer an all-encompassing solution, as they are not easily scalable.

[0004] Reference is made to **FIG. 1**, which is a prior art illustration of a conventional touch screen system. Such systems include an LCD display surface **606**, a resistive or capacitive overlay **801** that is placed over the LCD surface, and a controller integrated circuit (IC) **701** that connects to the overlay and converts inputs from the overlay to meaningful signals. A host device (not shown), such as a computer, receives the signals from controller IC **701**, and a device driver or such other program interprets the signals to detect a touch-based input such as a key press or scroll movement.

[0005] Reference is made to **FIG. 2**, which is a prior art illustration of a conventional resistive touch screen. Shown in **FIG. 2** are conductive and resistive layers **802** separated by thin spaces. A PET film **803** overlays a top circuit layer **804**, which overlays a conductive coating **806**. Similarly, a conductive coating **807** with spacer dots **808** overlays a bottom circuit layer **805**, which overlays a glass layer **607**. When a pointer **900**, such

[0048] **FIG. 33** is a simplified diagram of a wide beam touch screen, with emitter and receiver lenses that have micro-lens patterns, in accordance with an embodiment of the present invention;

[0049] **FIG. 34** is a simplified diagram of two emitters with lenses that have micro-lens patterns integrated therein, in accordance with an embodiment of the present invention;

[0050] **FIG. 35** is a simplified diagram of two receivers with lenses that have micro-lens patterns integrated therein, in accordance with an embodiment of the present invention;

[0051] **FIG. 36** is a simplified diagram of a side view of a single-unit light guide, in the context of an electronic device with a display and an outer casing, in accordance with an embodiment of the present invention;

[0052] **FIG. 37** is a simplified diagram of side views, from two different angles, of a lens with applied feather patterns on a surface, in accordance with an embodiment of the present invention;

[0053] **FIG. 38** is a simplified diagram of a portion of a wide-beam touch screen, in accordance with an embodiment of the present invention;

[0054] **FIG. 39** is a top view of a simplified diagram of light beams entering and exiting micro-lenses etched on a lens, in accordance with an embodiment of the present invention;

[0055] **FIG. 40** is a simplified diagram of a side view of a dual-unit light guide, in the context of a device having a display and an outer casing, in accordance with an embodiment of the present invention;

[0056] **FIG. 41** is a picture of light guide units, within the context of a device having a PCB and an outer casing, in accordance with an embodiment of the present invention;

[0057] **FIG. 42** is a top view of the light guide units of **FIG. 41**, in accordance with an embodiment of the present invention;

[0095] **FIGS. 89** and **90** are simplified illustrations of a lens for refracting light in three directions, having a lens surface with a repetitive pattern of substantially planar two-sided and three-sided recessed cavities, respectively, in accordance with embodiments of the present invention;

[0096] **FIGS. 91** - **93** are simplified illustrations of a touch screen surrounded with alternating emitters and receivers and diagonal wide beams crossing the screen, in accordance with an embodiment of the present invention;

[0097] **FIG. 94** is a simplified graph of light distribution across a diagonal wide beam in a touch screen, in accordance with an embodiment of the present invention;

[0098] **FIG. 95** is a simplified graph of light distribution across three overlapping diagonal wide beams in a touch screen, in accordance with an embodiment of the present invention;

[0099] **FIG. 96** is a simplified graph of touch detection as a finger glides across three overlapping diagonal wide beams in a touch screen, in accordance with an embodiment of the present invention;

[00100] **FIG. 97** is a simplified graph of detection signals from a diagonal wide beam as a fingertip moves across the screen at three different locations, in accordance with an embodiment of the present invention;

[00101] **FIG. 98** is a simplified illustration of a first embodiment for a touch screen surrounded with alternating emitters and receivers, whereby diagonal and orthogonal wide beams crossing the screen are detected by one receiver, in accordance with an embodiment of the present invention;

[00102] **FIG. 99** is a simplified illustration of a second embodiment for a touch screen surrounded with alternating emitters and receivers, whereby diagonal and orthogonal wide beams crossing the screen are detected by one receiver, in accordance with an embodiment of the present invention;

[00129] **FIG. 131** is a simplified diagram showing a stylus and a mirror image of the stylus, moved closer to the bottom of a touch area vis-à-vis **FIG. 129**, in accordance with an embodiment of the present invention;

[00130] **FIG. 132** is a simplified diagram showing a stylus and a mirror image of the stylus, separated from one another, in accordance with an embodiment of the present invention;

[00131] **FIG. 133** is a simplified flowchart of a method for determining a three-dimensional location of a pointer, in accordance with an embodiment of the present invention;

[00132] **FIG. 134** is a simplified diagram of a touch area that displays six touch icons, used for determining a camera orientation, in accordance with an embodiment of the present invention;

[00133] **FIGS. 135** and **136** are illustrations of opposing rows of emitter and receiver lenses in a touch screen system, in accordance with an embodiment of the present invention;

[00134] **FIG. 137** is a simplified illustration of a technique for determining a touch location, by a plurality of emitter-receiver pairs in a touch screen system, in accordance with an embodiment of the present invention;

[00135] **FIG. 138** is an illustration of a light guide frame for the configuration of **FIGS. 135** and **136**, in accordance with an embodiment of the present invention;

[00136] **FIG. 139** is a simplified flowchart of a method for touch detection for a light-based touch screen, in accordance with an embodiment of the present invention;

[00137] **FIGS. 140** – **142** are illustrations of a rotation gesture, whereby a user places two fingers on the screen and rotates them around an axis;

[00212] Shown in **FIG. 26** is a graph of detected light intensity. Total detected light corresponds to a shaded area under the graph. An object touching the screen blocks a portion of this light. If the object touching the screen moves across the wide beam, from left to right, the amount of blocked light increases, and correspondingly the total detected light decreases, as the object progresses from the left edge of the beam to the center of the beam. Similarly, the amount of blocked light decreases, and correspondingly the total detected light increases, as the object progresses from the center of the beam to the right edge of the beam.

[00213] It is noted that the detected light intensities at the edges of the light beam are strictly positive, thus ensuring that a touch at these edges is detected.

[00214] Reference is made to **FIG. 27**, which is a simplified diagram of a wide-beam touch screen, showing intensity distributions of overlapping light signals from two emitters, in accordance with an embodiment of the present invention. **FIG. 27** shows light detected from emitters **201** and **202**. A touch point **980** on display **636** blocks light from these emitters differently. Area **973** indicates attenuation of light from emitter **201** by touch point **980**, and the union of areas **973** and **974** corresponds to the attenuation of light from emitter **202** by point **980**. By comparing the light attenuation of the two emitter-receiver pairs, **201**-**302** and **202**-**302**, a precise touch coordinate is determined.

[00215] Reference is made to **FIG. 28**, which is a simplified diagram of a wide-beam touch screen, showing intensity distributions of two sets of overlapping light signals from one emitter, in accordance with an embodiment of the present invention. As shown in **FIG. 28**, touch point **980** is inside the area detected by emitter-receiver pair **201**-**301** and emitter-receiver pair **201**-**302**. The attenuation of the light signal at receiver **302**, depicted as area **976**, is greater than the attenuation at

an upper portion **463** and a lower portion **464**. The micro-lenses are located at an upper surface **466** of lower portion **464**. As such, the micro-lenses are not embedded in the collimating lens portion of light guide **464**.

[00238] In configuration no. 2, the curved shape of the collimating lens necessitated a fan/feather pattern for the micro-lenses etched thereon. In distinction, in configuration no. 3 the micro-lenses are etched on rectangular surface **466**, and are arranged as parallel rows. Such a parallel arrangement, referred to herein as a "tubular arrangement", is shown in **FIG. 42**. Specifically, a parallel series of micro-lenses **467** is shown along an upper surface of light guide **464** in **FIG. 42**.

[00239] An advantage of configuration no. 3 is that the flat upper surface of the light guide may be molded as nearly parallel with the screen surface as possible, since the mold is one flat surface that lifts off the top of light guide **464**. Furthermore, in configuration no. 3, only portion **464** of the light guide has a low tolerance requirement for positioning. Portion **463** has a higher tolerance, since its surfaces are not placed at a focal point of an element.

[00240] As shown in **FIG. 40**, light beams **100** emitted by emitter **200** enter light guide unit **464** at surface **465**, are reflected by reflective surface **451** through surface **466**, and into light guide unit **463**. Inside light guide unit **463**, light beams **100** are reflected by surface **452**, and exit through surface **453** over display **637**.

[00241] **FIG. 40** indicates that the height, **H3**, added by the light guide over display **637** comprises the sum of the height, **H1**, of internal reflective surface **452**, and the height, **H2**, of the thickness of outer casing **827**.

[00242] Reference is made to **FIG. 41**, which is a picture of light guide units **463** and **464**, within the content of a device having a PCB **700** and

[00261] It is noted that placement of emitters and receivers underneath a device screen, and placement of a collimating reflective element opposite each emitter or receiver, imposes restrictions on the thickness of the device. A first restriction is that the thickness of the device be at least the sum of the screen thickness and the emitter or receiver thickness. A second restriction is that in order to properly collimate light that is reflected upward above the screen, the reflective element opposite the emitter or receiver be curved into a convex "smile" shape, as shown inter alia in **FIGS. 37** and **38**. The convex shape adds to the total thickness of the device.

[00262] Designers of tablets and e-book readers strive to achieve as slim a form factor as possible. As such, according to an embodiment of the present invention, the receivers and collimating lenses are placed inside a border surrounding the screen, instead of being placed underneath the screen. This is particularly feasible for tablets and e-book readers that provide a non-screen border area for holding the device.

[00263] Reference is made to **FIG. 49**, which is a simplified diagram of a touch screen device held by a user, in accordance with an embodiment of the present invention. Shown in **FIG. 49** is a device **826** with a touch screen **800** surrounded by a frame **849** held by hands **930**.

[00264] Reference is made to **FIG. 50**, which is a simplified diagram of a touch screen with wide light beams covering the screen, in accordance with an embodiment of the present invention. **FIG. 50** shows a top view and a side view of a touch system with a touch screen **800**, in the context of an electronic device such as a tablet or an e-book reader. **FIG. 50** also shows emitters **200** and receivers **300**, each coupled with a pair of lenses **550** and **551**, separated by an air gap **555**, for collimating light. The side view shows a device casing **827** and a frame **849** surrounding touch screen **800**. Frame **849** provides a grip for a user to

in the upper portion of **FIG. 67** shows three detection signals of a fingertip as it traverses the three paths **925** – **927**, labeled in the graph legend as LED edge, Midscreen and PD edge, respectively. The three detection signals in the graph are substantially overlapping. As such, the signal is uniformly detected along its depth, and the signal varies as a function of the touch along only one axis of the screen. Thus determining a touch location along a first axis is independent of the detection signal along a second axis. Moreover, the intensity of the signal is uniform along the second axis, making the signal robust.

Supporting Various Screen Sizes

[00296] Some embodiments of Configuration no. 5 include optical elements with alternating facets that are focused on two neighboring light emitting or receiving elements. When such an optical element is separate from the light emitters or receivers, the emitters or receivers are generally spaced at a particular pitch. When such an optical element is formed as a rigid module together with an emitter or a receiver, the embedded emitter or receiver is precisely positioned with respect to the reflective facets. The facets aimed at a neighboring module, are aimed in accordance with the embedded emitter or receiver in the neighboring module that is similarly situated in its module. Such positioning potentially restricts the size of a screen to integral multiples of the pitch. E.g., with a pitch of 10 mm between emitters, the screen dimensions must be integral multiples of 10 mm. Embodiments of the present invention are able to overcome this restriction, as described in what follows.

[00297] Reference is made to **FIG. 68**, which is a simplified diagram of four optical elements and four neighboring emitters, in accordance with an embodiment of the present invention. Shown in **FIG. 68** are four

overlapping wide beams on the second axis set, such that touch detection on the second axis set is also precise.

[00307] A dual-unit light guide is described hereinabove with reference to **FIGS. 41** and **42**. As described there, the lower portion **464** of the light guide contains reflective facets or lenses that are focused on the emitters and receivers, and the upper portion **463** includes a reflective surface and lenses that do not require precision placement vis-à-vis the emitters and receivers. In Configuration No. 5, the alternating reflective or refractive facets form part of the lower portion. A three-sided refractive cavity for distributing light beams in three directions is formed as part of the upper portion. In Configuration No. 5, use of micro-lenses **467** is not required. Alternatively, the alternating facets are formed in transparent plastic modules that include an emitter or receiver, as described hereinbelow with reference to **FIG. 105**. An arrangement of these modules replaces lower portion **464**, and upper portion **463** remains.

[00308] Reference is made to **FIG. 82**, which is a simplified illustration of a touch screen with light beams directed along four axes, in accordance with an embodiment of the present invention. Shown in **FIG. 82** is a row of light emitters **200** along the top edge of a screen **800**, and a row of light receivers **300** along the bottom edge of screen **800**. The left and right edges of screen **800** include opposing rows of combined emitter-receiver elements **230**. Elements **230** act as emitters and as receivers. In an embodiment of the present invention, an emitter and a receiver are combined in a single unit, such as the reflective and transmissive sensor manufactured by VISHAY® Corporation of Malvern, PA. In another embodiment of the present invention, an LED is used for both light emission and detection. An integrated circuit that both emits and detects light using an LED and a current limiting resistor, is described in Dietz, P.H., Yerazunis, W.S. and Leigh, D.L., "Very low cost sensing and

communication using bidirectional LEDs", International conference on Ubiquitous Computing (UbiComp), October, 2003.

[00309] Reference is made to **FIG. 83**, which is a simplified illustration of an alternate configuration of light emitters and light receivers with two grid orientations, in accordance with an embodiment of the present invention. Shown in **FIG. 83** are light emitters **200** in an alternating pattern with light receivers **300** around a screen perimeter. Light emitted by each emitter is detected by two receivers at an opposite screen edge, the two receivers being separated by an emitter therebetween.

[00310] In order that the light from an emitter arrive at the outer edges of two opposite receivers, the wide beams emitted from each emitter must span a distance of three optical lenses. This is in contrast to the configuration described above with shift-aligned emitters and receivers, where the two receivers that detect light from a common emitter are positioned adjacent one another, and thus the wide beams emitted from each emitter need only span a distance of two optical lenses.

[00311] Reference is made to **FIG. 84**, which is a simplified illustration of a configuration of alternating light emitters and light receivers, in accordance with an embodiment of the present invention. As shown in **FIG. 84**, emitter **201** is situated between receivers **303** and **304** along the bottom screen edge, and emitter **202** is situated between receivers **301** and **302** along the top screen edge. Light from emitter **201** is detected by receivers **301** and **302**, and light from emitter **202** is detected by receivers **303** and **304**.

[00312] Reference is made to **FIG. 85**, which is a simplified illustration of two wide light beams from an emitter being detected by two receivers, in accordance with an embodiment of the present invention. Shown in **FIG. 85** are two wide beams from emitter **201** that exit lens **440** and arrive at

screen, and a second pair of light beams emitted from emitter **200** to receivers **304** and **305** along the adjacent left edge of the display screen. A third pair of light beams (not shown) is emitted from emitter **200** to receivers at the adjacent right edge of the display screen. The second and third pairs of light beams are each oriented at an angle of approximately 45° relative to the first pair of light beams.

[00317] Also shown in **FIG. 88** is a lens **439**, used to refract light from emitter **200** to lenses **442** and **443**, which are oriented at approximately 45° to the left of lens **439**. In an embodiment of the present invention, lens **439** is made of a plastic material, which has an index of refraction on the order of 1.4 – 1.6. As such, an angle of incidence of approximately 84° is required in order for the light to be refracted at an angle of 45°. However, for such a large angle of incidence, the amount of light lost due to internal reflection is large. In order to improve throughput, two air/plastic interfaces are used to achieve an angle of refraction of approximately 45°, as described hereinabove.

Tri-Directional Micro-Lenses

[00318] Reference is made to **FIGS. 89** and **90**, which are simplified illustrations of a lens for refracting light in three directions, having a lens surface with a repetitive pattern of substantially planar two-sided and three-sided recessed cavities, respectively, in accordance with embodiments of the present invention. The flat surface opposite the emitter or receiver is distal to the emitter or receiver in **FIG. 89** forming a three-sided cavity, and is proximal thereto in **FIG. 90** separating two two-sided cavities.

[00319] Such three-sided lenses are used in several embodiments. In a first embodiment, the lens is used without an additional optical component with alternating facets for interleaving neighboring beams. In

this embodiment, wide beams cover the screen but do not necessarily overlap to provide two or more detection signals for interpolation. A typical use case for this embodiment is finger input, but not stylus input. The tri-directional lens enables detection on four different axes, to eliminate ambiguity and ghosting in multi-touch cases. The tri-directional lens also provides additional touch location information; namely, four axes instead of two, and the additional information increases the precision of the touch location, even for a single touch.

[00320] In a second embodiment, the lens is used with an additional optical component with alternating facets for interleaving neighboring beams, or with an alternative arrangement providing overlapping detection signals. In this embodiment, overlapping wide beams provide two or more detection signals for interpolation. Typical use cases for this embodiment are finger and stylus input. The tri-directional lenses and the interleaving facets may be formed in two distinct components. The interleaving facets component is positioned closer to its emitter or receiver than the tri-directional component, since the tolerance for imprecise placement of the interleaving facets component is low, whereas the tolerance for imprecise placement of the tri-directional lens component is high. Alternatively, the tri-directional lenses and the interleaving facets may be formed in a single rigid component. For example, a diffractive grating interleaves signals from two sources and also splits the beams in three directions.

[00321] Shown in **FIG. 89** is a lens **527** with a pattern of micro-lenses **528** on its bottom surface. The micro-lens pattern shown in **FIG. 89** has three substantially planar sides, each side refracting light in a different direction. The pattern of micro-lenses **528** forms a saw-tooth repetitive pattern along the bottom edge of the upper section of the lens. The three

emitters and receivers, whereby diagonal and orthogonal wide beams crossing the screen are detected by one receiver, in accordance with an embodiment of the present invention. **FIG. 99** shows an embodiment with different numbers of elements positioned along adjacent screen edges. Three beams **167** – **169** are shown for one receiver **300**; namely, one directed to an opposite emitter **200**, and the other two directed at substantially 45° angles to emitters **201** and **202**, one of which is on an opposite edge and another of which is positioned on an adjacent edge. These diagonal beams generate two axes that are perpendicular to one another.

Palm Rejection

[00333] When a user rests his hypothenar muscles, located on the side of his palm beneath his little finger, on a touch screen when writing with a stylus, ghosting generally occurs. This part of the palm blocks a large area of the touch screen, and often blocks a series of light beams along the screen's vertical axis, thereby hiding the stylus' touch position along the vertical axis.

[00334] Reference is made to **FIG. 100**, which is a simplified illustration of a user writing on a prior art touch screen with a stylus. Shown in **FIG. 100** is a hand **930** holding a stylus **931**, and drawing a line **932** on a touch screen **800**. The user's palm is resting on screen **800**, blocking two series of light beams depicted as dotted lines; namely, a series **113** along the screen's horizontal axis, and a series **114** along the screen's vertical axis. The location of the stylus tip on the vertical axis is within series **114**. Beam **115** does detect the tip of the stylus, but it only provides a horizontal axis location.

[00335] Embodiments of the present invention overcome the drawback illustrated in **FIG. 100**. Reference is made to **FIG. 101**, which is a

simplified illustration of light beams detecting location of a stylus when a user's palm rests on a touch screen, in accordance with an embodiment of the present invention. By providing two sets of detection axes; namely, an orthogonal set and a diagonal set, a two-dimensional location of a stylus is determined. **FIG. 101** shows that beams **115** and **116** uniquely detect a stylus. Since each detection comprises overlapping wide beams whose signals are interpolated, as described hereinabove, the stylus position is determined with high precision, despite beams **115** and **116** not being perpendicular to one another. When the bottom of the user's palm does not block diagonal beam **117**, then beam **117** also detects the stylus location separately from the palm. In such case, beams **116** and **117** are used to detect the stylus location. Alternatively, all three detecting beams **115** – **117** may be used.

[00336] Another challenge with touch screens that support both stylus and finger input arises when a user places his palm on the screen in order to write with a stylus, and the initial contact between palm and screen is misinterpreted as being a tap on an icon, in response to which the device launches an unintended application whose icon was tapped. Once the palm is resting on the screen, an area of contact is used to reject the palm touch as a screen tap. Nevertheless, the initial contact may cover a small surface area of the screen and thus be misinterpreted as a screen tap.

[00337] According to embodiments of the present invention, light beams above the screen are used to detect a palm as it approaches the screen. In one embodiment this is accomplished by projecting light from each emitter at several heights above the screen, as illustrated in **FIG. 14** showing an approaching finger **900** blocking beam **101** but not beam **102**. In another embodiment, multiple layers of emitters and receivers are arranged around the screen, and used to detect objects at different

heights above the screen, as described herein with reference to a user input gesture cavity and, in particular, with the cavity frame folded on top of the screen.

[00338] Reference is made to **FIG. 102**, which is a simplified illustration of a frame surrounding a touch screen, in accordance with an embodiment of the present invention. **FIG. 102** shows a frame **849** surrounding a touch screen, similar to frame **849** of **FIG. 49**. Two stacked rows of emitters **200** and receivers **300** are provided in the frame. When assembled together with a display in an electronic device, the stacked rows of emitters and receivers are raised above the display surface and provide object detection at two heights, namely, on the screen by the lower row of emitters and receivers, and above the screen by the upper row of emitters and receivers. When a user's palm begins to touch the screen, a large palm area is detected hovering above the screen. This enables the device to determine that a palm is approaching the screen, and that any screen tap is inadvertent.

[00339] In another embodiment of the present invention, only one row of emitters and receivers is provided for detecting a palm hovering above the screen, and touches on the screen are detected by conventional detection systems imposed on the display including inter alia capacitive or resistive touch sensors.

[00340] According to an embodiment of the present invention, a user interface disables screen taps for activating functions when a palm is detected. When the palm is detected, the user interface is configured to launch applications in response to a user touching an icon and gliding his finger away from the touched location along the touch screen. I.e., two sets of user interface gestures are provided. When no palm is detected, the first set of gestures is used. With the first set of gestures, a tap on an icon activates an application or function associated with the icon.

placing an emitter or receiver in exactly the correct position vis-à-vis the reflective or refractive facets, are handled during manufacture of the modular blocks, thus removing the burden of high precision assembly from a device manufacturer.

[00346] Simplified manufacturing is achieved by integrating optical elements and electronic components into a single unit. As such, complex surfaces may be gathered into one component, thereby reducing the need for high precision during assembly.

[00347] Reference is made to **FIG. 105**, which is an illustration of optical components made of plastic material that is transparent to infrared light, in accordance with an embodiment of the present invention. Shown in **FIG. 105** is an optical component **488** that includes a forward-facing LED **236**, and electronics to handle the LED signal. Optical component **488** is connected to electrical pads **760** and **761**. Optical component **488** is used to transmit collimated light beams from two emitters; namely, emitter **235** and emitter **236**. Emitter **235** is included in a neighboring optical component **489**. In the alternating emitter-receiver embodiment described hereinabove, optical component **488** is used to transmit collimated light beams for one emitter and one receiver. E.g., neighboring module **489** includes a receiver instead of emitter **235**.

[00348] Light beams from emitter **235** exit optical component **489** through a tight-fitting surface **491**, and enter optical component **488** through a tight-fitting surface **490**. **FIG. 105** shows non-parallel light beams from emitters **235** and **236** hitting alternating facets on a wave-like multi-faceted reflective surface **493**. Components **488** and **489** are substantially identical, and fit together. A device manufacturer can thus use these components as building blocks to create a touch screen, by arranging a series of these building blocks in a row along each edge of the display. Typical arrangements are (a) two adjacent display edges are

before exiting optical element **497**. Another portion of the non-parallel beams is collimated by a neighboring module, not shown in **FIG. 105**. The beams **100** that exit optical element **497** are directed upwards and are reflected over display **642** by a light guide **498**. In an embodiment of the present invention, three-way refracting cavities are etched, or otherwise formed, on the lower surface of optical element **498** to refract the light beams in three directions in order to provide two coordinate systems for determining a touch location. The light beams **100** enter a light guide **499** on the opposite side of screen **642**, and are reflected below display **642** into optical element **496**. In embodiments supporting the two coordinate systems, the three-way refracting cavities are present on the underside of optical element **499** as well. As described hereinabove, optical element **496** and its neighboring optical element, not shown, focus the incoming light beams on photo diode **394**. In one embodiment of the present invention, the light guides **498** and **499** are constructed as a frame that surrounds display **642**.

[00353] In the touch screen of **FIG. 106**, two types of light beam redirection occur. A first redirection requires multiple facets directed at a single focus point. A second redirection uniformly redirects incoming beams at a 90º angle, or folds incoming light beams into a narrow waist or focus, as described hereinabove with reference to configuration no. 4. In some embodiments, the collimated beams are refracted in three directions, in between the first and second redirections, by refracting cavities.

[00354] The first type of redirection requires that the emitter or receiver be positioned at a specific location relative to the focal point of many facets. As such, the positioning of the emitter or receiver and its reflective surfaces, is sensitive to variations in placement. Thus the assembly of the emitter or receiver, together with its corresponding

pressure is released, the resilient member returns the screen to its original position within the light guide frame.

[00365] Reference is made to **FIGS. 112** – **115**, which are illustrations of a touch screen **800** that detects occurrence of a hard press, in accordance with an embodiment of the present invention. **FIG. 112** shows touch screen **800** in rest position, screen **800** being supported by resilient supporting members **841** and **842** that create a flex air gap **843**, which are mounted on a printed circuit board **700**. **FIG. 112** shows two light guides, **518** and **519**, one on either side of screen **800**, for directing light **100** from an emitter **200** over screen **800** to a receiver **300**. Only a small upper portion of each light guide **518** and **519** extends above screen **800**. Receiver **300** communicates detected light intensities to a calculating unit (not shown).

[00366] **FIG. 113** shows a finger **900** pressing down on the screen, causing members **841** and **842** to compress and to narrow flex air gap **843**. As a result, a larger portion of light guides **518** and **519** is exposed above screen **800**, thus allowing (a) more light **100** from emitter **200** to traverse screen **800** and be detected by receiver **300**, and (b) more ambient light **101** to reach receiver **300**. In various embodiments, either or both of these increases in detected light are used to indicate a hard press. In other embodiments, the amount of downward pressure applied is determined based on the amount of additional detected light, thus enabling discrimination between more hard and less hard touches.

[00367] In some embodiments, the light guide frame includes protruding lips **520** and **521**, shown in **FIG. 114**, that extend over the edges of screen **800**, to counter balance the upward force of resilient members **841** and **842** when no downward pressure is applied to screen **800**. Resilient members **841** and **842** may comprise inter alia a flexible

screen surface and of a pointer, or a plurality of pointers, touching the screen surface. In some embodiments of the present invention, the screen pixels include light sensors, each of which generates a pixel of an image of the underside of the screen glass, the image being referred to herein as the "screen glass image".

[00371] As described hereinbelow, methods according to embodiments of the present invention determine precise touch coordinates using spatial and temporal filters. Application of these methods to configuration no. 8 yields sub-pixel precision for touch coordinates.

[00372] Pixels in the screen glass image at the center of a touch location are generally completely blocked; i.e., the level of light detected at each such pixel is below a designated threshold, indicating that the pixel is occluded by a touch object. Pixels in the screen glass image along the edges of a touch location are generally only partially blocked; i.e., the level of light detected at each such pixel is above the designated threshold, indicating that the pixel is only partially occluded by the touch object.

[00373] A calculating unit that receives the screen glass image data assigns a relative weight to each pixel coordinate, based on a touch detection intensity associated with that pixel, as indicated by the pixel's value. The calculating unit further interpolates the pixel coordinates, based on their associated weights, to determine a touch coordinate. In some embodiments, the calculating unit calculates a touch area having a perimeter, wherein the edges of the touch area are calculated on a sub-pixel level based on the above interpolations. The temporal filters described hereinbelow are applied inter alia when a series of connected touches is concatenated into a glide movement over a time duration.

[00374] Reference is made to **FIG. 118**, which is a simplified diagram of an image sensor **844** positioned beneath a screen glass display **635**, to

methods are of advantage for pen and stylus support, which have fine touch points, and provide highly accurate touch location determination for single-finger and multi-finger touches as well.

[00395] Reference is made to **FIGS. 135** and **136**, which are illustrations of opposing rows of emitter lenses and receiver lenses in a touch screen system, in accordance with an embodiment of the present invention. Positioned behind each emitter and receiver lens is a corresponding respective light emitter **200** or light receiver **300**. As shown in **FIG. 135**, each emitter **200** is positioned opposite two receivers **300** that detect light beams emitted by the emitter. Similarly, each receiver **300** is positioned opposite two emitters **200**, and receives light beams emitted from both emitters.

[00396] **FIG. 135** shows **(A)** a single, full beam **173** from an emitter **200** that spans two receivers **300**; **(B)** the portion of the full beam, designated **174**, detected by the left one of the two receivers **300**; **(C)** the portion of the full beam, designated **175**, detected by the right one of the two receivers **300**; **(D)** multiple beams **176**, for multiple emitters **200**, covering the touch screen, and **(E)** multiple beams **177**, for multiple emitters **200**, covering the touch screen. Generally, each emitter **200** is activated alone. Precision touch detection is described hereinbelow, wherein a touch point is detected by multiple beams. It will be appreciated from **(D)** and **(E)** that points on the screen are detected by at least one beam **176** and one beam **177**.

[00397] To conserve power, when the touch screen is idle only one set of beams, namely, beams **176** or beams **177**, is scanned in a scanning sweep, and only for the axis with the smallest number of emitters **200**. The scanning toggles between beams **176** and beams **177**, and thus two scanning sweeps along the axis activate every emitter-receiver pair along the axis. The other axis, with the larger number of emitters, is only

[00437] In embodiments with optical elements with three-way lenses that create light beams along two sets of axes, similar calculations are performed on the diagonal detection beams to determine locations on the second axis system. As described hereinabove, touch objects typically block a larger portion of the diagonal signals than of the orthogonal signals.

[00438] The spatial and temporal filters described hereinabove with reference to shift-aligned emitter-receiver arrangements are applied in aligned emitter-receiver arrangements as well.

Calibration of Touch Screen Components

[00439] Reference is made to **FIG. 153**, which is a simplified flowchart of a method of calibration and touch detection for a light-based touch screen, in accordance with an embodiment of the present invention. In general, each emitter/receiver pair signal differs significantly from signals of other pairs, due to mechanical and component tolerances. Calibration of individual emitters and receivers is performed to ensure that all signal levels are within a pre-designated range that has an acceptable signal-to-noise ratio.

[00440] In accordance with an embodiment of the present invention, calibration is performed by individually setting (i) pulse durations, and (ii) pulse strengths, namely, emitter currents. For reasons of power consumption, a large current and a short pulse duration is preferred. When a signal is below the pre-designated range, pulse duration and/or pulse strength is increased. When a signal is above the pre-designated range, pulse duration and/or pulse strength is decreased.

[00441] As shown in **FIG. 153**, calibration (operation **1051**) is performed at boot up (operation **1050**), and is performed when a signal is detected outside the pre-designated range (operation **1055**).

expected noise level, a new measurement is performed, and both results are compared to the previous result, to get a best match. If the final value is within the expected noise level, a counter is incremented. Otherwise, the counter is cleared. The counter is subsequently used to determine if a signal is stable or unstable, when updating reference values and when recalibrating.

[00445] After each complete scan, signals are normalized with their respective reference values. If the normalized signals are not below a touch threshold, then a check is made if a recalibration or an update of reference values is necessary. If a normalized signal is below the touch threshold, then a touch is detected (operation **1053**).

[00446] To reduce risk of a false touch detection, due to a sudden disturbance, the threshold for detecting an initial point of contact with the screen, such as when a finger first touches the screen, is stricter than the threshold for detecting movement of a point of contact, such as gliding of a finger along the screen while touching the screen. I.e., a higher signal difference is required to detect an initial touch, vis-à-vis the difference required to detect movement of an object along the screen surface. Furthermore, an initial contact is processed as pending until a rescan verifies that the touch is valid and that the location of the touch remains at approximately the same position.

[00447] To determine the size of a touch object (operation **1057**), the range of blocked signals and their amplitudes are measured. For large objects, there is a wait for detecting an initial point of contact with the screen, until the touch has settled, since the touch of a large object is generally detected when the object is near the screen before it has actually touched the screen. Additionally, when a large object approaches the screen in a direction not perpendicular to the touch area, the subsequent location moves slightly from a first contact location.

application U.S. Serial No. 12/371,609 entitled LIGHT-BASED TOUCH SCREEN filed on February 15, 2009, the contents of which are hereby incorporated by reference. Inter alia, reference is made to paragraphs [0073], paragraphs [0087] – [0091] and FIG. 11 of this application as published in U.S. Publication No. 2009/0189878 A1 on July 30, 2009.

[00467] Emitter driver circuitry **740** includes circuitry **742** for configuring individual photoemitter pulse durations and pulse currents for each emitter-detector pair via a programmable current source. Circuitry **742** is described in applicants' co-pending patent application U.S. Serial No. 13/052,511 entitled LIGHT-BASED TOUCH SCREEN WITH SHIFT-ALIGNED EMITTER AND RECEIVER LENSES filed on March 21, 2011, the contents of which are hereby incorporated by reference. Inter alia, reference is made to paragraphs [00343] – [00355] and FIGS. 99 – 101 of this application as published in U.S. Publication No. 2011/0163998 on July 7, 2011.

[00468] Chip package **731** includes detector driver circuitry **750** for selectively activating a plurality of photo detectors **300** that are outside of the chip package, and signal conducting pins **733** for connecting photo detectors **300** to detector driver circuitry **750**. Detector driver circuitry **750** includes circuitry **755** for filtering current received from photo detectors **300** by performing a continuous feedback bandpass filter, and circuitry **756** for digitizing the bandpass filtered current. Circuitry **755** is described inter alia at paragraphs [0076], paragraphs [0107] – [0163] and FIGS. 14 – 23B of the above-referenced U.S. Publication No. 2009/0189878 A1. Chip package **731** also includes detector signal processing circuitry **753** for generating detection signals representing measured amounts of light detected on photo detectors **300**.

[00469] Chip package **731** further includes I/O pins **736** for communicating with a host processor **772**. Chip package **731** further includes controller circuitry **759** for controlling emitter driver circuitry

TABLE IV: LED multiplex mapping to LED_ROW and LED_COL pins		
LED	**LED_ROW pin enabled**	**LED_COL pin enabled**
1	1	1
2	2	1
3	3	1
4	4	1
5	5	1
6	6	1
7	1	2
8	2	2
9	3	2
10	4	2
11	5	2
12	6	2
13	1	3
14	2	3
15	3	3
16	4	3
17	5	3
18	6	3
19	1	4
20	2	4
21	3	4
22	4	4
23	5	4
24	6	4
25	1	5
26	2	5

[00474] Advantages of having a dedicated controller for emitters and receivers in a light-based touch screen are power savings and performance. In conventional systems, a conventional chip, such as the MSP430 chip manufactured by TEXAS INSTRUMENTS® of Dallas, TX, controls emitters and receivers. Regarding power savings conventional chips do not provide access to all of the power consuming chip elements. Moreover, with conventional chips it is not possible to power on and off external elements in sync with the emitters. For example, with a conventional chip the amplifier unit connected to the receivers and the analog-to-digital convertor (ADC) for digitizing receiver light detection current, cannot be turned on and off in sync with activation of the emitters. In conventional systems, these elements are left powered on throughout an entire scan sequence. In distinction, the dedicated

9. When placing two fingers on the screen, there is an inherent delay between the first and second touches. Completing multiple scan sequences in a very short time allows the system to determine the first touch, which is unambiguous. Then, assuming that the first touch is maintained when the second touch is detected, the second touch location is easily resolved. E.g., if it is determined that one touch is in the upper left corner and the touch detection pattern is as shown in **FIGS. 8** and **9**, then the second touch location must be at the lower right corner of the screen.

[00485] Thus it will be appreciated by those skilled in the art that a dedicated controller in accordance with the present invention is power-efficient, highly accurate and enables high sampling rates. The host configures the controller for low power, corresponding to 100 Hz or less, or for high frequency scanning, such as 500 Hz – 1000 Hz.

[00486] Determination of which configuration is appropriate is based inter alia on the area of the touch screen covered by a touch pointer, since jitter and lag are less prominent for a touch covering a relative large area, such as a finger touch, than for a touch covering a relatively small area, such as a stylus touch. Based on the area covered by the pointer, as determined by the size of the shadowed area of light-based touch screen signals, the host determines whether a finger or a stylus is being used, and configures an appropriate scan rate based on the trade-off between power and accuracy.

[00487] In accordance with an embodiment of the present invention, the dedicated controller includes scan range registers for selectively activating LEDs, and current control and pulse duration registers for specifying an amount of current and a duration, for each activation. The scan range registers designate a first LED and a first PD to be activated along each screen edge, the number of LEDs to be activated along each

CLAIMS

1. An optical touch detection system, comprising:

a housing;

a surface mounted in said housing;

light emitters mounted in said housing;

light receivers mounted in said housing;

a set of first optical elements positioned along one edge of said surface, each optical element comprising a concatenated plurality of first segments, not all having the same length, each first segment being paired with a respective one of said light emitters, each first segment comprising an undulating series of pairs of reflective or refractive facets, wherein a first facet in each pair is oriented so as to collimate light emitted from a first light emitter associated with that segment and a second facet in each pair is oriented so as to collimate light emitted from a second light emitter associated with that segment, and wherein the first light emitter associated with that segment is the light emitter paired with that segment and the second light emitter associated with that segment is the light emitter paired with a neighboring segment;

a set of second optical elements positioned along an edge of said surface opposite the one edge, comprising a concatenated plurality of like second segments, not all having the same length, wherein each second segment is paired with a respective one of said light receivers, each second segment comprising an undulating series of pairs of reflective or refractive facets, wherein a first facet in each pair directs collimated light to a first light receiver associated with that segment and a second facet in each pair directs collimated light to a second light receiver associated with that segment, and wherein the first light receiver associated with that segment is the light receiver paired with that segment and the second

light receiver associated with that segment is the light receiver paired with a neighboring segment; and

a calculating unit, mounted in said housing and connected to said light receivers, for determining a location of a pointer touching said surface, based on amounts of light emitted from said light emitters that are blocked by the pointer, as determined by outputs of said light receivers.

2. The optical touch detection system of claim 1 wherein, for each of said plurality of segments of said set of first optical elements, the collimated light directed by the first facets of each of the series of facet pairs of the segment at least partially overlaps with the collimated light directed by the second facets, and wherein said calculating unit determines the location of the pointer touching the surface based on outputs of at least three light receivers that receive light emitted by three neighboring light emitters.

3. The optical touch detection system of claim 1, further comprising an additional set of first optical elements, arranged along an edge of said surface adjacent to said one edge, wherein one of the segments of one of said set of first optical elements and one of the segments of one of said additional set of first optical elements are paired with the same emitter.

4. An optical element for a light based touch surface, comprising a concatenated plurality of segments, wherein alternating ones of said segments are respectively paired with alternating light emitters and light receivers, each segment comprising an undulating series of pairs of reflective or refractive facets, wherein a first facet in each pair is oriented so as to collimate light emitted from a light emitter associated with the

segment, and a second facet in each pair is oriented so as to direct collimated light onto a light receiver associated with the segment, and wherein the light receiver associated with the segment is one of the light receivers that neighbor the light emitter associated with the segment.

5. The optical element of claim **4** wherein, for each of said plurality of segments, light emitted from the light emitter associated with the segment is directed by the segment to generate a local spatial light intensity distribution of collimated light beams across an area of the touch surface, wherein a first plurality of the first facets of its series of facet pairs, near the light emitter associated with the segment, comprises facet sizes that decrease as a function of the first facet's distance from the light emitter, and a second plurality of the first facets, further from the light emitter, comprises facet sizes that increase as a function of the first facet's distance from the light emitter, and wherein the local spatial light intensity distribution is substantially linear as a function of spatial position.

6. A modular component for a light based touch surface assembly, comprising:

at least one of said plurality of segments of the optical element of claim **4** and the light emitters and receivers paired therewith in a single unit; and

two oppositely contoured outer edges, to facilitate inter-fitting the modular component with a similar neighboring modular component that contains a segment adjacent to one of the segments comprised in the modular component, by positioning one of the contoured outer edges of the modular component alongside the oppositely contoured outer edge of the neighboring modular component.

7. An optical touch detection system, comprising:

a housing;

a surface mounted in said housing;

a frame, comprising optical elements in accordance with claim **4**, surrounding said surface;

the alternating plurality of light emitters and light receivers paired with the segments in the optical elements of said frame, mounted in said housing; and

a calculating unit mounted in said housing and connected to said light receivers to determine the location of an object on said surface based on amounts of light emitted from said emitters that are blocked by the object, as determined from outputs of said light receivers.

8. The optical touch detection system of claim **7**, further comprising a frame comprising lenses inside said frame of optical elements, each of said lenses comprising a pattern of recessed cavities formed by a repetitive pattern of three substantially planar facets, for refracting collimated light emitted by said emitters in three directions and for directing collimated beams from three directions onto said receivers.

9. The optical touch detection system of claim **8**, wherein said calculating unit determines the locations of at least two objects that are on said surface simultaneously.

10. The optical touch detection system of claim **8**, wherein said calculating unit determines the locations of at least three non-aligned objects that are on said surface simultaneously.

11. The optical touch detection system of claim **8**, wherein said calculating unit determines the locations of at least four non-aligned objects that are on said surface simultaneously.

12. The optical touch detection system of claim **8**, wherein said calculating unit determines the location of a stylus on said surface, the stylus being held by a user, when the user's palm blocks some of the light emitted from said emitters from reaching the stylus.

13. The optical touch detection system of claim **1**, wherein, for each of said plurality of first segments, light emitted from the first light emitter associated with that segment is directed by that segment to generate a first local spatial light intensity distribution of collimated light beams across an area of said surface, and light emitted from the second light emitter associated with that segment is directed by that segment to generate a second local spatial light intensity distribution of collimated light beams across the area of said surface, and wherein the first and second local spatial light intensity distributions are different distributions.

14. The optical touch detection system of claim **13** wherein, for each of said plurality of first segments, a first plurality of the first facets of its series of facet pairs, near the first light emitter associated with that segment, comprises facet sizes that decrease as a function of the first facet's distance from the first light emitter, and a second plurality of the first facets, further from the first light emitter, comprises facet sizes that increase as a function of the first facet's distance from the first light emitter, such that the first local spatial light intensity distribution is substantially linear as a function of spatial position.

15. The optical touch detection system of claim **1**, wherein at least one of said plurality of segments of the first optical elements and the light emitters paired therewith are formed as a modular component comprising two oppositely contoured outer edges, to facilitate inter-fitting the modular component with a similar neighboring modular component that contains a first segment adjacent to one of the first segments comprised in the modular component, by positioning one of the contoured outer edges of the modular component alongside the oppositely contoured outer edge of the neighboring modular component.