US009741184B2

(12) **United States Patent**
**Iyer et al.**

(10) **Patent No.: US 9,741,184 B2**
(45) **Date of Patent: Aug. 22, 2017**

(54) **DOOR HANDLE WITH OPTICAL PROXIMITY SENSORS**

(71) Applicant: **Neonode Inc.**, Santa Clara, CA (US)

(72) Inventors: **Sairam Iyer**, San Jose, CA (US); **Stefan Holmgren**, Sollentuna (SE); **Per Rosengren**, Solna (SE)

(73) Assignee: **Neonode Inc.**, San Jose, CA (US)

( * ) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 250 days.

(21) Appl. No.: **14/555,731**

(22) Filed: **Nov. 28, 2014**

(65) **Prior Publication Data**

US 2015/0248796 A1 Sep. 3, 2015

**Related U.S. Application Data**

(63) Continuation-in-part of application No. 14/312,787, filed on Jun. 24, 2014, now Pat. No. 9,164,625, and (Continued)

(51) **Int. Cl.**
***G05B 19/00*** (2006.01)
***G07C 9/00*** (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ..... ***G07C 9/00007*** (2013.01); ***G06F 1/169*** (2013.01); ***G06F 3/021*** (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC ..... G06F 3/017; G06F 3/038; G06F 1/169
(Continued)

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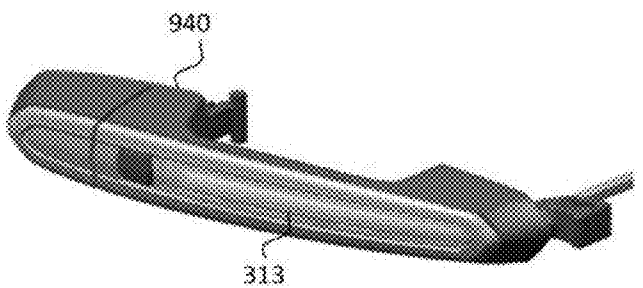
*Primary Examiner* — Vernal Brown
(74) *Attorney, Agent, or Firm* — Soquel Group LLC

(57) **ABSTRACT**

A door handle including light emitters for emitting light out of the handle, light detectors, lenses oriented relative to the emitters and detectors such that for each emitter-detector pair, when a reflective object is located at a target position near the handle, corresponding to that emitter-detector pair, then the light emitted by that emitter passes through one of the lenses and is reflected by the object back through one of the lenses to that detector, a keyless lock that, when activated, scans for a digital key via wireless communication, and a processor operable to synchronously activate emitter-detector pairs, to recognize from the amounts of light received by the activated detectors, and from the target positions corresponding to the activated emitter-detector pairs, that the object is approaching the handle and performing a sweep gesture and, in response thereto, to activate the keyless lock.

**23 Claims, 88 Drawing Sheets**



**Related U.S. Application Data**

a continuation-in-part of application No. 14/311,366, filed on Jun. 23, 2014, now Pat. No. 9,063,614, and a continuation-in-part of application No. 14/140,635, filed on Dec. 26, 2013, now Pat. No. 9,001,087, said application No. 14/140,635 is a continuation of application No. 13/732,456, filed on Jan. 2, 2013, now Pat. No. 8,643,628, said application No. 14/311,366 is a continuation of application No. PCT/US2014/040579, filed on Jun. 3, 2014, said application No. 14/312,787 is a continuation of application No. PCT/US2014/040112, filed on May 30, 2014, said application No. 14/312,787 is a continuation-in-part of application No. 13/775,269, filed on Feb. 25, 2013, now Pat. No. 8,917,239.

(60) Provisional application No. 61/986,341, filed on Apr. 30, 2014, provisional application No. 61/972,435, filed on Mar. 31, 2014, provisional application No. 61/950,868, filed on Mar. 11, 2014, provisional application No. 61/929,992, filed on Jan. 22, 2014, provisional application No. 61/923,775, filed on Jan. 6, 2014, provisional application No. 61/713,546, filed on Oct. 14, 2012, provisional application No. 61/828,713, filed on May 30, 2013, provisional application No. 61/838,296, filed on Jun. 23, 2013, provisional application No. 61/846,089, filed on Jul. 15, 2013.

(51) **Int. Cl.**

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|---|---|
| ***G06F 1/16*** | (2006.01) |
| ***G06F 3/042*** | (2006.01) |
| ***G06F 3/0488*** | (2013.01) |
| ***G06F 3/02*** | (2006.01) |
| ***G06F 3/0354*** | (2013.01) |

(52) **U.S. Cl.**

CPC ..... ***G06F 3/03547*** (2013.01); ***G06F 3/0421*** (2013.01); ***G06F 3/0428*** (2013.01); ***G06F 3/04883*** (2013.01); ***G07C 9/00309*** (2013.01); *G07C 2009/00396* (2013.01); *G07C 2009/00769* (2013.01)

(58) **Field of Classification Search**

USPC ..... 340/5.62

See application file for complete search history.

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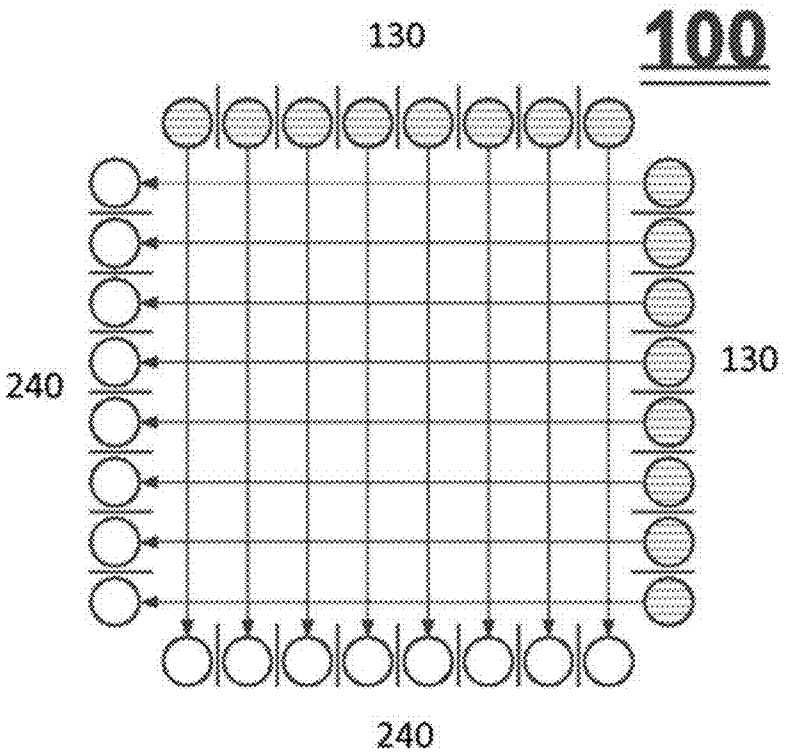


FIG. 1
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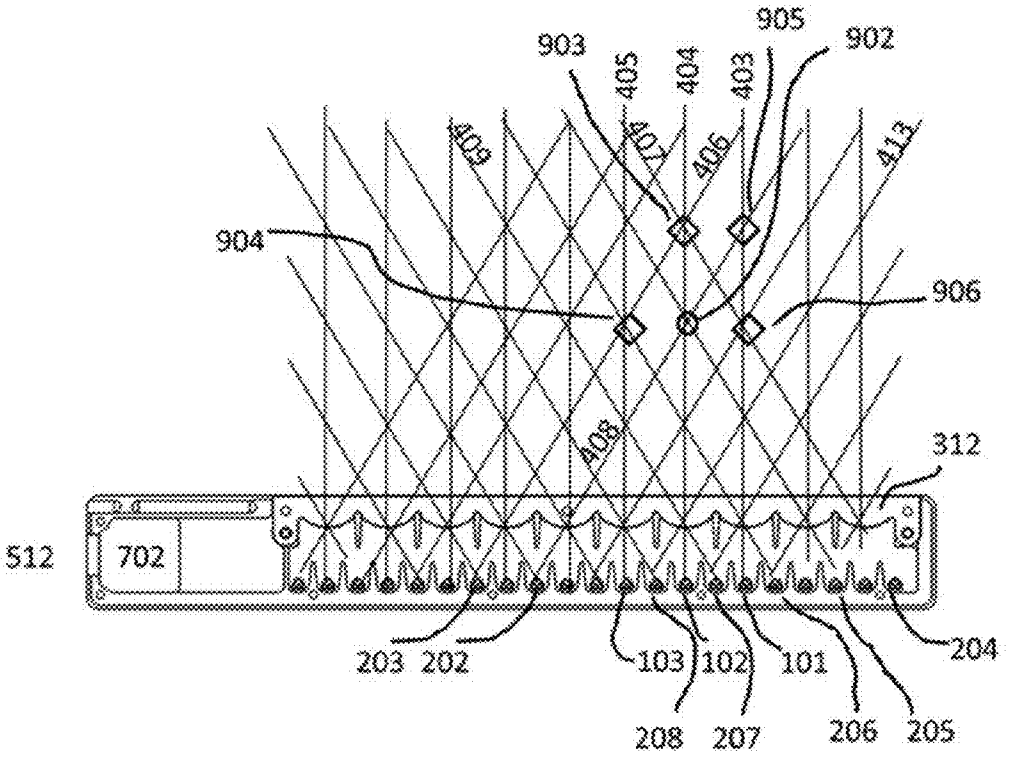
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FIG. 2

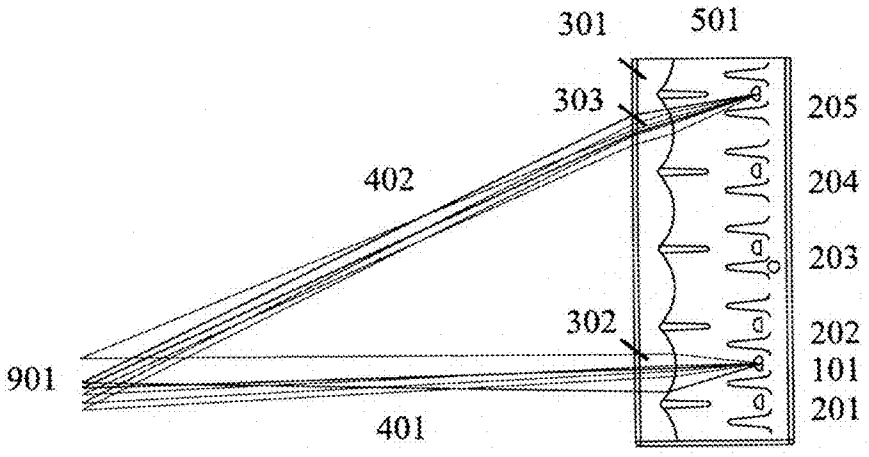
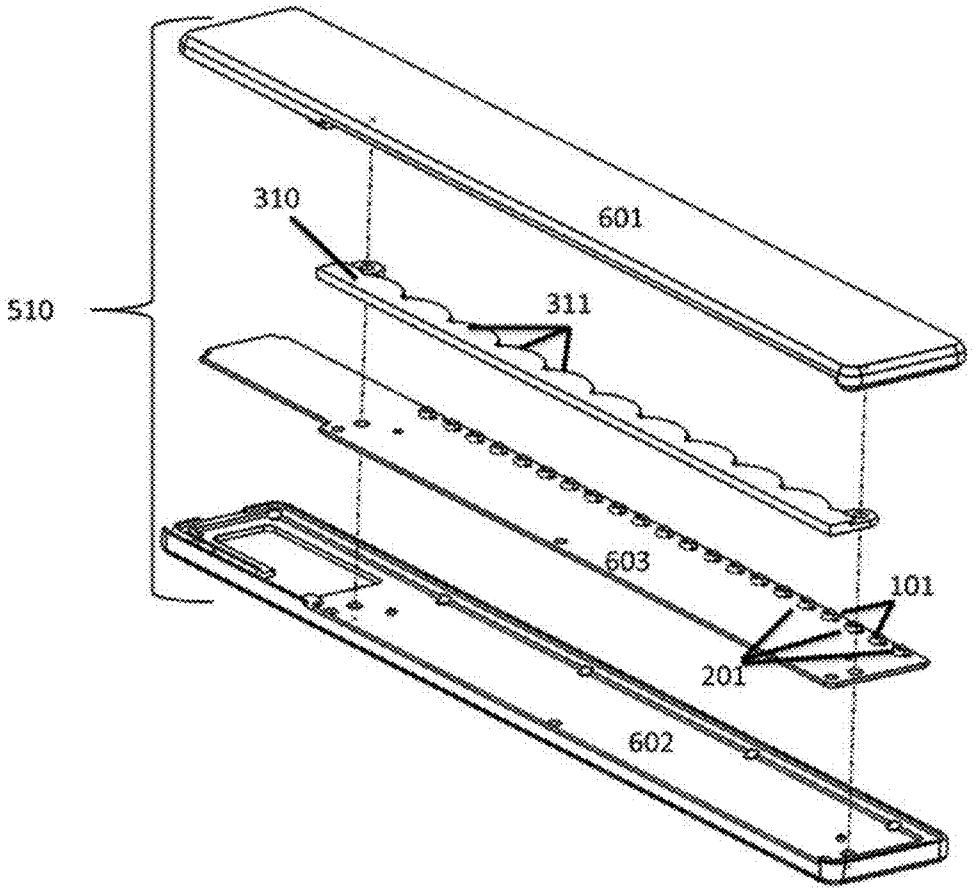



FIG. 3

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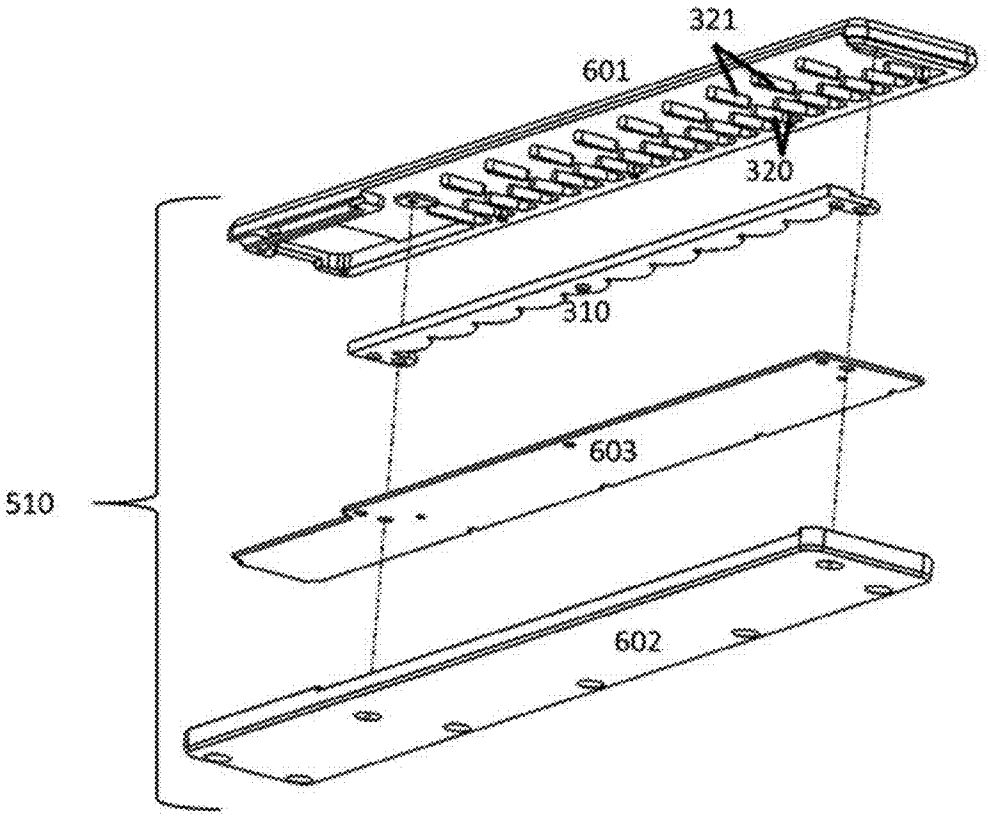


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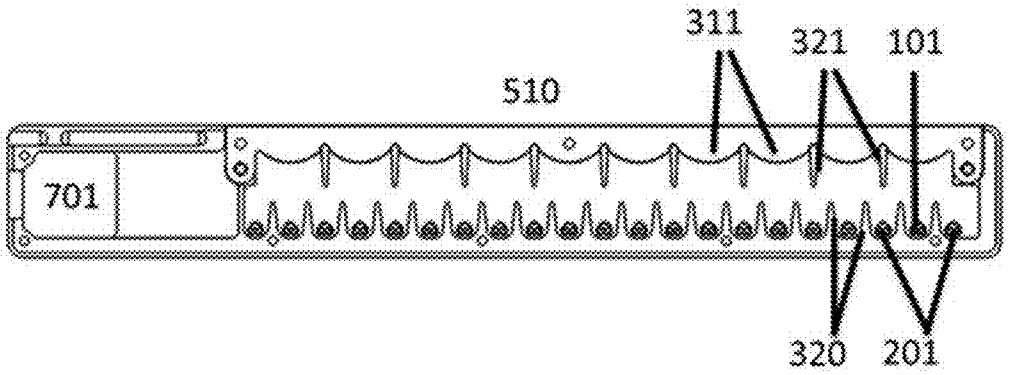


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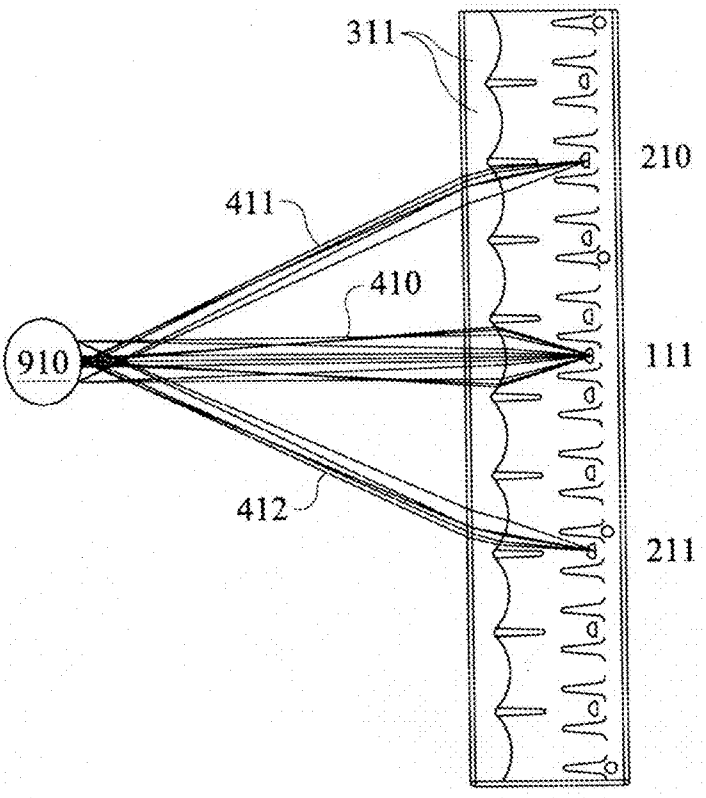


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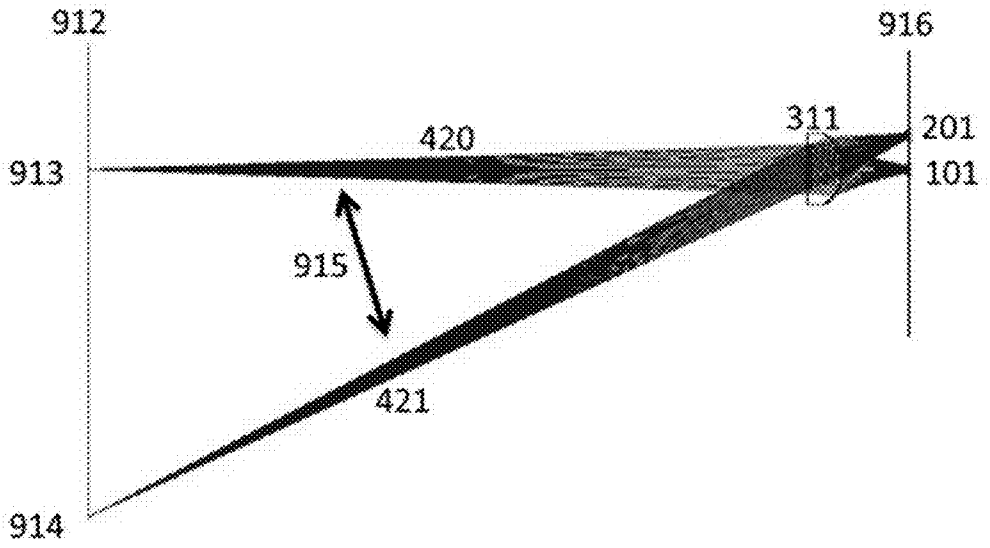


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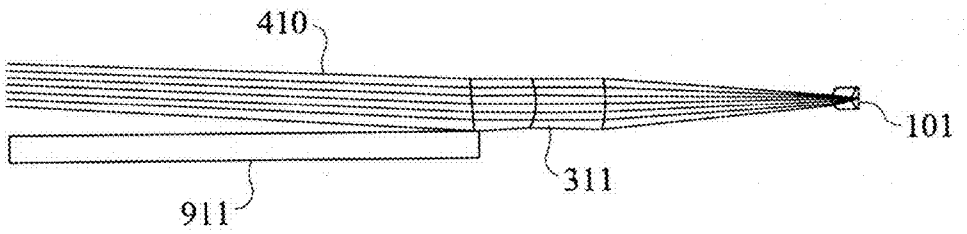


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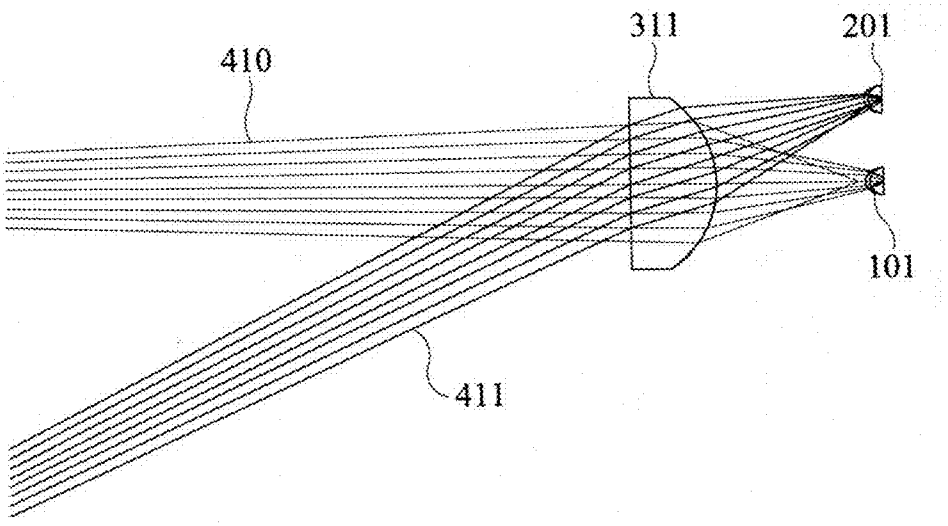


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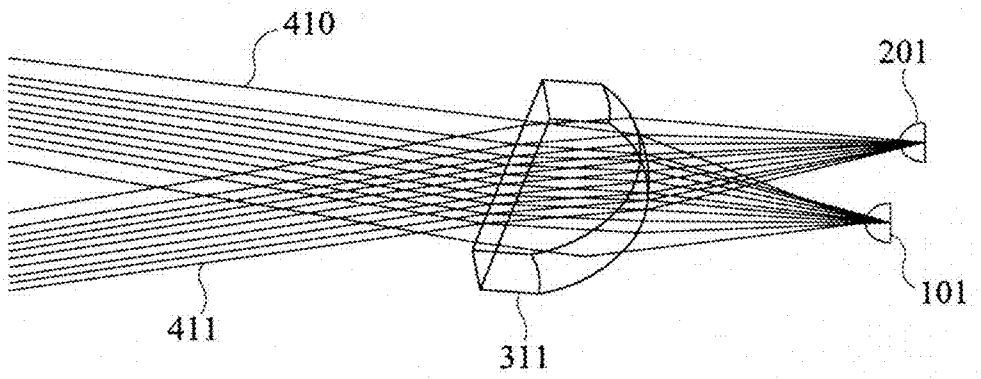


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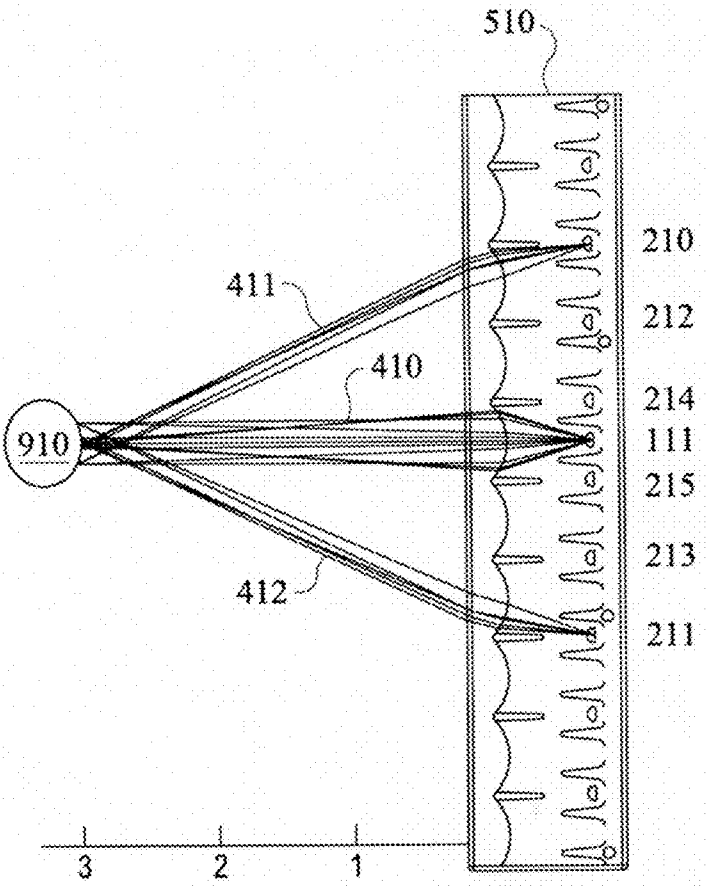
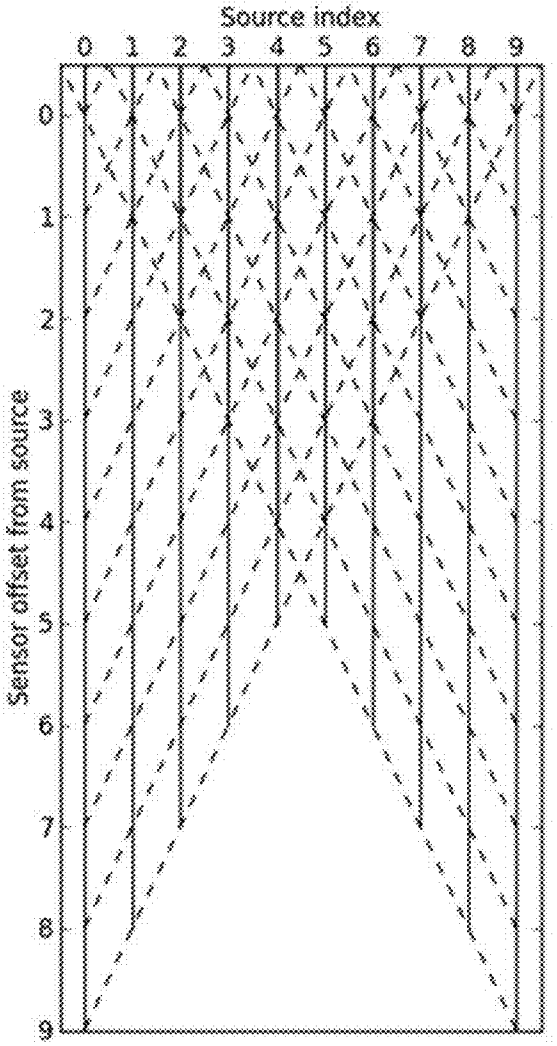



FIG. 12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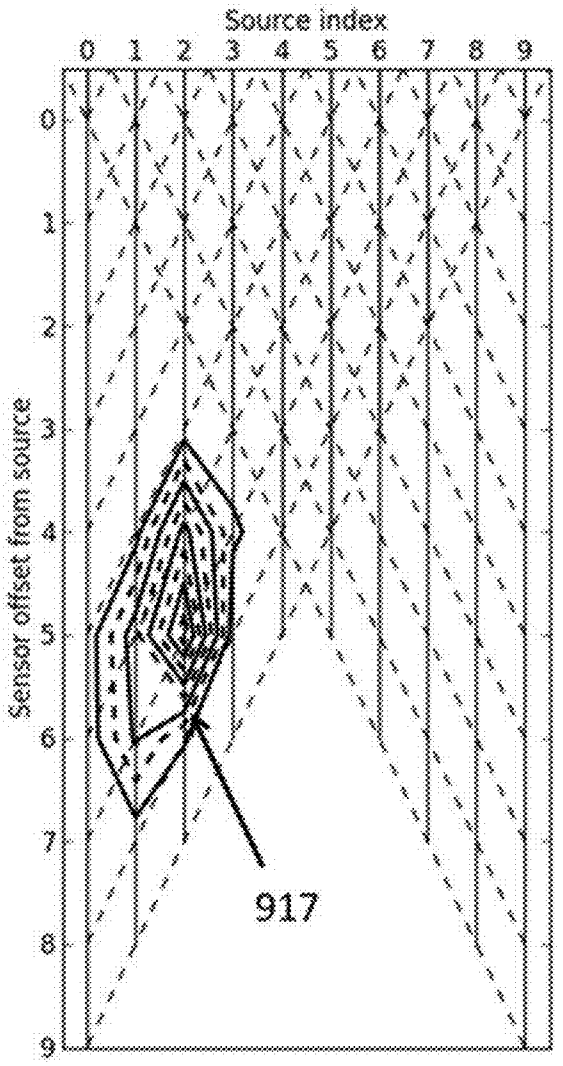
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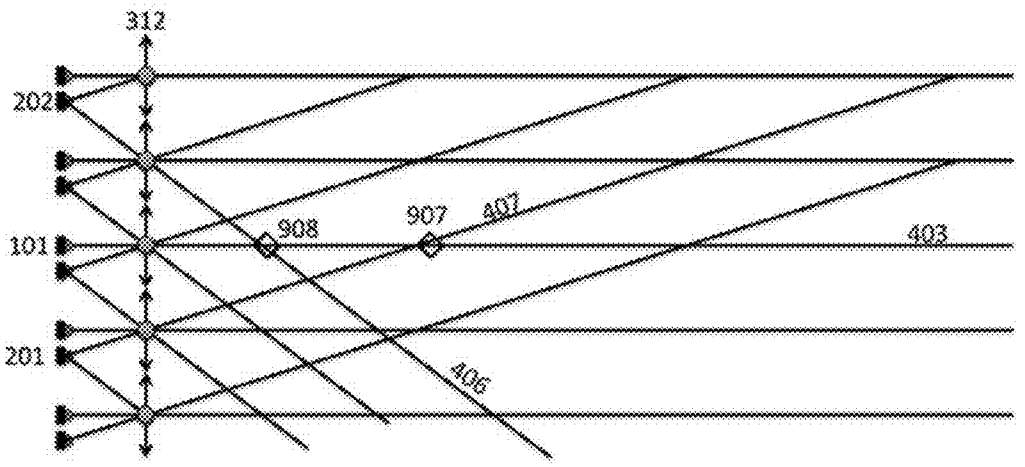
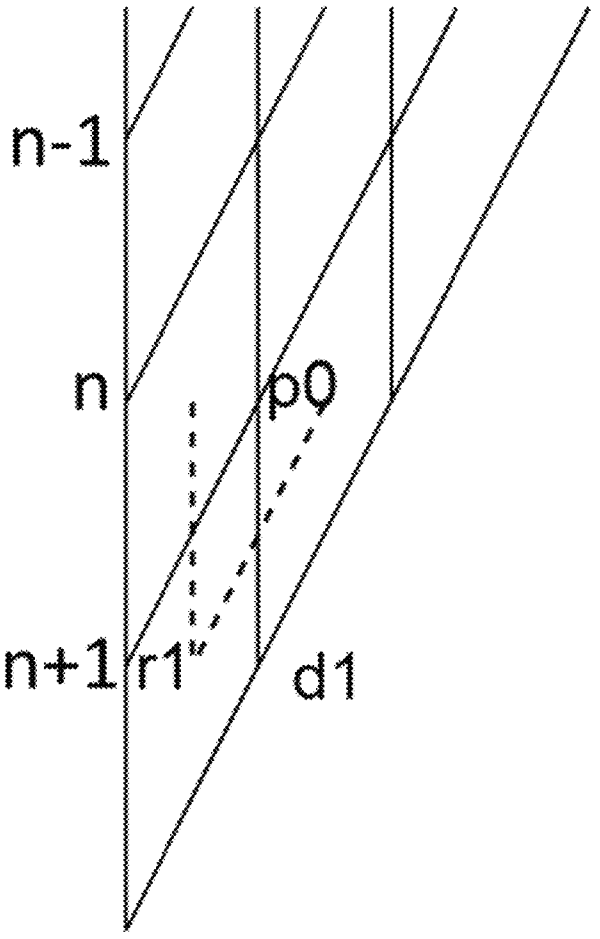



FIG. 15

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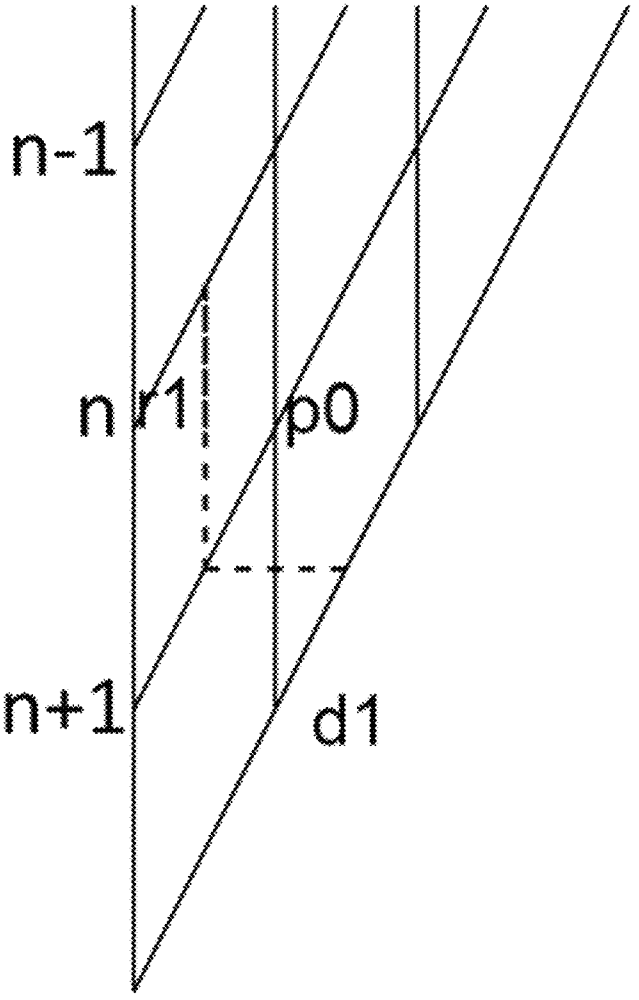


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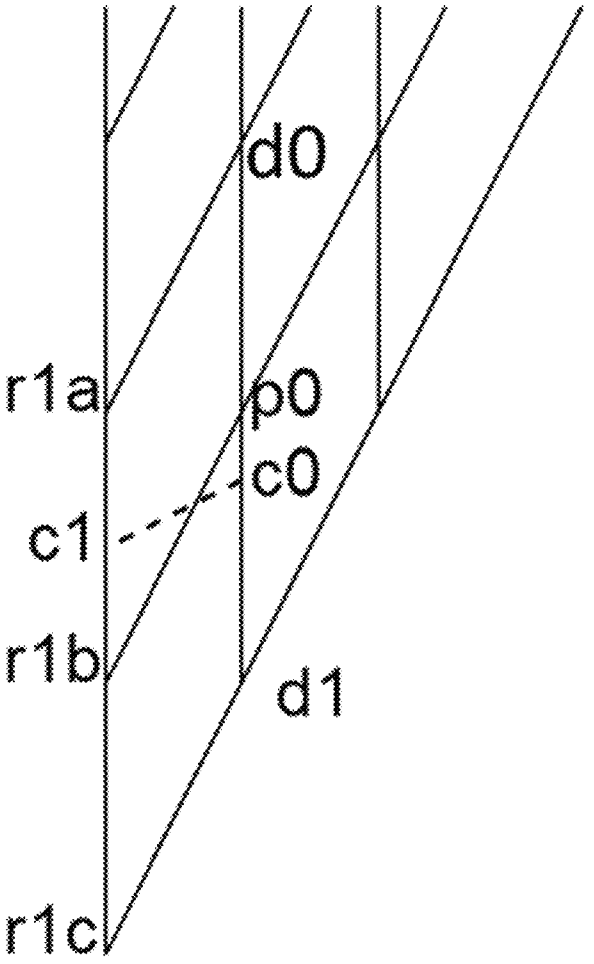


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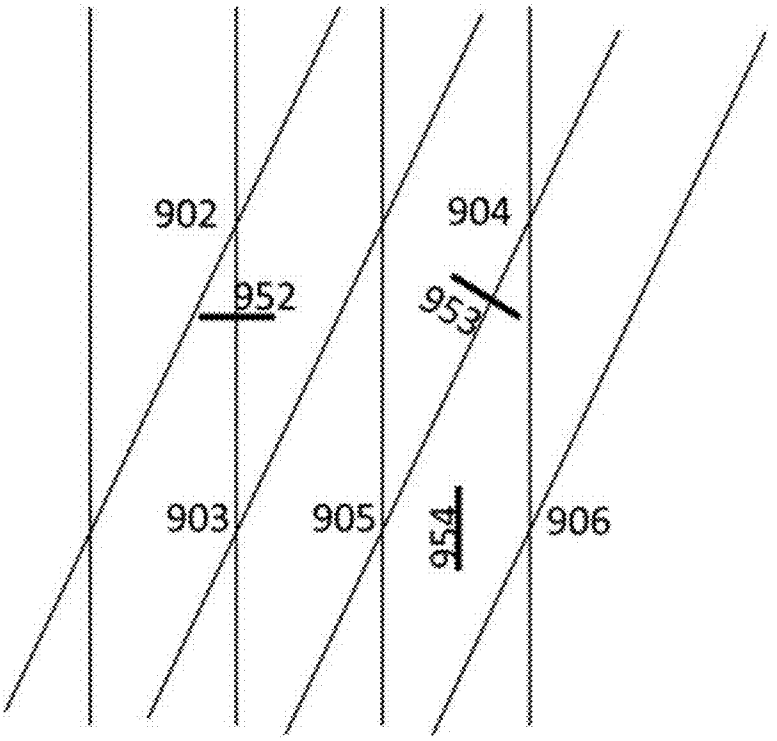



FIG. 19

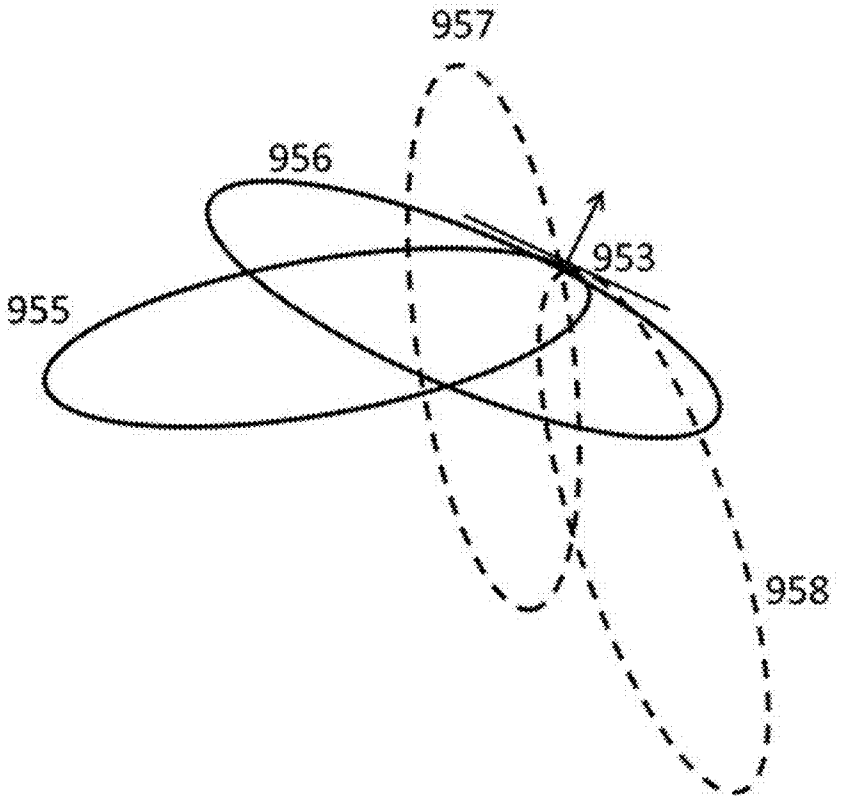
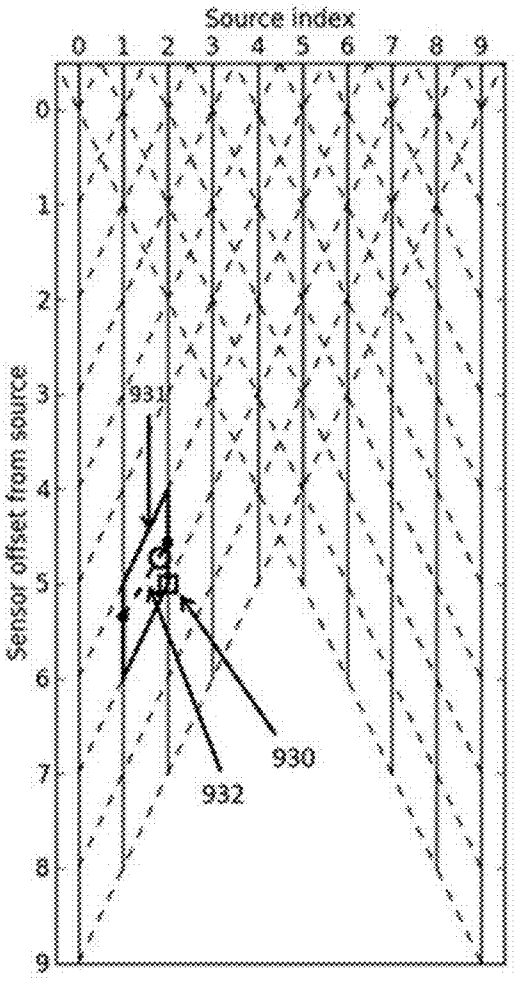



FIG. 20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932

FIG. 21

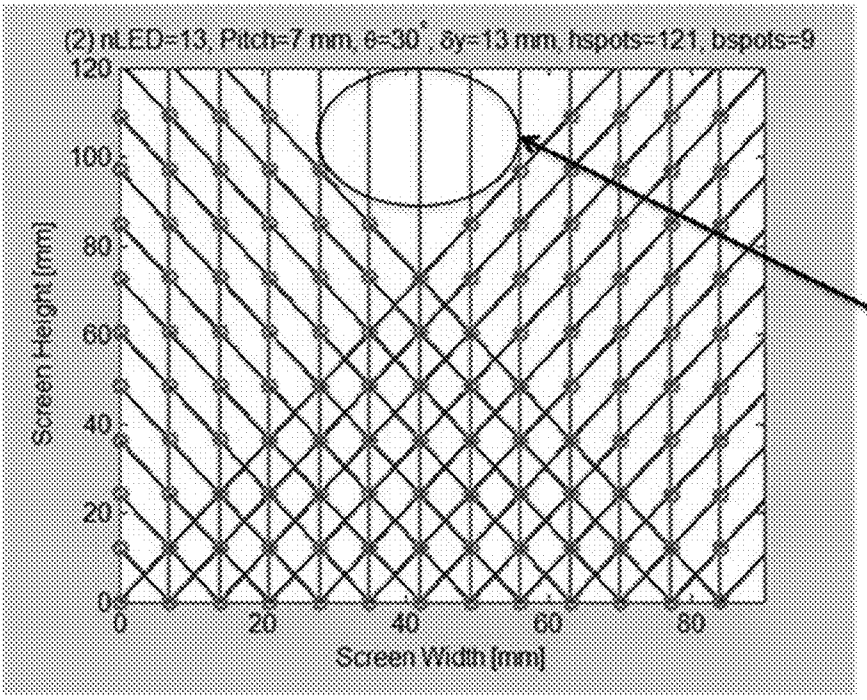

(2) nLED=13, Pitch=7 mm, θ=30°, δy=13 mm, hspots=121, bspots=9
120
100
80
60
40
20
0
Screen Height [mm]
0
20
40
60
80
Screen Width [mm]
919

FIG. 22

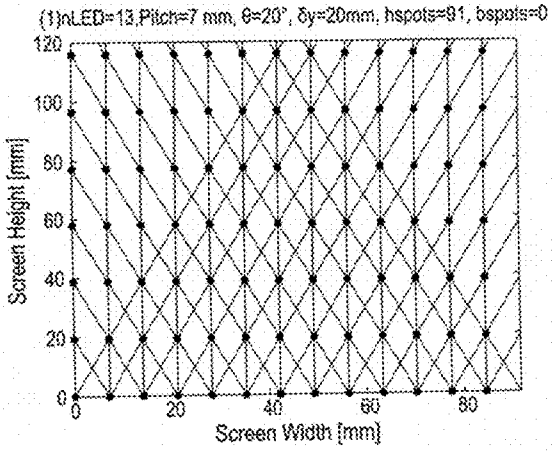



FIG. 23(a)

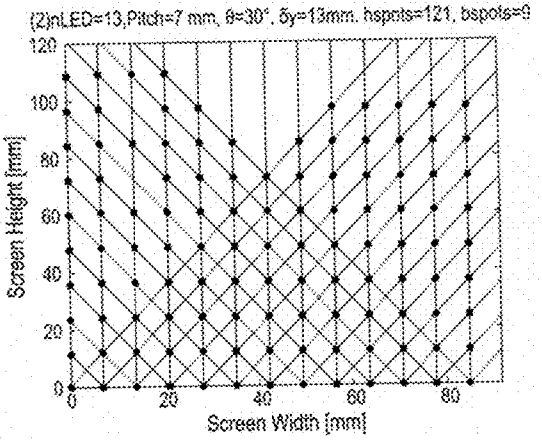



FIG. 23(b)

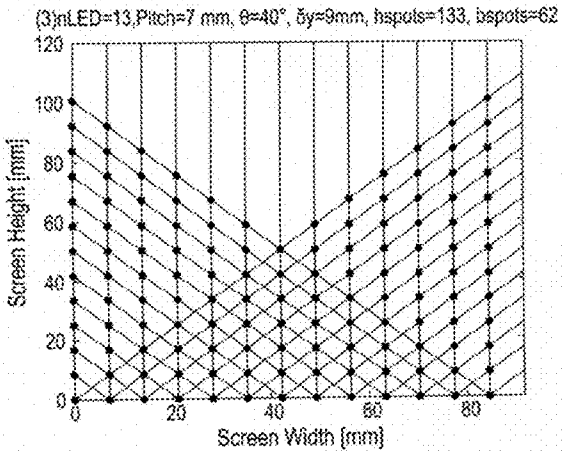



FIG. 23(c)

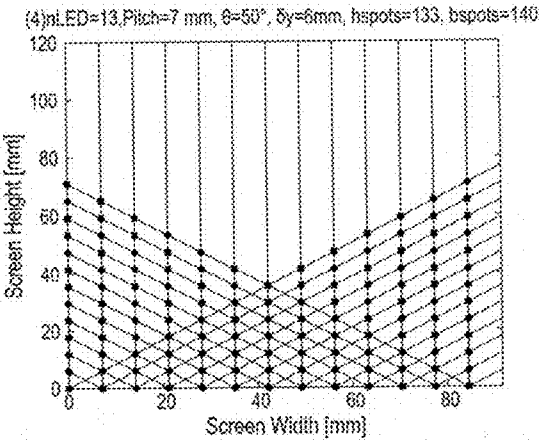



FIG. 23(d)

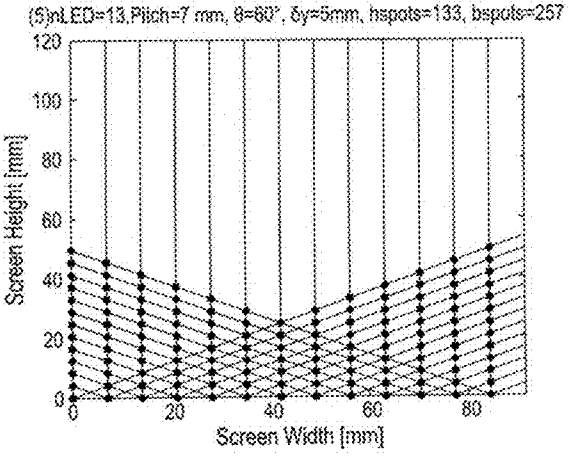



FIG. 23(e)

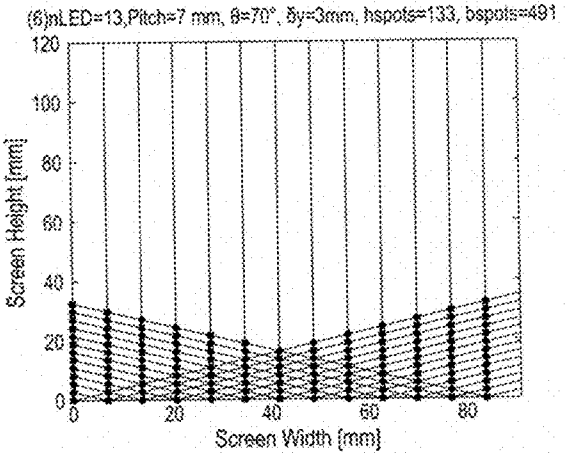



FIG. 23(f)

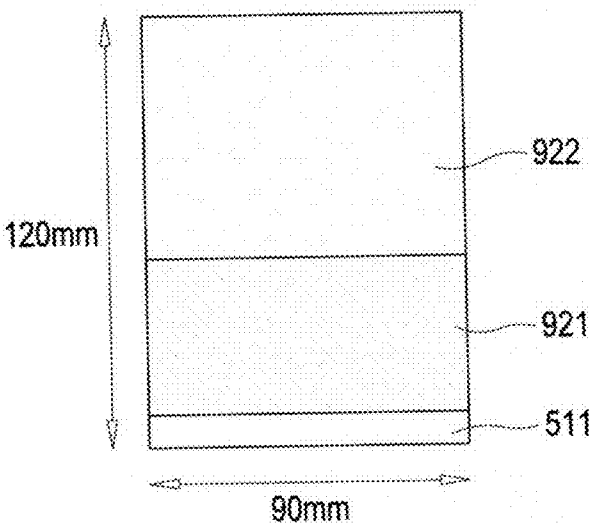



FIG. 24

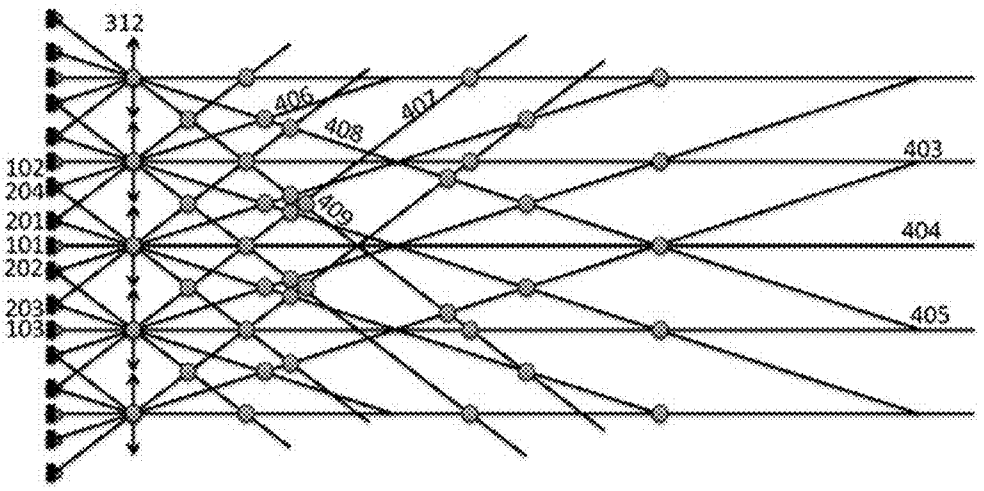



FIG. 25

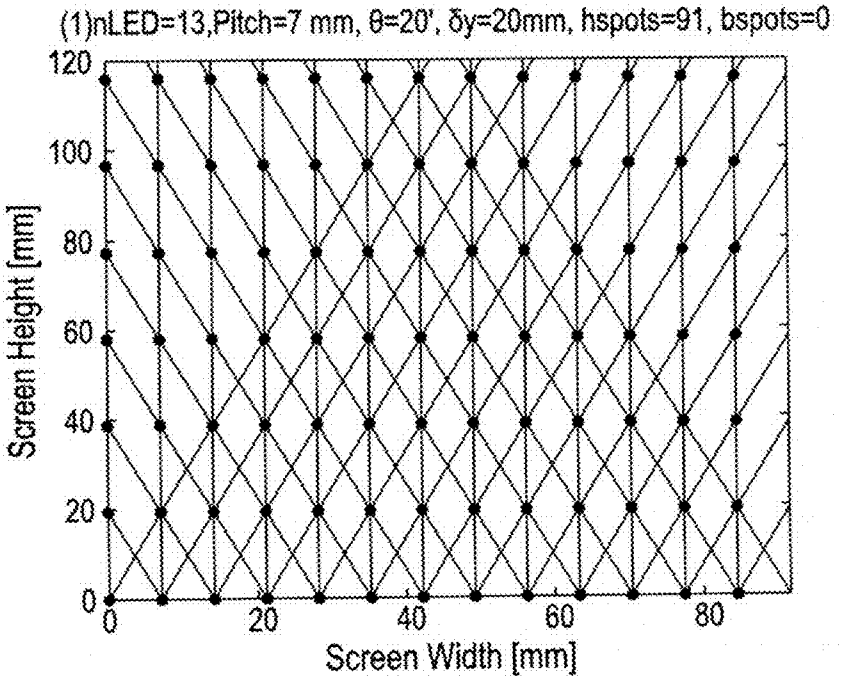



FIG. 26(a)

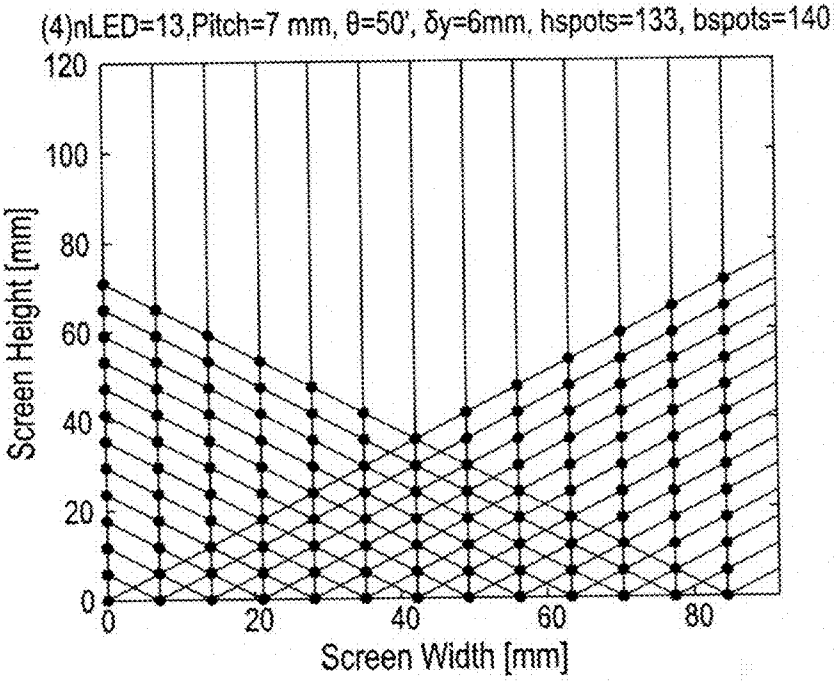



FIG. 26(b)

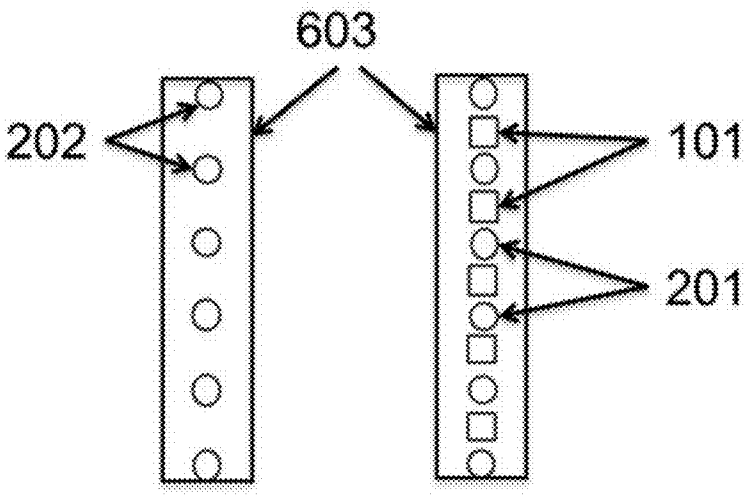



FIG. 27

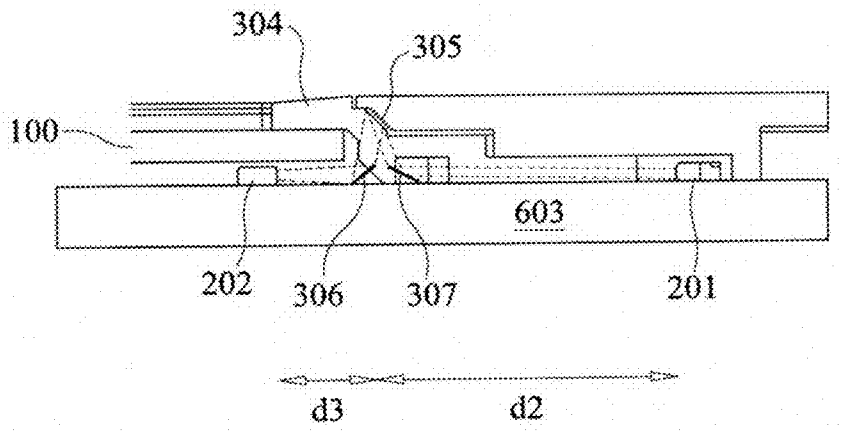



FIG. 28

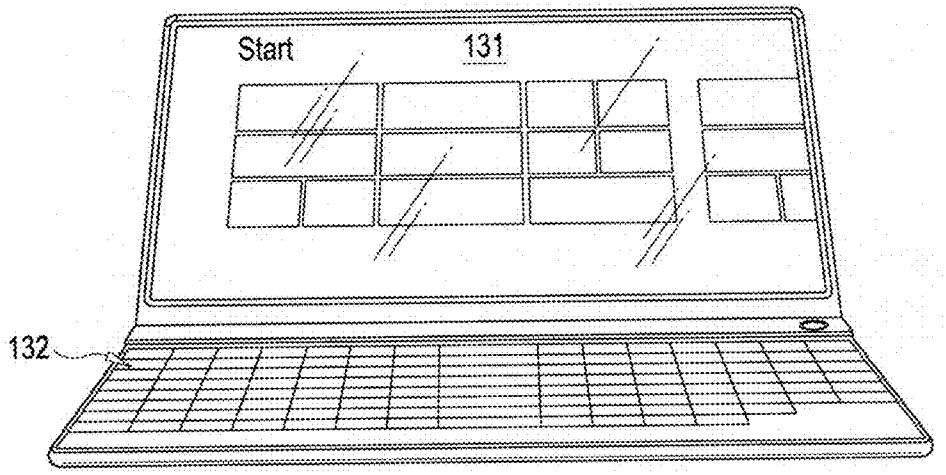



FIG. 29

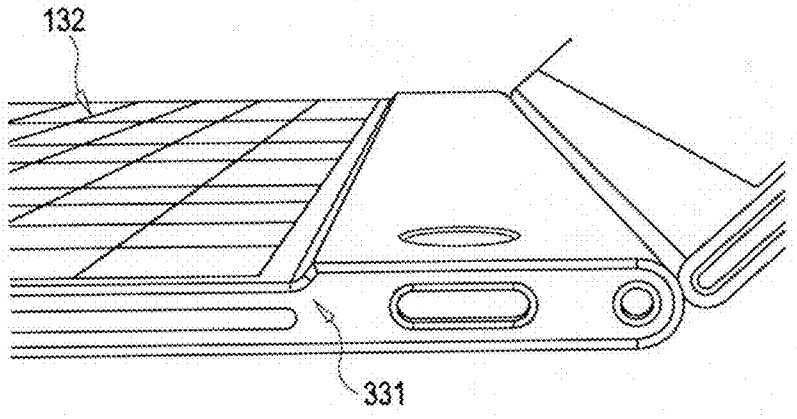



FIG. 30

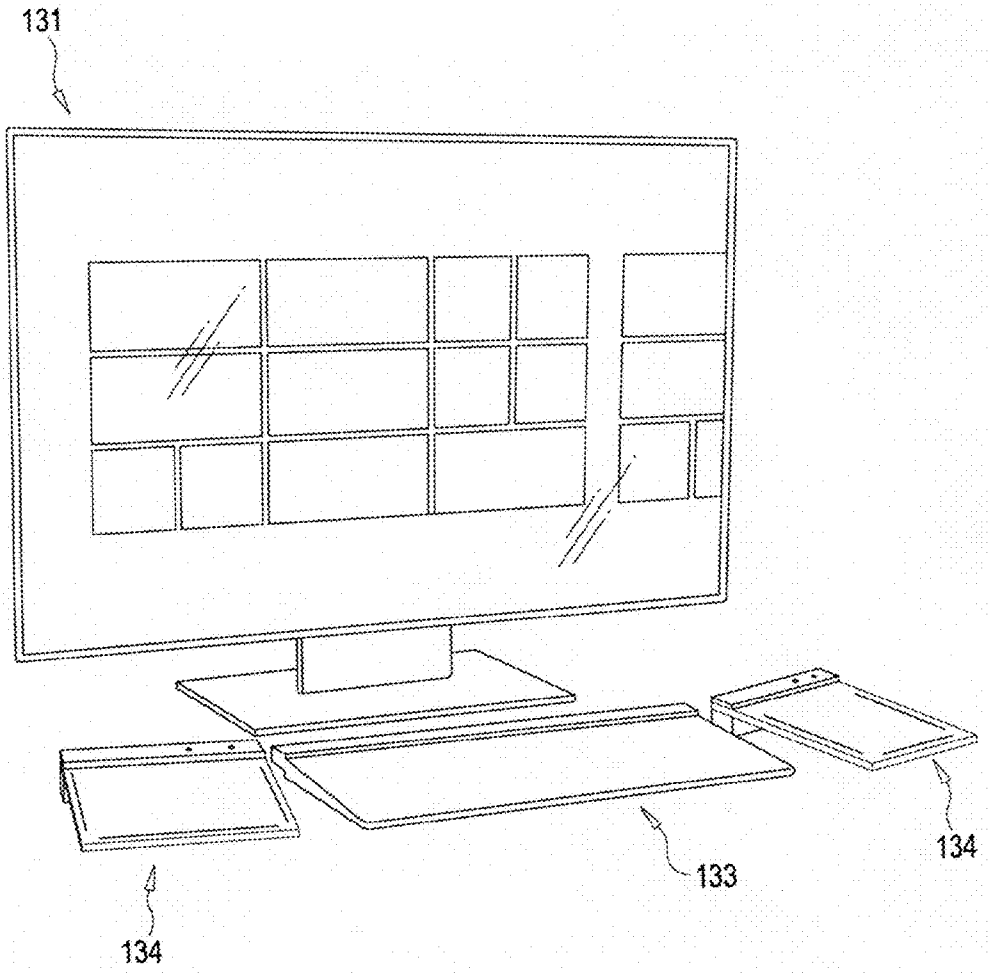



FIG. 31

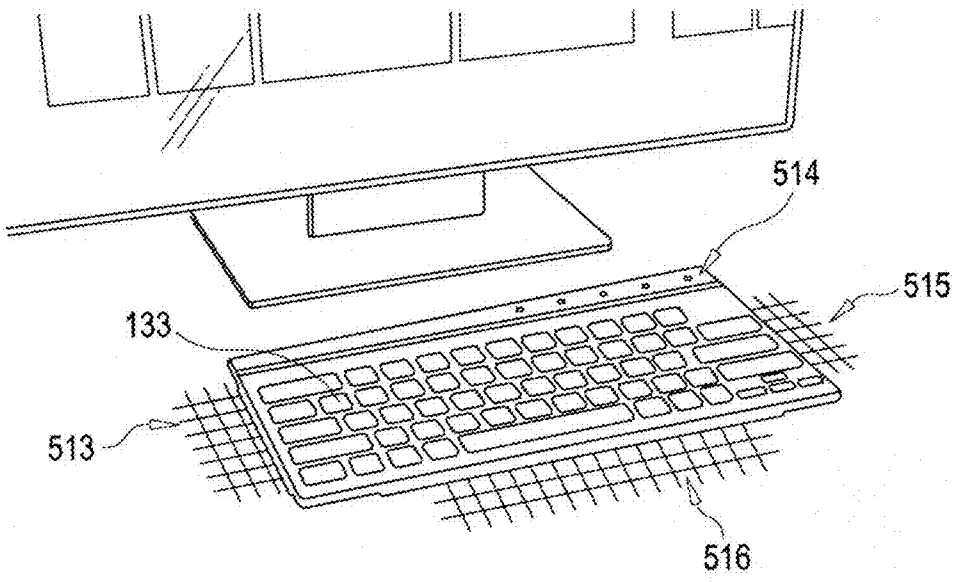



FIG. 32

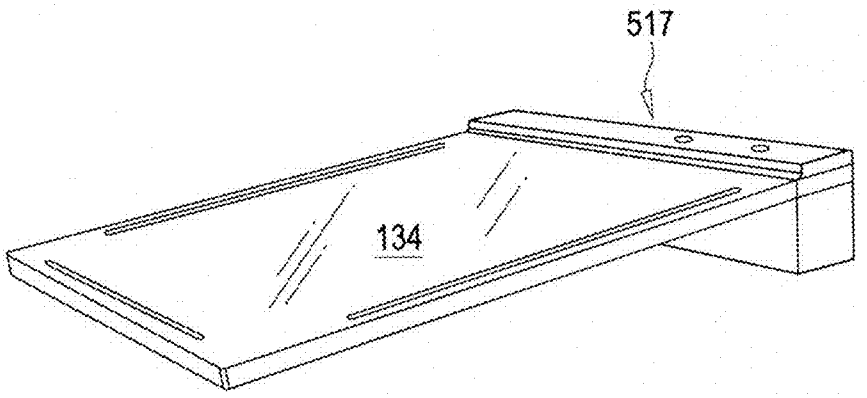



FIG. 33

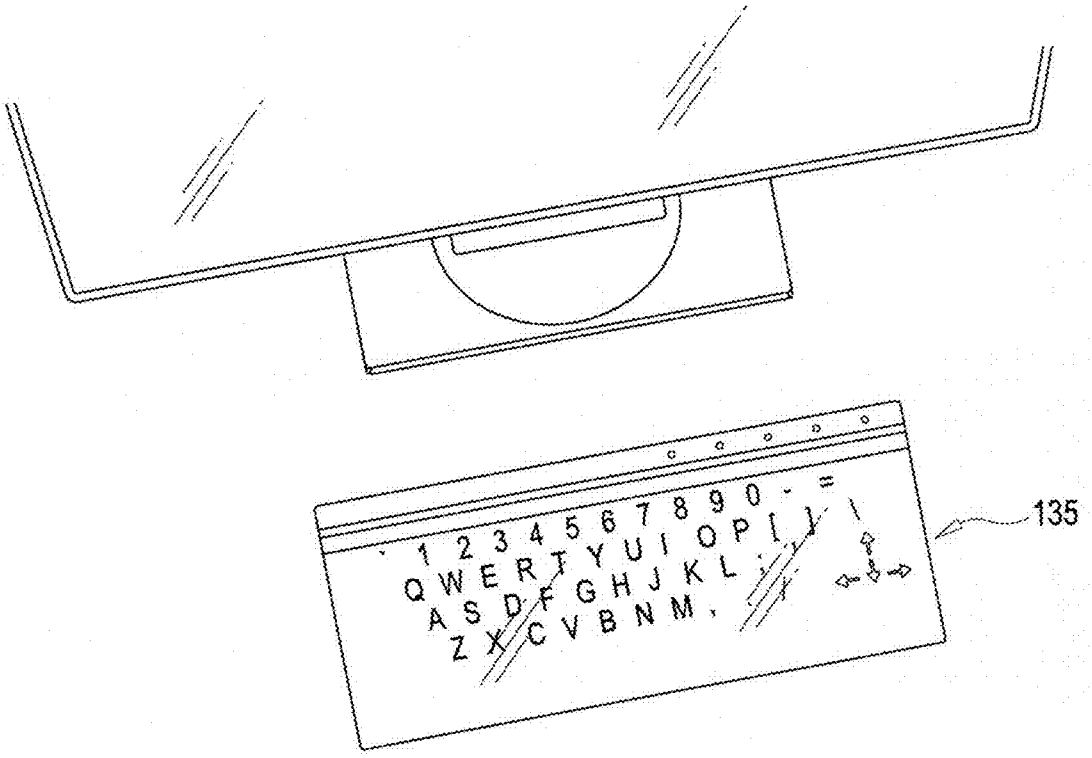



FIG. 34

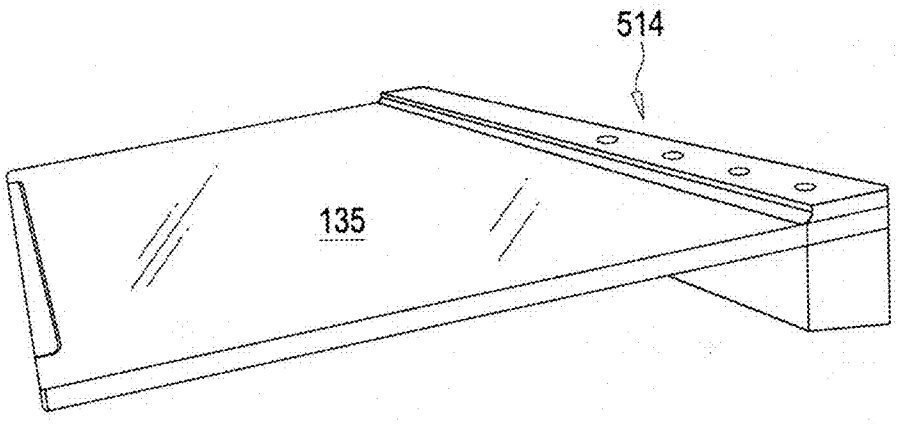



FIG. 35

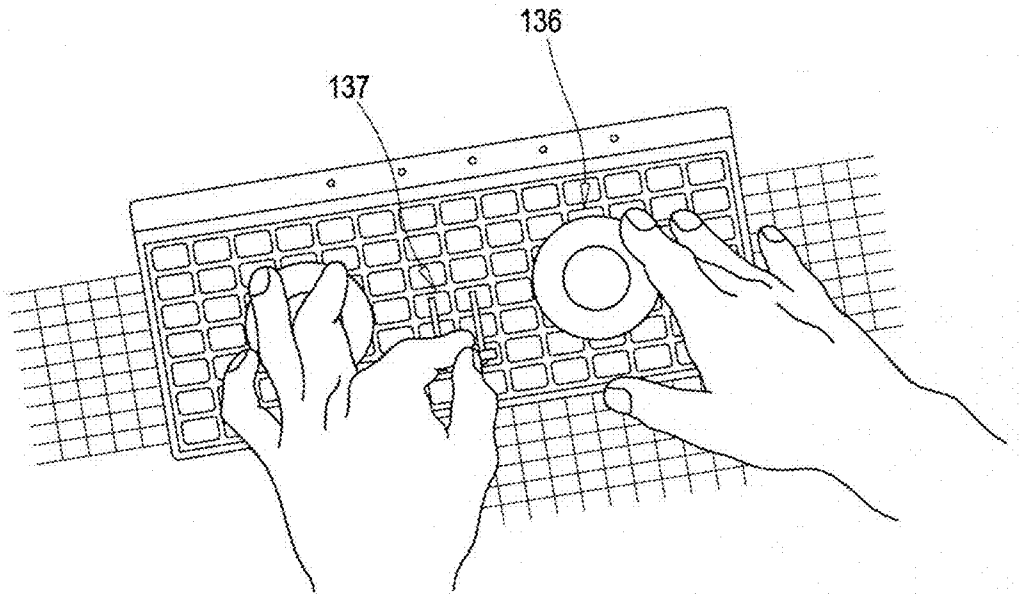



FIG. 36

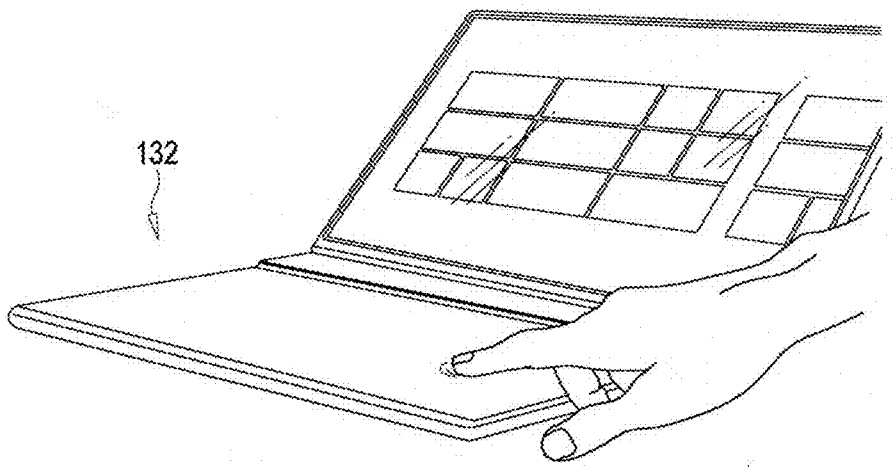



FIG. 37

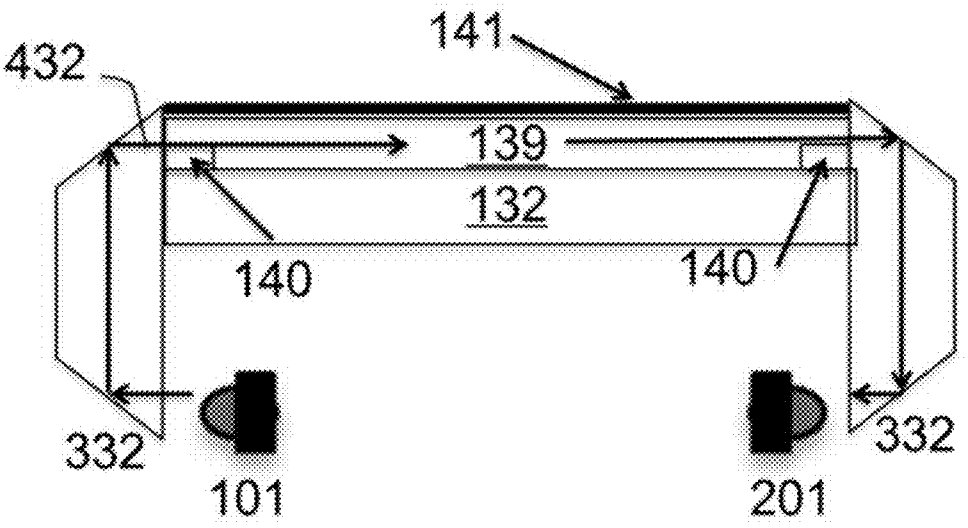



FIG. 38

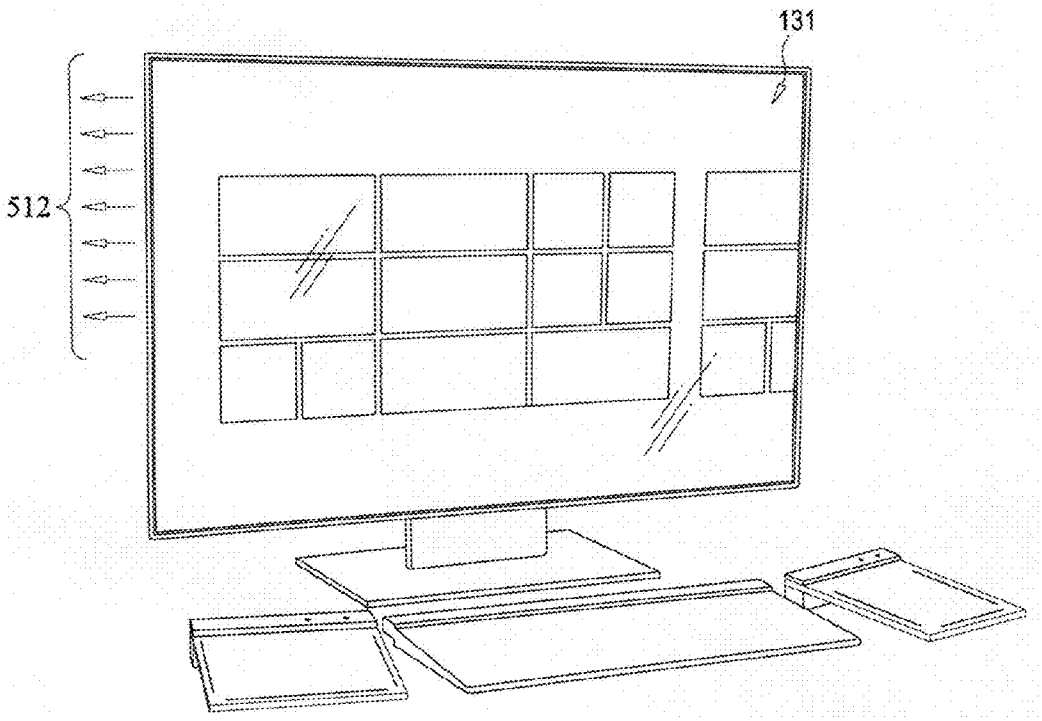



FIG. 39

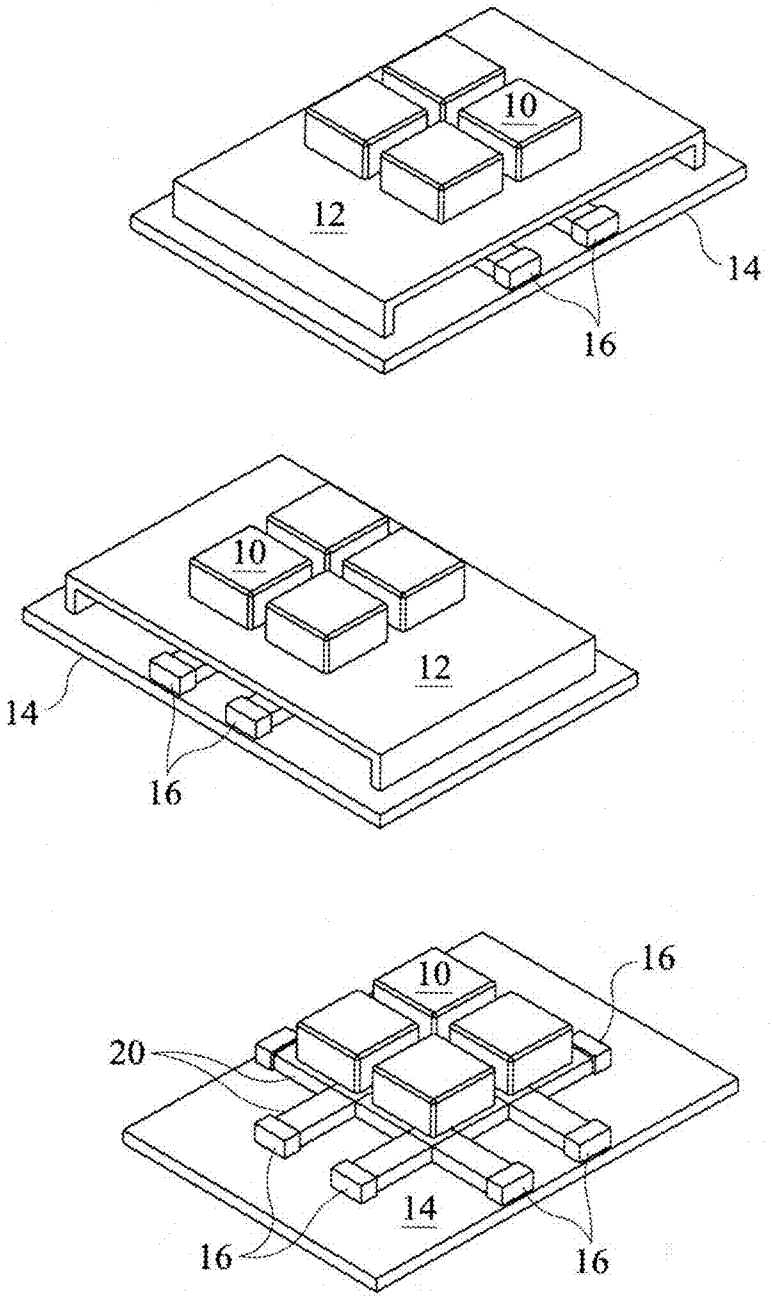
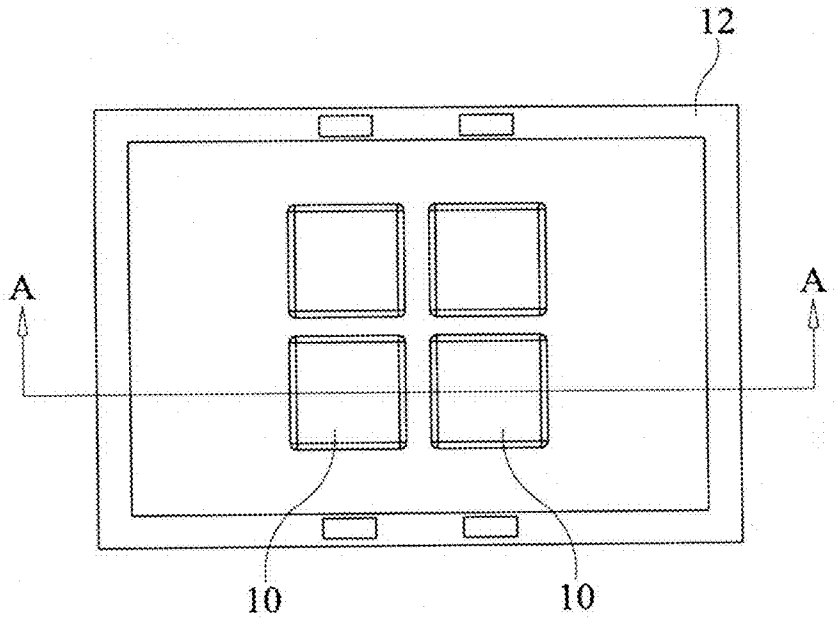



FIG. 40



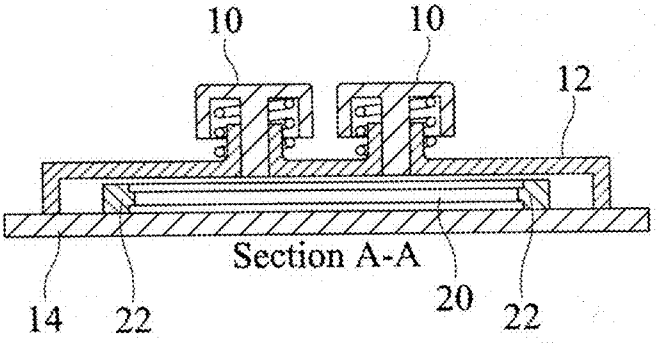




FIG. 41

FIG. 42(a)

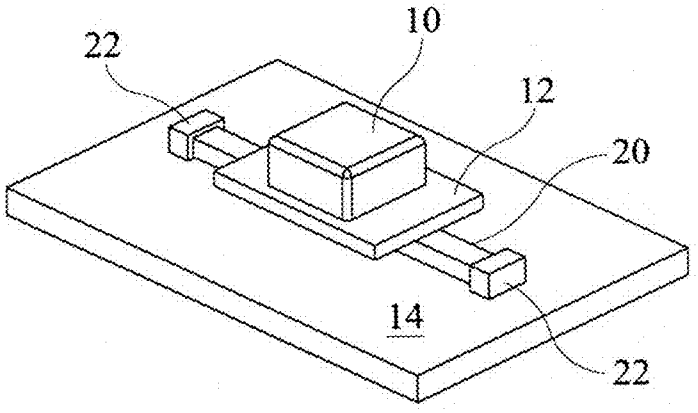



FIG. 42(b)

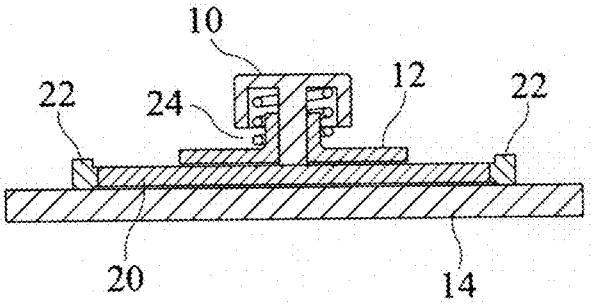



FIG. 42(c)

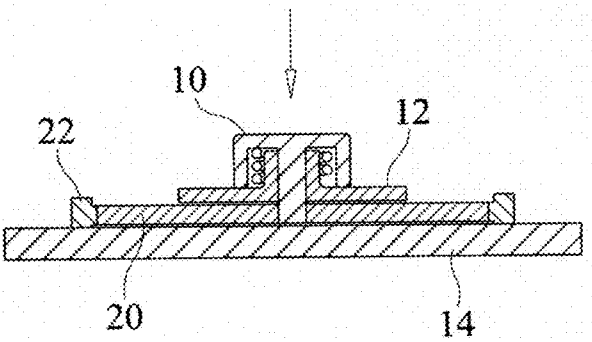


FIG. 43(a)

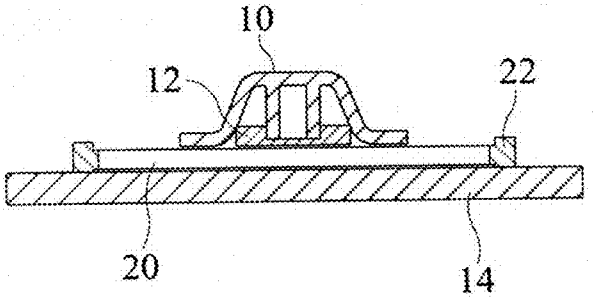



FIG. 43(b)

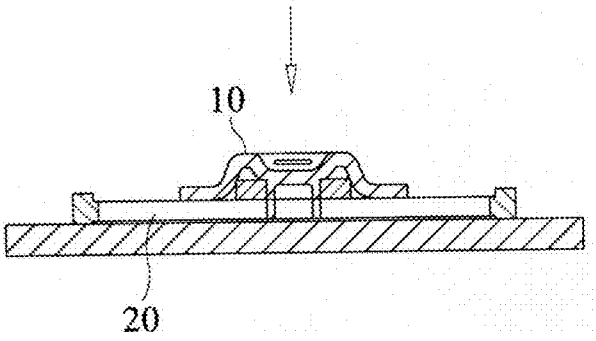


FIG. 44(a)

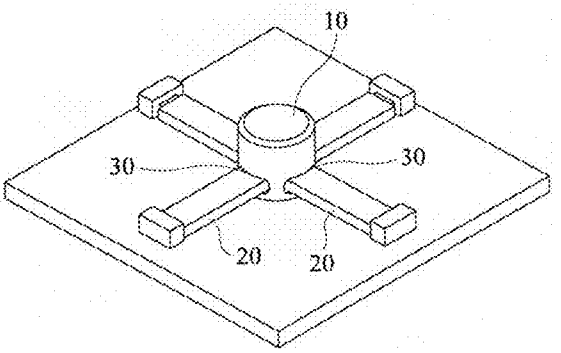



FIG. 44(b)

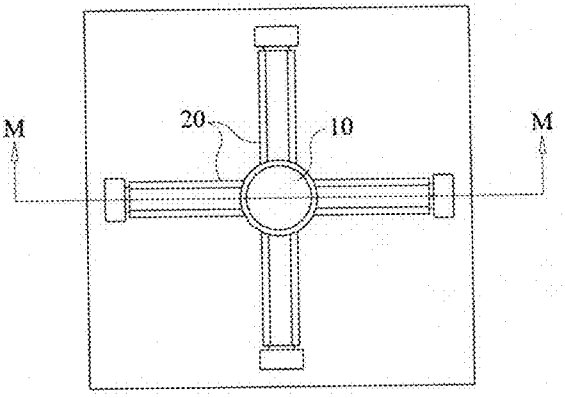



FIG. 44(c)

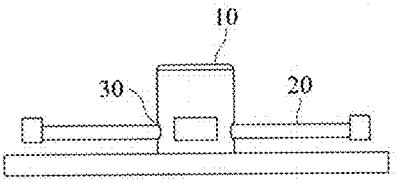
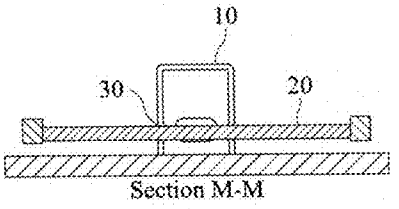



FIG. 44(d)



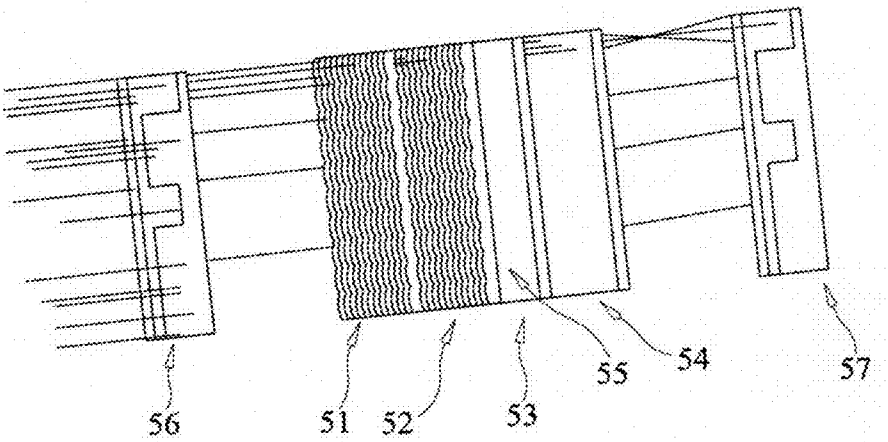



FIG. 45

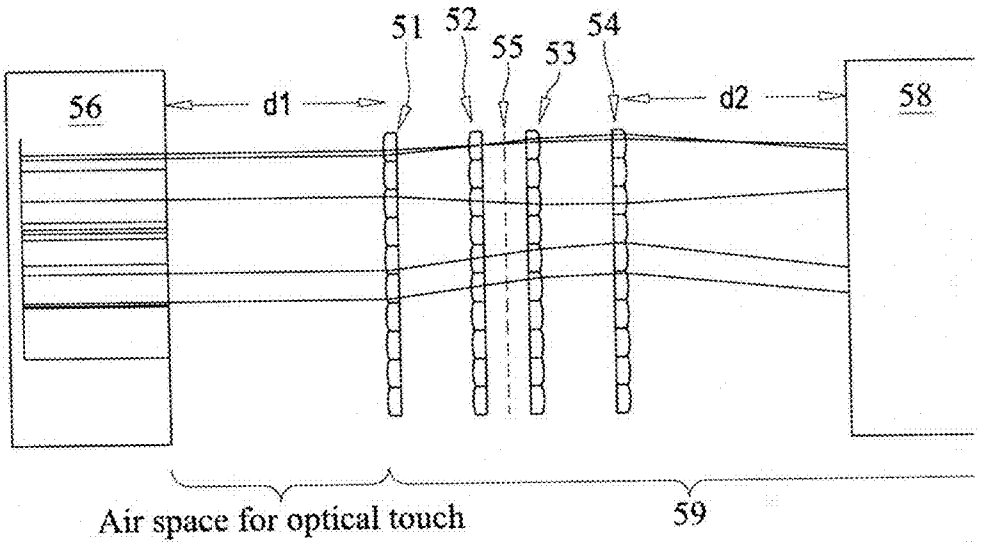



FIG. 46

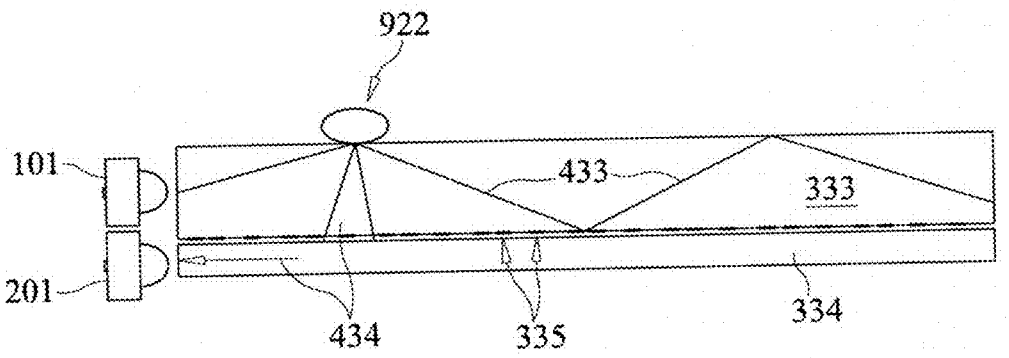



FIG. 47

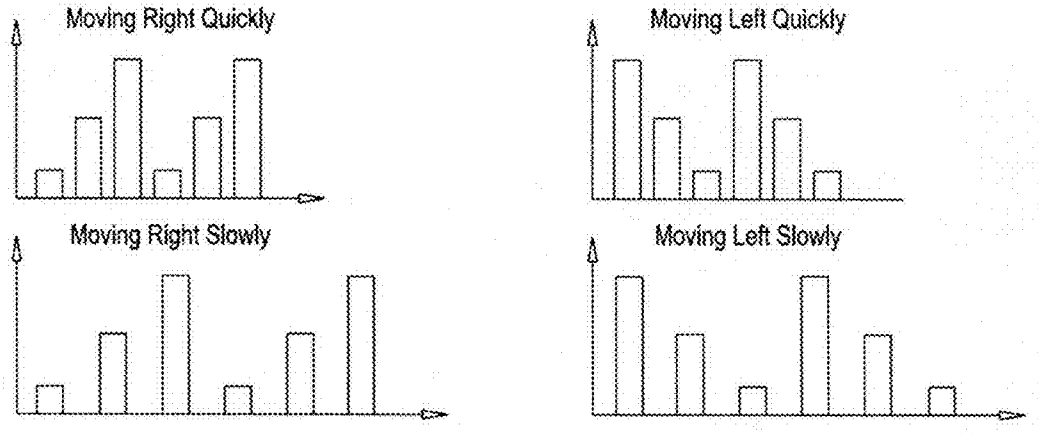

Moving Right Quickly
Moving Left Quickly
Moving Right Slowly
Moving Left Slowly

FIG. 48

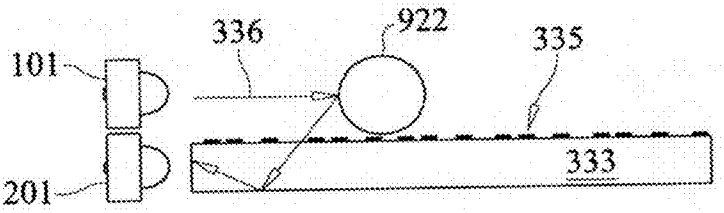



FIG. 49

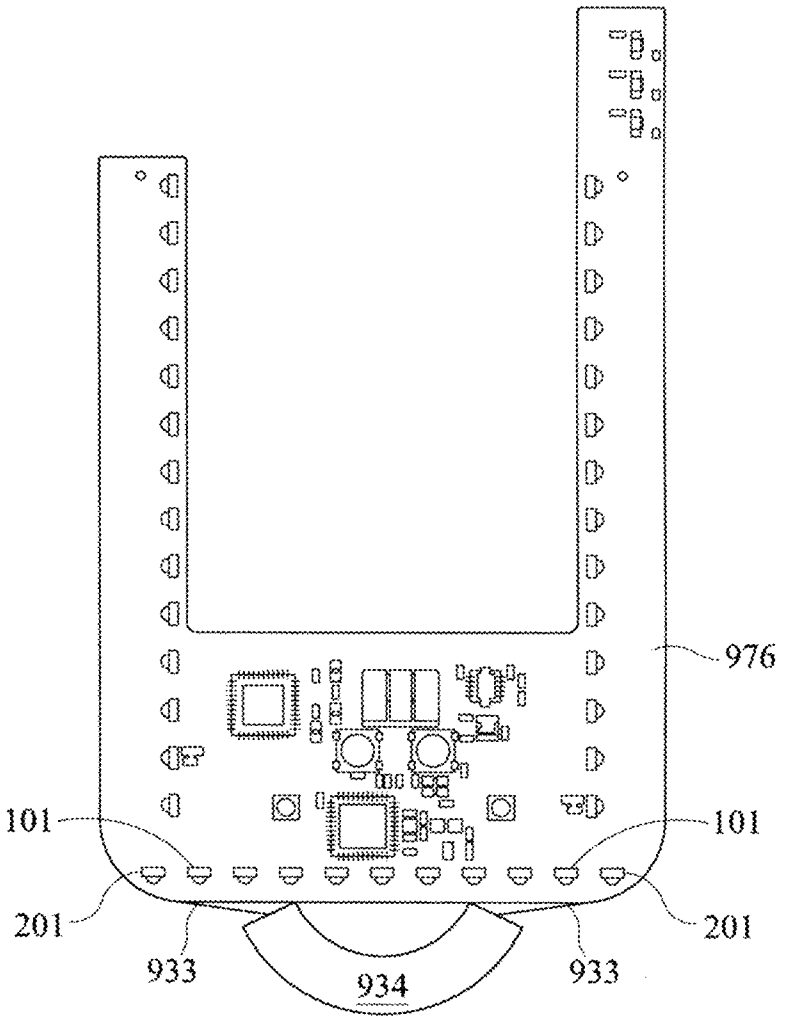



FIG. 50

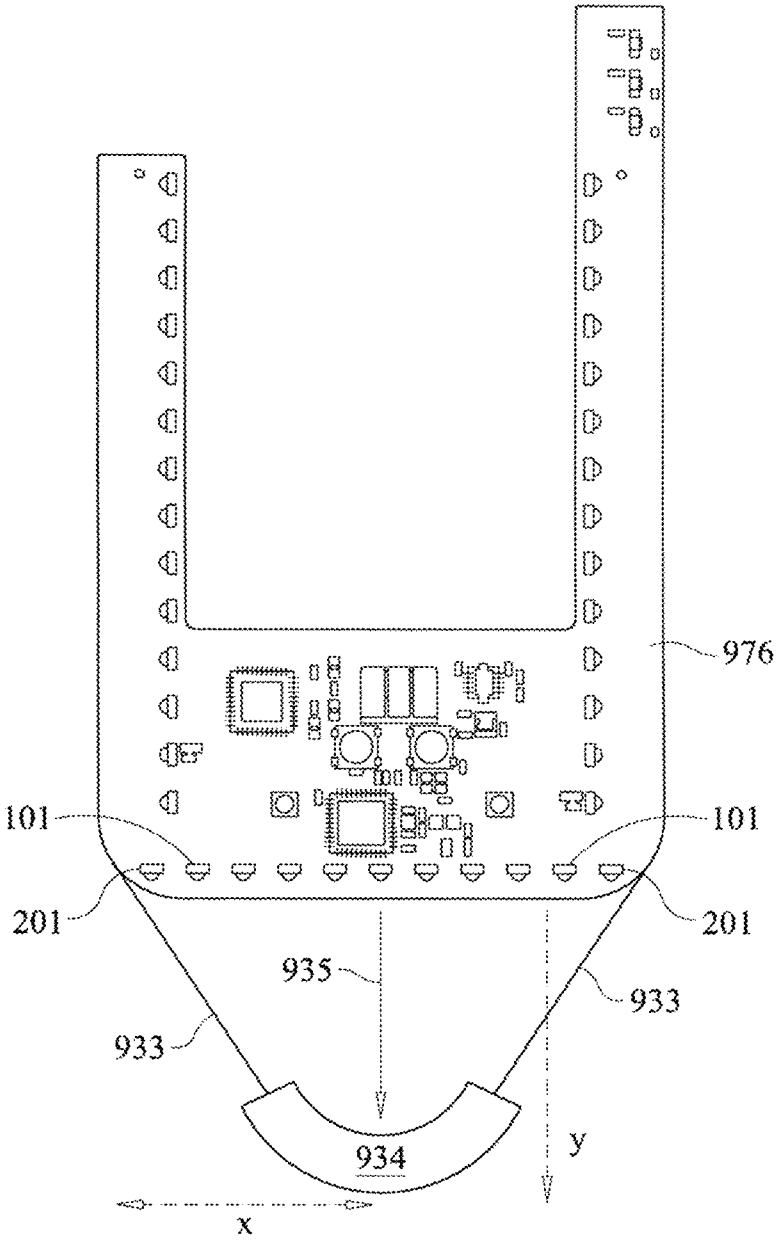



FIG. 51

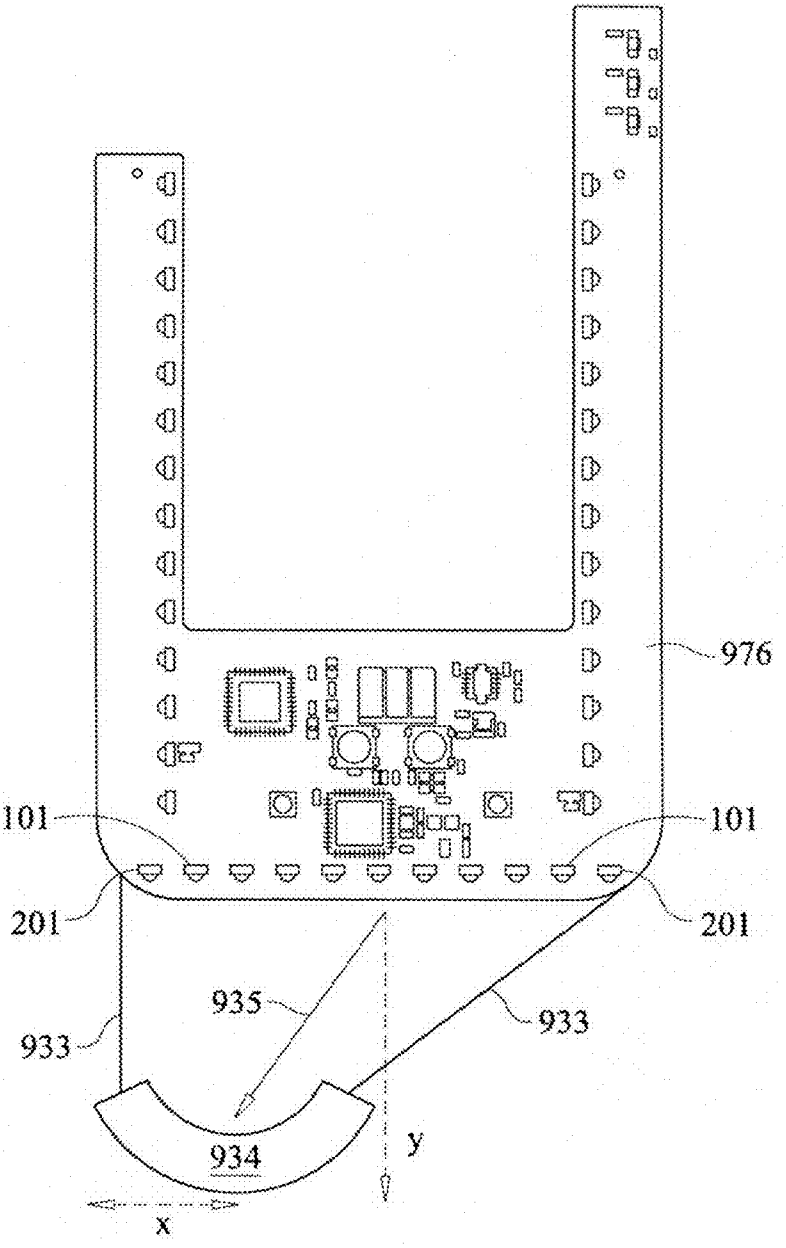



FIG. 52

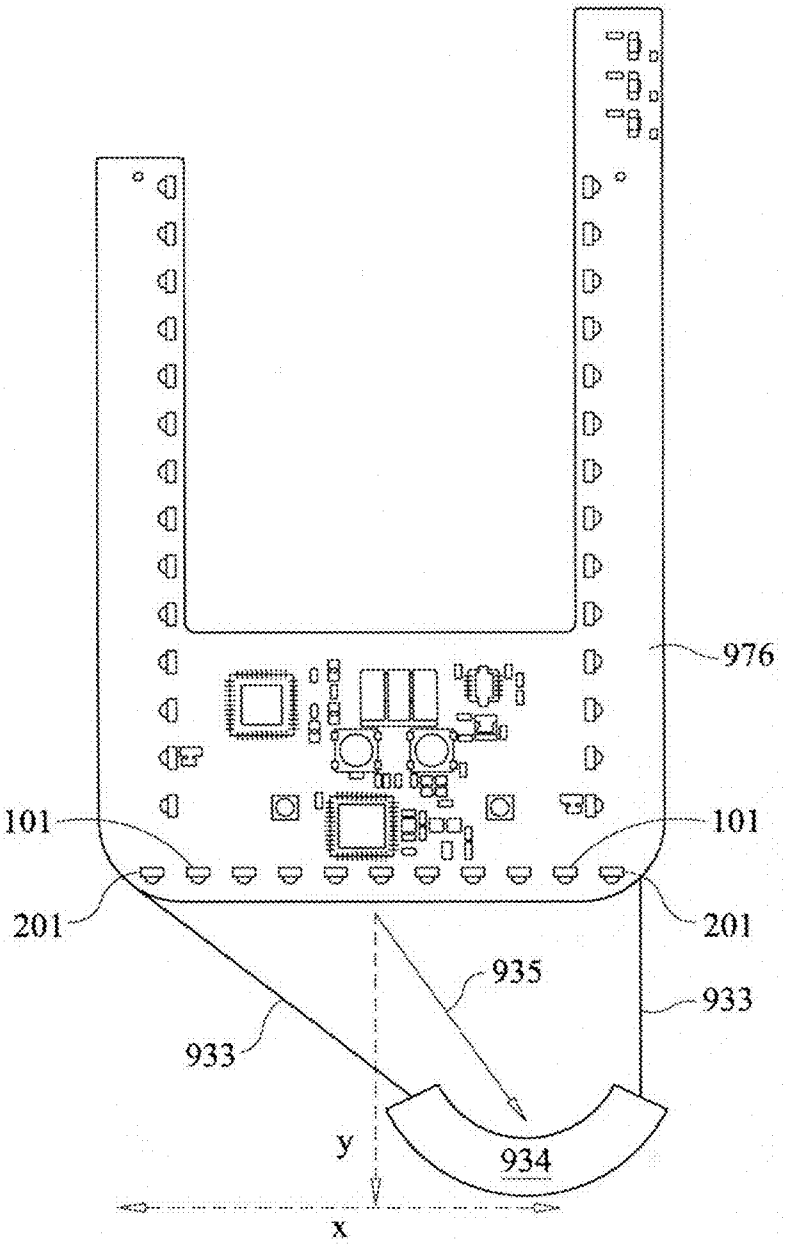



FIG. 53

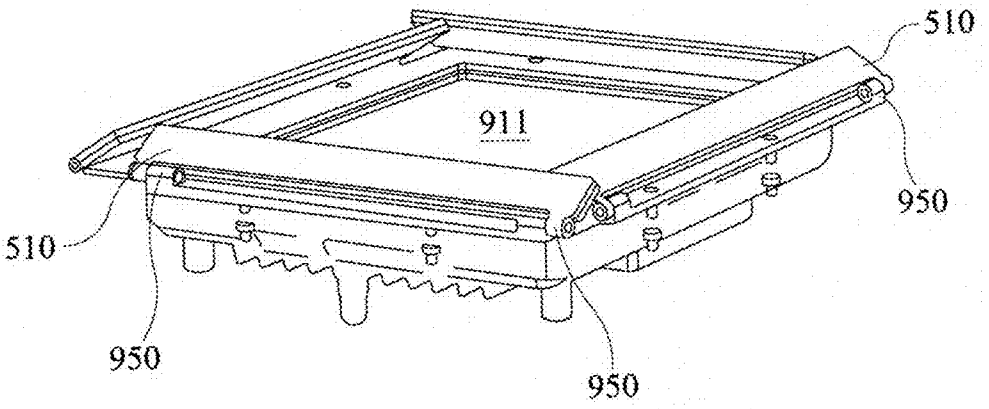



FIG. 54

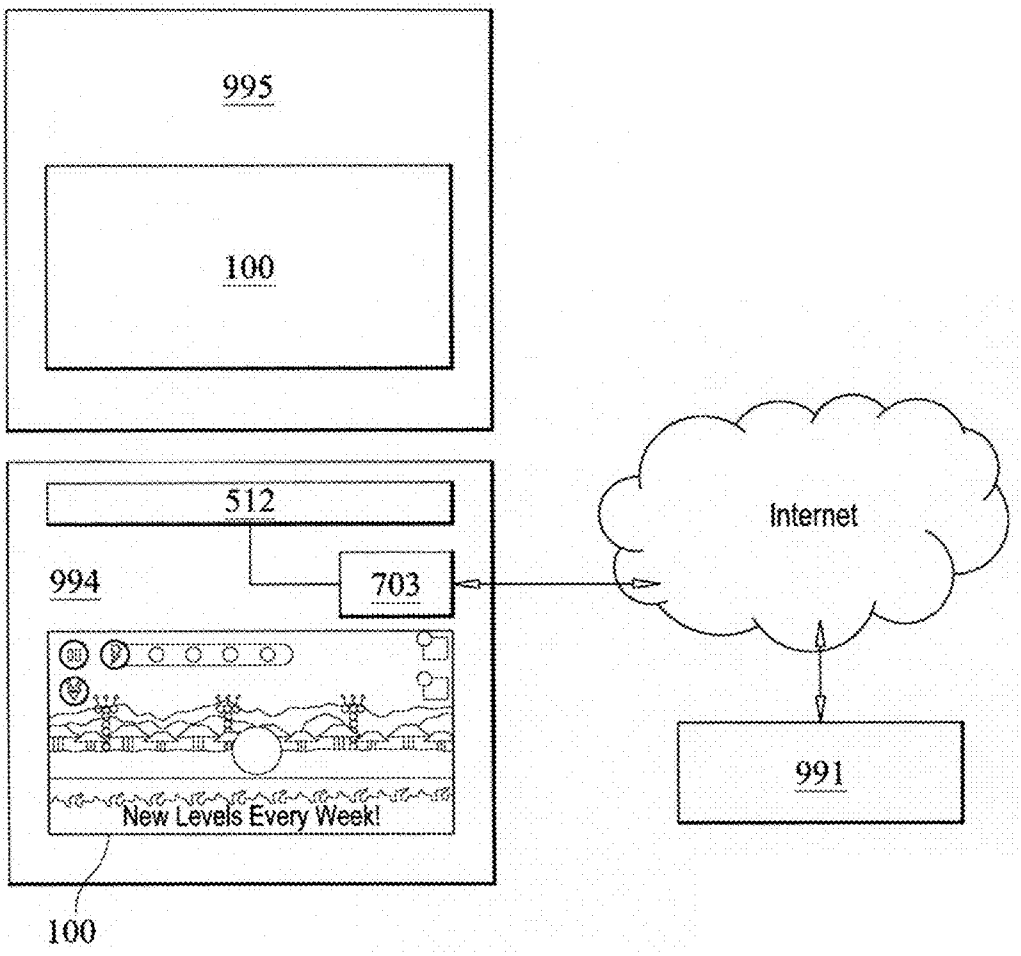



FIG. 55

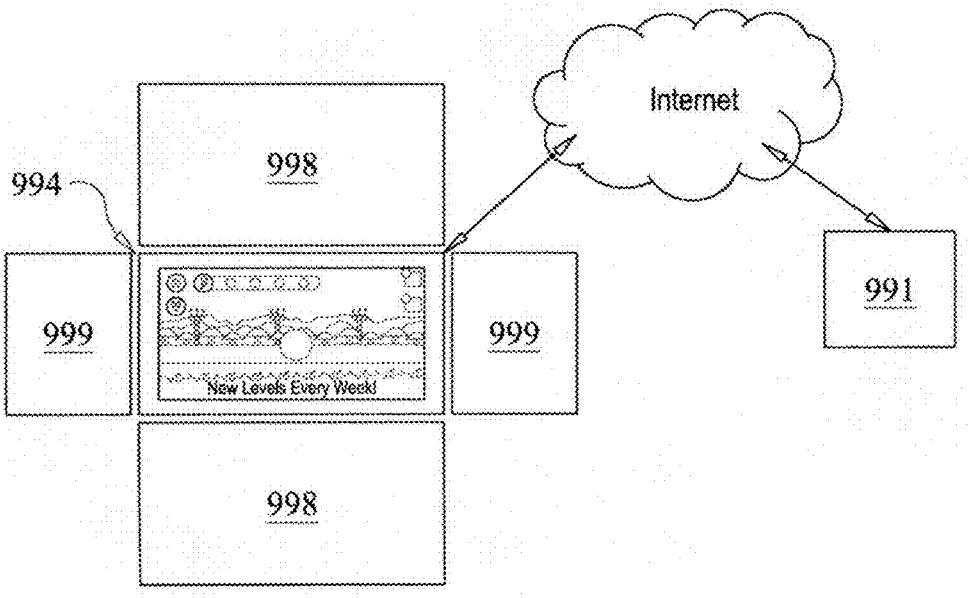



FIG. 56

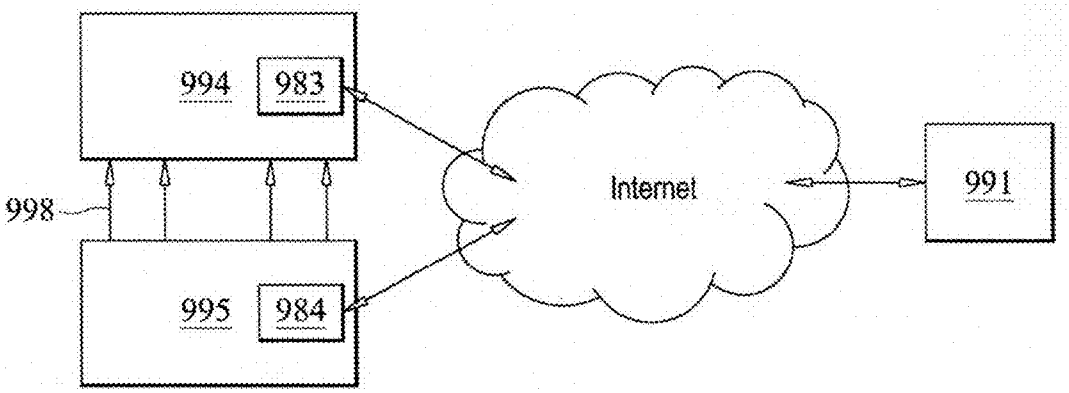



FIG. 57

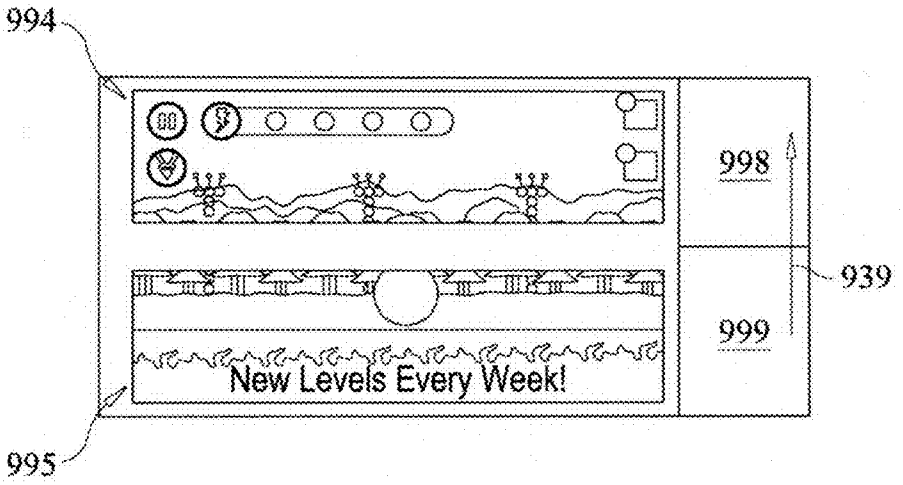
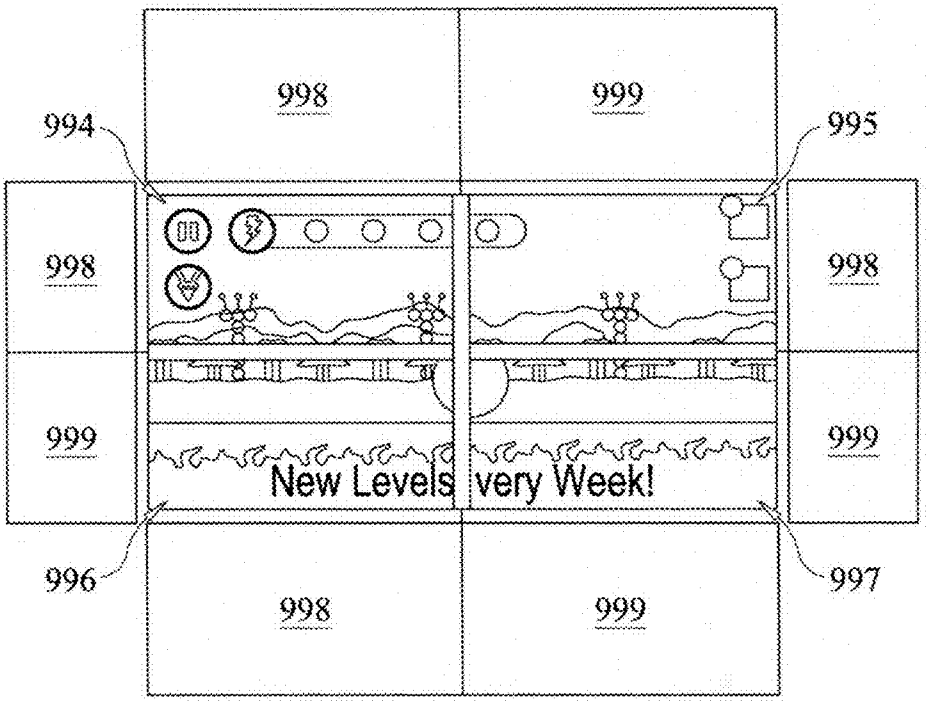



FIG. 58


998
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999
New Levels very Week!
996
997
998
999

FIG. 59

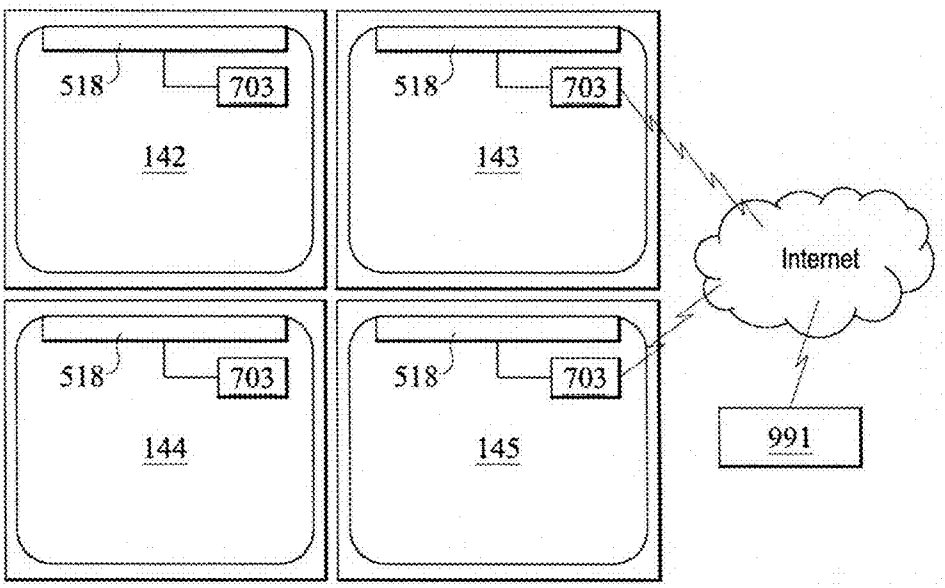



FIG. 60

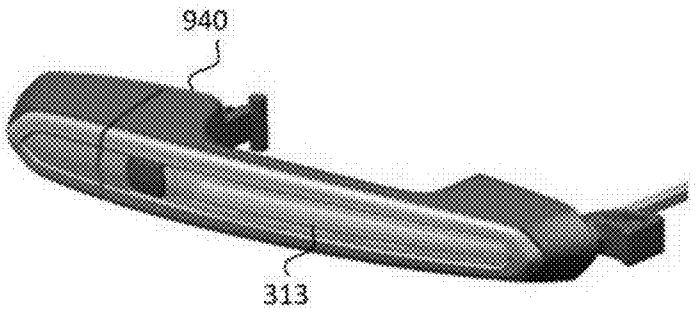



FIG. 61

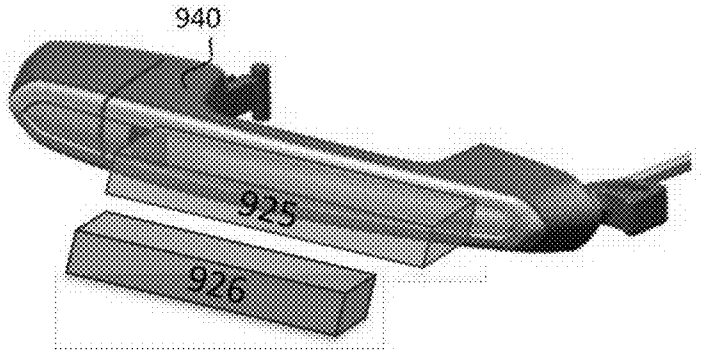



FIG. 62

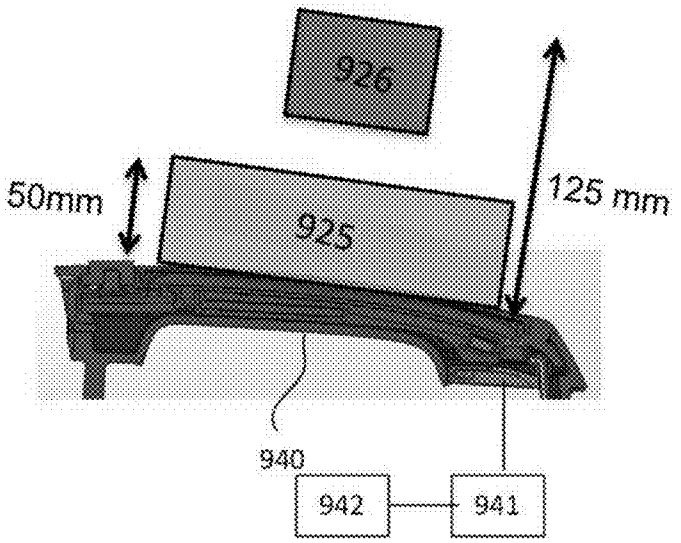



FIG. 63

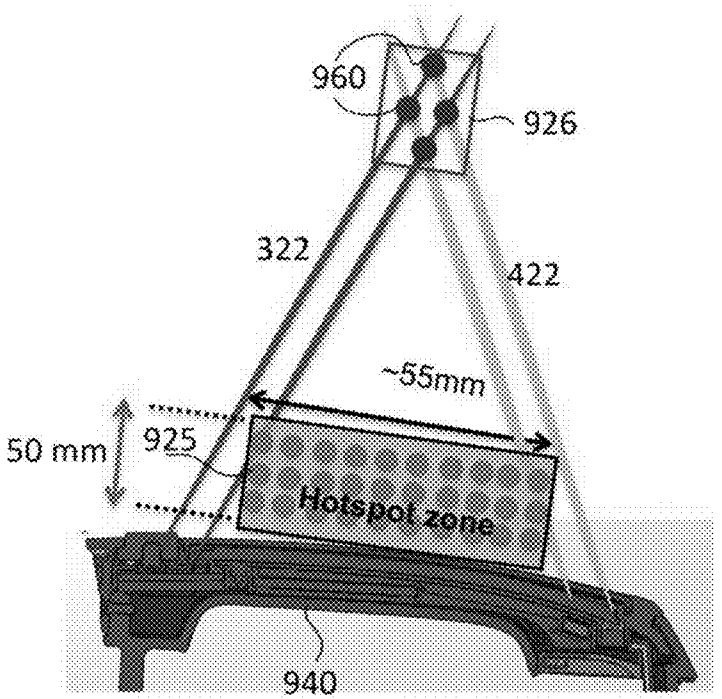



FIG. 64

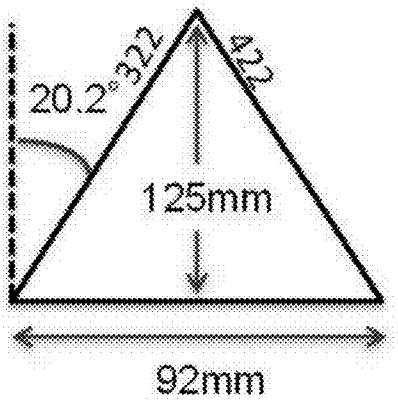



FIG. 65

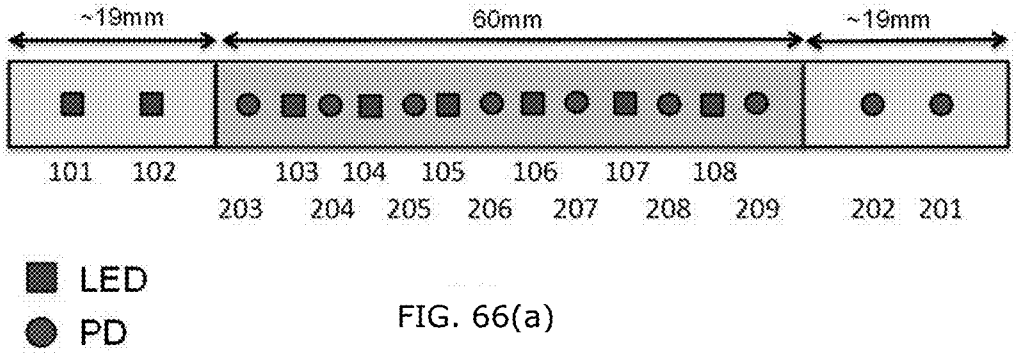



FIG. 66(a)

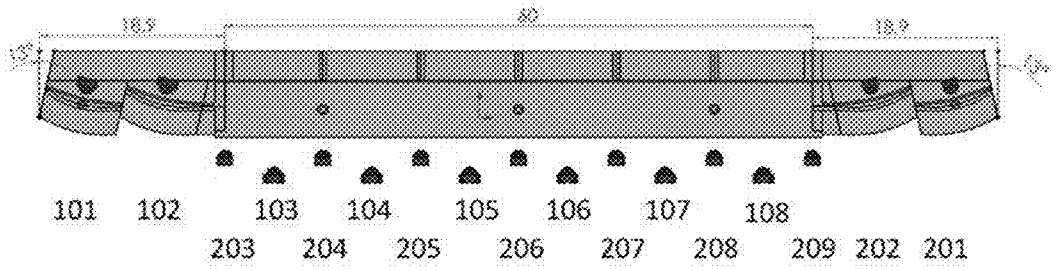



FIG. 66(b)

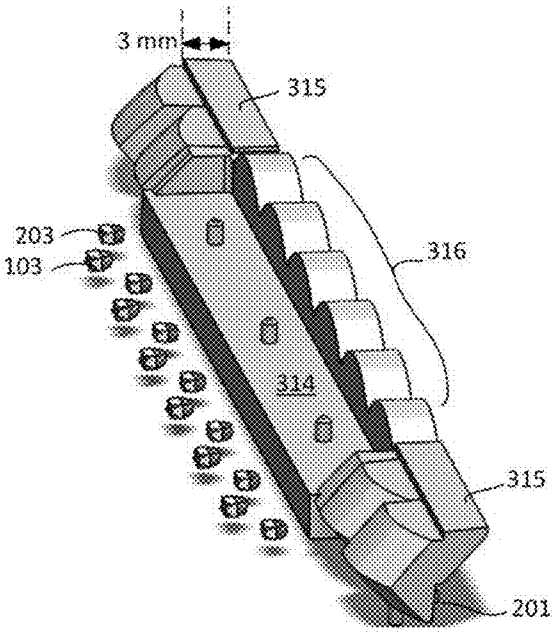



FIG. 67(a)

Long range
Cross-sectional view

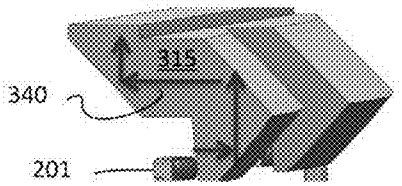



FIG. 67(b)

Short range
Cross-sectional view

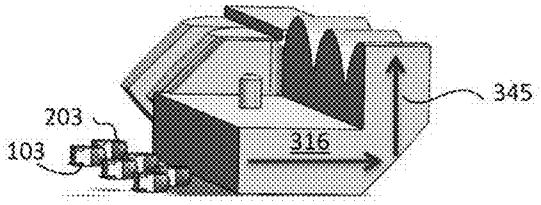
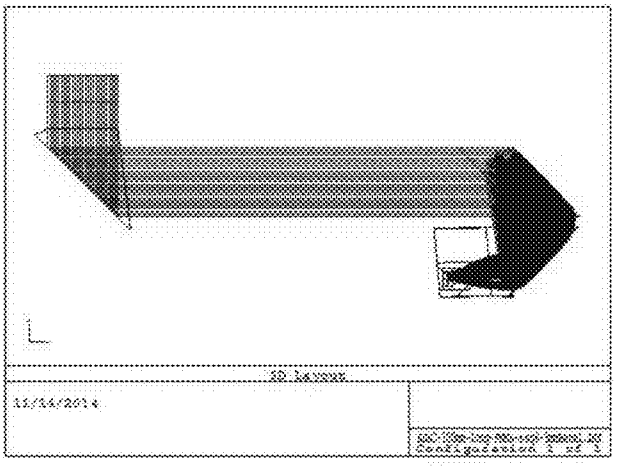



FIG. 67(c)

Key: ⟶ Light Path

Side



Top

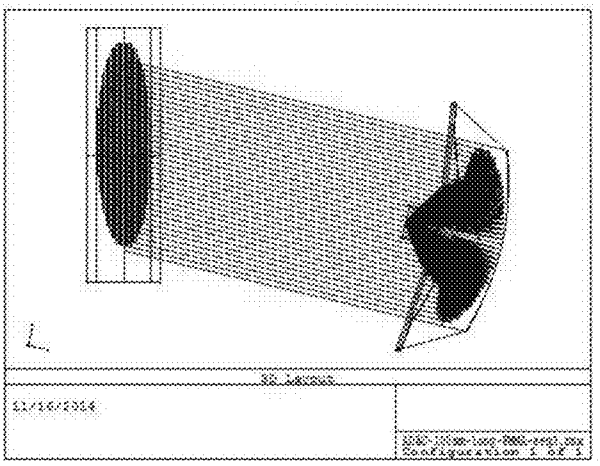
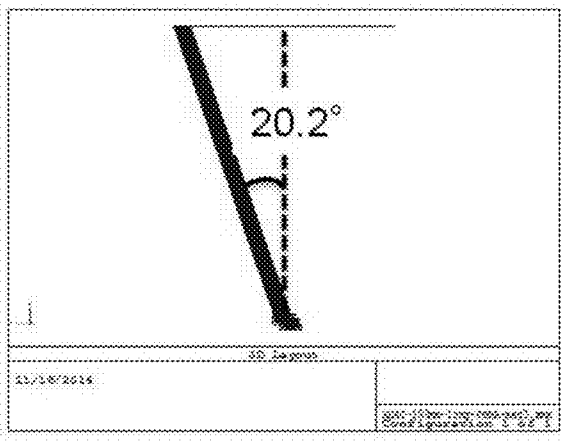


FIG. 68

Back




Back [zoomed]

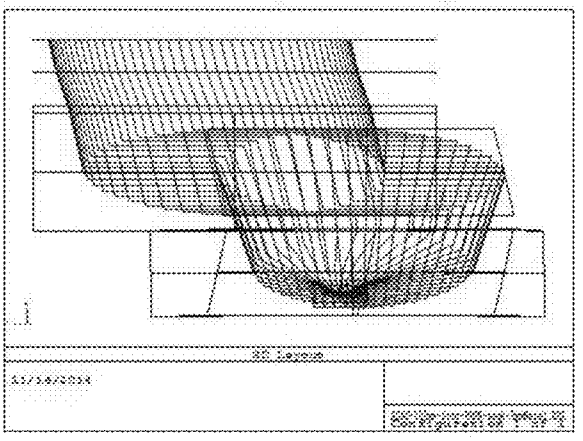


FIG. 69

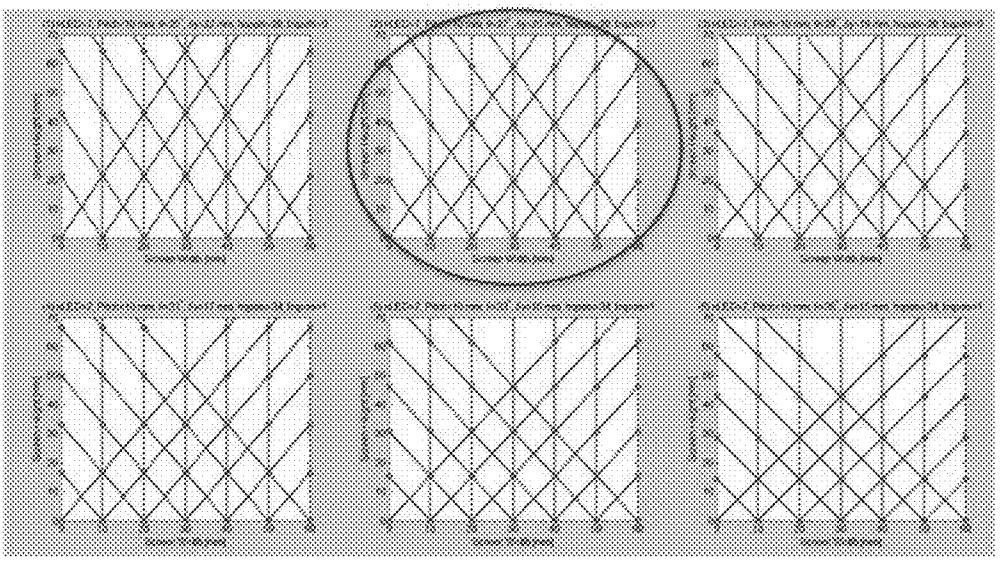
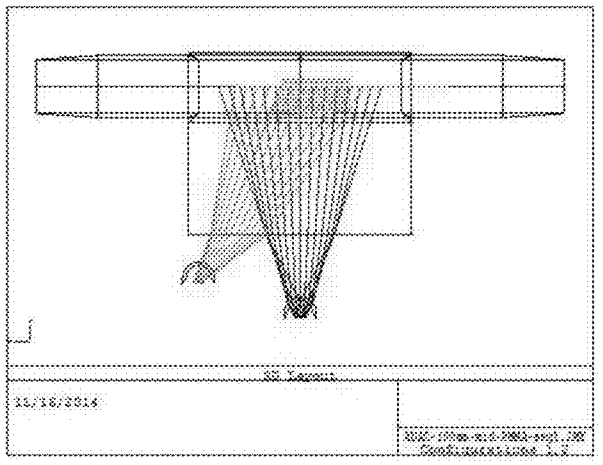


FIG. 70

Top



Side

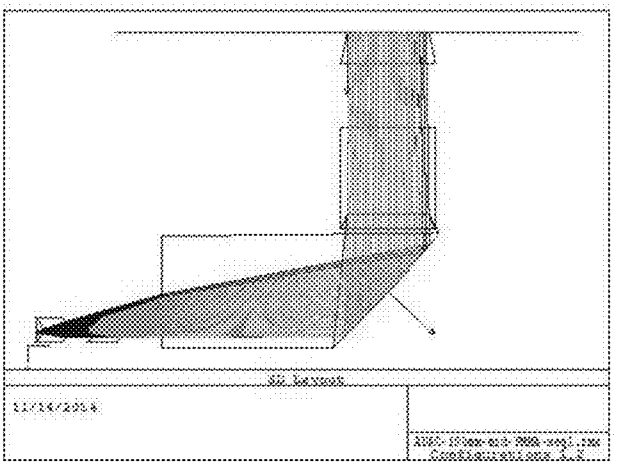
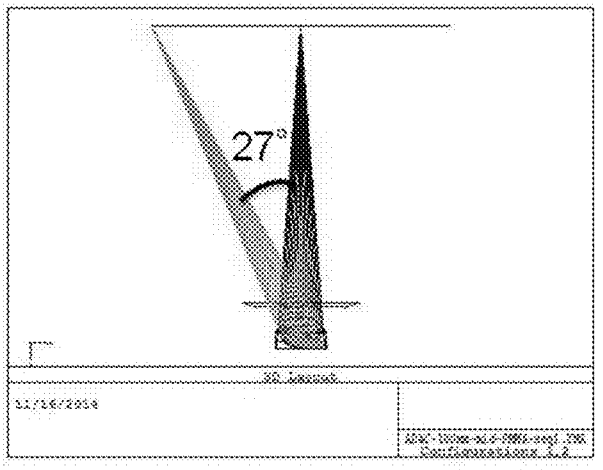


FIG. 71

Back




Back [zoomed]

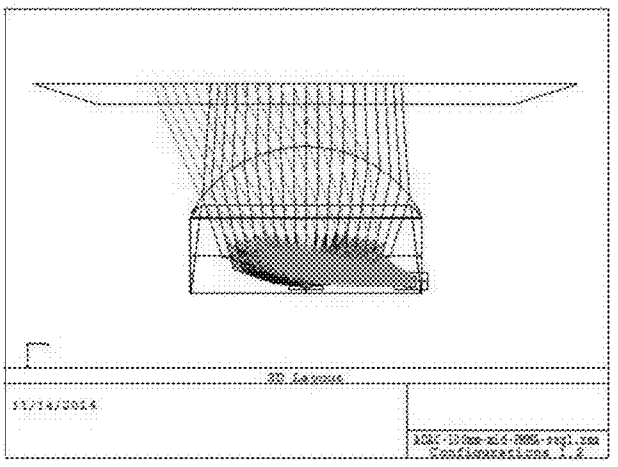


FIG. 72

FIG. 73(a)

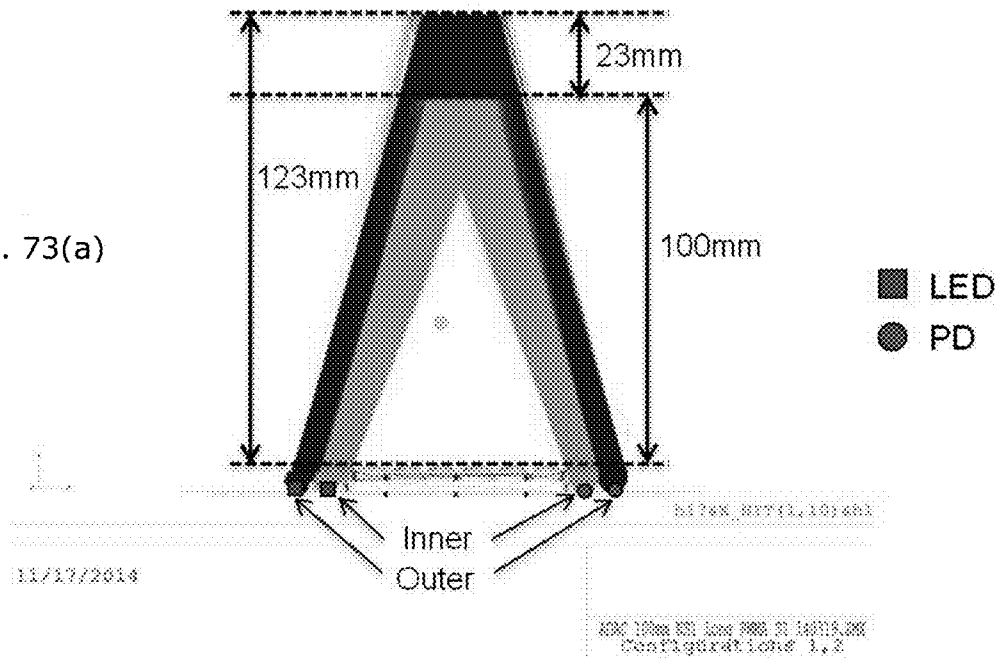



FIG. 73(b)

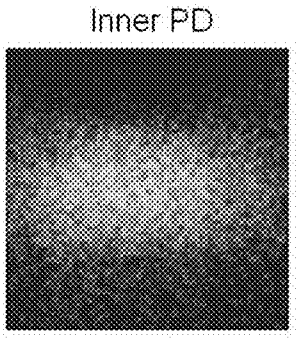
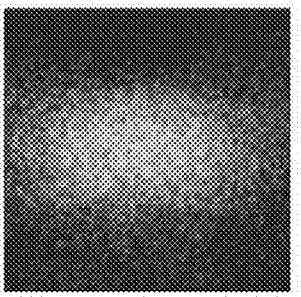



FIG. 73(c)



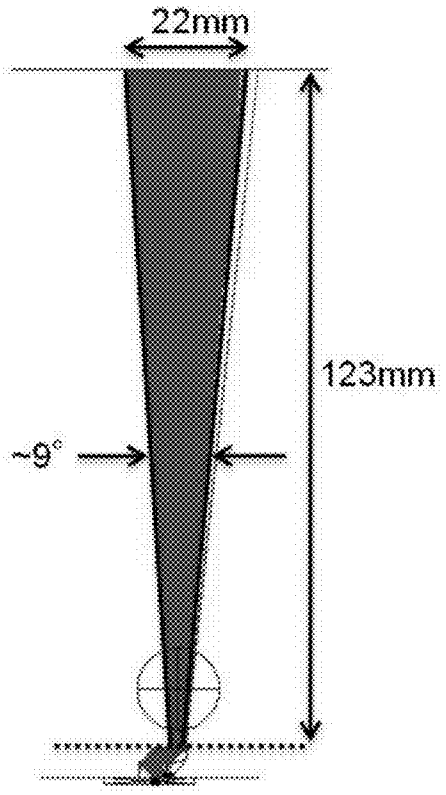



FIG. 74

FIG. 75(a)

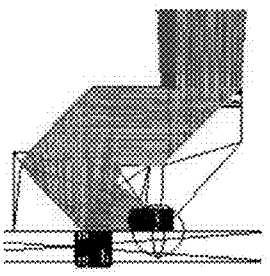


FIG. 75(b)

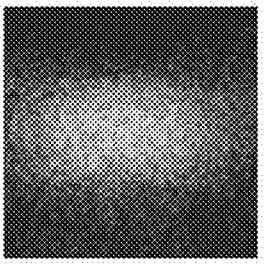


FIG. 75(c)

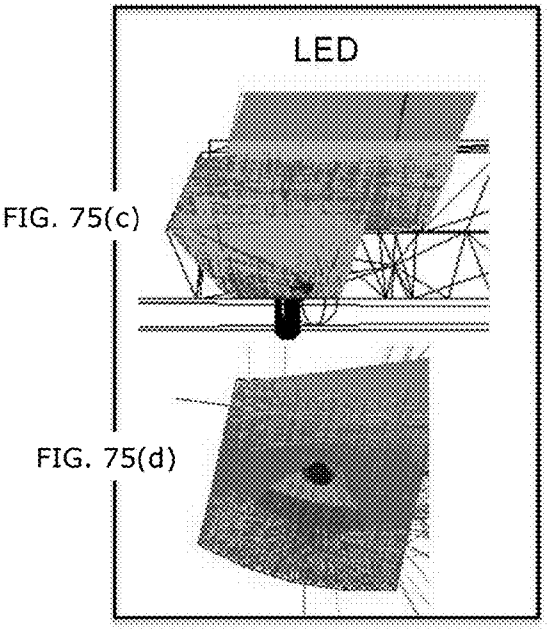



FIG. 75(d)

FIG. 75(e)

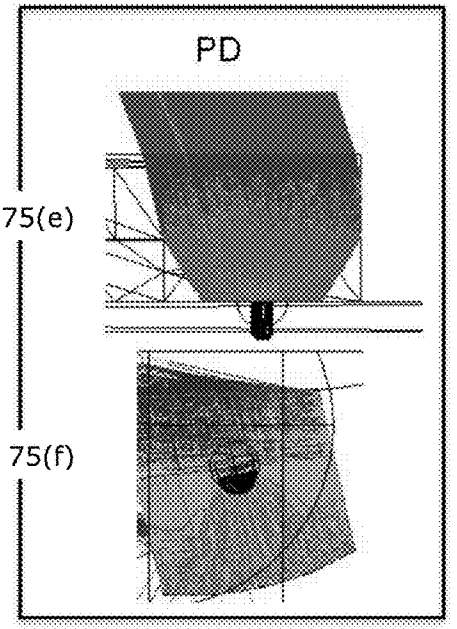



FIG. 75(f)

FIG. 76(a)

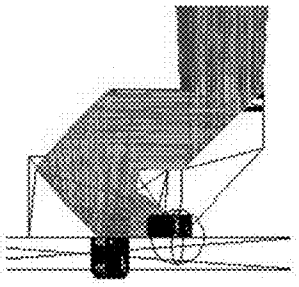
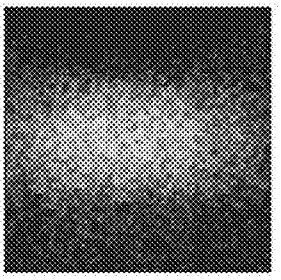


FIG. 76(b)



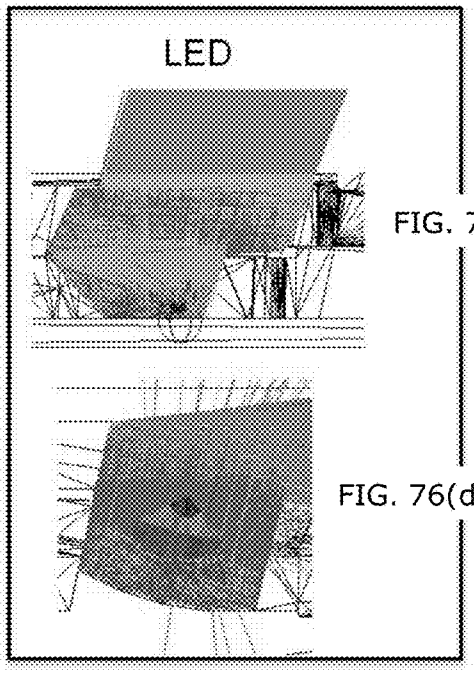



FIG. 76(c)

FIG. 76(d)

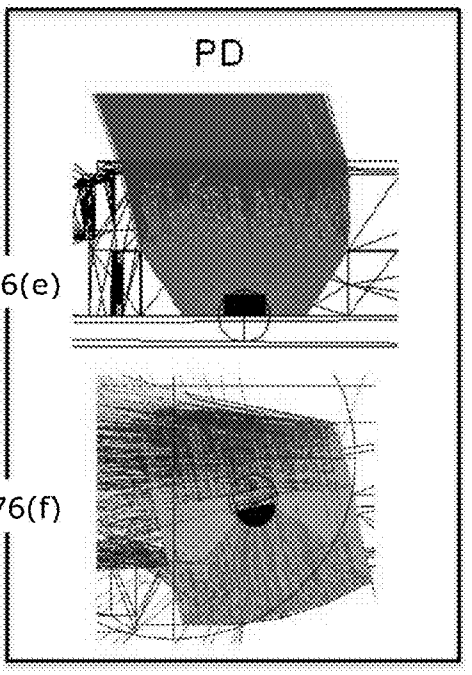



FIG. 76(e)

FIG. 76(f)

Short Range– Optimized Signal Regions

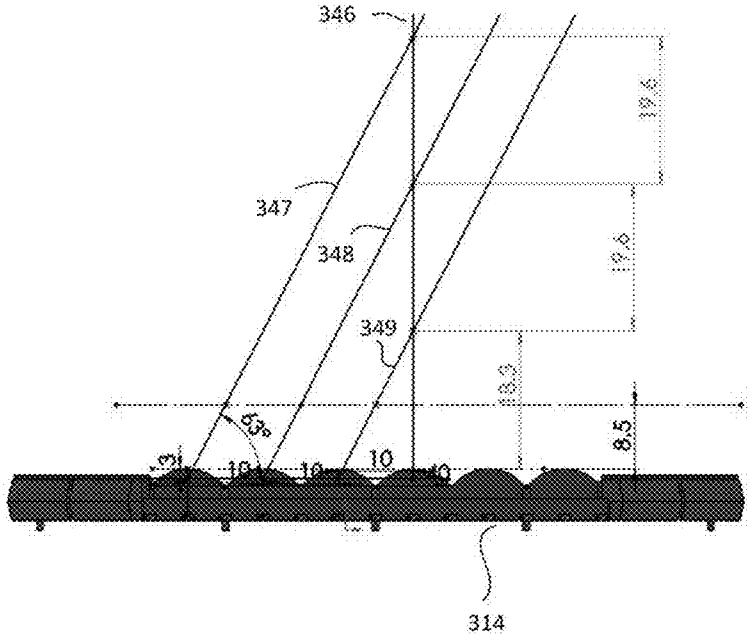



FIG. 77

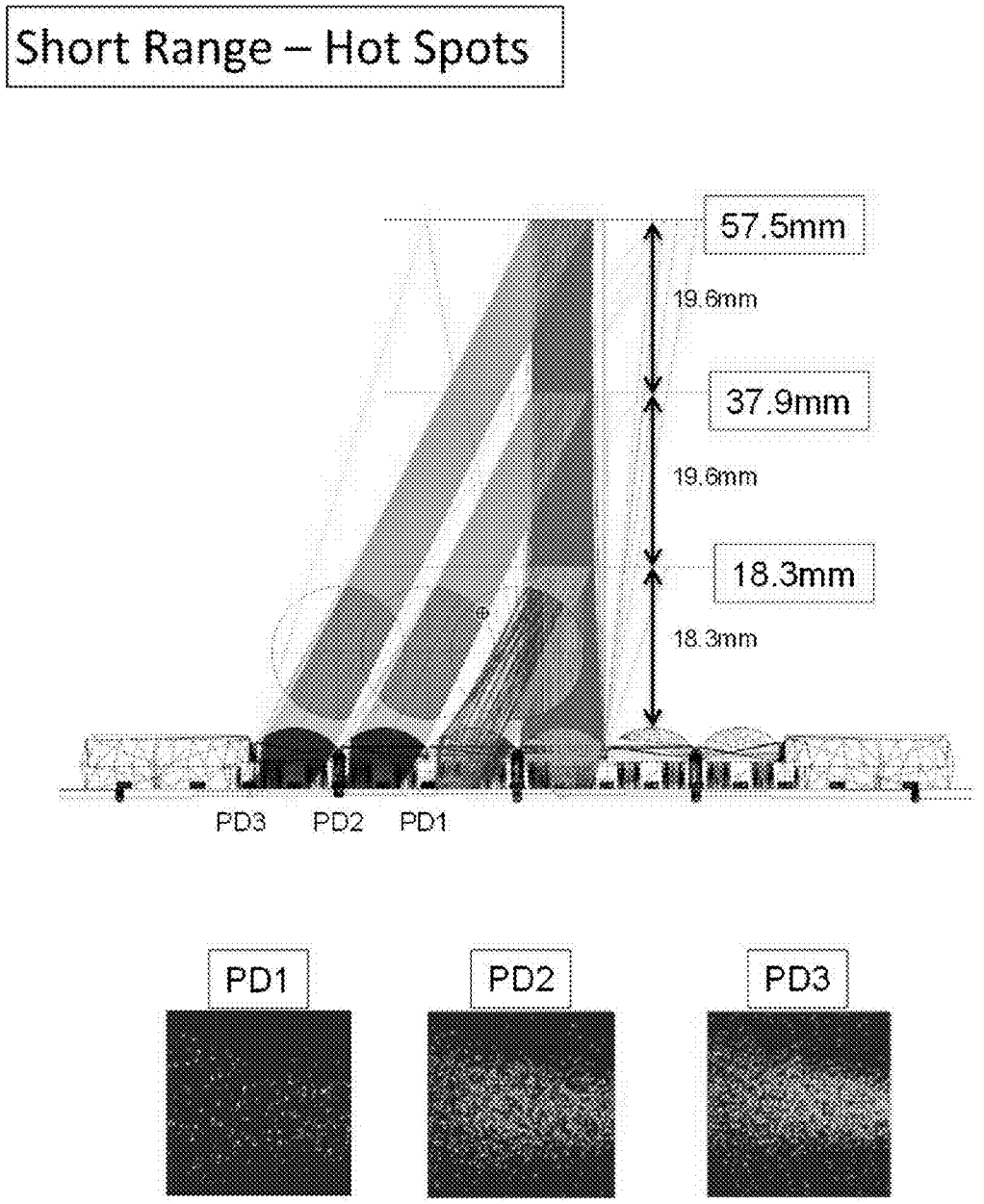

Short Range – Hot Spots
57.5mm
19.6mm
37.9mm
19.6mm
18.3mm
18.3mm
PD3
PD2
PD1
PD1
PD2
PD3

FIG. 78

Short Range Fill Factors – Back

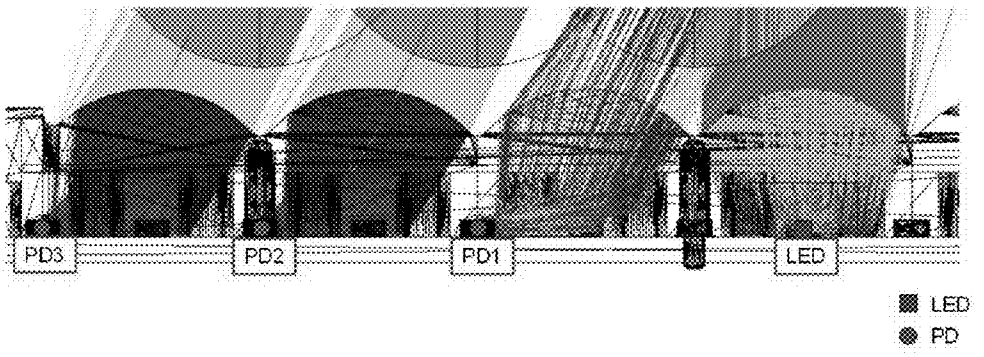
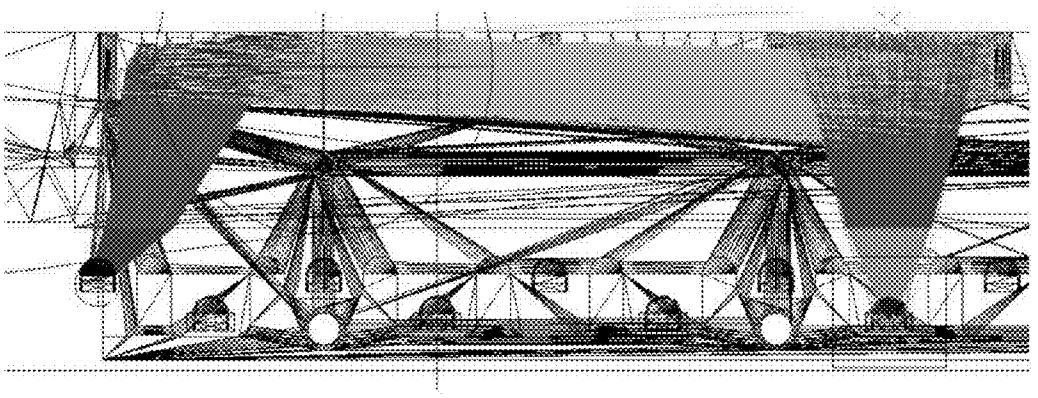



FIG. 79

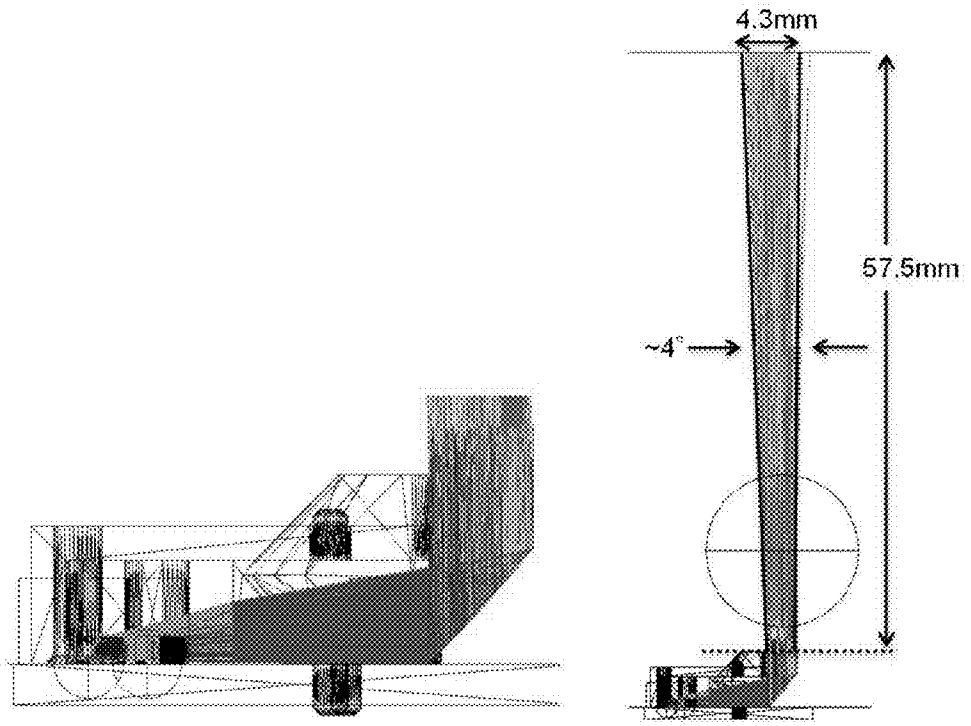
Short Range Fill Factors – Top



Example of PD3, which detects the farthest signal in the short range

FIG. 80

Short Range Beam Divergence – Side




Farthest scatterer plane example
~4 degrees or 4.3mm spread at 57.5mm
Excellent fill factors

FIG. 81

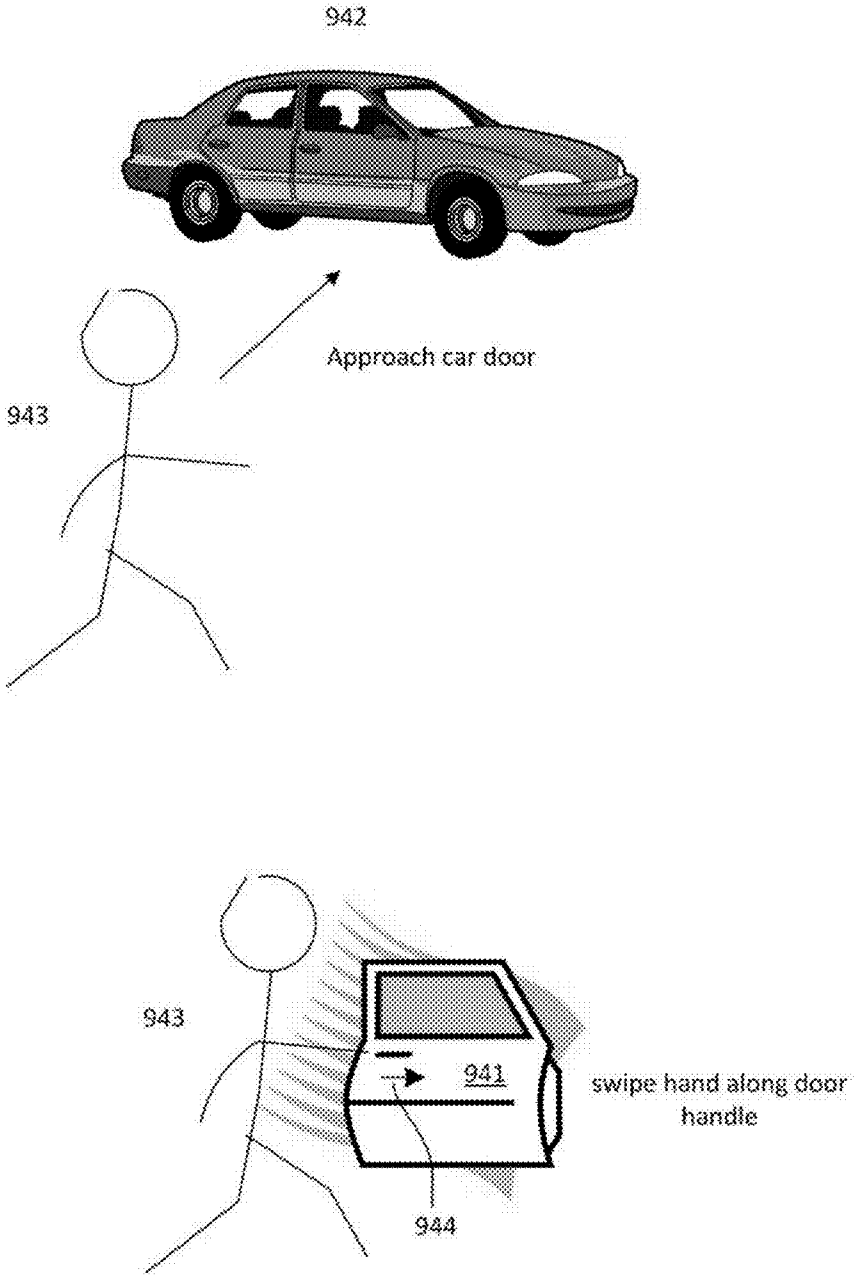

942
Approach car door
943
943
941
swipe hand along door handle
944

FIG. 82

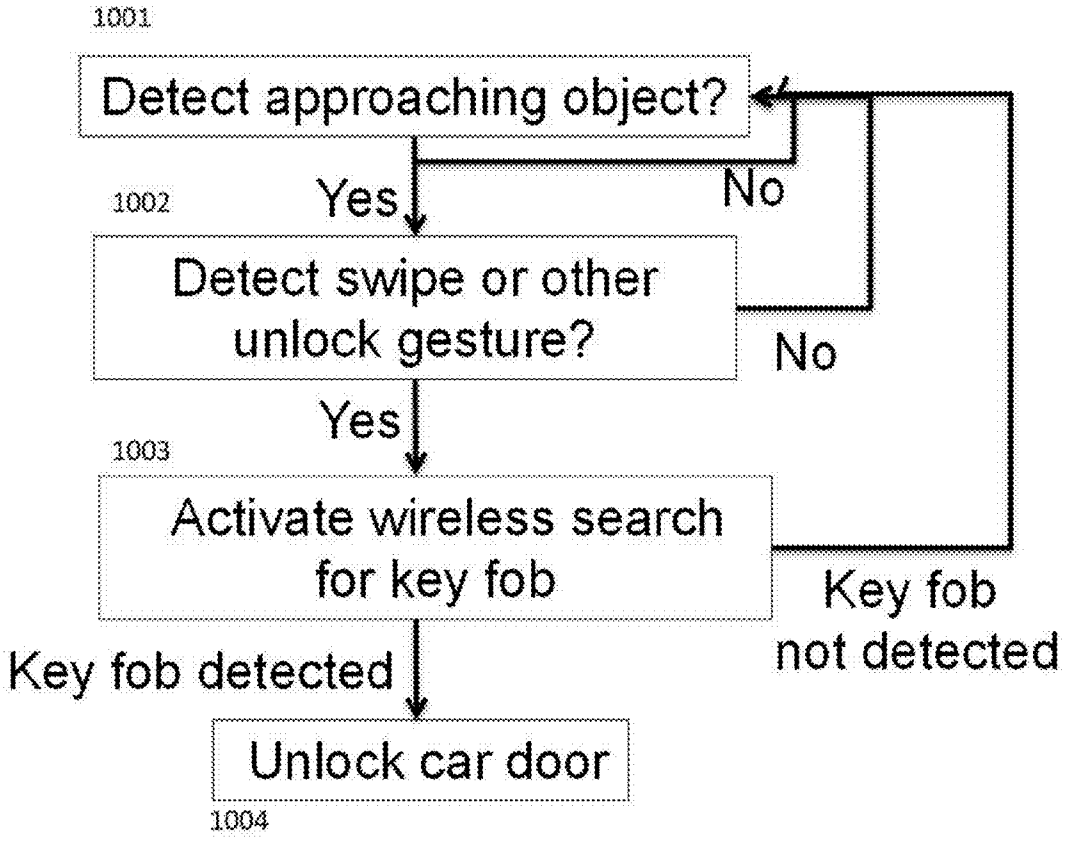

1001
Detect approaching object?
Yes
No
1002
Detect swipe or other unlock gesture?
No
Yes
1003
Activate wireless search for key fob
Key fob not detected
Key fob detected
Unlock car door
1004

FIG. 83

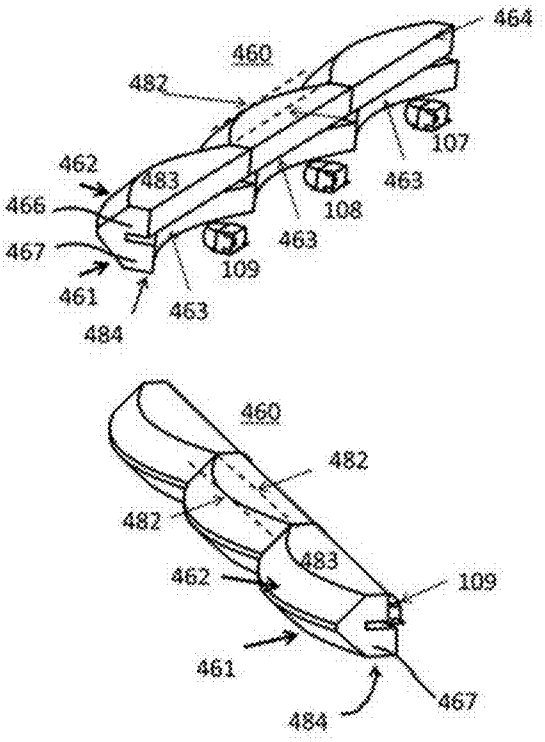

464
460
482
107
462
483
463
466
108
463
467
109
461
463
484
460
482
482
483
462
109
461
467
484

FIG. 84

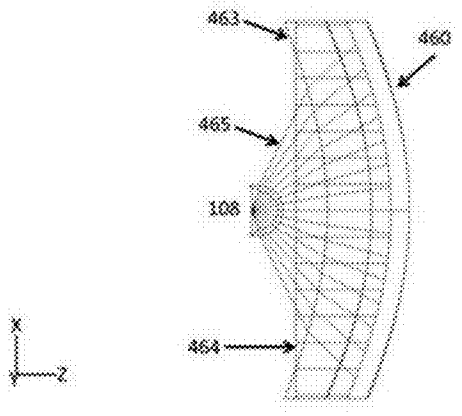



FIG. 85

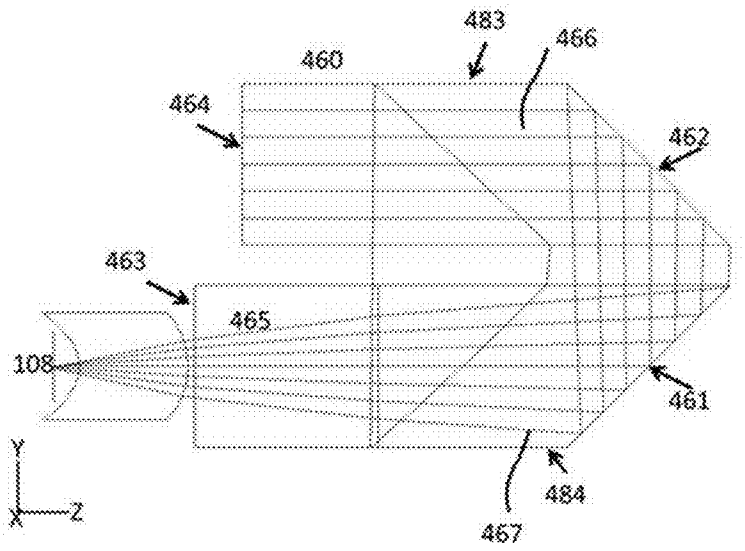



FIG. 86

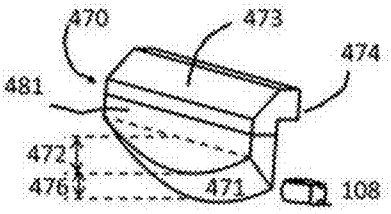



FIG. 87

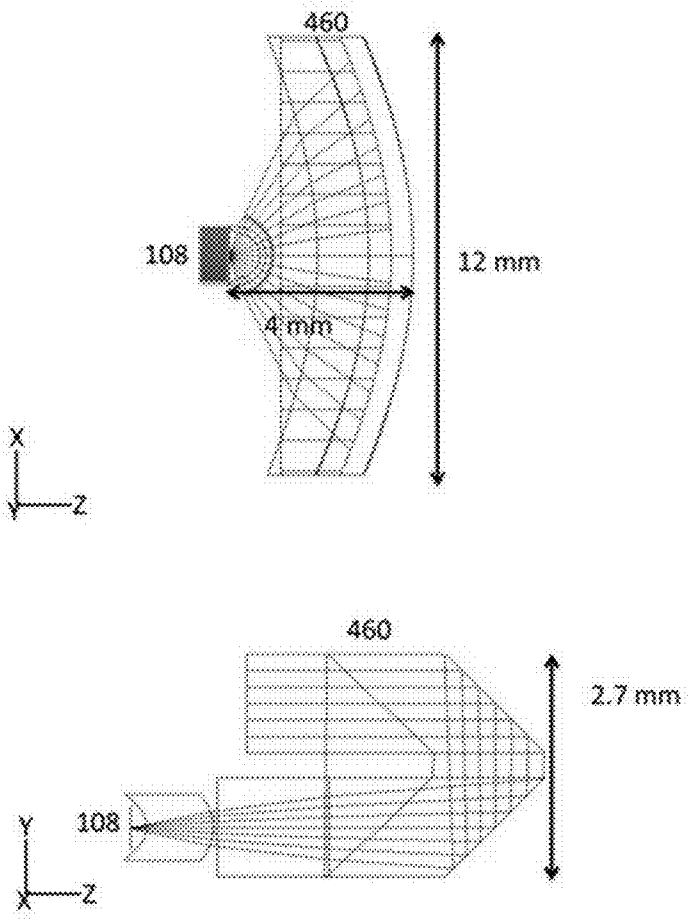



FIG. 88

# DOOR HANDLE WITH OPTICAL PROXIMITY SENSORS

## CROSS REFERENCES TO RELATED APPLICATIONS

This application claims priority benefit from

U.S. Provisional Patent Application No. 61/986,341, entitled OPTICAL TOUCH SCREEN SYSTEMS, and filed on Apr. 30, 2014 by inventors Sairam Iyer, Karl Erik Patrik Nordström, Lars Sparf, Per Rosengren, Erik Rosengren, Thomas Eriksson, Alexander Jubner and Joseph Shain;

U.S. Provisional Patent Application No. 61/972,435, entitled OPTICAL TOUCH SCREEN SYSTEMS, and filed on Mar. 31, 2014 by inventors Sairam Iyer, Karl Erik Patrik Nordström, Per Rosengren, Stefan Holmgren, Erik Rosengren, Robert Pettersson, Lars Sparf and Thomas Eriksson;

U.S. Provisional Patent Application No. 61/950,868, entitled OPTICAL TOUCH SCREENS, and filed on Mar. 11, 2014 by inventors Karl Erik Patrik Nordström, Per Rosengren, Stefan Holmgren, Erik Rosengren, Robert Pettersson, Lars Sparf and Thomas Eriksson;

U.S. Provisional Patent Application No. 61/929,992, entitled CLOUD GAMING USER INTERFACE, and filed on Jan. 22, 2014 by inventors Thomas Eriksson, Stefan Holmgren, John Karlsson, Remo Behdasht, Erik Rosengren, Lars Sparf and Alexander Jubner; and

U.S. Provisional Patent Application No. 61/923,775, entitled MULTI-TOUCH OPTICAL TOUCH SCREENS WITHOUT GHOST POINTS, and filed on Jan. 6, 2014 by inventors Per Rosengren, Stefan Holmgren, Erik Rosengren, Robert Pettersson, Lars Sparf and Thomas Eriksson.

This application is a continuation-in-part of U.S. patent application Ser. No. 14/140,635, now U.S. Pat. No. 9,001,987, entitled LIGHT-BASED PROXIMITY DETECTION SYSTEM AND USER INTERFACE, and filed on Dec. 26, 2013 by inventors Thomas Eriksson and Stefan Holmgren.

This application is a continuation-in-part of U.S. patent application Ser. No. 14/311,366, now U.S. Pat. No. 9,063,614, entitled OPTICAL TOUCH SCREENS, and filed on Jun. 23, 2014 by inventors Robert Pettersson, Per Rosengren, Erik Rosengren, Stefan Holmgren, Lars Sparf, Richard Berglind, Thomas Eriksson, Karl Erik Patrik Nordström, Gunnar Martin Fröjdh, Xiatao Wang and Remo Behdasht.

This application is a continuation-in-part of U.S. patent application Ser. No. 14/312,787, now U.S. Pat. No. 9,164,625, entitled OPTICAL PROXIMITY SENSORS, and filed on Jun. 24, 2014 by inventors Stefan Holmgren, Sairam Iyer, Richard Berglind, Karl Erik Patrik Nordström, Lars Sparf, Per Rosengren, Erik Rosengren, John Karlsson, Thomas Eriksson, Alexander Jubner, Remo Behdasht, Simon Fellin, Robin Åman and Joseph Shain.

U.S. patent application Ser. No. 14/140,635 is a continuation of U.S. patent application Ser. No. 13/732,456, now U.S. Pat. No. 8,643,628, entitled LIGHT-BASED PROXIMITY DETECTION SYSTEM AND USER INTERFACE, and filed on Jan. 2, 2013 by inventors Thomas Eriksson and Stefan Holmgren, the contents of which are hereby incorporated in their entirety.

U.S. patent application Ser. No. 13/732,456 claims priority benefit of U.S. Provisional Patent Application Ser. No. 61/713,546, entitled LIGHT-BASED PROXIMITY DETECTION SYSTEM AND USER INTERFACE, and filed on Oct. 14, 2012 by inventor Stefan Holmgren, the contents of which are hereby incorporated herein in their entirety.



U.S. patent application Ser. No. 14/311,366 is a continuation of PCT Patent Application No. PCT/US14/40579, entitled OPTICAL TOUCH SCREENS, and filed on Jun. 3, 2014 by inventors Robert Pettersson, Per Rosengren, Erik Rosengren, Stefan Holmgren, Lars Sparf, Richard Berglind, Thomas Eriksson, Karl Erik Patrik Nordström, Gunnar Martin Fröjdh, Xiatao Wang and Remo Behdasht.

U.S. patent application Ser. No. 14/312,787 is a continuation of PCT Application No. PCT/US14/40112, entitled OPTICAL PROXIMITY SENSORS, and filed on May 30, 2014 by inventors Stefan Holmgren, Sairam Iyer, Richard Berglind, Karl Erik Patrik Nordström, Lars Sparf, Per Rosengren, Erik Rosengren, John Karlsson, Thomas Eriksson, Alexander Jubner, Remo Behdasht, Simon Fellin, Robin Åman and Joseph Shain.

PCT Application No. PCT/US14/40112 claims priority benefit from

U.S. Provisional Patent Application No. 61/846,089, entitled PROXIMITY SENSOR FOR LAPTOP COMPUTER AND ASSOCIATED USER INTERFACE, and filed on Jul. 15, 2013 by inventors Richard Berglind, Thomas Eriksson, Simon Fellin, Per Rosengren, Lars Sparf, Erik Rosengren, Joseph Shain, Stefan Holmgren, John Karlsson and Remo Behdasht;

U.S. Provisional Patent Application No. 61/838,296, entitled OPTICAL GAME ACCESSORIES USING REFLECTED LIGHT, and filed on Jun. 23, 2013 by inventors Per Rosengren, Lars Sparf, Erik Rosengren, Thomas Eriksson, Joseph Shain, Stefan Holmgren, John Karlsson and Remo Behdasht; and

U.S. Provisional Patent Application No. 61/828,713, entitled OPTICAL TOUCH SCREEN SYSTEMS USING REFLECTED LIGHT, and filed on May 30, 2013 by inventors Per Rosengren, Lars Sparf, Erik Rosengren and Thomas Eriksson.

U.S. patent application Ser. No. 14/312,787 is a continuation-in-part of U.S. patent application Ser. No. 13/775,269, now U.S. Pat. No. 8,917,239, entitled REMOVABLE PROTECTIVE COVER WITH EMBEDDED PROXIMITY SENSORS, and filed on Feb. 25, 2013 by inventors Thomas Eriksson, Stefan Holmgren, John Karlsson, Remo Behdasht, Erik Rosengren and Lars Sparf.

The contents of these applications are hereby incorporated by reference in their entireties.

## FIELD OF THE INVENTION

The field of the present invention is door handles with light-based proximity sensor mechanisms for unlocking the door.

## BACKGROUND OF THE INVENTION

The mechanism of keyless entry into cars is a popular feature that many current automotive companies have adopted. By simply swiping the door handle, a signal is sent to look for a key fob, and if a proper fob is found on the user then the door is unlocked. Current capacitive touch door handles include such a mechanism, but they do not perform well when the hand that swipes is wearing regular leather gloves or when the handle is wet. Nor do they offer off-surface gesture recognition.

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.

Prior art light-based touch screens surround the screen borders with light emitters and light detectors to create a light beam grid above the screen surface. An object touching the screen from above blocks a corresponding portion of the beams.

Reference is made to FIG. **1**, which is a diagram of a prior art, light-based touch screen having 16 LEDs and 16 PDs. Screen **100** in FIG. **1** is surrounded by emitters **130** along two edges and photodiode (PD) receivers **240** along the remaining two edges, which together enable a lattice of light beams covering the screen.

One drawback of prior art light-based touch screens is the need to accommodate the numerous light emitters and light detectors along all four edges of the screen. This requirement makes it difficult to insert light-based touch detection into an existing electronic device without significantly changing the layout of the device's internal components. It would be advantageous to reduce the number of components required and to enable placing them in a limited area rather than surrounding the entire screen. Reducing the total number of light emitters and light detectors required has the added benefit of reducing the bill-of-materials (BOM).

## SUMMARY

Embodiments of the present invention provide two-dimensional (2D) touch detection using a one-dimensional array of alternating light emitters and detectors. Other embodiments of the present invention provide 2D touch detection using a one-dimensional array of light emitters along only one edge of the screen and an opposite array of light detectors along the opposite edge of the screen. The present invention also provides a three-dimensional (3D) touch or hover detection based on the same principles as the 2D detectors.

There is thus provided in accordance with an embodiment of the present invention a row of alternating light emitters and detectors. The light emitters project collimated light beams perpendicular to the row and parallel to each other in sequence. The light detectors detect light from the emitters that has been reflected by an object inserted into the light beam path. Each detector detects light in the plane of the emitter beams, but at a fixed angle relative to those beams. The distance between an emitter and a detector that detects light reflected from the emitter's beam, together with the fixed angle, is used to determine the location of the reflecting object by triangulation.

There is additionally provided in accordance with an embodiment of the present invention a row of light emitters along the bottom edge of a screen and a row of light detectors along the top edge of the screen. Each light emitter projects a very wide beam that is detected by all of the light detectors. The x-coordinate of an object touching the screen corresponds to a blocked beam that runs parallel to the side edges of the screen. The y-coordinate is determined by identifying the intersections between diagonal blocked beams.

There is further provided in accordance with an embodiment of the present invention a proximity sensor for determining two-dimensional coordinates of a proximal object, including a housing, a plurality of light pulse emitters mounted in the housing for projecting light out of the housing along a detection plane, a plurality of primary light detectors mounted in the housing for detecting reflections of the light projected by the emitters, by a reflective object in the detection plane, a plurality of primary lenses mounted and oriented in the housing relative to the emitters and the primary detectors in such a manner that for each emitter-detector pair, light emitted by the emitter of that pair passes through one of the primary lenses and is reflected by the object back through one of the primary lenses to the detector of that pair when the object is located at a two-dimensional position, from among a primary set of positions in the detection plane, that position being associated with that emitter-detector pair, and a processor connected to the emitters and to the primary detectors, for synchronously co-activating emitter-detector pairs, and configured to calculate a two-dimensional location of the object in the detection plane by determining an emitter-detector pair among the co-activated emitter-detector pairs, for which the detector detects a maximum amount of light, and identifying the position associated therewith, determining additional positions that are associated with co-activated emitter-detector pairs and that neighbor the thus-identified position, and calculating a weighted average of the thus-identified position and the thus-determined additional positions, wherein each position's weight in the average corresponds to a degree of detection of the reflected light beam for the emitter-detector pair to which that position is associated.

There is yet further provided in accordance with an embodiment of the present invention a proximity sensor for determining directional movement of a finger along a slider control, including a housing, a multi-layer, light transmissive cover mounted in said housing and having an exposed upper surface for a slider control, wherein a border between the layers of the cover comprises a pattern of light-transmissive portions separated by opaque or reflective portions, wherein the sizes of the light-transmissive portions, or of the opaque or reflective portions, increase across the pattern, a light pulse emitter mounted in the housing for projecting light into an upper layer of the cover, the projected light being confined to the upper layer by total internal reflection (TIR), wherein a finger touching the exposed upper surface frustrates the TIR light, causing a portion of the light to enter a second layer, underneath the upper layer and separated therefrom by the pattern, through the light-transmissive portions in the pattern, the portion of light entering the second layer corresponding to the sizes of the light-transmissive portions beneath the finger touching the exposed upper surface, a light detector mounted in the housing for detecting intensities of light in the second layer, and a processor connected to the light detector for determining directional movement of the object across the pattern, wherein the direction of the movement corresponds to whether the light detector detects an increasing series or a decreasing series of detected light intensities over time.

There is moreover provided in accordance with an embodiment of the present invention a proximity sensor for determining directional movement of an object along a slider control, including a housing, a light transmissive cover mounted in the housing having an exposed upper surface for a slider control, including a pattern of light-transmissive portions separated by opaque or reflective portions, wherein the sizes of the light-transmissive portions, or of the opaque or reflective portions, increase across the pattern, a light pulse emitter mounted in the housing for projecting light above the cover, a light detector mounted in the housing for detecting intensities of projected light that is reflected into the cover by a reflective object, wherein the

amount of light reflected by the object into the cover depends upon the sizes of the light-transmissive portions beneath the object, and a processor connected to the light detector for determining directional movement of the object across the pattern, wherein the direction of the movement corresponds to whether the light detector detects an increasing series or a decreasing series of detected light intensities over time.

There is additionally provided in accordance with an embodiment of the present invention a handheld electronic game device, including a housing, a communicator mounted in the housing for communicating with an internet game server, a display mounted in the housing for rendering a portion of a game user interface received by the communicator from the game server and sensors mounted in the housing and connected to the communicator for detecting a second game device placed nearby, wherein the communicator communicates detection information, regarding a nearby second game device, provided by said sensors to the game server.

There is further provided in accordance with an embodiment of the present invention an internet gaming system including an internet game server, and a number, greater than one, of game devices, each of which is a handheld electronic game device in communication with the game server, each game device including a housing, a communicator for communicating with the game server, a display mounted in the housing for rendering a respective portion of a game user interface (UI) received by the communicator from said game server, and sensors mounted in the housing and connected to the communicator for detecting presence of a neighboring game device, wherein the game server determines the size of each respective portion of the game UI based on the number of the game devices.

There is yet further provided in accordance with an embodiment of the present invention a door handle that includes a plurality of light emitters for emitting light out of the handle, a plurality of light detectors, a plurality of lenses oriented relative to the emitters and detectors such that for each emitter-detector pair, when a reflective object is located at a target position near the handle, corresponding to that emitter-detector pair, then the light emitted by that emitter passes through one of the lenses and is reflected by the object back through one of the lenses to that detector, a keyless lock that, when activated, scans for a digital key via wireless communication, and a processor connected to the keyless lock, to the emitters and to the detectors, operable to synchronously activate emitter-detector pairs, to recognize from the amounts of light received by the activated detectors, and from the target positions corresponding to the activated emitter-detector pairs, that the object is approaching the handle and performing a sweep gesture and, in response thereto, to activate said keyless lock.

There is moreover provided in accordance with an embodiment of the present invention a method for controlling a processor to unlock a door, the door including a handle that has a plurality of light emitters, denoted E, for emitting light out of the door handle, that has a plurality of light detectors, denoted D, and that has a plurality of lenses oriented relative to the emitters and detectors such that for each emitter-detector pair (E, D), when a reflective object is located at a target position P(E, D) near the door handle, corresponding to that emitter-detector pair (E, D), then the light emitted by emitter E passes through one of the lenses and is reflected by the object back through one of the lenses to that detector D. The method includes the steps of, synchronously activating a plurality of emitter-detector pairs (E, D) for each of a sequence of times, $t_1, \ldots, t_n$, and for each time $t_i$, calculating a position, $P_i$, of the object, based on the amounts R(E, D) of light received by D, at time $t_i$, for the emitter-detector pairs (E, D) that are synchronously activated at time $t_i$. The method includes the additional steps of, recognizing from the thus-calculated positions $P_1, \ldots, P_n$ of the object that the object is approaching the door handle and performing a sweep gesture along the door handle, and activating a keyless lock to scan for a digital key via wireless communication.

## BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will be more fully understood and appreciated from the following detailed description, taken in conjunction with the drawings in which:

FIG. **1** is a diagram of a prior art, light-based touch screen having 16 LEDs and 16 PDs;

FIG. **2** is a simplified diagram of a proximity sensor for detecting two-dimensional coordinates of an object in a two-dimensional detection area, in accordance with an embodiment of the present invention;

FIG. **3** is a simplified diagram of a touch screen system using the proximity sensor of FIG. **2**, in accordance an embodiment of the present invention;

FIGS. **4** and **5** are exploded views of an optical proximity sensor, in accordance with an embodiment of the present invention;

FIG. **6** is a view from above of an optical proximity sensor, in accordance with an embodiment of the present invention;

FIGS. **7-12** are simplified diagrams of emitted and reflected light beams used in an optical proximity sensor, in accordance with an embodiment of the present invention;

FIGS. **13** and **14** are illustrations of touch detection maps, in accordance with an embodiment of the present invention;

FIG. **15** is a simplified illustration of a lens array with alternating emitters and detectors, in accordance with an embodiment of the present invention;

FIGS. **16-18** are simplified touch detection maps used for illustrating the algorithms used to calculate a touch location using an optical proximity sensor, in accordance with an embodiment of the present invention;

FIG. **19** illustrates an interpolation of detection signals, in accordance with an embodiment of the present invention;

FIG. **20** illustrates a Hough transform, in accordance with an embodiment of the present invention;

FIG. **21** is a detection map, in accordance with an embodiment of the present invention;

FIGS. **22** and **23**(*a*)-(*f*) are simplified touch detection maps for various touch screen system embodiments, in accordance with the present invention;

FIGS. **24** and **25** are simplified illustrations of a dual-resolution sensor, in accordance with an embodiment of the present invention;

FIGS. **26**(*a*) and (*b*) are simplified illustrations of two detection maps used in a dual-resolution sensor, in accordance with an embodiment of the present invention;

FIG. **27** is a simplified view from above of LEDs and PDs on a PCB for a dual-resolution sensor, in accordance with an embodiment of the present invention;

FIG. **28** is a simplified cross-section illustration of a dual-resolution sensor, in accordance with an embodiment of the present invention;

FIG. **29** is a simplified illustration of a dual-display laptop, in accordance with an embodiment of the present invention;

FIG. **30** is a simplified illustration of a portion of a dual-display laptop, in accordance with an embodiment of the present invention;

FIG. **31** is a simplified illustration of a PC, in accordance with an embodiment of the present invention;

FIG. **32** is a simplified illustration of the keyboard of the PC of FIG. **31**, in accordance with an embodiment of the present invention;

FIG. **33** is a simplified illustration of a PC trackpad, in accordance with an embodiment of the present invention;

FIG. **34** is a simplified illustration of a transparent PC keyboard, in accordance with an embodiment of the present invention;

FIG. **35** is a simplified side perspective view of the transparent keyboard of FIG. **34**, in accordance with an embodiment of the present invention;

FIG. **36** is a simplified illustration of a secondary display that provides keyboard and GUI functionality, in accordance with an embodiment of the present invention;

FIG. **37** is a simplified illustration of a laptop keyboard, in accordance with an embodiment of the present invention;

FIG. **38** is a simplified cross-section of the laptop keyboard of FIG. **37**, in accordance with an embodiment of the present invention;

FIG. **39** is a simplified illustration of a PC with proximity sensors for detecting wave gestures that approach a side edge of the display, in accordance with an embodiment of the present invention;

FIG. **40** is a simplified illustration of three views of an exemplary four-button keypad chassis, situated over a virtual keypad portion of a touch panel, in accordance with an embodiment of the present invention;

FIG. **41** is a simplified illustration of a cross-section of an exemplary four-button keypad chassis, situated over a virtual keypad portion of a touch panel, in accordance with an embodiment of the present invention;

FIGS. **42**(*a*)-(*c*) are simplified illustrations of a spring-resilient key that is released and depressed, in accordance with an embodiment of the present invention;

FIGS. **43**(*a*) and (*b*) are simplified illustrations of a cross-section of a button comprised of an elastic, resilient material such as rubber, in accordance with an embodiment of the present;

FIGS. **44**(*a*)-(*d*) are simplified illustrations of an alternative button configuration, in accordance with an embodiment of the present invention;

FIG. **45** is a simplified illustration of an arrangement of micro lens arrays between a keyboard display and a fiber optic face plate key, in accordance with an embodiment of the present invention;

FIG. **46** is a simplified illustration of a key or button, in accordance with an embodiment of the present invention;

FIG. **47** is a simplified illustration of a slider control, in accordance with an embodiment of the present invention;

FIG. **48** is a simplified illustration of various detection patterns of gestures using the slider control of FIG. **47**, in accordance with an embodiment of the present invention;

FIG. **49** is a simplified illustration of an alternative slider control, in accordance with an embodiment of the present invention;

FIGS. **50-53** are simplified illustrations of a game accessory, in accordance with an embodiment of the present invention;

FIG. **54** is a simplified illustration of a 3-dimensional sensor using multiple optical proximity sensors, in accordance with an embodiment of the present invention;

FIG. **55** is a simplified illustration of a handheld electronic game device having a communicator for communicating with an internet game server, in accordance with an embodiment of the present invention;

FIG. **56** is a simplified illustration of an internet game rendered on a handset, in accordance with an embodiment of the present invention;

FIG. **57** is a simplified illustration of two handsets being used together to render an internet game, in accordance with an embodiment of the present invention;

FIG. **58** is a simplified illustration of a two-panel display for an internet game, the display being made up of two handsets, in accordance with an embodiment of the present invention;

FIG. **59** is a simplified illustration of a four-panel display for an internet game, the display being made up of four handsets, in accordance with an embodiment of the present invention;

FIG. **60** is a simplified illustration of a configuration of the four game devices of FIG. **59**, whereby the game GUI is distributed among the four displays according to each display's relative position and orientation, as detected by sensors and communicated to a game server, in accordance with an embodiment of the present invention;

FIGS. **61-64** are simplified illustrations of a door handle with embedded proximity sensors, in accordance with an embodiment of the present invention;

FIG. **65** is a simplified illustration of dimensions of a proximity sensor zone in the airspace opposite the door handle, in accordance with an embodiment of the present invention;

FIGS. **66**(*a*) and (*b*) and **67**(*a*)-(*c*) are simplified illustrations of a light-based proximity sensor, in accordance with an embodiment of the present invention;

FIGS. **68** and **69** are simplified illustrations of light beam paths through a light guide, in accordance with an embodiment of the present invention;

FIG. **70** is a simplified illustration of different configurations of light beams for a proximity sensor, in accordance with an embodiment of the present invention;

FIGS. **71** and **72** are simplified illustrations of light beam paths through a light guide, in accordance with an embodiment of the present invention;

FIGS. **73**(*a*)-(*c*) and **74** are simplified illustrations of light beam paths in the airspace opposite proximity sensors, in accordance with an embodiment of the present invention;

FIGS. **75**(*a*)-(*f*) and **76**(*a*)-(*f*) are simplified illustrations of light beam paths through light guides, in accordance with an embodiment of the present invention;

FIGS. **77-81** are simplified illustrations of light beam paths in the airspace opposite proximity sensors, in accordance with an embodiment of the present invention;

FIG. **82** is a simplified illustration of unlocking a door handle using proximity sensors, in accordance with an embodiment of the present invention;

FIG. **83** is a flowchart of a method for unlocking a door handle using proximity sensors, in accordance with an embodiment of the present invention;

FIGS. **84-86** are simplified illustrations of a light guide, in accordance with an embodiment of the present invention;

FIG. **87** is a prior art illustration of a light guide; and

FIG. **88** is a simplified illustration of a light guide, in accordance with an embodiment of the present invention.

The following tables catalog the numbered elements and list the figures in which each numbered element appears. Similarly numbered elements represent elements of the same

type, but they need not be identical elements. Numbers above 1000 are used for operations of a method.

Numbered Elements

| Element | Description | FIGS. |
|---|---|---|
| 10 | key or button | 40-44 |
| 12 | chassis | 40-44 |
| 14 | touch panel | 40-43 |
| 16 | emitter/photo-detector | 40 |
| 20 | light beam | 40-44 |
| 22 | lens | 41-43 |
| 24 | spring | 42 |
| 30 | cavity | 44 |
| 51-54 | micro-lens array | 45, 46 |
| 55 | aperture mask | 45, 46 |
| 56 | display | 45, 46 |
| 57 | fiber optic face plate (FOFP) input surface | 45 |
| 58 | FOFP | 46 |
| 59 | key or button | 46 |
| 100 | screen | 1, 28 |
| 101-108, 111, 130 | emitters | 1-4, 6-12, 15, 25, 27, 38, 47, 49-53, 66, 67, 84-88 |
| 131 | primary display | 29, 31, 39 |
| 132 | secondary display | 29, 30, 37 |
| 133 | keyboard | 31, 32 |
| 134 | track board | 31, 33 |
| 135 | keyboard | 34, 35 |
| 136, 137 | GUI control | 36 |
| 139 | liquid layer | 38 |
| 140 | light blocker | 38 |
| 141 | plastic film | 38 |
| 142-145 | display | 60 |
| 201-210, 211, 215, 240 | photo-detectors | 1-4, 6-8, 10-12, 15, 25, 27, 28, 38, 47, 49-53, 66, 67 |
| 301 | light guide | 3 |
| 302, 303 | lenses | 3 |
| 304 | light guide | 28 |
| 305-307 | reflective facets | 28 |
| 310 | light guide | 4, 5 |
| 311 | lens | 4, 6, 8-11 |
| 312 | lens array | 2, 15, 25 |
| 313 | proximity sensor array outer surface | 61 |
| 314 | Light guide | 67, 77 |
| 315 | Light guide | 67, |
| 316 | Light guide | 67, |
| 320, 321 | light barrier | 4-6 |
| 322 | light beams | 64, 65 |
| 331 | bezel | 30 |
| 332 | light guide | 37 |
| 333 | TIR upper light guide | 47, 49 |
| 334 | TIR lower light guide | 47 |
| 335 | opaque elements | 47, 49 |
| 336, 401 | light beams | 3, 49 |
| 340, 345, 346 | light beams | 67, 77 |
| 347-349 | reflected light beam path | 77 |
| 402 | reflected light beam | 3 |
| 403-405 | light beams | 2, 15, 25 |
| 406-409 | reflected light beams | 2, 15 |
| 410 | light beams | 9-12 |
| 411-413 | reflected light beams | 2, 7, 10-12 |
| 420 | light beam | 8 |
| 421 | reflected light beams | 8 |
| 422 | reflected light beam detection paths | 64, 65 |
| 432 | light beams | 37 |
| 433 | TIR light | 37 |
| 434 | FTIR light | 37 |
| 460 | lens | 84-86, 88 |
| 461 | curved reflective surface | 84, 86 |
| 462 | curved reflective surface | 84, 86 |
| 463 | entry surface | 84-86 |
| 464 | exit surface | 84-86 |
| 465 | light beam | 85, 86 |

-continued

Numbered Elements

| Element | Description | FIGS. |
|---|---|---|
| 466 | upper lens portion | 84, 86 |
| 467 | lower lens portion | 84, 86 |
| 470 | light guide | 87 |
| 471 | curved reflective surface | 87 |
| 472 | height of parabola | 87 |
| 473 | reflector | 87 |
| 474 | bezel height | 87 |
| 476 | height for light channel | 87 |
| 482 | depth of parabola | 84 |
| 483 | top horizontal plane | 84, 86 |
| 484 | bottom horizontal plane | 84, 86 |
| 501, 510, 511 | touch sensor bar | 4-6, 12, 24, 54 |
| 512-517 | proximity sensor | 2, 32, 33 |
| 518 | game device sensor | 55, 60 |
| 601, 602 | casing | 4, 5 |
| 603 | PCB | 4, 5, 27, 28 |
| 701 | controller | 6 |
| 702 | processor | 1 |
| 703 | communications processor | 55, 60 |
| 901 | object | 3 |
| 902-909 | position in detection plane | 2, 15, 19 |
| 910 | object | 6 |
| 911 | screen | 9, 54 |
| 912 | image plane | 8 |
| 913, 914 | point in image plane | 8 |
| 915 | angle | 8 |
| 916 | object plane | 8 |
| 917 | concentric shapes | 14 |
| 919 | area in detection map | 22 |
| 921, 922 | detection zone | 24 |
| 924 | finger | 47, 49 |
| 925,926 | detection zone | 62-64 |
| 930 | location on detection map | 21 |
| 931 | area in detection map | 21 |
| 932 | line in detection map | 21 |
| 933 | elastic band | 50-53 |
| 934 | slingshot pad | 50-53 |
| 935 | extension | 51-53 |
| 939 | arrow | 58 |
| 940 | Door handle | 61-64 |
| 941 | Car door | 82 |
| 942 | Car | 82 |
| 943 | Person | 82 |
| 944 | Arrow | 82 |
| 950 | hinge | 54 |
| 952-954 | interpolated position and direction | 19, 20 |
| 955-957 | candidate ellipse | 20 |
| 960 | location on detection map | 64 |
| 976 | PCB | 50-53 |
| 983, 984 | communications processor | 57 |
| 991 | server | 55-57, 60 |
| 994-997 | handset/game console | 55-59 |
| 998, 999 | detection zone | 56-59 |

## DETAILED DESCRIPTION

Aspects of the present invention relate to light-based touch screens and light-based touch surfaces. Throughout this specification, the term "touch screen" includes a touch surface that does not include an electronic display, inter alia, a mouse touchpad as included in many laptop computers and the back cover of a handheld device. It also includes an unenclosed airspace adjacent to the sensor provided by the present invention. In one set of embodiments, the sensor provided by the present invention is mounted in, or near, a door handle. The sensor detects a user approaching the door handle and performing a swipe gesture on, or in the airspace next to, the door handle. In response to this detection a keyless lock, that scans for a digital key via wireless communication, is activated. When the digital key is detected, the keyless lock unlocks the door.

According to embodiments of the present invention, a light-based touch sensor includes a plurality of infra-red or near infra-red light-emitting diodes (LEDs) and a plurality of photodiodes (PDs) arranged along one edge of a detection plane. In some embodiments, the detection plane is the surface or interface area of a touch screen, as defined above. The LEDs project collimated light along the detection plane, and when this light is reflected by an inserted object, such as a finger or a stylus, the reflected light is detected by the PDs. The geometry of the locations of the activated LED and the PD that detects the reflected light, suffices to determine two-dimensional coordinates of the pointer within the detections area by triangulation. The LEDs and PDs are selectively activated by a processor. Generally, each LED and PD has I/O connectors, and signals are transmitted to specify which LEDs and which PDs are activated.

Reference is made to FIG. **2**, which is a simplified diagram of a proximity sensor for detecting two-dimensional coordinates of an object in a two-dimensional detection area, in accordance with an embodiment of the present invention. FIG. **2** shows proximity sensor **512** featuring a row of alternating emitters and detectors along the bottom edge, an array of lenses **312** along the upper edge and processor **702** at the left edge. Not all of the emitters and detectors are numbered in order to simplify the illustration. Thus, only emitters **101-103** and detectors **202-208** are numbered in FIG. **2**. The alternating arrangement of emitters and detectors is illustrated by emitters **101-103** and detectors **206-208**.

Each emitter is situated on the optical axis of a respective collimating lens in array **312**. In FIG. **2** emitters **101-103** are shown projecting respective light beams **403-405**.

FIG. **2** also shows reflected light beams for each detector. Five of these are numbered **406-409** and **413**. Each lens in array **312** transmits reflected light to the two detectors neighboring the lens's emitter. For example, the lens opposite emitter **102** directs reflected beam **413** onto detector **207** and also directs reflected beam **409** onto detector **208**. As will be explained below, the detectors are positioned along the lens's object plane to receive maximum intensity from beams that enter the lens at a particular angle. This enables determining a location in the two-dimensional area corresponding to each emitter-detector pair. In FIG. **2** these locations are the intersections between emitter beams and reflected beams. In FIG. **2** five such locations are numbered **902-906**.

According to an embodiment of the present invention, each emitter is synchronously co-activated with each of the detectors by processor **702**. If reflected light is detected during a co-activation, it indicates that an object is located in the vicinity of the corresponding intersection location between the activated emitter beam and the corresponding reflected beam for the co-activated detector, as illustrated in FIG. **2**. Processor **702** calculates the object's coordinates by determining an emitter-detector pair among the co-activated emitter-detector pairs, for which the detector detects a maximum amount of light, and identifying the position associated therewith. For example, the maximum detection is identified for the emitter-detector pair **102-202**, namely, when emitter beam **404** is reflected along beam **408**. The position corresponding to this detection is position **902** in the detection plane. Processor **702** determines additional positions that are associated with co-activated emitter-detector pairs and that neighbor the identified position of the maximum detection, e.g., emitter-detector pair **102-203** whose corresponding position is **903** and emitter-detector pair **101-202** whose corresponding position is **905**. Additional detections and their corresponding positions can also be used, e.g., detections corresponding to positions **904** and **906**. Processor **702** calculates a weighted average of the identified position of the maximum detection and the thus-determined additional positions, wherein each position's weight in the average corresponds to a degree of detection of the reflected light beam for the emitter-detector pair to which that position is associated.

Processor **702** is operable to synchronously co-activate one emitter with more than one detector simultaneously. In some embodiments, processor **702** calculates the object location using the Hough transform as described herein below.

Emitters such as LEDs and detectors such photo diodes (PDs) typically come mounted on individual substrates and encased in individual lens covers. In order to reduce the cost of proximity sensor **512**, in some embodiments the emitters and detectors are mounted as bare diodes on a PCB or other substrate in proximity sensor **512** without individual lenses and without individual substrates. The lens array **312** serves as the only lens for these diodes. In this case proximity sensor **512** can be viewed as a large, multi-diode component. This component can be pre-manufactured and inserted either by an ODM or by an end user into a device to provide touch detection.

For example, this component can be placed above or below a car window to enable the user to perform tap and gesture input on the car window. Processor **702** includes a communicators processor e.g., BLUETOOTH® for communicating wirelessly with the car stereo or with a user's phone. Similarly, this component can be placed above or below a window in a house or on the wall in a house to enable the user to perform tap and gesture input on the window or wall. A transparent sheet with digits and icons can be placed on or in the window glass or on the wall to indicate what input operations the user's touches at each location activate.

In the description, proximity sensor **512** is also referred to as touch sensor bar **501** and touch sensor bar **510**.

Reference is made to FIG. **3**, which is a simplified diagram of a touch screen system using proximity sensor **512**, in accordance an embodiment of the present invention. FIG. **3** shows a touch sensor bar **501** detecting light reflected by a remote object **901**. Touch sensor bar **501** includes five PDs, **201-205**. An LED is inserted between each pair of PDs. Thus, there are 4 LEDs in touch sensor bar **501**. However, only one of the LEDs, LED **101**, is shown in FIG. **3**.

Touch sensor bar **501** includes a light guide **301** in front of the LEDs and PDs, that performs two functions: first, it collimates light from the light emitting diodes and projects it across the screen surface, as illustrated by light beams **401**; second, it focuses reflected light **402** entering the light guide **301** at fixed angles, onto the photodiodes. Thus, light guide **301** includes a connected series of collimating lenses, of which lenses **302** and **303** are indicated in FIG. **2**B. Lens **302** is shown collimating the emitter **101** beams, and lens **303** is shown focusing reflected light **402** entering the light guide **301** at a particular fixed angle onto photodiode **205**.

Reference is made to FIGS. **4** and **5**, which are exploded views of a touch detection apparatus, in accordance with an embodiment of the present invention. FIG. **4** shows an exploded view of touch sensor bar **510**, viewed from above. In between top and bottom casing parts **601** and **602**, a PCB **603** and light guide **310** are shown. PCB **603** has a row of alternating LEDs **101** and PDs **201**, whereby the outermost diodes at both ends of the row are PDs **201**. Thus, there are 11 PDs interleaved with 10 LEDs on PCB **603**. FIG. **3** also shows light guide **310** being formed of 10 collimating lenses

311—one lens directly opposite each LED. As mentioned above, each collimating lens **311** performs two functions: collimating outgoing beams and focusing incoming reflected beams onto a PD. The LED is situated at the focus of its opposite lens. The lateral offset of each PD from this focal point ensures that the lens will only direct incoming beams within a narrow range of angles onto the PD. Incoming beams whose angle of incidence on lens **311** is greater or less than the narrow range of angles are focused away from the target PD.

In order to prevent stray LED light from saturating a neighboring PD, a series of light barriers **320-321** separates each LED from its neighboring PDs. FIG. **5** shows another exploded view of touch sensor bar **510**, viewed from below. The light barriers **320** and **321** are shown protruding from the underside of top casing **601**.

Reference is made to FIG. **6**, which is a view from above of a touch detection apparatus, in accordance with an embodiment of the present invention. FIG. **6** shows a view of touch sensor bar **510** from above. FIG. **6** shows alternating row of LEDs **101** and PDs **201**, each diode isolated by barriers **320** and **321**; lenses **311** opposite each LED **101** and a controller **701** for activating LEDs **101** and PDs **201** in a sequence and for receiving the PD detection signals. Touch calculations performed based on the PD detection signals are executed either by controller **701**, or offloaded to a separate processing unit, e.g., a host.

Reference is made to FIGS. **7-12**, which are simplified diagrams of emitted and reflected light beams used in a touch screen system, in accordance with an embodiment of the present invention. FIG. **7** shows detection of a distant object **910** based on two sets of reflected beams **411** and **412** detected by PDs **210** and **211**, respectively. FIG. **7** shows how beams from one emitter **111** are detected by two PDs **210** and **211**. Reflected beams **411** and **412** each enter respective ones of lenses **311** at an angle whereby the lens focuses the beam into a respective PD.

FIG. **8** shows the design considerations for lens **311** and placement of emitter **101** and PD **201**. Lens **311** is aspherical and optimized to achieve a flat image plane **912** to maintain focus on both LED **101** and PD **201** simultaneously. LED **101** sits on the optical axis, centered on lens **311**. Point **913** is the image of LED **101** in image plane **912**. PD **201** sits at the edge of the field of view. Point **914** is the image of PD **201** in image plane **912**. In terms of an image captured through the lens on object plane **916**, LED **101** is the center pixel and PD **201** is a pixel at the edge of the captured image. The field of view for PD **201** is determined by the PD chip size, seen through the width of lens **311**. Rays that hit lens **311** from an angle outside the field of view of PD **201** will form an image in the same plane **916** but somewhere between LED **101** and PD **201**. Thus, these rays will not be captured by PD **201**.

Angle **915**, between emitter **101** beams **420** and reflected PD **201** beams **421**, is selected to fit the intended shape of the active touch-detection area. When the active touch-detection area is square, angle **915** is the diagonal of half a square, i.e., $\tan^{-1}(½)\approx 26.6°$. When the depth of view is longer than the width of the touch sensor bar, angle **915** is smaller.

FIG. **9** shows a side view of LED **101** projecting light beams **410** above and across the surface of screen **911**. In addition to being collimated by lens **311**, beams **410** are directed slightly upwards, away from the screen surface. This reduces the amount of light reflected by the surface of screen **911** in order to maximize the light utilized for touch detection.

FIG. **10** shows a view from above of one collimating lens **311**, an emitter **101** and a PD **201**. Reflected light beams approaching lens **311** at an angle of incidence between that of beams **410** and **411** are focused on a location between emitter **101** and PD **201**. Reflected light beams approaching lens **311** at an angle of incidence more acute than beam **411** are focused on a location above PD **201**. Thus, the lens and PD arrangement ensures that the system is sensitive to reflected light entering lens **311** at a specific angle.

FIG. **11** shows the lens and components of FIG. **10** from a perspective view.

FIG. **12** shows beams **411** and **412** reflected by an object **910** at distance 3 from touch detection bar **510**. Based on the detection angle for which the PDs and lenses are configured, as described above, the greatest detection signal is generated at PDs **210** and **211**. Thus, the touch location is determined to be opposite the activated emitter **111**, at a distance 3. These coordinates are easily converted to x, y screen coordinates. If, for example, the touch location were along beams **410** but at a distance 2 from touch detection bar **510**, the maximum detection signal would arrive at PDs **212** and **213**. Similarly, if the touch location were along beams **410** but at a distance 1 from touch detection bar **510**, the maximum detection signal would arrive at PDs **214** and **215**. More generally, each unit of distance along the emitter beam corresponds to a PD offset from the emitter. Thus, PDs **214** and **215** are at offset 0 from emitter **111**, PDs **212** and **213** are at offset 1, and PDs **210** and **211** are at offset 2. Right and left detection angles are illustrated by beams **411** and **412**.

Reference is made to FIGS. **13** and **14**, which are illustrations of touch detection maps, in accordance with an embodiment of the present invention. FIG. **13** shows the PD offsets mapped to corresponding touch locations on the screen for light beams from emitters, 0-9. In FIG. **13** PD offsets are indicated as sensor offsets, and emitter indices are indicated as source indices. Each emitter beam is represented by a vertical line beginning at one of the source indices. Each vertex in the diamond pattern on the mapped touch sensitive area corresponds to a touch location on the screen, and the dashed diagonal lines represent reflected beams at the specific right and left detection angles. The height of each vertex corresponds to its PD offset from the emitter. Thus, although the PDs are interleaved in a single row with the emitters, the PD offsets are arranged along a second axis in FIG. **13** for clarity.

In the example described above, each detector receives beams from two lenses and is situated at first location within the first lens's object plane at the opposite location with the second lens's object plane. As a result, it is positioned to detect reflected beams entering the first lens at an angle $\theta$ with respect to the lens's optical axis, and reflected beams entering the second lens at an angle $-\theta$ to the optical axis. As a result, many of the positions associated with a first emitter-detector pair are also associated with a second emitter-detector pair. In order to provide more unique positions associated with emitter-detector pairs, the detector is situated at non-symmetrical locations with respect to its two lenses. This is illustrated in FIG. **15**.

Reference is made to FIG. **15**, which is a simplified illustration of a lens array **312** with alternating emitters and detectors, in accordance with an embodiment of the present invention. FIG. **15** shows the detector being at two non-symmetrically opposite locations with respect to the two lenses of lens array **312**. Thus, emitter beam **403** is intersected at two different locations **907** and **908** by reflected beams **407** and **406**. In some embodiments, each detector is positioned at a slightly different pair of locations within the

object planes of its lenses. This provides a non-uniform distribution of positions associated with the emitter-detector pairs.

Touch Coordinate Algorithm

This section describes in detail the operations performed to determine a tracked object's location. As explained in the previous section, for each activated emitter any of the PDs may receive the focused, reflected beams depending on the distance between the emitter and the reflecting object. Therefore, a scan of the entire screen outputs a table of PD detection values, where columns correspond to LEDs and rows correspond to PDs. Thus, for a detector having 10 LEDs and 11 PDs, the output table has 11 rows and 10 columns, wherein, the 11 entries in column 1 contain the detection values at each PD when emitter 1 is activated, the 11 entries in column 2 contain the detection values at each PD when emitter 2 is activated, etc. TABLE I is an example table containing raw detection values.

TABLE I

| | Raw detection values | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | LED 0 | LED 1 | LED 2 | LED 3 | LED 4 | LED 5 | LED 6 | LED 7 | LED 8 | LED 9 |
| PD 0 | 0 | 2 | 3 | 7 | 4 | 4 | 2 | 6 | 3 | 6 |
| PD 1 | 1 | 2 | 1 | 3 | 4 | 3 | 3 | 5 | 5 | 5 |
| PD 2 | 4 | 1 | 1 | 0 | 8 | 5 | 13 | 11 | 5 | 5 |
| PD 3 | 3 | 1 | 1 | 1 | 28 | 14 | 7 | 4 | 4 | 3 |
| PD 4 | 2 | 5 | 2 | 0 | 2 | 141 | 10 | 7 | 6 | 8 |
| PD 5 | 3 | 8 | 3 | 1 | 1 | 4 | 6 | 4 | 5 | 6 |
| PD 6 | 6 | 10 | 4 | 1 | 8 | 4 | 1 | 1 | 8 | 9 |
| PD 7 | 6 | 6 | 6 | 6 | 8 | 144 | 4 | 2 | 3 | 6 |
| PD 8 | 10 | 5 | 9 | 7 | 6 | 25 | 28 | 3 | 2 | 2 |
| PD 9 | 8 | 4 | 8 | 4 | 5 | 1 | 5 | 2 | 1 | 1 |
| PD 10 | 4 | 2 | 5 | 1 | 5 | 4 | 5 | 5 | 3 | 2 |

The two maxima in TABLE I, namely, raw detection values 141 and 144, are obtained from PD 4 and PD 7, respectively, when LED 5 is activated. PD 4 and PD 7 have an offset of 1 from LED 5, as PDs 5 and 6 are the immediate left and right neighbors of LED 5 and have an offset of 0.

The amount of light reflected by a near object onto a PD at offset 0 or 1 from the activated LED is greater than the amount of light reflected by a distant object onto a PD at offset 7 or 8 from the activated LED. Indeed, the greater the PD offset, the less light will reach the PD, assuming all other parameters remain constant. The PD value is digitized by an A/D converter having a given resolution, such as 12 bits or 16 bits. In order to fully utilize the range of values, in certain embodiments each emitter is activated with different amounts of current, or for different durations, depending on the offset of the target PD. The greater the offset, the greater the current and/or activation time, in order to utilize the full range of values without the risk of reaching the maximum detection value and possibly overflowing that value. Other factors contribute to the range of possible or expected PD detection values including the height of the lens **311** and the reflectivity of the pointing object. In particular, a greater lens height above the screen surface admits more light onto the target PD. In some embodiments, the amounts of expected PD detection values for the different PD offsets are determined heuristically based on experiment.

In some embodiments, the A/D converter outputs more bits than are used by the processor to calculate the touch location. For example, in some embodiments the A/D converter outputs 12-bit values and the processor uses 8-bit values. In these cases, it is important to determine the maximum expected 12-bit value. Based on this maximum, the system will remove most-significant-bits (msb) only when there is no risk that the value contains non-zero values in the removed msb. If the risk of overflow prevents the system from discarding msb, the system will remove least-significant-bits (lsb) to arrive at an 8-bit value. These maximum values are also determined by heuristics and depend on the PD offset.

Heuristics are also used to prepare a reference detection value for each LED-PD pair. Thus, each of the detected PD values in the detection table described above is divided by a respective reference value to normalize all values in the table to a range of 0-1. FIG. **14** shows a detection map of normalized detection values for a touch corresponding to LED 2 and the PDs at offset +/−5. Since there is no corresponding PD at offset −5 from LED 2, only the PD at offset +5 generates this maximum detection signal. The detection map of FIG. **14** includes concentric solid- and dashed-line shapes **917** where each inner shape is greater than its outer neighbor, such that the maximum detection signal is at the center. If FIG. **14** were to be rendered in color or varying degrees of grayscale, the innermost shape would be darkest, and the shapes would become progressively lighter as they expand. However, color and shading has been removed from FIG. **14** in order to render it in pure black and white.

Not only is the absolute value of a detection signal useful for determining the touch location, but the relationship between neighboring signals is also an important factor.

Reference is made to FIGS. **16-21**, which are simplified touch detection maps for illustrating the algorithms used to calculate a touch location in a touch screen system, in accordance with an embodiment of the present invention. FIG. **16** shows a portion of the detection map of FIG. **13**. As described above, the solid vertical lines represent emitter beams. More precisely, each vertical line represents the center of the beams from a given emitter. The emitter beams are considered to have a normal, bell-shaped distribution around the center of the beam. Similarly, the solid diagonal lines in FIG. **16** represent the optimal reflected beam that generates a maximum detection value at a PD at a given offset. The detection values for beams parallel to, and in between, these diagonal beams are considered to have a normal, bell-shaped distribution of detection at the PD with the given offset. These distribution properties provide the ability to determine locations between the solid vertical and diagonal lines, or between the vertices in the detection map of FIG. **13** that indicate points of maximum detection, by comparing neighboring detection signals. Thus, the point of contact is based on six lemmas listed below.

Lemma 1: If the reflecting object is translated parallel to the diagonal detection lines of the PDs, the relationship between detection signals of neighboring PDs detecting the same LED remains constant.

Lemma 1 is illustrated in FIG. **16**. FIG. **16** shows a portion of the detection map of FIG. **13** wherein the three solid vertical lines represent portions of 3 emitter beams and the four solid diagonal lines represent 4 detector beams. As mentioned above, points of maximum detection levels are at the vertices where an emitter beam crosses a detector beam. Three such vertices are labeled in FIG. **16**, namely p**0**, r**1** and d**1**, each label being to the right of its corresponding vertex. In a case where the touch object is at the midpoint between p**0** and d**1**, the ratio of the detection signal representing point p**0** and the detection signal representing point d**1** would be roughly equal. Moreover, as long as the touch object is translated along the dashed diagonal line between p**0** and d**1**, this ratio remains constant. Thus, based on the ratio between the two highest detection signals of neighboring PDs detecting the same LED, a line can be drawn parallel to the diagonal dashed line in FIG. **16**, and the touch location should be somewhere on that drawn line. The drawn line will be closer to vertex p**0** or d**1** depending on the magnitude of this ratio.

Lemma 2: If the reflecting object is translated parallel to the vertical emitter lines of the LEDs, the relationship between detection signals of one PD detecting two, neighboring LEDs remains constant.

Lemma 2 is also illustrated in FIG. **16**. Vertex p**0** represents an LED beam whose reflection is detected at a PD with an offset n from the activated LED. Vertex r**1** represents a neighboring LED beam whose reflection is detected at a PD with an offset n+1 from the activated LED. However, since the activated LED for r**1** is a neighbor of the activated LED for p**0**, the same PD used for p**0**, whose offset is n, is used for r**1**, since this PD's offset from the r**1** LED is n+1. In a case where the touch object is at the midpoint between p**0** and r**1**, the ratio of the detection signal representing point p**0** and the detection signal representing point r**1** would be roughly equal. Moreover, as long as the touch object is translated along the dashed vertical line between p**0** and r**1**, this ratio remains constant. Thus, based on the ratio between the two highest detection signals of one PD detecting two, neighboring LEDs, a line can be drawn parallel to the vertical dashed line in FIG. **16**, and the touch location should be somewhere on that drawn line. The drawn line will be closer to vertex p**0** or r**1** depending on the magnitude of this ratio.

Lemma 3: Combining Lemmas 1 and 2 provides a rhomboid area in which the touch is located. Three of the vertices of this rhomboid area are vertices r**1**, p**0** and d**1**. Moreover, the exact touch location is at the point of intersection between the drawn line of Lemma 1 and the drawn line of Lemma 2.

Lemmas 1-3 apply to small touch objects that reflect light from a single point. Larger touch objects reflect along a side of the object, perpendicular to the LED beams. Thus, in the case of a large touch object, there is a wider, more even distribution of maximum detection values representing a series of reflection points that are equally distant from their respective LEDs. Lemmas 4-6 relate to large touch objects.

Lemma 4: If the reflecting object is translated perpendicular to the vertical emitter lines of the LEDs, the relationship between detection signals of neighboring PDs detecting the same LED remains constant.

Lemmas 4-6 are illustrated in FIG. **17**. FIG. **17** shows a portion of the detection map of FIG. **13** wherein the three solid vertical lines represent portions of 3 emitter beams and the four solid diagonal lines represent 4 detector beams. As mentioned above, points of maximum detection levels are at the vertices where an emitter beam crosses a detector beam. Three such vertices are labeled in FIG. **17**, namely p**0**, r**1** and d**1**, each label being to the right of its corresponding vertex. In a case where a large reflecting object is placed between p**0** and d**1**, the ratio of the detection signal representing point p**0** and the detection signal representing point d**1** would be roughly equal. Moreover, as long as the touch object is translated along the dashed horizontal line between p**0** and d**1**, this ratio remains constant. Thus, based on the ratio between the two highest detection signals of neighboring PDs detecting the same LED, a line can be drawn parallel to the diagonal dashed line in FIG. **17**, and the touch location should be somewhere on that drawn line. The drawn line will be closer to vertex p**0** or d**1** depending on the magnitude of this ratio.

Lemma 5: If the reflecting object is translated parallel to the vertical emitter lines of the LEDs, the relationship between detection signals having similar offsets from their respective LEDs remains constant.

Because Lemma 5 relates to wide reflective objects that reflect light at many locations equally-distant from the row of LEDs, the two highest detection values will come from neighboring PDs having similar offsets from their respective LEDs. Accordingly, Lemma 5 is also illustrated in FIG. **17**. Vertex p**0** represents an LED beam whose reflection is detected at a PD with an offset n from the activated LED. Vertex r**1** represents a neighboring LED beam whose reflection is also detected at a PD with an offset n from its activated LED. In a case where the touch object is at a point between p**0** and r**1**, the ratio of the detection signal representing point p**0** and the detection signal representing point r**1** would be roughly equal. Moreover, as long as the touch object is translated along the dotted vertical line between p**0** and r**1**, this ratio remains constant. Thus, based on the ratio between the two highest detection signals of two neighboring PDs detecting two, neighboring LEDs, a line can be drawn parallel to the vertical dashed line in FIG. **17**, and the touch location should be somewhere on that drawn line. The drawn line will be closer to vertex p**0** or r**1** depending on the magnitude of this ratio.

Lemma 6: Combining Lemmas 4 and 5 provides a rectangular area in which the touch is located. Three of the vertices of this rectangular area are vertices r**1**, p**0** and d**1** in FIG. **17**. Moreover, the touch location is at the point of intersection between the drawn line of Lemma 4 and the drawn line of Lemma 5.

According to certain embodiments of the invention, the touch location is derived based on a combination of Lemmas 1-6. This method proceeds in three steps. Step 1 calculates two interpolated points along two neighboring LED beams. Step 2 draws a line connecting the two interpolated points. Step 3 calculates a point along the line drawn at step 2 by interpolating the amplitudes of the two endpoints calculated at step 1. This method is described with reference to FIG. **18**.

FIG. **18** shows a portion of the detection map of FIG. **13**, wherein the three solid vertical lines represent portions of 3 emitter beams and the four solid diagonal lines represent 4 detector beams. As mentioned above, points of maximum detection levels are at the vertices where an emitter beam crosses a detector beam. Six such vertices are labeled in FIG. **18**, namely, p**0**, d**0** and d**1**, each labeled to the right of a corresponding vertex, and, r**1***a*, r**1***b* and r**1***c*, each labeled to the left of a corresponding vertex. When performing this method, point p**0** is the maximum detection signal for this

touch object. The PD for point **p0** has two neighboring PDs, one to the left (for detection point **d1**) and one to the right (for detection point **d0**), that also detect the same LED as used for **p0**. The PD having the higher detection signal is used. In FIG. **18**, this second detection signal of the neighboring PD detecting the same LED as **p0**, is **d1**. The normalized detection signals at **p0** and **d1** are interpolated to generate a new location, **c0**, on the LED beam between vertices **p0** and **d1**. In addition to location **c0**, the interpolation also calculates an amplitude of the signal at **c0**.

Next, the method calculates a second new location, along a neighboring LED beam. Thus, relevant reflections from left and right neighboring beams are compared and the beam returning the greater signal is used. In FIG. **18**, the beam to the left of the **p0** beam is selected. Vertex **r1***b* uses the same PD as used for **p0**, but it detects a left-neighbor LED. Next, the normalized signals at **r1***a* and **r1***c* are compared and the greater signal is selected. The **r1***b* detection signal and the selected **r1***a*/**r1***c* signal are interpolated to generate a new location, **c1**, on the LED beam between vertices **r1***b* and **r1***a* or **r1***c*. In addition to location **c1**, the interpolation also calculates an amplitude of the signal at **c1**.

The two points **c0** and **c1** define a line along which the touch location is to be found. This is the dashed line in FIG. **17**. The calculated signal amplitudes at **c0** and **c1** are interpolated to determine the touch location along this line.

As mentioned above, the relationship between two signals is expressed as the quotient (q) between them. The source beam light intensity is assumed to behave as a normal distribution on both sides of the beam center line. The reflection intensity is proportional to the light intensity. The detection signal value of a reflection is also assumed to be distributed as a normal distribution on both sides of the detection center line. The standard deviations of these distributions vary according to the distance of the reflecting object, but are assumed to be constant within a small range of distances.

Since the reflection (r) and detection (d) intensities of a signal s—$f_{sr}$ and $f_{sd}$ respectively, are of the normal distribution, they are expressed as the Gaussian function:

$$f_{si} = p_i(x)Ae^{-\frac{(x-x_{si})^2}{2\sigma_{si}^2}}, \quad \text{(EQ. 1)}$$

where i is r or d, x is the reflection location, $x_{si}$ is the location of the source beam or sensor detection line, $p_i(x)$ is the typical peak strength at the current reflection distance, and A is the amplitude. The quotient between two intensities is then:

$$q_{s_0,s_1,i} = \frac{f_{s_1 i}}{f_{s_0 i}} = e^{-\frac{(x-x_{s_1 i})^2-(x-x_{s_0 i})^2}{2\sigma_{s_{0,1} i^2}}}. \quad \text{(EQ. 2)}$$

Assigning $x \in [0,1]$, and approximating $\sigma_{s_{0,1}i} \approx \sigma_{s_0 i} \approx \sigma_{s_1 i}$, EQ. 2 can be simplified to:

$$q_{s_0,s_1,i} = e^{\frac{x-1/2}{\sigma_{s_{0,1} i^2}}}. \quad \text{(EQ. 3)}$$

That gives the interpolated coordinate x:

$$x = \frac{1}{2} + \sigma_{s_{0,1} i^2} \ln \frac{f_{s_1 i}}{f_{s_0 i}}, \quad \text{(EQ. 4)}$$

and the amplitude A:

$$A = \frac{f_{si}}{p_i(x)} e^{\frac{(x-x_{si})^2}{2\sigma_{si}^2}}, \quad \text{(EQ. 5)}$$

In some embodiments, when the size and shape of the object to be detected by the proximity sensor is known, the Hough transform is used. For example, when a finger is used to perform input, its expected shape within the detection plane is an ellipse of a known size. In this case, processor **702** is provided with a plurality of candidate ellipses within the detection plane. Processor **702** determines which co-activated emitter-detector pairs generated a detection signal, and identifies the positions associated therewith. Next, processor **702** interpolates the detection signals for any two of the co-activated emitter-detector pairs whose two associated positions are neighbors, to determine an intermediate location between those two associated positions. Processor **702** then assigns an orientation to each intermediate location, the orientation being perpendicular to the line connecting the two neighboring associated positions. This process is illustrated in FIG. **19**.

FIG. **19** shows positions **902-906** each associated with an emitter-detector pair. Position **902** is interpolated with position **903** to produce intermediate location **952** having a horizontal orientation. The detection signal corresponding to position **902** is, in this illustrative example, greater than the detection signal corresponding to position **903**. Hence, the location of intermediate location **952** is closer to **902** than **903**. Similarly, intermediate location **953** is interpolated using positions **904** and **905**, where the detection signal corresponding to position **904** is greater than that corresponding to position **905**; and intermediate location **954** is interpolated using positions **905** and **906**, where the detection signals corresponding to these positions are roughly equal, hence the location of **954** is at the midpoint between positions **905** and **906**.

For each candidate ellipse, processor **702** assigns a match value to the candidate ellipse, the match value representing a degree of match between an edge of the candidate ellipse and the location and orientation of an intermediate location. FIG. **20** shows four ellipses **955-958**. Interpolated location **953** is assigned a high match value to ellipses **955** and **956** and a very low (or zero) match value to ellipses **957** and **958** because the orientation of interpolated location **953** does not match that of its corresponding location in these ellipses.

Processor **702** calculates a sum of the thus-assigned match values for each candidate ellipse, and designates that candidate ellipse with the maximum thus-calculated sum as being the location of the object in the detection plane.

Implementation

The signals are filtered for maxima. A maximum is a signal greater than its 8 immediate neighbors: top, button, left, right and four diagonal neighbors. For the portion of the touch-sensitive area in which a reflective object produces two detection signals, namely, one at an offset +n from the active LED and one at an offset −n, two maxima will be generated by the reflective object. In this case, in some embodiments, only the greater of these two maxima is used. FIG. **21** shows maximum **930**.

As explained above, the maximum signal is one corner of an area in which the reflecting object is located. This area is a rectangle or rhombus connecting adjacent neighbors. The area is chosen to include the strongest signals. The deduced reflection location will be somewhere inside this area.

Next, two signals neighboring the maximum signal are compared, namely, the two PDs on either side of the maximum signal PD detecting the same LED as the maximum signal. These correspond to vertices above and below maximum **930** in FIG. **21**, along the same emitter beam. The greater of these two signals is selected, and accordingly, one side of the rectangular, or rhomboid, object location area extends from the maximum signal vertex to the selected neighboring vertex. In FIG. **21**, the vertex above maximum **930** was selected.

Next, the signals from neighboring LEDs to the left and right are compared to decide whether to extend the area in which the reflecting object is located to the left or right. On the left side, the two locations directly left of the locations on the first area side, plus one more directly below them are used. On the right, it is the two points to the right, plus one more above them. The side that contains the highest signal is the side the area is extended to. On the left side, if the top-most signal is stronger than the bottom-most, the area in which the reflecting object is located is determined to be a rectangle. If not, it is a rhombus extended to include the bottom-most location. On the right side, the same comparison is made. If the bottom-most signal is stronger than the top-most, then the area in which the reflecting object is located is determined to be a rectangle. If not, it is a rhombus that extends to include the top-most location. In FIG. **21**, the area in which the reflecting object is located is a rhombus extended to the left and down, i.e., rhombus **931** with vertex **930** at its lower right corner.

As explained above, each pair of selected vertices representing two reflection detections from one LED is interpolated to find two points (**c0**, **c1**, in FIG. **18**) that define a line **932** on which the reflecting object is located. Both the location and amplitude of the points are calculated, as described above.

The same interpolation method is used again to find the reflection location along this line and its amplitude. The amplitude may be interpreted as reflectivity, which in turn is proportional to the diameter of the reflecting object.

At times, multiple, unconnected maxima are identified. In such cases, the interpolated location and reflectivity of each maximum is calculated. Those coordinates found to have a reflectivity or amplitude value above a defined threshold are stored as reflective object locations. Thus, a frame representing the entire scanned touch area may contain a list of simultaneous touch objects, each object having a corresponding location.

In a sequence of such frames, reflective objects in the frame at time t+1 are compared to the reflective objects of the previous frame, at time t. The objects in the two frames are paired using a greedy pairing algorithm according to a minimum distance between paired objects. Paired objects are tracked as being the same object. New obstacles not paired are added as new tracking targets, and old tracking targets not paired to new ones are removed.

The location and reflectivity parameters of the tracked obstacles are calculated as the old parameters (at time t), updated with a prediction based on constant speed, and a fractional interpolation towards the new parameters (at time t+1). The detected location $l_d$ is used to update previous tracked location $l_0$ together with the tracked velocity vector $v_0$ to determine the updated location and velocity $l_1$ and $v_1$:

$$l_1=(1-\alpha)(l_0+\beta v_0)+\alpha l_d, \quad \text{(EQ. 6)}$$

$$v_1=l_1-l_0, \quad \text{(EQ. 7)}$$

where $\alpha$ is the relative weight applied to the detected (t+1) position in the interpolation, and $\beta$ represents how constant the velocity is assumed to be.

Reference is made to FIGS. **22** and **23**(*a*)-(*f*), which are simplified touch detection maps for various touch screen system embodiments, in accordance with the present invention. As mentioned hereinabove, the optical proximity sensor PDs are paired with lenses that optimize detections of reflected light for an angle $\theta$, indicated by the diagonal lines shown in FIGS. **22** and **23**(*a*)-(*f*). The vertical lines in FIGS. **22** and **23**(*a*)-(*f*) represent light emitted by the sensor LEDs. Detection hotspots are points of intersection between the vertical emitter beams and the diagonal optimized detection paths. These hotspots are indicated by a small circle at each intersection.

FIG. **22** shows a triangular section **919** where objects are not detected by the sensor. FIG. **23**(*a*)-(*f*) illustrates how the size of the area in which an optical proximity sensor can detect an object depends on the angle for which the sensor's PDs are optimized. In FIG. **23**(*a*) $\theta$=20°; in FIG. **23**(*b*) $\theta$=30°; in FIG. **23**(*c*) $\theta$=40°; in FIG. **23**(*d*) $\theta$=50°; in FIG. **23**(*e*) $\theta$=60°; and in FIG. **23**(*f*) $\theta$=70°. In the examples of **23**(*a*)-(*f*) the maximum distance from the sensor bar is 120 mm and the bar is 91 mm long with a pitch between neighboring light elements along the bar of 7 mm. In FIG. **23**(*a*) the height of the screen (120 mm) is covered with detection hotspots.

The density of these hotspots can be broken down into an optical x resolution, which is the pitch between neighboring light elements within the sensor bar, and an optical y resolution that depends on the angle $\theta$. The examples illustrated in **23**(*a*)-(*f*) show how increasing resolution in the y dimension corresponds to shallower detection zones.

Accordingly, the present invention teaches a dual-resolution screen whereby a narrow area adjacent to the sensor bar provides high-resolution touch detection and a second area further from the sensor bar provides low-resolution touch detection. Reference is made to FIGS. **24** and **25**, which are simplified illustrations of a dual-resolution sensor, in accordance with an embodiment of the present invention. FIG. **24** shows touch sensor bar **511**, a narrow, high-resolution detection zone **921** and a low-resolution detection zone **922**. One application for this dual-resolution sensor is to provide a GUI wherein keypads and other tap-activated controls are placed in the high-resolution zone, and coarse gestures such as sweep gestures and pinch gestures are supported in the low-resolution zone.

Two solutions provide multiple resolution zones. A first solution places two detectors between every two emitters. Thus, every lens pitch has two detectors and one emitter, and every lens directs four different reflected beams onto four different detectors. This is illustrated in FIG. **25**, which shows emitters **101-103** and detectors **201-204**.

A second solution teaches a touch sensor bar in which some of the PD lenses are optimized for a first detection angle, e.g., $\theta_1$=50°, and other PD lenses are optimized for a different detection angle, e.g., $\theta_2$=20°. The first detection angle provides a high-resolution detection zone adjacent to the bar, and the second detection angle provides detection further away from the sensor bar at a lower resolution.

Reference is made to FIGS. **26**(*a*) and (*b*), which are simplified illustrations of two detection maps used in a dual-resolution sensor, in accordance with an embodiment of the present invention. FIG. **26**(*a*) shows a zone that

extends 120 mm from the sensor but has a low optical y resolution of 20 mm, and FIG. **26**(*b*) shows a detection zone near the sensor, having a higher optical y resolution of 6 mm.

In certain embodiments of the proposed dual-resolution sensor bar, the layout alternating LEDs **101** and PDs **201** described hereinabove with reference to FIGS. **4** and **5** is maintained and PDs **101** are positioned to receive maximum amount of light from a first detection angle $\theta_1$. In addition, a second, parallel row of PDs is provided for receiving a maximum amount of light from a second detection angle $\theta_2$. Thus, twice as many PDs are used in the dual resolution sensor than in the sensor of FIGS. **4** and **5**, and the reflected light beam in the dual-resolution sensor is split between the two PDs.

Reference is made to FIG. **27**, which is a simplified view from above of LEDs and PDs on a PCB for a dual-resolution sensor, in accordance with an embodiment of the present invention. FIG. **27** shows a top view of the layout of light elements on PCB **603** in an embodiment of the dual-resolution sensor. FIG. **27** shows the first row of alternating LEDs **101** and PDs **201** and a parallel row of PDs **202**. The pitch between PDs **202** in the second row is the same as that between PDs **201** in the first row.

Reference is made to FIG. **28**, which is a simplified cross-section illustration of a dual-resolution sensor, in accordance with an embodiment of the present invention. FIG. **28** shows the lenses and placement of the PDs in a dual resolution sensor. PD **202** provides the narrow, high-resolution detection zone **921** near the sensor bar, and PD **201** provides the longer, low-resolution detection zone **922** that extends farther away from the sensor bar. Shown in FIG. **28** are screen **100**, PCB **603** on which PDs **201** and **202** are mounted together with light guide **304**. Light guide **304** includes three reflective facets: **305**, **306** and **307**. Light reflected by an object touching screen **100** enters light guide **304** and is redirected downward by reflective facet **305**. This downward beam is then split by two reflectors **307** and **306** which direct different portions of the beam onto PDs **201** and **202**, respectively.

Applications

The present invention has broad application to electronic devices with touch sensitive screens, including small-size, mid-size and large-size screens. Such devices include inter alia computers, track pads for laptops and computers, home entertainment systems, car entertainment systems, security systems, PDAs, cell phones, electronic games and toys, digital photo frames, digital musical instruments, e-book readers, TVs and GPS navigators.

Secondary Keyboard Display

Reference is made to FIG. **29**, which is a simplified illustration of a dual-display laptop, in accordance with an embodiment of the present invention. The laptop features two panels connected by a hinge. The upper panel contains the primary laptop display **131**. The lower panel contains a touch-sensitive, secondary display **132** that is used as an input device to the laptop. Thus, a keypad is rendered on secondary display **132** and text is entered by the user tapping on the displayed keys. Tap gestures are characterized by a brief contact, i.e., touch-and-release, with the secondary display. Thus, tap gestures are distinguishable from glide gestures which are characterized by prolonged contact with the display during which the point of contact is translated along the display. Thus, in addition to text entry, the secondary display controls a mouse cursor on the primary display when the user glides his finger on the secondary display.

According to an embodiment of the present invention the touch sensor used in conjunction with secondary display **132** is optical proximity sensor **512**, as described hereinabove, situated along one edge of the secondary display. Reference is made to FIG. **30**, which is a simplified illustration of a portion of a dual-display laptop, in accordance with an embodiment of the present invention. FIG. **30** shows a bezel **331** along the top edge of the secondary display for housing the optical proximity sensor.

Reference is made to FIG. **31**, which is a simplified illustration of a PC, in accordance with an embodiment of the present invention. FIG. **31** shows a PC having a display **131**, keyboard **133** and two trackpads **134**, in accordance with an embodiment of the present invention.

Reference is made to FIG. **32**, which is a simplified illustration of keyboard **133** of the PC of FIG. **31**, in accordance with an embodiment of the present invention. The keyboard has four embedded optical proximity sensors **513**-**516**. Optical proximity sensors **513**, **515** and **516** are placed along the left, right and bottom edges of keyboard **133** facing away from the keyboard to detect hand and finger gestures in the airspace surrounding the keyboard. These gestures serve as inputs to the computer, e.g., to control a mouse pointer or to enlarge or rotate an image on the display. Optical proximity sensor **514** is along the top edge of keyboard **133** and faces the keyboard. It is used to detect glide gestures along the surface of the keys as inputs to the computer, e.g., to control a mouse pointer or to enlarge or rotate an image on the display. The keyboard's large size relative to traditional trackpads enables dividing the keyboard surface into two trackpad sections. The left half of keyboard **133** serves as an absolute position trackpad. This means that every location on this half of the keyboard is mapped to a corresponding location on the screen. Before a glide gesture is performed, the mouse cursor is at some initial location on the screen. When a glide gesture is performed on the left half of the keyboard the mouse cursor is suddenly moved to the corresponding location on the display. For example, when the mouse cursor is at the upper right corner of the display and the user begins a glide gesture in the lower left corner of the keyboard, the mouse cursor begins its corresponding movement from the lower leftover of the screen. This spares the user the effort of having to perform a long mouse gesture to move the cursor across the screen. The right half of keyboard **133** serves as a relative-position trackpad meaning that when a glide gesture is detected in this half of the keyboard the mouse cursor is translated from its initial screen location according to the relative movement of the glide gesture. Thus, the user can perform an initial slide gesture in the left half of the keyboard to place the mouse cursor in a desired area of the screen and then apply a glide gesture in the right half of the keyboard to move the cursor.

Reference is made to FIG. **33**, which is a simplified illustration of a PC trackpad **134**, in accordance with an embodiment of the present invention. Trackpad **134** is a transparent slab of acrylic slightly tilted toward the user. Optical proximity sensor **517** along the top edge of the trackpad tracks the user's gestures on the slab. Because no electronics are needed on the trackpad outside the optical sensor, trackpad **134** is made of entirely clear, transparent acrylic or glass.

Reference is made to FIG. **34**, which is a simplified illustration of transparent PC keyboard **135**, in accordance with an embodiment of the present invention. Reference is also made to FIG. **35**, which is a side perspective view of transparent keyboard **135** of FIG. **34**, in accordance with an

embodiment of the present invention. Similar to trackpad **134** of FIG. **33**, keyboard **135** is enabled by an optical proximity sensor along its upper edge and a transparent slab of acrylic. The transparent acrylic slab has the keyboard characters etched inside it such that, when visible light is projected to the acrylic slab, the light is reflected by the etchings making the letters visible. When this light is turned off, the etchings are not visible and the keyboard appears as an empty transparent slab. Thus in keyboard mode the visible light is turned and in mouse or sweep-gesture input mode the visible light is turned off. The visible light source is mounted together with the optical proximity sensor along the upper edge of the acrylic slab.

Reference is made to FIG. **36**, which is a simplified illustration of a secondary display that provides keyboard and GUI functionality, in accordance with an embodiment of the present invention. FIG. **36** shows a keyboard having a touch sensitive display. The keyboard characters are rendered by the display. However, an application can also render other UI controls to indicate what gestures to perform on the keyboard display. In FIG. **36** two slider wheels **136** and two slider bars **137** are rendered indicating available rotation gestures and slide gestures to the user.

Reference is made to FIG. **37**, which is a simplified illustration of a laptop keyboard, in accordance with an embodiment of the present invention. Reference is also made to FIG. **38**, which is a simplified cross-section of the laptop keyboard of FIG. **37**, in accordance with an embodiment of the present invention. FIG. **37** shows the laptop of FIGS. **29** and **30**, except that in FIG. **37** secondary display **132** uses light beams **432** that cross above the display between emitter **101** and receiver **201** placed along opposite edges of display **132**. Light guides **332** provide a bezel that extends above display **112** to project light beams **432** over and across the display. In the embodiment of FIGS. **37** and **33** the cavity above the display formed by the surrounding bezel is filled with clear liquid **139**. The light beams from emitter **101** to receiver **201** pass through clear liquid **139**. Above liquid layer **139** a thin, transparent, elastic plastic film **141** is placed. The underlying secondary display **132** is viewable through liquid **139** and plastic film **141**. When the user presses elastic plastic film **141**, for example to select a keyboard character displayed on secondary display **132**, his finger causes an impression in liquid **139** that disrupts light beams **432** underneath the finger's location. The liquid and elastic also provide the user with a tactile feel when he presses this malleable layer above secondary display **132**. An optional haptic generator connected to plastic film **141** or liquid **139** provides additional haptic feedback. In order that the user's finger impression block a sufficient amount of the beams such that a touch causes a substantial reduction in detected light, light is only transmitted through a thin upper layer of liquid **139** near the top of the bezel. This is achieved by the light blockers **140** that prevent light beams **432** from entering liquid **139** near the surface of display **132**. In other embodiments, instead of filling the cavity with a liquid, the cavity is filled with a transparent gel or elastic gelatinous solid material.

Vertical Toolbar Approach Gestures

The Windows 8 operating system from Microsoft Corporation features a vertical toolbar known as the charms that is accessed by swiping from the right edge of a touchscreen, or pointing the cursor at hotspots in the right corners of a screen. WINDOWS® is a registered trademark of Microsoft Corporation. The charms toolbar provides access to system and app-related functions, such as search, sharing, device management, settings, and a Start button. Swiping from the left edge of the touchscreen primary display or clicking in the top-left corner of the primary display allows one to switch between apps and the Desktop. In order to make these sweep gestures convenient for users, many computers support sweep gestures that begin in a border outside the active display area. According to an embodiment of the present invention an alternative gesture is provided for the same functions as sweeping from an edge of the primary display. This gesture is performed by placing a hand in the airspace beyond an edge of the primary display and moving the hand towards the edge. If the gesture is continued until the hand touches the primary display housing, the hand would touch the thickness of the display. I.e., the hand would touch the edge of the housing connecting the front of the display to the rear of the display. However, the hand need not reach the display; the detection of an object approaching the display from the side is recognized as the gesture.

Reference is made to FIG. **39**, which is a simplified illustration of a PC with proximity sensors for detecting wave gestures that approach a side edge of the display, in accordance with an embodiment of the present invention. FIG. **39** shows PC display **131** having optical proximity sensor **512** arranged along the outer left edge of the display housing for detecting this approach gesture in the airspace beyond the edges of the display. In order to make these sweep gestures convenient for users, many prior art computers support sweep gestures that begin in a border outside the active display area. The approach gesture according to the present invention enables maximizing the active display area as no border area around the display is required for this gesture. The gesture according to the present invention also does not require touching the active display area and thereby avoids smudges on the display resulting from the prior art sweep gestures that draw a finger into the active display area.

Using Secondary Display for Key Press and Mouse Gestures

As mentioned hereinabove, embodiments of the present invention provide a secondary display that is touch sensitive and is used for both keyboard input and mouse input. The present invention provides several methods to distinguish between keyboard key presses and mouse gestures.

In a first embodiment tap gestures are associated with keyboard key presses and glide gestures are associated with mouse gestures that move the mouse cursor. In addition, three mouse click gestures are provided that are distinct from keyboard key presses: single-click, double-click and right-click.

A right-click gesture according to the present invention is a prolonged touch that remains in one location, as opposed to a tap gesture which is a quick touch-and-release.

A double-click gesture activates an item located at the location of the mouse cursor. According to the present invention a double-click gesture is distinguished from a key press in that a double-click gesture necessarily follows another mouse gesture, i.e., it is the first tap after a mouse gesture. Thus, after a mouse translation gesture is performed, the next tap gesture may be either the first half of a double-click gesture or a key press gesture. The system disambiguates this tap based on what follows the tap. If this tap is quickly followed by a second tap at approximately the same location as the first tap, both taps are treated as a double-tap gesture; if the first tap is not quickly followed by a second tap at approximately the same location as the first tap, the first tap is associated with a keyboard key press. Thus, with respect to this first tap following a mouse glide operation, the system does not immediately enter the character associated with the corresponding key press gesture.

Rather, the system waits until it determines that the tap is in fact an intended key press and not the beginning of a double-click gesture. However, all subsequent taps are unambiguously determined to be keyboard key presses until another mouse glide gesture is performed. In addition, a double-click does not immediately follow a double-click gesture, so even when a double-click is executed, the third tap is definitely a key press gesture. Therefore, the delay in presenting the character on the screen only occurs only with regard to the first tap gesture following a mouse operation such as a glide or right-click, but not for any other key presses.

A single-click is used to perform a mouse drag operation. According to an embodiment of the invention, a mouse drag operation is only performed with respect to a second mouse glide gesture that quickly follows a first mouse glide gesture. Thus a first glide gesture only moves the mouse cursor on the screen. If the user then lifts his finger and then, within a short amount of time, replaces his finger on the screen and performs a second glide gesture, the second glide gesture is interpreted to be a drag gesture. The short amount of time is configured based on observed user behavior, but in some cases may be 1 or 2 seconds. In order to perform a second operation of moving the mouse cursor without a drag operation there must be a pause—longer than the configured short amount of time—between the first and second glide gestures.

In an alternative embodiment the distinguishing factor between key presses and mouse gestures is the number of fingers performing the gesture. Thus, single-finger gestures are keyboard key presses and two-finger gestures are mouse gestures. Gestures performed by more the two fingers are also mouse gestures.

A system according to the teachings of the present invention that detects a touch based on shadowed light pulses determines the number of fingers performing a gesture based on the size of the shadowed area. A larger area indicates that multiple fingers are being used. Similarly, a system according to the teachings of the present invention that detects a touch based on reflected light pulses determines the number of fingers performing a gesture based on the number of different emitter-receiver channels that detect reflections. A larger number of channels, corresponding to more touch locations, indicates that a large surface area of the screen is being touched, i.e., multiple fingers are being used.

In certain embodiments an array of up/down translatable buttons is situated on top of the secondary display to provide a traditional push-button user experience when entering data through the keyboard. Reference is made to FIG. **40**, which is a simplified illustration of three views of an exemplary four-button keypad chassis, situated over a virtual keypad portion of a touch panel, in accordance with an embodiment of the present invention. FIG. **40** shows keys **10** in removable chassis **12**. Touch panel **14** is situated beneath chassis **12**. Emitters and receivers **16** are shown as part of touch panel **14**. Emitters and receivers **16** are placed beneath surface **14** but are shown above the screen in FIG. **40** in order to clearly indicate touch detection light beams **20**.

Reference is made to FIG. **41**, which is a simplified illustration of a cross-section A-A of an exemplary four-button keypad chassis, situated over a virtual keypad portion of a touch panel, in accordance with an embodiment of the present invention. FIG. **41** shows keys **10** in removable chassis **12**. Touch panel **14** is situated beneath chassis **12**. Emitter and receiver lenses **22** are shown with touch detection light beam **20** above the surface of touch panel **14**.

Reference is made to FIGS. **42**(*a*)-(*c*), which are simplified illustrations of a spring-resilient key that is released and depressed, in accordance with an embodiment of the present invention. FIG. **37**(*a*) shows key **10** in a portion of removable chassis **12**. Touch panel **14** is situated beneath chassis **12**. Emitter and receiver lenses **22** are shown with touch detection light beams **20** above the surface of touch panel **14**.

FIG. **42**(*b*) is a cutaway of button **10** showing spring mechanism **24** for maintaining button **10** upward in chassis **12** and above light beam **20**. FIG. **42**(*c*) is a cutaway of button **10** showing spring mechanism **24** being compressed by downward pressure exerted by a user pressing button **10**. In this case, the bottom of button **10** is lowered to block light beam **20**. When the user releases this downward pressure, spring **24** returns button **10** to its position in FIG. **42**(*b*).

Reference is made to FIGS. **43**(*a*) and (*b*), which are simplified illustrations of a cross-section of a button made of an elastic, resilient material such as rubber, in accordance with an embodiment of the present invention. FIG. **43**(*a*) is a cutaway of elastic button **10** upward in chassis **12** and above light beam **20** projected through emitter and receiver lenses **22** over and across touch panel **14**.

FIG. **43**(*b*) is a cutaway showing button **10** being depressed by downward pressure exerted by a user pressing button **10**. In this case, the bottom of button **10** is lowered to block light beam **20**. When the user releases his downward pressure button **10** returns to its position in FIG. **43**(*a*) due to its resilient and elastic properties.

Reference is made to FIGS. **44**(*a*)-(*d*), which are simplified illustrations of an alternative button configuration, in accordance with an embodiment of the present invention. Button **10** of FIG. **44** has two intersecting cavities **30** through its trunk that allow light beams **20** to pass. When button **10** is depressed, the cavity is lowered and a solid portion of the trunk blocks the light beams.

FIG. **44**(*a*) is a 3-D view of the button. FIG. **44**(*b*) is a top view of the button, and FIG. **44**(*c*) is a side view of the button. FIG. **44**(*d*) is a cross section along line M-M of the button. Button **10** of FIG. **44** is maintained in its upward position using either the spring loaded embodiment of FIG. **42** or the resilient material embodiment of FIG. **43**.

According to the present invention, these buttons are made of Fiber Optic Faceplates. A Fiber Optic Faceplate (FOFP) is a coherent fiber optic plate that precisely transmits an image from its input surface to its output surface. Thus, the displayed image underneath each key is transmitted by the FOFP to the upper surface of the key and appears to the user as if the image is on the upper surface of the key.

However, the present invention provides an air gap between each FOFP key and the display in order to enable lowering the key when the key is pressed. In addition, light beams are projected underneath the keys such that a lowered key blocks beams indicating which key is being depressed, as explained hereinabove, and in U.S. patent application Ser. No. 1/602,217, entitled LIGHT ACTUATOR FOR MOVABLE BUTTONS ON A KEYPAD, and filed on Sep. 3, 2012, the contents of which are incorporated herein by reference. This air gap causes the displayed image to be out of focus at the FOFP input surface. In some embodiments the height of the air gap is 1.5 mm.

In order to correct this problem the present invention provides a plurality of micro lens arrays that reproduce an object—in this case the display screen, over a distance of a few millimeters. Reference is made to FIG. **45**, which is a simplified illustration of an arrangement of micro lens arrays between a keyboard display and a fiber optic face plate key

in accordance with an embodiment of the present invention. FIG. **45** shows four micro lens arrays **51-54** axially aligned in a symmetric fashion between secondary display **56** and the FOFP input surface **57** of an FOFP button. In each optical channel, the first and second micro lens arrays **51** and **52** produce a de-magnified, inverted image of the respective part of the display screen in the intermediate image plane. A reversed group of the same micro lenses, **53** and **54**, relays the intermediate image onto FOFP input surface **57**. Since each partial image has unity magnification, a total image of all partial images results in a complete reconstruction of the final image. The size and possible overlap of adjacent partial images is controlled by aperture mask **55** which lies in the center of axial symmetry.

In an exemplary embodiment the lens arrays are polycarbonate, 0.1 mm thick; each lenslet is 0.2 mm square; the aperture mask has 0.076 mm square holes; and object to image distance is 4.7 mm.

Reference is made to FIG. **46**, which is a simplified illustration of a key or button **59**, in accordance with an embodiment of the present invention. The micro lens arrays **51-54** are connected to FOFP **58** and they move up and down together. When the button is in a resting, non-actuated position, the distance d**1** between the micro lens arrays and the display surface equals the distance d**2** between the micro lens arrays and the FOFP. This ensures that the image on the display is sharply reproduced on the FOFP. When the button is lowered, by the user pressing on the button, the distance d**1** is reduced causing the image on FOFP **58** to be out of focus. However, this is not problem for the user because his finger is covering the output surface of FOFP **58** so the out-of-focus image is not viewable. When the user removes his finger from the key, the key has returned to its resting position and FOFP **58** is again in focus.

Bar Code for Proximity Sensor

Embodiments of the present invention provide a low-cost proximity sensor for detecting directional glide gestures along a linear UI control. For example, a volume control is realized as a narrow window along an edge of a device. A slide in one direction along the window increases the volume and a slide in the opposite direction along the window decreases the volume.

Reference is made to FIG. **47**, which is a simplified illustration of a slider control, in accordance with an embodiment of the present invention. FIG. **47** shows a side cutaway view of a slider window operative to detect a directional glide. The window includes two adjacent light guides: upper light guide **333** is coupled to emitter **101** and lower light guide **334** is coupled to a detector **201**. Between the two light guides there is a staggered series of opaque or reflective light-blocking elements **335** that do not allow light to pass between the two light guides. The spaces between these opaque or reflective elements are of different sizes. Light **433** from emitter **101** enters the light guide **333** where it is contained due to total internal reflection (TIR). When a finger touches the light guide **333** it scatters the light and frustrates the TIR such that a large portion **434** of the FTIR light is scattered directly into lower light guide **334** and toward detector **201**. However, the light can only pass into light guide **334** through the spaces between opaque or reflective elements **335**. Therefore, when the finger is situated opposite an area where the spaces between opaque or reflective elements **335** are large, much light will pass into the light guide **334** and arrive at PD **201**. Whereas, when the finger is situated opposite an area where the spaces between opaque or reflective elements **335** are small, less light will pass into the light guide **334** and arrive at PD **201**. As the finger glides along the light guide **333** it passes across sections having different sized gaps between elements **335**. As a result, the movement of the finger can be inferred from the pattern of light detections at PD **201** over time.

Reference is made to FIG. **48**, which is a simplified illustration of various detection patterns of gestures using the slider control of FIG. **47**, in accordance with an embodiment of the present invention. FIG. **48** shows four different detection patterns. Each graph shows samples of light detection at the PD over time. The x-axis represents time and the y-axis represents the amount of light detected. Thus the direction of movement along the light guide is indicated by the pattern of detections: in this example, an ascending pattern corresponds to sliding right whereas a descending pattern indicates movement in the opposite direction. The speed of the movement is indicated by the rate of change in the detections: faster rates of change correspond to faster movement.

Reference is made to FIG. **49**, which is a simplified illustration of an alternative slider control, in accordance with an embodiment of the present invention. FIG. **49** shows an embodiment wherein emitter **101** projects light beams **336** directly onto finger **922** touching the upper surface of light guide **333**, on which there is a pattern of opaque or reflective elements **335** that prevent reflected light from entering light guide **333**. Therefore different amounts of light **336** reflected off finger **924** enter light guide **333** and are detected by detector **201**, depending on the pattern of light blocking elements near the finger.

Recreational Applications for Optical Proximity Sensor

One application for the present invention is interactive glasses such as GOOGLE® GLASS®. GOOGLE and GOOGLE GLASS are registered trademarks of Google Inc. of Mountain View, Calif. Interactive glasses include a head-up display in one or both glasses lenses. Interactive glasses are typically supported by pads on the bridge of the nose and by temple arms (sides) placed over the ears. In some interactive glasses the temple arms include touch sensors that enable user commands to be communicated by tap gestures or sliding gestures on the temple arms.

Thus, in some embodiments of the invention, the optical proximity sensor of the present invention is embedded in the temple arms of interactive glasses to enable user input gestures within a range of distances apart from the temple arms. This enables a 2D airspace opposite the temple arm for in-air user input gestures. Multiple rows of optical proximity sensors stacked along the temple arms provide a 3D sensor. In other embodiments, a first optical proximity sensor faces away from the user's temple and a second optical proximity sensor faces skyward, to detect gestures to the side of, and above, the user's head.

Another application is a sensor worn as a wristwatch. In various wrist-worn embodiments of the present invention, the optical proximity sensor is a one-dimensional row of diodes; a two dimensional grid of diodes; a two-dimensional snowflake pattern of diodes; two or more one-dimensional rows of diodes along two or more edges of the worn item. In one exemplary embodiment the optical proximity sensors are embedded in a wristwatch and project light beams upward through the watch face or its surrounding bezel. The user issues commands to the watch by performing hover gestures such as waving a hand over the watch. Alternatively, when the user rotates the wrist wearing the watch, he changes the amount of reflected light detected in the optical proximity sensor and this is translated into a command. For example, the optical proximity sensor communicates over BLUETOOTH® with the user's cell phone, and a rotation of

the wrist is a command to answer an incoming call. BLUETOOTH is a trademark of Bluetooth SIG, Inc. A slower rotation gesture is a command to raise or lower the cell phone headset volume.

The optical proximity sensor also distinguishes between a finger gesture that returns localized reflections and a gesture made by a flat palm that returns reflections across a large portion of the optical proximity sensor. This enables responding to only one type of gesture (finger or palm).

Moreover, the optical proximity sensor of the present invention distinguishes between a flat palm above the sensor and a tilted palm above the sensor. When the palm is tilted over the optical proximity sensor, the reflections are not uniform—according to the various distances between portions of the tilted palm and the sensor. By contrast, a flat, even palm perpendicular to the sensor emitter beams reflects all of the sensor beams in the same way.

Another application is a bracelet with the detection plane aimed below the user's palm to detect curled fingers. The four fingers on a hand represent four bit positions and the user forms four-bit words by curling his fingers, where a curled finger is a bit value of '1' and a prone finger is a bit value of '0'. These four-bit values are detected by the optical proximity sensor and translated into commands.

An additional application uses two such bracelets, one on each wrist. The user creates 8-bit words by curling combinations of four fingers on each hand. This provides 256 unique combinations whereby a subset of these combinations is assigned to every letter of the alphabet. The user types text by curling his fingers to form the various 8-bit letter combinations. This provides an alternative method to input text without a keypad.

Another application is a protective casing for a mobile phone. This application is explained in detail in U.S. patent application Ser. No. 13/775,269, now U.S. Pat. No. 8,917,239, for REMOVABLE PROTECTIVE COVER WITH EMBEDDED PROXIMITY SENSORS, which is hereby incorporated in its entirety by reference. An application for a game accessory based on this protective casing is described with reference to FIGS. **50-53**.

The accessory is a slingshot, which can be used in many games, inter alia, ANGRY BIRDS®, published by Rovio Entertainment Ltd., of Espoo, Finland, and owner of the ANGRY BIRDS trademark. In this video game, players catapult birds as projectiles using a slingshot or catapult. The player draws back the catapult to a desired extent to provide power for the projectile birds by sliding his or her finger along the screen. Lifting the finger from the screen releases the catapult, hurling the bird through the air at a target. The angle at which the catapult is drawn back determines the direction in which the bird is hurled. The degree to which the catapult is draw back determines the force of the projectile.

The present accessory enables the player to draw back an actual elastic slingshot attached to an edge of the phone casing. Reference is made to FIG. 36 in U.S. patent application Ser. No. 13/775,269 showing an example of a phone cover with embedded proximity sensors. FIG. 34 in U.S. patent application Ser. No. 13/775,269 illustrates a phone in the cover of FIG. 36. FIG. 39 in U.S. patent application Ser. No. 13/775,269 illustrates a layout of components on a PCB in the phone cover of FIG. 36.

Embodiments of the present invention incorporate optical proximity sensor **512**, described hereinabove, into a protective phone cover. Different embodiments will have the optical proximity sensor along 1-4 edges of the cover.

Reference is made to FIGS. **50-53**, which are simplified illustrations of a game accessory in accordance with an embodiment of the present invention. Thus a PCB **976** is shown having an array of alternating emitters **101** and detectors **201** along a bottom edge of the casing. Attached to the two corners at the bottom edge of the casing are elastic bands **933** tied to slingshot pad **934**. This array of emitters and detectors identifies how the player draws back slingshot pad **934**.

FIGS. **51-53** show three different extensions **935** of slingshot pad **934**. In each figure, the x and y offsets detected by the one-dimensional array along the bottom edge are indicated by dashed arrows.

Several different methods are used to determine the extent and angle to which the slingshot is drawn back, e.g., as indicated by extension arrow **935** in FIGS. **51-53**. In a first embodiment, elastic band **933** is substantially thinner than slingshot pad **934**. Therefore, the amount of light reflected by elastic band **933** is substantially less than what is reflected by slingshot pad **934** to enable the system to track the position of slingshot pad **934**. In a similar vein, even if slingshot pad **934** is not present, the two fingers with which a user pinches elastic band **933** in order to draw it back are much larger than the elastic band, and therefore, the user's two fingers can be tracked. In yet another embodiment the elastic band **933** is situated at a different height than the light beams projected by the proximity detector. Thus, the elastic band **933** is not detected by the detector. However, the larger slingshot pad and/or the user's fingers drawing back the elastic band, extend through the plane of light beams projected by the detector and are therefore detected. In yet another embodiment, the detector is formed by two, stacked arrays of emitters, detectors and lenses. The combined height of the two arrays is greater than the width of elastic bands **933**. Therefore, elastic band **933** will not generate the same detection signals in both arrays. However, the combined height of the two arrays is less than the width of slingshot pad **934** and the user's two fingers and therefore these items generate similar detection signals in both arrays. In yet another embodiment, elastic band **933** does generate a significant detectable signal. In this case a signal pattern is generated across the entire detector array corresponding to the different distances between each section of the drawn-back elastic band and the detector array. The farthest distance is at the location of the slingshot pad or the user's fingers. Thus, by mapping the detection signals, a triangular shape will be mapped corresponding to the shape of the drawn-back slingshot.

In another embodiment an optical proximity sensor **512** is attached via a hinge to an edge of a display. In some embodiments multiple optical proximity sensors **512** are attached to multiple edges of the display. Reference is made to FIG. **54**, which is a simplified illustration of a display surrounded by four proximity sensor bars connected to the display by rotating hinges, in accordance with an embodiment of the present invention. FIG. **54** shows display **911** surrounded on four sides by optical proximity sensors **512**. Each touch sensor bar is attached via hinges **950** to the display housing. As explained hereinabove, each optical proximity sensor **512** projects a 2D detection plane. Thus, hinges **950** enable aiming the 2D detection plane for each touch sensor bar **510** at an angle to display **911**. When rotated to aim the 2D detection plane at an angle above display **911**, touch sensor bar **510** provides hover detection. When rotated to aim the 2D detection plane parallel to the screen surface, optical proximity sensor **512** provides touch detection. Moreover, when one or more optical proximity sensor **512** is rotated to aim the 2D detection plane parallel to the screen surface, and a second one or more array is

rotated to aim the 2D detection plane at an angle above the screen, both touch detection and hover detection are provided. In FIG. **54**, all four optical proximity sensors **512** are rotated to aim their respective detection planes at respective angles above and across display **911**. The four intersecting detection planes in this case provide a 3D detection volume above screen **911**.

Another recreational application enables cloud gaming applications to be displayed on multiple handsets as a multi-panel display. A user arranges the handsets as tiles to form a large, rectangular multi-panel display. The game server identifies where each handset display is located within the multi-panel display. The game server streams respective portions of the game GUI to each handset such that the full screen game GUI is distributed across the handsets. In some embodiments, each handset in the multi-panel display has an optical proximity sensor **512** as described hereinabove.

Reference is made to FIG. **55**, which is a simplified illustration of a handheld electronic game device **994** having communicator **703** for communicating with internet game server **991**, in accordance with an embodiment of the present invention. Display **100** in device **994** renders a portion of a game user interface (UI) received by communicator **703** from game server **991**. Sensor **512** detects a second game device placed nearby and is connected to communicator **703** to send the detection information to the game server. In accordance with an embodiment of the present invention, this sensor is similar to optical proximity sensor **512** discussed above.

Reference is made to FIG. **56**, which is a simplified illustration of an internet game rendered on a handset, in accordance with an embodiment of the present invention. FIG. **56** shows an internet game server **991** in communication with handset **994**. The game logic is processed by server **991** which sends the game GUI to handset **994**. The game's GUI is rendered on a single screen. The area surrounding all four edges of handset **994** is used for user gestures to control the game, as described hereinabove. These gestures are detected by proximity sensors **512** along the edges of the handset, or along the edges of a protective cover used together with the handset, which form top and bottom detection zones **998** and left and right detection zones **999**.

Reference is made to FIG. **57**, which is a simplified illustration of two handsets being used together to render an internet game, in accordance with an embodiment of the present invention. FIG. **57** shows an internet game server **991** in communication with two handsets **994** and **995**, via respective communication processors **983** and **984**. The two handsets are aligned along a common edge, namely the long lower edge of handset **994** is aligned with the long upper edge of handset **995**. As such, these edges between the two handsets are not usable for detecting gestures outside the handsets. However, these edges detect each other. For example, detection zone **998** along the upper edge of handset **995** detects handset **994**. Thus, handset **995** communicates to server **991** that the entire long upper edge above **995** is occupied by a proximal object. Similarly, handset **994** communicates to server **991** that the entire long bottom edge of handset **994** is occupied by a proximal object. Based on this information, server **991** determines that the proximal object detected by each handset is the neighboring handset. Accordingly, server **991** sends the upper half of the game GUI to handset **994** and the lower half of the game GUI to handset **995**. Furthermore, based on the screen orientation, e.g., the location of the detecting edge in relation to pixel (0,0) on the detecting handset's display, server **991** determines whether to rotate one or both of the half-GUI images in order that they will be rendered properly on their target handsets. This ensures continuity from one handset display to the next, so that together the two handsets display a contiguous GUI.

Reference is made to FIG. **58**, which is a simplified illustration of a two-panel display for an internet game, the display being made up of two handsets, in accordance with an embodiment of the present invention. FIG. **58** shows an internet game rendered on two handsets **994** and **995**, i.e., the game GUI is rendered on two screens: the upper half of the GUI is rendered on handset **994**, and the lower half of the GUI is rendered on handset **995**. Because the number of devices communicating with the Internet game server in this instance of the current game is two, the game server divides the GUI into two portions. The number portions the game server divides the GUI into, is according to the number of devices communicating with the Internet game server in a particular instance the game.

As explained above with reference to FIG. **57**, the edges between the two handsets are not usable for detecting gestures outside the handsets. However, the remaining three exposed edges of each handset are usable for detecting user input gestures in the open space outside the handsets. The exposed handset edges form the periphery of the multi-panel display and are used for detecting user gestures in the open space outside the multi-panel display. The handset alignment information described above, whereby server **991** determines how the two handsets are oriented in relation to each other and what part of the GUI is rendered on each handset, also enables the game server to map a gesture that spans the open space of two handsets as a single gesture. For example, if the user performs a glide gesture by gliding his finger upwards opposite the right edge of the multi-panel display, as illustrated by arrow **939**, the gesture is first detected at zone **999** of handset **995** and then at zone **998** of handset **994**. Each handset sends its proximity zone detection information to server **991**. Server **991** stores information relating to the arrangement of the panels. Based on the handset alignment information, server **991** combines these two glide detections to form one long upward glide gesture opposite the right edge of the multi-panel display.

Reference is made to FIG. **59**, which is a simplified illustration of a four-panel display for an internet game, the display being made up of four handsets, in accordance with an embodiment of the present invention. FIG. **59** shows an internet game on four handsets **994-997**. The game GUI is rendered on four screens, each screen displaying a respective quarter of the GUI. As explained hereinabove, each of the edges between neighboring handsets detects a neighboring handset. Thus in a four-handset arrangement each handset detects two neighbors. By sending this information to the server, the server maps how the four handsets are arranged and sends an appropriate quarter of the GUI to each handset so that the four handsets together display a contiguous GUI. As mentioned, it may be necessary that the server rotate some of the images sent to the different handsets.

In some embodiments, the detector along each device edge is an alternating series of light emitters and light detectors, whereby the detectors detect light reflected by an object, such as a neighboring device. However, in some embodiments, an activation pattern of light emitters along a device edge is detected by the opposite array of detectors on its neighboring device. This is an alternative method for detecting a neighboring active device. It also enables determining the relative orientation of the two devices. For example, if the emitters near the top of the display are

activated in an activation pattern different than those activated near the bottom of the display, the neighboring device determines where the top of the neighboring device is situated based on the different detections at its light detectors.

As explained hereinabove, the remaining exposed handset edges form the periphery of the multi-panel display and are used for detecting user gestures in the open space outside the multi-panel display. The alignment information described above, based on the handset edges situated between handsets, also enables the game server to map a gesture that spans the open space opposite two handsets, indicated as zones **998** and **999** in FIG. **59**, as a single gesture.

In some embodiments each device includes a dedicated emitter and sensor that employ an automated process of negotiation that dynamically sets up a communications channel between the two devices. In information technology, telecommunications, and related fields, this process is known as handshaking. Thus, for example, a first device's emitter generates a handshake signal that is detected at the sensor on the neighboring device. The neighboring device emitter generates a reciprocal handshake signal that is detected at the first device's sensor. Light emitters and light sensors are capable of handshaking. However, other types of emitter/sensor are also within the scope of the invention, inter alia, RFID. Thus, regardless of the technology used: (a) the neighboring devices detect each other; (b) each device communicate this detection to the Internet game server; and (c) based on this information, the Internet game server send respective portions of the game GUI to each device.

Reference is made to FIG. **60**, which is a simplified illustration of a configuration of four game devices, as shown in FIG. **59**, whereby the game GUI is distributed among the four displays **142-145** according to each display's relative position and orientation detected by sensors **518** and communicated to game server **991**, in accordance with an embodiment of the present invention. Thus, FIG. **60** illustrates an internet gaming system featuring internet game server **991** and a number of game devices, each of which is a handheld electronic game device in communication with the game server via individual communicators **703** embedded in each device. Each device has a respective display **142-145** for rendering a respective portion of a game user interface (UI) received by communicator **703** from game server **991**. Each device also has a respective sensor **518**, connected to communicator **703**, for detecting presence of a neighboring game device. Game server **991** determines the size of each respective portion of the game UI based on the number of game devices.

Vehicle Door Handle with Optical Proximity Sensors

Another application is a vehicle door handle having a proximity sensor that is operative to detect objects in two zones, namely, a near zone and a far zone. Thus the proximity sensor is configured for short range and long range proximity detection. When an object, such as a black leather gloved hand, approaches the handle, the long range detection proximity sensing detects if the object is coming towards the handle. If the object is detected to be approaching the vehicle, the short range proximity sensing is activated to detect whether a swiping gesture, inter alia, left to right, is performed near the handle. In response to detecting this swiping gesture, a signal is sent to a wireless detector such as an RFID detector, to look for an RFID chip in the key fob, and, if this is found, then the door is unlocked. The invention is also applicable to a door in a building.

Reference is made to FIGS. **61-64**, which are simplified illustrations of a door handle with embedded proximity sensors, in accordance with an embodiment of the present invention. FIG. **61** shows a handle **940** for a car door. An exposed outer surface **313** of a proximity sensor array mounted in the handle is shown along the length of handle **940**.

FIGS. **62** and **63** show the two proximity sensing zones provided according to embodiments of the invention, namely, short range detection zone **925** nearer to handle **940** and long range detection zone **926** further from handle **940**. FIG. **62** is a front view and FIG. **63** is a cutaway view from above. In some embodiments, the long range detection is sensitive to objects between 100 mm from the handle and 125 mm from the handle, and the short range detection is sensitive to objects within 50 mm of the handle, as shown in FIG. **63**. Also shown in FIG. **63** is processor **941** connected to the proximity sensors in handle **940** and keyless lock **942** connected to processor **941**.

FIG. **64** shows how long range detection zone **926** is realized. As described hereinabove, each emitter-detector pair is configured for maximum detection of reflected light wherein the reflective object is at a specific two-dimensional location within the detection plane. These specific locations art referred to as "hot spots" or "target spots". FIG. **64** shows four hot spots **960** that provide long range proximity detection in zone **926**.

The four hot spots **960** in FIG. **64** are provided by two emitters at the left end of handle **940** and two detectors at the right end of handle **940**. These emitters and detectors are not shown in FIG. **64**. The two emitters project two beams **322** and the two detectors with their associated lenses are configured to receive reflected light beams along light paths **422**, to provide four emitter-detector combinations corresponding to the four hot spots **960**.

Reference is made to FIG. **65**, which is a simplified illustration of dimensions of a proximity sensor zone in the airspace opposite the door handle, in accordance with an embodiment of the present invention. FIG. **65** shows that when the emitter and detector of the outermost emitter-detector pair are 92 mm apart, and detection zone **926** extends to 125 mm from handle **940**, that emitter beam **322** should project at an angle of roughly 20° from the y-axis of the detection plane, and detection path **422** should extend along a path roughly −20° from the y-axis of the detection plane. These numbers are examples only.

Using hot spots **960**, a location of the object is calculated as follows. The light emitters are denoted E, the light detectors are denoted D, and an emitter-detector pair is denoted (E, D). A hot spot, or target position, P for a given emitter-detector pair (E, D) is denoted P(E, D). A processor controlling the door-mounted proximity sensor array determines that emitter-detector pair ($E_{max}$, $D_{max}$), for which the amount of received light R(E, D) is a maximum, for the emitter-detector pairs (E, D) that are synchronously activated at time $t_i$. The processor then determines one or more others ($E_{neighbor}$, $D_{neighbor}$) of the emitter-detector pairs (E, D) that are synchronously activated at time $t_i$, whose corresponding target positions P(E, D) neighbor the target position P($E_{max}$, $D_{max}$). The processor calculates position $P_i$,

$$P_i=\Sigma W(E,D)*P(E,D),$$

as a weighted average of the target positions P($E_{max}$, $D_{max}$) and P($E_{neighbor}$, $D_{neighbor}$), with respective weights W(E, D) corresponding to the respective amounts of received light R($E_{max}$, $D_{max}$) and R($E_{neighbor}$, $D_{neighbor}$).

A series of positions of the object is calculated for a sequence of times, $t_1, \ldots, t_n$. The processor recognizes from the thus-calculated positions $P_1, \ldots, P_n$ of the object that the

object is approaching the door handle. In this embodiment, the initial determination is whether the object is approaching the handle or not. As such in some embodiments only the y-coordinate of the object's position interpolated.

Reference is made to FIGS. **66**(*a*) and (*b*) and **67**(*a*)-(*c*), which are simplified illustrations of a light-based proximity sensor, in accordance with an embodiment of the present invention. FIG. **66** shows two similar arrangements of the emitters, inter alia, LEDs or laser diodes, and detectors, inter alia, PDs, in a door handle. FIG. **66** shows two emitters **101** and **102** at the left end of the handle and two receivers **201** and **202** at the right end of the handle. There four elements are used for long range proximity detection. Between these four elements, FIG. **66** also shows an alternating arrangement of emitters **103**-**108** and detectors **203**-**209** used for short-range proximity detection. In some embodiments baffles separate the emitters from the detectors to prevent stray emitter light from entering the detectors. The baffles are not shown in FIG. **66**.

Calculation of object positions in short range detection for zone **925** uses the alternating arrangement of emitters **103**-**108** and detectors **203**-**209**. Object position calculation with such an arrangement has been discussed hereinabove in the context of a touch sensor bar. In the present embodiment of a vehicle door handle, this stage of the process requires determining whether a sweep gesture is being performed along the length of the door handle. As such, in some embodiments only the x-coordinates of the object positions are interpolated.

Furthermore, it is possible to determine a size of the object based on the number of hot spots detected along the length of the handle. When a certain object size is expected, e.g., a finger or a hand, the processor determines the size of the object performing the sweep gesture and rejects gestures performed by an object whose detected size differs from the expected size. This enables avoiding false detections, e.g., resulting from falling snow (small objects) or passing persons and cars (large objects).

FIGS. **67**(*a*)-(*c*) show the lenses used in an embodiment of the invention. FIG. **67**(*a*) shows light guide **314** made up of light guide **315** for long range detection and light guide **316** for short range detection. FIG. **67**(*b*) shows a cross-section of light guide **315** and how light beam **340** passes through this light guide. FIG. **67**(*c*) shows a cross-section of light guide **316** and how light beam **345** passes through this light guide. The top side of light guide **314** in FIG. **67** is its outward-facing side. Thus, the detection plane is upward with respect to the light guides shown in FIGS. **67**(*a*)-(*c*).

Reference is made to FIGS. **68** and **69**, which are simplified illustrations of light beam paths through a light guide, in accordance with an embodiment of the present invention. FIGS. **68** and **69** show top, side and back views of long range light guide **315** and the fill of light through this light guide. The entrance surface of light guide **315** is a negative lens followed by two reflecting surfaces, each curved in both x and y dimensions. The two reflecting surfaces are an extremely efficient system, in terms of emitting and receiving light. The entire optical part of the long range detection system, i.e., light guide **315** and its respective emitters and detectors, is rotated 13°, as shown in the top view of FIG. **68**, so that when the light emerges out of light guide **315**, it makes an angle of 20.2° with respect to the vertical, shown in back view. This angle aids in the triangulation of the long range zone, by decreasing spurious signals.

With regard to short range detection, reference is made to FIG. **70**, which is a simplified illustration of different configurations of light beams for a proximity sensor, in accordance with an embodiment of the present invention. FIG. **70** shows different configurations of light beam paths that distribute hot spots in the short range detection zone. For a pitch of 10 mm between neighboring emitters, it has been determined that an optimum angle is 27°, for a detection zone depth of ~50 mm. This configuration is circled in FIG. **70**.

Reference is made to FIGS. **71** and **72**, which are simplified illustrations of light beam paths through a light guide, in accordance with an embodiment of the present invention. FIGS. **71** and **72** show top, side and back views of short range light guide **316** and the fill of light through this light guide. The optics of light guide **316** includes a y-curved mirror and an x-curved lens. The width of the bezel along the outward facing edge of light guide **314**, i.e., for both light guides **315** and **316**, is 3 mm. The pitch between neighboring emitters in the arrangement of alternating emitters and detectors used for short range detection is 10 mm. The emitter beams used for short range detection are projected along the vertical and the PDs are configured to receive reflected beams at an angle of 27° with respect to the vertical. This 27° PD acceptance angle is shown in the back view of FIG. **72**. FIGS. **71** and **72** show very good fill factors for light guide **316**.

Reference is made to FIGS. **73**(*a*)-(*c*) and **74**, which are simplified illustrations of light beam paths in the airspace opposite proximity sensors, in accordance with an embodiment of the present invention. FIGS. **73**(*a*)-(*c*) show an analysis of detections at the near and far edges of the long range detection zone. FIG. **73**(*a*) shows the two emitters and two detectors used for long range detection. The inner emitter-detector pair is configured for maximum detection when the reflective object is opposite the midpoint between the emitter and the detector at a distance of 100 mm from the door handle. FIG. **73**(*b*) shows the detected scattered light by the inner PD when the reflective object is at this hot spot location. The PD is divided into a 99×99 cell grid to illustrate the distribution of light detections across the surface of the PD. The outer emitter-detector pair is configured for maximum detection when the reflective object is opposite the midpoint between the emitter and the detector at a distance of 125 mm from the door handle. FIG. **73**(*c*) shows the scattered light detected by the outer PD when the reflective (scattering) object is at this hot spot location. The PD is divided into a 99×99 cell grid to illustrate the distribution of light detections across the surface of the PD. Both the inner and outer PDs exhibit bell-shaped distributions of light with the center of the distribution at the center of the PD. If, for example, the reflective object were placed at a distance of only 75 mm from the door handle, instead of 100 mm, the distribution of light would be shifted toward one side of the inner PD and not centered. This would also result in less light arriving at the inner PD.

FIG. **74** shows a spread of ~9° in the x dimension for the emitters used for long range detection. This translates to a spread of 22 mm at a distance of 123 mm from the door handle.

Reference is made to FIGS. **75**(*a*)-(*f*) and **76**(*a*)-(*f*), which are simplified illustrations of light beam paths through light guides, in accordance with an embodiment of the present invention. FIGS. **75**(*a*)-(*f*) show the fill factor for the lenses used for the long range detection outer emitter and outer detector. FIG. **75**(*a*) is a side view of this lens and illustrates how light along the height of the emitter or detector is efficiently collected. FIG. **75**(*c*) is a back view of this lens, and FIG. **75**(*d*) is a top view of this lens, showing how light along the width of the emitter is efficiently collected. FIG.

75(*e*) is a back view of this lens, and FIG. 75(*f*) is a top view of this lens, showing how light is efficiently collected onto the width of the detector. FIG. 75(*b*) shows the scattered light detected by the outer PD when the reflective (scattering) object is at this hot spot location.

FIGS. 76(*a*)-(*f*) show the fill factor for the lenses used for the long range detection inner emitter and inner detector. FIG. 76(*a*) is a side view of this lens and illustrates how light along the height of the emitter or detector is efficiently collected. FIG. 76(*c*) is a back view of this lens, and FIG. 76(*d*) is a top view of this lens, showing how light along the width of the emitter is efficiently collected. FIG. 76(*e*) is a back view of this lens, and FIG. 76(*f*) is a top view of this lens, showing how light is efficiently collected onto the width of the detector. FIG. 76(*b*) illustrates the scattered light detected by the inner PD when the reflective (scattering) object is at this hot spot location.

FIGS. **77-81** are simplified illustrations of light beam paths in the airspace opposite proximity sensors, in accordance with an embodiment of the present invention. FIG. **77** shows an emitter beam **346** and three reflective light paths **347-349** used for short range detection, in accordance with an embodiment of the present invention. As illustrated in FIG. **77**, the pitch between neighboring lenses is 10 mm and the distance between hot spots along beam **346** is 19.6 mm. The optimized detection path for each detector is 27° with respect to the vertical, illustrated as 63° with respect to the horizontal. FIG. **78** shows detections at each of the hot spots of FIG. **77**.

FIGS. **79-81** show back, top and side views of light guide **316**. FIG. **81** is a side view of light guide **316**, showing how light is efficiently collected along the height of the emitter and detector that share lenses in this light guide. FIG. **79** is a back view of this lens, and FIG. **80** is a top view of light guide **316**, showing how light along the width of the emitter and detector that share lenses in this light guide is efficiently collected.

Reference is made to FIG. **82**, which is a simplified illustration of unlocking a door handle using proximity sensors, in accordance with an embodiment of the present invention. FIG. **82** shows use of a door handle, according to the present invention, in a car. Owner **943** approaches locked car **942**. Long range proximity detectors mounted in door **941**, and preferably mounted in the handle, detect this approach and in response thereto, activate short range proximity detectors also mounted in door **941**. Next, owner **943** performs a gesture along the door handle, such as swiping his hand from left to right along the door handle as indicated by arrow **944**, which is detected by the thus-activated short range proximity detectors. As the short range proximity detectors detect objects and gestures within a distance of the handle, this gesture can be performed in the airspace opposite the handle without touching the handle. In response to the thus detected swipe gesture, a keyless lock in car **942** is activated to scan for a digital key via wireless communication. Other gestures are also possible. Swipe gestures are mere examples.

Reference is made to FIG. **83**, which is a flowchart of a method for unlocking a door handle using proximity sensors, in accordance with an embodiment of the present invention. At operation **1001** long range proximity detectors mounted in the door are activated to detect an approaching person. If detected, the method proceeds to operation **1002**. If not, the method returns to operation **1001**. At operation **1002** short range proximity detectors mounted in the door are activated to detect a user gesture on or near the car door. If detected, the method proceeds to operation **1003**. If not, the method returns to step **1001**. At operation **1003** a keyless lock mounted in the vehicle is activated to detect a digital key carried by the person performing the approach and swipe gestures. If detected, the method proceeds to operation **1004** and unlocks the car. If not, the method returns to operation **1001**.

Reference is made to FIGS. **84-86**, which are simplified illustrations of a light guide, in accordance with an embodiment of the present invention. FIGS. **84-86** show light guide **315**. FIG. **84** shows three lenses **460** of a light guide that also captures a wide viewing angle, and has the added advantages of no gaps in the light field and the light field can be easily shaped, e.g., to provide linear light intensity distributions. Lens **460** uses refraction and reflection to capture and collimate light across a wide viewing angle. Each lens in FIG. **84** is opposite respective emitter **107-109**. This lens features an upper portion **466** and a lower portion **467**. Lower portion **467** features refractive surface **463** facing the lens's respective diode and curved internally reflective surface **461** cut horizontally by a bottom horizontal plane **484**. Upper portion **462** features refractive surface **464** above the lens's respective diode and curved internally reflective surface **462** cut horizontally by a top horizontal plane **483**.

In some embodiments, refractive surface **463** is a single-curved (x-dimension) surface. In other embodiments the surface facing the diode is straight. Internally reflective surfaces **461** and **462** further collimate the light in both the x- and y-directions. When diodes **107-109** are emitters, collimated light exits lens **460** through flat exit surface **464**. When diodes **107-109** are receivers, collimated light enters lens **460** through flat exit surface **464**. By cutting reflective surfaces **461** and **462** horizontally with horizontal planes **483** and **484**, instead of vertically, the lens has a lower height, as explained above.

FIG. **85** shows a view from above of lens **460**. Diode **108** is either an LED or PD. FIG. **85** shows curved entry surface **463** and flat exit surface **464** of lens **460**. Light beams **465** are refracted at entry surface **463**.

FIG. **86** shows a cutaway view from the side of light guide **460**. FIG. **86** shows how reflective surfaces **461** and **462** collimate light beams **465** in the y and x directions. Surfaces **461** and **462** are curved in both the x and y directions to collimate the light in both these directions, and are cut horizontally by respective horizontal planes **484** and **483**. Surfaces **461** and **462** are vertically aligned mirror images of each other. This ensures that any light reflected by one of these surfaces is also reflected by the other surface. Entry surface **463** and exit surface **464** of lens **460** are also shown.

Lens **460** is an extremely fast lens suitable for applications requiring much light, yet is extremely compact. For example, in prior art systems in which a diode is placed underneath the screen, light guides for collimating light in the x-direction, i.e., parallel to the screen surface, employ a curved reflective surface that receives the light traveling downward, perpendicular to the x-direction. In prior art lenses, a double-curved reflector is cut vertically by a rear vertical plane of the light guide. The advantages of lens **460** are evident when it is compared to a prior art light guide illustrated in FIG. **87**.

Reference is made to FIG. **87**, which is a prior art illustration of a light guide. FIG. **87** shows diode **108** opposite a prior art collimating light guide **470** having a single reflector curved in two-dimensions for collimating light from LED **108**. The reflector has a height **478** which is the sum of two heights: (a) height **476** which is determined by the height of exit surface **474**. This is the height of the incoming light channel which must be maintained as the

light travels through light guide **470**; and (b) height **472** of the parabola resulting from the fact that double-curved reflector **471** is intersected by backplane **481**. The magnitude of height **472** depends on the width of the pitch between neighboring LEDs and the proximity of LED **108** to light guide **470**. Namely, a wider viewing angle requires a greater parabolic height.

Reference is made to FIG. **88**, which is a simplified illustration of a light guide, in accordance with an embodiment of the present invention. In contrast to FIG. **87**, the minimum height of lens **460** of FIGS. **84**, **85**, **86** and **88**, is limited only to twice the height of the incoming light channel, i.e., the sum of the heights of surfaces **463** and **464**. The parabola of FIG. **87** is rotated from the vertical plane to the horizontal plane in lens **460**. Therefore height **472** in light guide **470** is transposed into depth **482** in the horizontal plane in lens **460**, as illustrated in FIG. **84**.

Moreover, because lens **460** has two double-curved reflectors it is more powerful, nearly twice as powerful, as light guide **470**. Thus, for wide viewing angles the parabolic depth required in lens **460** is substantially less than the parabolic height required in light guide **470**.

In the foregoing specification, the invention has been described with reference to specific exemplary embodiments thereof. It will, however, be evident that various modifications and changes may be made to the specific exemplary embodiments without departing from the broader spirit and scope of the invention. Accordingly, the specification and drawings are to be regarded in an illustrative rather than a restrictive sense.

The invention claimed is:

**1**. A proximity sensor for a door of a structure, comprising:

a printed circuit board (PCB) mounted in a structure;

a plurality of light emitters mounted on said PCB emitting light out of the structure;

a plurality of light detectors mounted on said PCB;

a plurality of lenses mounted on said PCB and oriented relative to said emitters and to said detectors such that for each emitter-detector pair, when a reflective object is located at a target position near the structure, corresponding to that emitter-detector pair, then the light emitted by that emitter passes through one of the lenses and is reflected by the object back through one of the lenses to that detector, wherein at least one of said lenses comprises:

an upper portion, comprising:

an upper refractive surface located nearer to said emitters and detectors; and

an upper reflector located further from said emitters and detectors, and being curved in two dimensions and cut horizontally by a top horizontal plane of the lens; and

a lower portion, coplanar with said emitters and detectors, comprising:

a lower refractive surface located nearer to said emitters and detectors; and

a lower reflector located further from said emitters and detectors, the lower reflector being curved in the two dimensions and cut horizontally by a bottom horizontal plane of the lens, wherein said upper and lower reflectors are symmetrical and vertically aligned, and wherein non-collimated light reflected by said lower reflector onto said upper reflector is partially collimated by said lower reflector and further collimated by said upper reflector; and

a processor mounted in the structure and connected to said emitters and to said detectors, (i) synchronously activating emitter-detector pairs, (ii) recognizing from the amounts of light received by the activated detectors, based on the target positions corresponding to the activated emitter-detector pairs, that the object is approaching the structure and is performing a sweep gesture, and (iii) in response to the recognized sweep gesture, activating a keyless lock for locking and unlocking a door of the structure, wherein the keyless lock, when activated, scans for a digital key via wireless communication.

**2**. The proximity sensor of claim **1**, wherein at least some of said lenses are oriented so that for each emitter-detector pair from a group of said emitters and a group of said detectors, when the object is located at the target position corresponding to that emitter-detector pair, the light emitted by the emitter of that pair is projected at an angle $\theta$ with respect to an optical axis of one of said lenses, and is reflected by the object back to the detector at an angle $-\theta$ with respect to the optical axis.

**3**. The proximity sensor of claim **2**, wherein $\theta$ is approximately 20°.

**4**. The proximity sensor of claim **1**, wherein at least some of said lenses comprise a curved refractive surface for collimating light in one dimension.

**5**. The proximity sensor of claim **1**, wherein said lenses are oriented so that for each emitter-detector pair from a group of said emitters and a group of said detectors, when the object is located at the target position corresponding to that emitter-detector pair, the light emitted by the emitter of that pair is reflected by the object back to the detector of that pair at an angle $\theta$ or $-\theta$ with respect to an optical axis of one of said lenses.

**6**. The proximity sensor of claim **5**, wherein $\theta$ is approximately 27°.

**7**. The proximity sensor of claim **1**, wherein at least some of said lenses are situated between said emitters and said detectors.

**8**. The proximity sensor of claim **1**, wherein said emitters and said detectors comprise diodes that are mounted on said PCB without individual plastic casing lenses and without individual substrates.

**9**. The proximity sensor of claim **1**, wherein the structure is a vehicle.

**10**. The proximity sensor of claim **1**, wherein the structure is a building.

**11**. A method for activating a keyless lock for a structure, the structure including (i) a door, (ii) a keyless lock that locks and unlocks the door, (iii) a processor, (iv) a printed circuit board (PCB), (v) a plurality of light emitters, denoted E, mounted on the PCB and connected to the processor, for emitting light out of the structure, (vi) a plurality of light detectors, denoted D, mounted on the PCB and connected to the processor, and (vii) a plurality of lenses mounted on the PCB and oriented relative to the emitters and detectors such that for each emitter-detector pair (E, D), when a reflective object is located at a target position P(E, D) near the structure, corresponding to that emitter-detector pair (E, D), then the light emitted by emitter E passes through one of the lenses and is reflected by the object back through one of the lenses to that detector D, the method comprising:

for each of a sequence of times, $t_1, \ldots, t_n$, synchronously activating a plurality of emitter-detector pairs (E, D);

for each time $t_i$, calculating a position, $P_i$, of the object, based on the amounts R(E, D) of light received by D, at time $t_i$, for the emitter-detector pairs (E, D) that are

synchronously activated at time $t_i$, and based on the corresponding target positions P(E, D);

recognizing from the thus-calculated positions $P_1, \ldots, P_n$ of the object that the object is approaching the structure and is performing a sweep gesture along the structure; and

activating the keyless lock to scan for a digital key via wireless communication, in response to said recognizing.

**12**. The method of claim **11**, wherein said calculating a position, $P_i$, comprises:

determining that emitter-detector pair ($E_{max}$, $D_{max}$), for which the amount of received light R(E, D) is a maximum, for the emitter-detector pairs (E, D) that are synchronously activated at time $t_i$;

determining one or more others ($E_{neighbor}$, $D_{neighbor}$) of the emitter-detector pairs (E, D) that are synchronously activated at time $t_i$, whose corresponding target positions P(E, D) neighbor the target position P($E_{max}$, $D_{max}$); and

calculating position $P_i$

$$P_i = \Sigma W(E,D) * P(E,D),$$

as a weighted average of the target positions P($E_{max}$, $D_{max}$) and P($E_{neighbor}$, $D_{neighbor}$), with respective weights W(E, D) corresponding to the respective amounts of received light R($E_{max}$, $D_{max}$) and R($E_{neighbor}$, $D_{neighbor}$).

**13**. The method of claim **11**, wherein the structure is a vehicle.

**14**. The method of claim **11**, wherein the structure is a building.

**15**. A proximity sensor for a door of a structure, comprising:

a printed circuit board (PCB) mounted in a structure;

a plurality of light emitters mounted on said PCB for emitting light out of the structure;

a plurality of light detectors mounted on said PCB;

a plurality of lenses mounted on said PCB and oriented relative to said emitters and to said detectors such that for each emitter-detector pair, when a reflective object is located at a target position near the structure, corresponding to that emitter-detector pair, then the light emitted by that emitter passes through one of the lenses and is reflected by the object back through one of the lenses to that detector, wherein at least some of the lenses comprise a curved reflector for collimating light in a first dimension and a curved refractive surface for collimating light in a second dimension; and

a processor mounted in the structure and connected to said emitters and to said detectors, (i) synchronously activating emitter-detector pairs, (ii) recognizing from the amounts of light received by the activated detectors, based on the target positions corresponding to the activated emitter-detector pairs, that the object is approaching the structure and is performing a sweep gesture, and (iii) in response to recognizing the sweep gesture, activating a keyless lock for locking and unlocking a door of the structure, wherein the keyless lock, when activated, scans for a digital key via wireless communication.

**16**. The proximity sensor of claim **15**, wherein at least some of said lenses are oriented so that for each emitter-detector pair from a group of said emitters and a group of said detectors, when the object is located at the target position corresponding to that emitter-detector pair, the light emitted by the emitter of that pair is projected at an angle $\theta$ with respect to an optical axis of one of said lenses, and is reflected by the object back to the detector at an angle $-\theta$ with respect to the optical axis.

**17**. The proximity sensor of claim **16**, wherein $\theta$ is approximately 20°.

**18**. The proximity sensor of claim **15**, wherein said lenses are oriented so that for each emitter-detector pair from a group of said emitters and a group of said detectors, when the object is located at the target position corresponding to that emitter-detector pair, the light emitted by the emitter of that pair is reflected by the object back to the detector of that pair at an angle $\theta$ or $-\theta$ with respect to an optical axis of one of said lenses.

**19**. The proximity sensor of claim **18**, wherein $\theta$ is approximately 27°.

**20**. The proximity sensor of claim **15**, wherein at least some of said lenses are situated between said emitters and said detectors.

**21**. The proximity sensor of claim **15**, wherein said emitters and said detectors comprise diodes that are mounted on said PCB without individual plastic casing lenses and without individual substrates.

**22**. The proximity sensor of claim **15**, wherein the structure is a vehicle.

**23**. The proximity sensor of claim **15**, wherein the structure is a building.

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