

SIDE-LIGHT DISPLAY ILLUMINATOR

CROSS REFERENCES TO RELATED APPLICATIONS

[0001] This application claims priority benefit of U.S. Provisional Patent Application Serial No. 61/609,956, entitled SIDE-LIGHT DISPLAY ILLUMINATOR, filed on March 13, 2012 by inventors Thomas Eriksson, Lars Sparf and Björn Le Normand, the contents of which are hereby incorporated herein in their entirety.

FIELD OF THE INVENTION

[0001] The field of the present invention is illuminators for displays of electronic devices.

BACKGROUND OF THE INVENTION

[0002] Conventional computer displays are illuminated by back lights underneath the display. As computing devices become ever more pervasive, adults and even children, work with computer displays for hours on end, often for the greater part of each day.

[0003] Excessive exposure to backlit displays may cause fatigue and may impair eyesight.

[0004] It would thus be of advantage to provide displays that are illuminated by sources other than back lights.

SUMMARY

[0005] Aspects of the present invention relate to display screens of electronic devices that are illuminated by side lights, instead of by back lights.

[0006] There is thus provided in accordance with an embodiment of the present invention a light guide for illuminating a display screen, including a vertical cone-shaped entrance surface including an aperture for admitting light beams emitted by an LED, a folding mirror for reflecting the admitted light beams at an angle of approximately 90°, and for horizontally collimating the admitted light beams, a horizontal guide for guiding the reflected light beams to an exit surface, and an exit surface positioned above a perimeter of a display screen for directing the guided light towards a portion of the display screen, the exit surface being tilted vertically from the horizontal at a slight angle to direct the guided light beams towards the display, and being shaped horizontally as a concave lens to spread the guided light beams horizontally over an angular expanse of the display screen.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] The present invention will be more fully understood and appreciated from the following detailed description, taken in conjunction with the drawings in which:

[0008] **FIG. 1** is a top view of an electronic device with a display screen that is illuminated by light transmitted through light guides positioned at the four corners of the display screen, in accordance with an embodiment of the present invention;

[0009] **FIG. 2** is an exposed top view of the electronic device shown in **FIG. 1** with the peripheral casing removed, in accordance with an embodiment of the present invention;

[0010] **FIG. 3** is an illustration of a prior art light-based touch screen;

[0011] **FIG. 4** is a top view of the outer frame of the electronic device shown in **FIG. 1**, in accordance with an embodiment of the present invention;

[0012] **FIG. 5** is a top view of the outer frame of the electronic device shown in **FIG. 1** showing one of the light guides positioned at a corner of the display screen, in accordance with an embodiment of the present invention;

[0013] **FIG. 6** is a simplified illustration of a light guide for transmitting light to illuminate a portion of a display screen, in accordance with an embodiment of the present invention;

[0014] **FIG. 7** is a simplified vertical cross-sectional view of light beams transmitted through a light guide for illuminating a portion of a display screen, in accordance with an embodiment of the present invention;

[0015] **FIG. 8** is a simplified vertical cross-sectional view of a light guide transmitting light beams to illuminate a portion of a display screen, in accordance with an embodiment of the present invention;

[0016] **FIG. 9** is a simplified horizontal cross-sectional view of light beams transmitted through a light guide for illuminating a portion of a display screen, in accordance with an embodiment of the present invention;

[0017] **FIG. 10** is a simplified horizontal cross-sectional view of a light guide transmitting light beams to illuminate a portion of a display screen, in accordance with an embodiment of the present invention;

[0018] **FIG. 11** is an illustration of an illumination pattern produced by light transmitted through a single light guide positioned at a corner of a display screen, in accordance with an embodiment of the present invention;

[0019] **FIG. 12** is a simplified illustration of distribution of illumination via a light guide over the surface of a display screen, in accordance with an embodiment of the present invention; and

[0020] **FIG. 13** is a log plot of étendue/ dS (in radians) for a display screen illuminated by a light guide, vs. z (in mm), for each of four light guide height parameter values, in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION

[0021] Aspects of the present invention relate to display screens of electronic devices that are illuminated via light guides by side lights positioned near the perimeters of the display screens.

[0022] Reference is made to **FIG. 1**, which is a top view of an electronic device **100** with a display screen **110** that is illuminated by light transmitted through light guides **200** positioned at the four corners of the display, in accordance with an embodiment of the present invention. A casing **120** surrounds the perimeter of display screen **110**.

[0023] Reference is made to **FIG. 2**, which is an exposed top view of electronic device **100** with peripheral casing **120** removed, in accordance with an embodiment of the present invention. **FIG. 2** shows a printed circuit board **300** on which the circuitry for display screen **110** is mounted.

[0024] **FIG. 2** also shows a projector **130**, which is used in an embodiment of the present invention in which display screen **110** is a touch-sensitive display screen. In this embodiment, a plurality of infrared light emitters (not shown), for emitting infrared light, are provided near the perimeter of display screen **110**, and a plurality of infrared light receivers (not shown), for receiving infrared light emitted by the infrared light emitters, are provided near the perimeter of display screen **110**. Projector **130** projects the infrared light emitted by the infrared light emitters across display screen **110** in order to enable detection of touch position when an object touches display screen **110**. Use of infrared emitters and infrared receivers for providing touch detection is described in assignee's US Patent No. 8,339,379 entitled LIGHT-BASED TOUCH SCREEN, the contents of which are hereby incorporated in their entirety.

[0025] Light-based touch screens operate by emitting light beams across a touch screen from two adjacent edges, and detecting whether the light

beams are blocked from reaching detectors at the two opposite edges. Reference is made to **FIG. 3**, which is an illustration of a prior art light-based touch screen. **FIG. 3** shows infrared light emitters **320**, which emit infrared light, aligned along two adjacent edges of a display **310**. Across from light emitters **320** are corresponding infrared light receivers **330**, which receive the infrared light emitted by emitters **320**. However, when an object **340** touches display **310**, it blocks light emitted by one or more specific emitters **320** from reaching their corresponding specific receivers **330**. As such, object **340** is detected when light is not detected by the specific receivers **330**. Since infrared receivers **330** are arranged along two dimensions of display **310**, the blocked receivers on each edge suffice to determine the spatial location of object **340** on display **310**.

[0026] It will be appreciated from **FIG. 3** that the corners of display **310** are vacant of emitters and receivers, and thus provide an opportune location for placement of side light illuminators.

[0027] Reference is made to **FIG. 4**, which is a top view of the outer frame of electronic device **100**, in accordance with an embodiment of the present invention.

[0028] Reference is made to **FIG. 5**, which is a top view of the outer frame of electronic device **100** showing one of the light guides **200** positioned at a corner of display screen **110**, in accordance with an embodiment of the present invention.

[0029] Reference is made to **FIG. 6**, which is a simplified illustration of a light guide **200** for transmitting light to illuminate a portion of a display screen **110**, in accordance with an embodiment of the present invention. **FIG. 6** shows an LED **210** that emits light beams into an aperture at the entrance of light guide **200**, mounted on printed circuit board **300**.

[0030] Reference is made to **FIG. 7**, which is a simplified vertical cross-sectional view of light beams **220** transmitted through a light guide **200** for illuminating a portion of display screen **110**, in accordance with an embodiment of the present invention. Light beams **220** are emitted by LED **210** into an entrance surface of light guide **200**. The exit surface of light guide **200** is tilted slightly downward so as to aim the central light beams at a location on display screen **110** somewhere between 25% - 50% along the extent of display screen **110**.

[0031] Reference is made to **FIG. 8**, which is a simplified vertical cross-sectional view of a light guide **200** transmitting light beams **220** to illuminate a portion of display screen **110**, in accordance with an embodiment of the present invention. As seen in **FIG. 8**, light guide **200** has a vertical cone-shaped entrance surface **230** with an aperture **240** for admitting light beams emitted by LED **210**. Light guide **200** has a folding mirror **250** for reflecting the admitted light beams at an angle of approximately 90°. Light guide **200** has a horizontal guide portion **260** for guiding the reflected light beams to an exit surface **270** positioned above a perimeter of a display screen. Exit surface **270** is tilted vertically from the horizontal at a slight angle, to direct the guided light beams towards the surface of display screen **110**. In other words, the exit surface is not perpendicular to the screen surface in order to direct light beams onto the screen surface.

[0032] Reference is made to **FIG. 9**, which is a simplified horizontal cross-sectional view of light beams **220** transmitted through a light guide **200** for illuminating a portion of display screen **110**, in accordance with an embodiment of the present invention.

[0033] Reference is made to **FIG. 10**, which is a simplified horizontal cross-sectional view of a light guide **200** transmitting light beams **220** to illuminate a portion of display screen **110**, in accordance with an

embodiment of the present invention. As seen in **FIG. 10**, folding mirror **250** horizontally collimates the light beams **220** emitted at the center of LED **210** (not shown in **FIG. 10**). As further seen in **FIG. 10**, exit surface **270** is shaped horizontally as a concave lens, and spreads the guided light beams horizontally over an angular expanse of display screen **110**.

[0034] Reference is made to **FIG. 11**, which is an illustration of an illumination pattern produced by light transmitted through a single light guide **200** positioned at a corner of a display screen **110**, in accordance with an embodiment of the present invention. As seen in **FIG. 11**, the light transmitted through light guide **200** effectively illuminates one quadrant of display screen **110**. Use of four light guides **200**, one light guide at each corner of display screen **110**, effectively illuminates the entire display screen.

Construction of Light Guides 200

[0035] Regarding the amount of illumination, four LEDs, each having luminous flux of 7 lm, suffice to illuminate a display screen of dimensions 120 mm x 90 mm for reading. Williams, "Footcandles and Lux for Architectural Lighting", <http://www.mts.net/~william5/library/illum.htm>, recommends a luminance of 300 – 500 lx for reading. As such, the flux needed for a 120 mm x 90 mm reading surface is at most $500 \text{ lx} * 0.11 \text{ m}^2 = 5.5 \text{ lm}$. Assuming a 20% illumination efficiency, four LEDs each having luminous flux of 7 lm provide $0.2 * 4 * 7 \text{ lm} = 5.6 \text{ lm}$, which is sufficient for reading. LEDs with illumination of 7 lm are commercially available.

[0036] Regarding the distribution of the illumination, it is of advantage to design the four light guides **200** so as to provide uniform illumination of display screen **110**, instead of over-illuminating some portions and

under-illuminating others. Moreover, it is important that the center of display screen **110** be well-illuminated, since this is the critical portion of the display. Distribution of illumination is characterized by “*étendue*”, which is defined as the area of the entrance pupil times the solid angle a source subtends as seen from the pupil,

<http://en.wikipedia.org/wiki/Etendue>. The *étendue* is conserved as light travels through free space, and is conserved at refractions or reflections. When light passes through an optical system, the *étendue* does not increase; it is either conserved or reduced.

[0037] Reference is made to **FIG. 12**, which is a simplified illustration of distribution of illumination via a light guide over the surface of a display screen, in accordance with an embodiment of the present invention. **FIG. 12** shows light transmitted from exit surface **270** of light guide **200** illuminating a differential element dS of display screen **110**, in accordance with an embodiment of the present invention. In terms of the dimensions h , h_0 and z shown in **FIG. 12**, the *étendue*, dG , for the surface area at dS is determined as follows:

$$d\theta \approx \frac{h \cdot z}{z^2 + \left(\frac{h}{2} + h_0\right)^2} , \quad (1)$$

$$\cos(\theta) = \frac{\frac{h}{2} + h_0}{\sqrt{z^2 + \left(\frac{h}{2} + h_0\right)^2}} , \quad (2)$$

$$dG = d\theta \cdot \cos(\theta) \cdot dS \approx \frac{h \cdot z \cdot \left(\frac{h}{2} + h_0\right)}{\left[z^2 + \left(\frac{h}{2} + h_0\right)^2\right]^{\frac{3}{2}}} dS . \quad (3)$$

For one embodiment of the present invention, $h = 4$ mm, $h_0 = 0.9$ mm and z ranges from 2 mm – 160 mm along the diagonal from the corner at which light guide **200** is located to the opposite corner.

[0038] Reference is made to **FIG. 13**, which shows four log plots of *étendue*/ dS (in radians) vs. z (in mm), corresponding to values of $h = 1$ mm, 2 mm, 4 mm and 8 mm and $h_0 = 0.9$ mm, derived from **EQS. (1) – (3)**.

[0039] The total illumination is limited by the one-dimensional étendue of LED **210**, which has a size of 2 mm and a spread angle of 90°; namely, $G = (\pi/2 \text{ rad}) * (2 \text{ mm}) \approx 3 \text{ mm-rad}$. Assuming the étendue is limited by light guide entrance **230** to a 30° angle and 1 mm size, then the maximum illumination is $G_{max} = 0.5 \text{ mm-rad}$. The dashed line in **FIG. 13** shows the corresponding uniform illumination that such an LED can generate, where $\text{étendue}/dS = G_{max} / 160 \text{ mm} = 0.003 \text{ rad}$, over the full 160 mm extent of the range of z .

[0040] Considering **FIG. 13**, two cases for limitation of the illumination of the display are identified. For low values of z , the étendue/ dS is higher than the light provided from the LED (dashed curve), which means that the LED is a limiting factor and all light received by the light guide can in principle be used. However, for high values of z where the étendue/ dS is below the dashed line (e.g., at $z > 60 \text{ mm}$ for $h = 4 \text{ mm}$), the geometry of the illumination of the screen, as shown in **FIG. 12**, limits the maximum illumination possible; i.e., not all light of the LED can be used due to the étendue limitation. Thus, a design objective is to illuminate over the 25% to 50% range of the abscissa. As an example, for $h = 4 \text{ mm}$, the integrated étendue for $z = 38 \text{ mm}$ to 76 mm is 0.15 mm-rad, as compared to the LED étendue, G_{max} . Since the value of the display étendue is still lower than the LED étendue, the light guide entrance surface limited size, e.g., 1 mm, and acceptance angle, e.g., 30°, do not limit the achievable illumination.

Advantages of the Construction of Light Guides 200

[0041] As explained above, light guides **200** are constructed so as to achieve strong illumination towards the center of the display screen, away from the light guide exit surfaces **270**.

[0042] Aperture **240** in entrance surface **230** blocks light that originates off-center of LED **210**, which serves to reduce unnecessary excess illumination close to exit surface **270**. Generally, the size of the light emitting area of LED **210** is larger than the opening of aperture **240** and, as such, movements of aperture **240** relative to the emitting area of LED **210** do not impact performance.

[0043] The cone shape of entrance surface **230** reduces the interference from light not passing through aperture **240**, and thus increases the efficiency of aperture **240**.

[0044] The downward tilt of exit surface **270** reduces demand on folding mirror **250**, since folding mirror **250** may be used at larger angle of incidence which, in turn, gives a larger margin to the limit of total internal reflection.

[0045] The upper and lower walls of horizontal guide **260** are painted black, in order to absorb light beams at the floor and ceiling of horizontal light guide **260** and thereby eliminate or reduce undesired reflections. Indeed, reflection of light at the upper and lower walls of horizontal guide **260** generates light in undesired directions, with excess illumination near the corner of the display screen at which light guide **200** is positioned.

[0046] The side walls of horizontal guide **260** are used to reflect light horizontally, which increases utilization of the light beams, and improves the horizontal spread of the light beams emerging from exit surface **270**.

[0047] Folding mirror **250** horizontally collimates light beams emitted from the center of LED **210**. The off-center light beams emitted by LED **210** are also approximately horizontally collimated by folding mirror **250**, but with a different angle of propagation than the on-center light beams. In turn, this causes the desired horizontal spread of light over the display screen.

[0048] The horizontal cross-sectional shape of exit surface **270** as a concave lens serves to provide an approximately 90° spread angle for the light beams emerging from exit surface **270**.

[0049] 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 as set forth in the appended claims. Accordingly, the specification and drawings are to be regarded in an illustrative rather than a restrictive sense.

CLAIMS

What is claimed is:

- 1.** A light guide for illuminating a display screen, comprising:
a vertical cone-shaped entrance surface comprising an aperture for admitting light beams emitted by an LED;
a folding mirror for reflecting the admitted light beams at an angle of approximately 90°, and for horizontally collimating the admitted light beams;
a horizontal guide for guiding the reflected light beams to an exit surface; and
an exit surface positioned above a perimeter of a display screen for directing the guided light towards a portion of the display screen, the exit surface being tilted vertically from the horizontal at a slight angle to direct the guided light beams towards the display, and being shaped horizontally as a concave lens to spread the guided light beams horizontally over an angular expanse of the display screen.
- 2.** The light guide of claim **1** wherein said horizontal guide comprises upper and lower walls are painted black to absorb light and prevent internal reflections off of said upper and lower walls.
- 3.** The light guide of claim **1** wherein said exit surface is tilted so as to direct a central light beam emitted by the LED to a location that is between 25% and 50% along the extent of the display screen.
- 4.** The light guide of claim **1** wherein said exit surface is tilted at an angle of approximately 4°.

- 5.** The light guide of claim **1** wherein said horizontal entrance surface, said horizontal guide and said exit surface are comprised of a plastic material.
- 6.** A display for an electronic device, comprising:
a rectangular display screen;
four LEDs positioned near the four corners of said rectangular display screen;
four light guides positioned near said four LEDs, each light guide comprising a light guide in accordance with claim **1**, for transmitting light beams generated by said four LEDs over said rectangular display screen so as to illuminate said display screen.
- 7.** The display of claim **6** further comprising:
a plurality of infrared light emitters positioned near the perimeter of said rectangular display screen for emitting infrared light;
a plurality of infrared light receivers positioned near the perimeter of said rectangular display screen, for receiving infrared light emitted by said infrared light emitters; and
a projector mounted near the perimeter of said rectangular display screen for projecting the infrared light emitted by said infrared light emitters across said rectangular display screen in order to enable detection of touch position when an object touches said rectangular display screen.