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(54) **HIGH EFFICIENCY ILLUMINATION UTILISING MULTIPLE LIGHT SOURCES COMBINED WITH ON AXIS AND OFF AXIS LENSES**

(57) There is disclosed an illumination system comprising a plurality of light emitting diodes (LEDs) arranged on a flat plane having an axis perpendicular to the plane. There is further provided a plurality of lenses each associated with at least one LED and mounted above the plane to direct light emitted by the LEDs towards a target area. At least some of the plurality of lenses are configured as off-axis lenses so as to direct light from their associated LEDs in a direction that is angled relative to the perpendicular axis, so as to provide generally even or homogeneous illumination of the target area.

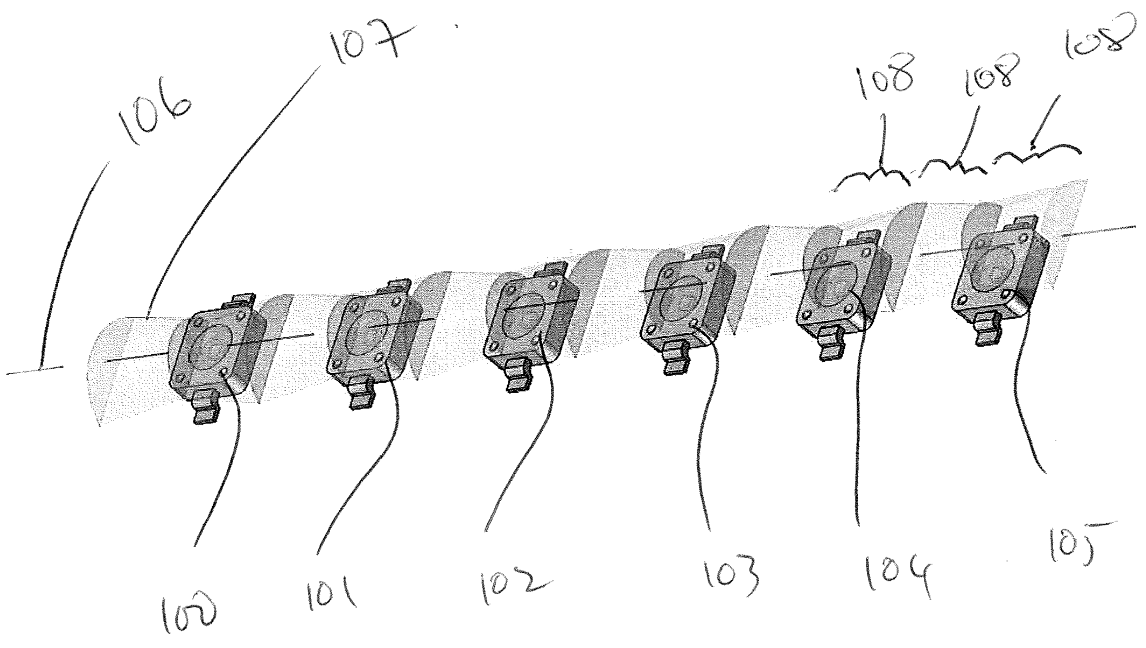


Fig 18

EP 3 054 210 A1

Description

[0001] This invention relates to an illumination system, in particular but not exclusively in the field of facial recognition systems.

BACKGROUND

[0002] In the area of computer-implemented facial recognition systems, for example to provide access control or at airport e-passport facilities, it is necessary to acquire images of faces. The shape of the face is taller than it is wide, making the use of portrait shaped imaging appropriate. Additionally the height range of the subject means that the head position within the image has a large positional movement in the vertical axis. The combination of head shape and height results in a working image shape that in many applications is significantly higher than the width of the image. To consistently achieve the image quality required, artificial illumination can be employed. Such artificial illumination may be from several sources, although recent advancement in LED technology has resulted in the common use of LEDs for the light source. The light source is used to ensure that a subject's image has minimal variation in appearance under a wide range of lighting conditions. To achieve this, the ratio of artificial illumination generated for the image acquisition to the ambient light must be such that changes in ambient light levels have minimal impact on the illumination of the target face. This generally entails employing high brightness illumination sources.

[0003] From a geometric point of view, the LED forms a close approximation to a point source with a high intensity central region which reduces with distance away from the central axis. When clusters of LEDs are used in close proximity to each other, this still results in a bright central area with reducing intensity with distance away from the central axis. To overcome this fall off in intensity, large area LED panels are often employed to provide overlapping illuminated areas, thus providing an even illumination over the target. However, this results in bulky illumination systems with generally poor efficiency. An alternative is the use of extremely wide angle point sources where most of the light output is outside the field of view of the imaging device. This provides even illumination over the central region but results in very low efficiency as the energy outside the central region is not utilised.

[0004] The energy output of LEDs can be represented by a chart such as that shown in Figure 1. This shows the typical radiated output for an LED 3 without a lens. In this example, the radiated output falls to 90% intensity at an angle of ±30° and is down to 50% at an angle of ±60°. Since the LED produces light having a circular pattern, this can be considered as a central circle 1 with a centre of 100% intensity, falling off to 90% at its edge, as shown in Figure 2. This circle is defined by the 30° angle. An outer circle 2 is centred on the inner circle 1 and is defined by the 60° angle. The outer edge of the outer circle 2 has a relative intensity of 50%, and at the boundary between the two circles the intensity is 90%. The total energy in the central circle 1 is determined by the energy per unit area multiplied by the area. The energy in the outer circle 2 is the energy per unit area multiplied by the total area of circle 2 less the total area of circle 1.

[0005] From Figure 3 it can be seen that the ratio of the areas is given by:

$$(\tan A1)^2/[(\tan A2)^2 - (\tan A1)^2]$$

[0006] This results in an area ratio of 8:1 between the outer 2 and the inner 1 circles. This means that, in simple terms, eight times the area is illuminated with intensities between 50% and 90% compared to the area illuminated with intensities between 90% and 100%. As the total energy is a function of the complex curve in Figure 1 and is different for each make of LED, approximations can only be made as to the total energy ratios between the two areas, and this lies between approximately 4:1 and 8:1. It should be noted that a significant amount of light is still emitted outside the 60° angle. Therefore it can be concluded that the best energy utilisation could be 25% and could be as low as 12.5%. This results in very poor efficiency of the optical system.

[0007] LEDs with built-in or integral lenses are known, and are commonly found in pocket torches. In these known torches, a cluster of LEDS, each with an integral domed lens, is provided. The focussing properties of the domed lenses are determined by the dome curvature and distance from the LED die. Such LEDs are manufactured in a pre-focussed configuration, and no end user adjustment is possible. Each lensed LED unit will produce a beam projecting a circular pattern of light with a centroid centred on the beam axis, which will be generally perpendicular to the LED die. The lensed LEDs are arranged so that their projected centroids are displaced relative to each other by the same distance that the LED units are separated from each other in the torch. Accordingly, in a six LED torch with the LEDs arranged in a hexagonal arrangement, for example, six substantially overlapping centroids will be projected. Importantly, all of the integral lenses are configured as on-axis lenses.

[0008] Figure 4 shows a circular pattern 4 of substantially even illumination projected by a closely-spaced cluster of LEDs each having an integral on-axis lens, for example as projected by the six LED torch described in the preceding paragraph. The circular pattern has a radius of 1.1 units. Assuming that it was desired to provide even illumination over a rectangular area 5 of height 2 units and width 1 unit, and assuming that all of the light emitted by the LED fell within the circular pattern 3, it can be seen that the area of the circular pattern is $\pi(1.1)^2$ or approximately 3.8 units^2. The area of the rectangle is 2 units^2. Consequently, only about 53% of the total illumination is actually used in the imaging area of the rectangle.

BRIEF SUMMARY OF THE DISCLOSURE

[0009] Viewed from a first aspect, there is provided n illumination system comprising a plurality of light emitting diodes (LEDs) arranged on a flat plane having an axis perpendicular to the plane, wherein there is further provided an elongate cylindrical lens mounted above the plane to direct light emitted by the LEDs towards a target area, the lens mounted such that light from at least some of the plurality of LEDs is directed in a direction that is angled relative to the perpendicular axis, so as to provide generally even or homogeneous illumination of the target area.
[0010] Each of the LEDs preferably generates a light intensity profile on the target area having a substantially Gaussian distribution, and the LEDs and/or the lens are preferably configured such that the substantially Gaussian light intensity profiles generated by the LEDs overlap so as to provide generally even or homogeneous illumination of the target area.
[0011] At least one LED may be positioned such that light from the LED is directed along or parallel to the perpendicular axis.
[0012] The lens may be positioned and configured such that each LED illuminates a strip of the target area, adjacent strips being substantially parallel and at least partially overlapping so as to provide generally even or homogeneous illumination of a rectangular area.
[0013] The elongate cylindrical lens may have a longitudinal axis, and the LEDs may be arranged along a line that is sloped relative to the longitudinal axis.
[0014] The elongate cylindrical lens may have a substantially constant radius. Alternatively, the elongate cylindrical lens may have a radius that varies along a length of the lens. The radius of the elongate cylindrical lens may be smallest at positions along its length closest to each LED. The radius of the elongate cylindrical lens may be greatest at positions along its length substantially halfway between adjacent LEDs.
[0015] The elongate cylindrical lens may be formed as a monolithic piece. Alternatively, the elongate cylindrical lens may be formed from a plurality of smaller pieces that are bonded together in an end-to-end arrangement.
[0016] Viewed from a second aspect, there is provided an illumination system comprising a plurality of light emitting diodes (LEDs) arranged on a flat plane having an axis perpendicular to the plane, wherein there is further provided a plurality of lenses each associated with at least one LED and mounted above the plane to direct light emitted by the LEDs towards a target area, wherein at least some of the plurality of lenses are configured as off-axis lenses so as to direct light from their associated LEDs in a direction that is angled relative to the perpendicular axis, wherein each of the LEDs generates a light intensity profile on the target area having a substantially Gaussian distribution, and wherein the LEDs and/or the lens are configured such that the substantially Gaussian light intensity profiles generated by the LEDs overlap so as to provide generally even or homogeneous illumination of the target area.
[0017] Embodiments of the present invention seek to maximise the useful light from LEDs thus reducing the total energy required by a lighting system.
[0018] This may be achieved by using a cluster of point sources such as LEDs combined with lenses to reduce the output angle of the light source thus improving efficiency whilst employing novel geometric positioning of the light sources and lenses to produce an evenly illuminated area with high overall efficiency.
[0019] The beam of each LED, directed by way of the associated lens, will illuminate a particular area of the target. A spherical, aspherical, convex or plano-convex lens may be configured to project a narrow conical beam that illuminates a circular or elliptical area on a planar target. A generally cylindrical lens may be configured to focus light in one orientation only, generating a beam that illuminates a generally rectangular or trapezoidal area on a planar target. The illuminated area may, for present purposes, be considered to have a boundary where the intensity of the illumination drops to a predetermined level, for example 90% (although other levels may be appropriate depending on the degree of illumination homogeneity required). The area bounded by the boundary may be termed the centroid of the beam.
[0020] Each LED may be provided with its own lens, or groups of LEDs may share respective lenses. The latter may be more appropriate in embodiments having elongate cylindrical lenses.
[0021] The LEDs may be clustered and their associated lenses configured so that they generate beams having centroids that partially overlap or tessellate so as to provide sufficiently even or homogeneous illumination over a larger area than would be possible with a single beam. It is to be understood that the centroids do not all overlap each other, only that adjacent centroids may have an area of mutual overlap.
[0022] At least one of the lenses may be mounted on-axis with respect to its associated LED or LEDs, thereby to direct light along the direction of the perpendicular axis. The remaining lenses must be mounted or configured as off-axis lenses so as to direct lights in directions at a small but significant angle to the perpendicular axis.

[0023] Advantageously, the lenses are not built-in or manufactured integrally with the LEDs, but are provided as separate units which are mounted over the LEDs. The lenses may be spaced from the LED dies. This allows the focussing and beam directing properties of each LED and lens to be configured as required for any given application. Moreover, this allows the use of high-power LEDs which are typically not provided with integral domed lenses.

[0024] In facial recognition systems, there is a particular advantage in being able to provide even illumination of a rectangular area, where the height is significantly larger than the width. This is because human faces tend to have a width that falls within fairly tightly defined limits, but peoples' heights are much more variable. Moreover, the human face is typically longer than it is wide. Accordingly, present embodiments are preferably configured to provide even illumination of a rectangular target area having an aspect ratio (height to width) of at least 2:1, optionally from 2:1 to 3:1, optionally from 2:1 to 4:1.

[0025] Because the LED dies are mounted on a flat plane, this allows the use of standard pick and place technology for positioning the LED dies.

[0026] In some embodiments, the LEDs are provided with control circuitry to illuminate the LEDs simultaneously to generate a flash of light. Because of the improved efficiency by directing light only where it is needed, it is possible to use LEDs powered by a USB power source.

[0027] For facial recognition applications, specular reflections from spectacles are a significant problem. This is primarily due to the detail of the eye being lost due to the saturation of the imaging system from reflections of the light from the illumination system. A way of reducing this is to ensure that the illumination system is significantly off-axis with respect to the spectacles and the imaging system. This arrangement allows the use of large area illumination systems. An additional or alternative technique is to use polarising filters for the light source and the imaging system. Provided that the polarising axis is the same for both illumination source and imaging system, specular reflections will be significantly reduced. This allows the illumination system to be mounted on a similar axis to the imaging system. Polarising filters operating in the near infra-red region are expensive and the use of small filters is commercially preferable to larger filters. The use of off-axis cylindrical lenses described in the present application allows the use of small polarising filters covering a single face of each cylindrical lens.

[0028] Embodiments of the present disclosure may provide a highly efficient means of illumination of the facial region. Due to the improvement in efficiency, a reduced number of light emitting diodes can be employed, thereby reducing the size of any required polarising filter. Certain embodiments provide a system for illuminating and capturing a facial image using a highly efficient illumination device operating close to an axis of an image capture device and employing small polarising filters, resulting is a small low cost energy efficient solution to facial image capture.

[0029] One potential limiting factor is the change in width of the illuminated area with the change in angle from the light source. This can become problematic when using cylindrical lenses mounted close to the light source as the change in distance from the surface of the lens with angle may be significant. The geometry employed in certain embodiments works best when the lens does not focus the light from the LED to a sharp image of the LED. Instead, optimal results are obtained when overlapping blurred images of the LEDs are produced, as this removes visible artefacts of the LED. This then gives a more homogeneous illumination of the target area. In this configuration, the light projected from the LED through the defocused cylindrical lens tends to form an oval shape due to the distance between the light source and the curved surface of the cylindrical lens increasing with increase in angle from the perpendicular. The magnification factor of the cylindrical lens therefore changes with change in angle. To reduce this effect, the curvature of the cylindrical lens can be changed in relation to the distance from the perpendicular such that the magnification factor remains essentially constant with change in angle from the perpendicular. This in turn results in a substantially rectangular illumination pattern instead of a diamond shaped illumination pattern as is obtained with normal cylindrical lenses.

BRIEF DESCRIPTION OF THE DRAWINGS

[0030] Embodiments of the invention are further described hereinafter with reference to the accompanying drawings, in which:

Figure 1 is a chart of normalised output power against beam divergence angle for a single LED without a lens;

Figure 2 shows an illumination pattern of a single LED without a lens;

Figure 3 shows a single LED without a lens illuminating a target area;

Figure 4 shows a rectangular target area being illuminated by several substantially coincident illumination centroids;

Figure 5 is a chart of normalised output power against beam divergence angle for a single LED with an on-axis lens;

Figure 6 shows an embodiment with three LEDs;

Figure 7 shows an illumination pattern generated by seven LEDs;

Figure 8 shows a first arrangement of seven LEDs configured to generate the illumination pattern of Figure 7;

Figure 9 shows an alternative illumination pattern generated by 16 LEDs;

Figure 10 shows a second arrangement of seven LEDs configured to generate the illumination pattern of Figure 7;

Figure 11 shows an alternative embodiment with six LEDs and three cylindrical lenses, together with their illumination pattern;

Figure 12 shows another alternative embodiment with five LEDs and a single cylindrical lens, together with their illumination pattern;

Figure 13 is a plot of angular deviation against relative intensity three different arrangements of LEDs;

Figures 14a and 14b show an embodiment with polarising filters fitted to flat surfaces of cylindrical lenses;

Figure 15 shows an LED transmitting light through a cylindrical lens;

Figure 16 shows an illumination pattern obtained with an unfocussed cylindrical lens;

Figure 17 shows an illumination pattern obtained with a variable radius cylindrical lens; and

Figures 18 to 20 show an embodiment comprising six LEDs and a variable radius cylindrical lens.

DETAILED DESCRIPTION

[0031] The radiated output from a typical LED with a lens is shown in Figure 5. In this instance all the output energy is captured within the same ±30° angle, resulting in a high illumination efficiency. However, the edges of the illuminated area are inadequately illuminated. Placing additional LEDs on a flat plain would require significant spacing such that each LED would illuminate a specific area of the target. This is a typical configuration in a large area LED light array and results in a physically large system. Embodiments of the present invention employ off-axis lenses on an array of LEDs to position the centroid of each LED beam such that each beam forms a partially overlapping area of illumination. The LEDs and lenses are assembled onto a flat plain allowing standard PCB assembly techniques.

[0032] Figure 6 shows a plain 21 with three LEDs mounted thereupon. LED 11 is mounted with an off-axis lens 14 such that the output beam 18 of the LED is tilted off-axis. LED 12 is mounted with an on-axis lens 15 such that the output beam 19 is perpendicular to the plain 21. LED 13 is mounted with an off-axis lens 16 such that the output beam is tilted off-axis. The positions of the lenses 14 and 16 in relation to the LEDs 11 and 13 respectively are such that their beam edges coincide with the beam edge of LED 12 at the illuminated plain 17. The beam edge in this instance is defined as the point at which the intensity of the beam falls to 90%. However, other definitions may equally apply depending on the required level of beam homogeneity. Embodiments of the invention may use any number of LEDs, with Figure 5 representing just one example of a three LED configuration.

[0033] Figure 7 shows the illuminated areas of a seven LED system where seven centroids are generated and are tessellated to give good homogeneity. The beam 30 represents the circular light pattern from the on-axis LED, while the circles 31 to 36 represent the light pattern from LEDs with off-axis lenses. It should be noted that the circles defined only represent an arbitrary intensity boundary and the region 37 would be illuminated by light from LEDs illuminating areas 30, 32 and 36. The cluster of circles shown can be generated by many configurations of LEDs and is shown to demonstrate tessellation. This tessellation pattern could be created using a circular configuration as shown in Figure 8 whereby a circular pattern of off-axis lenses as shown 43 and 44 are arranged around a central on-axis LED 41, 42.

[0034] An alternative, and preferred, configuration is shown in Figure 9. A 16 LED cluster (not shown), each LED being provided with a spherical or aspherical or convex or plano-convex lens, generates a pattern of circular centroids 80 that together provide substantially even illumination of a rectangular target area 81. Each centroid 80 overlaps slightly with adjacent centroids so as to provide relatively even illumination across the rectangle 81. Although not strictly tessellating, since this is impossible with circular or elliptical centroids, it will be appreciated that that the intention is to give generally even illumination by close packing and judicious overlapping of adjacent centroids 80. It will further be appreciated that the LEDs need not be arranged on the plane in the same pattern as the centroids 80. This is because on-axis and off-axis lenses can together be used to direct the beams appropriately as discussed further in relation to Figure 10.

[0035] An alternative configuration is shown in Figure 10 where the tessellation pattern in Figure 7 is created from a line of LEDs and lenses. In this configuration the central LED/lens 50 provides the central spot. LEDs 53 and 54 provide the left and right hand spots. LEDs 52 and 51 provide the upper left and lower left spots, and LEDs 55 and 56 provide the upper right and lower right spots respectively. It can therefore be seen that the mounting positions of the LEDs is not critical and a wide range of LED positions can be employed. What is important is the relative positioning of LEDs or other point sources in combination with on-axis and off-axis lenses to produce a number of illumination areas. The illumination areas utilise a high proportion of the light output from the source while producing a relatively homogeneously illuminated area closely matching the area viewed by the imaging system, thus resulting in high energy efficiency of the system.

[0036] For applications that require rectangular illumination areas (where the length is significantly different from the width), the arrangement of the illumination centroids can be such that the centroids form a shape similar to that required by the imaging system. Where significant elongation of the illumination is required, as in many facial recognition systems, focusing the light only yields benefits in one orientation. The use of cylindrical lenses provides focusing of the emitted light in one axis only. The use of off-axis light sources in combination with cylindrical lenses allows the focusing of the light into shapes approaching rectangles whose position side-by-side is determined by the off-axis position of the light sources. Figure 11 shows a six LED, three lens configuration. Lens 62 is mounted centrally over the pair of LEDs 66 and 67. This generates a strip of light that is focused in the X axis only, where the X axis is defined as the axis perpendicular to the lens. This for example could produce the radiant intensity distribution shown in Figure 1 in the Y axis, where the Y axis is defined as parallel to the lens and the radiant intensity distribution of that shown in Figure 4 in the X axis. For each LED, this would produce an illuminated area that covers an angle of ±12° in the horizontal axis and ±40° in the vertical axis, as based on the data from Figure 1 and Figure 5 to the 80% intensity point. Positioning the cylindrical lens 61 off-axis over LEDs 64 and 65 produces a strip of light projected to the right, and positioning the cylindrical lens 63 over LEDs 68 and 69 produces a strip to the left. The net result is an illumination pattern 70 where the boundaries represent the 90% illumination from each LED. Embodiments of the invention allow the use of any number of LEDs placed in combinations of on-axis and off-axis configurations to provide the most homogeneous illumination. Furthermore, when cylindrical lenses are employed, multiple illumination centroids can be produced using a single cylindrical lens with multiple LEDs mounted either in a straight line or staggered relative to each other.

[0037] Figure 11 shows a configuration where LEDs 71 to 75 are mounted behind a cylindrical lens 76. The pattern of LEDs is such that the central LED 73 is central to the cylindrical lens, with the other LEDs mounted progressively off-axis. This produces the rectangular illumination pattern 77 where the drawn boundaries represent the 90% illumination point for each of the LEDs.

In the illumination diagrams of Figures 7, 9, 11 and 12, the 90% illumination point for each LED has been used to indicate the general principle of the present invention. The interaction between each of the LED illumination areas has not been considered. Based on the lensed LED, the response of which is shown in Figure 5, Table 1 provides a more detailed analysis.

Table 1

Angular Deviation	Single LED	3 LED Configuration	5 LED Configuration
-65	0	0	0
-60	0	0	0
-55	0	0	0.25
-50	0	0	0.5
-45	0	0	0.75
-40	0	0.25	1.15
-35	0	0.5	1.45
-30	0	0.75	1.75
-25	0.25	1.15	2.1
-20	0.5	1.45	2.35
-15	0.75	1.75	2.5
-10	0.9	2.1	2.6

(continued)

Angular Deviation	Single LED	3 LED Configuration	5 LED Configuration
-5	0.95	2.35	2.6
0	1	2.5	2.5
5	0.95	2.35	2.6
10	0.9	2.1	2.6
15	0.75	1.75	2.5
20	0.5	1.45	2.35
25	0.25	1.15	2.1
30	0	0.75	1.75
35	0	0.5	1.45
40	0	0.25	1.15
45	0	0	0.75
50	0	0	0.5
55	0	0	0.25
60	0	0	0

[0038] Column 1 of Table 1 gives angular deviations from the axis perpendicular to the plane on which the LEDs are mounted.

[0039] Column 2 shows the illumination values of a single LED with an on-axis lens for deviation angles in steps of 5° (see Figure 5).

[0040] Column 3 shows the illumination values for the sum of the first LED (from Column 2) and two additional LEDs disposed either side of the first LED (see Figure 6). The two additional LEDs are provided with off-axis lenses so as to deviate their beams by ±15° respectively to either side of the perpendicular axis.

[0041] Column 4 shows the illumination values for the sum of the first LED (from Column 2), the two additional LEDs of Column 3, and a further two LEDs disposed either side of three LEDs of Column 3. The two further LEDs are provided with off-axis lenses so as to deviate their beams by ±30° respectively to either side of the perpendicular axis.

[0042] The values from Table 1 are plotted in Figure 13, from which it can be seen that the central region of the three LED arrangement (Column 3) is significantly higher in intensity than that of the single LED (Column 1). However due to the selected positioning of the centroids of the two side projections there is significant overlap in the central region. This results in a steep drop-off in intensity with increase in angle from the centre. This configuration, while increasing peak output, results in rapid loss of light in the side regions. The five LED configuration (Column 4) introduces light to the side areas only resulting in no increase of light in the central region but a lifting of the light in the side areas. By increasing the number of off-axis LEDs and adjusting the position of the centroids, the central region of the illuminated area can be evenly illuminated, with a sharp drop outside the required area. This helps to maximise the usage of the available energy from the light source in this axis. This can be achieved by using several light sources with individual lenses mounted off-axis or can be achieved with a single cylindrical lens with the light sources arranged in an appropriate pattern for the required illumination. While the examples given are based on specific LED and lens characteristics, the illuminated area can be controlled by selecting the number of light sources. The light source positions relative to the lens axis, the focal length of the lens and the distance of the lens from the light source can all be adjusted so as to determine the overall size, intensity, intensity homogeneity and efficiency of the illumination system.

[0043] Embodiments of the present invention provide the means of producing such illumination characteristics while using a closely packed group of light sources in combination with on-axis and off-axis lenses.

[0044] Figure 14a shows an embodiment in which three cylindrical lenses 80 (here shown from below) are each provided with a polarising filter 81 on their flat surfaces. The arrangement may be better understood from Figure 14b, which shows one of the lenses 80 from end on, with the polarising filter 81 mounted on the flat surface of the cylindrical lens 80. It will be noted that the polarising filters 81 are much smaller than would be the case if a single polarising filter were located above the curved faces of the cylindrical lenses 80. In this way, the light that illuminates the target area is polarised, and if another polarising filter is provided for an image capture device (not shown) used to capture an image of the target area, specular reflections from eyeglasses or spectacles worn by a person standing in the target area can be significantly reduced.

[0045] Figure 15 shows an LED 91 located under a cylindrical lens 90 of constant radius, here seen from the side. It can be seen that the change in distance travel by light rays through the lens 90 changes appreciably with angle. Light ray 92, for example, travels a short distance through the lens 90, whereas light ray 93 travels a longer distance through the lens 90. The magnification factor of the lens 90 therefore changes with angle. This results in barrel distortion, giving rise to an oval or barrel-shaped illumination field 94, as shown in Figure 16. In order to counter this effect, the curvature of the cylindrical lens 90 may be configured so as to change in relation to the angle of incident light from the LED 91 such that the magnification factor is substantially constant with change of angle from the perpendicular. This can allow a substantially rectangular illumination field 95, as shown in Figure 17, to be obtained.

[0046] Particular embodiments making use of this design feature are shown in Figures 18 to 20. Six LEDs 100, 101, 102, 103, 104 and 105 are arranged generally in a line, following an axis 106 of a cylindrical lens assembly 107. The LEDs 100-105 are arranged such that the left-most LED 100 is positioned to one side of the axis 106 and the right-most LED 105 is positioned to the opposite side of the axis 106, with the intervening LEDs 101-104 following a slope drawn from the left-most LED 100 to the right-most LED 105. The central LEDs 102 and 103 are closest to the axis 106, and the end-most LEDs 100 and 105 are furthest from the axis 106 and on opposite sides thereof. The cylindrical lens assembly 107 does not have a constant radius, but instead is shaped so as to have a minimum radius at points directly above each LED 100-105, and a maximum radius at points substantially halfway between adjacent LEDs 100-105. The radius changes along the axis 106 so as preferably to maintain a substantially constant magnification factor with the changing angle of incident light from each LED 100-105, thereby promoting a substantially rectangular illumination field at the target area.

[0047] The lens assembly 107 may be formed as one piece, or may be formed from smaller elements 108 that are bonded together in an end-to-end arrangement.

[0048] Figure 20 additionally shows a polarising filter 81 mounted on the flat underside of the lens assembly 107.

[0049] In the embodiment of Figure 20, it will be noted that the cylindrical lens assembly 107, as well as having a flat underside on which the polarising filter 81 is mounted, also has a constant maximum height along its longitudinal axis. When viewed from the side, as in Figure 20, the top of the lens assembly 107 will appear to be level, and substantially parallel to the flat underside. In certain embodiments, each element 108 may have a shape defined by taking a section through a substantially frustoconical volume with substantially parallel top and bottom faces, from the top face to the bottom face, along a plane substantially parallel to a tangential plane on the curved sidewall of the frustoconical volume.

[0050] In some embodiments, the spacing between the LEDs 103 and the underside of the cylindrical lens assembly 107 may be from 0.5mm to 3mm, preferably from 1mm to 2mm, optionally around 1.6mm.

[0051] Throughout the description and claims of this specification, the words "comprise" and "contain" and variations of them mean "including but not limited to", and they are not intended to (and do not) exclude other moieties, additives, components, integers or steps. Throughout the description and claims of this specification, the singular encompasses the plural unless the context otherwise requires. In particular, where the indefinite article is used, the specification is to be understood as contemplating plurality as well as singularity, unless the context requires otherwise.

[0052] Features, integers, characteristics, compounds, chemical moieties or groups described in conjunction with a particular aspect, embodiment or example of the invention are to be understood to be applicable to any other aspect, embodiment or example described herein unless incompatible therewith. All of the features disclosed in this specification (including any accompanying claims, abstract and drawings), and/or all of the steps of any method or process so disclosed, may be combined in any combination, except combinations where at least some of such features and/or steps are mutually exclusive. The invention is not restricted to the details of any foregoing embodiments. The invention extends to any novel one, or any novel combination, of the features disclosed in this specification (including any accompanying claims, abstract and drawings), or to any novel one, or any novel combination, of the steps of any method or process so disclosed.

[0053] The reader's attention is directed to all papers and documents which are filed concurrently with or previous to this specification in connection with this application and which are open to public inspection with this specification, and the contents of all such papers and documents are incorporated herein by reference.

Claims

1. An illumination system comprising a plurality of light emitting diodes (LEDs) arranged on a flat plane having an axis perpendicular to the plane, wherein there is further provided an elongate cylindrical lens mounted above the plane to direct light emitted by the LEDs towards a target area, the lens mounted such that light from at least some of the plurality of LEDs is directed in a direction that is angled relative to the perpendicular axis, so as to provide generally even or homogeneous illumination of the target area.

2. A system as claimed in claim 1, wherein each of the LEDs generates a light intensity profile on the target area having a substantially Gaussian distribution, and wherein the LEDs and/or the lens are configured such that the substantially Gaussian light intensity profiles generated by the LEDs overlap

3. A system as claimed in claim 1 or 2, wherein at least one LED is positioned such that light from the LED is directed along or parallel to the perpendicular axis.

4. A system as claimed in any preceding claim, wherein the elongate cylindrical lens has a longitudinal axis, and wherein the LEDs are arranged along a line that is sloped relative to the longitudinal axis.

5. A system as claimed in any preceding claim, wherein the elongate cylindrical lens has a substantially constant radius.

6. A system as claimed in any one of claims 1 to 4, wherein the elongate cylindrical lens has a radius that varies along a length of the lens.

7. A system as claimed in claim 6, wherein the radius of the elongate cylindrical lens is smallest at positions along its length closest to each LED; optionally wherein the radius of the elongate cylindrical lens is greatest at positions along its length substantially halfway between adjacent LEDs.

8. A system as claimed in any preceding claim, wherein the elongate cylindrical lens is formed as a monolithic piece.

9. A system as claimed in any one of claims 1 to 7, wherein the elongate cylindrical lens is formed from a plurality of smaller pieces that are bonded together in an end-to-end arrangement.

10. An illumination system comprising a plurality of light emitting diodes (LEDs) arranged on a flat plane having an axis perpendicular to the plane, wherein there is further provided a plurality of lenses each associated with at least one LED and mounted above the plane to direct light emitted by the LEDs towards a target area, wherein at least some of the plurality of lenses are configured as off-axis lenses so as to direct light from their associated LEDs in a direction that is angled relative to the perpendicular axis, wherein each of the LEDs generates a light intensity profile on the target area having a substantially Gaussian distribution, and wherein the LEDs and/or the lenses are configured such that the substantially Gaussian light intensity profiles generated by the LEDs overlap so as to provide generally even or homogeneous illumination of the target area.

11. A system as claimed in claim 10, wherein each LED is provided with an individual lens.

12. A system as claimed in claim 10, wherein at least some of the LEDs are configured to share a lens.

13. A system as claimed in any one of claims 10 to 12, wherein at least one lens is configured as an on-axis lens so as to direct light from its associated LED in a direction along or parallel to the perpendicular axis.

14. A system as claimed in any preceding claim, configured to project a substantially rectangular field of substantially homogeneous illumination on the target area.

15. A system as claimed in any preceding claim, further comprising a polarising filter provided on the or each lens; optionally wherein the or each lens has a substantially flat surface facing its associated LED, and wherein the polarising filter is provided on the substantially flat surface.

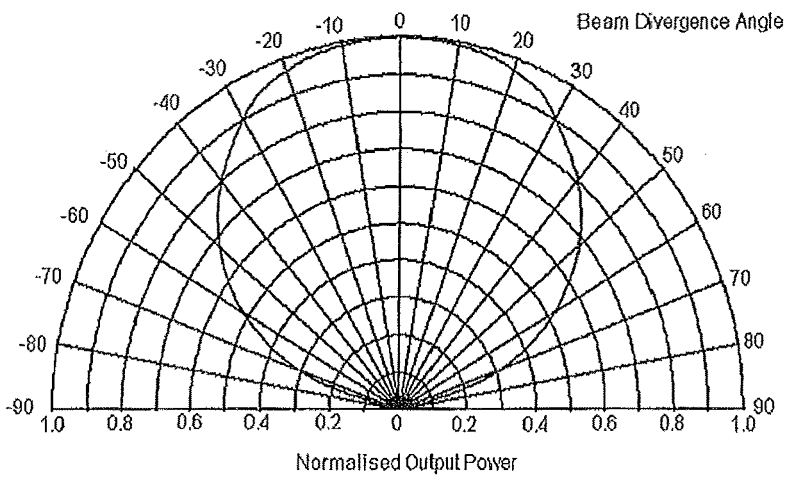


Fig 1

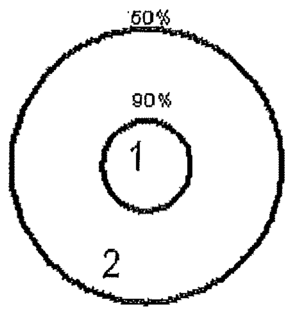


Fig 2

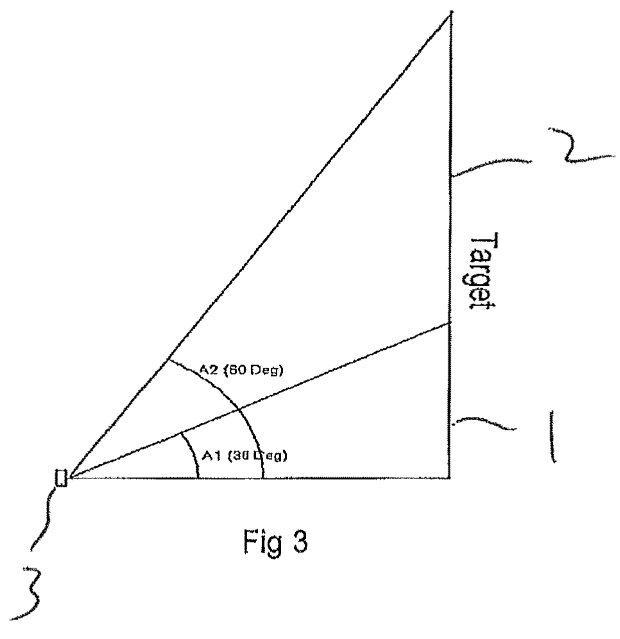


Fig 3

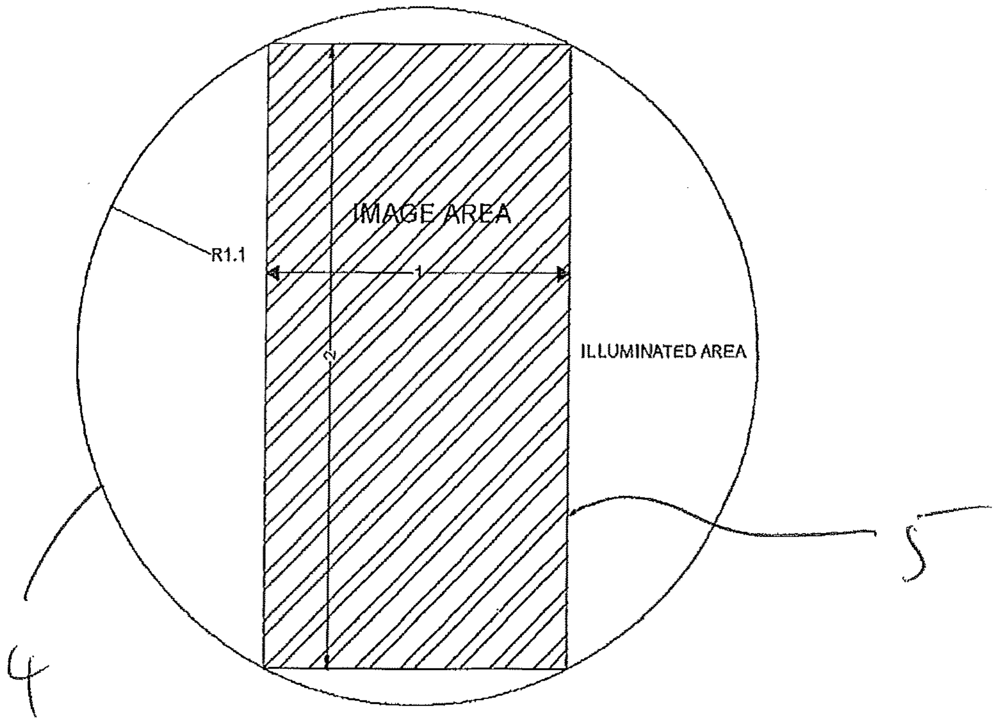


IMAGE AREA
R1.1
1
2
ILLUMINATED AREA
4
5

Fig 4

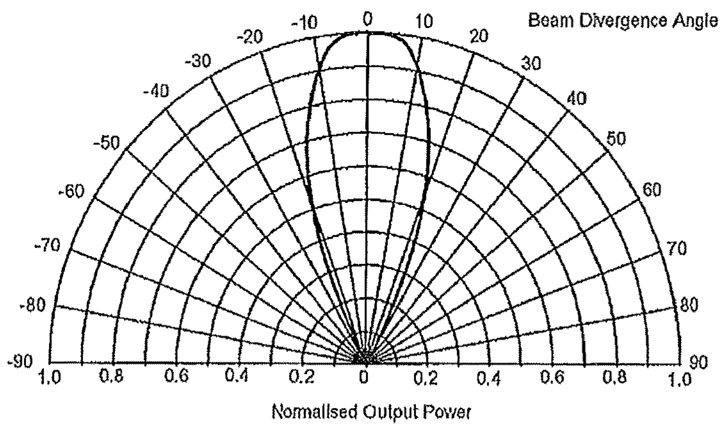

Beam Divergence Angle
-90
-80
-70
-60
-50
-40
-30
-20
-10
0
10
20
30
40
50
60
70
80
90
1,0
0,8
0,6
0,4
0,2
0
0,2
0,4
0,6
0,8
1,0
Normalised Output Power

Fig 5

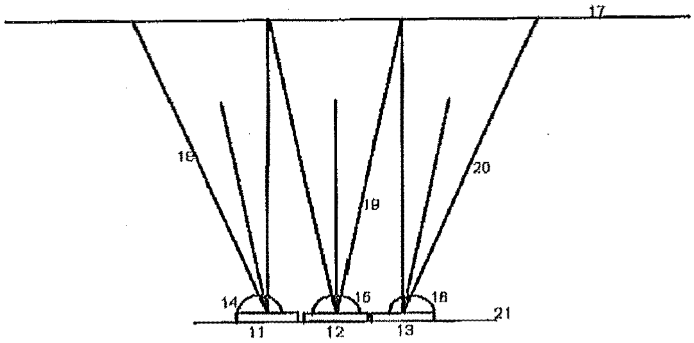


Fig 6

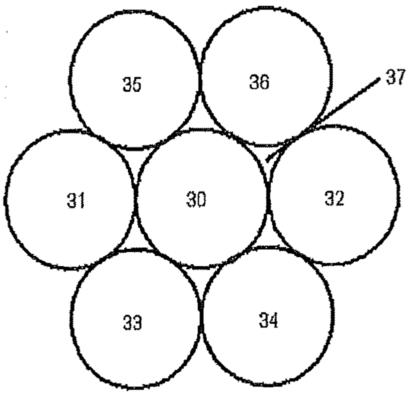


Fig 7

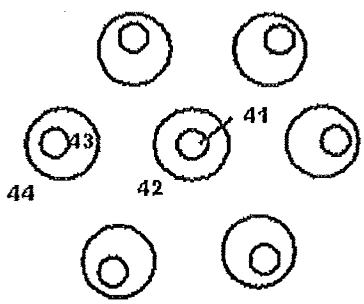


Fig 8

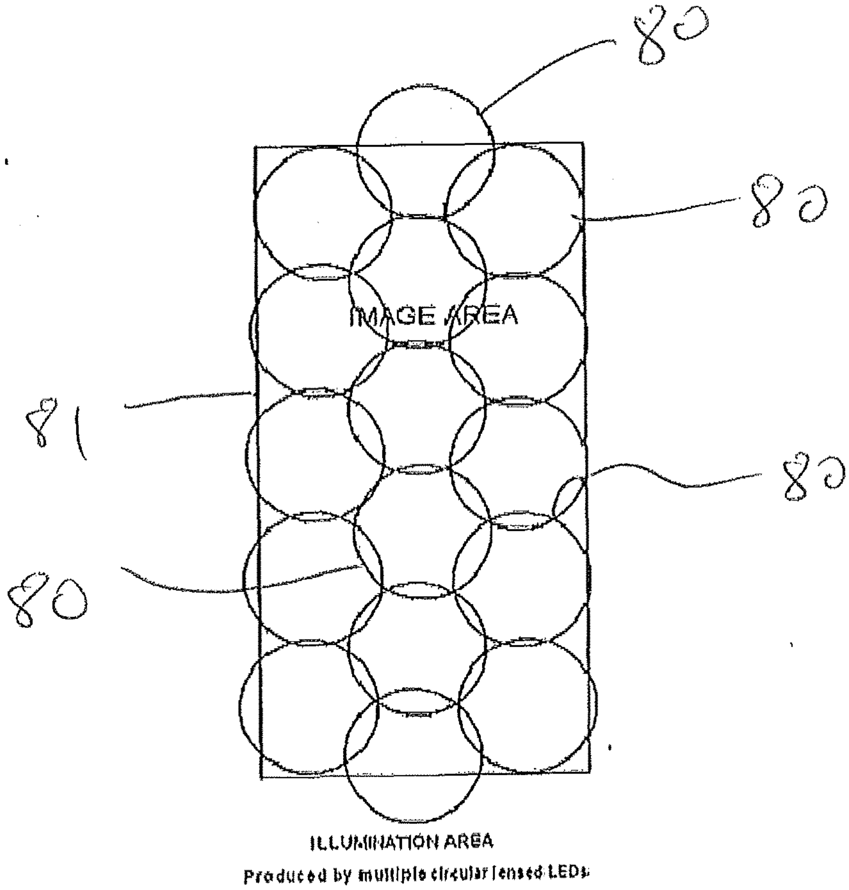

80
80
IMAGE AREA
81
80
80
ILLUMINATION AREA
Produced by multiple circular lensed LEDs

Fig 9

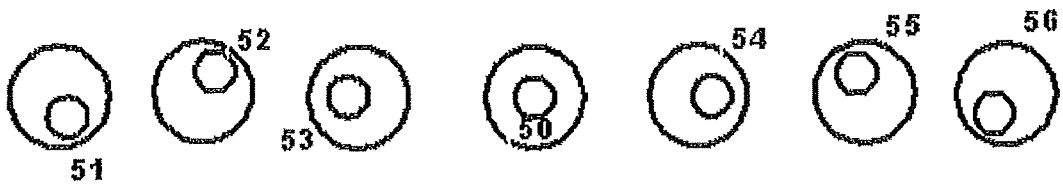

52
54
55
56
53
50
51

Fig 10

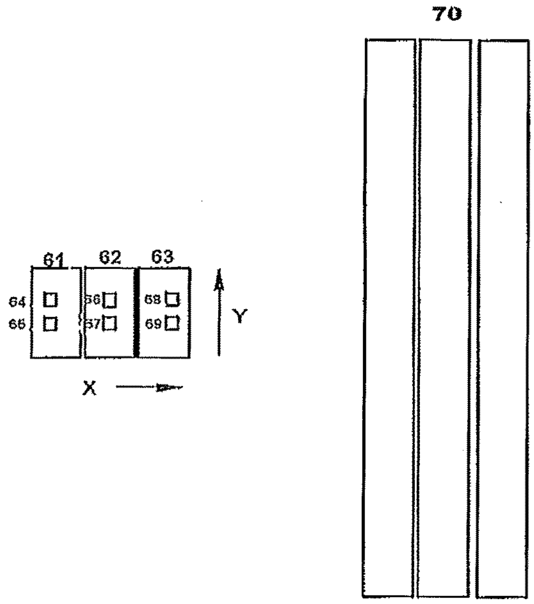


Fig 11

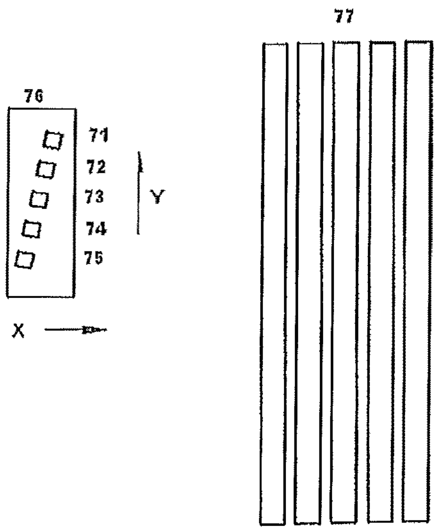
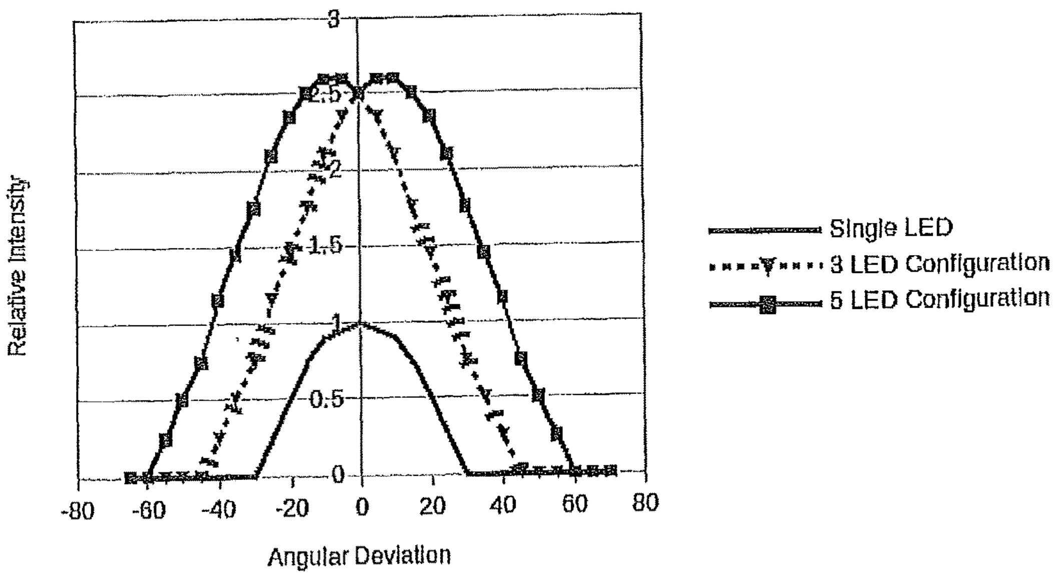


Fig 12



3
2.5
2
1.5
1
0.5
0
-80
-60
-40
-20
0
20
40
60
80
Relative Intensity
Angular Deviation
Single LED
3 LED Configuration
5 LED Configuration

Fig 13

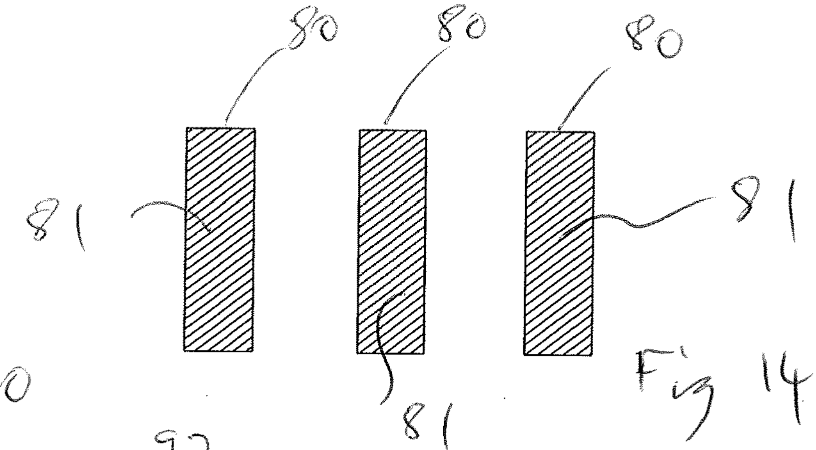


Fig 14a

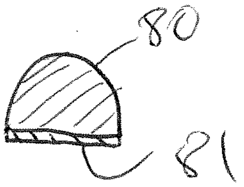


fig. 14b

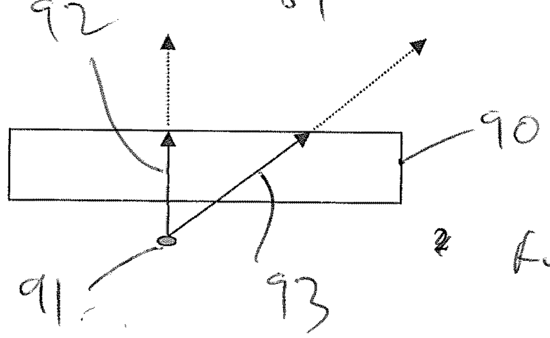


fig 15

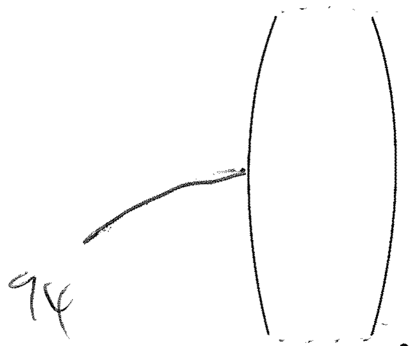


fig. 16

fig. 17

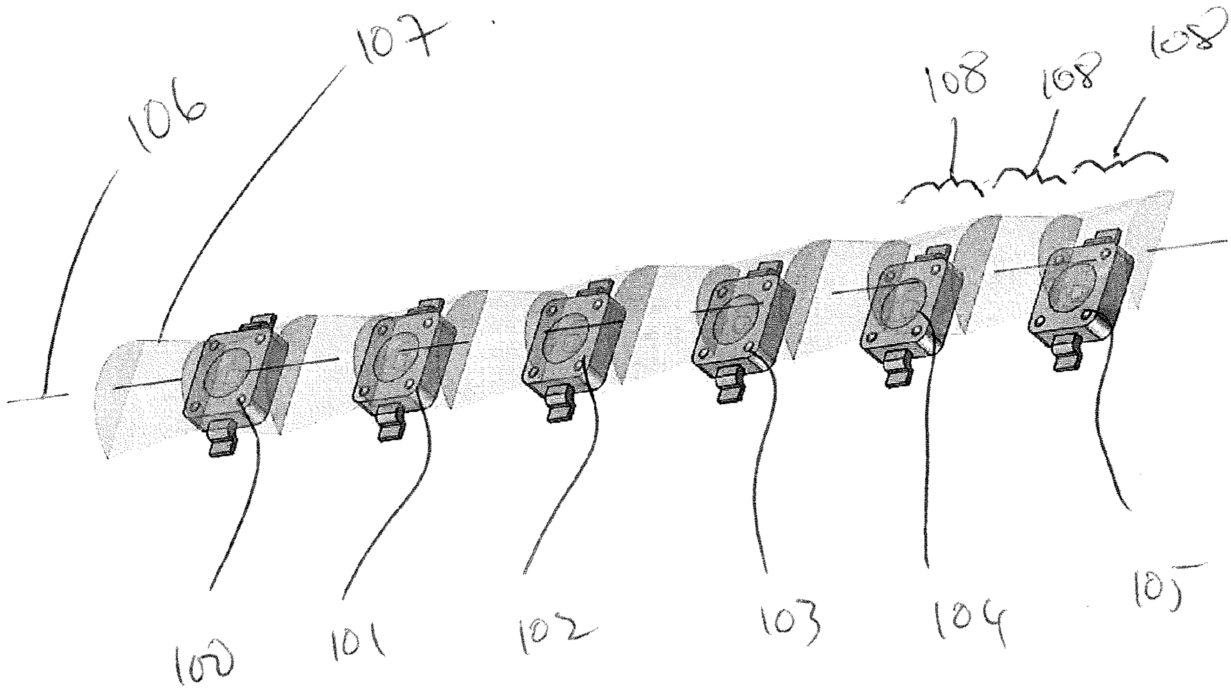


Fig 18

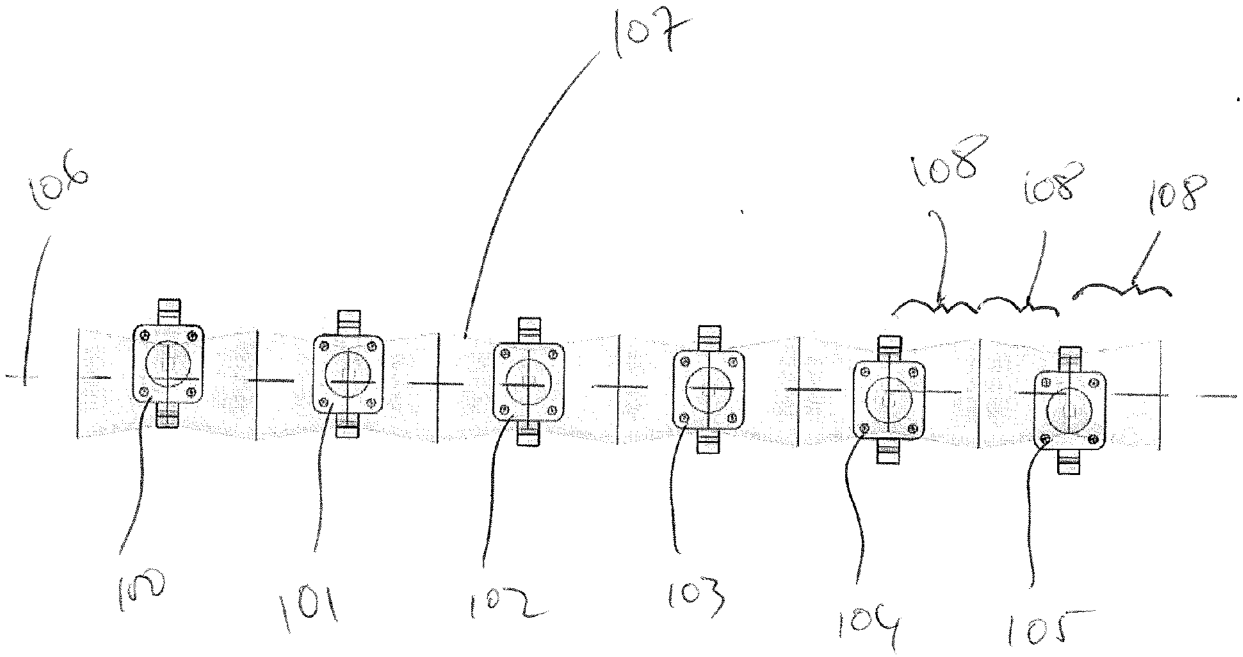


Fig. 19

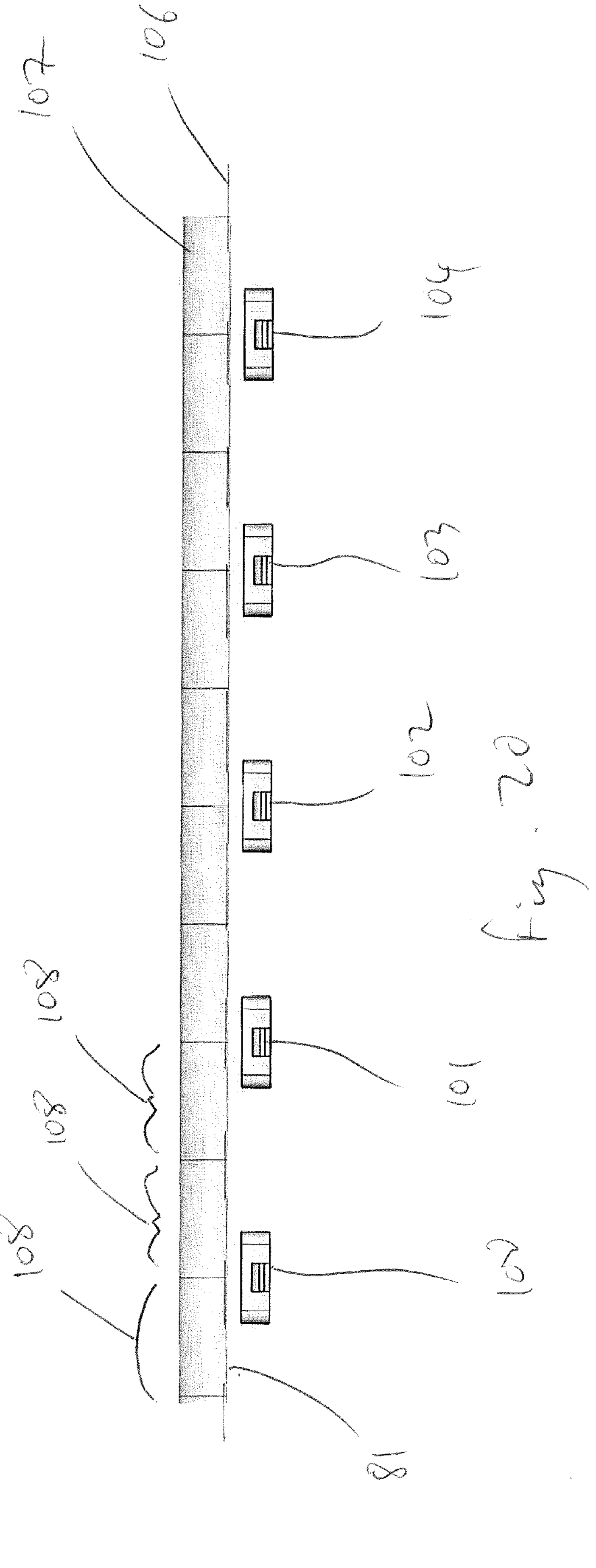


Fig. 20

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Office européen des brevets

EUROPEAN SEARCH REPORT

Application Number
EP 16 15 2702

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X	US 2009/225551 A1 (CHANG HSUEN-CHIH [TW] ET AL) 10 September 2009 (2009-09-10) * figures 1-5 * -----	10-15	
X	US 2011/149548 A1 (YANG HAITAO [US] ET AL) 23 June 2011 (2011-06-23) * figures * -----	1,11-15	
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X	WO 2014/004923 A1 (INTEMATIX CORP [US]) 3 January 2014 (2014-01-03) * figures 7-26 * -----	1,2,4-9	F21V F21K F21Y
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The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
The Hague	29 June 2016	Kebemou, Augustin

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EUROPEAN SEARCH REPORT

Application Number
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TECHNICAL FIELDS SEARCHED (IPC)

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
The Hague	29 June 2016	Kebemou, Augustin

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