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(54) **Brightness correction for LCD displays with backlight modulation**

(57) This invention relates to a system and a method for providing backlight to a backside of a display panel which system comprises a backlight driving unit for driving said backlight, a dimming control unit to vary said backlight in accordance with the image content to in-

crease image contrast, an LCD control unit for controlling areas of an LCD transmittance panel, **characterized in that** said LCD control unit varies the LCD transmittance to compensate the intensity variation of the pixel levels due to dimming.

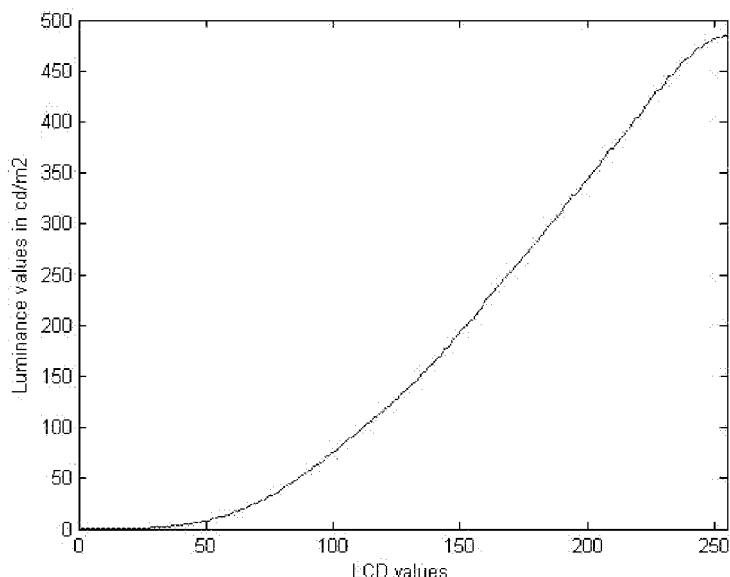


Figure 1

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Description**Field of the invention**

[0001] This invention relates to a method and a system for improving the contrast in displays illuminated by individually controlled led blocks.

[0002] The Led blocks placed behind the LCD layer of the displays are controlled individually to locally dim or boost the illumination level such that the local characteristics of the image can be better visualized. The major advantage of this approach lays in a remarkable improvement in the contrast performance of the display where a local dimming of the Leds enables minimal light leakage thorough the LCDs. The proposed method describes how local LCD pixel values are enhanced (compensated) after the local variation of illumination level.

[0003] The proposed method provides a solution for LCD compensation for any given Led driving intensities. The objective metric used for performance comparison is used as the main reference algorithm for performing the correct compensation.

[0004] The method mathematically simulates the screen intensity and depending on the accurate display measurements (Led point spread function (PSF) and LCD sweep characteristics) it provides a compensation of the LCD pixels. As shown in figure 8, initial LCD value is used to compute the initial reference intensity (1), the Led screen intensity (simulation output) is used to find the intensity after local dimming (2), using the LCD sweep measurement the updated LCD values are defined (3).

State of the art

[0005] Conventional LCD displays are formed by a constant and uniform backlight and a LCD panel. The backlight supplies constant light source and liquid crystal cells work as switches controlling the brightness of corresponding pixels.

Conventional LCDs suffer the drawback of poor image contrast due to the light leakage from liquid crystals.

[0006] There is an increasing interest in the Led Backlight Displays in the market due to the notable performance increase and energy saving characteristics. However many different outcomes of Led Backlight can be created by using the temporal characteristics of the image or by using different scanning methods to achieve better motion picture performance. These benefits encouraged researchers to study on methods to utilize this technology to achieve higher image quality using the conventional LCD characteristics.

[0007] The brightness of the pixel (the amount of light passing through each LCD) perceived by the viewer is the result of the combined effect of backlight intensity, filter transmittance and LCD level in the display. For a conventional display the ratio of minimum and maximum light leakage (corresponding to the 0 and 255 values of LCD) is constant for a constant backlight. However, with locally controlled Led Backlight the minimum light leakage level may be decreased to lower levels; hence boosting up the contrast performance of the display. The benefits come with difficulties in deciding the correct values of the Led backlight levels and LCD values corresponding to updated backlight luminance. This represents a remarkable drawback of the solutions currently available on the market.

[0008] The proposed method utilizes the main idea of making the pixel brightness after the local dimming equal to the reference brightness for the three main colour channels R, G and B channels and hence compensating the local decrease in the intensity by an increase in the LCD transmittance. On the other hand the decrease in the dark regions (where a soft thresholding idea is employed) is not compensated in order to realize the minimal light leakage and a real black screen.

[0009] Similar methods have been proposed in:

- Dynamic Backlight Gamma on High Dynamic Range LCD TVs Fang-Cheng Lin et al., Journal of Display Technology, June 2008 Page(s):139 - 146;
- SID Symposium Digest of Technical Papers, June 2006, Volume 37, Issue 1, pp. 1242-1245;
- High Contrast LCD TV Using Active Dynamic LED Backlight SID Symposium Digest of Technical Papers -- May 2007 -- Volume 38, Issue 1, pp. 1336-1338.

[0010] All these three methods depend though on the rough idea that the decrease in the intensity can be compensated by an exponential calculation taking the gamma value of the screen into consideration. Although the results of these prior art contributions seem to be promising for many type of image contents, when it comes to an objective and exact calculation of the deviation to the real reference intensity, all of them lack in performance when compared to the solution of the method and system of the present invention.

[0011] All the aforementioned state of the art contributions are based on the main idea of compensating the variation in pixel intensity by employing estimates of the intensities at full or reduced backlighting power.

[0012] Mainly the following rules well known in the literature are used:

$$I_{Full} = BL_{Full} \times (CV_{Full} / 255)^{\mu} \quad (1)$$

$$I_{Reduced} = BL_{Reduced} \times (CV_{Reduced} / 255)^{\mu} \quad (2)$$

$$BL_{Reduced} \times (CV_{Reduced} / 255)^{\mu} = BL_{Full} \times (CV_{Full} / 255)^{\mu} \quad (3)$$

$$BL_{Reduced} = (BL_{Full} / BL_{Reduced})^{1/\mu} \times CV_{Full} \quad (4)$$

where the pixel compensation is tried to be realized using the estimate in (1) and (2). However the parameterization of the intensity output of a display presents quite some difficulties and it is not a straightforward computing by employing the above equations. The empirical measurements show that this rough estimate deviates from the real values.

[0013] The compensation methods in the prior art all depend on the compensation in the Y domain which mostly contains the intensity information (some use also the idea to compensate in R, G and B channels independently). The main idea stems from the basic fact that the increase in the Y value of the image causes an increase in the output intensity, and it can be used to compensate the effect of the backlight dimming. But since no gamma curve is able to represent the display characteristics without error, the assumption produces a solution which, de facto it is only a rough estimation of the correct solution. Since our method does not use a mathematical model to estimate the display parameters, (but uses only the experimental outputs) it ends up with the correct value in order to reach the real required intensity, overcoming in this way the limitations of the approaches of the state of the art.

Summary of the invention

[0014] So there is certainly a need for overcoming the limitations of the faulty intensity corrections of present state of the art displays using local dimming.

[0015] This problem is solved by employing a backlighting system where the LCD control unit varies the LCD transmittance to compensate intensity variations as claimed in claim 1.

[0016] Another aspect of the present invention relates to varying the LCD transmittance to keep the intensity value of a pixel faithful to the intensity value of the image to be displayed.

[0017] Another aspect of the present invention relates to a backlighting system formed of a plurality of backlighting areas, each controlled by relevant backlighting driving units and dimming control units.

[0018] Another aspect of the present invention relates to adapting the LCD transmittance in accordance with the values of the Point Spread Function.

[0019] Another aspect of the present invention relates to employing an L^2 norm to measure the error between the required pixel intensity and the intensity changed by dimming, so to vary adequately the LCD transmittance for compensating such error.

[0020] Another aspect of the present invention relates to the usage of look-up tables for changing the transmittance of the LCD panel.

[0021] Another aspect of the present invention relates to the usage of predetermined thresholds to recover the intensity level.

Brief description of the drawings

[0022]

Fig. 1 shows an LCD transparency measurement for a conventional LCD display with a static contrast ratio of about 800:1. Specifically, it shows a LCD Transparency Curve for a grey level sweep from 0 to 255. The figure demonstrates that a parametric model for the intensity is an ill-posed approach.

Fig. 2 shows the unwanted behaviour that the light emission does not go to zero as the LCD levels approach zero. Instead, the target characteristic that is plotted with bold line is the one which should be targeted as it shows that

for an ideal behaviour of zero light leakage the luminance should be zero at minimum LCD values.

Fig. 3 shows the Led PSF distribution for one Led Block, namely the intensity distribution of one led Block (a group of Leds all assigned to the same value). The intensity distribution is not same for all Leds, corner Leds and the ones near the edges should be treated differently, as they have different PSF.

Fig. 4 is a diagram of the LCD Transparency Curve for the red channel, namely it shows the intensity distribution for the sole R channel. (ie. B and G channels are set to 0, R is swept from 0 to 255)

Fig. 5 is a diagram of the LCD Transparency Curve for the green channel, namely it shows the intensity distribution for the sole G channel. (ie. B and R channels are set to 0, G is swept from 0 to 255).

Fig. 6 is a diagram of the LCD Transparency Curve for the blue channel, namely it shows the intensity distribution for the sole B channel. (ie. R and G channels are set to 0, B is swept from 0 to 255)

Fig. 7 shows a possible Led Arrangement. The Led arrangements inside one Led block are a property of the display that is supplied by the display vendor.

Fig. 8 shows the phases involved in a possible compensation algorithm. The algorithmic flow is depicted in the figure: arrow 1 shows the calculation of reference LCD intensity, arrow 2 shows the calculation of reference intensity with the updated Led values, arrow 3 shows calculation of updated LCD values corresponding to the required intensity values.

Detailed description of exemplary embodiments

[0023] The invention is directed to a system and method for improving the faithfulness of images to be used in any kind of display (or projector) whose backlight can be locally enhanced in order to obtain better contrast characteristics. The method uses the predetermined Led driving values to calculate the led intensity on the display and then enhance the LCD pixels to compensate for the possible image deterioration due to misrepresented low pass behaviour caused by a little number of Leds (possible configuration 16x8)

[0024] The invention uses the information of carefully measured display characteristics: the display sweep intensities for R, G and B channels, the PSF (Point Spread Function) and the placement of the Led groups in the display. Figure 1 shows the grey level sweep intensity levels for a conventional display with static contrast ratio 800:1. Such sweep intensity is aimed to keep the maximum value constant and to decrease the minimum value which is the light leakage, namely reduce the intensity to a minimum value when the LCD values are set to 0. Diagrams of the individual intensity values for R, G and B channels, parameters which play a major role in the present method, are given in figures 4, 5 and 6.

[0025] The present invention can use the Led value estimates from any algorithm proposed in the literature. The estimated Led intensities are used to produce (more precisely to simulate) the display intensity using the PSF of the display. It is worth noting that the PSFs of the Led groups in different parts of the display may vary due to the reflections differences in different display areas (ie, corners may have more reflection components and hence produce higher intensity distribution).

[0026] Initial step of the algorithm consists in simulating the Led intensity on the display when the Leds are driven with the estimated values. This simulation, as previously mentioned, can be any kind of simulation already available, and it is of paramount importance that it is as accurate as possible. Figure 3 shows a simulation result for the display intensity when only one of the Leds in the middle of the screen is driven with 255 (white) while others are assigned to 0 (black). By using the superposition principle (intensity of light is cumulatively added) for all Led blocks, the final distribution of the light intensity as in Fig. 3 is reached. The final intensity distribution is then used to calculate how much the intensity has diverged from the reference intensity. Here it is introduced an objective metric for quality assessment of the final solution. The square of the difference between the original and final intensities are calculated and then later used to judge the performance of the method. Notice that the error criterion is a square error type (L^2 type).

$$\text{Error} = \sum \{ \sum (\{ \text{Int}(\cdot) - \text{IntRef}(\cdot) \}^2) \}; \quad (5)$$

[0027] The Error is calculated before and after the compensation. Since it is possible to calculate the error for different methods, regardless which is the estimation method employed, it provides an objective metric to judge the algorithm. As stated before, since this method proposes an objective measurement dependent approach, it suffices the minimum

error criterion.

[0028] Having calculated the Led intensities, the following step is to enhance the LCD pixel values so that the reference intensity is preserved. The intensity measurements for R, B and G channels which are plotted in figures 4, 5 and 6 are used as look up tables to decide on the update values corresponding to the required intensity. For each pixel on the screen the Led intensity measurement is combined with the original LCD value.

[0029] The initial intensity L_{init} is computed with the condition that all Leds are assigned to 255 (max value). After the local dimming algorithm the Led and intensity values have been updated and the light leakage through each pixel (for the three components) has changed. Using the look up table the new values are obtained.

[0030] The method is described in figure 8. The bold continuous line shows conventional grey level sweep intensity where the dotted line represents an updated intensity after the Led value estimation (a local dimming of 50% is shown in the example). The intensity level corresponding to the initial LCD values are computed using the Look Up Tables (LUTs) for three channel components (1); the intensity has then to be compensated with the updated Led values (2); finally the updated LCD level is obtained using the LUTs. This operation is repeated for each channel R, G, B.

[0031] A major problem that may arise in any kind of compensation method is clipping. Clipping is the situation when more than one (usually 10 to 30) initial LCD values (say from 230 to 255) are assigned to 255 after compensation. The reason is that the initial intensity with all Leds at full brightness may not be compensated with the updated Led brightness (ie. initial LCD level of 200 may produce a brightness of 400 cd/m², when the updated Led values are driven, the same intensity level may be reached with LCD value of 255). Hence all the LCD values from 200 to 255 may be assigned to 255, which cause a great loss of detail in the bright regions. This problem can not be tolerated; hence a soft thresholding idea is used with a gradual decrease in the required intensity as the LCD level goes above the given threshold.

[0032] In the following the initial intensity level is indicated as $intRef$, and the intensity threshold value above which the intensity won't be perfectly recovered is indicated as $thrHigh$.

[0033] If $intRef > thrHigh$

$$intRefUpd = intRef * (1 - (intRef - thrHigh) / (maxInt - thrHigh)) \quad (6)$$

[0034] A similar approach (mirrored to reflect the behaviour at the low level of the scale of the intensities to be thresholded) can be used for the dark pixels which may also need special attention. The pixels below the given threshold should not necessarily reach the initial intensity; on the contrary they should decrease in order to achieve better contrast performance.

Claims

1. A backlighting system for providing backlight to a backside of a display panel comprising:

- a backlight driving unit for driving said backlight
- a dimming control unit to vary said backlight in accordance with the image content to increase image contrast
- an LCD control unit for controlling areas of an LCD transmittance panel, **characterized in that** said LCD control unit varies the LCD transmittance to compensate the intensity variation of the pixel levels due to dimming.

2. The backlighting system of claim 1 wherein said LCD control unit varies the LCD transmittance to keep the intensity value of a pixel faithful to the intensity value of the image to be displayed.

3. The system of any preceding claims wherein said backlighting is formed of a plurality of backlighting areas, each controlled by said backlighting driving unit and dimming control unit.

4. The system of any preceding claims wherein the LCD transmittance is varied in accordance with the values of the Point Spread Function.

5. The system of any preceding claims wherein the LCD control unit varies the LCD transmittance to compensate the intensity variation of the pixels due to dimming such that the L2 norm of the error between the required pixel intensity and the intensity changed by dimming is reduced.

6. The system of any preceding claims wherein the LCD control unit employs a lookup table for changing the transmittance of the LCD panel.

7. The system of claim 6 wherein when the initial intensity (intRef) is above a predetermined threshold (thrHigh), the updated intensity level (intRefUpd) is recovered as follows:

$$\text{intRefUpd} = \text{intRef} * (1 - (\text{intRef} - \text{thrHigh}) / (\text{maxInt} - \text{thrHigh}))$$

wherein intRef is the initial intensity level, thrHigh is the high reference threshold, intRefUpd is the updated intensity, maxInt is the highest intensity value.

8. A method for providing backlight to a backside of a display panel in a backlighting system comprising:

- driving said backlight in different areas of said display
- dimming said backlight in accordance with the image content to increase image contrast
- controlling areas of an LCD transmittance panel,

characterized in that the LCD transmittance is varied to compensate the intensity variation of the pixel levels due to dimming.

9. The method of claim 8 wherein the LCD transmittance is varied to keep the intensity value of a pixel faithful to the intensity value of the image to be displayed.

10. The method of claims 8-9 wherein the LCD transmittance is varied in accordance with the values of the Point Spread Function.

11. The method of claims 8-10 wherein the LCD transmittance is varied to compensate the intensity variation of the pixels due to dimming such that the L2 norm of the error between the required pixel intensity and the intensity changed by dimming is reduced.

12. The method of claims 8-11 wherein the LCD transmittance is varied by employing a lookup table.

13. The method of claim 12 wherein when the initial intensity (intRef) is above a predetermined threshold (thrHigh), the updated intensity level (intRefUpd) is recovered as follows:

$$\text{intRefUpd} = \text{intRef} * (1 - (\text{intRef} - \text{thrHigh}) / (\text{maxInt} - \text{thrHigh}))$$

wherein intRef is the initial intensity level, thrHigh is the high reference threshold, intRefUpd is the updated intensity, maxInt is the highest intensity value.

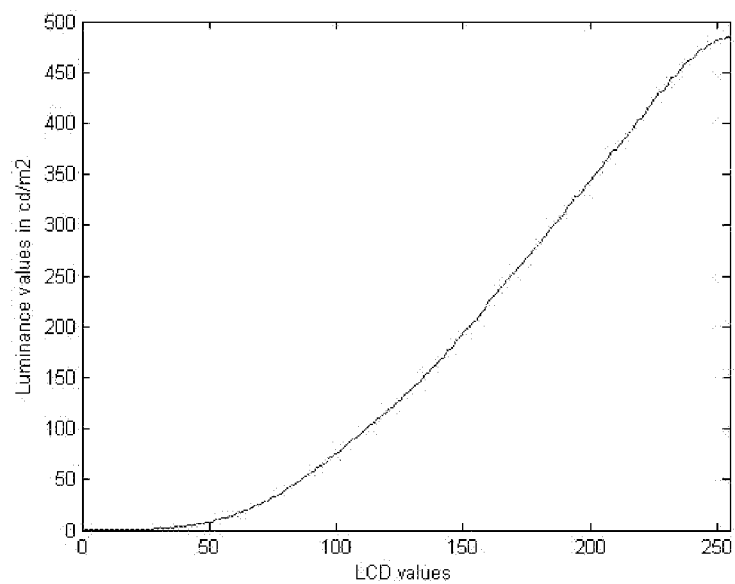


Figure 1

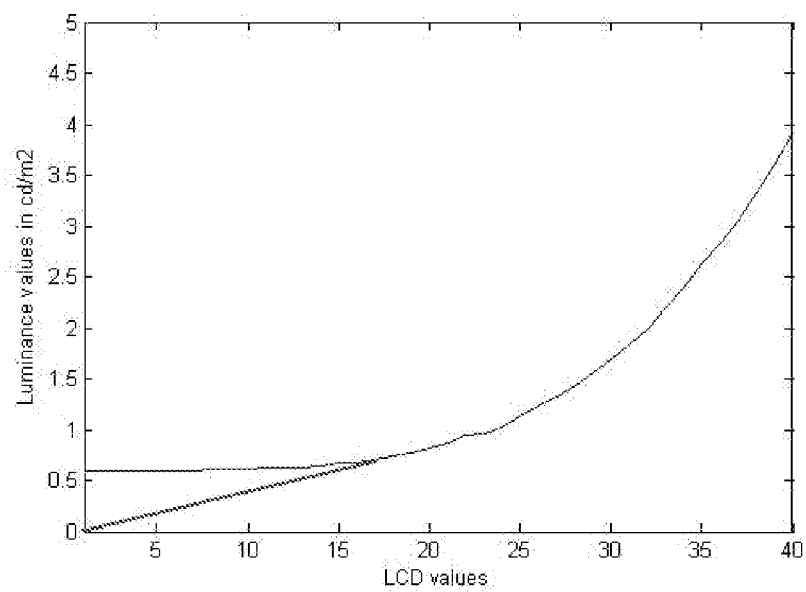


Figure 2

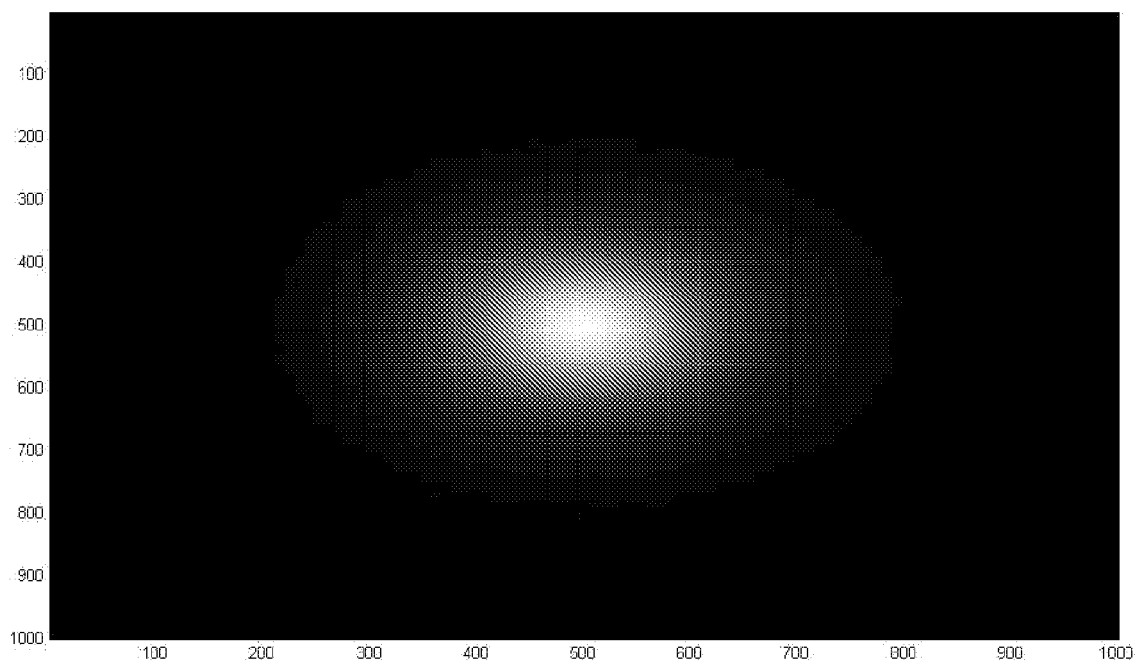


Figure 3

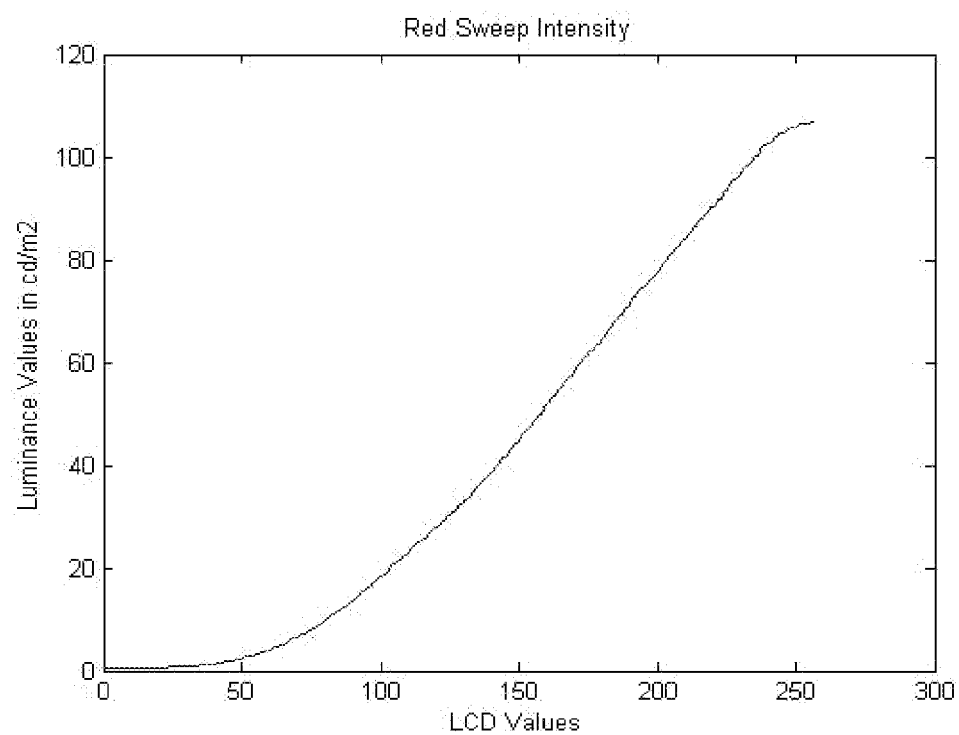


Figure 4

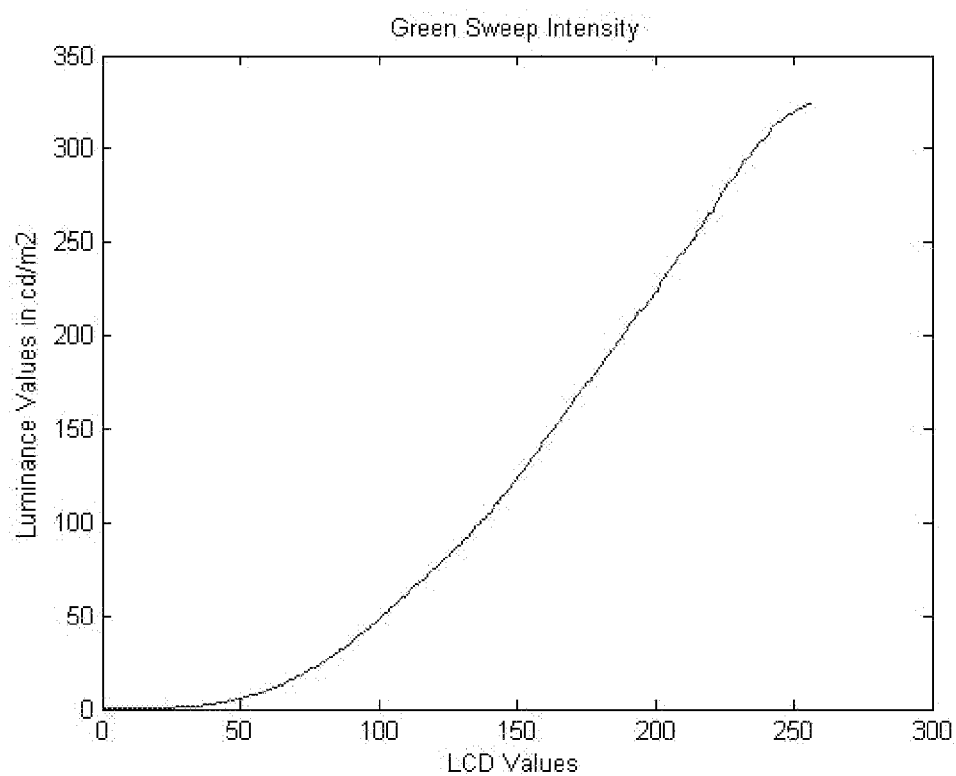


Figure 5

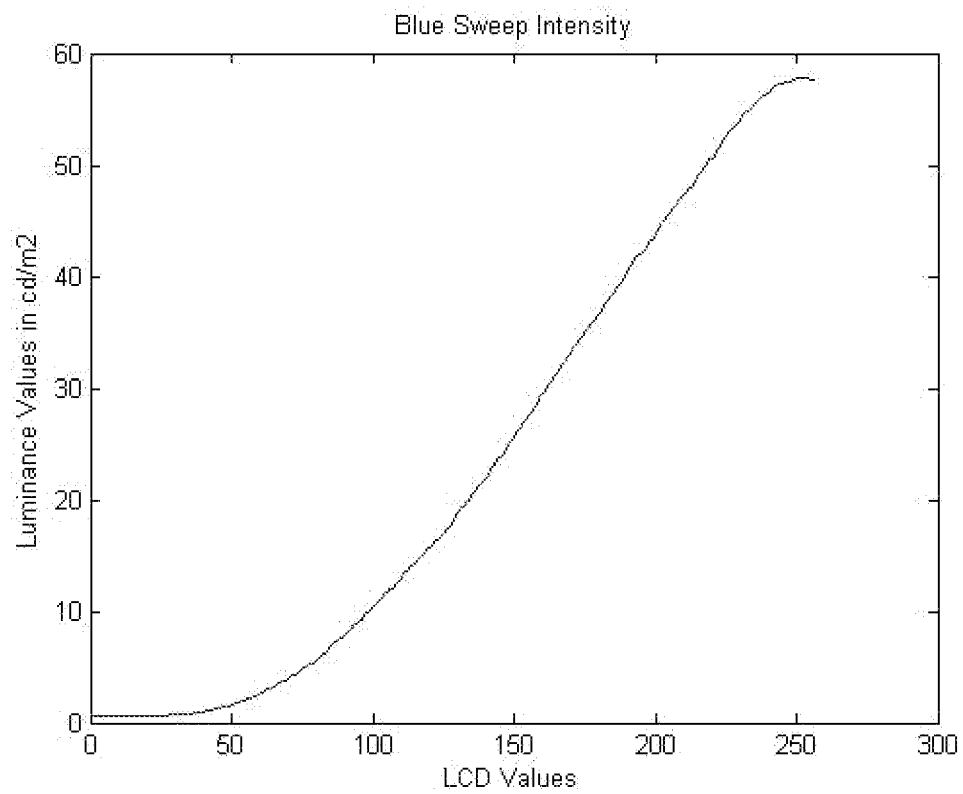


Figure 6

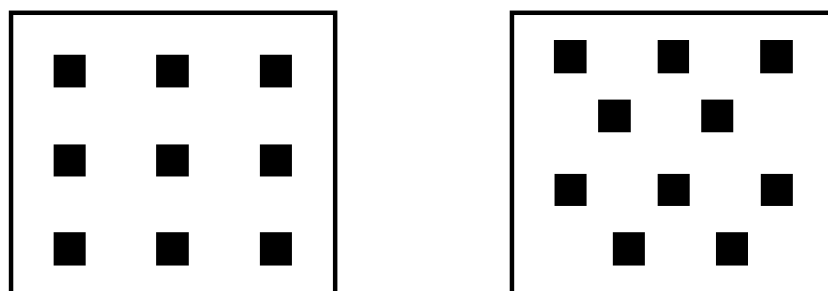


Figure 7

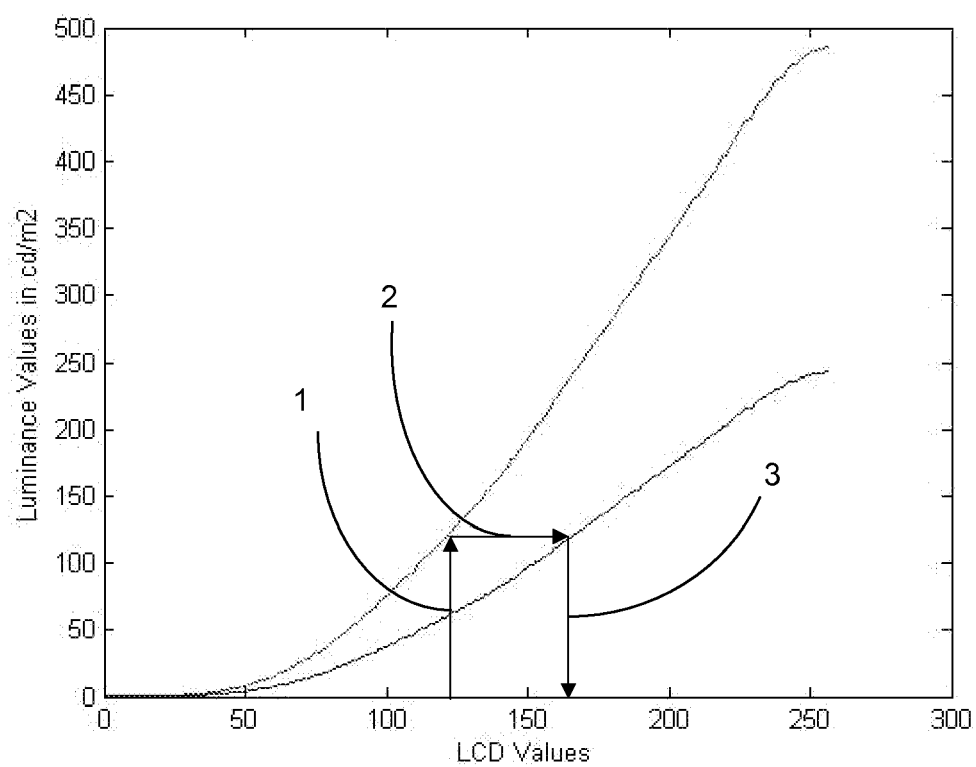


Figure 8



EUROPEAN SEARCH REPORT

Application Number
EP 10 17 9819

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	US 2009/141178 A1 (KEROFSKY LOUIS J [US] ET AL) 4 June 2009 (2009-06-04) * abstract * * paragraphs [0006] - [0007], [0010], [0016] * * paragraphs [0121], [0141]; figures 1-3 * * paragraph [0148]; figure 4 * * paragraphs [0152] - [0156]; figure 6 * * paragraphs [0175] - [0176]; figures 7-8 * * paragraphs [0198] - [0203]; figures 13-14 * * paragraphs [0204] - [0206]; figure 15 * * paragraphs [0209] - [0212]; figures 19-20 * * paragraphs [0247] - [0248], [0256] * * paragraph [0259]; figure 35 * -----	1,2,5-9, 11-13	INV. G09G3/34 G09G3/36
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X	US 2009/201245 A1 (NONAKA RYOSUKE [JP] ET AL) 13 August 2009 (2009-08-13) * abstract * * page 139, left-hand column, paragraph 1 * * page 139, right-hand column, paragraph 2 - page 142, left-hand column, paragraph 2; figures 3-7 * -----	1,8	
The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 9 December 2010	Examiner Corsi, Fabio
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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**ANNEX TO THE EUROPEAN SEARCH REPORT
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09-12-2010

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