Slope Calibration Algorithm for OLED Display Gamma-Tuning Instruments

Seong-Yeon Kim*, Yong-Hwan Lee**[1], and Hee-Jin Lee**[2]

Abstract

Unlike LCDs that use backlight, OLED display emits light by itself. Due to this, the accuracy of the gamma tuning process calibrated by the measurement of the photometric characteristics of panels plays a crucial role in the OLED manufacturing process. For accurate photometric measurements, measuring the tilt angle of the panel is essential because the horizontal angle of an OLED panel, when an optical instrument inspects it, must not exceed +/- 2.5°. In this paper, an algorithm that calculates the tilt angle through image processing on photo images of OLED panels placed on optical measuring devices is developed. The location of 4 corner points and the outline lengths of the tilted OLED panel can be measured. Then, the angles of the slope in the direction of the x- and y-axes with respect to the z-axis can be calculated to obtain the tilt of the panel. After that, to meet the range of errors required for optical instruments, the tilt of the panel can be corrected to be placed horizontally by providing information on the slope. The mean error comparing the slope calculated by this algorithm with the actual measured slope is about 1.09°.

요 약

백 라이트를 사용하는 LCD와는 다르게 OLED디스플레이는 자가 발광을 하기 때문에, 제품 생산 시 패널의 광 특성 측정에 의한 감마 튜닝 공정의 정확도가 중요시된다. 정확한 광 계측을 위해서는 광 계측 장비가 OLED 패널을 검사할 때의 측정 각도가 +/- 2.5를 벗어나서는 안 되며, 이에 따라 패널의 기울어진 각도 측정 기술은 필수적이다. 본 논문에서는 광 계측 장치에 놓인 OLED 패널의 영상을 받아 영상 처리를 통해 기울어짐을 판단하고 기울어진 각도를 계산하는 알고리즘을 개발한다. 기울어진 OLED 패널의 영상에 대한 이미지 처리 후, 이를 통해 얻어진 코너 점과 외곽선 길이를 측정한다. 다음으로, x, y축 방향의 회전각을 계산하여 액정 기울기를 얻을 수 있고, 기울기에 대한 정보를 제공하여 패널을 조정함으로써 광 계측 장비에서 요구하는 오차 범위를 만족시키도록 한다. 본 알고리즘에 의하여 계산된 기울기와 실제 측정된 기울기를 비교한 평균 오차는 1.09°도로 측정방법의 유효성이 검증되었다.

Keywords

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Ⅰ. Introduction

Recently, as the shortcomings of OLEDs such as short lifespan have been overcome, OLED panels that outperform conventional LCDs in terms of image quality have been spotlighted, and many products equipped with OLEDs have been produced. These OLEDs are a type of self-luminescence that do not require backlight. Therefore, gamma tuning process from measurement of panel light characteristics is more essential in the production process. In order to measure and calibrate the characteristics of OLED display light, it is important that the OLED panel is placed horizontally so that the measuring instrument can inspect it vertically from above. The excessive tilt horizontal angle should be leveled by adjusting OLED panel position manually or automatically before starting measurement. This is because the color may vary significantly depending on the distance or angle between the panel and the instrument. For accurate measurements, the range of horizontal angles of panels allowed by the optical instrument should be less than +/- 2.5°.

In this paper, an inclination angle measurement algorithm is developed to fast and accurately correct the tilt that may vary in the production line. With this algorithm, it is possible to increase accuracy in photometric measurement of the equipment for the gamma tuning. As shown in Fig. 1, to extract the tilted angle of the OLED panel, the image received from the camera is converted into gray scale[1][2].

Because the image obtained from the camera is a color image, the calculation speed is long and the size of the required memory is also large to calculate each RGB. Next, a median filter removes noise from the grayscale image[3][4]. Then, from the image, edges are detected through a Sobel mask filter[5][6], and four corner points are recognized through a Harris corner detection filter[7][8]. Applying the Euclidean distance formula to the coordinates of the four corner points, the length and midpoint of the four outlines are calculated[9].

Through the algorithm proposed and developed in this paper, it is possible to calculate how much the panel is tilted in the x-axis and y-axis directions with respect to the z-axis, thereby providing enough information to correct the tilt.

Ⅱ. Grayscale

The 24-bit RGB data provided by the camera is converted to 8-bit gray color to reduce the disadvantages in calculation speed and image size and to speed up processing. Grayscale is a black-and-white color image. It is an image that has only the brightness information indicating the intensity from 0 (black) to 255 (white) values. The reason for storing only the brightness information is that it is burdensome to process the color information, so only the brightness information (Y) is transmitted and the color information (U, V) is transmitted separately. The gray image already has RGB information, and when it is converted into a YUV value, the Y value which is created automatically has brightness information. Using this brightness value, a grayscale image is generated as in the equation (1).

$$Y = 0.299 \times Red + 0.587 \times Green + 0.114 \times Blue$$
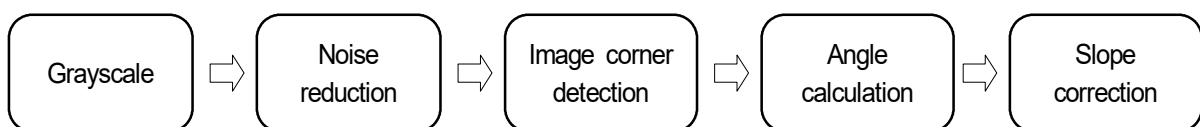
$$(1)$$

Fig. 1. System structure

Image format used is YPbPr, which is a kind of color space used in imaging devices. YPbPr is mathematically the same as YCbCr, but designed for analog systems. YPbPr is converted from RGB image signals and divided into three components: Y, Pb, and Pr. Y conveys Luma information, Pb conveys (Blue - Y), and Pr conveys (Red - Y).

III. Blurring and Corner Detection

Before extracting edges to detect corner points, noise must be removed from the image by a median filter for effective extraction. In the median filter, values in a mask of a specific size are sequentially aligned using a sorting algorithm. This filter replaces the pixel value with the central value of the values sorted in ascending or descending order.

Fig. 2 depicts how the median filter replaces the pixel value. 9 pixels in the 3×3 mask are arranged in ascending order to obtain the median value. It can be seen that the original pixel having a value of 10 is a noise component and is clearly removed. This is because pixel with extreme differences in value compared to neighboring values is biased left or right when sorted in ascending or descending order, and is not selected as the median value. A median filter rarely selects a noise component and does not chooses it as a pixel value thus reducing noise effectively.

As shown in Fig. 3, even when the median filter is applied to the edge region, the edge is completely preserved. In the case of average-value filters, the noise component is also included in the average calculation, so the output may be affected by noise, but the median filter is more effective for edge preservation.

For detecting the edge of the image, Sobel mask filter is used as illustrated in Fig. 4. Sobel mask is the most representative first-order differential operator for edge extraction, and has a high weight for the gradient of the center pixel. This mask well extracts edges in horizontal and vertical directions, and also

detects edges in diagonal directions well because of the high proportion of the difference in the center pixel. Because the boundary line of the image changes rapidly in color or brightness, it is possible to induce Sobel mask by using the differential of pixels. The difference in intensity when the windows are moved by 1 pixel in 4 directions is compared. For the flat case, there is no change in intensity in all directions, for the edge, only the edge direction changes, and when there is a corner, a change in intensity occurs in all directions. In order to know the amount of change in intensity of an image, a difference in gradient respect to flat, edge, or corner is obtained using Sobel mask.
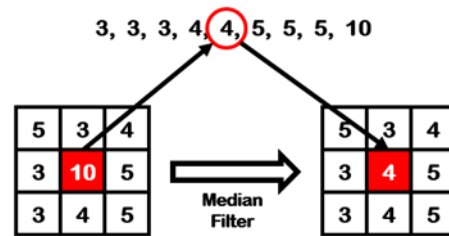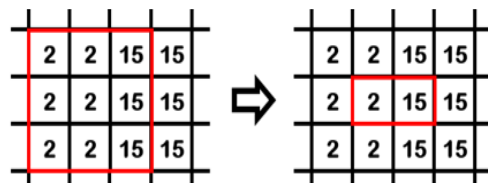

Fig. 2. Median filter mask
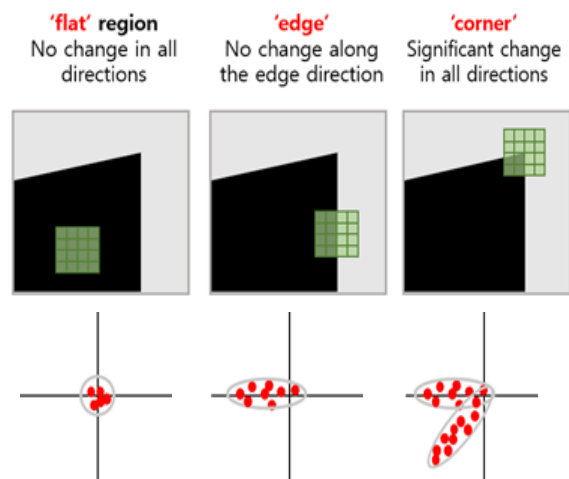

Fig. 3. Median filter applied on edge

Fig. 4. Edge detection

The matrix equation (2) is a measure of how large the eigenvectors of 2×2 matrix have a large value in the direction perpendicular to each other, where, Iy and Ix represent the differential values in the horizontal and vertical directions in the image, respectively. Obtaining unique vectors from this matrix results in two vectors perpendicular to the boundary direction. Two vectors, respectively, can be obtained if they are vertical, if they are smaller than vertical, and if they are larger than vertical. The best corner is when it is vertical. The vector of the corner can be obtained by using the differentiation. This requires the calculation of vectors which is complex and time-consuming, so Harris Corner detection uses the corner response function (3) rather than obtaining an eigenvector directly.

$$M = \begin{pmatrix} I_x^2 & I_{xy} \\ I_{xy} & I_y^2 \end{pmatrix} \tag{2}$$

$$\det(M) - K \cdot Trace(M)^2 = \tag{3}$$
$$\left(I_x^2 \cdot I_y^2 - I_{xy} \cdot I_{xy}\right) - K \cdot \left(I_x^2 + I_y^2\right)^2$$

Subsequently, a non-maximum suppression algorithm is used to find a local maximum value, leaving only that value and deleting all remaining values. Non-maximum suppression algorithms, which are mainly used for edge detection or object detection, examine whether the ambient value of a particular pixel is large or small. If there are ambient values greater than the current pixel, the values can be deleted to obtain the local maximum value of the color change or to find the maximum value of the color change to determine the existence of the outline.

IV. Algorithm

4.1 Measurement of Horizontal Tilt: x –axis and y–axis Relative to z–axis

The method of measuring the tilt of the OLED panel is to use an image that focuses on the OLED panel using a camera from the top. The height of the vertical line lowered from the camera to the bottom, and the triangle resemblance are used to calculate the tilt. Using these values, it is possible to calculate values in which the x and y axes of the OLED panel placed on the measurement device are inclined in the z-axis direction, respectively. The calculated z-axis movement amount and the original length of the non-tilted OLED are substituted into the triangular ratio, and the inclined angle of the x and y axes are obtained, respectively.

Before measuring the angle of the OLED panel, the length of the OLED itself can be measured by processing the image of the horizontally placed OLED. The center point of the OLED is displayed on the screen so that the position of the center point can be identified even if the OLED is tilted. The length of the outline can be measured by substituting the four coordinates obtained using the Harris Corner into the Euclidean distance formula (4). The Euclidean distance formula is a method of measuring distances using Pythagoras theorem (5). The shortest distance between two points in the n-dimensional space can be calculated by this formula.

$$\sqrt{(p_1 - q_1)^2 + (p_2 - q_2)^2 + \cdots + (p_n - q_n)^2} \tag{4}$$
$$= \sqrt{\sum_{i=1}^{n} (p_i - q_i)^2}$$

$$a^2 + b^2 = c^2 \tag{5}$$

As shown in Fig. 5, the position of the camera is perpendicular to the center point displayed in the image of the OLED panel. In addition, the intersection perpendicular to the floor from the display center point is marked as P point. The length of the line segment vertically lowered from the camera to the

center point, that is, the height from the floor to the camera is fixed as h. Fig. 6 shows the location of the camera. After taking the image of the tilted OLED, through the above process again, four corner points are extracted and four outlines are obtained.

Using the outlines l and l' parallel to the rotation axis of the angle to be calculated, the length of k'-k is calculated using the similarity ratio of the triangle as shown in the right of Fig. 5. The length from the camera to the P point is a fixed height h. The length of the line segment m connecting the midpoint of line l' and the P point can be obtained using the Euclidean formula. The length of k' is obtained by substituting h and m for Pythagoras theorem, and the length of k is obtained by substituting the value in equation (6) using the triangular similarity ratio.
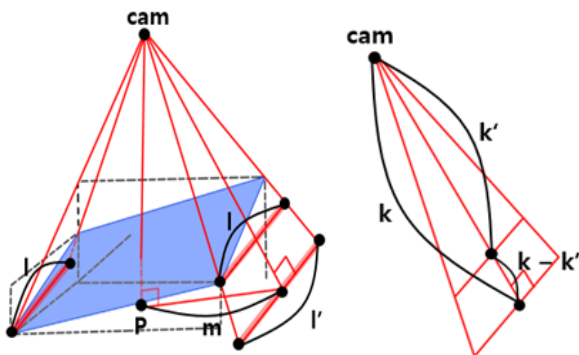
$$k = \frac{l' \cdot k'}{l'}, (l : l' = k : k') \qquad (6)$$

If the lengths k' and k'-k are known, it is possible to find the height of x, that is, the line segment in the z-axis direction using the similarity ratio of the triangle shown in Fig. 6. Calculation value x is the height which the line is raised to the z-axis. An equation (7) using a ratio of similarity is applied to a large triangle and a small triangle in this picture to obtain x. By substituting the height of raising the line and the length of the OLED panel that is not tilted with the inverse sine equation (8), the angle at which the floor and display are formed, in other words, the angle at which the display is tilted can be obtained. This method is used to calculate the rotation angles of the x- and y-axes relative to z-axis, respectively.

$$x = \frac{(k' - k) \cdot h}{k'}, (k' : k' - k = h : x) \qquad (7)$$

$$\arctan\left(\frac{height(=x)}{rela\ display\ lenght}\right) = \theta \qquad (8)$$

4.2 Measurement of Rotational Tilt: XY Plane

After correcting the inclination angles of x and y axes of OLED panel, it is necessary to determine whether the x-y plane of the panel is rotated and calculate the angle. Pythagoras theorem was used in the Euclidean distance equation, the x-coordinate difference (length X) and y-coordinate difference (length Y) of the two center points are obtained as shown in Fig. 7.

Fig. 5. Calculation method of the horizontal angle: the first phase
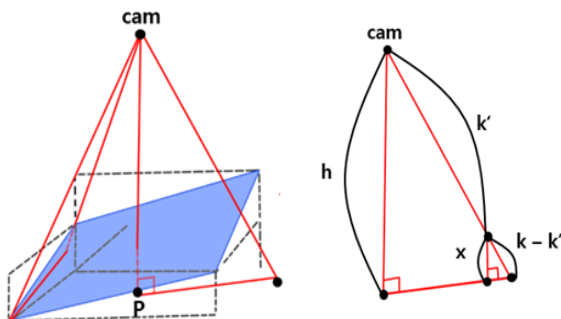
Fig. 6. Calculation method of the horizontal angle: the second phase
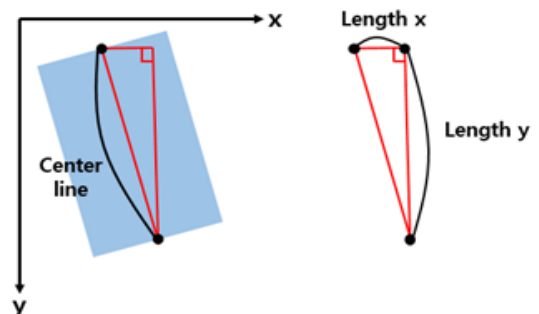

Fig. 7. Calculation method of the rotational angle: XY-plane

These differences are applied to the inverse tangent equation (9) to calculate the angle at which the OLED panel rotates relative to the y-axis.

$$\arctan\left(\frac{length\,X}{length\,Y}\right) = \theta \tag{9}$$

In order to know the direction in which the panel is rotated, the coordinates of the corner points are used to determine. When reading pixel values, values are read sequentially from the top left to the right. After reading the pixel value from the left end to the right end, it moves to the bottom row and starts reading the pixel from left to right again.

In the case of Fig. 7, the second read coordinate exists on the left rather than the first read coordinate. This is a left turn. Conversely, if the second coordinate exists to the right rather than the first coordinate, it rotates to the right.

Ⅴ. Experiment

In order to confirm the validity of the algorithm, the tilt of an OLED panel is measured as shown in Fig. 8(a). For the actual slope of the panel, after tilting the panel, the value is obtained using an angle meter. Then, it is compared with the experimental results through image processing. Its outline can be obtained using the four corner points of the OLED panel, as shown in Fig. 8(b). The angle of rotation obtained using image processing and actual angle of rotation are compared to obtain errors and determine accuracy.

Fig. 9 shows the procedure of obtaining the inclined angle of the OLED panel through image processing. The picture on the left shows the edge of the captured image after blurring it using a median filter then through the Sobel mask. The figure on the right shows the corner points and center points by applying to the algorithm, and then the length and inclination angles of the OLED panel.
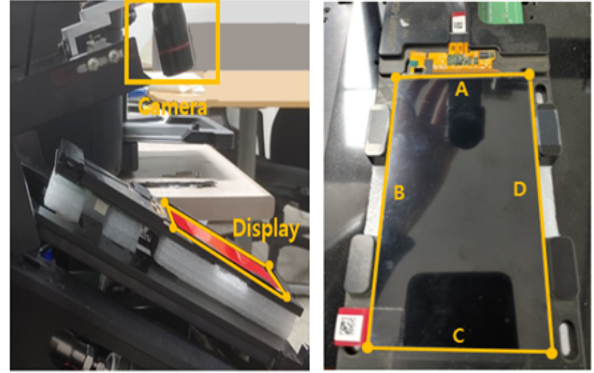

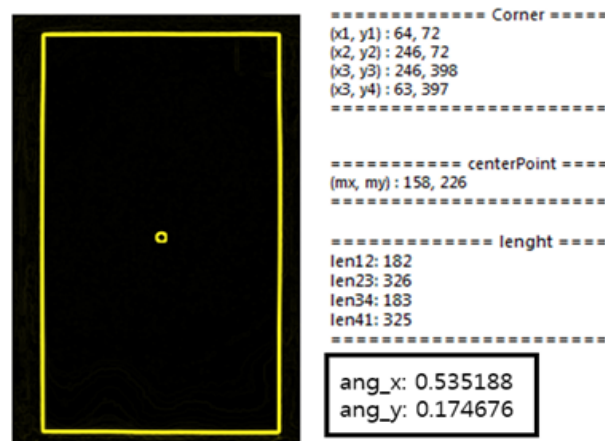Fig. 8. Optical measure equipment and photo of OLED display panel

Fig. 9. Example of calculating angles

The panel is placed in a horizontal position with little tilt. When checking the calculated value of the panel's tilted angle and the actual tilted angle, it can be seen that both the tilted angles in the x-axis and y-axis are close to zero.

After the process of obtaining the length and focus of the outline, the height at which the liquid crystal is raised to the z-axis is obtained using the method presented earlier. Use this value in the inverse tangent formula to measure the angle tilted by the x and y axes.

The results in Table 1 show that the error between the actual measured and calculated rotation angles is not significant. The measurement error by tilting the panel at random and then calculating the tilted angle through the algorithm. Except for cases where the slope of 2.5° required by the optical measuring device

is not exceeded, the average of the measured errors in the x-axis and the y-axis is calculated as 1.09°. If the panel is tilted only in the x-axis or y-axis direction, it can be seen that the error rate is relatively low.

Table 1. X & Y angular measurement and error

Actual angle (degree, °)		Calculated angle (degree, °)		Error (degree, °)	
x	y	x	y	x	y
8	0.8	8.5	2.51	−0.5	−1.71
13	0.9	13.3	3.38	−0.3	−2.48
10.5	1.6	12.36	3.44	−1.46	−1.84
0.7	10.5	2.88	9.97	−2.18	0.53
0.5	13.5	1.47	12.36	−0.97	1.14
13.5	9	14.89	7.59	−1.39	1.41
7	5	5.5	3.36	1.5	1.64
Error−value average(degree, °)		1.09			

After the tilts of the x and y axes of the panel relative to the z-axis direction are calculated, a process of measuring the degree of rotation of the x-y plane is performed. Table 2 shows the results of comparing the actual panel rotation angle with the measured value. If you look at the results of the table, you can see that the average error is 0.23°, which is very low. Note that when the rotation angle of the x and y axes plane is obtained, the correction result of the values tilted to the x-axis and y-axis becomes a variable. If the x-axis and y-axis rotation angles of the panel are not compensated suitably, the error value affects the formula for calculating the x-y plane rotation angle.

Table 2. XY− axis angular measurement and error

Actual angle (degree, °)	Calculation angle (degree, °)	Error (degree, °)
5	4.7	0.3
8	7.5	0.5
10	9.8	0.2
12	11.9	0.1
−7	−7.1	0.1
−11	−10.8	−0.2
Error−value average (degree, °)	0.23	

VI. Results

The length of the outline is calculated by using the coordinates of the corner points that can be obtained using image processing, and applied the height between the camera fixed to the center point of the OLED panel and the floor to the equation according to the algorithm. As a result, it is possible to measure the angle to correct the panel tilt even with a very small amount of information from photo. The maximum error value required for the use of optical instrumentation equipment for display gamma tuning is +/-2.5°. The average error of the measurement and calculation result in the case of more than 2.5° was not so significant. The advantage of this algorithm is that the panel angle can be calculated easily with fragmentary information that can be obtained from the photo taken from the camera. This does not require much processing of information, and it is also fast and easy to process by simply calculating the value in the equation. There is also a cost benefit because it does not require much information and high technology.

The information that can be obtained from only an image is very limited, resulting in a certain amount of errors which is within the acceptable range. If a stereo camera or TOF is used, accurate measurement with little error is possible. However, the use of such equipment is expensive, so the use of the single camera proposed in this paper has the advantage that there is no additional cost.

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