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A digital image-based measurement system for a LCD backlight module

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Abstract

A LCD light guide plate is an element of the LCD backlight module that is often used for the display of compact electronic devices. In this study, a vision system is proposed to detect the degree of uniformity of light reflection using a light guide plate before the diffuser has been attached. A new bright spot search and statistical software has been designed and the parameters for the LCD light guide plate can be adjusted before manufacture to provide greater economy and make the device user friendly. Since many different types of backlight modules had to be analyzed in this study, we used different methods to determine the nonuniform factors and the backlight module area for each type. A wrapping algorithm is presented in the searching and statistic process of bright spot. This algorithm can combine the procedures of segmentation process and nonlinear grey scale mapping. After revising carved depth of the poor brightness area, the diffuser was attached and the analysis performed again to verify the design procedure correction. When the source light density is adjusted, the lighting error for the on line inspection is retained to within 3%. © 2001 Published by Elsevier Science Ltd.

Keywords: LCD light guide plate; Vision system; Backlight module

1. Introduction

Liquid crystal displays (LCD) and backlight modules have become important in recent years with applications including monitors in notebook personal computers, screens for TV-games, screens for portable television sets, viewfinders for video-recorders, etc. Many automatic optical inspection (AOI) systems have been developed as measurement machines to deal with LCD product manufacturing processes [1–4].

The purpose of this study was to produce an online inspection method for LCD light guide plates that determined the best design parameters before manufacture and reduced the testing error to within 3%. A good light guide plate should have uniform light density and distribution. The essential design parameters are, accuracy of the light path, the intensity of the reflected light and the light density distribution. Our system is able to detect these factors and analyze each factor for correction. The optical portion of the vision system is a CCD camera that has a dynamic image-grabbing device to acquire the plane image of the entire light guide plate. The image is converted into a digital file by the image-grabber for software analysis [5]. The CCD Retiga 1300 with IEEE 1394 interface is fixed onto a rotational slide track for easy rotation to produce a suitable view angle of the tested object. There is no auto-gain control in CCD to avoid measurement errors and collect the raw data. In the rotational slide track there are ten mounting holes for each eighteen degree to inspect the LCD backlight module. The tested object is placed onto a high precision rotary stage with $\pm 10^\circ$ for angular adjustment, as shown in Fig. 1.

The software program has two processes; one for measuring LCD light guide plate with the diffuser attached and the other is for measuring plate without the diffuser. The image processing method adopts the intensity bias adjustment of the light field. We can judge the light distribution of the tested plate by analyzing the light distribution charts and pseudo color display on the monitor. Usually, the gray scale will be darker using the LCD as the plate lighting element. Conversely,

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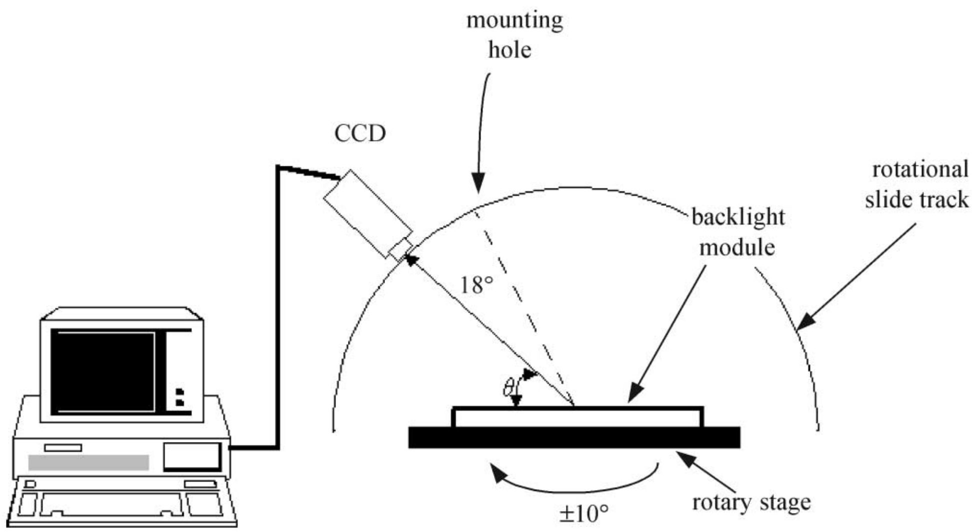

Fig. 1. The architecture of the digital image-based measurement system for LCD backlight module.

the (VFD) vacuum fluorescent display causes the plate to be too bright and saturates the plate light distribution. In order to measure the plate light distribution wide range and effectively, the setting control bias for the light intensity is in the image processing procedures. We divided the bias adjustment into four levels so that the total scale will be 4096 (4×1024) for brightness.

The light field measurement is an automatic inspection procedure and controlled by our software programs. The designed software program outputs the diagrams such as the plate light intensity, the R, G, B light distribution, the 3-D brightness mesh diagram and automatic inspection for the light distribution uniformity. The grey scale characteristic of the CCD camera has been calibrated by a photometer. That is, a gray level of each light spot on the plate $g(x, y)$ can be transferred to an intensity value $f(g(x, y))$ from a photometer. Function f is nonlinear. Hence, the intensity measurement of the guide plate is acquired by grabbing the image off the plate with the calculations performed automatically by a computer.

The gray scale is the weight of the R, G, B intensity. When the gray scale of the plate is known, the light intensity can be known. The algorithm we used scans all of the pixels in the image and records the coordinates and the gray scale of each pixel for plotting a 3-D intensity diagram. The R, G, B monochrome intensity distribution diagram is for analyzing the light distribution of the LCD light guide plate and judges whether the distribution is good enough.

As shown in Fig. 2(a), a LCD backlight module typically makes use of fluorescent lamp that possesses the characteristics needed to illuminate the LCD display [6]. The cold cathode fluorescent lamp is mounted along the single side or double sides of the backlight module, and a light guide plate is used to create uniform light across a diffuser screen. The lighting of the LCD backlight module depends on the optical design of the plate so that the light path can enter from either side of the module horizontally and reflects with a 90-degree rotation and goes out normal to the front surface. The tiny holes in the light guide plate were made by a laser-carving machine. The tiny holes contain prismatic specular surface which spreads the light uniformly across the front plane of the LCD backlight module. A laser-carving machine forms a reflective region, as shown in Fig. 2(b), and carves the optical design of the light guide plate to a special pattern (hole). The pattern could be a kind of optical element. The function of the pattern is like a special optical lens to reflect and refract the incident light to the designed angle and focus on the LCD panel or passes the light from one side to the other. When the incident light enters from both sides, the bright spots are the focus points of each optical element. The reflection effect of the intensity depends on the carved optical pattern and the depth of the carving has a strong influence on the reflection effect. Although the greater the carved depth, the better the reflection, but too deep carved depth will make the neighboring area excessively bright and the other area darker. So it is important to revise the carved depth of the poor brightness area and the excessively bright area.

The lighting of a LCD backlight must be very uniform. To achieve this uniformity, a light diffuser must be installed on top of the LCD light guide plate. When a diffuser is on the light guide plate, the bright spots disappear and the entire plate becomes soft bright. The carved pattern can be produced using numerous design methods but the minimum requirement is the correct reflection and refraction. The pattern array layout, which cannot be too tight or loose, must be designed correctly, otherwise bad focus or bad backlight

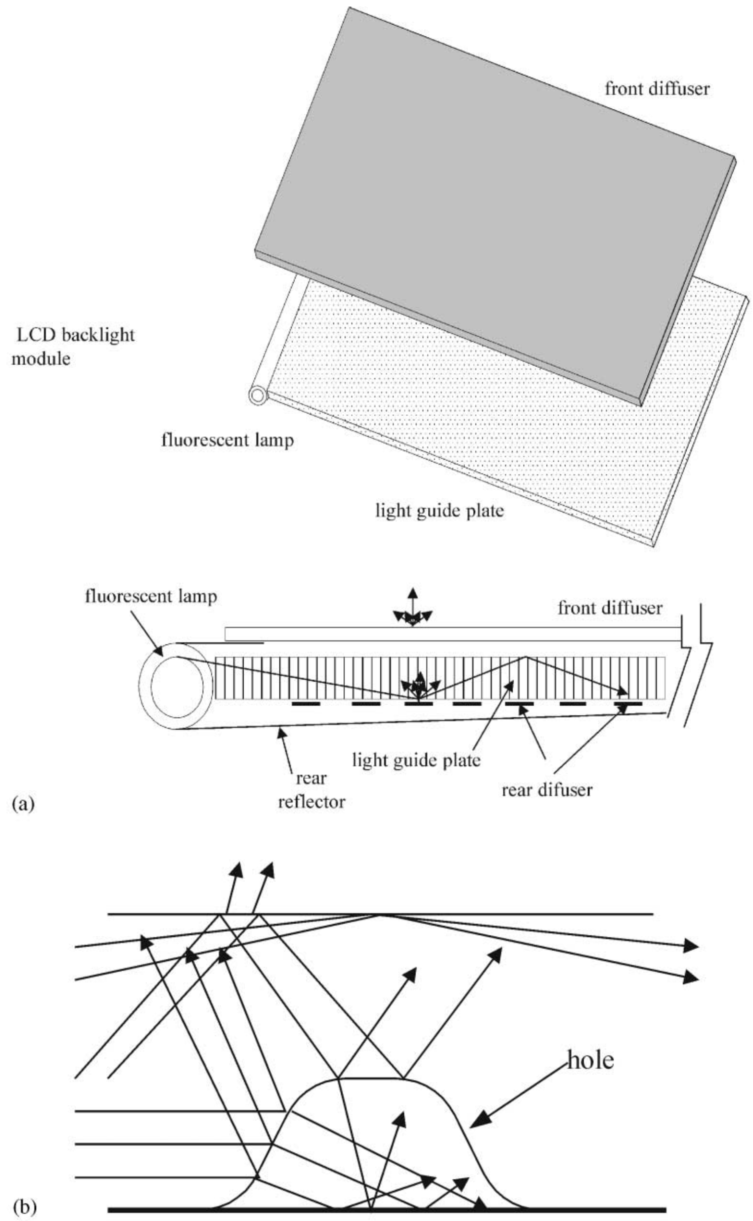

Fig. 2. (a) A LCD backlight module. (b) The ray path of a backlight plate.

transmission will produce a LCD module that is not bright enough.

2. The searching and statistic algorithm of bright spot

The simplest way to search for the bright spots in the light guide plate is to divide the image into many small blocks and process each block. This method is very time consuming [7,8]. Our proposed method uses a radial type mask for automatic bright spot detection and brightness value conversion. At the beginning, the entire image should be scanned to find a bright spot. The system then scans along the upper part to the edge of the spot. The distance from the lower boundary to the upper boundary of the spot is calculated. The center of the Y coordinate is the distance divided by 2. The same method is used to find the center of the X coordinate. The system scans the vertical line back and forth and finds the mid-distance of a bright spot between the left and right pixel edges. When the center of the bright spot is found, the area of the bright spot pixel is then determined. A circle wrapping method is proposed in this case where the scanning sequence follows a counter-clockwise rotation from one corner to the opposite corner until all of the bright spots have been marked. Here, the marked spots are flagged to avoid a repeated scan.

As shown in Fig. 3, the steps of calculation of the brightness of a bright spot are searching for the center, scanning

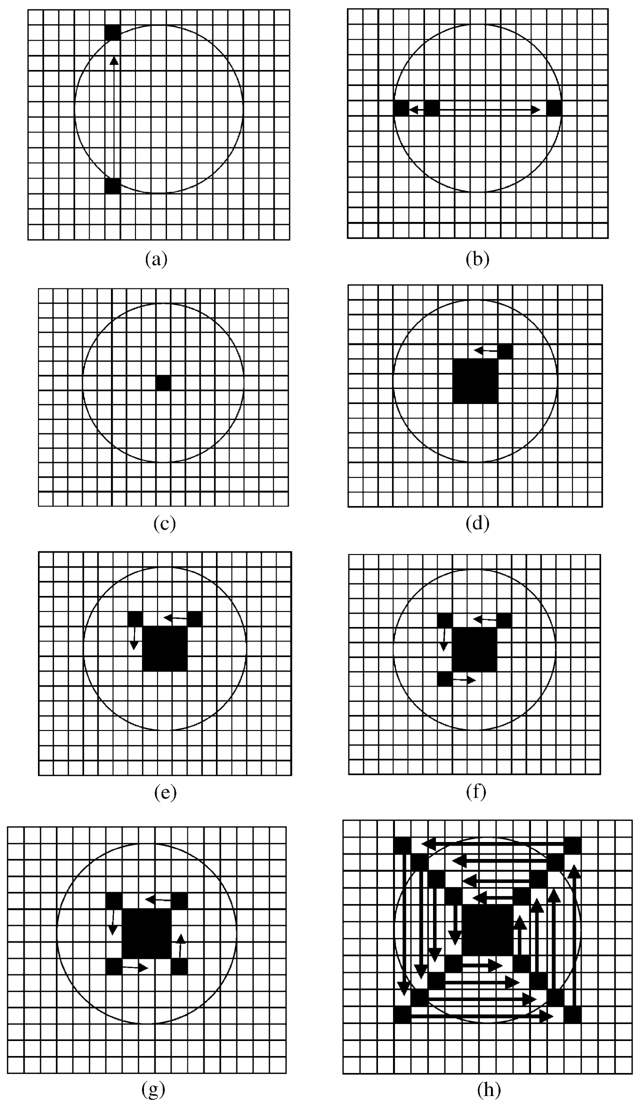

Fig. 3. Calculation of the brightness of a bright spot, (a) $y = y1\,\frac{y2-y1}{2}$, (b) $x = x1 + \frac{x2-x1}{2}$. (a)–(c) Searching for the center of a bright spot; (d)–(g) The scanning process; (h) The wrapping process.

process, and wrapping process. The total brightness of a spot can be expressed as

$$\sum_{i=1}^{n}\left\{\sum_{j=x-i+1}^{x+i} f_i(g(j,y+i)) + \sum_{j=y-i+1}^{y+i} f_i(g(x-i,j)) + \sum_{j=x-i}^{x+i-1} f_i(g(j,y-i)) + \sum_{j=y-i}^{y+i-1} f_i(g(x+i,j))\right\} + f_0(g(x,y)), \quad (1)$$

where f_i is the transformation function for different range of gray level to the intensity value.

From the above discussion, we found that when the center block is a square, the wrapping area should be a square. If the center block is a rectangle, then the wrapping area should be a rectangle. Why should the center area of a bright spot be rectangular? That is because the pattern is carved onto an elliptical shape. Here, the wrapping method for an elliptical spot is discussed. The wrapping algorithm for a vertical and a horizontal ellipse is shown in Figs. 4 and 5.

The vertical ellipse spot:

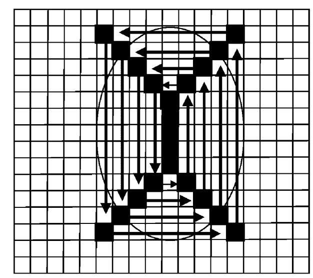

Fig. 4. The wrapping result of a vertical ellipse spot.

The total brightness of a spot can be expressed as

$$\sum_{i=1}^{n}\left\{\sum_{j=x-i+1}^{x+i} f_i(g(j,y+2+i)) + \sum_{j=y-i-1}^{y+2+i} f_i(g(x-i,j)) + \sum_{j=x-i}^{x+i-1} f_i(g(j,y-2-i)) + \sum_{j=y-2-i}^{y+i+1} f_i(g(x+i,j))\right\} + f_0(x,y) + f_0(x,y+1) + f_0(x,y+2) + f_0(x,y-1) + f_0(x,y-2). \quad (2)$$

The horizontal ellipse spot:

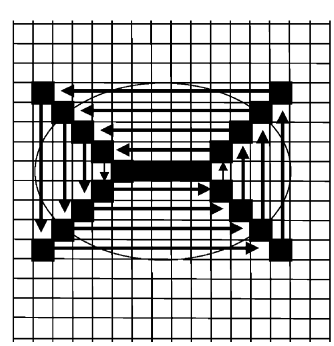

Fig. 5. The wrapping result of a horizontal ellipse spot.

The total brightness of a spot can be expressed as

$$\sum_{i=1}^{n}\left\{\sum_{j=x-1-i}^{x+2+i} f_i(g(j,y+i)) + \sum_{j=y-i+1}^{y+i} f_i(g(x-2-i,j)) + \sum_{j=x-2-i}^{x+i+1} f_i(g(j,y-i)) + \sum_{j=y-i}^{y+i-1} f_i(g(x+2+i,j))\right\} + f_0(x,y) + f_0(x+1,y) + f_0(x+2,y) + f_0(x-1,y) + f_0(x-2,y). \quad (3)$$

From the above algorithm, we can combine the procedures of segmentation process and nonlinear grey scale mapping. These equations calculate the distance ratio of the long and short axis to obtain the center coordinate of the bright spot and determine if the shape is square or rectangular. Based on the shape of the spot, the software scans and detects the size of the bright spots automatically and wraps each bright spot entirely.

Here, the automatic inspection spot configuration can ensure that the center of the spot area is set on the center of the LCD backlight module for advanced measurement calculation. In the following discussion, a one-dimensional array is used to represent the inspection spot distribution. When the number of inspection is odd, a symmetrical spot can be found. That symmetrical spot will be the mapping center for the backlight module. When the selected spot array elements are even, we add some extra (dummy) spots into the spot array, as shown in Fig. 6, where n1–n7 are the footnotes for the spots. That is, when the dummy spots have been added into the bright spot array, regardless of the number of bright spots is odd or even, the symmetrical spot can be found.

$2P-1$: the sum of the bright spots
P: the number of bright spots
Y center: The center of the Y axis of the backlight module
$Y1$: the point in the bright spot
$Y2$: the distance weight for two spots
$Y/2(p-1)$: the distance between two spots
$P-1$: the number of dummy spots

When the brightness (gravel level) of a bright spot has been grabbed, three criteria are necessary for a standard deviation, the largest difference, and variance used for the brightness judgement.

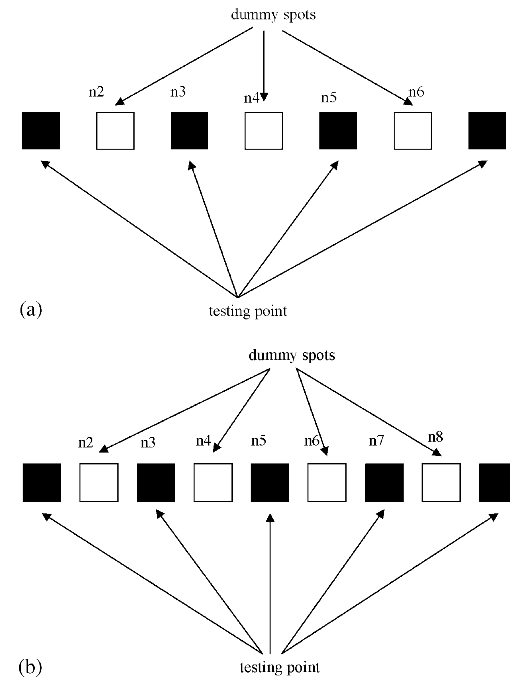

Fig. 6. (a) Adding extra spots under an even spot condition. (b) Adding extra spots under an odd spot condition.

3. The experimental results and discussion

Using our circle wrapping method, the X, Y coordinates, the size of the spot, and the gray scale are calculated and shown on the table by each bright spot. This analysis is able to detect defects in the bright spot profile and the factors that produce poor backlight.

The revising tablet can be established according to the relationship of the relative brightness variation in the different positions and carved depth as shown in Table 1.

After revising carved depth of the poor brightness area, the diffuser was attached and the analysis performed again to verify the design procedure correction. When the source light density is adjusted, the lighting error for the on line inspection is limited to within 3%. Following are the procedures of the brightness and distribution analysis experiments LCD backlight module (light guide plate with the diffuser), as shown in Fig. 7.

1. The basic brightness and distribution analysis of the LCD backlight module.

The purpose of this measurement is for checking if the gray scale of the tested spot meets the requirement or not. The screen shows that the gray scale data are on the right side table and the left two columns are the X–Y coordinates of the spot. The red dot is the marker that points to the test spot. The data in the table on the screen can be revised to adjust the distance between the horizontal or vertical spots and to choose the test points for any other place.

2. The entire plate brightness test.

Table 1
Revising tablet for a symmetric light guide pattern (light sources are on both sides of the light guide plate)

Relative brightness variation (%)	Carved depth of 10% column to 0% column (%)	Carved depth of 10% column to 20% column (%)	Carved depth of 20% column to 30% column (%)	Carved depth of 30% column to 40% column (%)	Carved depth of 40% column to 50% column (%)
1	−0.41	−0.26	−0.21	−0.2	−0.2
2	−0.95	−0.95	−0.87	−0.82	−0.82
3	−1.56	−1.53	−1.5	−1.46	−1.41
−1	+0.42	+0.24	+0.24	+0.19	+0.16
−2	+0.81	+0.81	+0.76	+0.67	+0.66
−3	+1.23	+1.17	+1.13	+1.11	+1.02
5	−2.63	−2.58	−2.52	−2.28	−2.26
8	−3.35	−3.21	−3.15	−3.14	−3.04
12	−5.65	−5.53	−5.46	−5.34	−5.27
−5	+2.63	+2.51	+2.44	+2.29	+2.06
−8	+4.61	+4.59	+4.56	+4.33	+4.23
−12	+5.83	+5.78	+5.76	+5.75	+5.62

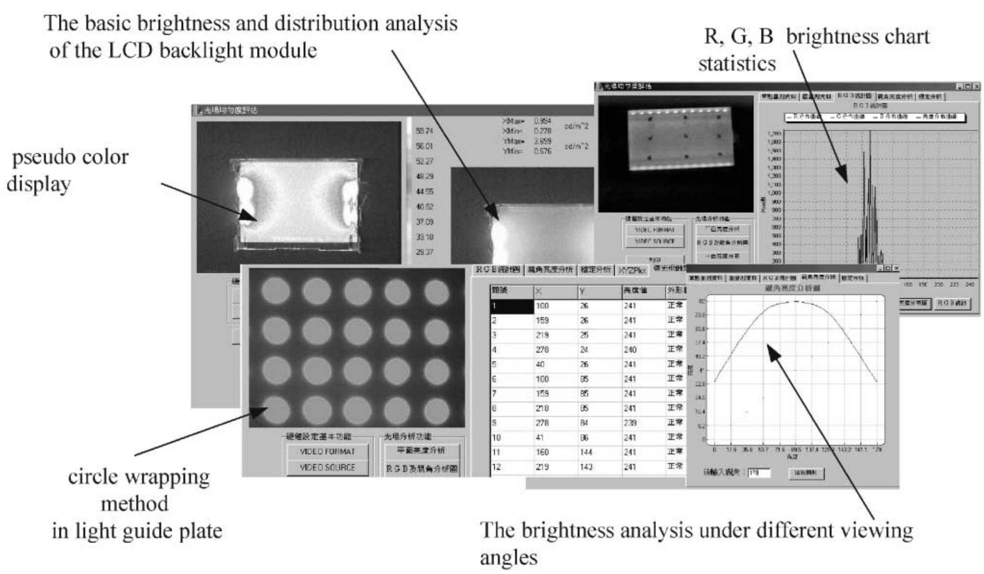

Fig. 7. The testing results of the backlight module and light guide plate.

The measurements include the maximum, minimum, minimum divided by maximum, deviation, and the degree of brightness uniformity. When the maximum test value is close to the minimum value, the greater the degree of uniformity in the backlight distribution and the smaller the deviation the better the backlight module brightness.

3. The R, G, B brightness chart statistics.

This brightness test is for the analysis of the LCD backlight which can also be displayed by pseudo color to measure the plate light distribution. When the light distribution is not uniform, the light distribution could be more than one cluster and the distribution peak will be greater than one.

4. The brightness analysis under different viewing angles.

This test is the measurement for different viewing angles to check whether the brightness of the backlight still meets the design specifications at different viewing angles.

5. The stability analysis.

This test is for the backlight stability analysis. When a backlight is used for a long periods time, does the backlight still have the same brightness?

6. The backlight plane brightness test.

In this test the user marks the X- and Y-axis to cross the estimated center of the plate, then the software calculates the brightness of each pixel on the selected X- and Y-axis and plots the brightness value on the side of the chart.

This process will determine the center of the plate and mark the X- and Y-axis. The backlight plate will not be uniform for all X- and Y-axis. Hence, we could choose a symmetrical or uniform area to determine the center and let the longest horizontal line be the X-axis and find the middle point as the center coordinate of the X-axis. The same method is used to find the center coordinate of the Y-axis.

In our test, the center of the backlight plate had better mapping to the tested center of the bright spots. When the number of bright spots is odd, a symmetrical spot can be found and that spot will be the mapping center for the backlight module. When the elements of the selected spot array are even, the symmetrical spot is not used. The solution is to add some extra spots into the spot array to make the symmetrical spot easy to find. After the two centers are mapped together, the operator can set the distance between the bright spots and the bright spots will appear close or far apart. The operator could also set the test area for the bright spots.

Here is the summary of our experiments.

1. Using the added spots to determine the center of the backlight plate prevents testing errors, caused by the non-uniform brightness of the edge portion of the plate. When the source light density is adjusted, the lighting error for the on line inspection is retained to within 3%.

2. The benefits of the matrix type bright spot layout are knowing the position of each spot and being able to revise a lot of spots at the same time.

3. Most of the fixed position light sources are on both sides of the backlight module. Hence, the LCD module edge brightness is always higher than the center area.

4. The wrapping algorithm with gray level conversion method is an easy ways to analyze the brightness of the entire backlight module.

4. Conclusion

This study completed the testing of a LCD backlight module using machine vision image processing techniques. The optical system consists of an optical lens and CCD camera that catches the LCD module test image. A frame grabber converts the test image into brightness value with our proposed analysis software. A wrapping algorithm is presented in the searching and statistic process of bright spot. The reflection effect of the intensity depends on the carved optical pattern and the depth of the carving has an essential influence on the reflection effect. After revising the carved depth of poor brightness area, the diffuser can be attached and the analysis performed again to verify the design procedure correction. This is an automatic inspection system for LCD backlight modules that is faster and more efficient.

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