附件：封面格式

行政院國家科學委員會補助專題研究計畫成果報告

用電腦視覺檢測與分類PLED面板瑕疵

計畫類別：■個別型計畫　　□整合型計畫
計畫編號：NSC 91-2212-E-002 -087-
執行期間：91年 8月 1日至 92年 7月 31日

計畫主持人 傅楸善(台灣大學資訊工程系)
共同主持人：
計畫參與人員：江嘉明

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行政院國家科學委員會專題研究計畫成果報告

用電腦視覺檢測與分類 PLED 面板瑕疵

PLED Panel Defect Inspection and Classification with Computer Vision

計畫編號：NSC 91-2212-E-002 -087-
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一、中文摘要

本計畫為期一年、目的是研究利用電腦視覺與數位影像處理方法，進行自動化聚合物發光二極體 (PLED: Polymer Light Emitting Diode) 或液晶顯示器 (LCD: Liquid Crystal Display) 面板瑕疵檢測及分類之研究。在計畫執行期間，我們將探討最佳的攝影機與光源設定，研究雜訊去除之數位影像處理步驟，並找尋 PLED 面板瑕疵之最佳檢測方法; 也希望藉由瑕疵分類, 用圖形識別及統計程序控制 (SPC: Statistical Process Control)分析, 找出瑕疵類別與產生瑕疵的原因的關聯性, 而得以改善製程及良率。

關鍵詞：PLED、瑕疵檢測、分類、電腦視覺、數位影像處理

Abstract

This is a one-year project to use computer vision and digital image processing methods to automatically inspect and classify PLED or LCD panel defects. We will study the best camera and light source set-up and noise-removal algorithms to inspects PLED panel defects. Through defect classification and clustering, we use pattern recognition and statistical process control methods to analyse and find the relationship between defect classes and causes in order to improve manufacturing process and yield rate.

Keywords: PLED, Defect Inspection, Classification, Computer Vision, Digital Image Processing

二、緣由與目的

目前各式各樣資訊家電 (IA: Information Appliance) 包括背投影電視, 投影機…等, 都使用了 PLED 或 LCD 面板元件, 類似元件包括液晶在矽上 (LCoS: Liquid Crystal on Silicon), 平面日光燈, 冷光顯示器 (EL: Electro-Luminescent)…等也都可以用相同的機台檢測瑕疵與控制品質。因此對這些元件作瑕疵檢測是格外重要, 因為進貨 PLED 或 LCD 面板的品質控制, 可以確保最後產品的品質更穩定, 且可以降低重工 (Rework) 浪費工時的機會, 使得產品的品質獲得提升。我們所能檢測的瑕疵包括功能和美觀瑕疵, 例如: 亮點 (Stick-on), 暗點 (Stick-off), 刮痕, 灰塵或汙點, 整條線不亮 (Line-out, 系統會自動判斷為列不亮 Row-out 或行不亮 Column-out), 泡泡汙損 (Bubble blemish), 像素無法和鄰點獨立運作, 反光一致性, 對比一致性, 色彩一致性, 反射率, 色度, …等。我們也將用頻譜儀做光學特性的分析。PLED 或 LCD 面板瑕疵偵測分為彩色濾光片的不點燈測試和模組點燈測試。在不點燈瑕疵偵測設備方面, 國內工研院機械所曾與本人及學生吳木杏合作開發 [1], 現已完成機台並技術移轉給東捷半導體, 實際應用於奇美電子的 LCD 廠內。模組點燈測試方面, 國外有兩大廠: Integral Vision 的 SharpEye (http://www.iv-usa.com/products/microdisplay/micro1.htm) 與 Westar Display Technologies 的 MDIS (Micro-Display Inspection System, http://www.westar.com/dis/mdis/mdis.html). 國內有宜昇科技從事 LCD 小面板的瑕疵

檢測, 主要應用於手機等小螢幕少色的瑕疵檢測, 和我們的應用於高解析度全彩的 LCD 面板有很大的不同。國內華東半導體有發展類似的設備, 但技術尚未完全成熟, 也尚未在市場上大量銷售。本計畫的目的，便是研究利用電腦視覺與數位影像處理方法，進行自動化 PLED 或 LCD 面板瑕疵偵測之研究。在計畫執行期間，我們將探討最佳的攝影機與光源設定，研究雜訊去除之影像處理步驟，並找尋 PLED 或 LCD 面板瑕疵之可行檢測方法。

找出瑕疵後, 我們將加以分類, 可以用監督式學習 (Supervised Learning) 或非監督式學習 (Unsupervised Learning) [13, 16, 21] 加以分類, 分類時可以嘗試各種方法, 例如: 降低最大亂度法 (Minimax Entropy) [2], 形狀特徵 (Shape Features) 及樹狀分類法 (Tree Classification) [3], 類神經網路 (Neural Network) 作圖形識別 (Pattern Recognition) [4], 外表的統計模型 (Statistical Models of Appearance) [5], 主動式形狀模型 (Active Shape Model) [6], 統計形狀分析 (Statistical Shape Analysis) [7], 馬可夫隨機場 (Markov Random Field) [8], 質料模型 (Texture Modeling) [9, 18], 背景模型 (Background Modelling) [10], 軟性競爭性適應 (Soft Competitive Adaptation) [11], 隨機複雜度及模型 (Stochastic Complexity and Modeling) [12], 最大可能性法 (Maximum Likelihood) [14], 貝氏模型 (Bayesian Model) [15], 高斯模型 (Gaussian Model) [17], 統計推論 (Statistical Inference) [19], 主要元件分析 (Principal Component Analysis) [20]...等。希望藉由瑕疵分類, 用圖形識別及統計程序控制分析, 找出瑕疵類別與產生瑕疵的原因的關聯性, 而得以改善製程及良率。

三、結果與討論

系統規劃與架構:

架構 CCD 攝影機與光源，並選用適當鏡頭: 我們在此計畫中將使用高解析度 CCD 攝影機與水晶鹵素燈光纖照明。此乃是因為水晶鹵素燈的光緣量度與品質也較佳。因為一般而言, 一個 PLED 面板像素必須至少對應到 9 個或 6 個攝影機像素。

架設高品質的電子控制變焦鏡頭及可控制光圈，要達到高重覆度而且避免影像扭曲, 變焦鏡頭允許我們檢測不同的面板像素大小而不必更換相機或光學系統; 可控制光圈允許亮度及對比的量測。

架設 XYZ 三軸精密位移與旋轉平台。

調整鏡頭焦距，並校正 CCD 攝影機位置與角度。

連接 CCD，影像擷取卡與個人電腦:由於影像擷取卡可同時連接多個 CCD 攝影機，我們將在實驗室中使用一台個人電腦，一張影像擷取卡與一個 CCD 攝影機，進行系統測試。

架設測試圖形產生器與連接介面, 以產生所有測試圖形, 例如: 全部亮以偵測暗點, 全部暗以偵測亮點…等。

安排影像擷取時程與處理步驟: 由於一張影像無法涵蓋整個 LCD 面板範圍, 必須移動或旋轉以精密定位，我們必須安排 CCD 攝影機的影像擷取時程, 每台 CCD 攝影機影像擷取速率為每秒 30 張。

影像處理軟體研發:

我們將利用 VC++與 Visual Basic 來發展此部份程式。

針對每一張影像，進行獨立雜點去除、低通濾波與高通濾波等工作。並將處理過後的影像進行影像比對亦即影像相減, 因為 PLED 面板應該是重覆的矩陣, 因此應該完全一樣, 如果有不一樣, 則其中一個必定有瑕疵。

求出每一像素的頻譜特性, 若有不同頻譜特性也是有瑕疵。

我們的系統可以有手動控制介面也可以有自動檢測狀態。

找出瑕疵類別與產生瑕疵的原因的關聯性, 而得以改善製程及良率。

功能分析與改進:

當軟體發展完成後，我們將與硬體架構結合，在實驗室內進行初步測試。針對測試結果，進行軟體程式修正。

由於 CCD 攝影機所擷取之影像，均為

較實物放大許多倍，些微移動 CCD 攝影機便會造成影像的巨幅改變。因此，在每次校正後必須將必要的參數輸入程式中，以期得到一致結果。

四、成果自評

1. PLED 面板瑕疵影像檢測系統之設計流程與參數設定。
2. PLED 面板瑕疵自動 CCD 影像擷取、分析與處理程式。
3. PLED 面板瑕疵判斷與分類程式, 找出瑕疵類別與產生瑕疵的原因的關聯性, 而得以改善製程及良率。
4. 詳細報告請見附件論文發表於 CVGIP 2003 [22].

五、參考文獻

[1] [1] 吳木杏, "彩色濾光片表面瑕疵檢測分析", 台大資訊工程系碩士論文, 2000.

[2] C. Liu, S. C. Zhu, and H. Y. Shum, "Learning Inhomogeneous Gibbs Model of Faces by Minimax Entropy," *Proceedings of International Conference on Computer Vision,* Vancouver, Canada, pp. 281-287, 2001.

[3] Y. Amit, D. Geman, and K. Wilder, "Joint Induction of Shape Features and Tree Classification," *IEEE Transactions on Pattern Analysis and Machine Intelligence,"* Vol. 19, No. 11, pp. 1300-1305, 1997.

[4] C. Bishop, *Neural Networks for Pattern Recognition,* Oxford University Press, Oxford, 1995.

[5] T. Cootes and C. Taylor, "Statistical Models of Appearance for Computer Vision," Technical Report, University of Manchester, 2000.

[6] T. Cootes, C. Taylor, D. Cooper, and J. Graham, "Active Shape Models---Their Training and Application," *Computer Vision and Image Understanding,* Vol. 61, No. 1, pp. 38-59, 1995.

[7] I. Dryden and K. Mardia, *Statistical Shape Analysis,* Wiley, New York, 1998.

[8] S. C. Zhu, "Embedding Gestalt Laws in Markov Random Fields," *IEEE Transactions on Pattern Analysis and Machine Intelligence,* Vol. 21, No. 11, pp. 1170-1187, 1999.

[9] S. Zhu, Y. Wu, and D. Mumford, "Minimax Entropy Principle and Its Application to Texture Modeling," *Neural Computing,* Vol. 9, No. 8, 1997.

[10] B. Stenger, V. Ramesh, N. Paragios, F. Coetzee, and J. Buhmann, "Topology Free Hidden Markov Models: Application to Background Modeling," *Proceedings of International Conference on Computer Vision,* Vancouver, Canada, pp. 294-301, 2001.

[11] S. J. Nowlan, "Soft Competitive Adaptation: Neural Network Learning Algorithm Based on Fitting Statistical Mixtures," Ph. D. Thesis, School of Computer Science, Carnegie Mellon University, Pittsburgh, 1991.

[12] J. Rissanen, "Stochastic Complexity and Modeling," *The Annals of Statistics,* Vol. 14, pp. 1080-1100, 1986.

[13] C. E. Guo, S. C. Zhu, and Y. N. Wu, "Visual Learning by Integrating Descriptive and Generative Methods," *Proceedings of International Conference on Computer Vision,* Vancouver, Canada, pp. 370-377, 2001.

[14] A. P. Dempster, N. M. Laird, and D. B. Rubin, "Maximum Likelihood from Incomplete Data via the EM Algorithm," *Journal of the Royal Statistical Society Series B,* Vol. 39, pp. 1-38, 1977.

[15] P. J. Green, "Reversible Jump Markov Chain Monte Carlo Computation and Bayesian Model Determination," *Biometrika,* Vol. 82, pp. 711-732, 1995.

[16] B. A. Olshausen and D. J. Field, "Emergence of Simple-Cell Receptive Field Properties by Learning a Sparse Code for Natural Images," *Nature,* Vol. 381, pp. 607-609, 1996.

[17] S. Roweis and Z. Ghahramani, "A Unifying Review of Linear Gaussian

Models," *Neural Computation,* Vol. 11, No. 2, 1999.

[18] J. Portilla and E. P. Simoncelli, "A Parametric Texture Model Based on Joint Statistics of Complex Wavelet Coefficients," *International Journal of Computer Vision,* Vol. 40, No. 1, 2000.

[19] M. Tanner, *Tools for Statistical Inference,* Springer, Berlin, 1996.

[20] F. De la Torre and M. Black, "Robust Principal Component Analysis for Computer Vision," *Proceedings of International Conference on Computer Vision,* Vancouver, Canada, pp. 362-369, 2001.

[21] R. Rao, "An Optimal Estimation Approach to Visual Perception and Learning," *Visual Research,* Vol. 39, No. 11, pp. 1963-1989, 1999.

[22] C. M. Chiang and C. S. Fuh, "Polymer Light-Emitting Diode Defect Inspection System," *Proceedings of IPPR Conference on Computer Vision, Graphics, and Image Processing,* Kingmen, Taiwan, 200[illegible]

Polymer Light-Emitting Diode Defect Inspection System

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Abstract

This paper has two parts: 1. low-resolution defect inspection, 2. high-resolution defect inspection. In low-resolution defect inspection, we use CCD (Charge-Coupled Device) camera to inspection defective blocks of PLED (Polymer Light-Emitting Diode) panels and replace photometer to measure luminance. In high resolution, we use CCD camera and high-resolution lens to grab image and detect defects based on computer vision and image processing. The experimental result shows that our inspection system achieves high accuracy and high speed for industry and meets our requirement.

1. Introduction

PLEDs work similarly as LEDs, which are semiconductor devices that emit visible light when electric current flows through them, except they have different materials. PLEDs use organic materials to produce and emit the light, but LEDs use semiconductor materials.

Our PLED defect inspection system has two parts. One is low-resolution defect inspection system, and the other is high-resolution defect inspection.

In low-resolution defect inspection, we use the Minolta CS-100 photometer to calibrate our CCD camera in order to measure the luminance that PLEDs emit.

In high-resolution defect inspection, we have to detect defects as precise as 10 micrometers. In the inspection process, we first select a golden image and set up parameters which depend on our requirement, and then we find and segment blocks to detect defects.

This paper is organized as follows. Section 1 gives introduction to how PLEDs work and PLED defect inspection system structure. Section 2 describes some theoretical background that we need to know for our inspection systems. Sections 3 and 4 explain the inspection methods and processes of our low-resolution and high-resolution inspection systems, respectively. Section 5 concludes our methods of PLED inspection systems.

2. Background and Algorithm

Our PLED defect inspection system is based on computer vision and digital image processing and this section describes the background and some algorithms.

2.1. Automatic Binarization

Because we need to segment bright blocks from PLED panels automatically, we use the minimizing within-group variance method [2] to segment images. The method introduced here is based on the minimizing within-group variance method. We can use variance to measure group homogeneity. A group with high homogeneity will have low variance. A group with low homogeneity will have high variance. Therefore, we choose a threshold that minimizes the weighted sum of group variance.

2.2. Pattern Matching

In order to detect defects of interest and register images, we have to find subimages of interest. Therefore, we use the correlation approach [1] to match patterns.

2.3. Image Comparsion

Image Comparison is a simple method to detect defects easily and quickly. First, we need a golden image (image without defect) to serve as a reference. We can compare the inspected image with the golden image pixel by pixel to gain a residual image. Setting a proper threshold to binarize the residual image, we can detect defects from the residual image.

2.4. Projection

Projection [2] is an easy edge detection method when the objects of interest are aligned along one image edge. Projection can be horizontal, vertical, or at any direction. In our PLED defect inspection system, we use horizontal projection and vertical projection to segment each block in an inspected image.

2.5. Gamma Correction

Because we use CCD camera to replace photometer to measure luminance that PLEDs emit, we have to consider whether our CCD camera need to do gamma correction. The gray value of every pixel in an image is generally not proportional to the light that CCD sensor absorbs. Generally speaking, when output signal generated by a physical device has power-law response to input signal, the value of the exponent in the power-law equation is referred to as gamma. Gamma correction is the process to correct the power-law response phenomena [1][4].

The power-law equation has the basic form

$$s = cr^{\gamma}$$

where c and γ are positive constants, s is output signal, and c is input signal. For example, CRT (Cathode Ray Tube) devices have an intensity-to-voltage response that a power-law equation has γ varying from 1.8 to 2.5. We do some experiments to decide whether our CCD camera has gamma correction problem.

3. Low-Resolution Defect Inspection

The inspection framework of our low-resolution defect inspection system is shown in Figure 1. Our system consists of CCD camera, lens, frame grabber, photometer, fixture, and personal computer. In our system, we use monochrome CCD camera to capture PLED images that we want to inspect and analyze and use frame grabber to grab images from CCD camera and store in our computer.

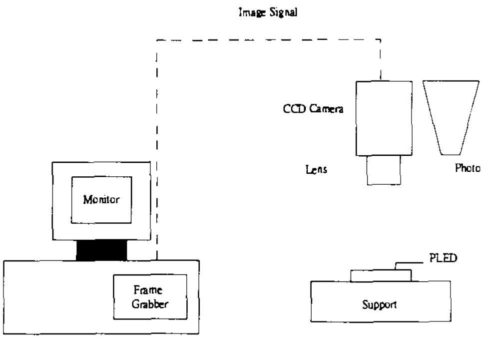

Figure 1 The framework of low-resolution defect inspection system.

In order to calibrate our CCD camera so that we can use the CCD camera to measure luminance, we use the photometer to do some experiments and calibrate the CCD camera. The fixture can supply PLED with power which PLED needs to illuminate. It also generates five signal patterns so that PLED can generate five patterns.

Because PLEDs are self-illuminant, we do not need any light source. On the contrary, in our inspection process we isolate ambient light from our inspection system so that we can measure luminance exactly.

In this inspection system we fix the CCD camera and the fixture. When the fixture generates five signal patterns respectively, the CCD camera captures pattern images one by one.

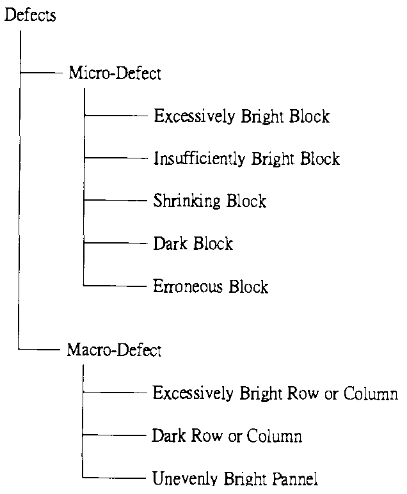

Figure 2 Classification of low-resolution defects.

3.1. Classification of Defects

In the low-resolution defect inspection system, we classify defects into macro-defects and micro-defects. Detailed defects are illustrated in Figure 2. Shrinking block means bright blocks shrink and erroneous block means bright block which should not emit light in some patterns, but they emit light. Defect of unevenly bright panel which means whole blocks emit light unevenly.

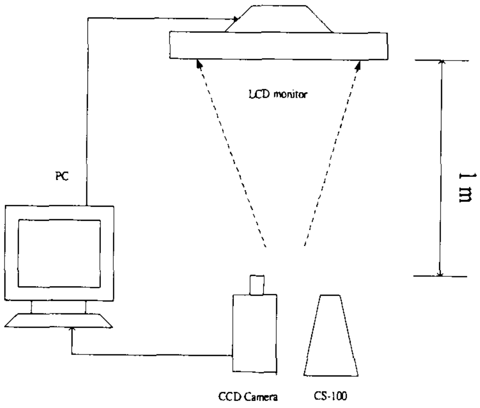

Figure 3 Calibration structure.

3.2. CCD camera calibration

In order to use CCD camera to replace photometer so that we can measure luminance, we do some experiments to calibrate our CCD camera and see whether we have to do gamma correction in this CCD camera or not. First, we have to check the relation between gray level that frame grabber captures and luminance that CCD sensor absorbs. Our experiment set-up is shown in Figure 3. We use LCD (Liquid Crystal Display) monitor, CCD camera, and Minolta CS-100 photometer. The experiment we do is in a dark room. Except the light that the LCD monitor emits, no light is in a dark room. The LCD monitor emits white, red, green, and blue light respectively. Each channel of light that the LCD monitor emits also has different intensities. To begin with, the intensity of light is the lowest. We gradually increase the intensity of light. In each light intensity, we compute the average gray level of the image that CCD camera captures and use the photometer to measure luminance that LCD monitor emits.

The relation between gray level and luminance is illustrated in Figure 4. We can find that gray level is proportional to luminance. Hence, this shows that our camera does not need gamma correction.

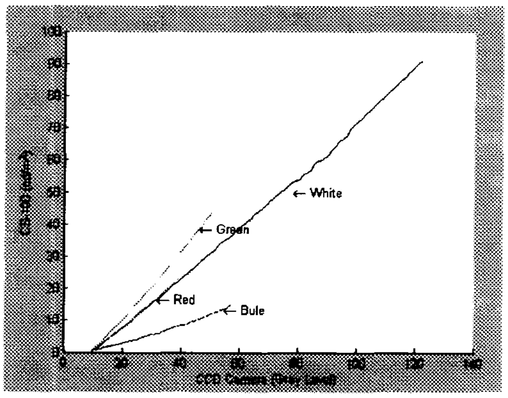

Figure 4 The relation between gray level and luminance.

How do we use CCD camera to replace photometer? We replace LCD monitor with PLED panel and tune voltage of PLED panel so that PLED panel emits various luminance. We use CS-100 to measure luminance and also compute average gray level that CCD camera captures. The result is shown in Figure 5. We build a table storing the relationship of luminance and gray level. When we inspect PLED panels, we compute the average gray level of image captured by CCD camera, and then use the average gray level to check the table to find the corresponding luminance. If the average gray level does not exactly conform to the gray level stored in the table, we use interpolation to find the corresponding luminance.

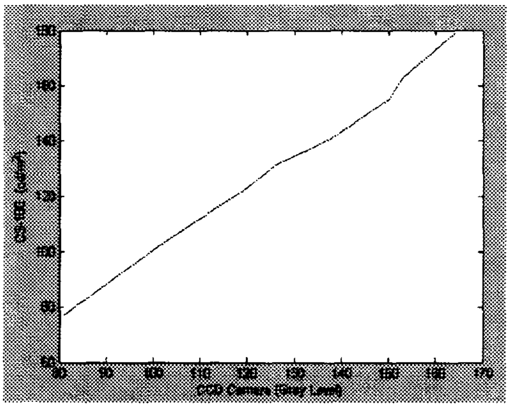

Figure 5 The relation between gray level and luminance that PLED panel generates.

3.2. Low-Resolution Defect Analysis

In the low-resolution defect inspection system, we have to inspect abnormal bright blocks. The judgment criterion of defect is shown as follows:

1. If the luminance of bright block is more than luminance upper bound we set up previously then we determine it as excessively bright block.
2. If the luminance of bright block is less than luminance lower bound we set up previously then we classify the defect into three classes:
    i. If the area percentage whose luminance is less than luminance lower bound is less than the area percentage of insufficient bright block then we determine it as insufficiently bright block.
    ii. If the area percentage whose luminance is less than luminance lower bound is less than the area percentage of shrinking block then determine it as shrinking bright block.
    iii. If the area percentage whose luminance is less than luminance lower bound is more than the area percentage of shrinking block then we determine it as dark block.

The process of defect detection is shown as follows:

Step 1: Use automatic binarization to segment an image and get the size of PLED panel.

Step 2: If the panel size is larger than the tolerance of standard panel size, we mark the panel as size defect.

Step 3: Divide the panel image whose size is 590 (w) × 189 (h) pixels into 61 (w) × 14 (h) blocks. Each block is about 9 (w) × 13 (h) pixels.

Step 4: Evaluate the centroids of blocks, and store centroids of blocks into an array.

Step 5: Expand 4 pixels from the centroid of block to left and to right respectively. Expand up and down 5 pixels from the centroid of block respectively. Each block is 9 (w) × 11 (h) pixels.

Step 6: Calculate average gray level of each block, and use the table we build from CCD camera calibration process to transform average gray level to luminance.

Step 7: Use the judgment criterion of defect we define previously to detect defects.

The defective signs are shown in Figure 6. We mark excessively bright blocks as orange, dark blocks green, shrinking blocks blue, insufficiently bright blocks red, and erroneous blocks yellow.

Figure 6 The defective signs.

Figure 7 shows that excessively bright column and dark block are inspected. Figure 8 shows that excessively bright blocks are inspected. Figure 9 shows that erroneous blocks, excessively bright blocks, and dark blocks are inspected. Figure 10 shows that the PLED panel is excessively bright. Figure 11 show that insufficiently bright blocks and shrinking blocks are inspected.

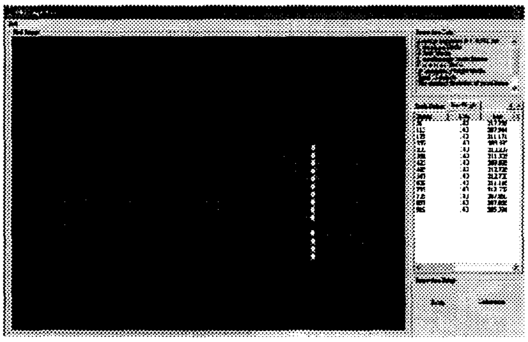

Figure 7 Inspection result.

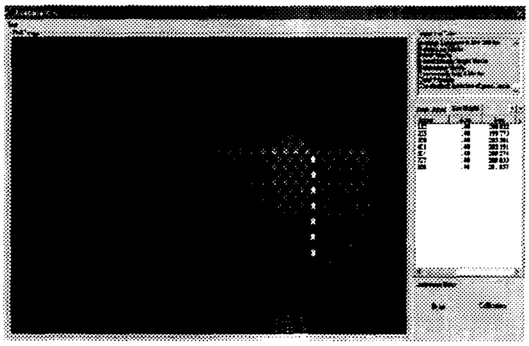

Figure 8 Inspection result.

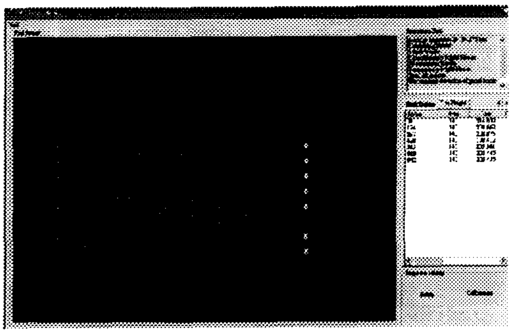

Figure 9 Inspection result.

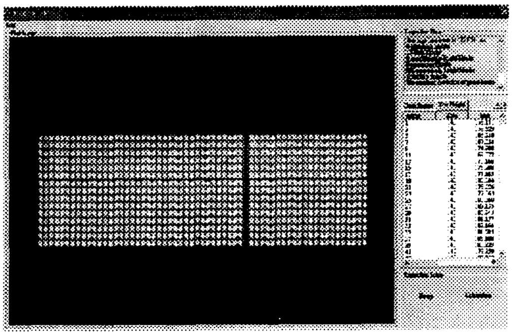

Figure 10 Inspection result.

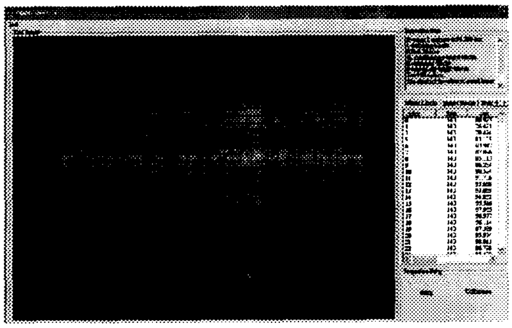

Figure 11 Inspection result.

4. High-Resolution Defect Inspection

The inspection framework of our high-resolution defect inspection system is shown in Figure 12.

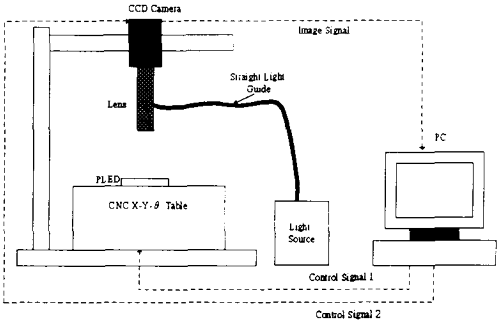

Figure 12 The framework of high-resolution defect inspection system.

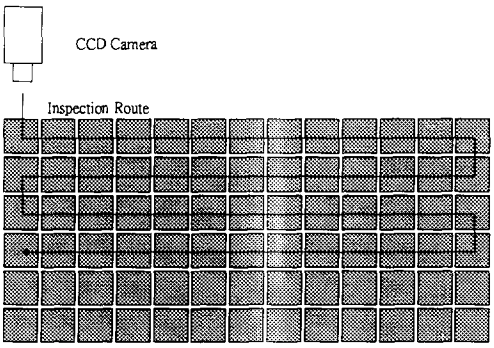

Figure 13 The PLED block inspection sequence.

In the system, we fix the CCD camera and send to the CNC X-Y-θ table control signals which trigger the CNC X-Y-θ table to move so that we can capture each block in PLED panels. Figure 13 shows the PLED block inspection sequence.

Because we use the telecentric, coaxial, and high-resolution lens and the PLED is not self-illuminant, we need a light source. We use coaxial light to illuminate PLED panels.

4.1. Image Segmentation

In the high-resolution inspection system, inspected images may have different sizes. Besides, it is hard to use a single threshold to binarize images to get defects. We have to divide a block into several sub-blocks. For each sub-block, we select a threshold to binarize to detect defects. In this section, we propose a method to segment images automatically.

We define two means,

$$M_1 = \frac{\sum_x \left\{ \frac{dP(x)}{dx} \mid \frac{dP(x)}{dx} >= 0 \right\}}{\# \left\{ \frac{dP(x)}{dx} \mid \frac{dP(x)}{dx} >= 0 \right\}}$$

and

$$M_2 = \frac{\sum_x \left\{ \frac{dP(x)}{dx} \mid \frac{dP(x)}{dx} < 0 \right\}}{\# \left\{ \frac{dP(x)}{dx} \mid \frac{dP(x)}{dx} < 0 \right\}}.$$

We also define two standard deviations,

σ_1 = a standard deviation for all $\frac{dP(x)}{dx} >= 0$

and

σ_2 = a standard deviation for all $\frac{dP(x)}{dx} < 0$.

The edge-finding algorithm is explained as follows:

Step 1: Take vertical and horizontal projections of an image to get projection values.

Step 2: Operate low-pass filter on vertical and horizontal projections.

Step 3: Perform the first-order derivative on vertical and horizontal projections.

Step 4: Evaluate M_1, M_2, σ_1, and σ_2. Use these values to find the ranges whose projection values are above 1.5~1.7 standard deviations.

Step 5: We can find edge positions whose projection values are the largest from these ranges.

4.2. Image Inspection and Defect Analysis

We divide a block into 16 sub-blocks and group these sub-blocks into two classes, edge blocks which cover an edge and flat blocks which do not cover any edge. Figure 14 shows sub-blocks which we divide into. Figure 15 shows sub-blocks classification.

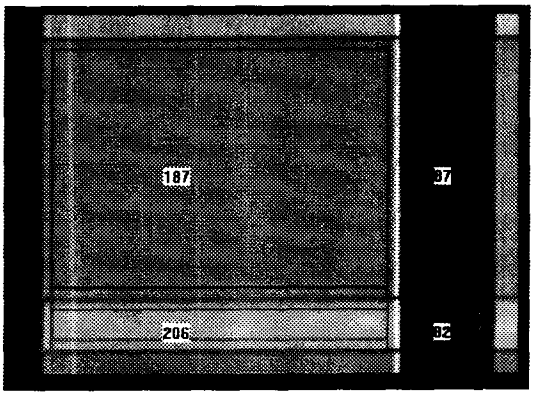

Figure 14 The sub-blocks that we want to segment.

Edge Block Defect Inspection

We propose a method for edge block defect inspection. Edge blocks have two kinds of edges, vertical edge and horizontal edge. For example, edge block 1 has a vertical edge and edge block 4 has a horizontal edge. In the following, we illustrate the method for edge blocks which have a horizontal edge.

Step 1: We sum up columns in an edge block. Evaluate column average.

Step 2: Compare each column with column average pixel by pixel to gain a residual column for each column.

Step 3: Using the threshold we set up previously to binarize each residual column, we can detect defects from the residual column.

For edge blocks which have a vertical edge, we replace column with row instead.

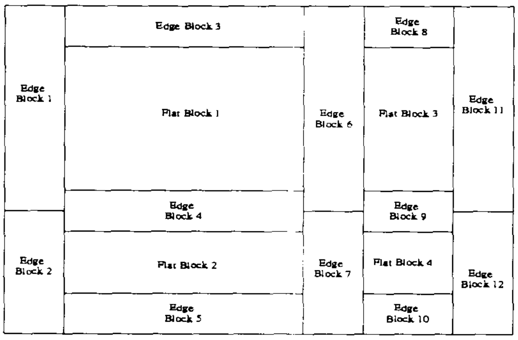

Figure 15 Sub-blocks classification.

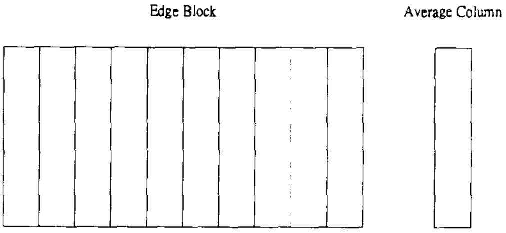

Figure 16 Compare each column with column average pixel by pixel to get a residual column for each column.

High-Resolution Defect Analysis

We have to inspect defects whose widths or heights are as small as 10 micrometers. Moreover, the resolution of the lens we used achieves 1 pixel equal to 2.136 micrometer. We define the defect bounding box width as w and height as h. The judgment criterion of defect is according to the following:

> If ($w > 4$ pixels and $h > 2$ pixels), or ($w > 2$ pixel and $h > 4$ pixel), we determine the defect as the fatal defect. Otherwise, we determine the defect as the non-fatal defect.

For all fatal defects we mark them as red color. The process of defect detection is shown as follows:

Step 1: Use the alignment we develop to align CCD camera and CNC X-Y-θ table and get how many micrometers a pixel is equal to.

Step 2: Grab a golden image from a non-defect block of PLED to get parameters such as block width, block height, and so on. Besides, we set up parameters such as gray level tolerance, blocks size tolerance.

Step 3: Segment the block to group sub-blocks into edge blocks and flat blocks to get sub-block sizes and sub-block average gray levels. If one of the block sizes of edge blocks or flat blocks is more than our set tolerance, determine it as size defect, compare the block with the golden block pixel by pixel, and go to Step 5.

Step 4: For flat blocks, compare every pixel with its average gray level. If it is more than our set tolerance, mark it as defect pixel. For edge blocks, use the method we develop above to detect defect pixels.

Step 5: Perform the connected component labeling on those defect pixels to get bounding boxes of defects. Use the judgment criterion of defect to get fatal defect and mark it as red color. Figures 17 and 18 show that defects in edge neighborhoods are easily detected.

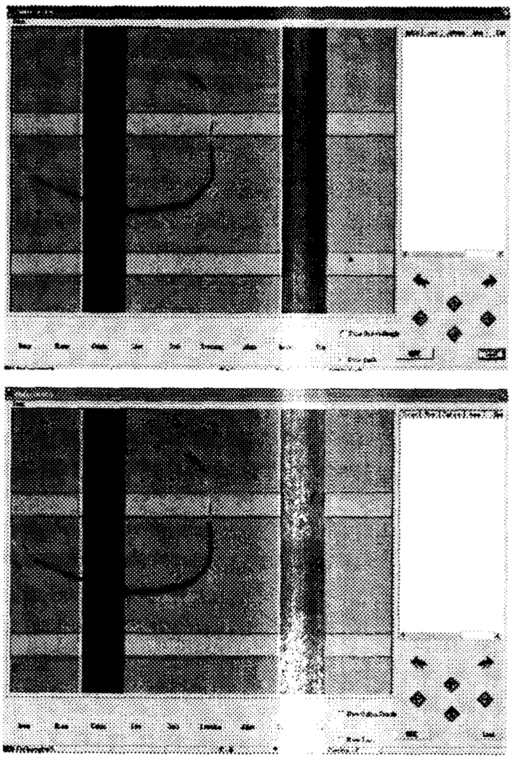

Figure 17 Inspected image (upper) and inspection result (lower).

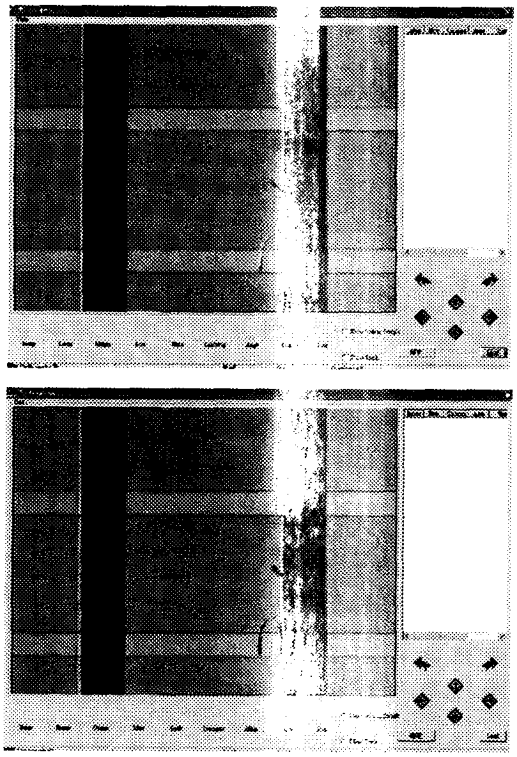

Figure 18 Inspected image (upper) and inspection result (lower).

5. Conclusions

In this paper, we develop two kinds of PLED defect inspection systems, the low-resolution defect inspection system and the high-resolution defect inspection system.

In the low-resolution defect inspection system, we use CCD camera to replace photometer so that we can measure luminance quickly. The judgment criterion is based on luminance. We previously set up luminance range. Therefore, if the luminance we get from inspection does not meet our requirement, we classify it as defect. In the low-resolution defect inspection system, we can inspect PLED panels quickly and robustly.

In the high-resolution defect inspection system, we can inspect PLED panels quickly and robustly and can detect defect size as small as 10 micrometers.

For edge blocks, the method we develop based on image comparison can detect defects easily.

REFERENCES

[1] R. C. Gonzalez and R. E. Woods, *Digital Image Processing*, Addison Wesley, Reading, MA, 2002.

[2] R. M. Haralick and L. G. Shapiro, *Computer and Robot Vision*, Vol. 1, Addison Wesley, Reading, MA, 1992.

[3] R. M. Haralick and L. G. Shapiro, *Computer and Robot Vision*, Vol. 2, Addison Wesley, Reading, MA, 1992.

[4] G C. Holst, *CCD Arrays, Cameras, and Displays*, SPIE Press, Bellingham, Washington, 1998.