Optics and Lasers in Engineering 70 (2015) 6–17

Contents lists available at ScienceDirect

Optics and Lasers in Engineering

journal homepage: www.elsevier.com/locate/optlaseng

Automated inspection of micro-defect recognition system for color filter

Chung-Feng Jeffrey Kuo [a,*], Kai-Ching Peng [b], Han-Cheng Wu [b], Ching-Chin Wang [b]

[a] Department of Materials Science and Engineering, National Taiwan University of Science and Technology, Taipei 106, Taiwan
[b] Graduate Institute of Automation and Control, National Taiwan University of Science and Technology, Taipei 106, Taiwan

ARTICLE INFO

Article history:
Received 18 July 2014
Received in revised form
15 January 2015
Accepted 26 January 2015
Available online 4 March 2015

Keywords:
Adaptive template matching
Image subtraction
Control limit law
Back-propagation neural network
Minimum distance classifier

ABSTRACT

This study focused on micro-defect recognition and classification in color filters. First, six types of defects were examined, namely grain, black matrix hole (BMH), indium tin oxide (ITO) defect, missing edge and shape (MES), highlights, and particle. Orthogonal projection was applied to locate each pixel in a test image. Then, an image comparison was performed to mark similar blocks on the test image. The block that best resembled the template was chosen as the new template (or matching adaptive template). Afterwards, image subtraction was applied to subtract the pixels at the same location in each block of the test image from the matching adaptive template. The control limit law employed logic operation to separate the defect from the background region. The complete defect structure was obtained by the morphology method. Next, feature values, including defect gray value, red, green, and blue (RGB) color components, and aspect ratio were obtained as the classifier input. The experimental results showed that defect recognition could be completed as fast as 0.154 s using the proposed recognition system and software. In micro-defect classification, back-propagation neural network (BPNN) and minimum distance classifier (MDC) served as the defect classification decision theories for the five acquired feature values. To validate the proposed system, this study used 41 defects as training samples, and treated the feature values of 307 test samples as the BPNN classifier inputs. The total recognition rate was 93.7%. When an MDC was used, the total recognition rate was 96.8%, indicating that the MDC method is feasible in applying automatic optical inspection technology to classify micro-defects of color filters. The proposed system is proven to successfully improve the production yield and lower costs.

1. Introduction

Color filter is a critical part of a liquid crystal display (LCD) panel, especially for a high quality color display. At present, the defect detection for color filters is performed by manual inspection during production. As the image capture and display equipments have become popular products, digital image processing-based computer vision is constantly renovated.

Some image-related algorithms have been proposed and image-processing technology has matured in recent years. In the field of industrial product testing, automated detection by computers has gradually replaced manual testing to improve yield and reduce production costs. To achieve automated inspection testing, camera has been used to capture images, and the image processing technology has been applied to obtain the characteristics of defects in the image to facilitate subsequent identification and classification.

In color filter micro-defect detection, Nakashima et al. [1] used the image subtraction method to detect color filter micro-defects. However, the image subtraction technology may be affected by deviation of positions or noise caused by sources of light. Lee et al. [2] captured four types of color filter images (normal, point defect, particle and the line defect image) for judgment and detection. Color saturation, period, and boundary characteristic diagram were captured first. The defective features were then highlighted by Gaussian filter and enhanced contrast. Finally, all the features in a result image were combined to present the clearly visible defective area. Chang et al. [3] utilized the orthogonal projection approach to distinguish validated and invalidated areas of the testing image. Defect detection was performed in invalidated areas, and fuzzy neural network was employed to detect the defective areas of the color filter. Tsai [4] performed thin film transistor LCD and color filter micro-defect detection by using the self-matching method coupled with the independent component analysis (ICA). The captured image for detection was scanned in top-down direction by horizontal scanning, and was transformed into one-dimensional signals for detection. With the two-dimensional matrix approach, the ICA method was applied to

* Corresponding author. Tel.: +886 2 27376535; fax: +886 2 27908821.
E-mail address: jeffreykuo@mail.ntust.edu.tw (C.-F. Jeffrey Kuo).

http://dx.doi.org/10.1016/j.optlaseng.2015.01.009
0143-8166/

compare currently and previously captured horizontal signals to learn whether there was any defect. Liu et al. [5] used the shearography fringe images to detect different material plates, and applied the periodic fringe variation to recognize the breaking holes and inner crack. Qiu et al. [6] proposed 3D digital image correlation method to detect surface and inner cracks in the tension test. The local deformed region was used to distinguish surface and inner cracks differences. However, the above-mentioned crack detection techniques are unable to detect color filter because the color filter has color differences and non-planar structures. Hence, this study proposed an image inspection algorithm to detect and classify the defects for color filter.

In terms of image processing technology, Tsai [7] used color graphics for directional textures, and proposed a graph-matching method, which contains two stages. The first stage, known as coarse matching, is the image correlation coefficient method for selecting color ring projections. This method is unaffected by the rotating object images. The second stage, known as fine matching, calculates the impact of the object rotation by the quadratic differential method coupled with color eigenvalues as the weight. By the color image correlation coefficient method, the fine matching results correlate to the standard graphic in the area selected at the first stage. Kaneko et al. [8] applied the selective correlation coefficient to match and compare images having shade or environments of insufficient light source. Before image matching, binary-coded increment sign-image technology was employed to produce a mask image from the target and sample images. The purpose of the mask image was to compute the correlation coefficient values when the target image is identical with the sample image in terms of brightness. The method incorporating quantitative variation method used by Lu et al. [9] is a single-band image subtraction method, which could subtract same band or index of before and after images. When there is significant change in the image, the result would present a relatively larger positive or negative value; otherwise, the result would be close to zero. Tsai [10] matched and compared the standard image with the defective image. The method used quantile–quantile (Q–Q) plot coupled with the normalized cross correlation method to attain the *p*-value. The *p*-value is the observed level of significance for hypothesis test on the statistics and angle between the two matching images. Image mask was employed to detect whether there was any defect. Frucci et al. [11] proposed a method to detect image-shaped edges by using image pyramid. The method separates the object frame and background by watershed transformation, where image pyramid could prevent excessively unnecessary segmentation of object frame and background. However, this method is based on the assumption that all captured images must be of high resolution. Chen [12] utilized the correlation coefficient method to quickly calculate the period image and the adaptive image subtraction method to perform defect detection by the masking approach. This method could overcome problems of rotation or displacement in the image for detection. The control limit law was applied to determine the threshold for image segmentation. Hu et al. [13] employed Robert operators to capture the edges of chess images, and then processed them by the morphology method. Round template was used to rapidly detect the chess and transform the image onto the polar coordinate plane by Hough transformation. Through the statistical projection histogram and fast Fourier transform (FFT), the displacement features of the histogram were eliminated. Finally, the testing template features and sample template features were calculated to identify chess words.

In terms of defect type classification method, Zoroofi et al. [14] utilized different spectral optical filters and charged coupled device (CCD) to capture the images of integrated circuit (IC) board with different brightness levels, in order to detect defects on the board. The back-propagation neural network (BPNN), minimum distance classifier (MDC), and maximum likelihood classifier (MLC) were employed to perform classifications of five different situations. Yang et al. [15] used the wavelet transformation approach to capture the textural features of eight defects of the fabric. BPNN, MDC, and MLC were employed for the fabric defect classification. Based on recent studies concerning color filter micro-defects detection and identification, this study proposed a color filter detection and classification method. Digital image processing technology was utilized to position each pixel of the image for detection and identify defects. The BPNN and MDC were employed as the defect classification decision-making theory. Chang et al. [16] introduced a method for detecting the lighting area and p-electrode of each grain by using the lighting area to capture five different eigenvalues, which were input into the neural network for classification. After the background and foreground image segmentation by the Otsu method [17], the p-electrode captured four different eigenvalues of defects to input into the BPNN.

This study used orthogonal projection to locate each pixel on a test image. An image comparison was then performed to mark similar blocks on the test image. The block that best resembled the template was selected as the new template. Then, image subtraction was applied to subtract the pixels at the same location in each block of the test image from that of the adaptive template matching, in order to obtain a new image. The control limit law was employed to separate the defected region. Then, a logic operation was carried out to remove the blocks, which were not compared around the test image, to set as the background. The complete defect structure was obtained by the morphology method. After that, five feature values (defect gray value, red, green, and blue color components, and aspect ratio) were acquired as classifier input. BPNN and MDC served as the defect classification decision theories for the five acquired feature values.

2. Research method

The color filter structure included the red, green and blue color resist, spacer and special spacer. After capturing various micro-defect images of the color filter by micro-lens, the image pre-processing was conducted. With the five eigenvalues as BPNN and MDC input values, the follow-up color filter micro-defect classification was performed. In practice, the image pixel size is at least one third of the defective size. The image processor used in this study was from Intel, the CCD for image capture was from Olympus, and the image capture card was from Matrox. The test image size was 640×450 pixel, the pixel size was 7×7 μm, and the minimum size of defects was 30 μm. There were 12 color filter cells in one image. The sample image included additional manufacturing information. As this information should be deleted, the image size was cropped into 640×450 pixel from 640×480 pixel.

The light source was a halogen lamp used as a diffusive backlight characterized with high contrast. Regarding the software, the program development tool Borland developed by the Borland Company was employed. The experimental procedure is shown in Fig. 1.

The originally captured image in this study for testing was a color image converted into a gray image. The period image was obtained by using the correlation coefficient method, and different standard templates were utilized for matching with the testing image. The individual blocks with the highest score after matching was regarded as the new template, also known as the matching adaptive template. They were closest to the test images as compared with the standard templates. The special Spacer was a random object, and its standard template was directly matched with the similar block in the testing image. Image subtraction and image segmentation were performed by the control limit law of these three new samples to achieve three binary images sized in 640×450 pixel. OR logical operation was then conducted to integrate these three binary images into a complete testing binary