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Evaluation of TFT-LCD defects based on human visual perception

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ABSTRACT

In this paper, we propose an evaluation method of the TFT-LCD defect. Although several detection methods based on image processing techniques detect TFT-LCD defects, the majority of them are un-noticeable to the human eye because of the low contrast and unclear defect boundary. Therefore, to minimize the yield loss, all defects are re-inspected by visual inspector. The proposed method evaluates each defect and gives a corresponding level that objectively agrees with the assessment of a group of inspectors. The basic idea is to use the characteristics of the human visual perception in the evaluation. Crucial features of the defect were selected and the human perception degree was approximated through the regression analysis. In the process, we define the "just noticeable difference surface" (JND) and evaluate the level of defect as the distance from a defect consisting of a vector of selected features to the JND.

1. Introduction

TFT-LCD defects are undesired region of non-uniformity and low contrast on the TFT-LCD panel that are perceived as a visual defect by the human eye. The main causes of these defects are uneven thickness of the coated layer, locally non-uniform chemical process, location shifts of cells, and local surface roughness. They are characterized by slight gray level differences between the defect and non-even background.

The quality of a TFT-LCD panel depends on accurate detection of the visual defects during the manufacturing stages. Visual inspection is accurate in most of the cases but is costly, slow, and human dependent. Automatic detection methods were thus developed to address these problems [1–4]. However, the majority of the detected defects using conventional methods are not perceived by the human eye. Mainly, this is because conventional methods rely only on the contrast threshold. When contrast is the only used feature in the detection, the detection method cannot distinguish different features such as the clarity of the boundary or the size of the defects. Particularly, a human detects a large defect with a clear boundary better even when the average contrast is low. In practice, to prevent the miss-detection of the visible defects the contrast threshold is set low. But, with a low threshold, a small defect with an unclear boundary and high contrast which is not visible to the human eye may be over-detected.

Mori et al. studied the influence of the defect size in the perception of a defect and concluded that a larger defect is more visible [5]. This result leads to the SEMU Index [6] and Lee [7] applied it to classify area type TFT-LCD defects. Unfortunately, the SEMU Index does not take into account the clarity of the defect boundary. Fig. 1 depicts two line type TFT-LCD defects having similar contrasts where one is thinner than the other. According to the SEMU Index the thinner one has lower index thus it is less visible. But, when the two defects are exposed, inspectors detect the thinner one better because the abrupt change of the edge contrast is perceived as a clearer boundary to the human eye.

In this paper we propose a new automated system that evaluates the area and line type TFT-LCD defects. The new system takes three key features to characterize a TFT-LCD defect and conducts a final evaluation step on each defect to detect only the noticeable defects. As a result, the new method maximizes the number of good panels by discarding only the perceptible defects, and minimizes the number of required visual re-inspections.

The proposed system consists three parts: defect detection, feature extraction and defect evaluation. First, when the image of the TFT-LCD panel is given, it is preprocessed and the defect region is detected from the preprocessed image. Second, the features are extracted from the detected region. Finally the level of each defect is evaluated using the Index: an evaluation function that uses the extracted features as input and outputs the objective visibility level. We describe the detection of defect in Section 2, the extraction of features from detected region in Section 3, and the approximation of the Index function which evaluated each defect in Section 4. With the experiments in Section 5 that show the performance of our system we conclude the paper.

2. Defect detection

In this section, we describe the two phases of detection process which consists of preprocessing (Section 2.1) and defect region detection (Section 2.2).

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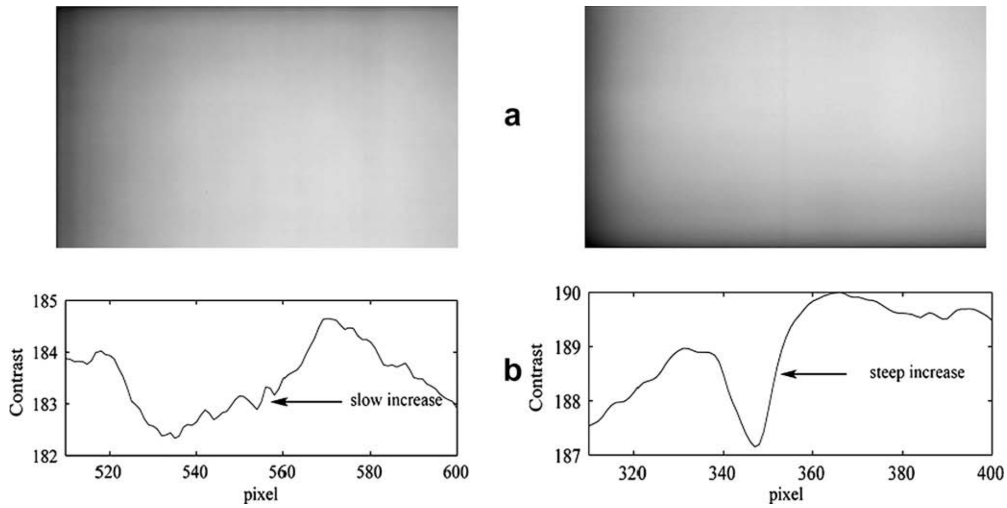

Fig. 1. Two Line TFT-LCD defect samples (a) Input defect images where the defect on the left is thicker than the defect on the right. (b) Line profiles $P(x)$ (defined in Eq. (1)) in the neighborhood of the defect region. Each x-coordinate in the line profile represents the intensity average of a column in the image.

2.1. Preprocessing

Four MegaPlusII ES11000 CCD cameras with a full resolution of 4008×2672 pixels and a maximum 12-bit depth captures six different full-screen constant test patterns of 693×394 pixels and 8-bit depth. Four gray pattern forms an image $A(x,y)$ of 1386×788 pixels and 8-bit depth.

2.1.1. Area defect

Each $A(x,y)$ is divided into overlapping windows $I(x,y)$ of size $W \times H$. The amount of overlapping, ΔW and ΔH, are estimated from a *priori* knowledge. Detection of area defect is performed locally on each window and the local detection results are merged into their original positions in the input image A.

2.1.2. Line defect

For each $A(x,y)$, the *line profile* $P(x)$ is computed by

$$P(x) = \frac{1}{1386}\sum_{y=1}^{1386} I(x,y) x = 1,\ldots,788 \tag{1}$$

The line profile P is then convolved l times using the mean filter (1/3,1/3,1/3) to form a smoothed line profile. By default l is set to 4.

2.2. Defect region detection

Once the preprocessing is done the region containing a TFT-LCD defect is detected as discussed below.

2.2.1. Area defect

The defect region of an area defect can be characterized by a bell shaped center region with a non-flat background surface as shown in Fig. 2b. To remove the influence of a non-uniform background, we first have to estimate the background surface robustly. Given a window image I of size $W \times H$ pixels, a data pixel $(x, y; z_{xy})$ denotes each pixel (x,y) with the intensity value z_{xy} for $x = 1,\ldots,W$, $y = 1,\ldots,H$. The *window data set* Ψ is then defined as a set of data pixels denoted by

$$\Psi = \{(x, y; z_{xy}) | x = 1,\ldots,W, y = 1,\ldots,H\}. \tag{2}$$

The window data set is approximated by using a bivariate polynomial model $f^{(d)}(x,y)$ of order d,

$$f^{(d)}(x,y) = \sum_{m+n \le d} a_{mn} x^m y^n, \tag{3}$$

such that $f^{(d)}(x,y)$ gives the estimated intensity value at (x, y) for $x = 1,\ldots,W$, $y = 1,\ldots,H$. The *residual* of the xyth data pixel with respect to $f^{(d)}$, denoted by r_{xy}, is the difference between the original and the estimated intensity of the xyth data pixel given by

$$r_{xy} = z_{xy} - f^{(d)}(x,y). \tag{4}$$

The model parameters a_{mn}'s may be estimated using the nonlinear least-squares (NLLS) regression method by minimizing the sum of the squared residuals:

$$\min \sum_{x,y} r_{xy}^2. \tag{5}$$

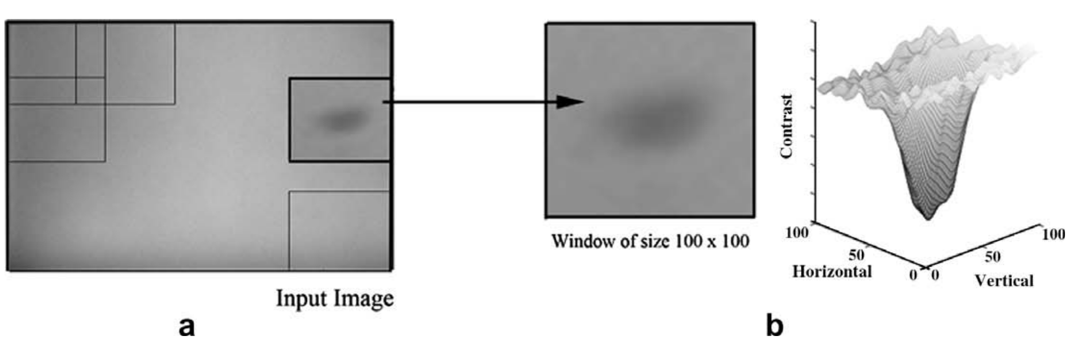

Fig. 2. An area TFT-LCD defect sample (a) Input image $A(x,y)$ containing an area defect. (b) The Window Image $I(x,y)$ of size 100×100. The brightness intensity shows a bell shaped surface with a non-flat background surface. Line profiles $P(x)$ (defined in Eq. (1)) in the neighborhood of the defect region. Each x-coordinate in the line profile represents the intensity average of a column in the image.