Expert Systems with Applications 36 (2009) 12332–12339

Contents lists available at ScienceDirect

Expert Systems with Applications

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

A hybrid approach based on Hotelling statistics for automated visual inspection of display blemishes in LCD panels

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ARTICLE INFO

Keywords:
Automated visual inspection
Liquid crystal display
Display blemishes
Hotelling statistic
Ant colony algorithm
Back propagation neural network

ABSTRACT

This paper presents an alternative hybrid approach based on Hotelling statistics, combining ant colony method and neural network model to automatically detect the display blemishes in liquid crystal display (LCD) panels. Owing to their space saving, energy efficiency, and low radiation, LCD's have been widely applied in many high-tech industries. However, the display blemishes such as abnormal spots (white and black spots) and slight color variations (bright and dark regions) often exist in LCD's. To detect these color unevenness blemish detection, this research proposes a multivariate statistic based hybrid defect detection approach. We first use multivariate Hotelling statistics to integrate different coordinates of color models and construct a Hotelling distance diagram to represent the degree of color variations for selecting suspected blemish regions. Then, an ant colony algorithm that integrates computer vision techniques precisely identifies the abnormal spot defects in the Hotelling distance diagram. And, the back propagation neural network model determines the regions of slight color variation blemishes based on the Hotelling distance values. Experimental results demonstrate the validness and efficiency of the proposed approach.

1. Introduction

Liquid crystal displays (LCDs) have become more and more popular in recent years as they occupy less space, weigh less, consume less power, possess larger display area, display crisper images, have no refresh-rate flicker, have excellent screen geometry, and emit no low-frequency electromagnetic radiation. The above advantages have fueled the wide application of LCDs in high-density products such as digital cameras, personal digital assistants, and cellular phones, but a similar popularity has not been gained in color reproduction applications which have high requirements of color precision and stability.

Inspection is the process of determining whether products deviate from a given set of specifications (Lin, 2007; Tam & Cheung, 2000). Various manufacturing techniques and inspection standards are presently used in the display panel industry (Chen, Chen, & Su, 2000; Kido, 1993). Accordingly, wide variances in image quality exist among LCD products. Quality control problems such as color unevenness blemish detection of displays frequently confront LCD manufacturers (Pratt & Hawthorne, 1998; Pratt, Sawkar, & O'Reilly, 1998). But the color unevenness blemish detection are seldom automatically inspected because: difficulties exist in comparing real colors and exhibit colors; display brightness spread is unsettled and inestimable; as the production of LCD's involves more innovative and precise manufacturing techniques, stricter specifications are required for LCD surface inspections.

Inspection of surface defects has become a critical task for manufacturers who strive to improve product quality and production efficiency (Lee & Vachtsevanos, 2002; Lin, 2008). Inspection of color unevenness blemish detection by human eyes is as difficult as automatic inspection because wrong judgments are easily made due to human subjectivity and eye fatigues. Therefore, developing an automated visual inspection system will significantly contribute to the quality improvement of LCD products. Automated visual inspection determines the properties of products using visual information and is most often automated by employing machine vision techniques (Parker & Hou, 2002). To meet consumer expectation, monitors should possess trustworthy display properties: maintaining sufficient color uniformity, revealing true colors, and assuring the reproducibility of precision. As the color uniformity of monitor displays can be affected by lighting conditions, environmental factors and subjective human visual perception, ensuring reliable visual quality of LCD's is an important problem that needs to be solved.

Non-uniformity defects are normally called MURA defects (Lee & Yoo, 2004). More specifically, MURA is a local lightness variation without a clear contour on a uniformly produced surface, which imparts an unpleasant sensation to human vision (Taniguchi, Ueta, & Tatsumi, 2006). Jiang, Wang, and Liu (2005) used luminance

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doi:10.1016/j.eswa.2009.04.066

measurement equipment to collect data of MURA-type defects and apply analysis of variance and exponentially weighted moving average techniques to develop an automatic inspection procedure. This procedure is limited to 15-in. LCD panels and has difficulties in identifying a defective area crossing two testing blocks. Lu and Tsai (2005) proposed a global approach for automatic visual inspection of micro defects (pinholes, scratches, particles and fingerprints) on TFT panel surfaces using the Singular Value Decomposition (SVD). The SVD is suitable for detecting defects in the patterned TFT–LCD images that contain highly periodical textural structures. Nevertheless, the variety of LCD manufacturing processes and the higher image resolutions of LCD products often lead to less periodical, more complicated textural structures in sensed images.

Since MURA-type defects have no clear contour or contrast, they are very difficult to be detected (Jiang et al., 2005; Lu & Tsai, 2005; Taniguchi et al., 2006). But, two common MURA-type defects, abnormal spots (white and black spots) and slight color variations (bright and dark regions), often exist in LCDs. To detect these display blemish detection, this research proposes a hybrid approach based on the multivariate Hotelling T^2 statistics, combining ant colony algorithm and neural network model.

2. Proposed methods

Commonly used in monitoring the mean vector of a multivariate process, the multivariate process control procedure is utilized in this research to locate color variations embedded in LCD displays. We first use multivariate Hotelling T^2 statistics to integrate coordinates of a color model and construct a T^2 distance diagram to present the degree of color variations. Then, an ant colony algorithm that integrates computer vision techniques is applied to detect the abnormal spot blemishes in the T^2 distance diagram. The back propagation neural network model is applied to determine the regions of slight color variation blemishes based on the T^2 distance values.

2.1. Multivariate statistics applied to different image color models

Multivariate quality control techniques are originally used for monitoring multivariate production processes. The current multivariate control chart includes general multivariate control models and small shift detection of multivariate processes. Lowry and Montgomery (1995), Mason, Chou, and Young (2001), Montgomery (2005) compare the procedures and functions of multivariate control charts in detail. It is assumed that the joint probability distribution of the p quality characteristics is the p-variate normal distribution.

This research uses color coordinates of the four common color models, RGB, XYZ, Yxy, and $L^*u^*v^*$, as the multivariate quality characteristics to calculate Hotelling T^2 statistics, respectively. The multivariate statistic T^2 integrates the multiple color coordinates into a T^2 value for each multivariate processing unit. This T^2 value can be regarded as a distance value of a multivariate processing unit. The larger the T^2 statistic value, the more distinctive the region is from the normal area. Thus, the more easily the region can be judged as defective. Fig. 1 shows the calculation procedure of T^2 statistics for the four different color models. The T^2 statistics are described as variations of color uniformity and the T^2 distance diagram presents the degree of different color variations.

The values of the T^2 statistics are calculated from many multivariate image processing masks, which are obtained by dividing an image into many image samples with sample size n and sample set m. For example, an image of 256×256 pixels can be divided into 51×51 sample sets, each of which has a sample size of 5×5 (pixels). The mean matrix ($\overline{X}$) and the covariance matrix (S) of the color coordinates in a mask can be written as follows:

$$\overline{X} = \begin{bmatrix} \overline{M}_1 \\ \overline{M}_2 \\ \vdots \\ \overline{M}_k \end{bmatrix}, \quad S = \begin{bmatrix} S^2_{M_1} & S_{M_1M_2} & \cdots & S_{M_1M_k} \\ S_{M_2M_1} & S^2_{M_2} & \cdots & S_{M_2M_k} \\ & & \ddots & \\ S_{M_kM_1} & & \cdots & S^2_{M_k} \end{bmatrix} \quad (1)$$

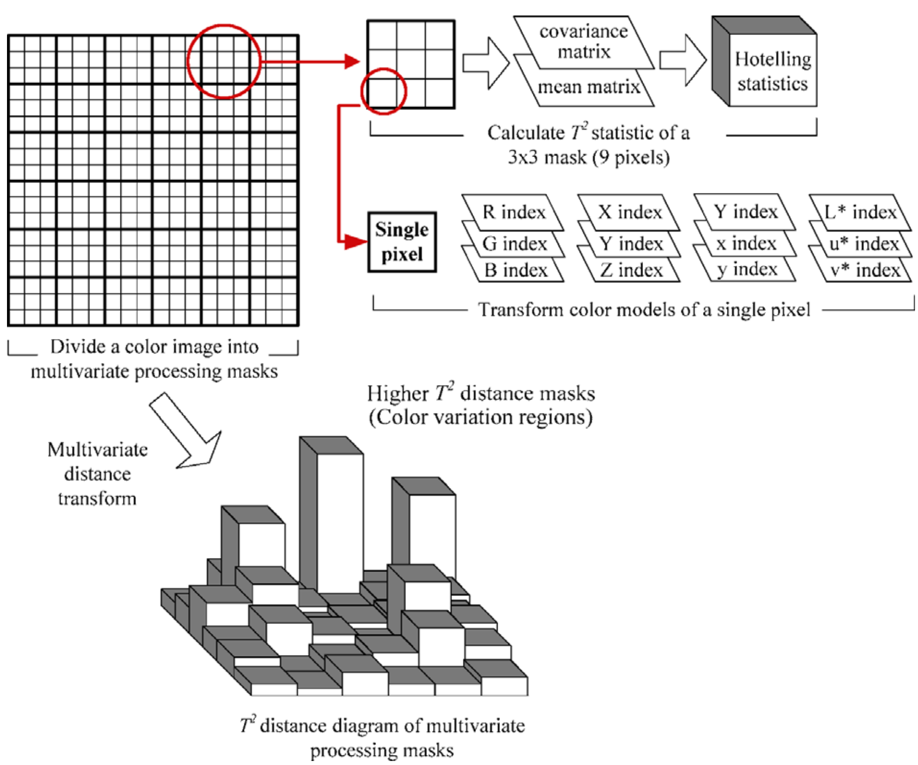

Fig. 1. Calculations of Hotelling statistics in a testing image for four different color models.