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Test method

Aesthetic defect characterization of a polymeric polarizer via structured light illumination

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A B S T R A C T

The aesthetic defects of polymeric polarizers have a serious impact on the quality of thin film transistor liquid crystal display (TFT-LCD) panels. However, some of these slight and transparent defects can barely be imaged and characterized using conventional illumination. To inspect these special defects, a new and automated inspection method is proposed that employs structured-light illumination. A machine vision system that uses a LCD monitor to produce a binary stripe pattern was designed to enhance the imaging defects. Thus, subsequent image processing is straightforward and simple because of this enhancement. One hundred and fifty defect samples were successfully imaged and then processed and characterized by the Robust Principal Component Analysis (RPCA) algorithm. The total inspection accuracy was up to 99%. The experiments demonstrate that the width of the luminous stripe should be optimized at 2 to 3 times the size of the defect. The mechanism of the imaging enhancement is preliminarily discussed.

1. Introduction

As a standard polarizing optical component, the polymeric polarizer has a wide range of applications. For instance, two pieces of polymeric polarizer with orthogonal polarization directions are indispensable in TFT-LCD panels. The polarizer used in the TFT-LCD panels typically consists of six layers of polymeric films including a layer of pressure-sensitive adhesive (PSA), as illustrated in Fig. 1. Each layer is tens of micrometers. The polyvinyl alcohol (PVA) is surrounded by triacetyl cellulose (TAC) and must be polarized. The TAC can isolate PVA from air and humidity. A separate film (SF) protects the PSA.

For a polymeric polarizer, imperfections in the materials and failures during manufacturing will produce aesthetic defects that can be visually perceived by end users. These tiny defects are aesthetically displeasing but do not have any functional disadvantages.

This paper characterizes 80 to several hundreds of micrometer aesthetic defects via human sight and human sight resolution limitations. There are many kinds of aesthetic defects including impurities, stains, scratches, dents and bubbles. These could occur at any layer of the polymeric polarizer. In addition, the classification would be more complicated if the location, size and shape of a defect are considered. Most aesthetic defects are located inside the polymeric polarizer and not on the surface.

Currently, most research on polymeric polarizers is focused on the polarizer's optical features including reflectivity, transmissivity and extinction ratio. The aesthetic defects are almost neglected, even although they actually play an even more important role in quality assurance [1]. Visual inspection by humans is widely adopted in the manufacture of both polymeric polarizers and TFT-LCD panels. This manual work is quite labor intensive, and the inspection accuracy is influenced by subjective nature of the human inspectors—they can be tired or have poor eyesight. Furthermore, the speed of manual inspection is difficult to improve. For instance, it will take at least 1 min for an experienced inspector to examine a 19-inch piece of polymeric polarizer. Hence, an automated and non-destructive detection technology with high accuracy and speed for such defects is quite important for quality assurance on production lines.

Machine vision has been widely used to inspect product defects. Jerjen et al. used X-ray Dark Field Imaging to visualize and detect the stress whitening of an injection-molded polyvinylidene fluoride [2]. Chou et al. designed a machine vision system based on a linear array CCD camera to detect the aesthetic defects of polymeric polarizer, and also studied applications of Down-sampling Compression, Wavelet Transform and Hough Transform [3]. Yeh and Wu developed an image-processing filter to enhance the

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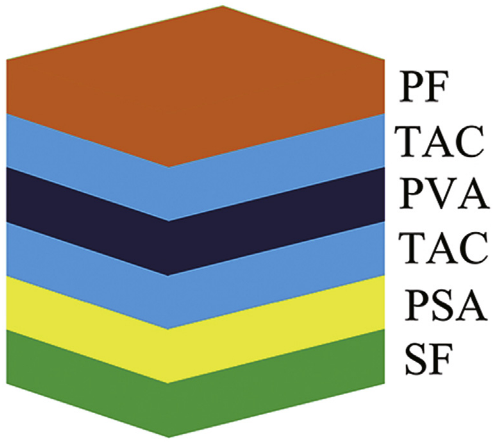

Fig. 1. Schematic of polymeric polarizer. PF: Protective Film, TAC: Triacetyl Cellulose, PVA: Polyvinyl Alcohol, PSA: Pressure Sensitive Adhesive, and SF: Separate Film.

defects for a higher inspection speed based on a Standard Deviation Algorithm [4]. Tsai proposed an improved rapid density-based clustering algorithm and used adaptive threshold values to segment the polarizer images [5].

There are some special aesthetic defects of the polymeric polarizer we report here for the first time which have nearly identical reflectivity and transmissivity with the normal region. These defects are difficult to image under conventional illumination. Thus, we propose to define them as "transparent defects" such as dents, transparent impurities and bubbles. These transparent defects are the main obstacle to the existing detection technology of the polymeric polarizer because of their extremely low contrast.

Structured-light imaging is mainly used for 3D rebuilding and 3D surface measurements [6,7]. Geng delivered an overall description and detailed discussion of structured-light imaging [8]. For higher accuracy and speed, current research of structured-light imaging is mainly focused on the algorithms of calibrating projects and cameras, mapping spatial coordinate systems, coding of surface spots, and phase demodulation [9–11]. Seulin et al. proposed a new method to detect the surface defects on a specular object by employing structured-light illumination in 2002. This report offers theoretical model and experimental results [12]. Aluze et al. employed structured lighting to detect the surface defects of a glass bottle and modeled the defects as surface bulges and dents to explain the imaging enhancement [13]. Martínze et al. employed structured lighting to detect the surface defects of a non-plane transparent headlamp lens. Defects appeared in the captured image as a set of luminous pixels in a dark zone—thus, the contrast was very good. The adaptive threshold segmentation algorithm was studied based on the aspect images to improve the detection accuracy and speed [14,15]. Macher and Gruber used phase measuring deflectometry with structured lighting to detect visually perceptible sink marks—a type of surface defects—on high gloss injection molded parts. They then modeled the surface defects for fast measurements of their visual perceptibility [16,17].

Here, we propose a new method to detect these inner transparent defects. The contrast of the defects was markedly enhanced under structured-light illumination in favor of better detection accuracy and speed. This scheme used a machine vision inspection system, and the validity of this new method was verified via experimental results.

2. Experimental setup

The machine vision inspection system is illustrated in Fig. 2. A LCD monitor served as a structured-light source to display the binary stripe pattern (Fig. 3). The pattern was produced and controlled by a window application. Thus, the widths of the stripes could be easily adjusted. The resolution of the camera and the structured-light source were 2592 × 1944 and 2048 × 1536, respectively. The pattern moved 1/4 of the width of the stripe each time, and the camera then captured a picture of the sample that was illuminated by the structured-light source. Thus, it would take four steps to cover the entire sample. This is called active light scanning without any mechanical movements. The computer processed the four static pictures captured in each step and identified the defects of the sample. More scanning steps per sample offer better inspection accuracy but longer scan times.

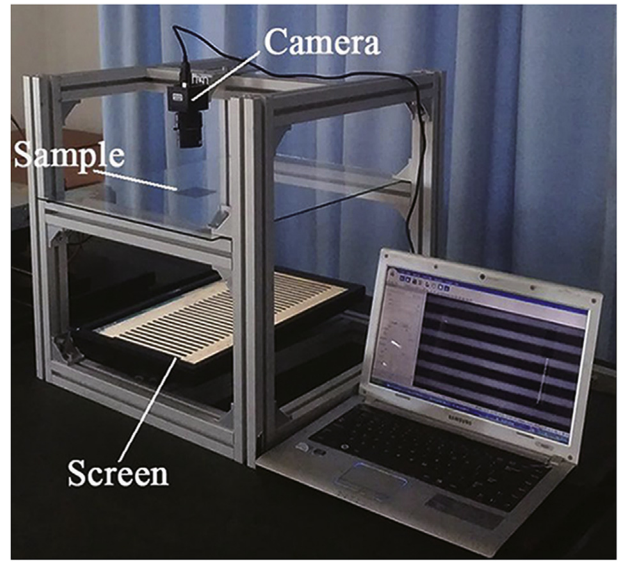

Fig. 2. Defect inspection system.

3. Imaging results and analysis

The contrast of defect imaging is defined as:

$$V = \frac{|G_B - G_D|_{\max}}{G_B + G_D} \times 100\% \qquad (1)$$

here, G_D and G_B are the gray levels of the defect and the adjacent area, respectively. There were three samples with defects located in the marking circles: No. 1 with a dent, No. 2 with a transparent

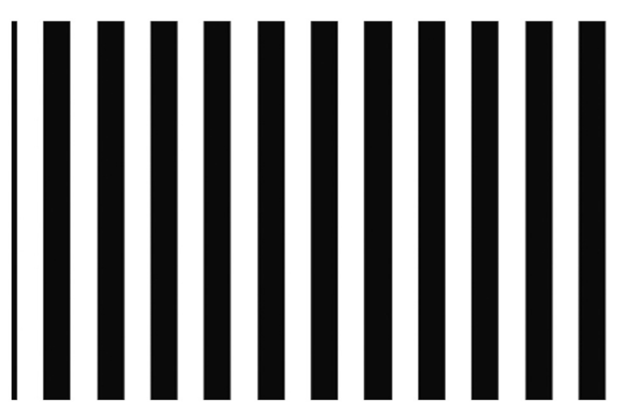

Fig. 3. Linear binary structured-light pattern.