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Fabric inspection based on the Elo rating method

Colin S.C. Tsang [a], Henry Y.T. Ngan [a,*], Grantham K.H. Pang [b]

[a] Department of Mathematics, Hong Kong Baptist University, Kowloon Tong, Hong Kong
[b] Industrial Automation Research Laboratory, Department of Electrical and Electronic Engineering, The University of Hong Kong, Pokfulam Road, Hong Kong

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ABSTRACT

Automated visual inspection of patterned fabrics, rather than of plain and twill fabrics, has been increasingly focused on by our peers. The aim of this inspection is to detect, identify and locate any defects on a patterned fabric surface to maintain high quality control in manufacturing. This paper presents a novel Elo rating (ER) method to achieve defect detection in the spirit of sportsmanship, i.e., fair matches between partitions on an image. An image can be divided into partitions of standard size. With a start-up reference point, matches between various partitions are updated through an Elo point matrix. A partition with a light defect is regarded as a strong player who will always win, a defect-free partition is an average player with a tied result, and a partition with a dark defect is a weak player who will always lose. After finishing all matches, partitions with light defects accumulate high Elo points and partitions with dark defects accumulate low Elo points. Any partition with defects will be shown in the resultant thresholded image: a white resultant image corresponds to a light defect and a grey resultant image corresponds to a dark defect. The ER method was evaluated on databases of dot-patterned fabrics (110 defect-free and 120 defective images), star-patterned fabrics (30 defect-free and 26 defective images) and box-patterned fabrics (25 defect-free and 25 defective images). By comparing the resultant and ground-truth images, an overall detection success rate of 97.07% was achieved, which is comparable to the state-of-the-art methods.

1. Introduction

Fabric is fundamental to many consumable products in daily life such as clothing, fashions, bags, bed coverings, nano-scale medical fabrics, and even air-conditioning ducts. Fabric inspection is a key component of quality control in textile manufacturing. Currently, most fabric inspection is conducted visually by human workers working at high cost, but it is not reliable due to human errors and eye fatigue. Automated visual inspection (AVI) of fabric applies computer vision techniques that offer not only an efficient, low-cost and accurate approach to replace the labour force but also expansion of inspection capabilities to cover a broader range of different fabric patterns, from the simplest to the most complicated. The aim of AVI is to detect and outline the shapes and locations of any defects on a fabric surface during or after weaving. There is much research on fabric inspection [1] of both simple and complicated patterned fabrics. This study focuses on fabric with complicated patterns (Fig. 1). A patterned fabric is composed of a basic fundamental unit, called the motif [2], which can be generated into the whole pattern by certain rules of symmetry. Based on these predefined rules, a patterned fabric can be classified into one of seventeen wallpaper groups [2].

Currently, AVI of fabric can be broadly classified into two main categories: motif- and non-motif-based. A number of methods have been developed for non-motif-based inspection. Most methods have been designed for the simplest patterns of the p1 group, plain and twill fabrics [1]. The five representative inspection approaches are statistical (e.g., regularity measure [3], fractal feature [4], morphological filter [5,6]), spectral (e.g., Fourier transforms [7–9], Gabor [10], wavelet [11–13]), model-based (e.g., Gaussian Markov random field [14], sparse dictionary reconstruction [15]), learning (e.g., neural network [16], support vector machine [4]) and structural (e.g., maximum frequency distance [17]). In contrast, only a few methods target other wallpaper groups, such as wavelet-pre-processed golden image subtraction (WGIS) [18], direct thresholding (DT) [18], co-occurrence matrix (CM) [19], Bollinger bands (BB) [20], regular bands (RB) [21] and image decomposition (ID) [22]. The method developed herein aims to inspect the patterned fabrics of the non-p1 fabric groups.

In this paper, a novel inspection method called the Elo rating (ER) method is proposed in which fabric inspection is treated as sporting matches between competing partitions (players). In other words, fabric inspection can be realised as sportsmanship during

* Corresponding author. Tel.: +852 3411 2531.
E-mail addresses: 11019700@life.hkbu.edu.hk (C.S.C. Tsang), ytngan@hkbu.edu.hk (H.Y.T. Ngan), gpang@eee.hku.hk (G.K.H. Pang).

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0031-3203/

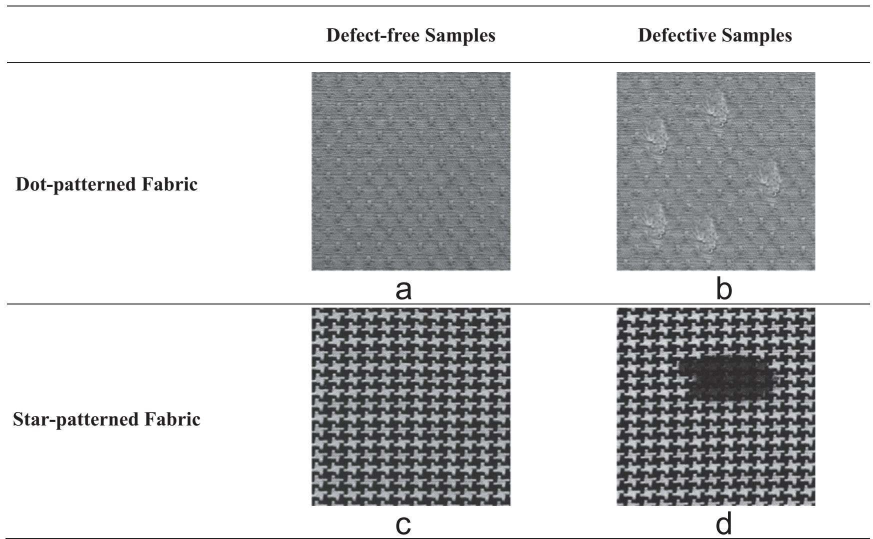

Fig. 1. Dot-patterned fabric images of (a) a defect-free sample and (b) a defective sample with light defects. Star-patterned fabric images of (c) a defect-free sample and (d) a defective sample with dark defects.

fairly played matches between competing partitions. The idea of the ER method originates from a logistic distribution-based statistical system called the Elo rating system, developed by Elo [23]. This system is used to measure a player's capability in many international chess matches, video matches [24] and even in many other international team sports including football, basketball, major league baseball, etc.

Fabric inspection is treated in the spirit of sportsmanship by the ER method, which provides a new perspective for the detection of fabric defects. The idea is that each $m \times n$ extracted image partition from an $M \times N$ testing image acts like a player. All partitions are considered as players and each player is assigned a starting Elo point (W.L.O.G. = 1000 as the starting number of base points). A player who wins a match gains some Elo points w.r.t. a formula suggested by Elo [23] based on a logistic distribution; otherwise the player loses some Elo points. In the long run, the Elo points accumulated are a fair indication of the player's performance even though some players do not encounter each other in the matches. In patterned fabric defect detection, image partitions of a patterned fabric image are considered the players and a match is regarded as the matrix operation between these partitions.

According to a score matrix of the ER method, a partition with light defective regions (Fig. 1(b)) will act like a strong player who tends to achieve a high score in the match and probably wins many matches. A partition with dark defective regions (Fig. 1(d)) will act like a weak player who tends to have a low score in the match and probably loses many matches. A partition that is defect-free will act like an ordinary player who tends to have an average score and ties many matches. Hence, a strong player with light defects should be able to gain Elo points by winning many matches, whereas a weak player with dark defects should lose Elo points by losing many matches. Therefore, an area of an image can be indicated as defective by tracking, partitions with relatively high or low Elo points. Match making in the ER method is designed as follows. For each partition (player), a certain number of other partitions (players) are randomly selected to have matches against it. The Elo points of a corresponding player will be updated after each match. In this paper, dot-, box-, and star-patterned fabrics comprising a total of 336 images (165 defect-free and 171 defective) are used.

This paper makes the following contributions to the literature.

1. A new application of the ER method is constructed by transforming its theoretical and physical properties for the purpose of patterned fabric inspection. Four key parameters in the ER method, including partition size, number of randomly located partitions, $w-$*variable*, and constant K, are carefully justified in the performance evaluation.
2. The ER method provides a binary classification of the nature of the defect in the final resultant image: white as a light defect, grey as a dark defect and black as defect-free.
3. From fabric databases with ground-truth images, the ER method achieves 96.89% accuracy for dot-patterned fabrics using 110 defect-free and 120 defective images, 98.82% accuracy for star-patterned fabrics using 30 defect-free and 26 defective images and 99.07% for box-patterned fabrics using 25 defect-free and 25 defective images. These results outperform those of the WGIS method and are comparable to those of the previously developed BB, RB and ID methods in [22].

The remainder of this paper is organised as follows. In section 2, we survey the literature on the detection of patterned fabric defects. Section 3 outlines the ER method and its procedures. In Section 4, we evaluate the performance of the ER method and compare it with the WGIS, BB, RB and ID methods. Lastly, Section 5 concludes the paper.

2. Literature review on defect detection in plain and twill fabrics

The AVI techniques for fabrics in motif-based classification [25] can be divided into two main categories. Only a few methods have been developed for the patterned fabrics of the non-p1 wallpaper group. Research into the inspection of these patterned fabrics has been increasing in the last decade. The developed methods can be classified into four approaches: statistical, spectral, model-based and learning approaches.

The statistical approach includes gray relational analysis with CM features [19] on Jacquard fabric images to study correlations