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Patterned Fabric Defect Detection and Classification (FDDC) Techniques: A Review

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Abstract— The capability to accurately locate defect points for assurance of fabric quality control process is a major aim of an automated patterned fabric defect detection and classification system. This must be achieved with a good processing speed, less computational complexity and at a less computational time. Thus, the systems to be designed require robust and efficient fabric defect detection algorithms. Although different fabric defect types had been referenced in literatures, only a few with patterned and coloured patterned fabrics have been referenced. The purpose of this paper, therefore, is to review various techniques and algorithms that have been developed to detect fabric defects in patterned and coloured patterned fabrics. It also aimed at presenting an evaluation of different state-of-the-art techniques and algorithms, the limitations of several promising techniques, and the analysis of the performances of such techniques in the context of their demonstrated results and intended application.

Index Terms— Fabric Defect Detection and Classification (FDDC), Patterned fabric, coloured patterned fabric, Defect location.

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1 Introduction

FABRIC defect detection is a quality control process that aims at identifying and locating defect on textile or fabric [1]. Fabric defect detection process is able to precisely locate the defect regions in the fabric for further processing, while it also provides rough information (for example, the total number of defects) for the grading of the fabric products. Until recently, the visual defect detection is still undertaken offline and manually by humans with many drawbacks such as tiredness, boredom, inattentiveness, lack of accuracy, which is time-consuming and costly [2]. Research has been ongoing to replace the manual visual defect detection and inspection with an automated or machine vision-based fabric defect inspection systems of Fabric Defect Detection and Classification (FDDC) systems. There are several techniques and FDDC algorithms published, which discussed the influence of fabric defects on the commercial aspects of the textile industry [3], [4], [5].

Defect detection have been viewed as a texture analysis problem with interesting surveys and literatures focused on automated fabric inspection and defect detection, [6], [7], [8], [9].

In [10], systems that can detect more complicated pattern fabric for both slanted pattern fabric and jeans was intriduced. However, despite various reviews and survey from different researchers on plain, woven and knitted fabrics, few works have been reported solely on patterned and coloured patterned fabrics. The challenge of embarking on patterned fabric defect detection and classification systems have been the issue of the repetitive design that provides a more underlying information, the complicated and varied fabric texture transform. There is the opinion of the challenging task of sophisticated texture structures known of patterned fabrics [11].

There is, therefore, the need for a review of most of the existing methods and algorithms on patterned fabric as reported in several literatures. The aim of this paper is also, to discuss different algorithms and developed systems that have been found in literatures for fabric defect detection and classification techniques of different patterned and coloured patterned fabrics for the purpose of review. In comparison with previously published review papers on fabric defect inspection, detection and classification techniques based on computer vision, this paper objectively offers survey of different defect detection methods on patterned fabrics with a description of their characteristics, strengths and weaknesses. It performs a qualitative analysis of the different methods that have been employed, the database sizes used, fabric type and performance metrics such as Success Detection Rate, Accuracy, Sensitivity and Specificity for some of the methods reviewed.

This will serve as a platform for development of more robust fabric defect detection and classification systems based on computer vision for patterned fabrics. Researchers in image processing and computer vision fields stand to benefit in understanding the characteristics of the different defect detection approaches in patterned and coloured patterned fabric.

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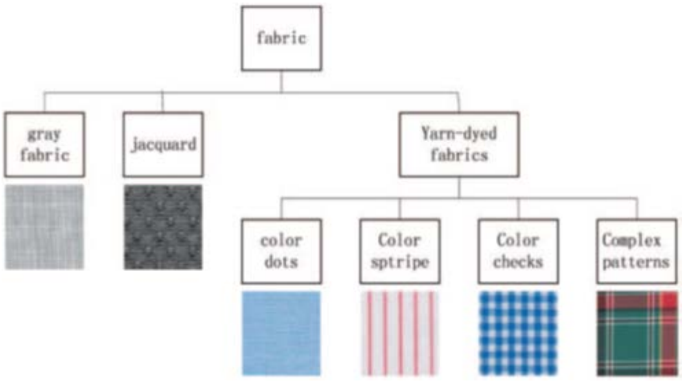

Figure 1. Catalogue of Patterned Fabrics

2. Existing Fabric Defect Detection and Classification Algorithms in Patterned Fabric

Ngan, Pang, Yung, and Ng [12] applied the direct thresholding method based on wavelet transform detailed sub-images as an automated visual inspection method for defect detection on patterned fabric. They reported that the wavelet pre-processed golden image subtraction method, which can segment out the defective regions on patterned fabric effectively, provided an overall detection success rate of 96.7% from 30 defect-free images and 30 defective patterned images for one common class of patterned jacquard fabric. In the report, wavelet-based methods were used to extract detailed and approximation sub-images from a histogram equalized defective image. The sub-images were further processed for defect detection.

A novel method for defect detection on surface patches was presented by Aiger and Talbot [13]. The algorithm is noted to be extremely simple as it consists mainly of a standard Fast Fourier Transform and can generally work for various pattern without prior knowledge because it is unsupervised. As the method is unsupervised, it is based on the Phase-Only Transform (PHOT) that is normalized by the magnitude. The PHOT removes any regularity, at arbitrary scales, from the image while preserving only irregular patterns considered to represent defects. The localization is obtained by the inverse transform followed by adaptive thresholding using a simple standard statistical method. In order to be able to use a totally unsupervised method with no learning phase, it is assumed that for each input image, the majority of the image pixels are intact so as to use simple statistics. The result of the PHOT is then used as a probability map of a pixel being a defect. Gaussian distribution is assumed and the use of Mahalanobis distance to compute the mean and variance of the distribution from the image obtained by the PHOT. The most appealing characteristic of the PHOT is that it removes any regularities from the image without the need to identify peaks in the Fourier domain. Only spikes that do not correspond to a sum of trigonometric functions inside the image domain are left. Every large enough regular pattern is removed by the transform by normalizing the resulted complex number by its magnitude which makes the work different from those who had previously worked on periodic patterns only. However, the limitation of the work was the fact that if the entire image is not regular but contains patterns that in some way are similarly perceived to be periodic or homogeneous, it may be removed by PHOT especially when 2D FFT is used.

Tajeripour Kabir & Sheikhi [14] implemented a simple multiresolution, and invariant to grey scale method for detecting irregularities in fabric texture using local binary patterns (LBPs). It should be noted that although LBP is basically used for texture classification, this was the first time it is used for detecting textural defects in fabric. In the training stage, at first step, LBP operator is applied to an image of defect-free fabric, pixel by pixel, and the reference feature vector is computed. Then this image is divided into windows and LBP operator is applied to each of these windows. Based on comparison with the reference feature vector, a suitable threshold for defect-free windows is found. In the detection stage, a test image is divided into windows and using the threshold, defective windows can be detected. Two types of unpatterned fabrics, twill and plain, are used. Six different types of the defects like double yarn, missing yarn, broken fabric, weft crack, float, and knots in these types of fabrics are considered. Patterned fabrics, dot-patterned, box patterned and star patterned, with defect like dirty yarn, hole, thick bar, broken end, netting multiple, knot and oil stain were as well considered. The proposed method is multiresolution and greyscale invariant and can be used for defect detection in patterned and unpatterned fabrics. Practically, despite the higher detection rate and detection speed that is higher privilege than the resolution of the defect pattern generated by the algorithm, the algorithm is ineffective for high-resolution defect pattern.

Ngan and Pang [15] studied regularity feature for finding common properties in patterned textures. They observed that regularity analysis of patterned textures involves two issues: the spatial relationship between intensity values and the repeat distance of a repetitive unit. These issues can also be defined as the periodicity of a patterned texture. However, the traditional periodicity is not effective for developing a patterned texture inspection algorithm. A new measure for the regularity of patterned textures is designed for defect detection. It is based on the idea of applying the periodicity as a new principle for patterned texture inspection. A break in periodicity is considered to be a defect in patterned texture inspection. This concept has been applied to the development of a new method called the Regular Band (RB) method. The regular band is defined by a moving average and standard deviation of the pixel intensity. It is specialized for defects which have differential intensity changes compared with the pattern on a repetitive unit of patterned texture. The RB method has been found very effective for defect detection of patterned fabric. In a comprehensive evaluation, the detection success rate of the RB approach has reached 99.4% in a total of 166 defective and defect-free images taken from three patterned fabrics. In this paper, the techniques and detection results of the RB method, as well as comparisons with other methods are given. The computational time for processing an image of size 256 by 256 is only 140ms using the C programming language. This new approach for automated patterned texture inspection is believed to be useful for quality control. It will also make contributions not only to practitioners in the textile industry but also in other industries like wallpaper and ceramics.

Fekri-Ershad and Tajeripour [16] proposed a one-dimensional local binary pattern (1DBP) approach for detecting any hole, damage and abnormalities in surface textures. The texture analysis operator was applied over the fabric image and two feature vectors were extracted from it. The proposed approach included two steps. Firstly, in training step, a single dimensional local binary patterns texture analysis operator was applied on full defect-less surface images and the basic feature vector for rows and columns was calculated. Then, the defect-less image was divided into windows while the non-similarity amount of the rows (columns) of these windows and basic vector based on Log-likelihood was computed. Finally, defect-less threshold was used to detect defect on test images. Some other advantages of this approach as reported are as follows: (i) 1DLBP operator that was proposed has less computational complexity than previous versions of LBP such as 2DLBP (ii) The proposed approach has low sensitivity to noise as a result of windowing technique and considering the relation between each pixel and its neighbours (iii) High detection rate of the proposed defect detection approach shows the suitability of the proposed defect detection approach with other feature operators. (iv) The proposed approach is a general one for two-class classification problems so that it can be used for every defect detection cases such as metal papers, ceramics and etc. (v) A novel feature vector is described that can be used for other image processing cases to analyze and classify the textures. (vi) Online ability is unique advantage of proposed approach comparing other defect detection methods. Detection Accuracy 96.6%, Sensitivity 97.8%, Specificity 96.8% when tested with Dot Pattern fabric surface, Detection Accuracy 93.2%, Sensitivity 94.4%, Specificity 96.2% when tested with Box Pattern fabric surface, Detection Accuracy 97.9%, Sensitivity 98.3%, Specificity 97.5% when tested with Star Pattern fabric surface.

Asha, Nagabhushan, and Bhajantri [17] proposed similarity-based methods for defect detection on patterned textures using five different similarity measures, viz., Normalized Histogram Intersection Coefficient, Bhattacharyya Coefficient, Pearson Product-moment Correlation Coefficient, Jaccard Coefficient and Cosine-angle Coefficient based on the fact that when two objects under inspection tend to become similar, the similarity coefficient tends to be 1. Image periodic blocks were then extracted from each input defective image and the similarity coefficient of histogram of each periodic block is obtained with respect to itself and other all periodic blocks. Asha, Nagabhushan, and Bhajantri [17] further transformed each similarity matrix into dissimilarity matrix containing true-distance metrics and Ward's hierarchical clustering is performed to discern between defective and defect-free blocks. Proposed method was evaluated using precision, recall and accuracy performance metric on each similarity measure for various real defective dot-patterned fabric images with defects such as broken end, hole, thin bar, thick bar, netting multiple, knot, and missing pick.

The development of fully automated web inspection system aimed to find independent components of the Regular Bands method of the patterned fabric images for the purpose of defect detection was studied by Ananthavaram, Rao, and Prasad [18]. Independent Component Analysis (ICA) was proposed to solve the problem of defect detection in patterned fabrics prior to Regular Bands (RB) method. A number of samples have been collected which are both defective and non-defective images. One sample image is taken for testing. The input images that are taken for testing are repetitive patterns. Fabric that contains defects is usually characterized by the higher pixel intensity levels. Each input sample is formed as a matrix for calculating the mean and standard deviation of the input samples. Gray level histogram with and without equalization is taken so that Gaussian noise can be reduced and defect can be detected easily. The next step was to calculate the mean for the input images of both defective and non-defective rows and columns which were not pixel by pixel. To improve the efficiency of the pixel intensity, for all the components that are extracted average is calculated. In the next step, defects are identified and comparison is done for both the defective and defect-free image so that the defective region can be easily identified and can be located perfectly. A threshold value is calculated for both rows and columns of the input images. If the threshold values exceed the normal range of the mean value than it is regarded as a defective image otherwise it is non-defective. In this way, the process continues for all the row and columns of the input images that are undergone for testing. However, the system has a drawback of increased computational time required to process.

Feng, Yiu, and Mak [19] approached the problem of defect detection for patterned textile fabrics which exhibit deformations of the patterns as a nonlinear functional optimisation problem. In textile defect literature, these researchers posited that most studies usually ignore the effects of deformations in patterned textile fabric. Deformations are easily caused by inner and outer forces, such as bending, torsion, tension and compression which results in an inevitable displacement of the textile surface and changes in the geometrical layout of the yarns. Upon parametrisation of the functional, the problem can be transformed into a general optimisation problem with the objective of selecting the parameters and the deformed functions such that the deviation between the defective image and the feature image is minimised. In this work, it was shown that deformed fabrics without defects can cause false alarms because normal deformations can easily be treated as defects by the defect detection process. Hence, possible deformations are first detected by employing a suitable coordinate transformation before conducting the defect detection. A feature image is first extracted from a template image by solving the problem of non-linear optimisation using gradient-based optimisation method and the resultant image is used for detection of the image with deformations. The images were then divided into many sub-windows for speedy computation. Parametrization method is then applied to each sub-window such that each sub-window contains many sub-regions. Optimal parameters (translation parameters and orientation) and the deformation functions are obtained by the simplified nonlinear optimisation problem with reduced numbers of variables and constraints to obtain the optimal solution. This nonlinear optimisation problem was solved using sequential quadratic programming. The results are then used to calculate the difference function between the feature image and the defective image which confirms the presence of deformation. It was recommended that the proposed scheme should be extended to detecting defects in non-woven fabrics and more complicated patterns.

Reddy, Reddy, and Reddy [20] had presented a texture classification system which has high tolerance against illumination variation based on a Gray Level Co-occurrence Matrix (GLCM) and various binary patterns (Local Binary Pattern (LBP), Simplified Local Binary Pattern (SLBP) and Local Line Binary Pattern (LLBP)). In the work, an automated similarity identification and defect detection model using GLCM and binary patterns, rotation-invariant scale invariant steerable decomposition filter, different classifiers (Probabilistic Neural Networks (PNN), k-nearest neighbour (K-NN) and Support Vector Machine (SVM)) with three different patterned fabric images (star, box and dot) was implemented. To implement this, adaptive histogram equalization (AHE) normalization technique is used on the intensity of the input image. Reddy, Reddy, and Reddy [20] calculates the histogram of a local image region centred at a given pixel to determine the mapped value for that pixel; this can accomplish a local contrast enhancement. Binary patterned images are then constructed using Local Binary Pattern (LBP), Simplified Local Binary Pattern (SLBP) and Local Line Binary Pattern (LLBP) feature extraction methods. A new rotation-invariant, scale-invariant steering basis filter decomposition is applied at different rotational angles {0, 45, -45,180} to filter arbitrary orientation which is produced as a linear combination of the benefits of "basis filter". By applying statistical measures, the filtered texture image (which can be seen as a set of basic cyclic primitives characterized by their spatial homogeneity) was extracted and used to capture the related image content as feature vectors. More precisely, Statistical features such as the mean, standard deviation of the filtered images, contrast, correlation, angular second moment, entropy, difference entropy are used by considering the presence of homogeneous regions in texture images to provide a variation measure of the intensity at the pixel of interest. Three classifiers, k-NN, PNN and SVM were employed for classification of texture's similarity and defect. In the proposed method, which combines binary patterns and GLCM, shows better defect classification accuracy of 100% for both SVM and K-NN classifiers. It was also shown that the proposed method has better similarity classification rate compare to individual binary pattern(s) based on both SVM and K-NN, with highest similarity classification rate of 93.75% and the highest similarity classification rate was 31.25% for PNN.

Javed, Ullah, and Aziz-ur-Rehman [21] worked on an analytical comparison of different fabric defect textural techniques; Regular Band-based (RB) Methodology, Gabor Wavelet Filter Methodology, Wavelet-Texture Analysis and LVQ Neural Network Methodology, Computer Vision and Artificial Neural Network, and Digital Image Analysis comparing some of these techniques on the basis of classification methods and accuracy. Regular Band-based fabric defect identification techniques is constructed on the impression of periodic synchronization [21]. The RB method uses only the duration of a period as a parameter on fabric in the final image with outlines of defective portion. It consists of two sub-bands; Light Regular Band (LRB) in which at the defective region, the original moving average (Avg) is greater than zero and standard deviation (SD) is smaller while for Dark Regular Band (DRB), at the defective region, the original moving average (Avg) is less than zero and standard deviation (SD) is smaller. The comparative study used different parameters and different dataset of information for the various techniques. Also, of importance in the detection process was the resolution of the images. For detection of small defects with box, star or dot patterns, Regular Band based Methodology was used on 166 sample images with an accuracy of 99.4%. 30 types of different defects were tested with Gabor Wavelet Filter Methodology from 71 fabric images with accuracy of about 96%. Wavelet-Texture Analysis technique gave an accuracy of 95% when tested over 350 images with 7 types of defects (including wrap missing, weft missing, double weft, materialize bar, oil pigment, hole, non-defected). Computer vision and neural networks techniques with stages from Image Acquisition, Image Restoration, Output to the neural network and backpropagation algorithm are applied to 200 images and accuracy was about 77% overall for 4 types of defects. It was noted that the size of image(s) also affects the algorithm efficiency. Digital Image Analysis techniques was tested over 2000 fabric images with accuracy of 83%. The techniques use calculation of volume of piles, total surface and Mean Height. After comparing different metrics and parameters, it was observed that RB gave a better accuracy than other described techniques as it revolved around the simple concept of standard deviation and moving average of one parameter; Length of Period [21]. It has an excellent detection capability of defective shape. However, deficiency is inability to detect defects near the border areas. Gabor Wavelet Filter Methodology with 96% accuracy is seen better considering number of defects along with the accuracy. However, the comparative study cannot be deemed accurate as it used different parameters and different dataset of information for the various techniques compared.

A patterned fabric has repetitive unit on its surface with a regular texture that proves a difficulty in the detection process. Hence, to reduce this difficulty, a fabric defect detection model that uses autocorrelation function to segment patterned fabric into texture primitives and a Gaussian Mixture Model to detect and locate the flawed area of the texture primitive before employing a rough theory classifier to detect the type of the defect was implemented by Li, Wang, and Cui [22]. In this method, the images were first divided into sub-images according to the repetitive pattern using the autocorrelation function. Then, the Gaussian Smoothing function (Gaussian Mixture

Model) modelled each pixel in the background as a mixture of Gaussians which used an online approximation for updating the model. This was used to smoothen and highlight the prominent peaks in the autocorrelation function so as to inspect and identify the flawed areas. After the smoothing process, the peaks compose an approximate parallelogram grid in which each quadrangle represents a texture primitive before the application of Hough transform. This was applied to obtain the pair of the placement vectors which can determine the shape and arrangement of the parallelograms, and the parallelogram is the texture primitive of the regular texture image. After that, an algorithm based on rough set theory with two steps; the training and testing stage, was used in the classification process. They proposed the use of 16 feature values of the flawed area as the condition attributes and 6 different fabric defects as the decision attributes. Lastly, six different fabric defects (Crack, Broken weft, Broken warps, Weaving Hole, Dotted oil spot, Linear oil spot) were chosen to test the ability of the proposed method. The result showed that such 95% of the defect types of patterned fabrics can be analysed by the system.

Hoseini, Farhadi and Tajeripour [23] introduced a fabric segmentation approach for detecting fabric defects using auto-correlation function. This was done by calculating the texture primitive template by auto-correlation function from defect-free fabric image in train phase, enhancing the defect areas through calculation of the difference between each texture primitive template and texture image, constructing the mean image to reduce high frequent information of background image, and computing a perfect automatic threshold by an Otsu's threshold approach to present a binary image as a defect pattern. In defect-free images, there is no difference between grey values of the pixels and grey level in texture primitive. In contrast, it could be seen an enormous difference in both intensity and geometrical defects and another striking change involve the grey values of the pixels in comparison to what was gain in a defect-free fabric. First, Auto-correlation function of vertical and horizontal images is used to calculate size of repetitive unit (size of texture primitive template). Then, the grey mean of each pixel is calculated to have primitive texture template. Because of the percentage of defects region is smaller than that of the defect-free fabric in fabric image, there is a little difference between every texture primitive and texture template calculated according to the above method in non-defective regions. But a great difference between them in defect regions is because the noticeable changes arising in their grey and texture structure. The images are subdivided into blocks again in the algorithm. The difference between every block and the primitive template is calculated to have an enhanced image. High-frequency noises are filtered through structure of the mean image by partitioning the image into 8x8 sub-images. This image is stretched to the original size using a bilinear interpolation mechanism. Otsu's threshold approach is then employed to segment the defect image. The simplicity and efficiency of robust algorithm make it suitable for on-line patterned and un-patterned fabric defect detection.

Anitha and Radha [24] compared the performances of three wavelet models in extracting fabric features that are suitable for quality inspection and detection. These three models which include the Tree structured wavelet transform, Gabor wavelet network and the wavelet transform with vector quantized principal component analysis (WTV-PCA) was combined individually with golden image subtraction for fabric defect identification. Defect like Broken Hole, Netting multiple, Oil stains, Dirty fabric for used for the performance comparison. Histogram equalization is used on the input image for the adjustment of the contrast of the input image. A lattice extraction was performed on the template image as well as the input image for extraction of features like energy and entropy using the corresponding wavelet-based method. Thresholding is applied for binary image generation after the difference between the template and input lattice had been calculated. To smoothen the binarized image, enhanced switching median filter is applied to determine whether the input image is defective or non-defective. The extracted features, entropy and energy are calculated from defect-free lattices which are then compared with the input lattice. The performances of the wavelet-based methods are evaluated using sensitivity, specificity and detection rate. The functionality of the approaches evaluated based on the segmented results of the input image and the performance metrics showed that the wavelet transforms with vector quantized principal component analysis combined with golden image subtraction (WTVP-GIS) method outperformed the other two methods for fabric defect detection from the dot patterned fabric.

The combination of Spatial and Spectral features extracted from grey-level co-occurrence matrix (GLCM) and Discrete Cosine Transform (DCT) respectively was used for automated fabric defect detection by Semiyya, Jyothi, and Najuma [25]. GLCM was used for extracting information about the spatial distribution of grey levels in an image while edge pattern in fabric images was fully captured from its DCT coefficients in frequency domain. The feature vectors were then classified with Artificial Neural Networks. However, very few samples (about 36 images) were used for the algorithm. Also, localization of the defect present in the fabric was not presented based on the features extracted in the proposed algorithm.

Venkateswaran and Arumugam [26] implemented a Defect Detection scheme in Fabric Images Using Two-Dimensional Discrete Wavelet Transformation Technique. In the algorithm, the choice of the Test Texture image was in BMP or JPEG format while noise reduction of the Test Texture image was by median filtering. Greyscale image Spatial Domain conversion into frequency domain was by Haar Wavelet. An Approximation Coefficient matrix image was extracted before computing the Otsu's threshold value and a number of regions in the approximation matrix image. Otsu's threshold value and the number of regions present in the test image with the reference image was compared in such a way that if the difference is greater than a detection sensitivity level (D), the test fabric image is declared defective; otherwise, test fabric image is defect free. Hole Defect, Stain, Miss-Pick, Miss-End, Double-Pick, Double-End Warp-Float, Course-Pick, Weft Density, Tear, Contamination, and Snarl were the defects considered in the analysis.

A novel Image Decomposition technique for patterned fabric inspection which is capable of determining the locations of faulty objects in patterned fabric images with sharp edges was proposed [27]. The method applied Artificial Neural Network (ANN) classifier to separate the faulty fabric from the fault-free ones, one sample for each type of defect (for training ANN). Considering the results obtained from 20 samples, the ANN affirmed a 95% accuracy with only a single error sample. In their work, Artificial Neural Network classifier is used for separation of faulty fabric from the fault-free ones. With 20 samples used the study, the ANN classifier performance gives a promising 95% accuracy with a single sample error. The Image Decomposition (ID) with ANN classifier defect detection technique presented in the study provides best results with ability to classify the defective and defect-free fabric images rather than using the standalone ID method.

Jing, Yang, and Li [28] proposed a Defect Detection technique based on Patterned Fabrics Using Distance Matching Function and Regular Band. Patterned fabrics were firstly disposed of by fabric average to form object images mixed with positive and negative pixels while distance matching function was computed to determine the periodic distance of patterned fabrics. The supervised defect detection method including training step and detection step was introduced in the work. Equalization pre-treatment was done on both non-defective fabrics and sample fabrics to reduce fabric noise and build a foundation for proposed algorithm. Patterned fabrics are dealt with grey pixels via row statistics and column statistics with certain length, and parameters m and n acted as the length are assigned to the size of patterned unit, which was calculated via distance matching function. The way of statistics fabric pixels was named as regular band. Feature one and feature two was computed on basis of regular band. In training step, feature one and feature two in regular band are calculated to receive the maximum and minimum. The gained extents of feature one and feature two in regular band are defined as threshold limits. In detection step, feature one and feature two of fabric defects would not be included in threshold limits, thus achieving defect detection on patterned fabrics. The proposed approach was able to achieve speedy online defect detection of patterned fabrics and matching the speed of detection system in the textile industry.

Kang, Yang, and Jing [29] applied genetic algorithm (GA) to select parameters of optimal Gabor filter for patterned fabric defect detection in MATLAB environment. Optimal Gabor filter was used for noise reduction information of printed fabrics as a means for achieving defect detection of printed patterned fabrics. Furthermore, distance matching function and Regular Band were utilised also to determine the unit of printed patterned fabrics. To realize defect segmentation of printed patterned fabrics, feature extraction was carried out on a moving unit of printed fabrics. These approaches were considered to be advantageous in that the fabric defect detection approach with Gabor filter using genetic algorithm (GA) has perfect detection results of random printed patterned fabrics and regular printed patterned fabrics correspondingly at little total detection time. In the experiments, 40 training samples and 90 testing samples with defects of patterned fabrics such as Hole, Thin Bar, Broken End, Netting Multiple and Thick Bar from TILDA database and Henry Y. T. Ngan of Industrial Automation Research Laboratory Department of Electrical and Electronic Engineering, the University of Hong Kong database are applied in the proposed methods. Overall Detection (OD), True Detection (TD), False Alarm (FA) and Misdetection (MD) were the performance metrics employed in the comparison of the detection result between regular band and Gabor filter method. Results showed that the Regular band has a good performance in detection of regularity of patterned fabrics for various defects by ignoring the background of patterned fabrics. The Gabor filter, on the other hand, can remove background influence and enhance defect region of fabrics. In addition, various defects with irregular fabrics can be inspected with Gabor filter. It has better performance in detection of random textures although defect region unclear to fabric background has difficulty in being recognized with Gabor filter especially when Netting Multiple Hole and Broken End defects are involved. It was found out also that when Fabric Background is close to the defect, Gabor filter is not suitable for detection while Regular band was not fit for irregular fabrics. Fabric defect must have difference with fabric background in colour for Gabor filtering. In general, Training of non-defective fabrics was implemented to extract parameters or calculate segmentation threshold, thus, achieving fabric detection and training step can avoid complicating calculations in detection step, so detection time can be small to realize real-time defect detection. Proposed methods are implemented fast which the regularity can satisfy the real-time of practice.

Nikam and Biadar [30] analysed Bollinger Band method for the representation of defective objects and repeated patterns textures in fabric images. The predominant feature of most Patterned texture material inspections is Regularity. Bollinger Band (BB) method was used for shape outlining of the defective region by calculating Bollinger Band based on standard deviation and moving average. The Bollinger Band method is not affected by the alignment and is based on shift-invariant approach. The defective areas in a patterned fabric are indicated by the development of upper Bollinger band and lower Bollinger bands. Bollinger Band (BB) method has a simple defined mathematics, large variation in the standard deviation occurs in the pattern when an abnormal change is made. The application of Bollinger Band for patterned texture (patterned regular textures and irregular textures) defect detection was divided into training stage and testing stage. To calculate the Bollinger band, the threshold values of Upper band of testing stage are compared with the threshold values of upper band of training stage (reference image) and the testing stage threshold values of lower band are compared with threshold values of lower band of training stage (reference image). The defected images with defect were histogram equalized before calculating the moving average or mean. This was followed by representation of Bollinger band for with defects by calculating the value of upper band and lower band. Comparison of threshold values in the testing stage and training stage was used to detect the defects in the image. The Bollinger band method was very effective for regular patterned fabric defect detection that offered numerous advantages such as its durability that is periodic in nature that affect the output, its suitability to optimise the period length if it selects a larger than repetitive unit, possibility to solve the alignment problems associated with wavelet subtraction techniques and its requirement of a less computational time. The turnoff for this method is its inability to detect light colour differences such as light shade.

Deshmukh, Raut and Biradar [31] implemented a fabric detection and classification system that was based on the principle of spectral estimation technique vision to locate defected regions accurately in patterned fabric and classifying them using rough set classifier theory. The Regular pattern from the patterned fabric image was extracted using Estimating Signal Parameter through Rotational Invariance Technique (ESPRIT), a high-resolution subspace-based method that can find the periods of a periodic signal, such that the defected region (the shape and location of the flawed areas) are detected by the comparison of the patterned image and the source image. The repetitive unit of patterned fabric is first estimated by ESPRIT algorithm. ESPRIT produces signal parameter estimates directly in terms of characteristic values. Then a subtraction and threshold method are used to detect and locate the position of the imperfect areas. Finally, the flawed areas are imported into a rough set classifier to classify the type of defects. The results from the experiment established that the proposed technique can detect and classify the defects for the patterned fabrics with an overall successful detection and classification rate of about 95% and a test speed of about 5 images per second on a 1.7 GHz Intel i5 core processor computer.

3 EXISTING FABRIC DEFECT DETECTION AND CLASSIFICATION ALGORITHMS IN COLOURED PATTERNED FABRIC

Yu, Hu, and Baciu [32] introduced a defect detection method for use on jacquard fabrics that is based on multiple colour-channel analysis such that when a number of colour yarns are employed, a number of colour channels can be extracted from an arbitrary jacquard fabric. Images of each colour channel are patterned. By first separating the colour channel of an input test fabric image, then eliminating noise and applying a pattern extraction process, it is possible to produce a set of channel patterns. Three kinds of micro-colour defects occurring in coloured jacquard fabric like missing coloured yarn, additional coloured yarn, and density variation as well as weave fabric defects were considered. First, all colour channels are extracted from the original input image. A series of steps are then applied to enhance and extract comparable colour channel patterns which include eliminating dotted noise, extracting accumulation histogram-based channel patterns, and combining cross colour channel. Finally, a pattern comparison method was introduced which makes use of a Fourier transform and frequency spectrum analysis. Seven significant features extracted from the frequency spectrum are used to characterize each of three defects. In the implementation of the work, the first step in a multiple-colour channel-based jacquard defect detection method involves colour channel separation using a Neural Network (NN) which segments the jacquard image into colour channel images. The Mutual Nearest Neighbour (MNN) method was used to cluster a sampled jacquard image. YCbCr colour space of jacquard fabric usually comprises woven yarns of colours relatively close in chrominance but of different depths. The YCbCr space ensured that this difference in chrominance is detected and maintained. The YCbCr space also has the advantage that its coordinate system is sensitive to the depth value. Colour classification tasks were carried out by the back-propagation (BP) neutral Networks. For the colour channel pattern extraction step, pattern from a colour channel image separated from the original jacquard image involved the elimination of dotted noise using a morphological opening operator in the raw colour channel image while the channel pattern is extracted by applying a Maximal Value Alternatively Taking (MVAT) method. Fourier transform and frequency spectrum analysis-based template comparison methods for characterizing and detecting defects in colour jacquard fabrics were then employed. Instead of using the whole spectrum, a substitute method that uses just seven significant features extracted from the spectrum was implemented. Experiments show that this defect detection method can efficiently classify and detect jacquard colour defects. However, there were limitations to the number of defects that were considered.

The yarn-dyed fabric is woven with dyed yarns. Its repetitive colour patterns depend on the variations of the permutations and combinations of differently coloured warps and wefts in its design. Yarn-dyed fabrics are divided into colour dots, colour stripes, colour checks and more complexly colour patterns based on repetitive colour units. Li, Xue, & Cheng [33], in their work implemented an algorithm for detection of defects of yarn-dyed fabric via computer vision where consideration was given to the inherent characteristics of texture (colour and structure). It was found that the defects of yarn-dyed fabrics are detected with difficulty, as they are hidden in the background of coloured patterns. The signal analysis shows that the edges of defects and regular coloured patterns belong to high-frequency components in the frequency domain, while the background areas of yarn-dyed fabric images are low-frequency components. Therefore, the yarn-dyed textured image fabrics are first enhanced by fractional order differentials for edge and texture enhancement, as well as smooth areas preservation of regular coloured patterns in the stage of defect detection. The enhanced textured coloured images are converted from RGB space to L*a*b* space where two chromatic channels are combined into plural chromatic channel. Then, the plural chromatic and grey channels are filtered by the Log-Gabor filters the energy spectrum of the two channels are fused and the energy-based local binary pattern (ELBP) feature vector is obtained to form the energy-based feature images of the yarn-dyed fabrics.

Habib and Rokonuzzaman [34] posited that works reported to the time of their research have claimed varying level of successes in detection and classification of different types of defects through back-propagation model. In those studies, Habib and Rokonuzzaman [34] reported no investigation has been carried out regarding the variation of major performance parameters of neural network (NN) based classifiers such as training time and classification accuracy based on network topology and training parameters. As a result, the research focused on the empirical investigation of interrelationship between performance metrics such as accuracy and training time and the network design parameters: momentum rate (α), learning rate (γ), and model architecture (number of hidden layer computing units) of back-propagation based classifier for textile defect classification which is mainly an optimisation problem. The intention was to increase accuracy and a reduced training time. Accuracy and training time depend on complexity of the model, learning rate and momentum rate. In this work, defects which frequently occur in knitted fabrics, namely hole, missing yarn (horizontal and vertical), colour yarn and spot were considered. About one hundred colour images of defective and defect-free knitted fabrics of seven colours are captured using a 9.5- megapixel Fuji camera whose model is FinePix S950 processed with inspection images of size 512×512 pixels, were converted into a greyscale image. The greyscale image was filtered by 7×7 low-pass filter convolution mask and the images are formed from greyscale histograms. Histogram peak technique was used to calculate two threshold values, θL and θH from each of these histograms for conversion to binary images. These binary images contain defects if any exists, defect-free fabric, and some noises such that the noises are smaller than the minimum defect wanted to detect. So, binary images get eliminated when any defects are smaller than the minimum-defect size in pixels. Then a number of features such as Height of Defect Window, Width of Defect Window, Height to Width Ratio of Defect Window, and Number of Defective Regions of defects are calculated, which forms feature vectors corresponding to defects present in images. The tasks in classification step involve finding proper back-propagation model from several back-propagation models. To determine these, hundred colour images of defect-free and defective knitted fabrics of seven colours were captured to obtain 100 number of calculated sample feature vectors for training and testing purposes. Features scaling is made for proper balance among the differences of feature values of defect types. Back-propagation (BP) model was trained with a maximum iteration of 106, maximum training time 1 hour and 0.001 as the maximum tolerable error. Retraining and testing Artificial Neural Network (ANN) is carried out in order to eliminate incoming and outgoing edges associated with some computing units. The process is carried on until an unacceptable level for the network performance reaches. Author did not explicitly compare their approach with other works due to the nature of intended application, performance evaluation and lack of uniformity in the image data set. Also, conclusive comment could not be made, due to the sample size (100 training samples) used in implementing the Back-propagation model. Moreover, very high-quality images could not be achieved when acquiring images due to poor lighting which impedes accurate classification of such textile images.

Zhu, Pan, Gao and Zhang [35] presented a new detection algorithm for yarn-dyed fabric defect based on autocorrelation function and grey level co-occurrence matrix (GLCM). Autocorrelation function was first used to determine the pattern period of yarn-dyed fabric and according to this, the size of detection window can be obtained. Secondly, GLCMs are calculated with the specified parameters to characterize the original image. Thirdly, Euclidean distances of GLCMs between the detected images and template image, which was selected from the defect-free fabric were computed and then the threshold value was given to realize the defect detection. A type of yarn-dyed fabric containing two colours was selected to verify the validity and accuracy of the algorithm and thereafter, another type of yarn-dyed fabric containing three colours was chosen to test the robustness of the algorithm. The tests of the algorithm show that the algorithm proposed for yarn-dyed fabric with small organization cycle not only has high accuracy but also has better adaptability. The application of the algorithm in online detection of weaving industry will be analyzed in the future study.

4 Conclusion

While some of the challenges of embarking on patterned fabric defect detection and classification have been the issue of the repetitive design that provides more underlying information, the complicated and varied fabric texture transform, regular and irregular patterns that are perceived to be periodic or homogeneous, spatial relationship between intensity values and the repeat distance of a repetitive unit, deformations that are easily caused by inner and outer forces, such as bending, torsion, tension and compression, illumination variation, colour-channel analysis have been overcome using different novel techniques, many of the existing FDDC approaches are still susceptible to lack of uniformity in the image data set and challenges with high-quality images. It is expected that future work in efficient dynamic texture segmentation and effective background subtraction will help in developing accurate FDDC systems. Also, as it is illustrated by previous studies, a more robust Patterned Fabric Defect Detection and Classification System with high detection accuracies for high quality patterned images in fast computation time can be obtained by combining multi-spectrum information using various image fusion techniques. Though such systems may be currently expensive, they will be very useful with decrease in the costs of multi-spectrum image acquisition devices.

Table 1. Performance of Some Reviewed Article of Patterned FDDC System

Method	Author(s)	Database & Size	Fabric Type	Success Rate		
				Accuracy	Sensitivity	Specificity
Wavelet Transform + Golden Image Subtraction (GIS)	Ngan, H.Y.T., Pang, G.K.H., Yung, S.P. and Ng, M.K	30 defect-free images and 30 defective patterned images	patterned jacquard	96.7%	NA	NA
Regular Band (RB) Method	Ngan, H.Y.T., and Pang, G.K.H	166 defective and defect-free images		99.4%	NA	NA
One Dimensional Local Binary Pattern (1DLBP)	Fekri-Ershad, S and Tajeripur, F	20 images	Dot Pattern	96.6%	97.8%	96.8%
		20 images	Box Pattern	93.2%	94.4%	96.2%
		20 images	Star Pattern	97.9%	98.3%	97.5%
	Reddy, R. O. K., Reddy, B. E., and Reddy E. K		Star, Box and Dot Pattern	SVM	K-NN	PNN
LBP				100%	100%	33.3333%
SLBP				100%	100%	33.3333%
LLBP				100%	100%	33.3333%
GLCM				33.3333%	33.3333%	33.3333%
LBP + GLCM				100%	100%	33.3333%
SLBP + GCLM				100%	100%	33.3333%
LLBP + GLCM				100%	100%	33.3333%
Regular Band (RB)	Javed, A., Ullah, M. A., and Aziz-ur-Rehman	166 images	Box, Star and Dot pattern	99.4%		
Gabor Wavelet Filter		71 images		96%		
Wavelet-Texture +LVQ Neural Network		350 images		95%		
Computer Vision + ANN		200 images		77%		
Digital Image Analysis		2000 images		83%		
Autocorrelation Function + Gaussian Mixture Model + Hough Transform + Rough Theory Classifier	Li, M., Wang, B., and Cui, S	150 defected and 30 defect-free images		95%		
Wavelet-Based Methods (WBM)	Anitha S., and Radha, V	100 images	Dot pattern	86.5%	84.6%	84.6%
Tree Structured Wavelet Transform + Golden Image Subtraction (TSWT-GIS)				90.1%	88.2%	88.5%
Wavelet Transform with Vector Quantized Principal Component Analysis + Golden Image Subtraction (WTVPCA-GIS)				91.0%	89.2%	89.7%
Gabor Wavelet Network + Golden Image Subtraction (GWN-GIS)				90.3%	88.7%	89.2%
Image Decomposition (ID) + Artificial Neural Network (ANN)	Karunamoorthy, Somasundareswari, and Sethu	20 sample images	Box, Star and Dot pattern	95%		
Estimating Signal Parameter Through Rotational Invariance Technique (ESPRIT)	Deshmukh, Raut, and Biradar			95%		

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