AN AUTOMATED FABRIC FAULT DETECTION AND CLASSIFICATION SYSTEM BASED ON COMPUTER VISION AND SOFT COMPUTING

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Abstract

Fabric inspection is one of the essential quality control processes in weaving mills. The automation of this process using computer vision systems is expected to increase the efficiency of the process and increase the total profit revenues on the long run. This work introduces a computer vision system that has the capability to detect and classify a relatively large number of fabric defects. Image enhancement techniques were used in processing the fabric acquired images. Spatial and spectral features were extracted from the processed images and used as inputs to soft-computing classifiers. Two approaches were used in the classification with the aim of reducing the calculation time required during the image analysis. The successful classification rate was 97.3% using the direct approach that has a slightly longer processing time. The performance of the classifiers in the series approach ranges between 91 to 100% depending on the classification level and the used image features. Results of this work with high classification rate and short processing time are promising to apply the introduced technique in real time fabric inspection systems.

Introduction

The conventional inspection process in the weaving mills usually depends on human visual inspection which only detects 60 to 70% out of the total fabric defects. The other defects pass without detection and cause several problems in the following processes of manufacturing. In addition, fixing defects is a complicated process and the defective parts are usually discarded as wastes that might be recycled or sold at low prices (usually 45 to 65% from the free defect price). Several researchers have tried to solve this problem using image processing techniques and implemented different spatial and spectral methods for image analysis and feature extraction. Kuo and Su [1] applied the co-occurrence matrix and gray relational analysis. The gray relational analysis was also used to investigate correlations of the analyzed factors among the selected features in a randomized factor sequence through image processing. The system classified different defects such as broken warps, broken wefts, holes, and oil stains with 94% recognition accuracy of the system.

Shady et al. [2] used image analysis and neural networks for six different knitted fabric defects detection and classification. Statistical approaches and Fourier Transforms were used for feature extraction and artificial neural networks were used to classify the defects. The results of using the Fourier transform features were slightly more successful than the statistical approach in detecting the defect-free samples and classifying most of the defects.

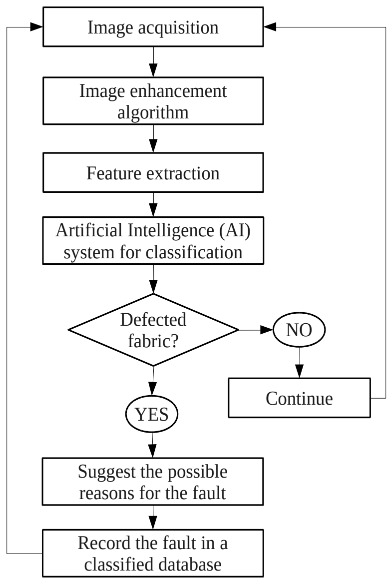
Mallik and Datta [3] presented a theoretical based technique for real-time fabric defect detection using a joint transform correlator that is extension of Fourier transform analysis. The joint power spectrum showed better classification results compared to the Fourier and experimental results. The technique introduced reasonable results for identifying and classifying some defects such as the existence of thick yarns, knots, and missing yarns.

Hu and Tsai [4] used wavelet packet transform and an artificial neural network (ANN) to inspect four kinds of fabric defects. The approach was reliable and effective in classifying fabric defects with a total classification rate of 100% for a wavelet function with a maximum vanishing moment of four and three resolution levels. Wen et al. [5] also used wavelet transform and co-occurrence matrix to extract features of textured images. The system was able to detect whether the fabric is defective or not at 92% rate of success. Also, the system was able to locate the defect position at 84% rate of success.

It can be seen from the survived literature that most of the applied detection systems were able to classify a few number of defects which may not efficient in practical production environments. Therefore, this work introduces an automated fabric fault detection and classification (FFDC) system to detect and classify a larger number of woven fabric defects.

1 Methods

The overview of the FFDC computer vision system is shown in Figure 1. The system utilizes a digital camera to acquire and transmit fabric images to a computer which enhances and extracts some features for each image. The features are then processed using an Artificial Intelligence (AI) technique to detect and classify the fabric defects. Also, the FFDC system predicts the sources of the defects to be fixed. These defects are recorded in a database providing a report of the frequent defects for fixing their sources and consequently increasing the quality of the manufactured fabrics. Therefore, applying such automatic system in weaving mills is expected to increase the profit and the product quality.

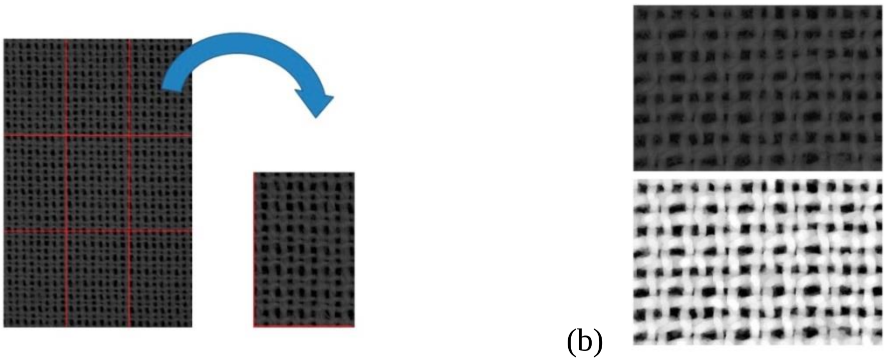


Source: Own

Fig. 1: *Flow chart of the FFDC algorithm*

1.1 Image enhancement

The size of the acquired images is 3088 x 2056 pixels which represents a fabric sample with dimension of 30 x 20 mm. To make defects more detectable in the acquired images, each image was divided into nine sub-images. Image enhancement was applied to remove the noise and hairiness from the woven fabric images and adjust their gray levels, shown in Figure 2. The enhanced images should facilitate the allocation of the fabric defects.



(a) (b)

Source: Own

Fig. 2: *(a) A fabric image that was divided into nine sub-images; (b) A true-color image (top) and enhanced image (bottom) after noise removal and gray level adjustment*

1.2 Feature extraction

The feature pool consists of three statistical and six spectral features. The statistical features (the mean, the summation, and the standard of deviation) were chosen for their simplicity and faster calculation. The determination of the statistical features was performed according to the following relations:

The mean

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \quad (1)$$

The summation of columns or rows:

$$R = \sum_{i=1}^{n} x_i \quad (2)$$

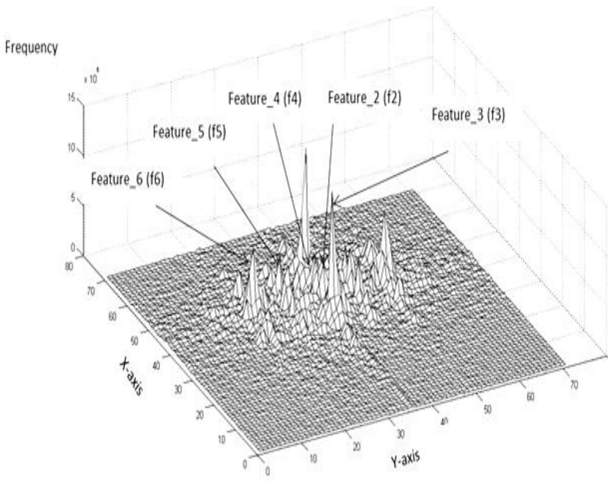
The standard deviation:

$$s = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2} \quad (3)$$

The spectral features were based on the Fourier transform technique that transforms pictures from their spatial domain to the spectral domain. If the image is considered as a function *f(m,n)* with two discrete spatial variables *m* and *n*, then the two-dimensional Fourier transform *F(m,n)* is defined by the relationship:

$$F(w_1, w_2) = \sum_{m=-\infty}^{\infty}\sum_{n=-\infty}^{\infty} f(m,n)\ e^{-j\omega_1 m}\ e^{-j\omega_2 n} \quad (4)$$

After transforming the image to the spectral domain, the power spectrum of the image can be calculated and some dominant peaks can be used as image features. An example of some of these features is illustrated in Figure 3.



Source: Own

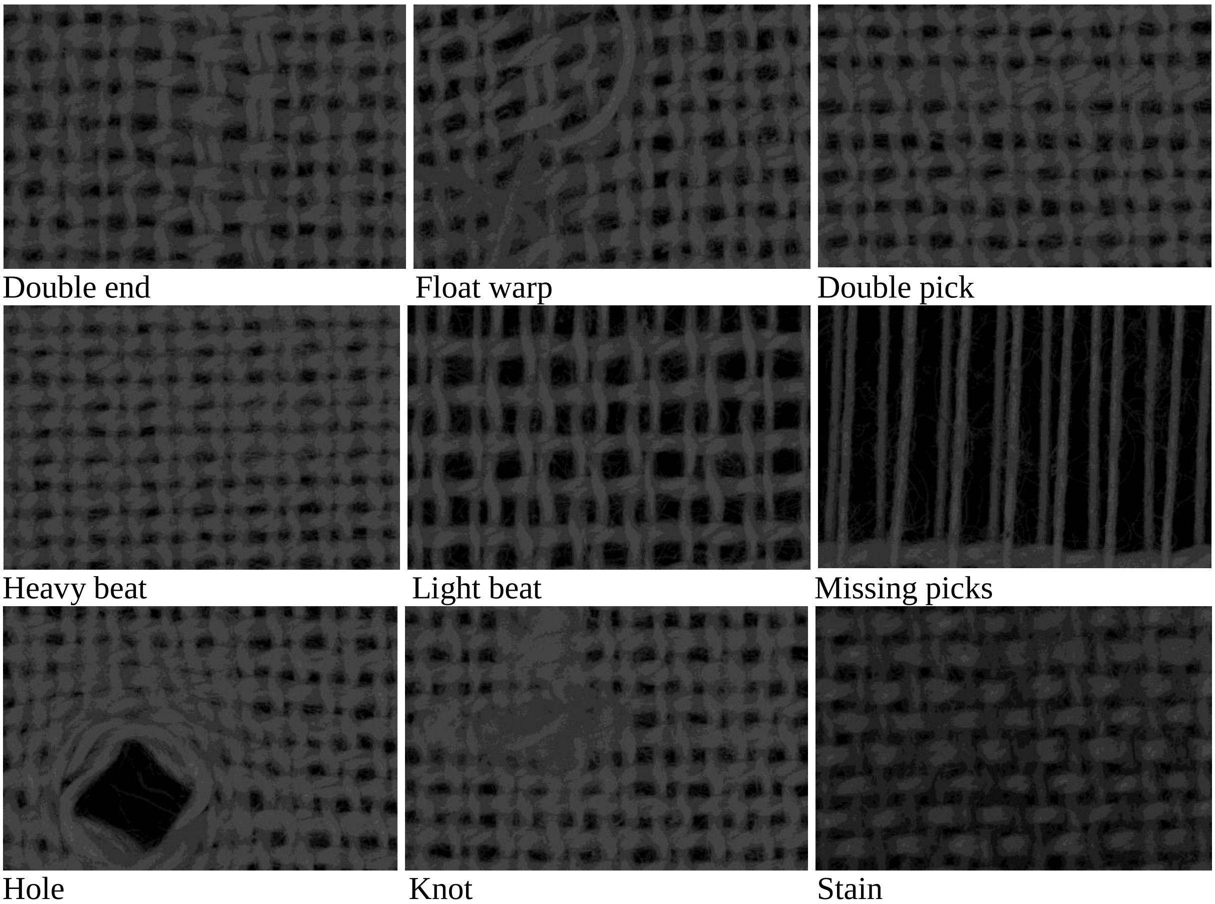
Fig. 3: *Some spectral features of the Fourier transformed image*

1.3 Artificial neural network

Artificial neural networks (ANN) were used as soft computing techniques for classifying defected and non-defected samples. Different network architectures were used and the optimized network structure includes a multi-layer network with two hidden layers (25 neurons per layer). The input and output layers were adjusted according to the used features and the required fault categories. Three groups of features were used: solely statistical features, solely spectral features, and combination of statistical and spectral features. The classification went through two approaches by either identifying the defect type directly from the input features (the direct approach) or by identifying the defect at different levels (series approach). In the series approach the classification three steps have been taken; the first step classifies if the fabric sample is defected or defect-free. The second step classifies the defect category (warp, weft, or areal) and the third step identifies the defect type.

2 Experimental setup

The fabric samples used in this study were manufactured at “Samanoud Company for Woven & Pile Fabrics” on a Sulzer-Ruti weaving machine. The fabric structure is plain weave 1/1 with a yarn count of 20/1 Ne for warp and 14/1 Ne for weft. The densities of warp and weft yarns are 20 and 18 per cm, respectively. The chosen defects were intentionally introduced on the machine based on the knowledge of defects sources. The used defects, shown in Figure 4, were categorized into three main categories; defects in warp direction (double end and float warp), defects in weft direction (double pick, heavy peat, light peat, and missing picks), and areal defects (hole, knots, and stains).



Source: Own

Fig. 4: *Images for some fabric faults*

3 Results and Discussions

The set of image features was divided into three groups for the artificial neural network (ANN) training, validating, and testing. The results of the testing sets are summarized in Table 1 for the direct and the series approaches. The results of the direct approach show that the classification using only Fourier features gets better results than using solely statistical features and the application of both features (statistical and spectral) gets the best results among the three inputs.

Tab. 1: *The overall performance of the ANN classification system*

		Statistical features	**Spectral features**	**Statistical and spectral features**
	Direct approach	84.5	92.7	97.3
Series approach	Defect or defect-free	91	89	87
	Warp, weft, or areal	89.3	95.3	94.7
	Warp defects	100	95	100
	Weft defects	100	100	100
	Areal defects	90	93.3	100

Source: Own

The series approach was suggested in this study to minimize the calculation time allowing a real time processing of the fabric samples. According to this approach, no further processing for the defect-free samples is required in the case of their classification at the first stage. Defected samples go for further classification in the next classifiers by categorizing the defect (warp, weft, or areal) in the second ANN. The category is considered as an input of the next classifier to determine the exact fault type.

The results of the series approach differ according to the level of classification as shown in Table 1 and the testing of the classifiers using different features show that:

- *First classifier*: The purpose of this classifier is to determine if the fabric is defected or not. The classification using only Fourier features gets better results than using both types of features (statistical and spectral) while using the statistical features only gets the best results. This result may be counter intuitive; however, the consideration of many features as inputs for the classifier may "confuse" the system and decrease its classification performance. Therefore, optimizing the input features should be considered to reduce the number of inputs for the system. The principle component analysis technique might be useful for input reduction and optimization.
- *Second classifier*: The purpose of this classifier is to categorize the fabric fault (warp, weft or areal). The best classification results were obtained using the Fourier spectral features while the combination of the spectral and spatial features performs better than the application of statistical features only.
- *Third classifier*: The purpose of this classifier is to identify the fault and produce its exact type. The performance of this classifier depends on the fault category as shown in Table 1 where the combination of statistical and spectral features gives the best classification results with 100% rate of successful classification. It is noticeable that the classifier has the ability to differentiate the weft defects using any set of features (statistical only, spectral only, or their combination) although having the highest number of faults in this category. The 100% successful classification for the warp and weft categories using solely statistical features may be useful in the real-time classification because of the short time calculation of these spatial features.

Conclusion

This work utilizes a digital camera to acquire and transmit fabric images to a computer which enhances and extracts the features for individual images. The features are then processed using an artificial intelligence technique to classify the fabric faults. Two approaches were implemented in this study with direct classification approach and series approach. The results of the direct approach show that the use of a combination of statistical and spectral features gives a 97.3% successful classification. The series approach aimed to reduce the processing time and its testing shows the dependence of the classifiers performance on the given set of features. The application of a whole set of statistical and spectral features performs best in most classification categories while solely statistical features only were sufficient (with their short calculation time) in determining whether the fabric was defected or not and in determining the faults within the warp and weft categories. The results of this study are promising and may allow the application of the introduced technique in real time fabric inspection systems because of the high successful classification rate and the relatively short processing time.

Literature

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AUTOMATIZACE KONTROLY TKANIN POMOCÍ POČÍTAČOVÝCH KAMEROVÝCH SYSTÉMŮ

Kontrola tkanin je jedním ze základních procesů řízení kvality v tkalcovnách. Od automatizace tohoto procesu pomocí počítačových kamerových systémů se očekává zvýšení efektivnosti procesu a z dlouhodobého hlediska celkové zvýšení zisků. Tato práce představuje počítačový kamerový systém, který má schopnost rozpoznat a klasifikovat relativně velké množství textilních vad. Při zpracovávání obrazu tkaniny byly použity techniky na jeho vylepšení. Ze zpracovaných obrazů byly extrahovány prostorové a spektrální vlastnosti a použity jako vstupy do výpočtových klasifikátorů. V klasifikaci byly použity dva přístupy s cílem snížit dobu výpočtu potřebnou při analýze obrazu. Úspěšná klasifikace činila 97,3 % pomocí přímého přístupu, který má o něco delší dobu zpracování. Výkonnost klasifikátorů série se pohybuje v rozmezí 91 až 100 % v závislosti na klasifikačním stupni a použitých obrazových funkcích. Výsledky této práce s vysokou mírou úspěšnosti klasifikace a krátkou dobou zpracování slibují možnost zavést tuto techniku do kontrolních systémů tkanin v reálném čase.

EINE AUTOMATISIERTE TEXTILFEHLERAUFDECKUNG UND EINE AUF COMPUTERVISION UND ELASTISCHE BERECHNUNGEN BASIERTE KLASSIFIZIERUNG

Die Kontrolle von Geweben ist eine der wichtigsten Vorgänge bei der Gestaltung von Qualität in Webereibetrieben. Von einer Automatisierung dieses Prozesses mit Hilfe von computergesteuerten Kamerasystemen werden eine Steigerung der Effektivität des Prozesses und insgesamt eine langfristige Gewinnsteigerung erwartet. Die vorliegende Arbeit stellt ein computergesteuertes Kamerasystem vor, welches die Fähigkeit besitzt, eine relativ große Menge an Textilfehlern zu erkennen und zu klassifizieren. Bei der Verarbeitung des Gewebebildes wurden Techniken zu dessen Verbesserung verwendet. Aus den verarbeiteten Bildern wurden räumliche und spektrale Eigenschaften extrahiert und als Eingang in Berechnungsklassifikatoren genutzt. Bei der Klassifizierung wurden von zwei Ansätzen ausgegangen mit dem Ziel, die Zeitdauer der zur Bildanalyse notwendigen Zeitdauer zu senken. Die erfolgreiche Klassifizierung betrug mit Hilfe des direkten Ansatzes 97,3%. Dieser Ansatz benötigt eine etwas längere Bearbeitungszeit. Die Leistungsfähigkeit der Klassifikatoren bewegt sich zwischen 91 und 100%, in Abhängigkeit vom Klassifikationsgrad und den verwendeten Bildfunktionen. Die Ergebnisse der vorliegenden Arbeit, die auf einem hohen Klassifikationsmaß und einer geringen Bearbeitungszeitberuhen, versprechen die Möglichkeit, diese Technik in einer realen Zeit in die Kontrollsysteme der Gewebe einzuführen.

AUTOMATYZACJA KONTROLI TKANIN PRZY POMOCY KOMPUTEROWYCH SYSTEMÓW WIZYJNYCH

Kontrola tkanin należy do podstawowych procesów zarządzania jakością w tkalniach. Od automatyzacji tego procesu przy pomocy komputerowych systemów wizyjnych oczekuje się zwiększenia efektywności procesu a długofalowo ogólnego zwiększenia zysków. Niniejsze opracowanie przedstawia komputerowy system kamer, który potrafi rozpoznać i klasyfikować stosunkowo dużą ilość wad tekstyliów. Przy przetwarzaniu obrazu tkaniny wykorzystano techniki mające na celu jego ulepszenie. Z przetworzonych obrazów ekstrahowano właściwości przestrzenne i spektralne, które wykorzystano jako dane wejściowe do klasyfikatorów obliczeniowych. W klasyfikacji zastosowano dwa podejścia w celu skrócenia czasu wyliczeń niezbędnego do analizy obrazu. Udana klasyfikacja wynosiła 97,3% przy podejściu bezpośrednim, które ma o nieco dłuższy czas wykonania. Wydajność klasyfikatorów serii mieści się w granicach 91 do 100% w zależności od stopnia klasyfikacyjnego i zastosowanych funkcji obrazu. Wyniki tej pracy z wysokim stopniem klasyfikacji i krótkim czasem opracowania są obiecującą możliwością wprowadzenia tej techniki do systemów kontroli tkanin w czasie rzeczywistym.