Defect Detection of Knitted Fabrics Using Image Analysis

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***Abstract*—A fabric defect is defined as any abnormality that spoils the aesthetics of the fabric which hinders its acceptability by the consumer. The defects in the fabric can cause to reduce the finish garment's price by 45–65%. This research is motivated on detecting defects of weft-knitted fabrics which have a unique surface that may lead to holding back the human vision defects inspection. It triggers the emerge of automated fabric defect inspection to replace manual inspection while increasing accuracy and convenience. The model identifies the images by 'defected' or 'defect-free' using digital photos on the manufacturing premises. To avoid an overfitting dataset, data augmentation techniques are used and grey-scale images to minimize the complication with RGB images that cause to increase in the accuracy of the model with a larger number of data. The model performed 98.00% and 95.67% of training and validation accuracy rates respectively.**

Keywords— fabric defect detection, image classification, weft-knitted, Convolutional Neural Networks (CNN)

I. Introduction

The apparel manufacturing industry can be thought-out as the lifeblood of Sri Lankan's economy. The apparel and textile industry contributes 6% to Sri Lanka's GDP while accounting for 40% of the country's total exports by 2019 [1]. In the apparel business, fabrics are taken as the main material. Among different kinds of fabrics, knitted fabrics are known as comparatively faster and more economical process-wise which could open up new manufacturing opportunities for countries like Sri Lanka. Knitted fabrics are different from other fabric types by nature, appearance and are often superimposed since these materials are more flexible and can be more readily constructed into smaller pieces. The surface of a knitted fabric is also somewhat complex which can be easily identified. According to the knitting method, knitted fabrics are classified into two parties as weft-knitted and wrap-knitted.

"Quality" simply indicates that customer needs are satisfied at the end of the day. Ensuring the quality of a product is considered a crucial point in contemporary industrial manufacturing. When it comes to the apparel industry, the quality of the finished garment decides the future of the business without a doubt. The ultimate goal of the quality control process is to maximize the production of garments within the specified tolerances correctly the first time and to achieve a satisfactory design of the fabric or garment concerning the level of choice in design, styles, colors, the suitability of components and fitness of the product for the market. Any abnormality in the fabric that hinders its acceptability by the consumer is considered as fabric defect. The statistics indicate that fabric defects may cause to reduce the price of a finish garment's 45–65% [2].

The traditional method of human vision based defect detection could be helped in finding minor defects immediately. Nonetheless, the efficiency of manual detection can reduce gradually with the working time. Hence, it is necessary to develop an automatic inspection model for fabric defects to improve the quality of the fabric, while reducing human labor costs and errors that tend to occur. Though many types of research are out there that focus on the very problem, the apparel industry resists to acquire them due to the costly investment they have to make. Fundamentally, automated fabric inspection involves two challenges as defect detection and defect classification. The methods for fabric defect detection can be varied with various fabric types, manufacturing methodologies, etc. The defect classification also follows the same. Through this research, a model for defect defection of weft knitted fabrics will be proposed that can be implemented at a minimal cost and computational power using Convolutional Neural Networks (CNN) with high accuracy. The model is capable of identifying the defects and categorizing them basically into four categories

Fig. 1 Defect-Free Weft-knitted Fabric Images

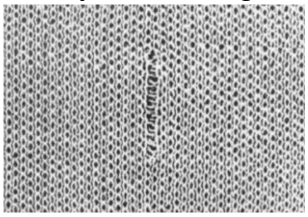

Fig. 2 Drop Stitch Defect of Weft-knitted Fabric

Fig. 3 . Holes Defect of Weft-knitted Fabric

Fig. 4 Oil Stains Defect of Weft-knitted

as defect-free, drop stitches, holes, and oil stains.

II. Review of Previous Work

For defect detection and classification purposes, various techniques have been used in researches. They are driven through either online or offline basis. According to the chosen method for fabric defect detection, the researches can be regarded into seven approaches as structural, statistical, spectral, model-based, learning, hybrid, and comparison [3].

The structural approach mainly considers texture as a composition of textural primitives. The overall texture of the fabric pattern can be achieved with the composition of simple texture structures according to this method. In statistical approaches, first-order statistics and second-order statistics are used to extract textural features in

texture classification. Bi-level Thresholding, Gray level statistics, Morphological operations, Autocorrelation, Normalized cross correlation, Multilevel thresholding rank order functions like techniques are used in this method. A large number of studies are conducted focusing on the spectral approach. Such researches need to have a high degree of periodicity. Some techniques such as Fourier transform Gabor filtering [14], Wavelet transform [15] is applicable to this approach. However, this approach is not recommended for fabrics containing random texture. In model-based approaches, with the help of the model built, identification of the texture as well as texture synthesis is carried out. Suitable for fabric images that have surface changes due to defects for instance yarn breakage and needle breakage. Under the learning-based approach, many pieces of research are there that cover up various techniques, naming a few, ANN, adaptive neuro-fuzzy system, Support Vector Machines (SVM), Gauss Markov random field, Poisons model, Model-based clustering, etc. By combining two or more approaches from above, some researches have used a hybrid approach. The main objective of using a hybrid approach is minimizing the computational complexity and increasing the rate of defect detection. Comparison studies are done by comparing the methods mentioned above which have great significance.

Some researches have been focused on fabric defect detection, have used Artificial Neural Networks (ANN), wavelet transform, mathematical morphology, Fourier transform, Gabor transform, etc as their technique. Zhoufeng Liu. et. al. has introduced a lightweight CNN to reduce the computational costs and storage services using depth-wise separable convolutions. For feature extraction, they have used a multi-scale feature extraction method. In the above research, the dataset consists of 3000 images and has achieved a 97.7% accuracy rate [4]. Research has been conducted based on uniform textured fabrics by Prasanna Bandara, et al. which used thresholding and morphological operations for feature extraction in fabrics under different light conditions for defect identification [5]. A novel detection algorithm based on Gabor-HOG (GHOG) for feature extraction and low-rank decomposition for decomposing the fabric image into normal background and defect, respectively has been introduced for Pattern fabrics (dot, box, and star-patterned). There's no guarantee in this method whether it will suit complex patterns as well since a limited number of patterns have been used [6].

The researches that have aimed the defect classification have been used some classification techniques like Bayesian classifier [13], Convolutional Neural Networks, Fuzzy C-mean method, and more. For example, the research base on the same domain, knitted fabrics, has done the classification of defects using Artificial Neural Networks which has mainly limited to holes and thick places in the knitted fabric. In this research, the best evaluation performance was obtained as 83.3% even with the limited defect types [7]. As the classification method, the Fuzzy C-Mean method is preferred in some researches. In this selected research, it has focused on the missing thread in weft or warp, oil stains, and holes kind of defects with a limited dataset of 45 samples [8]. Habib, et al. has conducted the research using a statistical approach for feature extraction and the Bayesian classifier to classify the revealed defects in the fabric. The results have reached 99.85% accuracy. The researchers considered 13 features from both geometric and statistic characteristics. As they mentioned, they completely relied on the dataset with features extracted with statistical techniques [9].

Related to the weft-knitted fabrics domain, there are a few kinds of research that have been conducted recently aiming at the knitted fabrics. The techniques varied from one another and even it can be varied with the knitting machines also. For instance, proposing Shearlet transform with segmented threshold de-noising to segment a warp-knitted fabric defect can be highlighted [10]. In another research, they have applied the same technique with single jersey knitting fabric defects using a comprehensive fabric database called Fabric Defect Detection Database (FDDD). This proposed system has achieved higher accuracy like 94% [11]. Bassel A. El-Azab, et al. targets to locate, classify defect of fabrics in order to control the circular weft knitting machine based on three critical weft-knitted fabric defects using log-gabor and neural network as a classifier with an acceptable accuracy of 80% [12].

III. Methodology

Methodology of this research is to implement a suitable model to identify defect detection and classify them accordingly with high accuracy and efficiency. The methodology carries out in five main phases as Image Acquisition, Image Preprocessing, Partitioning Data, Data Augmentation, and Training and Testing.

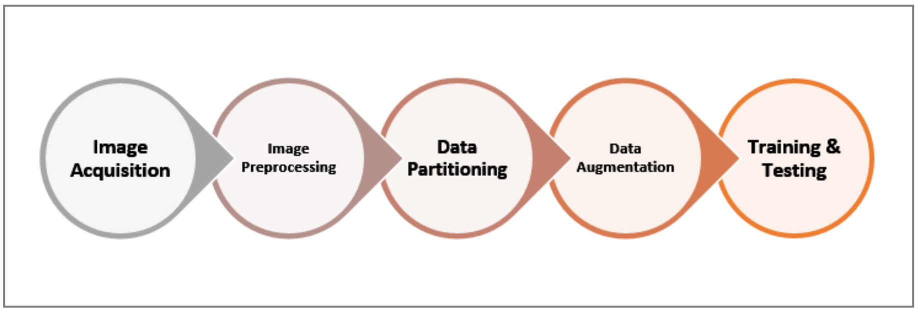

Fig. 1 Methodology of the Research

A. Image Acquisition

The inputs for the model would be weft-knitted fabric images that were taken from an 18MP digital camera from top-down view under white light beam (as per the previous literature this is proved as the best lighting condition for fabric defect detection [5]) at the manufacturing premises. The images are categorized as Defect-free, Oil Stains, Holes, and Drop Stitches where each category contains over 500 images in JPG format. The images are saved under JPG format as the initial dataset for this research study. This image dataset includes 500 images from each as defective and non-defective weft knitted fabric images.

B. Image Preprocessing

The acquired data consists of different characteristics and are messy by nature. Those images should be standardized and cleaned up before feeding them to the neural network. Image preprocessing helps to reduce the complexity of the images that will speed up the training of the CNN. Images were converted into grayscale, which is a range of shades of grey without apparent color. This model range is represented from 0 - 1. RGB (red, green, blue) images contain more information than black and white images which will cause to add unnecessary complexity and take up more space in memory. This conversion of RGB images to grayscale images makes the dataset with 3 channels to 2 channels. Convolutional Neural Network accepts data as a matrix of numeric values. In order to do that image pixel intensities are converted into numeric values in the range of 0-1. Then those numeric values are divided by 255 to range the intensities to 0-1. It can be illustrated simply as below.

C. Data Partitioning

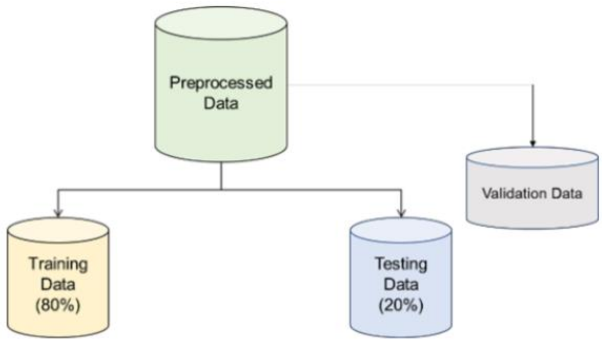

Fig. 2 Data Splitting Procedure

For the data partitioning, a classical statistical sampling technique called Simple Random Sampling (SRS) is used. In this research, the data will be divided into training, testing, and validation datasets. 10% of random images from the training dataset will be taken into the validation dataset where those will be used for validating the model trained. The rest of the data set is split into training (80%) and testing (20%) datasets.

D. Data Augmentation

Data augmentation is a technique that enables us to significantly increase the diversity of data available for training models by artificially creating from the existing data set. This is done by applying domain-specific techniques to images from the training data that create new and different training images. Image data augmentation is perhaps the most well-known type of data augmentation and involves creating transformed versions of images in the training dataset that belong to the same class as the original image.

Data augmentation can be achieved by transforming data cropping, padding, width-shift, height-shift, zoom, and horizontal flipping kind of techniques.

When training any neural networks, it is always encouraged to use a large volume of data. We account for these situations by training the neural network with additional synthetically modified data. Since the data set consists of 500 images from each defective and non-defective image, image data augmentation is used here to enhance the volume of data where a variety of algorithms for data augmentation can bring huge potential for improving data-greedy deep learning algorithms such as Convolutional Neural Networks. In this research data augmentation techniques like horizontal flip, vertical flip, scaling, image rotation by 450 and image zooming have been used to avoid data overfitting over the training and testing dataset.

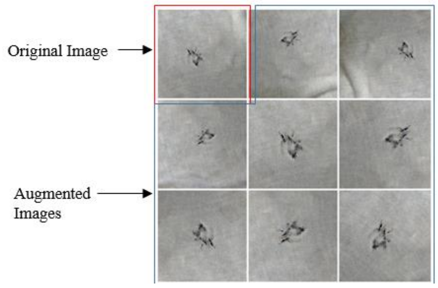

Fig. 3 Data Augmentation

E. Training and Testing

There are many different approaches for supervised learning, such as SVM, ANN, and CNN. The literature has shown that the CNN method performs best when it comes to feature extraction from images by itself and image Classification at a minimal cost. The labeled dataset will be used for training and testing the classifier model. The learning task is to predict the outcome of any valid input object after being trained to a satisfactory number of training examples. Therefore, Convolutional Neural Networks is chosen to perform the overall methodology of the study.

As mentioned earlier 500 images from four categories are used to train and test the model which were collected from weft-knitting manufacturing premises. After the training & testing using the CNN, model accuracy is calculated according to the following formula, with the validation dataset

IV. Experimental Results

Images of defect-free and other three types of defects were collected on knitting premises and a data set was created using those images.

As mentioned in previous literature, we were able to archive the mentioned accuracy level of 97.7% using the collected dataset with a multi-scale feature extraction method. The collected data of weft knitted fabrics was trained using a sequential CNN model using pre-processing techniques was able to archive a 98.00% of training accuracy and 95.67% of validation accuracy from the trained model. As in Fig. 3 and Fig. 4, it can be identifying that the model learns by reducing the training loss and increasing the training accuracy.

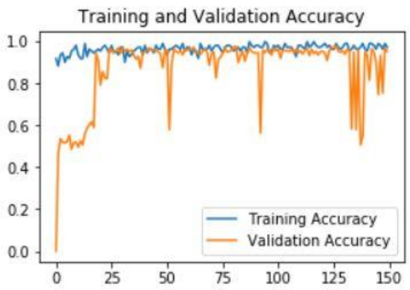

Fig.4 Training and Validation Loss for Trained CNN Model

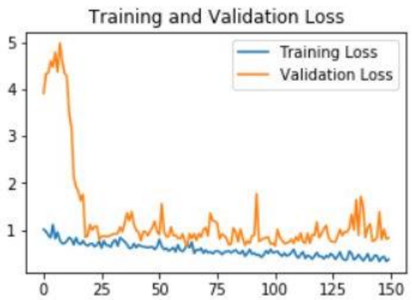

Fig. 5 Training and Validation Accuracy for Trained CNN Model

The following Table 1. shows the architecture of the developed sequential CNN for the defect detection and classification. The architecture was chosen considering the simplicity and the expected output follows the liner topology. The introduced sequential CNN consists of 12 layers which starts with an input layer. Rest of the layers consists as three set of layers of a convolutional layer [(16x2x2), (32x2x2), (64x2x2)] to extract the features from the input, a batch normalization layer to normalize the output of previous ReLU activation and accelerate the training and a max pooling layer to return the maximum value from the portion of the image covered by the Kernel. As the latter part of the model a flatten layer, dropout layer and a dense layer are used in this model.

$$\text{Accuracy (\%)} = \frac{\text{(Total number of correctly classified images)} * 100}{\text{Total number of test images}} \quad \textbf{(1)}$$

Layer (Type)	**Param #**
conv2d_1 (Conv2D)	80
batch_normalization_1	64
max_pooling2d_1	0
conv2d_2 (Conv2D)	2080
batch_normalization_2	128
max_pooling2d_2	0
conv2d_3 (Conv2D)	8256
batch_normalization_3	256
max_pooling2d_3	0
dropout_1 (Dropout)	0
flatten_1 (Flatten)	0
dense_1 (Dense)	6725
Total params:	17,589
Trainable params:	17,365
Non-trainable params:	224

Table 1 Architecture of the Sequential CNN for Defect Detection and Classification

V. Conclusion and Future Work

In this study, the Sequential Convolutional Neural Network was used for creating the models, which were built according to defected and defect-free images. The trained model shows that this can identify the defected weft-knitted fabrics with 98.00% of accuracy using the images captured using an 18MP digital camera.

Moreover, the model can be implemented as a complete solution from image acquisition to image classification for the weft-knitted fabric manufacturing industry specifying with the knitting machine type as well. The research will be extended to a comparison of the developed model with built-in CNN architectures like ResNet50 and VGG16 for image classification to select the most suitable model that can give a higher accurate and efficient solution at a minimal cost

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