Research into Development of the Defect Detection System for Knitted Fabric Produced by the Circular Knitting Machines by Image Analysis

TAKEUCHI Shunji a, b *, NISHIOKA Kazuki b, UEMATSU Hideyuki b, TANOUE Shuichi b

a Fukuhara Industrial & Trading Co., Ltd, 1-1-5, Honjo-cho, Higashinada-ku, Kobe-shi 658-0012, Japan
b Graduate School of Engineering, University of Fukui, 3-9-1, Bunkyo, Fukui-shi 910-8507, Japan

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Abstract

On the tubular knitted fabric produced by the circular knitting machine, the following defects in fabric sometimes appear such as vertical lines, horizontal lines, contamination, and holes, which are caused by malfunctions of the knitting machine or the poor quality of yarn used. The proposed detecting systems for these defects by other researchers have not been implemented in the industry because they appear to need excessive operating time. Therefore, development of a defect detection system using simple analysis is required. Therefore, the aim of this study is to find a simple analyzing system for vertical line defects because they often cause massive wastes of fabric. Vertical line defects could be recognized easily by analyzing brightness distribution obtained from the captured fabric image. The irregular brightness distribution obtained from our proposed method agreed with the vertical line defects; therefore, it was possible to identify the vertical line defects easily. As mentioned above, our proposed method is useful as a simple defect detection system.

Key Words: Circular knitting machine, Fabric defect detection, Vertical line defect, Image analysis

1. Introduction

1.1 Background

As described in Fig. 1, the circular knitting machine produces the knitted tubular fabric. Dozens or around one hundred yarns are fed to the needles through yarn feeders. The Cylinder, holding the needles, is rotating and the needles move up and down, and form yarn into horizontal and vertical successive loops which makes the tubular knitted fabric. The rotating tubular fabric is finally folded into a flat shape and rolled up at the bottom of the machine.

Typical defects are vertical lines, horizontal lines, holes, and stains. They often appear in the fabric during knitting. These defects are caused by malfunctions or faulty parts of the knitting machine or the poor quality of yarn used. In general, an operator is responsible for maintaining multiple circular knitting machines and is also responsible for overseeing production. The operator has to visually inspect defects during production. The simple circular knitting machines, for T-Shirts, Polo-Shirts and so on, are able to produce a lot of tubular fabric, for example 60cm diameter and 100cm length per minute. Therefore, it is impossible for operators to find all defects even though operators are required to have a great deal of skill to find defects accurately and quickly. Accordingly, defects found by the operator at this stage result in additional effort and an increase in the time and cost of production.

In order to solve the above problems, several researchers carried out studies to find these defects accurately and automatically during fabric production. For instance, Shaikhzadeh Najar, et al. [1] developed a computer vision aided fabric inspection system. This system can classify defects in circular knitted fabrics using texture-recognition methods, including pre-processing, clustering method...
and ANN (Artificial Neural Network). Other defect classification systems using conversion of fabric image and ANN have also been researched [2-4]. The basic concepts of these systems are as follows; the fabric image is finally converted into a binary image through gray-scale conversion, filtering, noise removal, and calculating threshold values. Then a feature vector is formed by calculating a number of features of the defect. Then this feature vector is inputted into an artificial network which has been programmed with a number of feature vectors, in order to classify the defect. In addition, a similar system based on ICA (Independent component analysis) instead of ANN [5] or Edge detection, Segmentation and Round off [6] has been proposed. Abou-Taleb and Sallam [7] developed the defects detection and classification system for circular knitted fabric based on the evaluation of common different texture recognition including thresholding analysis, Radon transform, a discrete Fourier transform and ANN. They found that the application of the discrete Fourier transform method is highly promising for the identification of knitted fabric defects. Furferi et al. [8] researched a new highly automated artificial vision inspection tool for real-time defect detection and classification on circular knitting machines. It is based on the combination of statistical analysis, Image Processing and Radon Transform. However, they have not been implemented by the industry because these proposed systems seem to need excessive operating time. Therefore, the development of a high-speed defect detection system with simple analysis, which can easily be implemented by the industry for simple and high-speed circular knitting machines is required. On the circular knitted fabric, loops are formed in an ordered sequence. Considering this, we decided to establish a simple image analyzing system for defect detection during the knitting process on circular knitting machines, utilizing loop structure features.

1.2 The objective of this study

For our goal, the objective of this study is to find a simple analyzing system for vertical line defects because they often cause massive wastes of fabric. Vertical line defects happen to the circular knitted fabric because of damaged needles due to their short lifespan of about a half year. Once a vertical line defect happens during knitting, this defect continues to exist unless the damaged needle is replaced with a new needle.

1.3 The concept for detecting defects

Plain jersey is the most produced fabric for the T-Shirts, Polo-Shirts and under wear. Fig. 2(a) describes the model of plain jersey without any defects. Loops are formed in an ordered sequence, so that colors of yarn and space are regularly repeated. On the other hand, Fig. 2(b) shows the model of plain jersey with the vertical line defect at the center. The vertical line defect is caused by vertical successive deformed loops or missing loops. We noticed that irregular periodic color distribution coincided with the defect, and that the defect could be recognized if this irregularity could be found.

2. Experiments

2.1 Samples of fabric and their images

We used the plain jersey fabric sample knitted with off-white cotton yarn produced by a circular knitting machine (Precision Fukuhara works, VX-3SRE 30" 24gauge) and prepared images of them with and without a vertical line defect. Image A has no defect as shown in Fig. 3 and Image B has a vertical line defect as shown in Fig. 4. This vertical line defect consists of vertical successive wider loops than the others. These images were captured by using a microscope (KEYENCE CORP. WHX-2000) with a 25x magnification.
magnification and follow light, which is from the lens to the fabric sample, with samples on the black stage of the microscope slightly extended to Wale (vertical successive loops) and Course (horizontal successive loops) [9] direction and were aligned to match their Wale direction to vertical. This is because the possible future system will have a camera fixed on the circular knitting machines and the camera will capture fabric images during knitting. Tubular fabric during knitting is generally extended to avoid any crease, and Wale directions are always just the vertical because of the knitting process of the circular knitting machine.

### 2.2 Extraction of color data from images

In order to recognize irregular periodic color distribution coincided with the vertical line defect, we focused on the fact that off-white (un-dyed) cotton yarn is always used for massive production of T-shirts, Polo-Shirts and under wear. Since off-white is almost always white and the spaces between loops is almost always black, brightness was considered to be useful instead of color such as Red, Green and Blue data in RGB color model. Therefore we decided to use the average brightness of Wale direction successive pixels (ABW). This ABW is obtained by getting the brightness of each pixel in the captured image and averaging the brightness of all vertical successive pixels. According to the conversion from RGB (Red, Green and Blue) color model to HLS (Hue, Lightness and Saturate) color model, brightness \((B_r)\), equivalent to Lightness in HLS color model, is calculated by maximum and minimum number among Red \((0\) to \(255\)), Green \((0\) to \(255\)) and Blue \((0\) to \(255\)) in a pixel and results will be from \(0\) to \(1.0\).

\[
B_r = \frac{\max(R, G, B) + \min(R, G, B)}{2}/255
\]

As shown in Fig. 3 and Fig. 4, Image A and Image B have 123 vertical pixels x 152 horizontal pixels. In order to get the ABW, brightness of each pixel in vertical sequence was calculated and averaged. This sequence was repeated to 152 times according to the horizontal pixels.

### 3. Results and Discussions

#### 3.1 Distributions of ABW in Images of Fabric

Fig. 5 describes charts for distributions of ABW. The Fig. 5 (a) is for Image A (152 vertical pixels x 123 horizontal pixels) without any defects, and regular periodic ABW distribution is entirely observed. On the other hand, the Fig. 5 (b) is for Image B (152 vertical pixels x 123 horizontal pixels), with a vertical line defect at the center, and the wide and low disordered ABW is observed. Except for this disordered ABW, Regular periodic ABW is observed. Therefore, the vertical line defect was visible by ABW distribution.

![Image B and its ABW](image6.png)

#### 3.2 Detail of ABW distribution

Fig. 6 matches Image B in Fig. 4 with its ABW shown in Fig. 5 (b). With considering distributions of ABW and loop shape in detail, each of the high peaks of ABW in the chart are observed at the each of the perpendicular portions of the loops in Image B. this is because vertical successive perpendicular portions of the loops have less space and makes brightness higher. On the other hand, each of the low peaks of ABW in the chart are observed at the each portion
of the center of the loops in the Image B. This is because vertical successive portions of the center of the loops mostly have dark spaces and make brightness higher. These two peaks repeat right and left according to horizontal successive loop repetitions except for the vertical line defect. Since this vertical line defect consists of vertical successive wider loops than the others, continuous low peaks of ABW due to mostly dark spaces were recognized.

3.3 Quantitative analysis of vertical line defects

The vertical line defect could be visible in ABW as shown in Fig. 6. Accordingly, it is necessary to quantitatively recognize this visible vertical line defect. Therefore, we examined the method using moving averages of ABW. Except for the disordered ABW, it is considered that Simple moving averages would be the same number when moving average calculation unit (MACU) is equivalent to the number of pixels within the horizontal interval of loops (Wale width). Then, the moving average would disorder at the defect if the vertical line defect exists. The following explanation is for the above theory in detail.

Fig. 7 (a) shows the model of plain jersey with the vertical line defect at the center of the image. This vertical line defect consists of loops with wider width and spaces than the other normal loops. Fig. 7 (b) is the model of captured image from Fig. 7 (a). The lattice in Fig. 7 explains each pixel for the resolution of 4 pixels per Wale width. The reason for 4 pixels will be explained later. Darker pixels are observed on the 13th and 14th pixel position in Fig. 7 (b) because of the wider loop space on the 13th and 14th pixel position in Fig. 7 (a). Fig. 8 shows the chart of the ABW for Fig. 7 (b) and their moving averages using 4 MACU. The lower two ABW are plotted at 13th and 14th pixel position and according to this, the disordered, which is lower, moving averages of the 13th through 17th pixel position are observed. For another example of resolution, if the resolution is 8 pixels per Wale width, MACU is also 8 and the four consecutive lower brightness would be plotted at the vertical line defect and the disordered, which is lower, moving averages will be observed at these lower ABW.

According to the above mentioned theory, we can expect to quantitatively determine vertical line defects by the range defined as the difference between the maximum moving average and minimum one (Diff A) shown in Fig. 8. The Diff A is theoretically zero if no vertical line defect exists in the captured image and Diff A is more than zero if vertical line defects exist.

The reason for resolution of 4 pixels per Wale width in Fig. 7 is as follows. The one pixel per Wale width would theoretically be able to create disordered ABW distributions at the possible minimum vertical line defects caused by vertical deformed loops in one Wale width. However, more than the one pixel per Wale width would be necessary to make ABW deference bigger and make moving average more accurate, while too much resolution would affect the operating time. Therefore, in addition, to make explanation easier, 4 pixels were used in Fig. 7.

3.4 Results of moving averages

In the case of Image A and Image B, MACU was 11, which was calculated from pixels of image width divided by the number of loops based on the Image A (152 pixels / 14 loops = 11). This means that one loop unit width has 11 pixels. In Fig. 9, the solid lines are identical to the ones in Fig. 5, show the ABW of Image
A and Image B, and the dotted lines show the results of moving averages of their ABW. The moving average for Image A (Fig. 9 (a)) is resulting in a mostly straight chart line. On the other hand, the moving average for Image B (Fig. 9 (b)) shows clearly disordered chart line at the defect and otherwise is almost straight.

Fig. 10 shows the chart for Diff A of the moving average shown in Fig. 9. Compared with Image A and Image B in Fig. 10, Diff A of Image B is clearly higher than that of Image A. The suitable threshold, depending on quality level of fabric, will be in between Diff A of Image A and Image B. Therefore, it will be possible to quantitatively recognize vertical line defects in Image B on the basis of Diff A of Image A and Image B.

4. Conclusion

Vertical line defects were able to be quantitatively detected by just only using Diff A of the moving averages of ABW in the captured fabric image. The possible future system will have a camera fixed on the circular knitting machines. Wale directions are always vertical because of the knitting process of the circular knitting machines. Therefore, captured images do not need to be adjusted for angles and this can avoid extra operating time. Just before production, thresholds for Diff A will be determined by the fabric image both with intentional vertical line defects and without any defects captured by camera.

The future works are as follows; (1) To proceed to examine factors, such as resolution, gray scaling, and lighting direction for images, which will affect the speed and accuracy of analysis. (2) To experiment with the proposed method to also detect horizontal line defects which is the other important defect and sometimes wastes a lot of fabric.

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