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Online Control of Knitted Fabric Quality: Loop Length Control

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Abstract**—**Circular knitting machine makes the fabric with more than two knitting tools. Variation of yarn tension between different knitting tools causes different loop length of stitches duration knitting process. In this research, a new intelligent method is applied to control loop length of stitches in various tools based on ideal shape of stitches and real angle of stitches direction while different loop length of stitches causes stitches deformation and deviation those of angle.

To measure deviation of stitch direction against variation of tensions, image processing technique was applied to pictures of different fabrics with constant front light. After that, the rate of deformation is translated to needed compensation of loop length cam degree to cure stitches deformation. A fuzzy control algorithm was applied to loop length modification in knitting tools.

The presented method was experienced for different knitted fabrics of various structures and yarns. The results show that presented method is useable for control of loop length variation between different knitting tools based on stitch deformation for various knitted fabrics with different fabric structures, densities and yarn types.

Keywords**—**Circular knitting, Radon transformation, Knitted fabric, Regularity, Fuzzy control

I. INTRODUCTION

MOST of the circular knitting machines have more than two cam system as knitting tools. Recent models of circular knitting machines have 12, 24 and some of them 48 knitting tools. The quality of weft knitted fabric is related to knitting parameter including the number and area of knitting faults which are produced by knitting process and faults is originated from yarn faults. It is assumed that poor quality of yarn appearance causes poor apparent quality of fabric but, the effect of yarn count, raw material and fabric structure is important too [1]. Recently, many attempts have been applied to grading of knitted fabrics based on both groups of parameters of knitting faults and grades of yarn as raw material. Although, those methods are useful for grading of knitted fabric based on knitting and yarn apparent faults but the inter grades of safe fabric depends on regularity of fabric surface which is related to direction of stitches in correct form as a approximately full relaxed fabric. This matter is depends on conformity of loop length and tensions on yarn among whole knitting tools [2, 3 and 4].

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Many researchers have applied computer vision to improve inspection method of human vision in textile products. In most of them, the image of a knitted garment had been considered to specify the fault features. In the method developed by Celik et al., the spiraled knitted fabric was analyzed for determination of angle of walls against various knitting parameters [5]. Whereas deviation of stitches angle from ideal angle causes spiral feature in fabric and this matter was not considered in mention research, therefore it is needed to define deformation of stitches based on geometrical relations of previous fundamental aspects [6]. Other work presented by Shady et al. is based on classification of defects in knitted fabric by using image analysis and neural network algorithm [7]. Also, Fuzzy logic and neural network were applied to specify total hand of knitted fabric by performing functional mapping between mechanical properties and total hand value [8]. Abouiiana et al. believed knit structure changes during process are effective on total quality of fabric in wet relaxation process. They made image analysis based studies for assessing and controlling structural changes during wet process [9]. The yarn appearance is strongly effective on knitted fabric appearance too. In previous research grading method of knitted fabric was presented based on yarn faults [10]. In all above mentioned methods, although it is possible to define an overall defect statement for knitted fabric appearance but stitch deformation in a safe knitted fabric have not been presented. The safe knitted fabric in any grade of appearance can be used to product apparel. To produce better qualified fabric, evaluation and control of fabric regularity is useful in advance.

Computer vision and modeling techniques have been applied to quality definition and structural surface analysis of both woven and knitted fabrics in many researches. There are many similar methods for measuring parameters of fabric and individual type of yarn. Although various methods are familiar in textile applications; but using the suitable technique for each application is remarkable [11, 12, 13 and 14]. In many works Fourier transformation in power spectrum form was applied for analyzing the fabric surface [15, 16 and 17]. Other works refer to applications of regional image analysis methods and tracing vectors [18 and 19]. Also, radon transformation has been applied for determination of irregularity orientation in some textile materials [20].

The objective of this research is to improve the limits of previous methods and provide an evaluation method suitable for every types of knitted fabric by image analysis technique and presenting a fuzzy control system to adjust suitable loop length on every knitting tools regarding to better regularity of stitches.

II. Methods and Experiments

A. Method of Deformation Assessing

The assessing of stitch deformation is not possible by mechanical methods because of flexible features of stitch loop. Therefore, the best method of assessing the changes of stitch direction along original form can be presented using image analysis technique. Camera based system was designed for taking online pictures during knitting process on the circular knitting machine. In hieratical time series some images are taken from fabric surface in size of 100 by 200 mm and resolution of 250 dpi. Sample image has a lot of blur caused by uniform linear motion during taking images. Restoration of blur image was done by using motion operator based on Liebnitz's rule [22].

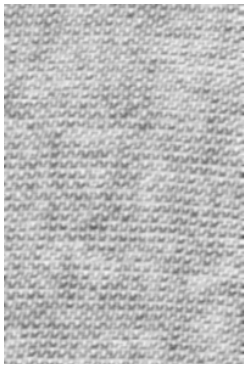
For detecting of stitches direction, the gray scale image of yarn is converted to edge remarked form by a differential mask. There are different methods of edge detection in image processing technique. In edge detection method an intensity image as its input is processed and returned to a binary image of the same size, with 1's where the function finds edges and 0's elsewhere. The Sobel, Prewitt and Roberts methods find edges using different directional approximation to the derivative. It returns edges at those points where the gradient is maximum value. The Laplacian of Gaussian method finds edges by looking for zero crossings after filtering the image with a Laplacian of Gaussian filter. The most powerful edge-detection method that edge provides is the Canny method. The Canny method differs from the other edge-detection methods in that it uses two different thresholds (to detect strong and weak edges), and includes the weak edges in the output only if they are connected to strong edges. This method is therefore less likely than the others to be "fooled" by noise, and more likely to detect true weak edges [21].

In this research we experienced all of common methods to find edge detected image of knitted fabric which is included edges of stitches in real formation in the image. Unfortunately, none of those methods was not capable to generate suitable edge image without point loss because of loop shape of stitches. To reach suitable mask of edge detection, some differential masks was experienced to sample images. The best mask was such as equation 1 where " $f_{i,j}$ " is each pixels of edge detected image and " $s_{i,j}$ " is each pixels of enhanced image after enhancement of sample image by motion operator. A sample of image enhancement as edge prepared image is shown in Fig. 1.

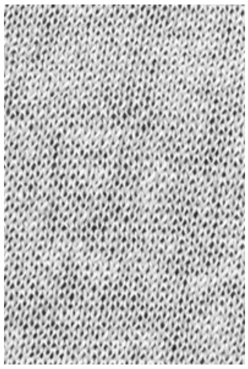
$$f_{i,j} = \begin{bmatrix} -1 & -2 & -1 \\ -2 & 12 & -2 \\ -1 & -2 & -1 \end{bmatrix} \cdot s_{i,j} \qquad (1)$$

After converting of original image to edge detected form it is possible to use the radon transformation for finding directions of stitches, based on radon intensity.

The radon function in the Image Processing computes projections of an image matrix along specified directions. A projection of a two-dimensional function *f(x,y)* is a set of line integrals. The radon function computes the line integrals from multiple sources along parallel paths, in a certain direction. The paths are spaced one pixel unit apart. To represent an image, the radon function takes multiple, parallel-path projections of the image from different angles by rotating the source around the center of the image. Projections can be computed along any angle. In general, the Radon transform is the line integral of f parallel to the y'-axis. The Radon transform for a large number of angles is often displayed as an image. While radon transformation specified in theta angle the result is a column vector. Radon transformation will be matrix of intensity for whole theta angles from 0 to 180 degrees. For example if radon transformation is repeated by 180 times in one degree step, the result will be a matrix of n by 180 where n is length of each column and number of columns is 180. R matrix is intensity matrix which can be presented as hot histogram. In hot histogram the light spots refer to maximum intensities where the direction of fabric stitches makes theta angle with horizontal direction. In this situation theta is the column of light spot (maximum intensity).



(a)



(b)

(c)

Fig. 1 A sample of knitted fabric (a) original image of fabric, (b) enhancement image (c) edge image

Finding of maximum intensity is not simple in histogram. Also, some equal values exist in each column. Therefore we moved out maximum raw of histogram where, large intensity values are located in that of raw. Fig. 2 shows plot of high intensity raw of radon transformation matrix of histogram. As it is presented in plot of Fig. 2, there is different picks of local maximum values. One of local maximums is the maximum value of plot which is refers to column number or angle of stitches direction [22]. The maximum value is repeated after 90 degree in mirror point of first repeat which is located before 90 degree. The reason of repeating of maximum value is radon transpose of edge image where, stitches direction is evaluated in both axis of X and Y. Therefore, only one of maximum value repeats before 90 degree could be detected before 90 degree. The angle of maximum value of radon intensity is stitches direction majority or “α”.Image processing toolbox of MATLAB 7 was applied for preparation of analysis routine of fabric images and measuring majority of stitch direction "α". In the analysis software the original image is modified and enhanced by using wiener filtering and motion operator. After that, enhanced image is converted to edge detected image by mask of equation 1. Edge detected image is transformed to projection intensity matrix by radon transformation. Maximum raw of radon intensity matrix is selected and majority stitch direction is detected from that of maximum pick.

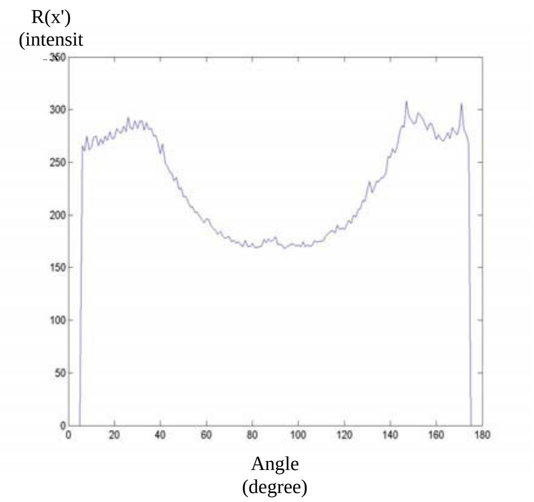


Fig. 2 Plot of high intensity raw of radon transformation matrix of image Fig. 1c

The variation of degree between stitches of consecutive knitting tolls in lag time of "t" is named “$p(t)$” which is occurred between two tools caused where, one of tools has more yarn tension during knitting process. If $p(t)$ is equal to zero, variation of stitches angles in consecutive courses in full relaxed fabric is acceptable as regular stitches and the index of deformation will be zero and the most regular fabric is produced. The more deference between stitches angles in consecutive courses causes more irregularity in appearance of fabric. The index of deformation or “D” is defined as equation 2 for n knitting tools.

$$D(t) = \frac{|p(t)|}{\alpha} \cdot 100 \qquad \text{k=1, 2..., n-1} \tag{2}$$

Whereas irregularity is a fuzzy sense in human vision, it is better to prepare a look up table of fuzzy definitions between “D” and stitch regularity as presented in Table I.

TABLE I
LOOK UP TABLE OF RELATION BETWEEN STITCH DEFORMATION INDEX (D) AND FUZZY DEFINITION OF STITCHES DEFORMATION

"D"	Description	Stitches Deformation Class
0-2	No Change	A
2-5	Low Change	B
5-10	Risk Change	C
10-25	Need to Readjust the Tools	D
25-45	Needs to Readjust Tools /Readjust Delivery	E
above 45	Machine Stop	F

Stitch angle measurement by the developed image processing system has a lag element, and dynamic characteristics of granule growth are so complex that it is difficult to construct a model-based system for stitch deformation. Application of fuzzy logic to the control system is very effective. In this research, we improve control stability and response using linguistic algorithms employing IF-THEN rules, in which stitches direction, its changing rate and process lag element were taken into consideration [23]. Deformation index of “D” in lag time of two successive tools and its changing rate “ΔD” were adopted as equation 3.

$$\Delta D = D(t) - D(t-1) \tag{3}$$

The result of fuzzy reasoning was used to control the loop length cam setting. Fig. 3 indicates the normalized membership functions for loop length cam control. Triangular representation was used for the input variables of “$D(t)$” and “. The range of “$D(t)$” was between 0 and “$D_d = D_A = 2$”, which was translated into 0 to +1 by a normalized parameter of “D_d”. The normalized parameter for “$\Delta D(t)$” was determined by a possible maximum granule growth rate of Table I class changing rate. To simplify the fuzzy logic, we used a real number for “$V(t)$”, despite the use of fuzzy set. The “$V(t)$”was also normalized by a maximum loop length cam degree of 6. In this research, the table I five fuzzy classes were used. Totally 6 rules were used for the fuzzy reasoning. Rule 1 was designed to change loop length cam setting by 1 and rule 6 decreases the cam setting by 6 in advance when the deformation index is maximum.

Also, output of the setting change was terminated beforehand when the size-changing rate is occurred.

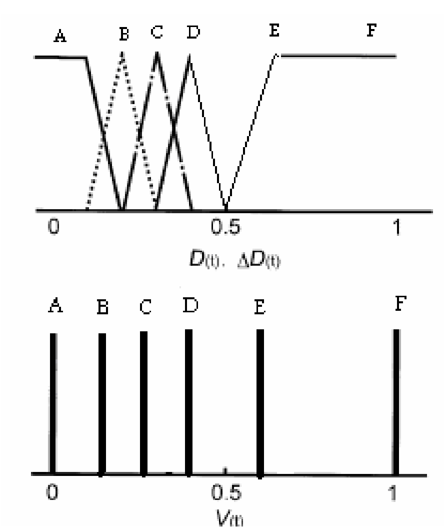


Fig. 3 Membership functions for fuzzy logic

Fuzzy rules were constructed based on the expert operator's knowledge and tuition. Deformation index under desired values of class A were conducted to modify the membership functions and the production rules with reference to a debug tool. In the fuzzy controller, fuzzy reasoning was conducted by means of a min–max composition method using triangular-shaped membership functions and if-then rules [24 and 25].

B. Samples and Experiments

To ensure the assessing method of stitch deformation, some experiments on a knitting machine (Model: Mayer&Cie SF4-3.2) were prepared based on real situations of knitting process. On of the most remarkable faults in knitted fabric is irregularity of stitches direction during knitting process. This matter causes poorer quality as other knitting faults. Usually, distorted stitches as surface irregularity events are observed in knitted fabrics of spun blended cotton yarns because of frictional properties of these yarns.

In this research we prepared various fabric samples of spun yarns of ring with different knitted structures of knit, tuck and miss-stitches to consider the effect of various raw materials and structures of knitted fabric on irregularity of stitches as distorted direction. The samples are the safe knitted fabrics without any knitting faults such as holes, drop stitches and stripes.

Four samples of various yarn types were prepared including polyester/cotton ring spun yarn of 15 and 30 Ne blended in 70/30, polyester/cotton ring spun yarn of 15 and 30 Ne blended in 30/70 and polyester/cotton rotor spun yarn of 15 and 30 Ne blended in 30/70. From each samples, three different kinds of fabric are knitted such as plain, cross- miss and plain pique fabrics which are included knit, knit/skip and knit/tuck stitches, respectively. These fabrics are more commonly used for main categories of knitted fabrics in apparels.

III. Results and Discussion

To investigate capability of presented method of stitch deformation assessing, fabric samples of knitted fabrics in sixteen categories of various yarn samples were analyzed by presented image analysis technique and were assigned in fussy classes of Table I. The results of knitted fabric samples assessing are shown in table II and table III. We did assessing of samples in both situation of changed loop length in consecutive tools and readjusted loop length tools to consider capability of our assessing method and readjusting system of loop length cam. Fabric samples are assessed by computer vision system in both situations as online system of inspection. After determination of required adjustment the loop length was decreased in consecutive knitting loop length cam to readjust yarn tension. After that, the vision system measured the enhanced stitches direction. The results show acceptable enhancement after readjusting the loop length cams. Although there is not a standard of inspection for knitted fabric irregularity but, the method of inspection by image analysis is usable for fabric assessing because, the presented definition of stitch deformation is based on ideal direction of stitches in fully regular and ideal knitted fabric as safe knitted fabric.

The experimental works shows that there is a interaction effect of type of used yarn and fabric structure on situation of cam setting. Also, the presented results show that the regularity of different fabrics is various for different categories of used yarns. This is for various reaction of yarn against internal fabric forces based on yarn frictional natures and effects of fabric elements structure (stitch, tuck and skip stitch). It is seemed that knitted fabric samples of blended yarns with high percent of cotton have more enhancements after readjustment in comparison with knitted fabric samples of blended yarns with high percent of polyester. This matter is because of used yarns frictional effects while knitted fabrics of polyester could be more relaxed in wet relaxation process.

The results show that knitted plain pique fabrics is a little better than cross-miss and plain fabrics, respectively, because of the more stability of knitted elements by tuck stitch in this kind of fabric. This matter is strong in thick yarns in comparison with thin ones. Also, regarding to the results the minor changes can be restore better than major changes where the changes of classes above D can not enhanced to classes A and B after readjusting functions, easily. This matter may be explained by interaction effect of hieratical stitches which causes internal tensions in stitches fabric and feeding yarn. Whereas the feeding system is a unique positive system with constant rate of yarn feed, the loop length cam setting is the only method of stitches shape control.

According to the results, it could be concluded that the presented method is capable for on line assessing of stitch deformation in various knitted fabrics, expanding of readjusting system of loop length cam to enhancement of knitted fabric quality during knitting process.

TABLE II
THE RESULTS OF ASSESSING OF STITCH DEFORMATION IN PET/COTTON (30%/70%) KNITTED FABRIC SAMPLES

yarn count (Nc)	Fabric Structure	Change of loop length cams (mm)	"D" before readjustment	"D" after readjustment
15	Plain	1	1.8	0.9
		2	12.3	1.2
		3	16.8	2.6
		4	47.9	6.8
		5	61.4	9.7
	Cross miss	1	1.4	0.8
		2	5.4	1.1
		3	11.6	2.3
		4	23.2	6.1
		5	32.6	8.7
	Plain Pique	1	1.3	0.7
		2	4.3	1.0
		3	10.4	2.1
		4	32.1	5.4
		5	47.9	7.8
30	Plain	1	1.5	0.6
		2	9.8	0.8
		3	12.9	1.8
		4	39.3	4.8
		5	51.2	6.8
	Cross miss	1	1.2	0.6
		2	4.5	0.8
		3	8.7	1.6
		4	19.8	4.3
		5	26.4	6.1
	Plain Pique	1	1.1	0.5
		2	3.6	0.7
		3	7.6	1.5
		4	26.8	3.8
		5	39.8	5.4

TABLE III
THE RESULTS OF ASSESSING OF STITCH DEFORMATION IN PET/COTTON (70%/30%) KNITTED FABRIC SAMPLES

yarn count (Nc)	Fabric Structure	Change of loop length cams (mm)	"D" before readjustment	D after readjustment
15	Plain	1	1.9	0.5
		2	13.6	0.7
		3	19.4	1.6
		4	55.6	4.1
		5	68.9	5.8
	Cross miss	1	1.5	0.5
		2	5.9	0.6
		3	13.5	1.4
		4	25.6	3.7
		5	35.8	5.2
	Plain Pique	1	14.4	0.4
		2	4.9	0.6
		3	11.5	1.2
		4	35.3	3.3
		5	54.9	4.7
30	Plain	1	1.6	0.4
		2	10.7	0.5
		3	14.9	1.1
		4	45.6	2.9
		5	56.8	4.1
	Cross miss	1	1.2	0.3
		2	4.9	0.5
		3	9.7	1.0
		4	21.8	2.6
		5	29.1	3.7
	Plain Pique	1	1.1	0.3
		2	3.9	0.4
		3	8.6	0.9
		4	29.8	2.3
		5	44.6	3.3

IV. Conclusion

In this research, it is tried to present a novel computer vision mixed fuzzy control method for control od loop length deviation regarding to stitch deformation as on line quality control on circular knitting machine. Developed system were presented for readjusting the loop length cam of knitting tools to control loop length and enhance fabric regularity based on defined deformation index of vision system measured. In this method, assessing of stitches deformation is based on computer vision and analyzing the images of knitted fabrics by using radon projection intensity matrix. It is possible to use the presented system for each kinds of knitted. The presented methods were collected and organized in an intelligent online fuzzy system with high speed ability in processing. The presented vision system can be used in quality control process after production and after relaxation treatments too. Also, it is possible to install the system on knitting machine easily for online controlling of fabric regularity.

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