ONLINE FAULT DETECTION SYSTEM FOR CIRCULAR KNITTING MACHINES

YUVARLAK ÖRME MAKİNELERİ İÇİN ON-LİNE HATA KONTROL SİSTEMİ

Tuba KIRCI TORUN
Textile Engineer

Arzu MARMARALI
Ege University Textile Engineering Department
e-mail: arzu.marmarali@ege.edu.tr

ABSTRACT

Due to the design of the circular knitting machines, it is not possible to see the faults on the fabric as soon as they occur. Faults become only as seen after some piece of, around 50 to 60 cm long, fabric is knitted. This situation causes loss of time and material for the manufacturers. In this article, a system that detects the faults that may occur during the production on circular knitting machines and automatically power off the machine upon detection of any fault is introduced. The developed on-line fault detection system combines and implements several state of the art methods available in the literature and in the industry. The system is a product of a multi-disciplinary study, including textile engineering, signal and image processing, electrical engineering.

Key Words: Circular knitting machine, Online fault detection, Fault detection methods.

ÖZET

Bu çalışmada, eğilme ve eksenel deformasyon rijitliğini içeren Lagrange Sonlu Elemanlar formülasyonu, kumaş ağırlığını içerecek Yuvarlak örme makinelerinin yapısı nedeniyle, kumaş üzerinde hata oluştuğu anda görülebilmesi mümkün değildir. Kumaştaki hata, ancak belirli bir miktar (yaklaşık 50 – 60 cm kadar) kumaş örüldükten sonra fark edilebilmektedir. Bu durum üreticilerin zaman ve mal kaybına yol açmaktadır. Bu makalede, yuvarlak örme makinelerinde üretilen kumaşlarda oluşabilecek hataları gerçek zamanlı olarak kontrol eden ve herhangi bir hatanın tespit edilmesi durumunda makineyi durdurabilen bir sistem tanıtılmaktadır. Geliştirilen sistem, literatürde mevcut olan ve endüstri standardı olan pek çok yöntemi birleştirip uygulamaktadır. Sistem, tekstil mühendisliği, sinyal ve imge işleme ile elektrik mühendisliğini de kapsayan çok disiplinli bir çalışmanın ürünüdür.

Anahtar Kelimeler: Yuvarlak örme makinesi, Gerçek zamanlı hata kontrolü, Hata kontrol yöntemleri.

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1. INTRODUCTION

Production speed and capacity are increased due to recent innovations in the knitting machines. However, this increase has caused several financial and manufacturing problems in quality control departments of companies where fabric control is conducted by visual check of the employees. Previous studies show that on the average a person can only detect 60-75% of the distinct faults (1). This insufficiency of visual check causes various problems like financial problems which include increase in the number of employees or complaints and/or discount requests from the buyers due to low quality products. Under these circumstances, it can be said that the main purpose of quality control is to check the fabric during whole stages of production in order to decrease the cost of quality control process after production and to increase the efficiency of the production. As a consequence, automatic quality control systems have gained notable importance for the knitting industry. However, most of the fault detection systems work offline. That means they can only control the fabrics after their production (2). The most efficient method to decrease the quality related issues is on-line control of fabrics.

In this article, a system that detects the faults that may occur during the production on circular knitting machines and automatically power off the machine upon detection is introduced. In the system, images of the fabric are taken periodically by a camera and transferred to a computer in order to apply some image processing algorithms. The developed system can stop the machine after the system reaches a predetermined faulty image quantity. The system gives the user the flexibility to adjust the acceptable count of faults, letting the system to become independent from the knitting machine and the environment.

By detecting and eliminating the fabric faults during the production, knitting industry would gain many advantages in terms of decrease in cost and in energy consumption. The developed system introduced in this article will add efficiency to the knitting industry due to its performance and its adjustable design that enables the system to be used on all kind of circular knitting machine.

2. LITERATURE

Various systems which can detect faults during the production are available in the industry. Among these Argus fault detection system developed by Mayer is the most well-known one. Working principle of Argus depends on images of the fabric. First, it captures a reference image from a fault-free fabric. Then, it captures images periodically during the production and compares these images with the reference image. Finally, when a difference occurs between the reference and the production images, the knitting machine is stopped by Argus (3). The biggest disadvantage of Argus is that it is affected by environmental factors such as a fly on the fabric, hence generates too many false alarms and stops the machine even when it is not necessary.

Catarino et al. (2004) (4) developed a system that can detect and define the faults by controlling the yarn tension with a sensor. However, there is a big financial disadvantage of this system since the user needs to place sensors on each yarn feeder in order to monitor the tension of each yarn.

Literature shows that image and signal processing algorithms are heavily used in this field of study. Examples for these algorithms can be given as; Fourier analysis, two dimensional Gabor filters, Markov random fields, and wavelet transforms.

Fourier analysis is used to define a signal as a sum of sinusoidal signals with different amplitudes and frequencies. Fourier analysis on fabric images performs well when the material is heavily damaged. Therefore this method is not suitable and is not preferred for detection of local faults (5).

Two dimensional Gabor filters are the filter banks where each filter is chosen according to the sub-image to be looked for within the image (6). To detect the fault, Gabor filters must be in the same trend (vertical, horizontal, or crosswise) with the fault image. Therefore, wide range of Gabor filters is needed to be used if it is desired to detect numerous faults at the same time, complicating the system and increase the cost.

Markov random fields (7) approach states that brightness level of a pixel in an image depends on the neighbor pixel's brightness level (8). Fault detection method introduced by Baykut (8) observes the difference in Markov random field transforms between the faulty and fault-free images.

Wavelet transform method is similar to the Fourier analysis. However, while Fourier analysis decomposes an image into its sinusoidal components, wavelet transform decomposes the image into small "wavelets." Wavelets are chosen according to the signal and the pattern to be found so that the desired properties of the signal can be emphasized (9). In terms of detecting a fault in the fabric, this method provides the type and exact location of the fault.

A reliable fault detection algorithm should provide both spatial and spectral information. Spectral information helps to detect a fault, whereas spatial information provides the location of the fault. Fourier analysis is undesirable since it does not provide spatial resolution. Gabor filter banks can provide information in both domains. However the number of filters to be used in the bank is in general too much to be computationally effective. Markov random field method also suffers from computational complexity due to its need of a preconditioning which would extract the fault image from the background. Wavelet transform is a promising tool in fault detection since they provide information in both spatial and spectral domain with low computational complexity.

Shady et al.(10) used statistical quantifier and Fourier transform to determine six different knitted fabric faults. Both systems were unsuccessful to determine barre fault due to the structure of the fault. Results of the Fourier transform were more successful in detecting the fault-free image and determining the fault category in comparison to the statistical quantifier.

Chan et al. (1) examined the density variation in frequency spectrum of the fabric images and they determined the faults according to that variation. The fault-free fabric has a repeating pattern. When a fault occurs, the repeating pattern is corrupted, hence the density variation changes. Since the signal (image) is two dimensional in this case, the estimated spectrum is three dimensional. Therefore, it is very difficult to analyze this spectrum due its computational complexity. Nevertheless, many faults are too small to be detected by density variation.

Saeidi et al. (11) calculated offline performance of Gabor filters, Fourier analysis, and Wavelet transform methods in terms of determining the faults in the knitted fabric. They found out that the Gabor filters are the most effective method with a success rate of 78.4%. As their next step, they used this system online to determine the faults. However, the designed system was restricted by the speed of the knitting machines. Further studies are required to examine and detect fabric faults at high speeds.

The faults in general occur horizontally or vertically on a fabric due to the nature of the knitting process (2). Hence, a fault can also be determined in one dimensional space instead of a two dimensional space. Kim et al. (12) developed a fault detection system by applying Mexican hat wavelet to horizontal and vertical projections of a fabric image. On the other hand, Kumar (13) applied Imaginer Gabor Filters (IGF) to the projections. This method is not only computationally light-weighted, its performance is among the best available in the literature. Therefore, the fault detection algorithm was suggested by Kumar (13) is employed in the developed system introduced in this paper.

3. MATERIAL AND METHODS

Specimens were knitted by using 30/1 Ne cotton yarn on FOUQUET interlock knitting machine which has 12 feeders and its gauge is E 13. To obtain a clear vision and determine faults more accurately, the fabric structure was chosen as rib rather. Both cylinder and dial needles of the machine were replaced with the new ones to eliminate the difference in the texture of the fabric due to needle aging.

Fabric winding is elliptical due to the structure of the winding device. Literature and preliminary tests showed that the distance between the camera and the fabric must always be same in order to determine the faults accurately. For this purpose, a black colored cylinder with a diameter of 25 cm was assembled to the knitting machine. Black color was chosen to prevent reflection due to the lighting system which will be introduced later in this section.

Main components of the developed system are the camera, the lighting system, the computer system, and the software (Fig. 1). Camera is used to capture the image of the fabric. Lighting system resolves the non-uniform and/or insufficient environmental lighting conditions. Personal computer contains a frame grabber card to convert the video signal into digital format, and the software developed under this study analyses the captured image, detects and classifies the problems in the fabric. Upon detection of a problem the software also triggers a special circuit to stop the knitting machine (14).

Amateur surveillance cameras are not suitable for this system, since frames per second (FPS) value of these cameras vary according to the ambient light. Considering that a camera with a fixed yet controllable FPS is desired. Hence, a JAI brand PULNIX TMC-73M model industrial camera is chosen to be used in the system.

Shutter speed is an important parameter of the camera since the object, the fabric being knitted in this study, is moving reasonably fast. Experiments showed that a shutter speed of 1/500 seconds is enough for this system. However, as the shutter speed increases the amount of light falling on the sensor of the camera decreases. Thus, the higher the shutter speed the lower the light received by the camera, so the darker the image captured. Nevertheless the environment light is generally non-uniform. Therefore, a lighting system is required in order to resolve these issues. There are numerous types of lighting systems available in the industry. A system called "ring light" which is mounted around the camera lens providing a homogenous light on the object is chosen for the system. Filament light sources are not suitable because under 1/500 seconds of shutter speed the image also captures the flickering effects due to 50 Hz outlet power. For this reason Light Emitted Diodes (LED) which are low-power, economic, and non-flickering light sources are used within the ring light.

The output of the camera used in the system is an interlaced composite video signal. When this signal which is generated by capturing a fast moving object is fed into a frame grabber, a problem called "combing" occurs. The simplest solution for this problem is called "discarding" and it is used in the developed software as well. This method simply ignores the even or odd numbered lines in the image.

The aim of this project is not only to detect and identify a problem within the fabric, but also to stop the knitting machine when the number of errors exceeds acceptable limits. The knitting machine has a built-in push-button used for stopping the machine in an emergency. In the system, this button is overridden by a relay and transistor switching circuit which is triggered by a signal from the serial port of the computer. The serial port of the computer is controlled by the software (14).

The desired location of the camera is the closest region to the needles. However it was not possible to mount the camera directly to the knitting machine since the vibrations affected the camera as well as the captured images. Since it is an experimental setup, the camera was mounted to a tripod. This setup not only eliminated the vibrations but also allowed users to easily experiment different distances between the camera and the fabric. When the camera is to be mounted directly on the knitting machine in a commercial system, one should take into account the serious vibration problem. The final setup of the experimental system is given in Fig. 2.

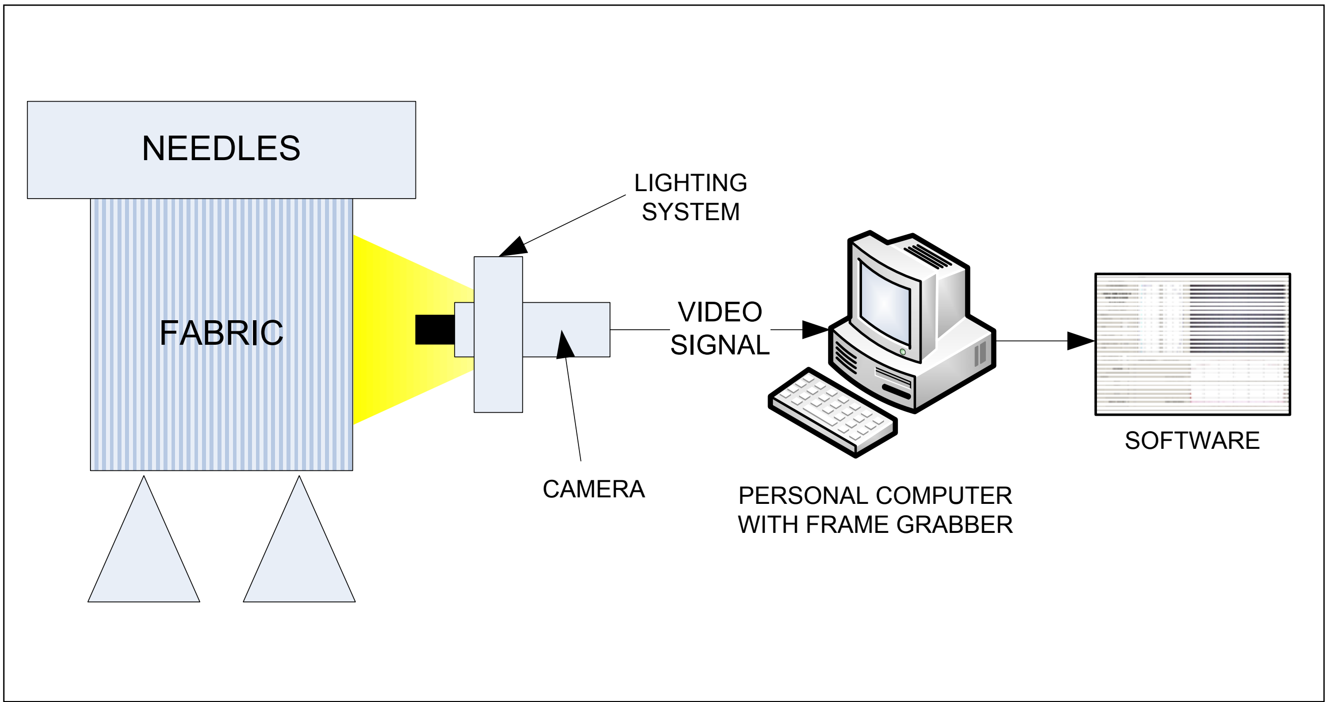


Figure 1. Main components of the developed online fault detection system.

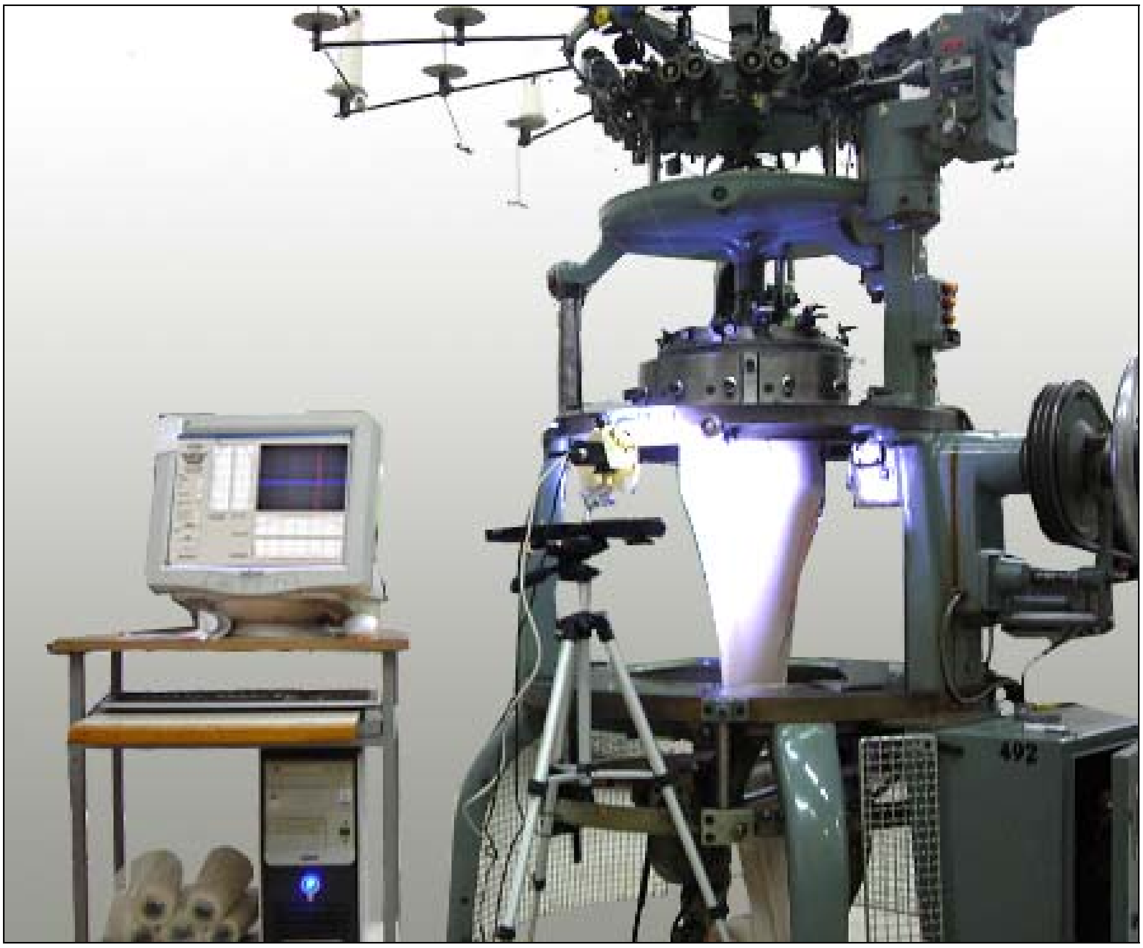


Figure 2 Final setup of the experimental system

4. SOFTWARE STUDIES

The software running on the personal computer communicates with the frame grabber card and whenever an image is received, it runs an algorithm given in Fig. 4.1. The idea is to filter the horizontal and vertical projections of the captured image with an Imaginary Gabor Function (IGF) and check if the resultant signal has values above the predetermined threshold. These samples correspond to the "edges" in the captured image, hence the "faults" in the fabric. The details of the algorithm are as follows.

Odd symmetric one dimensional IGF is a sinusoid enveloped with a Gaussian function centered at the origin as defined;

$$h(x) = \exp\left[-\frac{1}{2}\left(\frac{x^2}{\sigma_x^2}\right)\right]\sin(2\pi x f) \quad (1)$$

where f is the frequency of the sine wave and, σ_x is the standard deviation of the Gaussian envelope function. Please note that the main field of use of the IGF is to detect "edges" in a signal. In our study, the standard deviation of the envelope is selected as $\sigma_x = \left(3\sqrt{2\ln 2}\right)/\left(2\pi f\right)$ to ensure one octave half-peak magnitude bandwidth. Moreover, the frequency of the sinusoid is selected as $f = 1/32$ Hz which was determined experimentally (5).

Since the signal under study (projection of a digitized image) is already discrete, the IGF function is sampled to create a "digital mask." Since the maximum frequency of the function is $f = 1/32$ Hz, according to Nyquist theorem, the minimum sampling frequency is $f_s = 1/16$ Hz. For better accuracy, we choose to oversample it at $f_s=1$ Hz. We limit our attention to the interval $-4 \le x \le 4$. There are 9 samples in this interval when the sampling rate, f_s, is equal to 1 Hz. Moreover, the resultant mask vector is normalized such that its maximum value is *1* so that convolution of mask with a harmonic curve of the matching frequency gives unity peaks. Therefore we have the following *1x9* dimensional mask vector;

H = (-1 .00 -0.79 -0.55 -0.28 0.00 0.28 0.55 0.79 1.00) (2)

Every captured image *I(m,n)* is processed through the algorithm given in Fig. 4.1, where *m* is the row index and the *n* is the column index of an *m* by *n* digital 8-bit grayscale image. The algorithm first calculates the horizontal and vertical projections, $I_h'(n)$ and $I_v'(n)$, as follows;

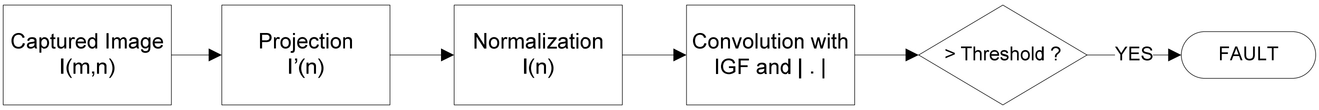


Figure 3. Algorithm for the captured images

$$I'_h(n) = \sum_{m=1}^{M} I(m,n)$$
$$I'_v(m) = \sum_{n=1}^{N} I(m,n) \tag{3}$$

Then, every projection signal is normalized by subtracting the estimated mean and dividing the resultant by the estimated standard deviation as follows;

$$I_h(n) = \frac{1}{\sigma_h}\left[I'_h(n) - \mu_h\right]$$
$$I_v(m) = \frac{1}{\sigma_v}\left[I'_v(m) - \mu_v\right] \tag{4}$$

Each normalized projection signal is convolved with the IGF mask as follows;

$$f_h(n) = \left|h(x) * I_h(n)\right| = \left|\sum_{l=1}^{N} I_h(l)h(x-l)\right|$$
$$f_v(m) = \left|h(x) * I_v(m)\right| = \left|\sum_{k=1}^{M} I_v(k)h(x-k)\right| \tag{5}$$

Please note that convolution operation can provide negative values, therefore in addition to the convolution operation in Eq. 5, absolute values of the convolution results are also taken since our interest is not on the sign but on the magnitude of the values.

The last step of the algorithm is to check if there are any values in $f_h(n)$ and/or $f_v(n)$ that are over a predetermined value. A value over the threshold corresponds to an edge in the projection signal which is in fact an edge in the corresponding image. Due to the camera and lighting setup, an edge in a fabric image corresponds to a "fault" in the fabric being knitted. The threshold is a key factor for the performance of the system and it can be easily determined by measuring the maximum value obtained from a fault-free fabric.

Since the lighting system is not perfectly homogenous and the frame of an image is by itself introduces four edges, the system can provide false-positive results in the far left, right, top, and bottom regions. Therefore a "dead zone" within the image has to be defined. Values of the projection functions that fall into this region should be ignored. (The only disadvantage of this solution is that a fault can be detected later than it appears in the visible region of the camera. The developed software gives the flexibility to the user to define the dead zones.

The image acquisition and image processing algorithms are developed using MATLAB which is a widely used development and testing platform in the engineering field due to its extensive ready-to-use function libraries (15). Another reason to choose MATLAB is that it provides an easy tool to create Graphical User Interfaces (GUI.) Snapshots of the GUI for fault-free fabric and the response of the system to horizontal lubricant stain and broken needle faults are given in Fig. 4 and 5 respectively.

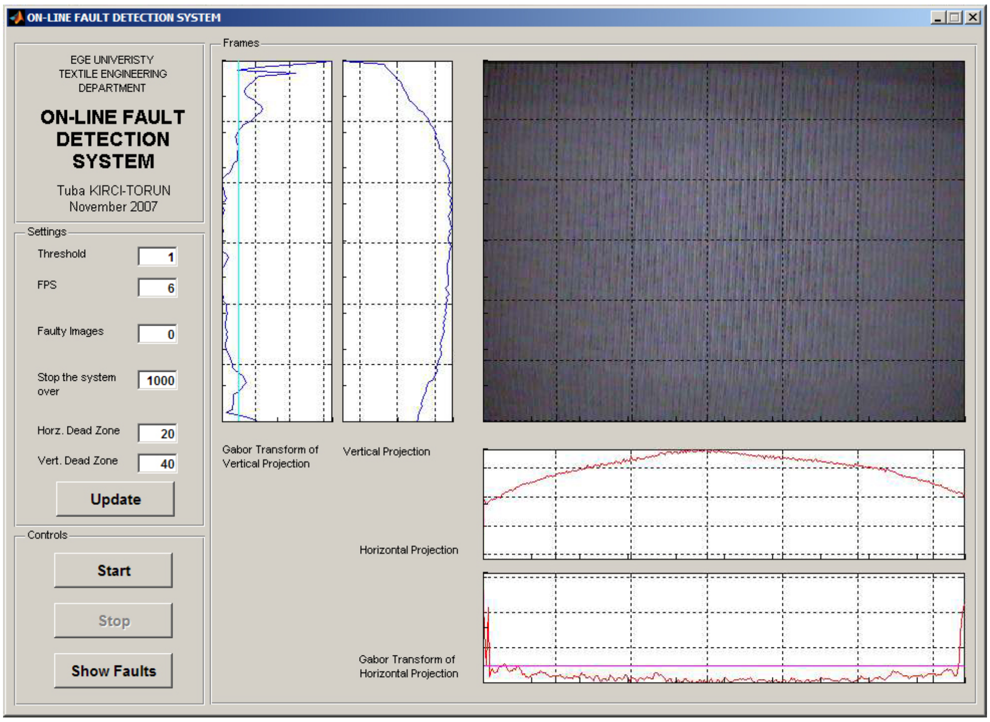
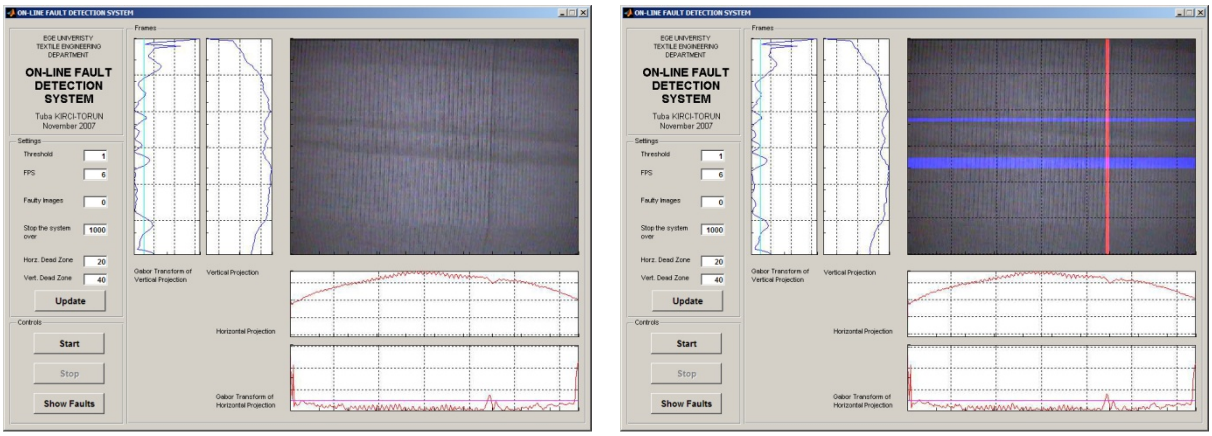


Figure 4. Graphical User Interface



a b

Figure 5. a) Snapshots of the GUI when horizontal lubricant stain and broken needle faults are detected, b) Developed system successfully detects these faults and provides the location of the fault within the fabric.

5. DISCUSSION AND CONCLUSION

In this article, a system that detects the faults that may occur during the production on circular knitting machines and automatically power off the machine upon detection is introduced. With this system, the image of fabric is taken periodically by a camera and transferred to the computer to apply some image processing algorithms.

Developed system can successfully determine eight different knitting fabric faults such as: hole, broken needle, colored yarn, thick yarn, thin yarn, cloth fall out, and vertical and horizontal lubricant stains.

In conclusion, the introduced system can be considered as an important step for knitting industry to decrease the production of faulty fabrics and production costs. Although satisfactory results were obtained on false alarm rate of the system during the preliminary tests, authors of this article are currently working to improve overall success rate. Further studies on the system will provide categorization of the faults. In addition, the system's current processing time, which is approximately 8 frames per second, can be improved by using more powerful computers for industrial applications. Nonetheless, it should be taken into consideration that physical components of the system must be improved as well. As a bottom line, it can be said that this system is a promising start for knitting industry in order to provide solutions for fault detection during the production.

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Bu araştırma, Bilim Kurulumuz tarafından incelendikten sonra, oylama ile saptanan iki hakemin görüşüne sunulmuştur. Her iki hakem yaptıkları incelemeler sonucunda araştırmanın bilimselliği ve sunumu olarak ***"Hakem Onaylı Araştırma"*** *vasfıyla yayımlanabileceğine karar vermişlerdir.*

NANO TEKNOLOJİNİN TEKSTİLDEKİ KULLANIM ALANLARI

- Koruyucu ve ısıya dayanıklı iş elbiseleri

WL Gore & Associates "Gore-Tex Workwear" nanoteknoloji ve Dupont's Teflon teknolojisini kullanarak kötü hava koşulları ve elektrostatik kalıntılara karşı koruyucu anti statik zar üretmiştir.

- Ferahlık ve tazelik hissi uyandıran giysiler

Nano tanecikleri hoş koku salımı sağlar ayrıca, çeşitli mantar ve mikrobakterilerin çoğalmasını önleyerek giyimde ferahlık yaratır. Ciba Speciality Chemicals, nano konteyner mikrokapsüllerini esas alarak, nanolifleri modifiye eder ve bu sayede anti-mikrobiotik ortaya çıkmasıyla bakteri üremesi engellenir. Aynı teknoloji koku emilmesinde de kullanılır.

- Yüksek nem absorbe edebilen elyaf

Kanebo Spinning Corp of Japan normal polyester lifinden 30 kat fazla nem absorbe edebilen polyester lifi ve ipliği üretmiştir. Bu iplik, iç giyim için uygun olup, yağ ve nem içeren yirmi tabakaya sahiptir. Bu tabakaların toplam kalınlığı 50 nanometredir. Ayrıca, Toray Industries tarafından yüksek nem absorbe edebilen ultra ince naylon lifi ve ipliği üretilmiştir.

- **Estetik kumaşlar**

Teijin Fibres of Japan firması, parlak polyester lifi üretimine başlamıştır. Işığın farklı kırılma indislerine sahip 60 polyester ve naylon tabakası, polyesterden oluşan bir özü çevrelemiştir. Sadece 69 nanometre kalınlıkta olan tabakalar ışığı kırarak, ışığın kumaşa geliş açısına bağlı olarak değişen mistik bir görüntü vermektedir.

- **Hafif ve dayanıklı malzemeler**

Nanolif üretimi ve bu teknolojinin gelişimi, daha hafif ama daha güçlü lif-polimer kompozitlerinin üretimini sağlamıştır. The Swiss Federal Institute of Technology şimdiden nanolif eğirmeye başladı, ayrıca University of Texas ve Irelands Trinity College kevlar lifinin 17 katı dayanıklılıkta karbon nano-tüp kompozit lifleri eğirme denemeleri yapmışlardır.

- **Buruşmaz kumaşlar**

Nano-tex, pamuk liflerine moleküler yapılar bağlayarak buruşmaya dayanıklı kumaş üretti.
(Kaynak Intennet)