JANUARY 2020 M.Sc. in Textile Engineering ELİF GÜLTEKİN

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DEVELOPMENT OF AN AUTOMATIC YARN BOBBIN ABRAGE DETECTION SYSTEM BY MACHINE VISION TECHNOLOGY

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IN

TEXTILE ENGINEERING

BY

ELİF GÜLTEKİN

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Supervisor

Assoc. Prof. Dr. Halil İbrahim ÇELİK

by

Elif GÜLTEKİN

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I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Elif GÜLTEKİN

ABSTRACT

DEVELOPMENT OF AN AUTOMATIC YARN BOBBIN ABRAGE DETECTION SYSTEM BY MACHINE VISION TECHNOLOGY

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In purpose of this study, a machine vision system which can automatically detect existence and area of abrage fault on yarn bobbin were developed. The fibers have different dyeability properties and different light reflection characteristics. As a result of accidental mixing of raw materials used at different stages of yarn production (in the blend or package phase), the fault known as "*abrage*" occurs. If the defective coils are converted to the fabric form, then there will be mistakes in color differences after dyeing process. The abrage faults are seen as color or shade difference on the dyed fabric. Nowadays abrage faults are controlled by the quality control personnel on the bobbins or on the fabric by eye. This process takes long time and it is very tiring. New developments in machine vision and automation technologies provide more sensitive process control and quality inspection in each stage of the production line. Developments in industry 4.0 technology and image processing techniques have been used in many areas in textile industry in last decade. Image processing techniques have been generally used for automatic detection of fiber, yarn and fabric characteristics with improved accuracy and quicker results. In this thesis study, a prototype machine vision system was designed and constructed for automatic detection of yarn bobbin abrage fault. Image processing software were developed and applied on bobbin samples including different types of abrage fault. Finally, the success of the developed machine vision system was statistically evaluated. It was determined that the bobbin abrage faults were detected with 95.84% accuracy.

Key Words: Image Processing, Machine Vision System, Yarn Faults, Yarn Bobbin, Yarn Abrage

ÖZET

ABRAJ HATALARININ İPLİK BOBİNİ ÜZERİNDE OTOMATİK OLARAK TESPİT EDİLEBİLECEĞİ BİR YAPAY GÖRME SİSTEMİNİN GELİŞTİRİLMESİ

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Bu çalışmada, iplik bobinindeki abraj hatası ve alanın otomatik olarak tespit edildiği bir yapay görme sistemi geliştirilmiştir. Lifler farklı boyanabilirdik özelliklerine ve farklı ışık yansıtma özelliklerine sahiptir. İplik üretiminin farklı aşamalarında (harman ya da bobinleme aşamasında) kullanılan hammaddelerin kazara karışmasının bir sonucu olarak "*abraj*" olarak bilinen hata meydana gelmektedir. Abraj hataları boyalı kumaşlarda renk ve ton farkı olarak görülmektedir. Günümüzde, abraj hataları bobinlerde veya kumaşta kalite kontrol personeli tarafından gözle kontrol edilmektedir. Bu uzun zaman alan yorucu bir süreçtir. Yapay görme sistemleri ve otomasyon teknolojilerindeki yeni gelişmeler, üretim hattının her aşamasında daha hassas proses kontrolü ve kalite denetimi sağlamaktadır. Endüstri 4.0 teknolojileri ve görüntü işleme tekniklerindeki gelişmeler, son on yılda tekstil endüstrisindeki birçok alanda kullanılmaktadır. Görüntü işleme teknikleri genellikle, elyaf, iplik ve kumaş karakteristiğinin belirlenmesinde yüksek doğrulukta ve daha hızlı sonuçlarla kullanılmaktadır. Bu tez çalışmasında, iplik bobinlerinde abraj hatalarının tespit edilmesi için yapay görme sistemi tasarımı ve kurulumu gerçekleştirilmiştir. Görüntü işleme yazılımı geliştirilmiş ve farklı tiplerde abraj hatası içeren bobin numuneleri üzerinde uygulanmıştır. Sonuç olarak, geliştirilen yapay görme sisteminin başarısı istatistiksel olarak değerlendirilerek bobin abraj hatalarının %95,84 doğrulukta tespit edildiği belirlenmiştir.

Anahtar Kelimeler: Görüntü İşleme, Yapay Görme Sistemi, İplik Hatası, İplik Bobini, İplik Abrajı

’’To my family and my professor’’

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CHAPTER I

INTRODUCTION

1.1 Introduction

The fibers have different dyeability properties and different light reflectance characteristics. Accidental mixing of raw materials used in different stages of yarn production (blending or winding) results in a fault called “Abrage”.

Abrage fault is detected on the bobbin after the yarn production and on the fabric before the read-made process. Nowadays, this fault control is currently performed by the human eye both on the yarn package and the fabric under the UV light (Figure 1.1). In the control of the bobbin, the yarn bobbins are placed in a creel prior to packing and transported to a room illuminated by UV light, where the bobbins are individually controlled (Figure 1.2). In an enterprise with an average daily production capacity of 15 tons of yarn, approximately 7500 bobbins are controlled daily. Four workers are to be employed at least. This process is time consuming and tiring. When the number of bobbins to be checked daily is considered, the risk of overlooked bobbin is high. On the other hand, the automated process flow in fully automated spinning mills is interrupted by visual evaluation (Figure 1.3). When a yarn bobbin including foreign material is used for fabric production, it will cause different appearance after finishing or dyeing processes. It is also a critical fabric fault. The fabric abrage is also detected on industrial fabric quality inspection machines. The fabric surface is scanned by human eyes under UV lightening. This detection process is also achieved manually by the workers.

If the abrage faults cannot be detected either on the yarn package or on the fabric surface, it will be eventuated as defective (second quality) end-use textile product. This situation is being reflected as a serious problem for the manufacturers and cause very high reclamation costs. In order to perform this operation automatically, a machine vision system based on the inspection of different fiber contents in yarn bobbin from their different reflectance values under the same lightening conditions is proposed.

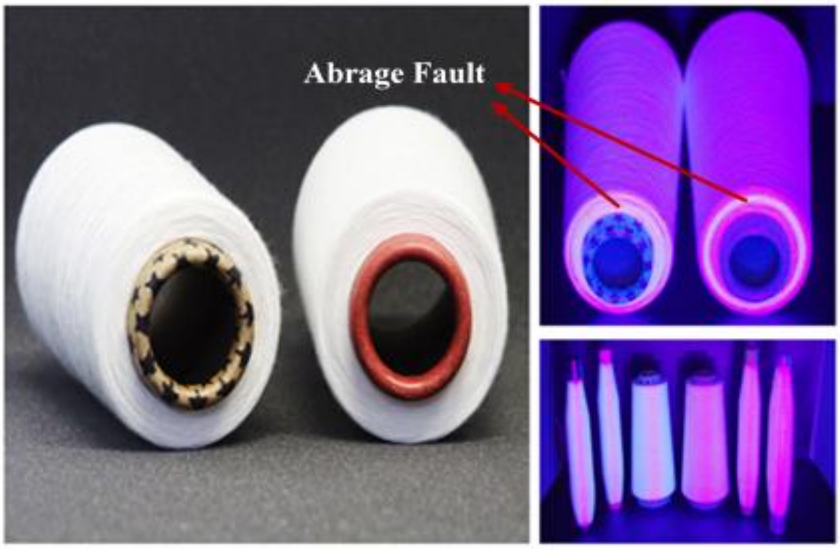

Figure 1.1 Abrage view under UV light [1]


Figure 1.2 Commercial abrage control [2]

Figure 1.3 Fully automated spinning mills [3]

1.2 Literature Survey

Machine vision systems developed using image processing techniques are becoming more common day by day. Many systems have been developed in order to perform subjective evaluations automatically with less errors and in shorter duration. Image processing techniques have many applications in textile sector as in many sectors. Applications of image processing techniques in the field of textile engineering are mainly;

1. Determination of fiber characteristics,

2. Determination of yarn characteristics,

3. Determination of fabric characteristics,

The literature background was investigated under these three main headings.

Studies on fiber characteristics have generally focused on the determination of the geometric properties of the fibers in the cross-section, such as diameter, length, fineness and crimp [4-15]. The studies which are suitable for the purpose of this study and which can guide the thesis are about the detection of foreign matter in the fibers by image processing techniques [16-21]. Studies on yarn characteristics are mostly about the determination of yarn hairiness, yarn unevenness and yarn defects (thick place, thin place and neps) [22-33].

In their study, Li et al. described a machine vision system on a cotton line where the colors and shapes of foreign fibers were automatically detected and classified on the conveyor during fiber opening. For this purpose, three different classification methods based on multi-class support vector machine (MSVM) were presented. First, the fiber images were taken as they pass through the machine vision system and then subjected to the foreign matter detection algorithm. Then, the color, shape and texture properties of the determined foreign substances were removed and the classification process was performed. It was claimed that the proposed machine vision system and classification methods showed an average success rate of 93.57%, 92.34% and 79.25% respectively [17].

Su et al. have proposed a machine vision system since polypropylene, packaging materials and black pigments blended into wool fibers because of cannot be dyed during the dyeing process and cannot be used as wool. The proposed system consists of a line camera (CCD camera), frame grabber, computer and air jets. As a result, it was observed that foreign objects of minimum 4x2 cm^2 can be on-line detected on the wool line process [18].

Yuhong et al. presented a model for the determination of foreign fiber defects in the specific yarn model, since many foreign fiber types may remain together, and this foreign fiber detection is not very effective in the fiber form. For this purpose, some data such as length, area and number of these foreign fibers were used as parameters of the regression equation. When the fiber sensing device detects a foreign substance, the calculated fiber size and fault point was used in the regression equation and then the foreign substances which are thought to be faulty could be identified. It has been found that the accuracy of the proposed model was more than 95% [19].

In another study, Pai et al. emphasized that wastes (contaminant) in cotton fibers adversely affect the quality of cotton and cause economic damage. In their research, they carried out the analysis of waste materials in cotton fibers using feature extraction of image analysis on X-ray microtomographic images. Despite some difficulties of the present system such as long scanning time (15-20 minutes), it is stated that the developed system can be effective in detecting wastes in cotton off-line detection [21].

Wang et al. in their paper, described the determination of hairiness which is one of the yarn quality parameters by image processing technique. Firstly, yarn images were taken with the help of digital camera, then the skeleton of the yarn was removed with the algorithm prepared in C ++ software. In the determination of hairiness index, extracted skeleton and yarn hairiness were calculated by pixel method. As a result, it was stated that the proposed algorithm was successful in determining the yarn morphology [22].

In their study, Kuzanski et al. stated the stages of the algorithm which was prepared for determining yarn shape and calculating yarn hairiness length. The method used to determine the yarn hairiness consists of 3 steps; removing the yarn core from the acquired image, trimming the yarn hairiness and calculating the protruding fiber length. As a result of the proposed algorithm, it was found that yarn hairiness was determined successfully [23].

Fabijanska et al. stated that yarn hairiness was one of the most important parameters affecting the fabric quality. Image processing and analysis algorithms developed for automatic determination of yarn hairiness were presented. In this study, necessary steps for developing image processing algorithms were explained. The main steps of the proposed algorithms were: Image preprocessing, yarn core extraction using the graphical cutting method, high-pass filtering based method and yarn segmentation using yarn extraction. In addition, statistical parameters (mean absolute deviation, standard deviation and coefficient of variation) of hairiness index were calculated. Finally, the results obtained were analyzed and discussed. It has been stated that the proposed approach for yarn hairiness measurement is universal and the presented algorithms can be successfully applied in different systems for yarn quantitative analysis [24].

Xu et al. propose an automatic measuring system in which the yarn snarl image frames were acquired in the water bath. After the images were obtained, the yarn profiles were separated from the binary images. In this study, Fast Fourier Transform (FFT) and Adaptive Directed Orthogonal Projective Decomposition (AOP) techniques were used. The information about the number of crimp turns, the height and width of the crimp were obtained from the taken images. The results indicated that very similar values were obtained in comparison to the results from the yarn twist tester. In addition, numerical simulations with induced variables were performed to evaluate the effects of yarn diameter, number of snarls and unevenness [25].

Guha et al. have described the requirements of a commercial tester in which yarn hairiness can be determined by image processing. Two difficulties were expressed for the developed system. Unlike other studies, an algorithm that can be used to process images taken at varying lighting conditions and changing yarn position and the minimum requirements of the system in which this process will be performed was emphasized. The images taken with the projection microscope were analyzed with the prepared algorithm and the actual length of the yarn feathers was found. A new hairiness index proposed as an alternative to the traditional hairiness index. As a result, a more sensitive hairiness calculation was obtained for the thin yarns with the proposed method [26].

In their article, Carvalho et al. presented an automated system for yarn hairiness analysis based on capacitive and optical sensors. In the system, different sensitivity values commonly used in textile industry were introduced to the system. Signal processing techniques were used to calculate yarn hairiness. Furthermore, the proposed system offers new parameters like -Coefficient of Variation-CV, Mean Deviation-U, number and length of faults- unlike traditional measurement. As a result, it was aimed to develop a low-cost system for online control of yarn hairiness [27].

In the study presented by Asgari et al. the appearance change in yarn samples as a result of yarn-yarn friction was evaluated by image processing method. Within the scope of the study, pure cotton ring spun yarn samples with four different yarn counts; Ne 10, Ne 16, Ne 20 and Ne 30 were used. Four different abrasion cycles; 200, 400, 600 and 800 were processed. After each abrasion cycle, images were taken from different regions of yarn samples and average diameter, hairiness index and average hairiness density values were calculated by using image processing software. Subsequently, the accuracy of the values obtained from the image processing was determined by the change in mass loss after yarn abrasion. Correlation analysis was performed between the values determined by mass loss and the values obtained after image processing. As a result, it was stated that there was a high correlation (0.92) between the mean diameter change and mass loss measurements and that all visual evaluation results decreased as the abrasion speed increased [28].

Özkaya et al. explained the spatial and frequency digital image analysis techniques for twist measurement in yarn structure. In this study, first of all a spatial analysis technique was developed to extract the twist angle of the yarn core by image analysis. Next, a Fourier transformation technique was applied to the yarn surface images to measure the direction of the fiber. Experiments showed that spatial analysis is a fast method and the yarn twist can be predicted successfully. The Fourier transformation technique is highly sensitive to protruding fibers on the yarn surface, which can result in measurements with high variations. The results obtained in the study were reported to be reasonably equivalent to the actual twist levels [29].

Yang et al. stated that in the textile industry, different types of foreign fibers can be mixed with cotton, which affects the quality of the final cotton textile products. The automated visual inspection system has now become a popular tool for the detection of foreign fibers in mohair in real time. Image processing is one of the basic techniques in this system. Foreign fibers used in this research were; feathers, papers, polypropylene yarns, chemical fibers, cloths, hemp threads, bristles, packaging materials, plastic films, and the like. This approach includes four main steps: image transformation, image enhancement, image segmentation and post-segmentation processing. The results showed that the proposed models can significantly improve the contrast between objects and background [30].

In their study, Roy et al. presented a system for measuring the length, diameter and neps of yarn by using a low-cost USB camera. A prototype system that consists of yarn guiding unit with a uniform tension and image acquisition software. By means of developed image processing algorithm, the yarn parameters were determined. The results were compared with manual measurements. It was concluded that the threshold parameters should be automatically adjusted by using artificial intelligence techniques. It was also stated that the proposed system should be improved for a real-time industrial application [31].

In the study conducted by Nateri et al. yarn defect assessment was identified as one of the most important problems in the textile industry, as it could greatly impair the quality of the product. The images of the yarn samples were first taken by the scanner, then the images were modified using a variety of filters. Yarn defects are mainly determined on geometric shapes and surface area. The results showed that the presented image processing methods were perfectly reliable in evaluating the number and types of yarn defects [32].

Silvestre et al. conducted a study in order to determine the abrage faults caused by the mixing the different types of fibers on the yarn spool (cops). Two types of yarn samples were used in the study; raw yarn and dyed yarn. In the study, information was given about system design and some camera features. It was stated that the detection of fault in HSV color space gives better results. The proposed system ultimately showed 100% detection of faulty yarn packages in the product with an error margin of 0.5%. It was concluded that the defective parts of the bobbin can be detected by using the different reflectance properties of the fibers the under the UV light [33].

In another study by Çelik [34], a simple prototype of vision inspection system was described for abrage fault detection and an algorithm was built. It was concluded that abrage faults of different bobbin samples were detected and labeled successfully.

In this study, different from the literature, a machine vision system that can be applied to different size and fiber types of yarn bobbins was designed and constructed. An image processing algorithm was developed to detect the abrage fault and label its boundaries. The abrage fault ratio to the yarn bobbin cross-section was determined automatically. The yarn bobbin diameter measurement is also important parameter for yarn packaging process. By using the developed image processing algorithm, the yarn bobbin diameter was also determined automatically and sensitively. A user-friendly software interface was prepared for camera system control and image processing software application.

It was considered that since a subjectively and manually performed quality control process will be achieved automatically and objectively, the developed machine vision system and image processing software will provide significant contribution to yarn manufacturing industry. By using proposed system, the abrage inspection process will be achieved in shorter time and with lower employment cost. On the other hand, although the abrage inspection is important problem for yarn manufacturing industry, any commercially available mechatronic system that was designed for automatic abrage inspection were not encountered. The designed machine vision system and developed image processing algorithm has also important novelty and improvement for scientific literature.

1.3 Layout of the Thesis

This thesis consists of five chapters. In Chapter 1, the subject of the thesis that is based on an industrial problem is explained briefly. The scope of the thesis is explained. A detailed literature review was also given. In Chapter 2, properties of the materials used in the thesis and the methods used in the study were given in detail. In addition, the steps of the algorithm prepared for yarn bobbin fault detection system were explained. The equipment's of machine vision system proposed in the study were introduced. The design of the system was explained in Chapter 3. In Chapter 4, application results of the prepared algorithm to the images frames acquired from the machine vision system were given. The properties of software interface were also explained. Statistical analysis was made to determine the success ratio of the proposed system and image processing algorithm. The conclusion of the study was presented in Chapter 5.

CHAPTER 2

MATERIAL AND METHOD

2.1 Material

The aim of this study is to determine the abrage fault on the yarn package by using image processing technique. For this purpose, the abrage bobbins samples used in the study consist of three groups: blend abrage, cops abrage and abrage free bobbins. The blend abrage was produced by deliberately blending different fibers during fiber opening. Cops abrage samples were produced by feeding different cops to the same bobbin winding machine in a controlled manner. In the production of abrage bobbins, different fiber materials; USA cotton, domestic cotton, Tencel and polyester were used. The samples were produced in two yarn counts Ne 40/1 and Ne 30/1. In addition, two commonly produced yarn samples with the yarn count of Ne 28/1 and Viscose fiber were also provided. The bobbin abrages for both yarn counts (Ne 40/1 and Ne 30/1) were produced in three different regions; at the beginning of the bobbin, in the middle of the bobbin and at the end of the bobbin and with different sizes. Totally, 36 different types of yarn bobbin samples were produced by KİPAŞ Mensucat R&D Center, Kahramanmaraş, Turkey. The properties of the produced samples are given in Table 2.1.

Table 2.1 Properties of abrage bobbin samples

COPS ABRAGE	BLEND ABRAGE
AT THE BEGINNING OF THE BOBBIN	
Ne; 30/1	**Ne; 30/1**
K1; Bobbin head: Tencel, Bobbin end: Cotton	**H1**; %100 USA Cotton + Local Cotton
K2; Bobbin head: Cotton, Bobbin end: Tencel	**H2**; %100 Brazil Cotton and Other Fiber
K3 Bobbin head: Tencel, Bobbin end: PES	**H3**; %100 Tencel and Other fiber
K4 Bobbin head: PES, Bobbin end: Tencel	
K5 Bobbin head: Cotton, Bobbin end: PES	**Ne; 40/1**
K6; Bobbin head: PES, Bobbin end: USA Cotton	**H4**; %100 Local Cotton and Other Fiber
Ne; 40/1	**Ne; 28/1**
K7; Bobbin head: Cotton, Bobbin end: Tencel	**H5**; %100 Viscose and Other Fiber
K8; Bobbin head: Tencel, Bobbin end: Cotton	
K9; Bobbin head: Viscose Bobbin end: Tencel	
K10; Bobbin head: Tencel, Bobbin end: Viscose	**ABRAGE FREE**
K11; Bobbin head: Cotton Bobbin end: Viscose	
K12; Bobbin head: Viscose Bobbin end: Cotton	**Ne; 30/1**
	A1; %100 USA Cotton
IN THE MIDDLE OF THE BOBBIN	**A2**; %100 Tencel
Ne; 30/1	**A3**; %100 Polyester
K13 Bobbin head: Cotton, Bobbin center: Tencel, Bobbin end: Cotton	**A4**; %100 Brazil Cotton
K14; Bobbin head: Tencel, Bobbin center: Cotton, Bobbin end: Tencel	
K15; Bobbin head: USA Cotton, Bobbin center: Local Cotton, Bobbin end: USA Cotton	**Ne; 40/1**
K16; Bobbin head: PES, Bobbin center: Tencel, Bobbin end: PES	**A5**; %100 USA Cotton
K17; Bobbin head; Brazil Cotton, Bobbin center: USA Cotton, Bobbin end: Brazil Cotton	**A6**; %100 Viscose
	A7; %100 Brazil Cotton
Ne; 40/1	
K18; Bobbin head: Tencel, Bobbin center: Cotton, Bobbin end: Tencel	**Ne; 28/1**
K19; Bobbin head; Cotton, Bobbin center: Tencel, Bobbin end: Cotton	**A8**; %100 Viscose
K20; Bobbin head: Viscose, Bobbin center: Tencel, Bobbin end: Viscose	
K21; Bobbin head: USA Cotton, Bobbin end: Local Cotton	
Ne; 28/1	
K22; Bobbin head: Brazil Cotton, Bobbin center: USA Cotton, Bobbin end: Brazil Cotton	
K23; Bobbin head: Viscose, Bobbin center: Polyester (Coolmax), Bobbin end: Viscose	
AT THE END OF THE BOBBIN	
Ne; 28/1	
K24; Bobbin head: Brazil Cotton, Bobbin end: USA Cotton	

2.2 Method

An image is defined as a two-dimensional function, F (x, y), where x and y are the spatial coordinates specifically arranged in rows and columns. The amplitude of F at any pair of coordinates (x, y) is called the intensity of the image at that point. Each digital image consists of a limited number of pixels with a specific location and value. Pixel is the smallest element of an image. The brightness values of the pixels in the spatial dimension x, y is called '*intensity*'. In order to express the analog image in the digital system, it must first be divided into a finite number of spatial dimensions (sampling), and then the analog intensity value in each part must be expressed in one of a number of discrete digital levels (quantization) [35].

The technique of image processing is the process of improving or analyzing the image frames obtained from the video or camera captures using mathematical functions. The image processing technique basically involves three steps; image acquisition, image processing and image displaying. In the image processing system, first of all, digital frame data is obtained from the video. Data acquisition is provided by the image acquisition element and the image frames are stored in the computer environment. The acquisition element is basically designed to perform three analyzes; image enhancement, image analysis and image coding. The main purpose of image analysis is to extract small data sets that provide relevant information in images of very large data. This is done by dividing the image into smaller independent sequences. Basically, all these operations are performed to remove unimportant and irrelevant information from the whole image and extract important data from their background. The operation of an image works the same as the working principle of the human visual system. It is based on the logic of separating the object in the image from each other and from the background [35, 36].

In the 1960s, the rapidly developing image processing technique began to take place in many sectors as well as the textile sector. It is used in textile production and inspection by examining textile surface properties. Image processing is a method performed by the machine vision system to achieve a predetermined task. When completing this task, two-dimensional images, or even three-dimensional images are analyzed to extract useful information about the task. As a result of the operation, certain attributes of objects such as the presence or absence of an object in an image, its position relative to other objects, completeness and perfection are obtained [36].

In the machine vision systems, the quality and characteristics of the image have a significant effect on the system success. Before, a robust image processing algorithm, high quality image frames must be acquired. Otherwise, the target success cannot be achieved, although the algorithm is robust. Conditions such as lighting, motion blur, camera resolution, and compression of images taken while storing are factors that affect image quality. Therefore, the images taken with the camera are digitized and transferred to a computer environment and then improved using various noise cleaning and image enhancement filters [35].

2.2.1 Steps of Algorithm

In this study, different image processing algorithms were prepared for abrage fault detection and applied to yarn bobbin images obtained from machine vision system. In accordance with the literature research, Gabor filter and Wavelet Transformation are proposed as successful methods for fabric defect detection. So, these methods were selected as alternative methods to be applied for abrage fault inspection. The general steps of flowchart of the algorithms prepared in the scope of the study, is as shown in the Figure 2.1.

If the basic steps in the algorithm are summarized briefly, first of all color images were taken from the machine vision system. In the preprocessing phase, the acquired images were then converted to gray format. The images converted to gray format were converted to binary form, where the bobbin was completely white and the rest was black. The center of the bobbin whose boundaries were completely defined was determined by using Hough transformation method by drawing its contour. Then, the image with known center and diameter was resized and the excess areas were removed. After this stage, the region occupied by yarn bobbin was cut out from the image frame and it was converted to rectangular size by using interpolating. The extracted yarn surface image was enhanced by applying relevant filters. After these main steps of the algorithm, three different methods; Gabor filter, Wavelet transform and local thresholding were applied for fault detection. Binarization process was used for Gabor and Wavelet transform alternatives. Since, the local thresholding method generates a binary image, another binarization method was not required for the third alternative application. In order to obtain more accurate fault boundary, morphological operations were applied for all three of alternative methods.

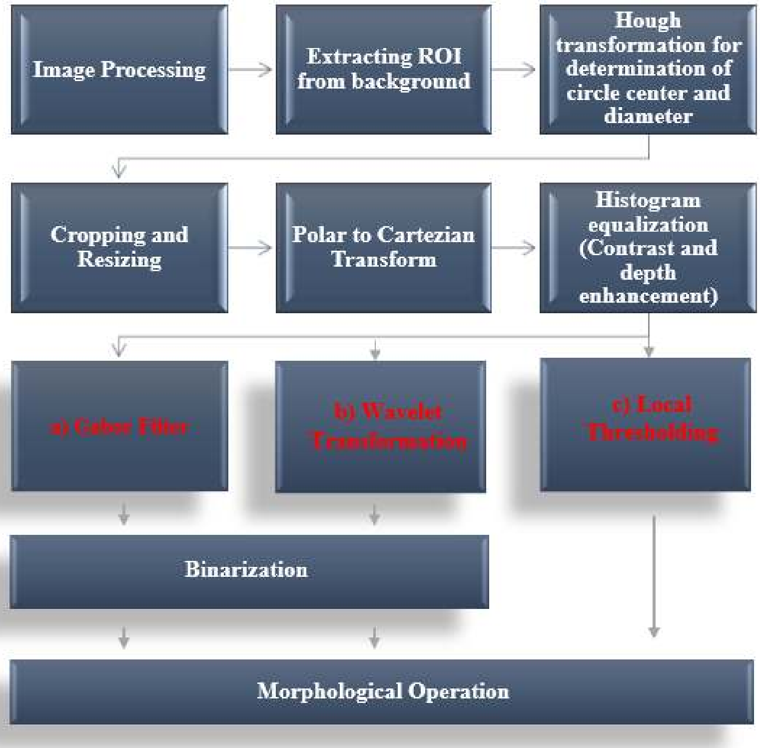

Figure 2.1 Flowchart of the algorithm

2.2.2 Circular Hough Transform

A 2D circle on the coordinate system can be defined by three parameters: the center point (a, b) and the radius (r). A Hough Transform specialized for circle detection consists of a cyclic voting process applied to the model parameters of possible circles providing points in the input image. This creates a 3D Hough space H (a, b, r) that is initialized to zero for all parameter values. The Hough space accumulates the votes cast by the individual candidate circles passing through each point in the image. The determination of the chambers is based on the accumulation of votes cast. If there is a circle in the image, a common set of parameters is voted by each of the points that make up that circle [35, 37].

2.2.3 Polar to Cartesian Transform

In the image processing technique, each color in the processed image frame has a pixel value. Therefore, when an operation is performed for an object in any image, it is desired that the applied filter or operation should affect only the target object in the image size. This process can only be possible when the image frame completely consists of the target object Considering the visual evaluation of the yarn bobbin in the image frame, it is seen that a circular area is occupied within a rectangular image frame with a size of MxN. The aim of this study is to detect the fault due to the difference in tone in the circular area (yarn bobbin) in the image. In the image frame of yarn bobbin cross-section view obtained from the machine vision system, the yarn bobbin has shades of gray, while the areas outside the circular bobbin area are seen as completely black (Figure 2.2). During processing of image frame with any filter, a neighborhood operation is performed in which the value of any given pixel in the output image is determined by applying some algorithm to the values of the pixels in the neighborhood of the corresponding input pixel. So, the applied algorithm of the filtering is valid for whole image matrix. Because of the filtering restrictions, it is considered that the area covered by yarn bobbin cross-section surface should be extracted from the image frame.

The method developed for this problem is based on the transformation of a polar coordinate object into a cartesian coordinate system by bilinear interpolation. In order to perform this process, firstly, the outer boundary of the bobbin the inner and outer diameters of the bobbin circle in the image (Figure 2.3) must be determined. Thus, the image was segmented according to the boundaries of an object whose diameter was known (Figure 2.4). Interpolation was then performed on the segmented image. In this conversion, M is the number of pixels from the minimum r to the maximum r along the radius. Eventually, the output image was an MxN image with M points along the r axis and N points along the theta (θ) axis. As a result, an object in the form of a circle was extracted and transformed into a rectangular image frame (Figure 2.5).

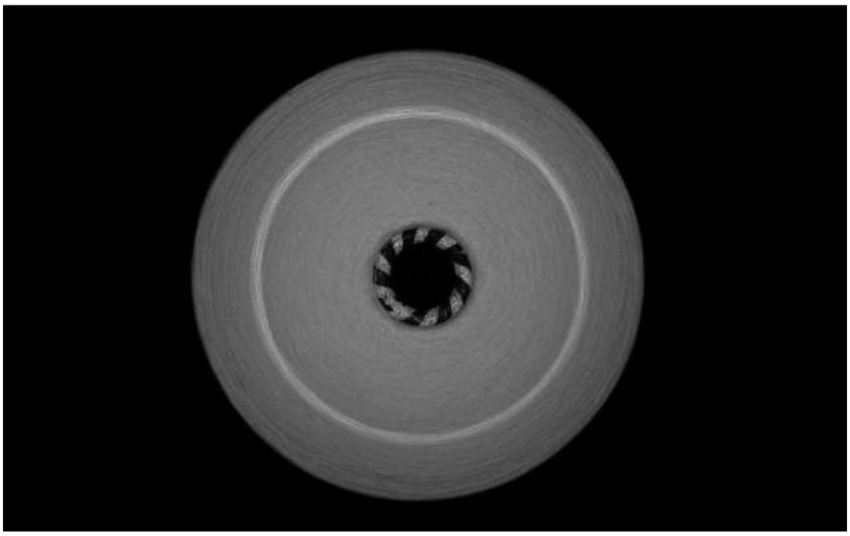

Figure 2.2 Image frame from machine vision system

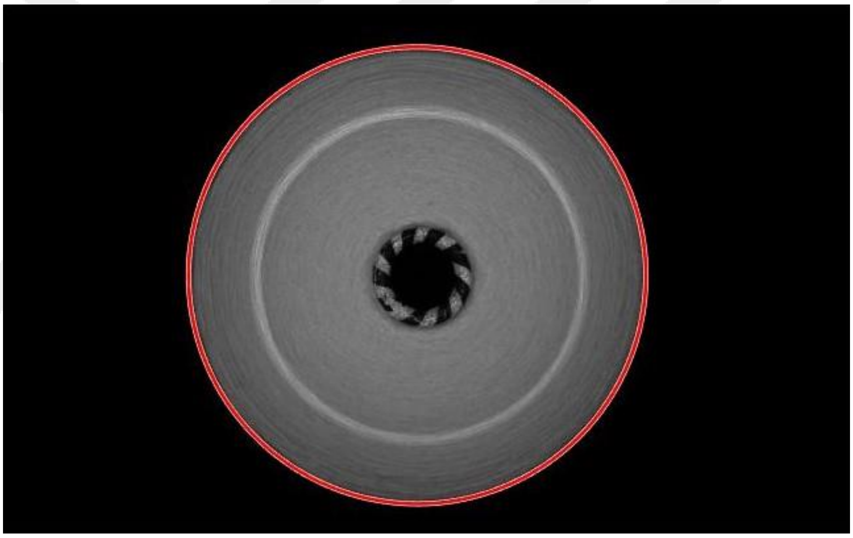

Figure 2.3 Plotted bobbin circle boundary

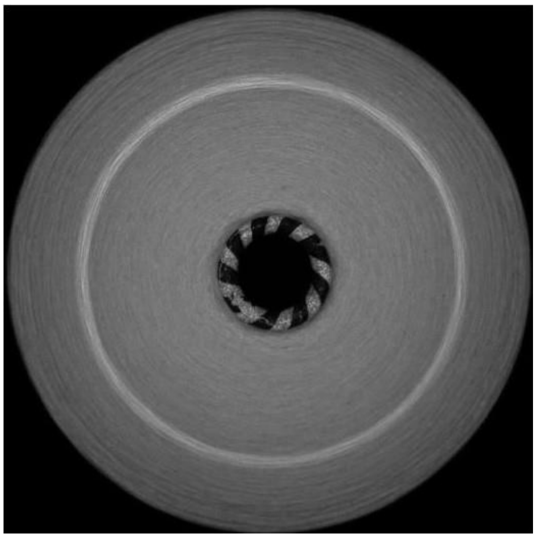

Figure 2.4 Image cropped according to bobbin circumference boundary

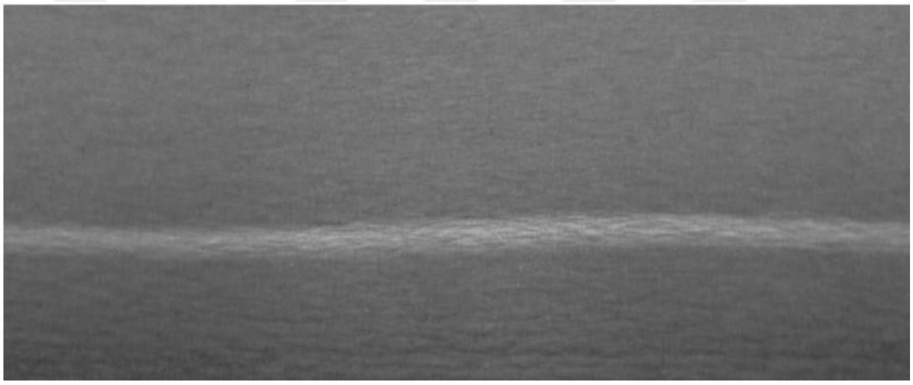

Figure 2.5 Bobbin surface extracted and transformed into rectangular image frame

2.2.4 Gabor Filter

Gabor filter is one of the important methods used in image analysis. By means of this filter, it is possible to detect the edges extending in a certain direction on an image. Gabor core can be adjusted to desired angle and wavelength, and patterns can be found in desired properties. The Gabor function allows us to represent a signal in the spatial and frequency domain simultaneous. This function is used in image analysis to identify different textured regions and subtract the boundaries of that region. These texture properties are used in the optimal Gabor filter, then applied to the image for weakening the background texture and highlighting defects. Some parameters must be pre-defined when creating a Gabor filter for correct detection. These parameters that has to be optimized according to the applications; "*wavelength* (λ)", "*orientation* (θ)", "*phase* *offset* (φ)", "*aspect ratio* (γ)", and "*standard deviation* (σ)" depending on "*bandwidth*" (*b*) [38, 40].

2D Gabor filter used in this study given in Equation 2.1. [38, 39].

$$g_{\lambda,\theta,\sigma,\gamma\varphi}(x,y) = \exp\left(-\frac{x'^2+y^2y'^2}{2\sigma^2}\right)\exp\left(i\left(2\pi\frac{x'}{\lambda}+\varphi\right)\right) \tag{2.1}$$

Gabor filter consists of two parts; the real and the imaginary part given in Equation (2.2) and Equation (2.3).

$$g_{\lambda,\theta,\sigma,\gamma\varphi}(x,y) = \exp\left(-\frac{x'^2+y^2y'^2}{2\sigma^2}\right)\cos\left(i\left(2\pi\frac{x'}{\lambda}+\varphi\right)\right) \tag{2.2}$$

$$g_{\lambda,\theta,\sigma,\gamma\varphi}(x,y) = \exp\left(-\frac{x'^2+y^2y'^2}{2\sigma^2}\right)\sin\left(i\left(2\pi\frac{x'}{\lambda}+\varphi\right)\right) \tag{2.3}$$

where;

$$x' = xcos(\theta) + ysin(\theta) \qquad \text{and} \qquad y' = ycos(\theta) - xsin(\theta) \tag{2.4}$$

(i) Wavelength (λ)

Determines the wavelength of the cosine multiplier. The unit is pixel. Values greater than 2 or 2 must be given to this parameter.

(ii) Orientation (θ)

This angle determines the direction of the edges to be detected. When the angle is '0', the perpendicular to the x-axis is seen. By using theta + 90 angle instead of theta angle, when theta is '0', it can detect horizontal edges. As the angle is increased, the edges with increasing angles relative to the direction of rotation of the rotation matrix are detected.

(iii) Phase Offset (φ)

It is the phase angle of the cosine multiplier. When this value is 0 and 180, the gaussian curve is positioned at the center (x = 0). Different phase angles shift the graph to the left or right relative to the x-axis and cause the curve to be asymmetric with respect to the y-axis. The asymmetry is reflected in the filtered image. That is, in the filtered image, parallel stripes representing the edges are asymmetric in brightness.

While the value of wavelength 2 is given, the phase angle 90 or -90 should not be given. Because in this case, the elements of the core matrix coincide with the zero crossing points of the Gabor function and the core matrix to be obtained resets all pixels of the image to be filtered.

(iv) Aspect Ratio (γ)

The Gaussian function creates a graph in the form of a bell curve. The aspect ratio is the ratio of the width of this curve to the length. This value is reflected in the filtered image to be obtained in the same way. As the value is changed, the aspect ratio of the edges to be obtained changes at the same rate.

(v) Standard Deviation (σ)

The second multiplier in the function is a gaussian function. This value is the standard deviation value of the second multiplier and can be calculated using the bandwidth and wavelength parameters.

2.2.5 Wavelet Transformation

Wavelet transform is a type of transformation used for the time-frequency analysis of a signal (Figure 2.6). Similar to the short-time Fourier transform (STFT), the window function in the wavelet transform takes on the function called the main wavelet, but it is both scaled and offset during the main wavelet transform process. Scaling corresponds to widening and narrowing of the wave and shifting corresponds to shifting the wave in the time axis. In STFD, since the width of the window function remains constant throughout the transformation, the resolution of both the time and frequency domain is increased, which makes the wavelet transformation superior to the Fourier transformation.

If we need to define roughly from the meaning of the word wavelet, it means the smallest wave. A wavelet is an effective waveform in limited time. Wavelet analysis is a windowing technique in variable dimensional regions (Figure 2.7). It also helps us to identify both low frequency information over a long period of time and high frequency information over a short period of time. Wavelet analysis unlike Short Time Fourier Analysis, uses the time-scale field, not the time-frequency field [38, 41, 42, 43].

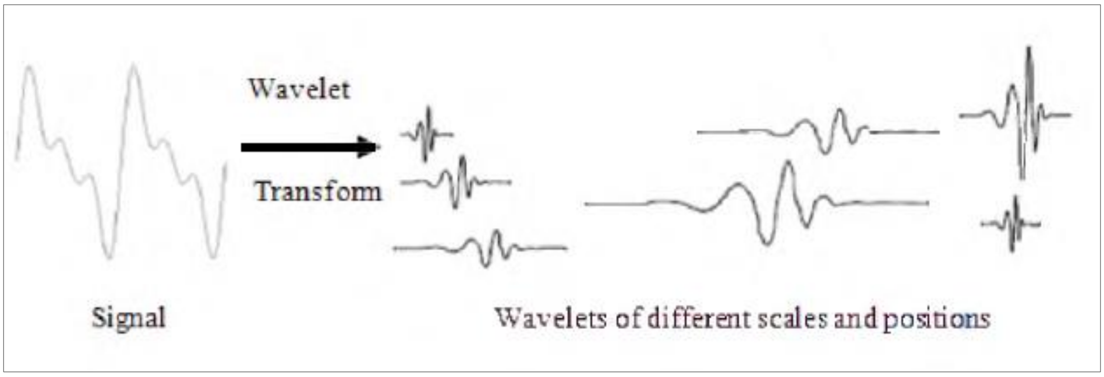

Figure 2.6 Wavelet transformation [38]

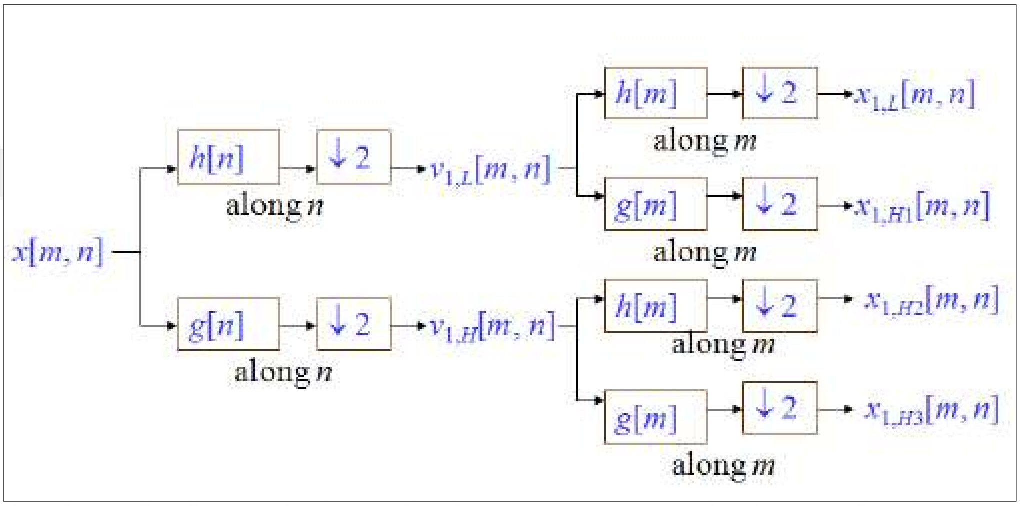

Figure 2.7 Working principle of 2D wavelet transform [43]

This is the general form of 2D wavelet transform. If the scaling and wavelet functions are separable, the summation can be decomposed into two stages. First the x-axis is calculated and then along the y-axis. For each axis, fast wavelet transform is applied to accelerate the speed. A schematic diagram that shows wavelet decomposition is given in Figure 2.8. The two-dimensional signal (usually image) is divided into four bands: LL (left-top), HL (right-top), LH (left bottom) and HH (right-bottom). The HL band represents the variation along the x-axis while the LH band shows the y-axis variation [43].

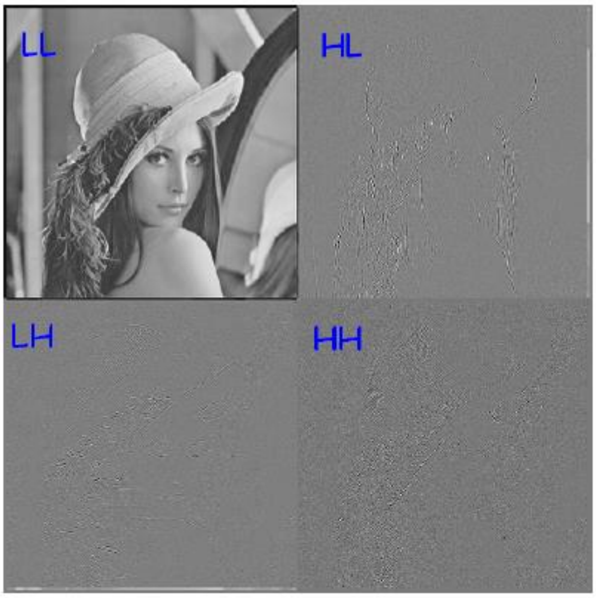

Figure 2.8 A schematic diagram of wavelet analysis

2.2.6 Variable Thresholding Based on Local Statistics

In the methods discussed in the previous section; sub-windowing, creating a specific filter and applying it to the pattern (Gabor) or in global thresholding methods non-homogeneous illumination causes failure. This problem can only be solved when the pixel distributions in the image are uniform or the problem of ghosting that deteriorates the quality of the image is eliminated. Variable thresholding should be preferred in cases where the ghosting in the image caused by the lighting source is high. The variable thresholding approach based on local image properties computes a threshold at each (x, y) point of the image based on one or more properties calculated for a neighborhood of (x, y). As the basic approach for local thresholding, the standard deviations and means of the pixels adjacent to each point in an image are used. Since these two values define local contrast (contrast) and average intensity, they are very useful in calculating local threshold. Although this process appears to be a laborious task, the modern algorithms and the hardware allow fast neighbor processing with common functions, in particular logical and arithmetic operations [35].

Let σ_{xy} and m_{xy} indicate *the standard deviation* and mean value of the set of pixels contained in a neighborhood centered at the coordinate (x, y) in an image. The common format of local thresholds (T_{xy}) is as follows Equations:

$$T_{xy} = a\sigma_{xy} + bm_{xy} \tag{2.5}$$

where a and b are nonnegative constants.

$$T_{xy} = a\sigma_{xy} + bm_G \tag{2.6}$$

where m_G is the global image mean. The segmented image ($g(x,y)$) is computed as:

$$g(x,y) = \begin{cases} 1 \; if \; f(x,y) > T_{xy} \\ 0 \; if \; f(x,y) \leq T_{xy} \end{cases} \tag{2.7}$$

where $f(x,y)$ is the input image. This equation is evaluated and applied at all pixel locations. Local thresholding is also qualified in terms of a logical AND as follows:

$$(x,y) = \begin{cases} 1 \; if \; f(x,y) > \; \sigma_{xy} \; AND \; f(x,y) > bm \\ 0 \qquad\qquad\qquad\qquad\qquad otherwise \end{cases} \tag{2.8}$$

2.2.7 Binarization Process

Binarization has an important place in image processing technique. It is the last step of extracting an object completely from the background. Binarization is called to create a binary image in a sequence (in the image matrix) by making portions below a certain threshold value 0, while portions above this threshold value are set to 1. However, it may not be possible to manually select a threshold value for a situation due to constantly changing environmental conditions. It is often difficult to determine a specific value, even when possible. Instead of dealing with this, looking at the image we give to the system and selecting an adaptive threshold value makes the process quite easy.

Global thresholding has a random threshold value entered by the user, but it is not known exactly whether it will be effective when image processing is started, it is found via the trial side. If the histogram graph showing the pixel distributions in an image has two peaks (bimodal image), the Otsu method takes the value between these two peaks as threshold. So, Otsu thresholding will not be very useful in non-bimodal images. Otsu's thresholding method is used to distinguish the object from the background and insulate only object (foreground) from the image. The image frames are converted into the binary form of black (0) and white (1). According to this, Otsu's method divides the image into two parts, white and black (T_0 and T_1). Here T_0 consists of intensity levels from 0 to t or in set notation $T_0 = \{0,1,2 \dots \dots \dots t\}$and region $T_1 = \{t, t+1, \dots \dots \dots 1-1,1\}$where t is the threshold value, l is the image maximum gray level. Otsu method, is based on calculated variance statistics of T_1 and T_0 sets. The optimum threshold level of the image is determined by the calculated variance values [35, 44].

2.2.8 Morphological Operations

Mathematical morphology is a necessary tool for applications such as borders and skeleton in the image, based on basic set operations, as defining and removing structures, noise removal and segmentation. In image processing, they are often used as pre / post treatment like morphological filtering, thinning and thickening. It can be done on grayscale images, but usually on binary images. Clusters in mathematical morphology correspond to objects in an image [35, 45].

The image preprocessing and post-processing such as noise filtering, shape simplification and object segmenting from the background can be achieved by means of morphological operations. The main morphological operations consist of '*dilation*', '*erosion*', '*opening*' and '*closing*'. Opening and closing, dilation and erosion operations are performed by sequentially applying on the two-valued image.

(i) *Erosion*: It is used to erode the boundary regions of the treated area. Erosion is a morphological process used to shrink objects in binary images (Figure 2.9) [35, 45].

Let 'A' be a binary image and 'B' be a structural element. In the process of erosion; The structural element B is placed on the image A. The pixel of the image A corresponding to the center of the B element is not changed when element B is fully positioned over the image A, if no element is outside the image A. If any element of structural element B is outside image A, the pixel in image A corresponding to the center of structural element B is deleted.

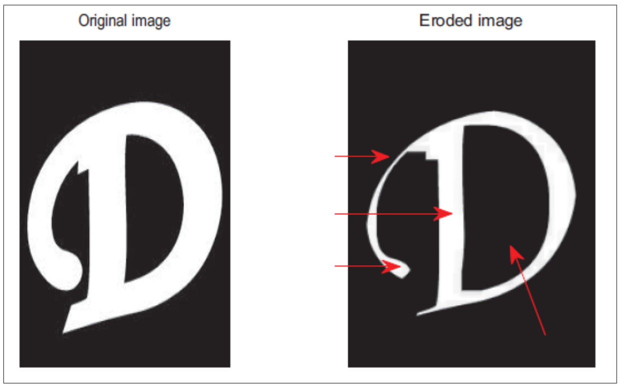

Figure 2.9 Erosion operation [45]

(ii) Dilation: It is used to expand the boundaries of the region under consideration (Figure 2.10). Dilation is a morphological process used to magnify or highlight objects in binary images. The technique of expansion is similar to spatial linear filtration.

Let 'A' be a binary image and 'B' be a structural element. Dilating image A with element B; if the structural element B corresponds to any pixel in the A image when the center of B is placed on the image A, all elements of the structural element B are placed in the image A. B is converted to all possible positions, if there are elements that overlap A, the center of this position belongs to the expansion.

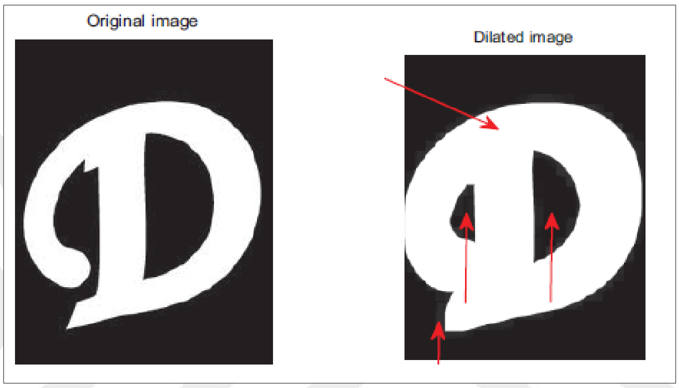

Figure 2.10 Dilation operation [45]

(iii) ***Opening*****:** Dilation is applied immediately after the erosion on the image (Figure 2.11). The objects in the image and the gaps between the objects are cleaned according to the size of the structural element. Objects remaining on the image become slightly smaller than their shape in the original image.

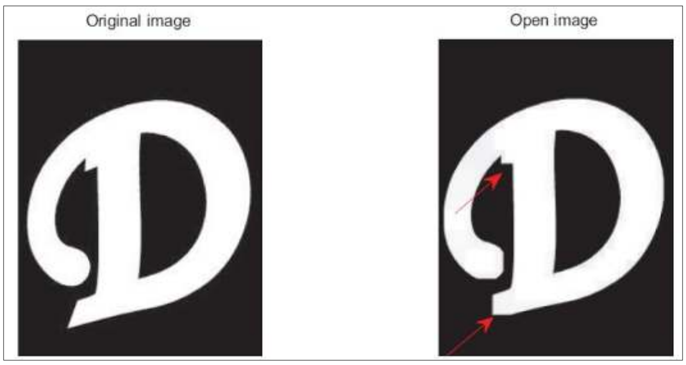

Figure 2.11 Opening operation [45]

(iv) *Closing*: Erosion process is obtained immediately after the dilation process on the image (Figure 2.12). Therefore, two objects that are close to each other are connected without making much changes in the image.

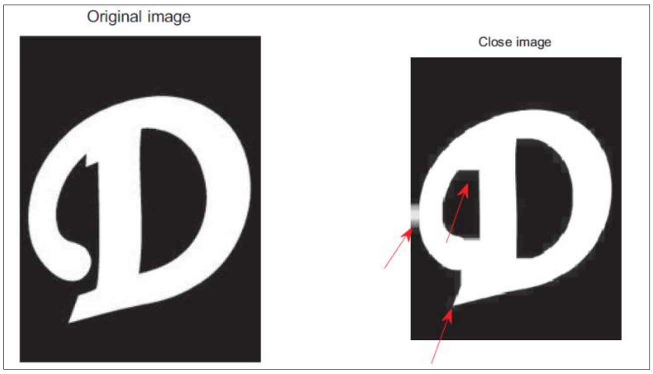

Figure 2.12 Closing operation [45]

2.2.9 Calculation of A Specific Area Percentage in Image Frame

After all image processing steps were completed, Equation (2.9) was used to determine the abrage percentage in the yarn package.

$$Image\ Frame\ Area\ = x * y$$

$$Abrage\ Ratio\ (\%) = \frac{\sum white\ pixels\ in\ binary\ image}{Image\ Frame\ Area} X100 \tag{2.9}$$

where; x, y are the sizes of the binary image.

CHAPTER 3

THE EXPERIMENTAL SET-UP

3.1 Design of Abrage Inspection System

A prototype vision inspection system was developed to acquire image frame of the yarn bobbin samples and to make image analyzing for abrage fault detection. The system consists of a lightening unit, a camera system (BASLER ace acA1920-40uc) a cabin and a computer (Figure 3.1.a). A top-lightening cabin design was made. The lightening unit consists of 12 LED UV fluorescent lamps was designed to position the camera system in the middle of the lightening unit. The dimensions of the cabin are 80 cm x 80 cm x 85 cm. Cabin stand was designed as 80 cm x 80 cm x 85 cm with four legs and wheels. The cabin was painted in matt black color to provide a homogeneous illumination and to eliminate reflection inside the cabin. The camera was placed the top of the cabin by using a properly designed attachment frame. An open area was prepared to the top of the cabin to allow camera view. A suitable apparatus was designed for positioning the bobbin samples at the bottom of the system. The distance of the bobbin sample to camera lens should be arranged so that the camera field of view can be adjusted according to the bobbin size (Figure 3.1.b). A simple screw system was used for sample to camera distance adjustment (Figure 3.1.c). The camera adjustments and algorithm running process were achieved via computer (Figure 3.1.d).

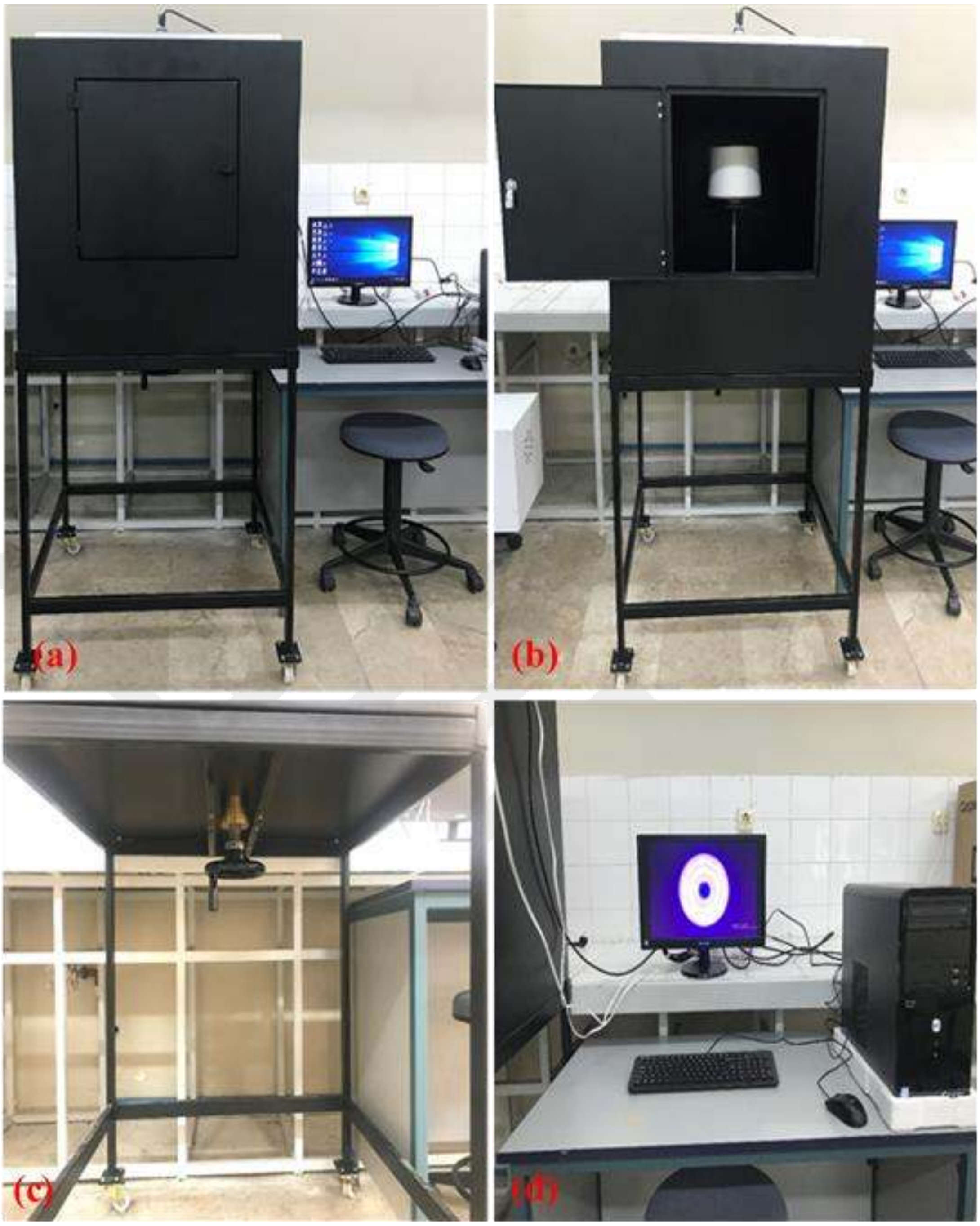

Figure 3.1 A prototype cabin design for machine vision inspection system

3.2 Camera System

BASLER ace acA1920-40uc type area scan camera was determined (Figure 3.2) for this thesis study. The camera has the following characteristics given in Table 3.1.

Table 3.1 Specifications of camera

Camera Brand	BASLER ace acA1920-40uc
Sensor Type	CMOS
Sensor Size	11.3 mm x 7.1 mm
Pixel Resolution	1920 px x 1200 px
Pixel Size	5.86 µm x 5.86 µm
Frame Rate	41 fps
Lens Type	Kowa Lens
Fixed Focal Length	8 mm
Sensor Size	2/3"
Wavelength Range	380 nm-780 nm
Focus Range	0.1 m - ∞ m

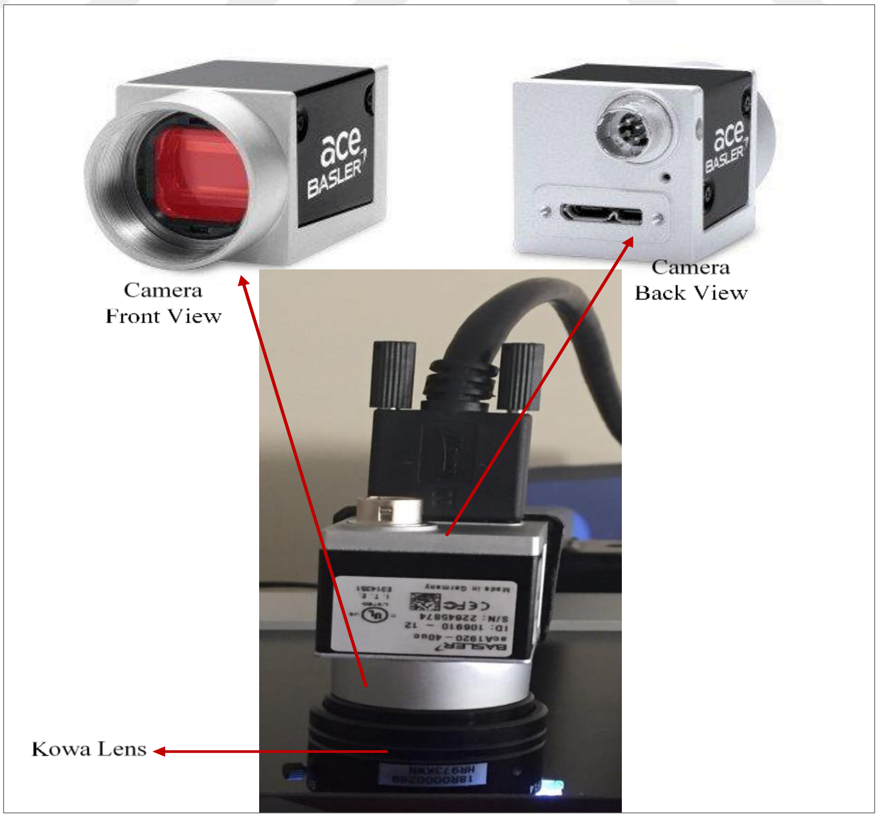

Figure 3.2 Camera system

3.3 Image Acquisition Parameters

According to the lighting conditions, to obtain high image quality, the parameters in the camera software interface (Pylon5) were analyzed (Figure 3.3). The related camera parameters; ***Light Source Pre-set, Gain, Gamma and Exposure time*** etc. have been adjusted until the required image frame was obtained. Different camera parameters were tried for abrage inspection tests, it was seen that these parameters were very effective on determining the abrage fault.

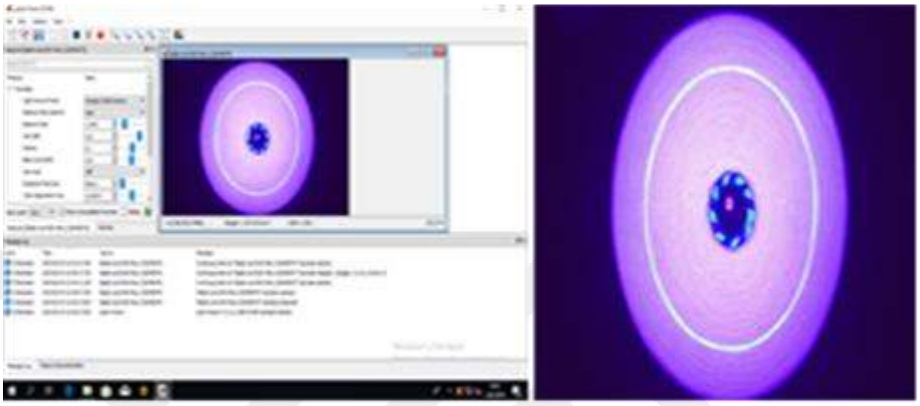

Figure 3.3 The effect of camera parameters on image frame

3.3.1 The Light Source Pre-set

The light source preset parameter provides correction of color bursts caused by certain light sources. Depending on the specific color temperature, the light used to produce the image may cause color changes in the image. So, the selecting correct corresponding color source preset is important. These light sources are;

Off: Without any light source preset, it remains connected to the light from the full illumination.

Daylight 5000K: Corrects color bursts caused by daylight illumination with a color temperature of approximately 5000 Kelvin.

Daylight 6500K: Corrects color bursts caused by daylight illumination with a color temperature of approximately 6500 Kelvin.

Tungsten 2800K: Corrects color shifts caused by tungsten lighting with a color temperature of 2500-3000 Kelvin.

Experiments on light source adjustment are shown in Figure 3.4.

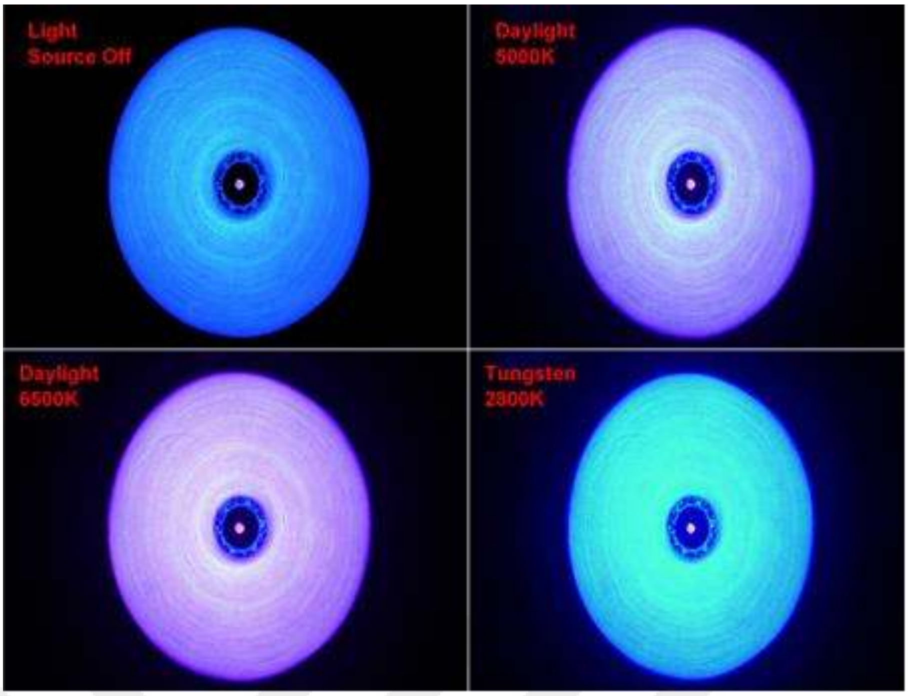

Figure 3.4 Effect of preset light source on image enhancement

3.3.2 Gain

The gain feature of the camera allows us to increase the brightness of the images coming out of the camera. Increasing this increases all pixel values of the image. Related trials are shown in Figure 3.5.

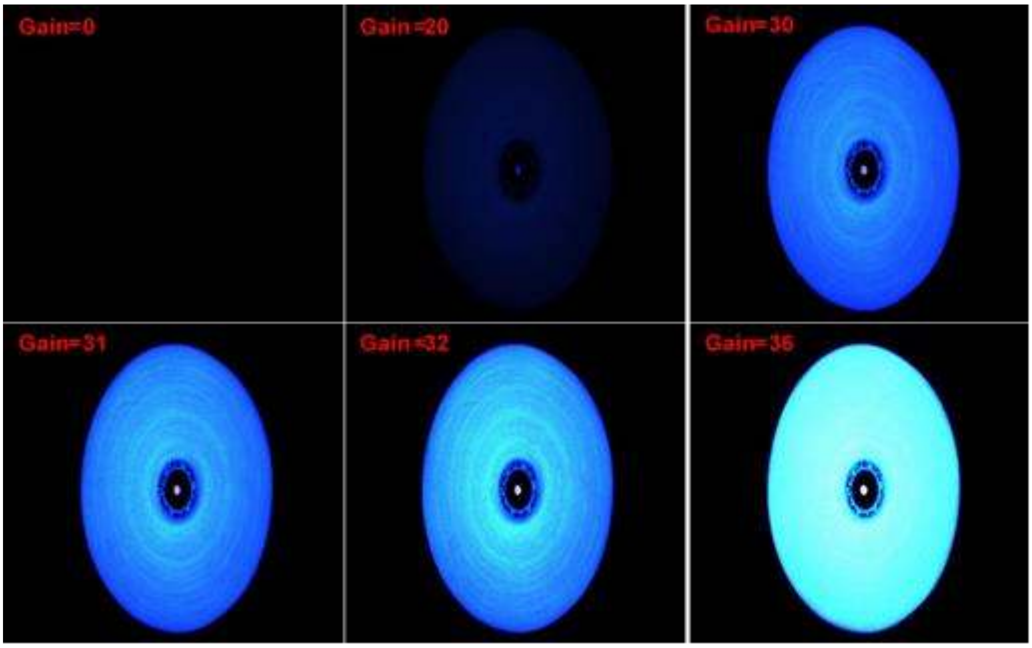

Figure 3.5 Effect of Gain parameter on image enhancement

3.3.3 Gamma

Gamma (Y) effect allows to optimize the brightness of acquired images to display on the monitor. The range of values of the gamma parameter is 0 to ≈4. Experiments on gamma adjustment are shown in Figure 3.6.

Gamma = 1: The overall brightness remains unchanged.

Gamma <1: The overall brightness increases.

Gamma> 1: The overall brightness decreases.

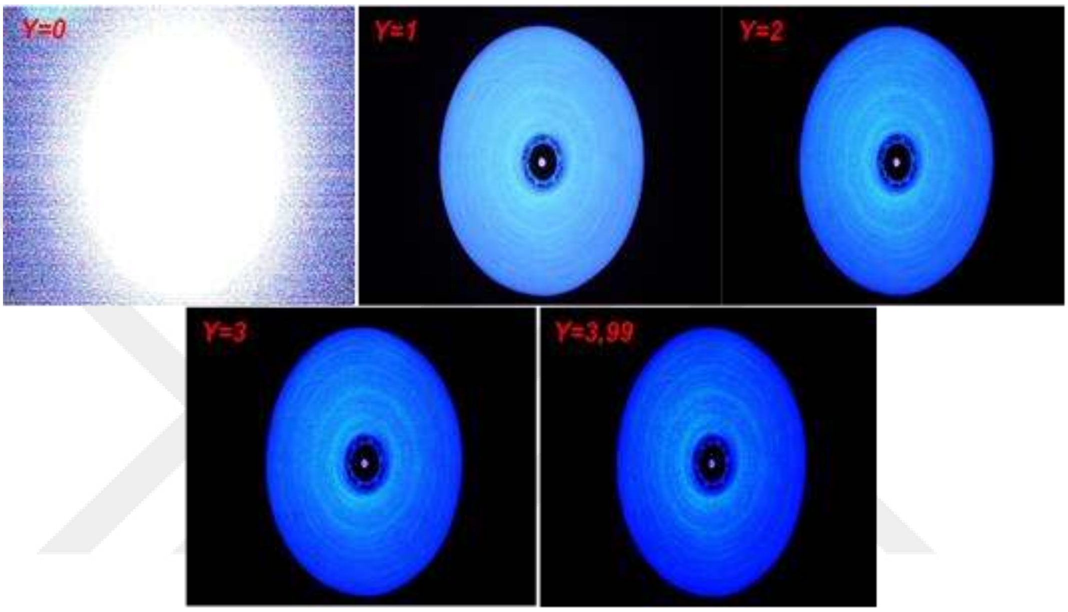

Figure 3.6 Effect of Gamma (Y) parameter on image enhancement

3.3.4 Exposure Time

The exposure time determines how long the image sensor is exposed to light during image acquisition. Experiments on setting the exposure time are shown in Figure 3.7.

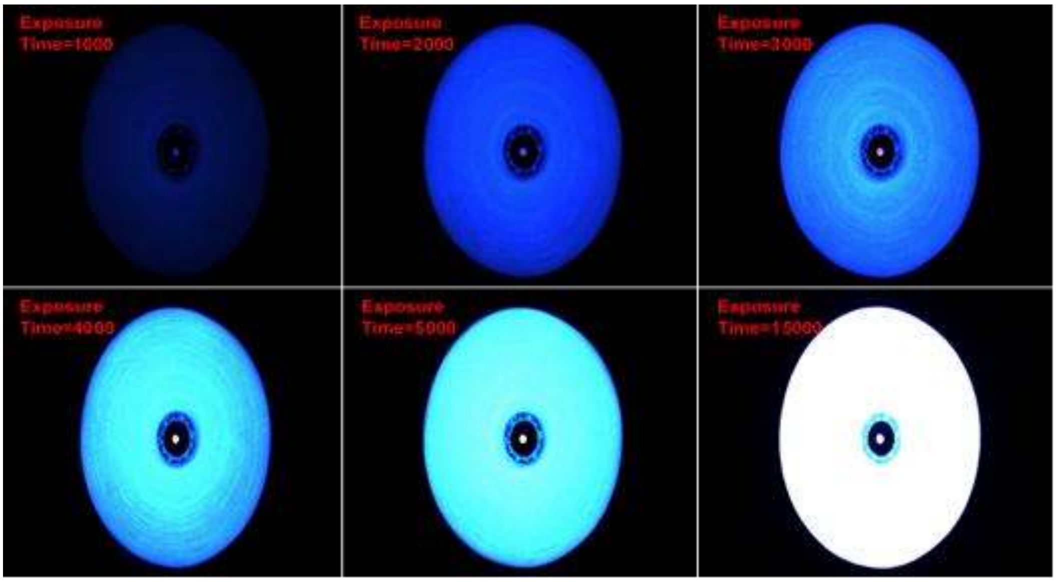

Figure 3.7 Effect of Exposure Time parameter on image enhancement

Apart from these settings, ***Balance White, Color Adjustment and Brightness*** and Contrast settings should also be examined to improve the image quality.

3.3.5 Balance White

Balance White camera feature allows to manually correct color shifts so that white objects appear white in images acquired. The following adjustment choices can be tried.

Balance ratio = 1: The intensity of the color remains unchanged.
Balance ratio > 1: The intensity of the color is increased relative to the other two colors.
Balance ratio < 1: The intensity of the color is decreased relative to the other two colors.

3.3.6 Color Adjustment

Color Adjustment camera feature allows to adjust the hue and saturation of individual colors in images. Hue and saturation separately for each primary and secondary color in the RGB color space (red, green, blue, yellow, cyan, and magenta). Diagram shows (Figure 3.8) how changing hue and saturation of the color red affects the colors of images.

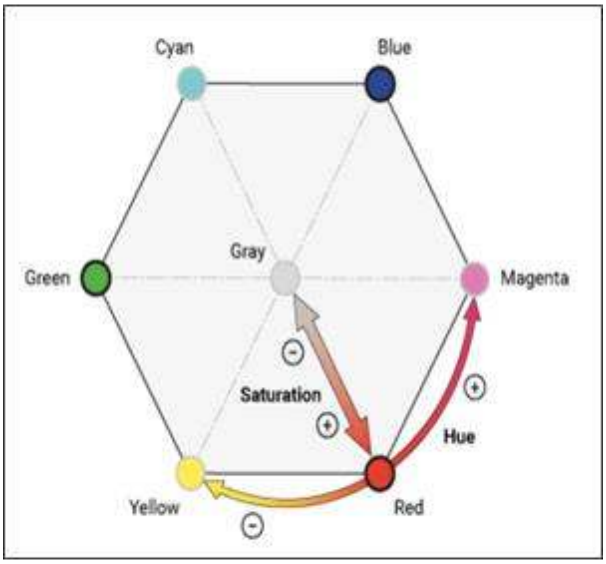

Figure 3.8 Diagram of hue and saturation of the color red on the colors of images

The following effects become apparent:

Decreasing the hue changes all red colors (i.e., colors with a predominantly red component) towards yellow.

Increasing the hue changes all red colors towards magenta.

Decreasing the saturation decreases the colorfulness of all red colors. At minimum, all red colors will be replaced by gray.

Increasing the saturation increases the colorfulness of all red colors. At maximum, all red colors are replaced by 100 % red.

3.3.7 Brightness and Contrast

Brightness and Contrast camera feature allows to adjust the tonal values of your images. Adjusting the contrast changes the degree of difference between light and dark areas in the image. The more contrast you apply, the more pronounced the difference will be. Increasing or decreasing the contrast, increases or decreases the gradient of the linear function. The difference between these two adjustments is shown Figure 3.9.

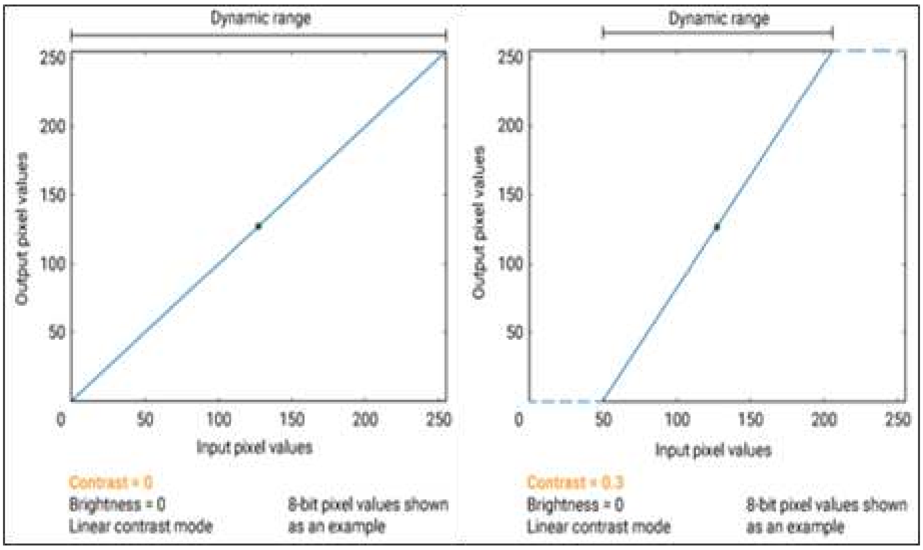

Figure 3.9 Effect of Contrast mode on the image

Adjusting the brightness allows to lightening or darkening the image by increasing or decreasing its tonal values.

Increasing the brightness moves the pivot point towards the upper left. This means that the image will appear lighter.

Decreasing the brightness moves the pivot point to the lower right. This means that the image will appear darker.

Figures 3.10 below show examples with Brightness Contrast mode selected

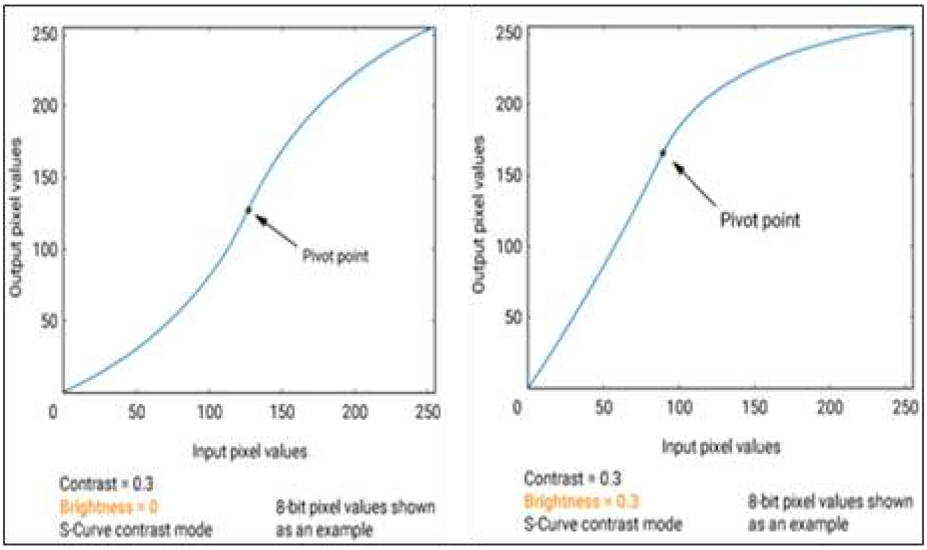

Figure 3.10 Effect of Brightness parameter on image

3.4 Lighting Unit

High quality images are needed for image-processing algorithm. The noise or shadow of the received image directly affects the success of the algorithm. Therefore, the prerequisite for creating a powerful algorithm is to obtain images with high quality and minimal noise factor. The hardware, lightening and other equipment details of the machine vision system are determined according to requirements of yarn and fabric manufacturing firms. Another important parameter in the image processing technique is the lighting system. Homogeneous illumination in the image environment has a significant impact on image quality. According to the researchers [46,47,48] lighting has been expressed as a major problem for many machine vision and image acquisition systems. In the literature, four different lighting plans are used for automatic machine vision control systems. These are;

- Front lighting,
- Back lighting,
- Fiber-optics and
- Structural lighting techniques.

Front Lighting: Technique is often used to inspect thick fabrics and it is placed in the same position as the camera on the front of the fabric. It is used to improve surface texture and determine variation in shade or color. In front illumination, the fibers reflect light from the surface, which creates bright spots on a darker background.

Back lighting: it is used to eliminate the effects of shading in semi-transparent fabric structures. Compared to the front illumination, the line LED source on the back of the fabric allows for better contrast (contrast) images. It can be used to improve the structure of translucent fabrics, eliminating shade and glare effects. In backlighting, the fibers block the incoming light by creating a shadow on the image, and the fibers appear darker on the bright background.

Fiber-optics: Since the fiber optic lighting type provides uniform illumination, it is also possible to use fiber optic lighting in the fabric inspection. It is not economical for fabric images larger than 1.82 m [48].

Some fabric defects may be detected better in transmitted light, while the other defects may be better in reflective light. The lighting module must be designed to reflect or transmit light. The reason for the use of UV light (100-400 nm) is generally used for the detection of abraj fault.; This is because each fiber in visible light has different spectral reflection in various colors. Under UV light, the spectral reflections of these fibers are more pronounced and give close reflection in equal contrast. Abrage detection of a white or ecru material under UV light is particularly good [46].

In the electromagnetic spectrum, the human eye can see radiation in the wavelength range of 400-700 nm. LED lighting provides a quality close to the human eye. Therefore, in the quality control systems developed in recent years, LED strip lighting is preferred to achieve an efficient and successful machine vision system. Different lighting systems; Light emitting diodes (LEDs), halogen lamps, fluorescent lamps, fiber optic lamps can be used for different applications (Figure 3.11).

Figure 3.11 Different lighting source

The size of lighting unit frame designed in the scope of this study (Figure 3.12) was determined as 73.5 cm x 49 cm in accordance with the cabin design. A total of 12 pieces of 240 Volt UV Fluorescent were placed on the aluminum profile at equal intervals. The central part of the lighting unit was left blank with a size of 4 cm x 4 cm for positioning the BASLER ace acA1920-40uc type camera. In addition, two cooling DC fans (12V) and 220-240V power supply were placed on the top of the system to minimize the heating problem in the lighting unit made of aluminum frame.

Figure 3.12 Machine vision system-Lighting unit

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Abrage Fault Inspection

In recent years, with the concept of industry 4.0, image processing applications, machine vision systems and artificial intelligence applications are spreading rapidly. As in other sectors, the requirements within the textile sector were evaluated and different industry 4.0 applications were introduced. It is thought that the prototype machine vision system prepared within the scope of this study will be an important application example. On the other hand, defect detection and classification in textile products has many difficulties in terms of image processing and artificial intelligence applications both in yarn or bobbin form and fabric form. The most important difficulties encountered in image processing applications are the flexibility of the material and ease of forming of textile materials, high fiber raw material range, the usage of many different fibers together in the same structure, and having many defect classes due to processes and raw materials. Due to the variation on the textile surface, it is difficult to find fault detection, which means that a suitable algorithm must be prepared for each material. As it is almost impossible to examine all materials with one type of algorithm, it is very important to be able to reach and interpret the correct source during the preparation of algorithms for the faults processing images. Therefore, different image processing approaches have been evaluated by considering the material properties to be inspected during this study and studies have been made with these approaches. With the designed machine vision system, three different algorithms have been prepared to detect abrage fault on the yarn bobbin. Fault detection algorithms used for defect detection method are Gabor Filtering, Wavelet Analysis and Local Thresholding. They were applied to the abrage bobbin samples. The fault detection performances of each method were evaluated and the most successful method was determined. Finally, the accuracy of the selected method was determined by means of statistical analysis.

4.1.1 Results of Gabor Filter Algorithm

Initially, an image was converted into digital form in RGB form(1208X1928X3). By using image enhancement filters and morphological processes given in Figure 4.1, an image processing algorithm was developed. The images captured from the yarn bobbin samples were first converted to gray level image. The gray image quality was enhanced by applying some noise filtering and image smoothing filters. The intensity levels in the lower and higher quarter of the range are not prominent in gray images so the intensity transform was used to sharpen the image. For this purpose, histogram equalization function in MATLAB Image Processing Toolbox was used for intensity transformation of gray-scale images. Before the binarization process, Gabor filter was applied. Filtered images were converted to binary form consisting of 0s and 1s. The opening and closing morphological operations were applied to trace the abrage boundaries on binary image. The opening operation was used to remove the excess parts of the abrage region. The closing operation was conducted to fill empty parts of the detected abrage region and so to determine the exact fault boundary. Then the abrage fault part was labeled. Finally, bobbin sample was evaluated for the abrage fault presence and so the faultless part was determined in black color. Correspondingly the faulty parts were labeled in white color.

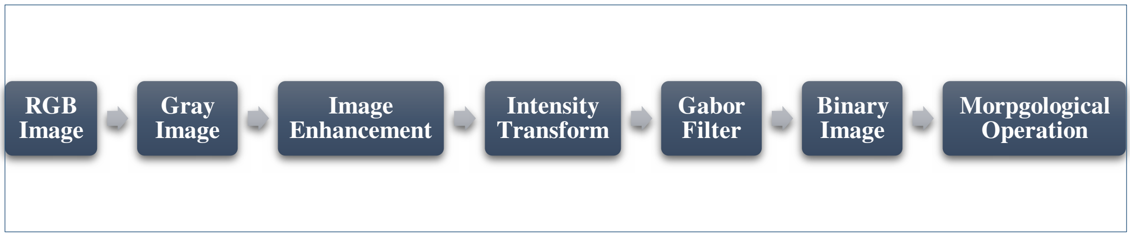

Figure 4.1 Flow chart of the Gabor filter algorithm

Gabor filter algorithm application result is given in Figure 4.2. Since the yarn bobbin cross-section has not a smooth and uniform surface, the light intensity values of the pixels at inner and outer sides are different from each other. Therefore, generally miss detections were obtained from Gabor filter algorithm applications due its high sensitivity to light intensity changes. According to the knowledge obtained from the literature, one of the most preferred filters especially used in fabric fault detection algorithms is Gabor filter. As a result of Gabor filter application, the defective region was brought to the forefront while the defect-free part was damped. However, since this filter was very sensitive to light intensity changes on the bobbin surface, regions with different reflection properties were detected in binary form besides the faulty parts.

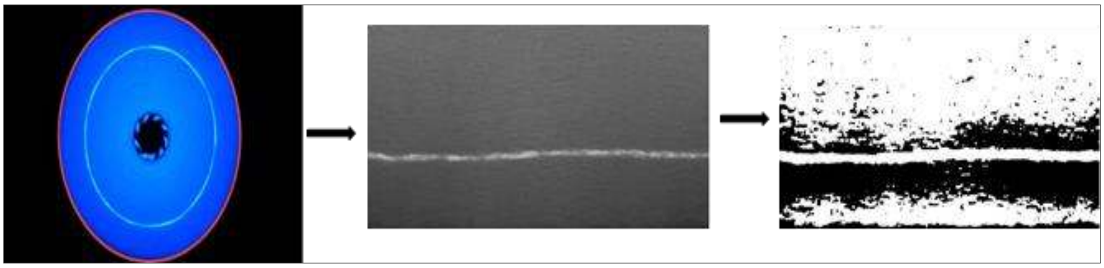

Figure 4.2 Algorithm results prepared with Gabor filter

4.1.2 Results of Wavelet Transformation Algorithm

Wavelet transform abrage fault inspection application was achieved by following flowchart given in Figure 4.3. Similar algorithm steps were applied like in Gabor filter. The image frame de-noised via image enhancement filtering was decomposed into sub-images by using ‘db3’ type wavelet.

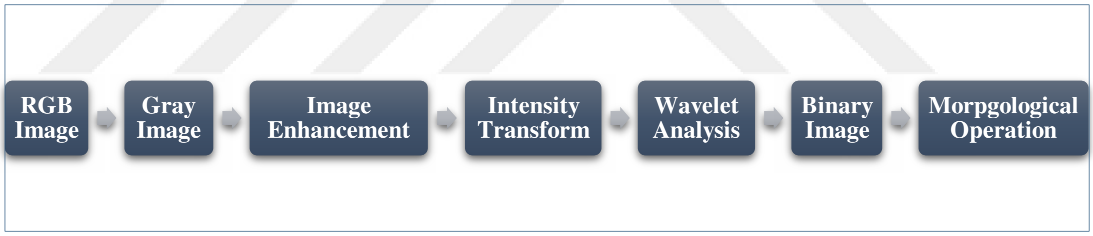

Figure 4.3 Flow chart of the Wavelet filter algorithm

The most important advantage of wavelet analysis is that it can perform local analysis. In other words, it is able to analyze the large signal in a small area. Briefly wavelet analysis is a suitable analysis method used in the analysis of signals with hollow, curved, breaking point and discontinuity point.

According to the findings obtained from the literature, the second most preferred filter in fabric fault detection is the wavelet transform method. As shown in Figure 4.4, the wavelet transforms yield almost the same result as the Gabor filter method. This high miss detection result unlike to fabric defect detection can be attributed to the fact that the yarn bobbin surface is not uniform and smooth. There are very different light intensity values among the yarn bobbin surface. On the other hand, the fabric surface is smooth and uniform. When the fabric winding process is achieved with a constant tension, the defective region can be easily distinguished by applying wavelet transform. Since the wavelet transform method is highly sensitive to these pixels value changes, different reflection regions along with the abrage region has been detected and faultless regions were also evaluated as fault.

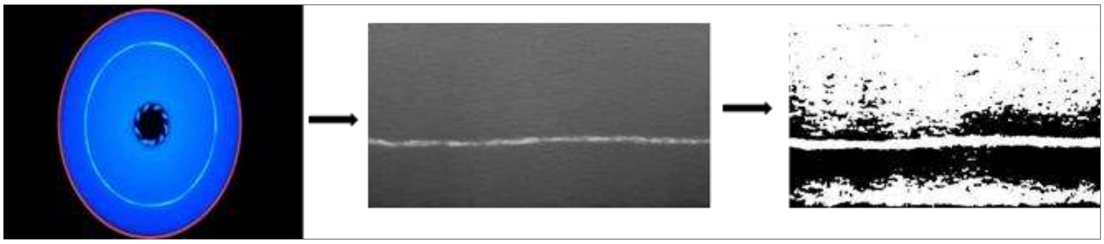

Figure 4.4 Application of Wavelet transformation algorithm

4.1.3 Results of Local Thresholding Algorithm

Abrage fault detection application was achieved by using the flowchart in Figure 4.5. Similar architecture was used for *Variable Thresholding* based on local statistical analysis. Same algorithm steps were applied as made with Gabor filter and Wavelet Transform except ***Local Thresholding*** application. Figure 4.6 shows the application results of the local thresholding method for three different abrage locations; at beginning (Figure 4.5.a), at middle (Figure 4.5.b) and at the end (Figure 4.5.c).

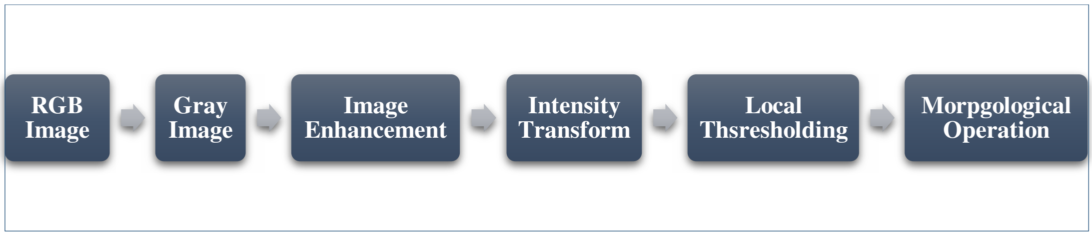

Figure 4.5 Flow chart of the Local thresholding algorithm

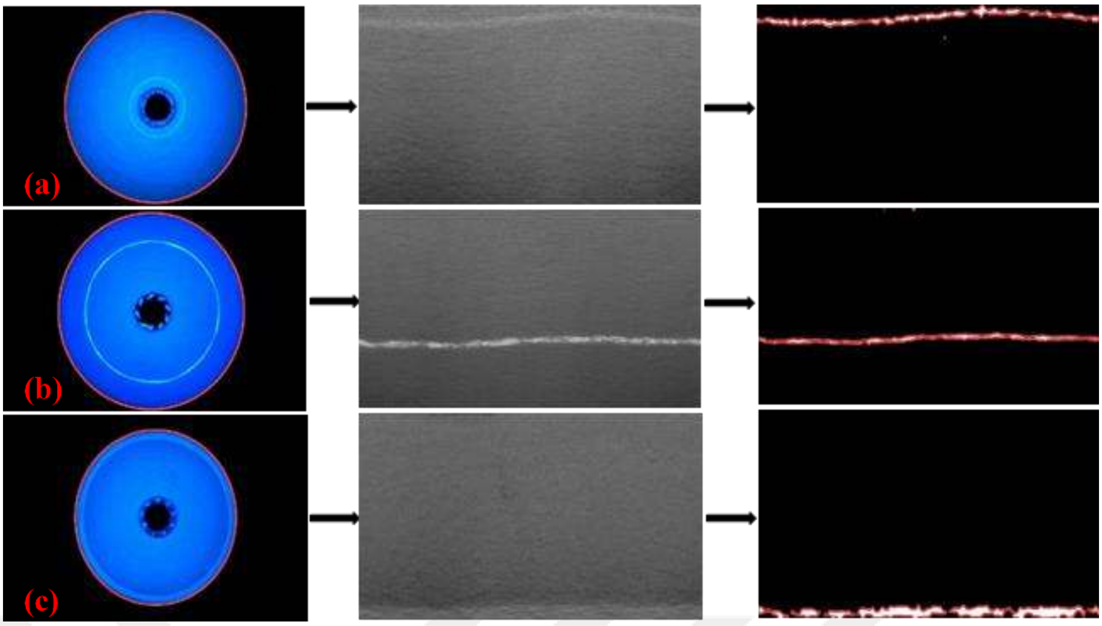

Figure 4.6 Algorithm results prepared by Local Thresholding method **(a)** abrage at the beginning of the bobbin **(b)** abrage in the middle of the bobbin **(c)** abrage at the end of the bobbin

Since the colors are close to each other in the bobbin abrage fault, the average and standard deviation calculated from the neighbor relations of each pixel give a more accurate result as in the local thresholding method. Therefore, when these three methods were compared, it was decided that local thresholding was the best method for determining the abrage defective region. The success rate was evaluated by applying the algorithm to all bobbin samples. The evaluation criteria were made according to the following parameters;

TD (True Detection): The state where the abrage region is precisely determined.
MD (Misdetection): The case where the abrage region is determined more or less than the actual dimensions.
FD (False Detection): The situation where the region with an abrage fault is detected without error or the error is detected with the wrong bobbin.

The yarn bobbins were evaluated visually in the cabin and the success evaluation of the image processing algorithm was made as given in Table 4.1.

Table 4.1 Local thresholding success evaluation

	Abrage Fault Type			
	Faultless Bobbins	Cops Abrage		
		At the Beginning of The Bobbin	In the Middle of The Bobbin	At the End of The Bobbin
Number of Sample	10	2	12	12
TD	10	2	9	9
FD	0	0	1	1
MD	0	0	2	2
% TD	**100**	**100**	**91.67**	**91.67**
% FD	**0**	**0**	**8.33**	**8.33**

According to the results of the analysis made on the obtained images, the success rate in abrage-free bobbins was 100%, at the beginning of the bobbin abrage 100%, in the middle of the bobbin abrage 91.67% and at the end of the bobbin abrage 91.67% were obtained. an average success rate of 95.8% and a margin of error of 4.2% were achieved. This ratio is considered to be a very good result for determining the abrage error in the yarn package. When the abrage fault, which are evaluated manually, are evaluated in the UV light room by the employees who require a certain experience and experience depending on the person, the success rate obtained from the machine vision system is considered to be acceptable.

Textile products; it has a flexible and heterogeneous physical structure in the form of yarn or fabric. Factors such as surface tension change or surface roughness, folding, creasing during image acquisition process significantly affect the image processing process. The structure of textile products in different forms; the difficulty in image acquisition and the limitations in obtaining a successful image processing from the resulting image are better understood when considering such as yarn, woven fabric, knitted fabric or bobbin surface. Considering these limitations and handicaps, the necessary lighting and camera equipment were selected. In addition, a suitable cabin design has been realized in order to obtain a smooth surface view of the bobbin. If an artificial vision system for fault detection is to be designed, a design that is appropriate for the structure of the materials containing the fault (fabric, bobbin, yarn, etc.) has been confirmed in accordance with the information obtained from the literature.

4.2 User Guide

Firstly, the success statistics of the faulty bobbins images was produced and the accuracy of the algorithm was shown in this study. Then, the Image Processing Toolbox and Image Acquisition Toolboxes in the MATLAB program were used in the interface preparation stage. The prepared user interface (Figure 4.7) has ***"Start Camera, Capture Image, Exposure Time, Image Processing and Exit"*** buttons. In order to perform each button with its functions separately, the relevant codes in the algorithm are inserted to the working extension of the interface. The camera is started via the interface (Figure 4.8). An option is then provided where you can enter the ***Exposure Time*** setting manually (Figure 4.9). The reason for adding the Exposure Time option is that the fibers on the yarn bobbin have a different degree of yellowness and therefore the pixel density value must be adjusted for different products. Otherwise, it is not healthy to use a fixed Exposure Time value for all fiber types. One of the factors that affect the success level of the prepared algorithm is Exposure Time. After the camera is started, the Exposure Time is set according to the fiber type. Then the ***Capture Image*** button is used to get a yarn bobbin image frame (Figure 4.10). After all these adjustments, the abrage detection process is started with the ***Image Processing*** button (Figure 4.11). When image processing is performed, some figure results such as the image of inspected bobbin, the histogram graph of the image, binary transform of the image were represented on related axes of user interface. In addition to all these fault detections, the bobbin diameter is also given to the user in mm. If there is an abrage fault in the inspected image, the percentage of the abrage fault to the total bobbin size is calculated and presented to the user. If any abrage fault is detected, the bobbin sample is named as "Abrage Found" and it is guided for saving (Figure 4.12). If the detected sample has not abrage fault, it is only displayed as "Faultless".

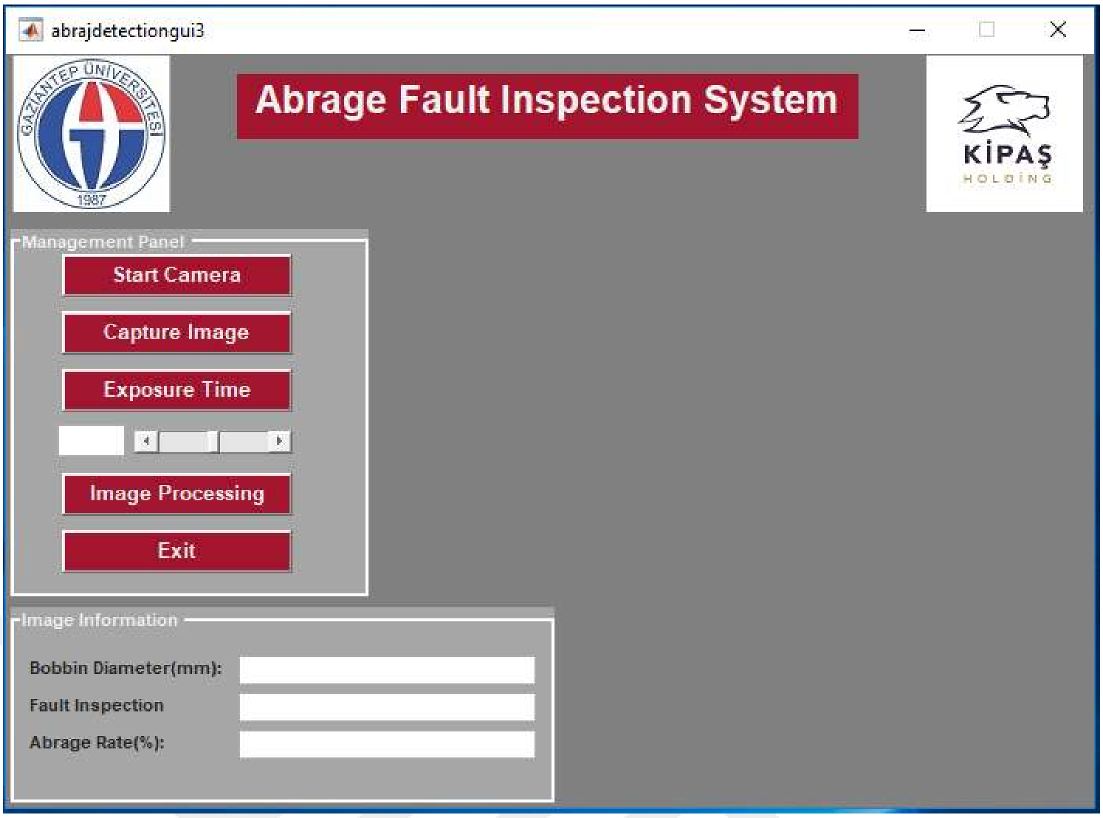

Figure 4.7 Abrage fault inspection system user guide

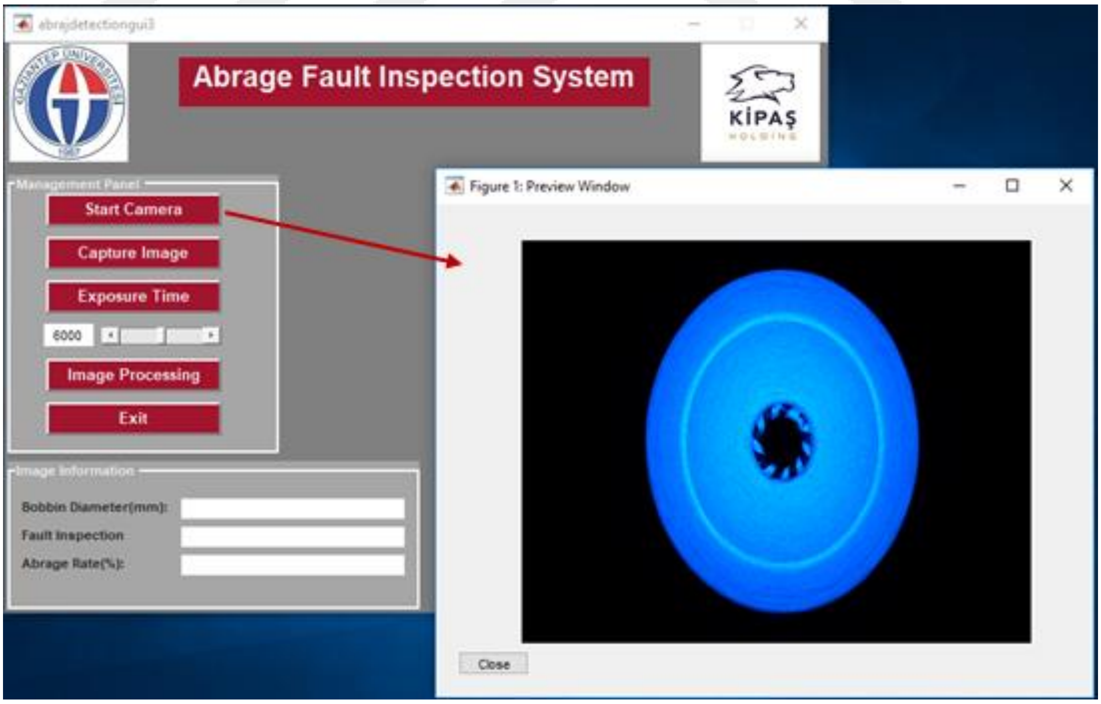

Figure 4.8 Camera start button

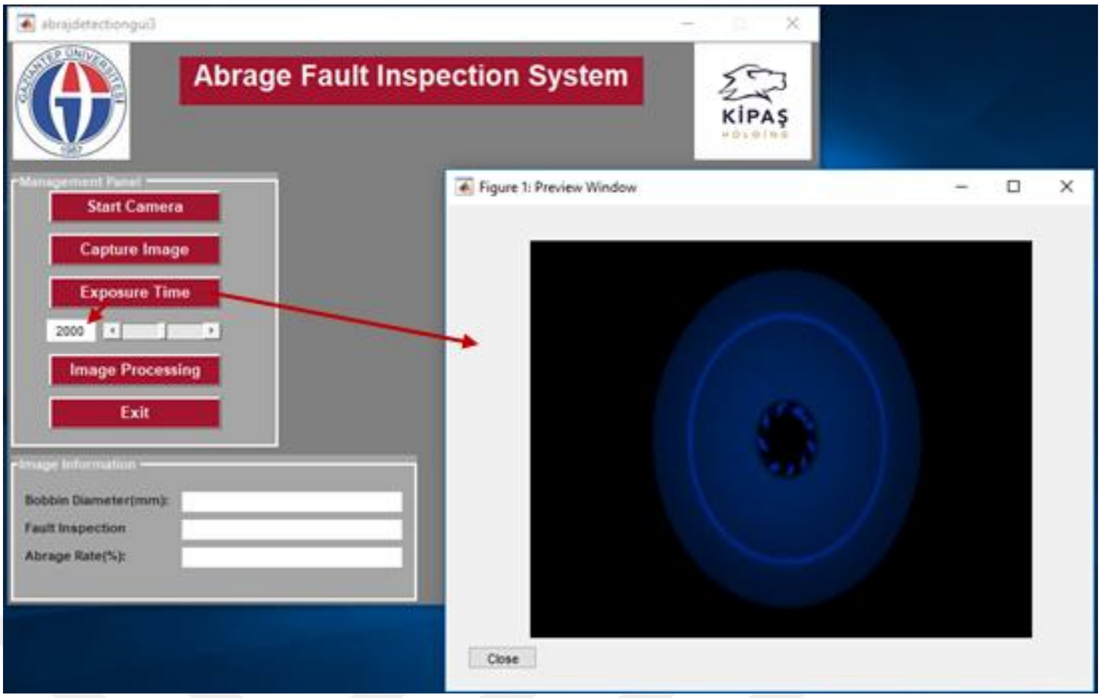

Figure 4.9 Exposure time button

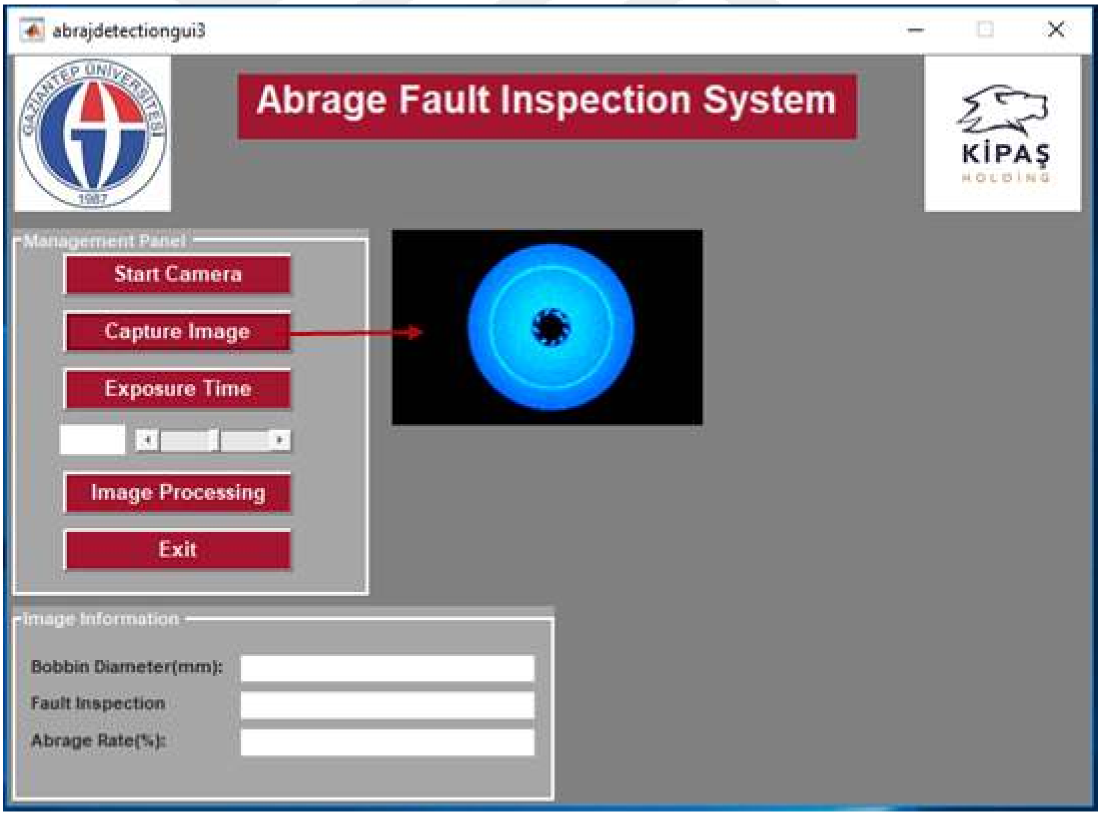

Figure 4.10 Capture image button

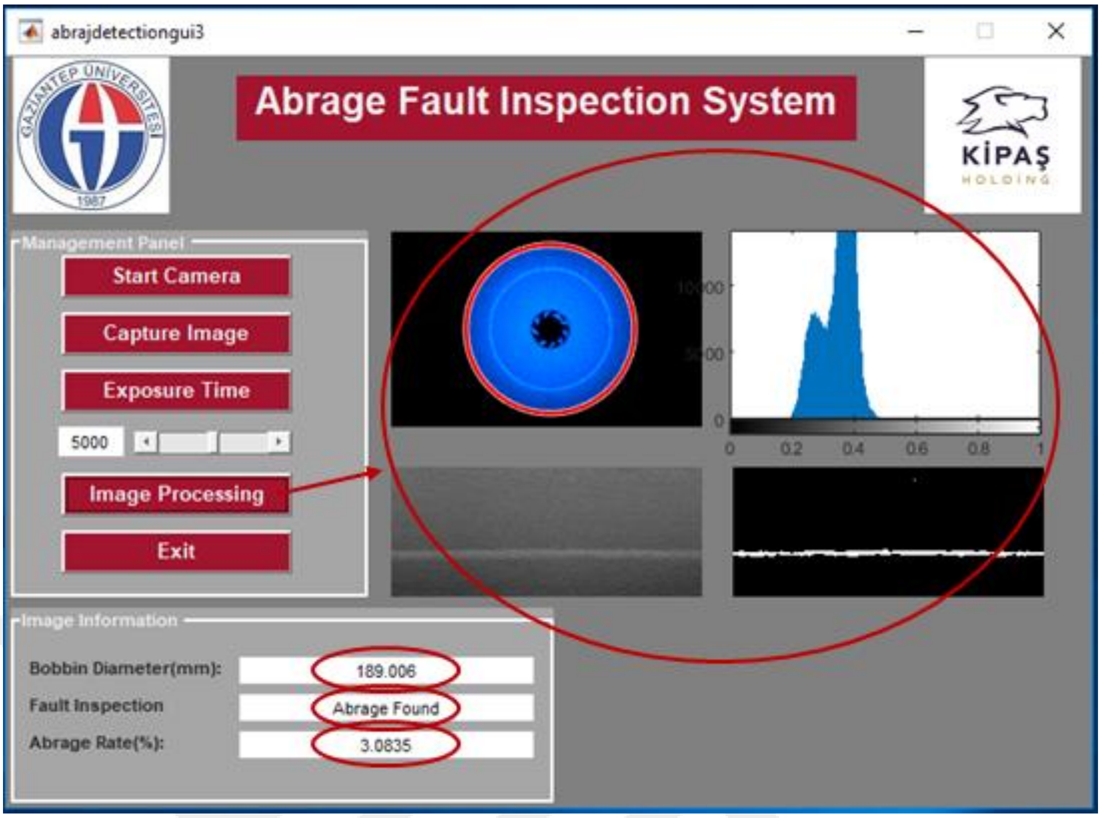

Figure 4.11 Image processing button

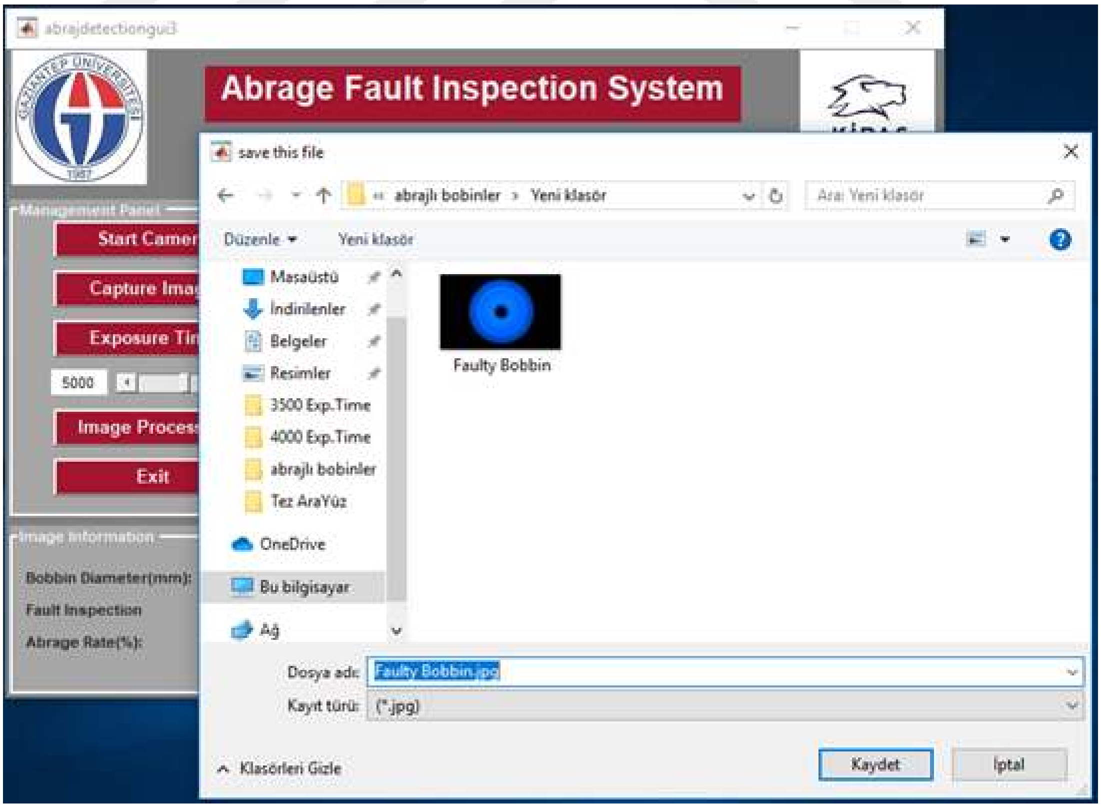

Figure 4.12 Saving the inspected bobbin in the folder

CHAPTER 5

CONCLUSION

5.1 Discussions and Conclusions on the Present Study

In accordance with the studies on image processing applications to yarn characteristics and fabric inspection, it was revealed that many subjective and manual inspection operations can be automatically and sensitively achieved by using different image processing methods. Most of these proposed methods can be adapted to industrial systems and run in real-time. By this way, the yarn manufacturing efficiency and yarn quality can definitely be improved.

The purpose of this study was to check the presence of the abrage in the bobbin sample. Only the abrage existence of the samples were tested. Finally, all of the abrage faults were successfully detected. The details of the faults such as area percentage in the bobbin cross-section was analyzed in the study.

In this study, a suitable machine vision system for bobbin abrage fault detection as an industrial application was explained. In order to obtain high quality images, the equipment in the machine vision system were investigated and the adjustments that are effective in obtaining high quality image frames were presented. Thus, the machine vision system created by using the correct illumination system with high resolution camera was suitable on an online production line.

The proposed system will be adapted to the automation system of the yarn spinning mill by replacing with the manual inspection process. The image processing technique can be used to achieve the time-consuming quality control process much shorter and faster. In addition, due to the high ratio of accuracy and detection sensitivity up to a few millimeter sizes, it is possible to detect even the fault that are too sensitive to be seen by the image processing method.

5.2 About the Experimental Set-Up

In this study, the experimental set-up was developed for real-time inspection of the abrage fault in the yarn bobbin. The experimental installation consists of a machine vision cabin, area scan camera, lighting unit and computer unit. This proposed machine vision system could be easily integrated to a spinning mill with full automation production line before the packaging line. It was forecasted that cross-section images of the bobbins will be taken and analyzed as the yarn bobbins moving on the conveyor belt pass through the machine vision cabin. The captured bobbin images will be processed using the developed abrage detection algorithm. At the end of the conveyor band, the bobbins will be transferred to different section according to having abrage fault or not. It was planned that a special bobbin transfer system that will be triggered by image processing software should be designed.

- ***Discussion on Lighting Source***

Lighting source is one of the most important parameters that affect the performance of the image processing algorithm. Abrage inspection process in yarn bobbins is done under UV light. For this reason, the illumination source used in the study should provide intense and homogeneous illumination. The location where the designed lighting unit is included in the machine vision system is very important. Because the bobbins are cross-sectional view, UV light source must be perpendicular to the bobbin samples. In this study, it was decided that 12 UV sources were sufficient for the prototype system and upper illumination was preferred. In addition, the exposure time of the camera was determined according to the intensity of the illumination source and the resolution setting of the camera when performing the yarn bobbin check. Illumination sources with higher light intensity allow lower exposure times. The exposure time has to be adjusted by the user in order to obtain higher image quality and see the details of bobbin texture.

- ***Discussion on the Camera System***

Image acquisition was performed using a BASLER ace acA1920-40uc area scan camera. The pixel resolution of the camera is 1920 pixels x 1200 pixels. Area scan cameras are very useful for offline work because they contain a pixel matrix of a specific region image. They are more general purposes than line scan cameras and offer easier installation and alignment. Area scanning cameras are best suited to applications where the object is stationary, even if it is only instantaneous. As with many applications, the camera image size can be adjusted to the desired pixel size. According to the required horizontal field of view, the working distance between the examined surface and the camera lens was determined. This was used to obtain the image frame that requests information. The angle of the camera was set as perpendicular to the bobbin surface. An additional camera attachment equipment was also designed to position and carry the camera. The resolution of the camera can be adjusted according to the distance between the yarn bobbin and the camera.

5.3 About the Method Used

The methods used for fault detection in this study are Gabor filtering, Wavelet transformation and Local Thresholding techniques.

- ***Discussion on Gabor Filter***

The general structure of the algorithms prepared in this study were the same, but the method used for abrage segmentation was different. Having tried different filters to improve the image, Gabor filter was used to identify faulty regions. The parameters of Gabor filter were examined using different experiments. However, the result in Figure 4.2 indicated that Gabor filter was not suitable for determining the abrage faults in the yarn package. It was considered that Gabor filter parameters should be optimized from abrage-free bobbins to increase the effectiveness and efficiency. It is under consideration that the abrage fault can be seen more clearly when the formed Gabor mask is attached to the defective bobbin. This method is one of the most common methods used in image processing technique. However, advances in computer technology reduce the frequency of use. As a result, the prepared algorithm was tried for all samples. But it was decided that it was not suitable for the study. This was because finding extra area outside the faulty region shown in Figure 4.2, so the success statistics of algorithm were not done.

Discussion on Wavelet Transformation

It is one of the most commonly used methods for fault detection in the literature. This method is preferred more for fabric defects this method works more accurately than other methods. Even small differences in the pixel distribution will affect the success of the method. Wavelet transform is a preferred technique in the classification of artificial neural networks, especially with texture analyzes. By dividing an image into sub-images, attribute vectors are generated to reveal the frequency values of the image. Thus, it performs a more detailed analysis. Contrary to the frequency-time values of the image, using the time-scale field, it creates areas in images, not one-dimensional lines. It then becomes more sensitive to the slightest change in the image by performing local analysis on the created areas. Consequently, wavelet transform applied to bobbin images was very sensitive to local pixel gray level. Because of this restriction, miss detection ratio in that some of the faultless area was also labeled as faulty were higher. As in Figure 4.4, it was decided that it was not suitable for the study. Therefore, no success statistics were obtained.

Discussion on Local Thresholding

It is the method in which the best results were obtained among the algorithms prepared within the scope of the study. It works by calculating the average and standard deviation of the pixels in the neighborhood of each pixel in the image frame. In order to determine the optimum filter parameter, many tries were applied on different bobbin samples as made for Gabor and Wavelet Transform methods. Firstly, a mask was created and the part to which the neighboring pixels will be applied was determined. Thus, the working accuracy of the algorithm can be changed for the samples to be used in different studies. The prepared algorithm was applied to all yarn bobbin images. Totally, 36 yarn bobbin samples were inspected with a success rate of 95.8%. This ratio is quite high for a spinning mill even it has full automation line. Thus, it is foreseen that production efficiency can be increased by at least 60% and labor costs can be saved by making abrage control with the proposed artificial vision system. Thanks to these developments in machine vision systems and automation technologies, more accurate and precise process and quality controls are provided in the production line. With this system, it is possible to access the system remotely with the new developments that will be achieved and added to the number of abrage and fault free bobbins obtained in production in real time.

5.4. Further Work

Further work includes the studies that may be carried out in the future include new work proposals by identifying the deficiencies of the subject. They are all given in the respectively.

- ⇒ The proposed system can be adapted to the full automation spinning system in real time.
- ⇒ A new machine vision system must be designed for the fault detection system on the yarn package in real time. The algorithm for real-time fault detection needs to be developed in accordance with the machine vision system to be designed.
- ⇒ In the next study, a statistical analyzed will also be performed to evaluate the accuracy and precision of the true detection in online detection. It is also planned that the upgraded algorithm will determine the location of the abrage and classify it according to its size.
- ⇒ The effect of the lighting system on image processing is quite high. For a more powerful and intense lighting system, more precise abrage faults can be detected. Fluorescent lighting was preferred in this study, another study could try a higher intensity LED lighting source.
- ⇒ In the following studies, by increasing the number of samples, the texture structure of the yarn bobbins in the images can be examined. Pixel distributions and histogram graphs can be taken into consideration to estimate the yellowness of the fibers used.

REFERENCES

[1] The Textile Association (India). (1939). Leopfe – Synthetic yarns don't need foreign matter detection, or do they? TTA Intl.: www.etextilemagazine.com/en/synthetic-yarns-dont-need-foreign-matter-detection-or-do-they.html. 17.06.2019

[2] Technocrat Industries India. Cotton yarn Overview. TII Intl.: https://www.technocraftgroup.com/Cotton-Yarn.aspx. 25.07.2019

[3] List of Spinning Machine. Balancing Machine in Cotton Spinning Mill. (2013). Intl.: https://autogarment.com/list-spinning-machine-cotton-spinning-mill/. 12.08.2019

[4] Besi, L., Stobart R., Magee M. (1994). *Fiber measurement using digital image processing*. *In Industrial and Engineering Applications of Artificial Intelligence and Expert Systems*. Gordon & Breach: New York, NY, USA.

[5] Belleli, T. (1993). The Measurement of Wool Fiber Diameters, *Industrie Textila*. **1249**, 25-27.

[6] Glasbey, C.A., Hitchcock, D., Russel, A.J.F., Redden, H. (1994). Towards the Automatic Measurement of Cashmere-tibre Diameter by Image Analysis, *The Journal of The Textile Institute*. **85**, 301 307.

[7] Baxter, B.P., Brims, M.A., Taylor, T.B. (1992). Description and Performance of the Optical Fibre Diameter Analyser (OFDA), *The Journal of The Textile Institute*. **83**, 507-526.

[8] Dehghan, N., Tavanaie, M. A., Payvandy, P. (2015). Morphology study of nanofibers produced by extraction from polymer blend fibers using image processing, *Korean J. Chem. Eng*. **32(9)**, 1928-1937.

[9] Lieberman, M.A., Bragg, C.K., Brennan, S.N. (1998). Determining Gravimetric Bark Content in Cotton with Machine Vision, *Textile Research Journal*. **68**, 94-104.

[10] Kang, T.J., Kim, S.C. (2002). Objective Evaluation of the Trash and Color of Raw Cotton by Image Processing and Neural Network, *Textile Research Journal*. **72**, 776-782.

[11] Shiau, Y.R., Tsai, I.S., Lin, C. S. (2000). Classifying Web Defects with a Back-propagation Neural Network by Color Image Processing, *Textile Research Journal*. **70**, 633-640.

[12] Wu, D.H. (1994). A Study of The Analysis of Fibre Cross Sections by Image Processing, *Journal of the China Textile Institute*. **4**,81-89.

[13] Xu, B., Pourdeyhimi, B., Sobus J. (1993). Fiber Cross-sectional Shape Analysis Using Image Processing Techniques, *Textile Research Journal*. **63**, 717-730.

[14] Zheng, S., Zou, Z. Y., Shen, W., Cheng, L. (2012). A Study of The Fiber Distribution in Yarn Cross Section for Vortex-Spun Yarn, *Textile Research Journal*. **82(15)**,1579-1586.

[15] Kang, T.J., Lee, J.Y. (2001). Filament Crimp in Three Dimensions Measured by Image Analysis and Fractal Geometry, *Textile Research Journal*. **71**, 112-116.

[16] Lawrence C.A. (2003). *Fundamentals of spun yarn technology*. CRC Press LLC, Boca Raton, London, New York, Washington, D.C.

[17] Li, D., Yang, W., Wang, S. (2010). Classification of Foreign Fibers In Cotton Lint Using Machine Vision and Multi-Class Support Vector Machine, *Computers and Electronics in Agriculture*. **74(2)**,274-279.

[18] Su, Z., Tian, Y. G., Gao, C. (2006). A Machine Vision System for On-Line Removal Of Contaminants In Wool, *Mechatronics*. **16(5)**, 243-247.

[19] Yuhong, D., Yongheng, L., Xiuming, J., Wenchao, C., Donghan, G. (2015). Research Of Foreign Fibers In Cotton Yarn Defect Model Based On Regression Analysis, *The Journal of The Textile Institute*. **107(9)**, 1089–1095

[20] Xinhua, W., Shu, W., Laiqi, X., Baoguo, S., Meijin, L. (2014). Identification of Foreign Fibers of Seed Cotton Using Hyper-Spectral Images Based on Minimum Noise Fraction, *Transactions of the Chinese Society of Agricultural Engineering*. **30(9)**, 243-248.

[21] Pai, A., Sari-Sarraf, H., Hequet, E. F. (2004). Recognition of Cotton Contaminants Via X-Ray Microtomographic Image Analysis, *IEEE Transactions on Industry Applications*. **40(1)**, 77-85.

[22] Wang, X. H., Wang, J. Y., Zhang, J. L., Liang, H. W., Kou, P. M. (2010). Study on The Detection of Yarn Hairiness Morphology Based on Image Processing Technique, *Proceedings of the Ninth International Conference on Machine Learning and Cybernetics*. 2332-2336.

[23] Kuzanski, M. (2008). The Algorithms of The Yarn Shape Detection and Calculation of The Protruding Fibres Length, *MEMSTECH*. 98-100.

[24] Fabijanska, A., Strumillo, L. J. (2012). Image Processing and Analysis Algorithms for Yarn Hairiness Determination, *Machine Vision and Applications*. **23**, 527–540.

[25] Xu, B. G., Murrells, C. M., Tao, X. M. (2008). Automatic Measurement and Recognition of Yarn Snarls by Digital Image and Signal Processing Methods, *Textile Research Journal*. **78(5)**, 439–456.

[26] Guha, A., Amarnath, C., Pateria, S., Mittal, R. (2010). Measurement of yarn hairiness by digital image processing, *The Journal of The Textile Institute*. **101(3)**, 214–222.

[27] Carvalho, V., Cardoso, P., Belsley, M., Vasconcelos, R. M., Soares, F. O. (2006). Development of a Yarn Evenness Measurement and Hairiness Analysis System, *IECON - 32nd Annual Conference on IEEE Industrial Electronics*. 3621-3626.

[28] Asgari, H., Mokhtari, F., Latifi, M. Amani-Tehran, M. (2014). Characterizing cotton yarn appearance due to yarn-to-yarn abrasion by image processing, *The Journal of The Textile Institute*. **105(5)**, 477-482.

[29] Ozkaya, Y.A., Acar, M. Jackson, M.R. (2010). Yarn twist measurement using digital imaging, *Journal of the Textile Industry*. **101 (2)**, 91 - 100.

[30] Yang, W., Li, D., Zhu, L., Kang, Y., Li, F. (2009). A New Approach for Image Processing in Foreign Fiber Detection, *Computers and Electronics in Agriculture*. **68(1)**, 68-77.

[31] Roy, S., Sengupta, A., Sengupta, S. (2013). Determination of the Diameter Spectrogram and Neps for Yarn Parameterization using Image Processing, International Journal of Electrical, *Electronics and Computer Engineering*. **2(2)**, 72-76.

[32] Shams Nateri, A., Ebrahimi, F., Sadeghzade, N. (2014). Evaluation of yarn defects by image processing technique, *Optik*. **125**, 5998-6002.

[33] Silvestre, J., Perez, R., Mufnoz, J. (2005). System Integration of a Mixed Fibre Detection Process in Raw Yarn Packages by Computer Vision. *IEEE*.

[34] Çelik, H.I., (2016). Development of a machine vision system for yarn bobbin inspection, *Industria Textila*. **67(5)**, 292-.296

[35] Gonzalez, R.C. (2004). *Digital Image Processing Using Matlab-Gonzalez Woods & Eddins 2nd edition*. Saddle River, New Jersey.

[36] Behera, B.K. 2004. *Image processing in textiles, Textile Progress*. **35(2)**,1-193.

[37] Rizon, M., Yazid, H., Saad, P., Shakaff, A. Y. M., Saad, A. R., Sugisaka, M., Karthigayan, M. (2005). Object detection using circular Hough transform, *American Journal of Applied Sciences*. **2(12)**, 1606-1609.

[38] Çelik, H. I. (2013). *Development of an intelligent fabric defect inspection system*. Gaziantep Universtiy, Graduate School of Natural & Applied Sciences, PhD. Thesis, Gaziantep, p.163.

[39] Grigorescu, S.E., Petkov N., Kruizinga, P. (2002). Comparison of texture features based on Gabor filters, *IEEE Transactions on Image Processing*. **11(1)**, 1160 - 1167.

[40] Petkov, N., Wieling, M.B. 2008. Gabor for image processing and computer vision.Intl.:http://matlabserver.cs.rug.nl/edgedetectionweb/web/edgedetection_params.html. 15.10.2019.

[41] Sonka, M., Hlavac, V., Boyle, R. (2008). *Image processing, analysis and machine vision. International student edition*. USA: Thomson Corporation.

[42] Misiti, M, Misiti, Y, Oppenheim, G, Poggi, JM. (1997). *Wavelet toolbox for use with Matlab*. Natick, MA: The MathWorks, Inc.

[43] Chun-Lin, L. (2010). A tutorial of the wavelet transforms. *NTUEE, Taiwan*.

[44] Yousefi, J. (2011). Image Binarization using Otsu Thresholding Algorithm. *University of Guelph. Ontario*, Canada.

[45] Ravi, S., Khan, A. M. (2013). Morphological operations for image processing: understanding and its applications, *In Proc. 2nd National Conference on VLSI, Signal processing & Communications NCVSComs*.

[46] Hamdi, A. A., Fouad, M. M., Sayed, M. S., Hadhoud, M. M. (2017). Patterned fabric defect detection system using near infrared imaging. *In 2017 Eighth International Conference on Intelligent Computing and Information Systems (ICICIS).* 111-117.

[47] Malek, A. S. (2012). *Online fabric inspection by image processing technology* Other. Université de Haute Alsace - Mulhouse, 2012. English. <NNT : 2012MULH4090>. <tel-00720041>

[48] Hanbay, K., Talu, M. F., & Özgüven, Ö. F. (2016). Fabric defect detection systems and methods—A systematic literature review. *Optik*, **127(24)**, 11960-11973.