Online Control System Design for Selvedge Waste Length in Rapier Weaving Loom

Vajiha Mozafary and Pedram Payvandy*

Abstract- **Controlling the selvedge waste length in shuttle-less weaving loom has great importance in the cost of production. In this study, an online control system is designed and implemented in a weaving loom. First, a high-speed camera records selvedge formation in several successive cycles with different weft yarn tensions. Then the length of weft yarn waste is measured by three methods based on image processing, namely Kalman filter, K-means method and background subtraction. The performances of three methods in terms of accuracy and processing time are evaluated and compared with each other. The results show that Kalman filter method has higher accuracy and it requires lower processing time. In addition, it shows that the results obtained from two other methods are very close to the actual result. There is an inverse relationship between weft yarn tension and selvedge waste length. By increasing the yarn tension, waste length is decreased. Therefore, based on the online measurement of selvedge waste length, the waste length can be measured in each cycle and adjusted by changing the weft yarn tension. So the proposed system has satisfactory performance in online control of weft yarn waste.**

Keywords: **rapier weaving, selvedge waste length, image processing technique, Kalman filter**

I. INTRODUCTION

Recently, applying machine vision techniques in industry has received a great deal of attention and many systems have been successfully implemented for a variety of applications. Image processing techniques based on machine vision system has been widely utilized in textile industry such as estimation of yarn and fabric properties, detection of fabric and yarn defects and so on. However, a few researches have been done on the online control in weaving loom. Dorrity and Vachtsevanos in 1996 [1] had implemented the charge-coupled device (CCD) camera mounted on a weaving machine for online fabric defect detection. Running defects were detected by Fuzzy Wavelet Analysis and would alert the operator to correct mistakes. Suh *et al.* in 2003 [2] developed the 3D prediction models for fabric properties by using data captured from an online control system based on CTT measurement of yarn diameters optically at more than one angle. The electronic imaging was used to investigate the quality properties (basic weights, appearance uniformity, physical properties, etc.) of woven and knitted fabrics from the online measurement system. Cho *et al.* in 2005 [3] proposed an online fabric inspection method for industrial application. Their technique was used to identify fabric defects including warp float, broken pick, hole, and oil spot. Mak and Peng in 2008 [4] presented an online defect detection method. Their method was based on Gabor wavelet network. Schneider *et al.* in 2011 [5] proposed an online fabric defect detection model based on image processing. In their study, fabric defects were extracted from yarn information such as the spacing between yarns and the yarn width. Malek in 2012 [6] proposed an online detection system of weaving defects by image processing technique. In his technique, fast Fourier transform and cross-correlation techniques were implemented to examine the structure regularity features of the fabric image in the frequency domain. Aziz *et al.* in 2013 [7] presented an online method based on morphological processing and discrete cosine transform to detect fabric defects automatically. A weft density online control model was designed and implemented in a weaving machine by Zefrehyee *et al.* in 2015 [8]. In their study, a machine vision system was prepared to calculate the number of weft yarns per inch. Based on the measured weft density, the take-up roller speed was adjusted by changing the supply voltage to the take-up motor. Vladimir *et al.* in 2017 [9] used vision system for online detection of weft density in weaving loom. In their work, if the measured density was lower than the original density, the rotation of the shaft would slow down, if the

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measured density was higher than the original density, the rotation of the shaft would increase. Akdenizi *et al.* in 2017 [10] determined the length of weft yarn waste in rapier loom and carried out this measurement by image processing technique. However, in their work, no solution was proposed to reduce the waste length online.

There are a few researches about the online control of selvedge formation in weaving loom. Therefore, the aim of this study is online control of selvedge waste length in rapier weaving to reduce production cost. First, the high-speed camera records selvedge weft yarn image. Then the weft yarn length between the last selvedge warp yarns and free end of weft yarn is measured by image processing. If the measured length is larger than usual length, the weft yarn tension will be increased to adjust the selvedge waste length.

A. Problem Definition

A rapier loom is a shuttle-less weaving loom in which the filling yarn is carried through the shed of warp yarns to the other side of the loom by rapiers. A stationary package of yarn is used to supply the weft yarns in the rapier machine. One end of a rapier, a rod or steel tape, carries the weft yarn. The other end of the rapier is connected to the control system. The rapier moves across the width of the fabric, carrying the weft yarn across the shed to the opposite side. The rapier is then retracted, leaving the new pick in place.

One of the important issues in shuttle-less weaving loom such as rapier loom is the selvedge formation. Selvedges of fabrics produced on shuttle-less weaving machines are markedly different from those produced on shuttle weaving machines. Insertion of single picks by weft carrier followed by action of weft cutters at both selvedges leaves a noticeable length of free weft yarn at the fabric selvedges. According to Fig. 1, there is a distance between yarn cutter and selvedge cutter, for this reason, the weft yarn is wastage in loom.

Selvedge waste is a critical problem of weavers because it directly affects the production cost, especially when weft yarns are expensive. In mass production, this amount of selvedge waste creates considerable cost. Therefore, optimization of selvedge waste length could significantly reduce the production cost.

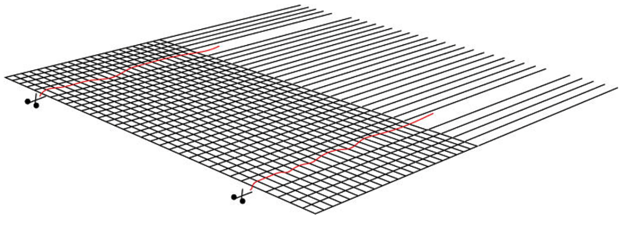


Fig. 1. Selvedge formation in shuttle-less weaving machines.

B. Methods

B.1. Kalman Filter Technique

In 1960, Kalman [11] described a recursive solution for the discrete-data linear filtering problem. Object tracking is performed by predicting the object position from the previous information and verifying the existence of the object at the predicted position. The Kalman filter is a set of mathematical equations that provides an efficient computational to estimate the state of a process in several aspects: it supports estimations of past, present, and even future states, and it can do the same even when the precise nature of the modeled system is unknown [12]. The whole filtering process is composed of a prediction equation and an update equation, which also serves to portray the entire system, as defined by Eqs. (1) and (2):

$$X(n) = F.X(n-1) + V_q(n-1) \tag{1}$$

$$Y(n) = H.X(n) + V_q(n) \tag{2}$$

Which in above equations, X(n) and Y(n) are the estimated state variable and measurement variable, respectively. F is the state transition matrix and H is the measurement matrix. $V_q(n)$ and $V_p(n)$ represent the system noise and measurement noise, respectively.

B.2. Thresholding Technique

Thresholding is a simple but effective technique for image segmentation. Finding a suitable thresholding value to segment an arbitrary object from its background is an important step in image processing and has wide applications in image processing [13]. The thresholding technique is based on image segmentation into different regions in which one segment consists of pixels more than or equal to the proposed threshold value and the other consists of pixels less than the proposed threshold value.

Thresholding techniques can be generally categorized into global and local thresholding. Global thresholding finds a single threshold value for the whole image. Each pixel is assigned to foreground or background based on gray value comparing to the threshold value. Local threshold uses various threshold values for each pixel according to the gray value of neighbor pixels.

B.3. K-means Clustering Technique

Clustering can be considered as one of the most important unsupervised learning methods, and it can be defined as identification of similar classes of objects. K-means algorithm is one of the most popular methods in flat clustering. This algorithm was first introduced by Mac Queen [14]. K-means algorithm is defined as following:

Step 1: Select K data as a center of the cluster.
Step 2: Determine the similarity of other data to the cluster centers.
Step 3: Assigning the data to the closed cluster.
Step 4: Calculate each average cluster as a new cluster center.
Step 5: Repeat steps 2 to 4 until the clusters converge.

II. EXPERIMENTAL

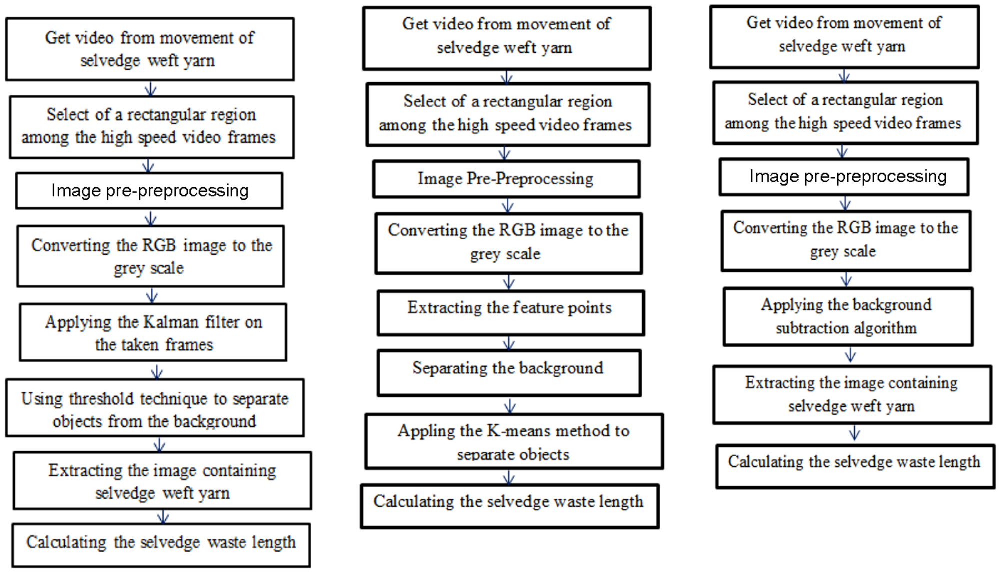
In order to control the selvedge waste length online, a high-speed camera (Sony RX10 II) with the speed of 1000 frames per second is used to detect the weft yarn movement in selvedge. The measurements are carried out on rigid rapier weaving loom. The weaving loom is equipped with leno selvedge at both sides. The videos are made during weaving of a plain fabric. Several successive frames containing the weft yarn are shown in Fig. 2. For calculating the selvedge yarn length, three methods (Kalman filter, K-means clustering, and background subtraction) are introduced. The general steps in every method are illustrated in the flowchart of Fig. 3.

A. Kalman Filter Method to Detect the Selvedge Yarn

According to the flowchart in Fig. 3a, the following steps of the first method are performed:
At first, to obtain the correct measurements of the weft waste length, a rectangular region of film is selected among the high-speed video frames. Selected region should be containing the whole length of the selvedge waste yarn. For the first time, after installing the online control system on the weaving loom, mentioned region is manually chosen. Because of the fixed position of the camera, this region will be same for all frames. By considering that the selvedge yarn length is just adjustable in receiver side, so measurements are only performed on this side of the loom. Fig. 4 shows the selected region in a video frame.

Video frames are transformed to a computer to be processed. Before detecting the selvedge weft yarn, pre-processing of the frame is performed. After receiving each frame, median filter is applied on it to remove noise. Then,

Fig. 2. Weft yarn exit in different times: (a) 0.001 s, (b) 0.002 s, (c) 0.003 s, (d) 0.004 s, (e) 0.005 s, (f) 0.006 s, (g) 0.007 s, (h) 0.008 s, (i) 0.009 s, (j) 0.01 s, (k) 0.011 s, and (1) 0.012 s.



(a) (b) (c)

Fig. 3. Flowchart of proposed methods for calculating the selvedge yarn length: (a) based on Kalman filter, (b) based on K-.means, and (c) based on background subtraction.

three layered color (RGB) image is converted to the grey colored image in the frames.

In the next step, the selvedge weft yarn will be extracted from online video frames. For this purpose, the knowledge of weft yarn movement in the video can be used. Therefore, Kalman filter has been utilized. After applying the Kalman filter on the online video frames, the movement of some objects is identified including weft yarn, rapier, loom reed, and warp yarn. In order to detect the selvedge weft yarn among the other objects, at first the objects are separated from the background. For this purpose, local thresholding technique is used. Local thresholding is carried out by cropping the original image into eight sub images. Once the cropping is done, OTSU algorithm [15] is applied on all the sub images individually, resulting in a distinct threshold for every sub image. These results in the original image are segmented with help of locally generated threshold. The result of a frame is shown in Fig. 5. After thresholding, the selvedge weft yarn, rapier, reed loom, and a part of selvedge warp yarn have been seen from resulting images (see Fig. 6). The results of thresholding for several successive frames are illustrated in Fig. 7. It is observed from these images that each frame can contain one or more of the mentioned objects.

Among the images shown in Fig. 7, the image containing selvedge weft yarn will be identified. The desired image is the frame at time exactly before beating up. In this frame, the selvedge waste length is completely specified. This frame is shown in the left corner at top of Fig. 7. In order to determine this frame, the pixels in top and bottom of the image should be investigated. If mentioned pixels are equal to zero, so the image is only containing the selvedge weft yarn.

Finally, the selvedge waste length that is weft yarn length between the last selvedge warp yarns and free end of weft yarn is calculated.

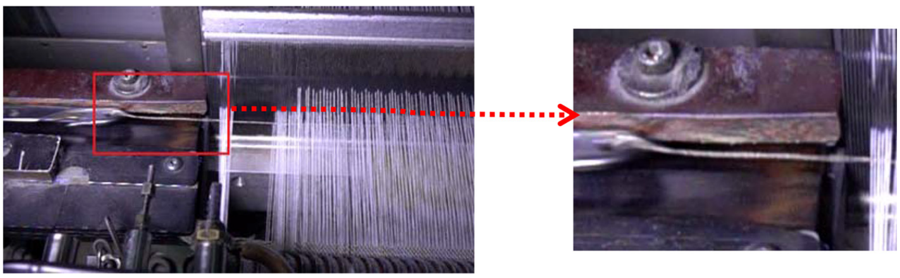


Fig. 4. Selected region covering the rapier exit and the selvedge weft yarn.

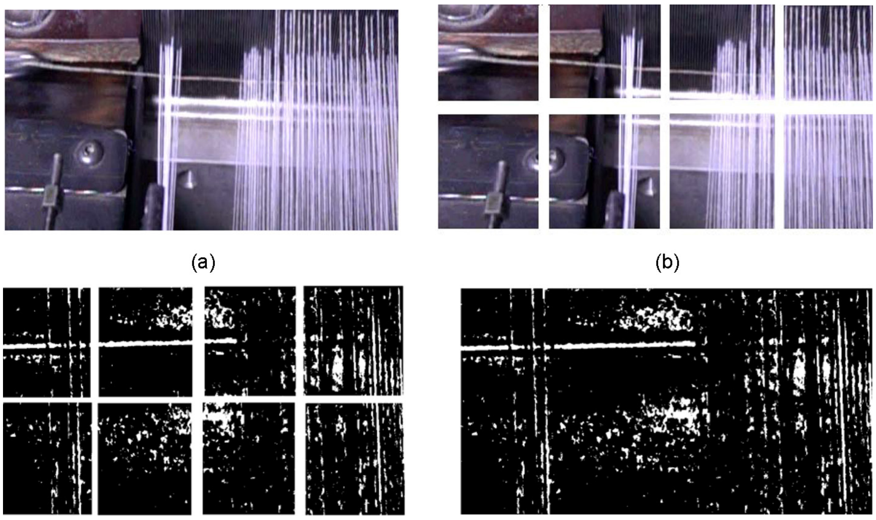

(a) (b) (c) (d)

Fig. 5. Local thresholding: (a) main image, (b) sub images, (c) sub images after thresholding, and (d) main image after thresholding.

B. K-means Method to Detect the Selvedge Yarn

B.1. Extracting the Feature Points

According to the flowchart in Fig. 3, steps 1 through 4 in method (b) are similar to those in method (a). However, in the second method, after image pre-processing, corresponding feature points in two successive frames are extracted using proposed algorithm by Lucas [16]. The main idea behind this algorithm is based on three assumptions brightness constancy, small movements, and spatial coherence. According to these assumptions, the brightness of pixels associated with an object will remain constant in the next frame and the movement of its pixels is very small. In addition, movement of the neighbor pixels of an object in the next frame remains constant. Therefore, by applying these criteria, the corresponding feature points are found in the next frame.

Then, motion directions (d_i) and motion magnitudes (m_i) of all the feature points in two successive frames are computed according to the following equations:

$$d_i = \arctan\left(\frac{y_i(t+1) - y_i(t)}{x_i(t+1) - x_i(t)}\right) \qquad i = 1, 2, ..., N \tag{3}$$

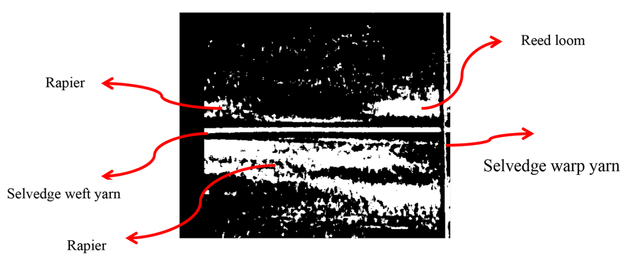


Fig. 6. Observed objects in resulted image from thresholding.

$$m_i = \sqrt{\left(x_i(t+1) - x_i(t)\right)^2 + \left(y_i(t+1) - y_i(t)\right)^2} \qquad i = 1, 2, ..., N \tag{4}$$

Where, in above equation, $x_i(t)$, $y_i(t)$ and $x_i(t+1)$, $y_i(t+1)$ are positions of i-th feature points in frame t and t+1, respectively. N is the number of corresponding feature points in two frames.

B.2. Separating the Background

In next step, moving objects should be identified. In this regard, feature points with zeros or small movement are considered as background points. Therefore, according to Eq. (5), the background points are separated from other points.

$$\text{feature point} = \begin{cases} \text{background} & \text{if } m_i < \lambda \\ \text{moving object} & \text{otherwise} \end{cases} \tag{5}$$

Where, in this equation, n is the number of pixels, m_i is motion magnitudes, λ is threshold motion magnitudes, which is equal to 0.5 in this paper.

B.3. K-means Clustering

Based on the motion magnitudes and directions of the feature points, these points are clustered into four clusters using K-means algorithm (K=4). The feature vector includes brightness, motion directions and the motion magnitudes. Number of clusters is equal to the number of moving objects in the video frame, namely rapier, weaving loom, selvedge weft yarn and selvedge warp yarn. After clustering, each cluster is considered as one object, Fig. 8 shows the results of this step.

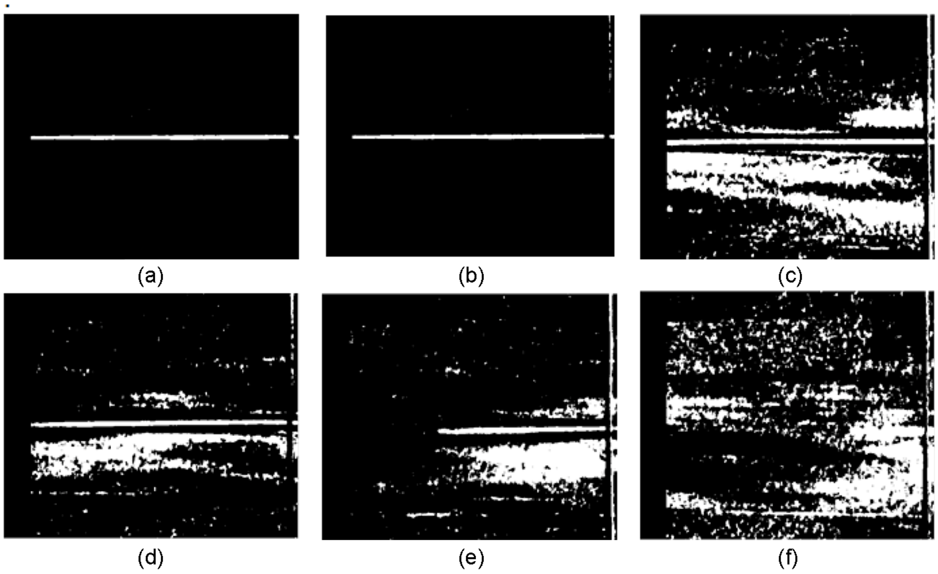


Fig. 7. Images extracted from online video frames after thresholding: (a) frame contains weft yarn, (b) frame contains weft yarn and warp yarn, (c) frame contains weft yarn, warp yarn, reed loom and rapier, (d) frame contains weft yarn, warp yarn, reed loom, and rapier, (e) frame contains weft yarn, warp yarn, reed loom, and rapier, and (f) frame contains weft yarn, warp yarn, reed loom, and rapier.

C. Background Subtraction Method to Detect the Selvedge Yarn

According to the flowchart in Fig. 3, steps 1 through 4 in method (c) are similar to those in method (a). However, in the third method, after image pre-processing, a Background subtraction algorithm proposed in [17] is used. The algorithm is briefly described as follows. The information of current frame in each pixel is compared to the background frame. If the difference between any pixel in current and background frames is lower than a set of thresholds, then the pixel will be classified as background. The pixels in current frame that their properties are significantly different from background frame are classified as moving pixels. After identifying the moving object, in order to detect the selvedge weft yarn among the other objects, the mention steps in method (a) are used. Therefore, this method is similar to the first method.

III. RESULTS AND DISCUSSION

In this section, the performance of three methods in terms of accuracy and processing time is evaluated, and compared which each other. Experiments were performed by Matlab 2014 software and a computer with the specifications of Cori7, 740 Qm, 1.74 GHz, and Ram 8 GB was used.

The obtained image using Kalman filter is shown in Fig. 9. To calculate the weft yarn length, the number of pixels in the horizontal direction is counted. Then by considering the magnification, weft yarn length is determined. It is observed that the length of weft yarn waste is calculated as 4.21 cm for the first pick, which is shown in Fig. 8, whereas the real length of weft yarn waste is manually measured as 4.15 cm. In addition, selvedge waste length is manually measured. This procedure is also performed for further images obtained from the successive weaving cycles in three different tensions of weft yarn (high tension, medium tension and low tension) by using three proposed methods. The comparison of the actual values with the values calculated by two proposed methods is given in Table I. Measurements are taken in five cycles and their averages and standard deviation are recorded. Comparison of time processing for calculating selvedge weft yarn in three methods is presented in Table II.

It is observed from Tables I and II that the Kalman filter method is efficient in terms of processing time and accuracy compared to the K-means method. The background

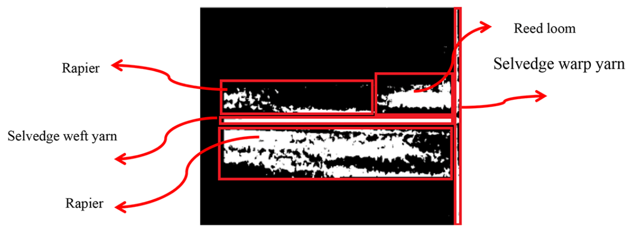


Fig. 8. Results of applying k-means algorithm for clustering corresponding feature points into the moving objects and the background.

Fig. 9. The obtained Image using Kalman filter.

TABLE 1
COMPARISON OF THE ACTUAL VALUES WITH CALCULATED VALUES OF SELVEDGE WASTE LENGTH BY THREE METHODS

Weft yarn tension		Measured value (cm)			Real value (cm)	Error (%)		
		Kalman filter	K-means clustering	Background subtraction		Kalman filter	K-means clustering	Background subtraction
	Number of cycle							
High tension	1	4.21	3.95	4.35	4.15	1.44	4.81	4.81
	2	3.92	4.11	4.24	3.93	0.25	4.58	7.88
	3	3.83	4.08	4.17	3.91	2.04	4.34	6.65
	4	4.11	4.14	3.76	3.96	3.78	4.54	5.05
	5	3.91	3.98	3.92	3.74	4.54	6.41	4.81
Average		3.99	4.05	4.08	3.93	2.41	4.94	5.84
Standard deviation (%)		0.15	0.082	0.24	0.14	1.74	0.84	1.23
Medium tension	1	5.42	5.34	5.84	5.55	2.34	3.78	5.22
	2	5.31	5.12	5.52	5.23	1.52	2.10	5.54
	3	5.52	5.43	5.88	5.67	2.64	4.23	3.7
	4	5.46	5.31	5.87	5.68	3.87	6.51	3.34
	5	5.63	5.76	6.23	5.99	6.01	3.83	4
Average		5.46	5.39	5.86	5.62	3.27	4.09	4.36
Standard deviation (%)		0.11	0.23	0.25	0.27	1.74	1.58	0.96
Low tension	1	8.13	8.33	8.29	7.78	4.49	7.06	6.55
	2	8.22	8.01	7.89	8.11	1.35	1.23	2.71
	3	8.34	7.78	7.77	8.12	2.70	4.18	4.31
	4	8.05	8.02	8.59	8.34	3.47	3.83	2.99
	5	8.17	8.24	8.91	8.56	4.55	3.73	4.08
Average		8.18	8.07	8.29	8.18	3.32	4.01	4.13
Standard deviation (%)		0.10	2.15	0.47	0.29	1.33	2.07	1.51

TABLE 1I
COMPARISON OF TIME PROCESSING FOR CALCULATING SELVEDGE YARN LENGTH USING THREE METHODS

Method	Time processing (s)
Kalman filter	70
K-means clustering	106
Background subtraction	50

subtraction method is easy to use and faster than two other methods, but this method has low precision.

In addition, it is observed from Table I that by increasing the weft yarn tension, selvedge waste length is decreased and vice versa. Therefore, when the selvedge waste length is larger than usual length, weft yarn tension can be increased to adjust the waste length. By considering the importance of waste on production cost, online control system of waste length can be useful. Also, Table I shows that the measurement values of the weft yarn waste by manual and image processing are very close. The error percent mean value between the measured and real values is equal to 2.79%. The designed system in this research is a simple mechanism that can be installed on other kinds of weaving machines without causing any deflection in the main work of the machine.

IV. CONCLUSION

In this study, an online control system is proposed to measure the selvedge waste length in rapier weaving. In this regard, a high-speed camera is used to record the weft movement in several successive cycles with different tensions. The selvedge waste length is excracted from online video frames using three methods based on image processing, namely Kalman filter, K-means clustering and background subtraction method. The performances of three methods in terms of accuracy and processing time are evaluated and compared with each other. The results show that the Kalman filter method has higher accuracy and the background subtraction method requires lower processing time. Also, it is obseved that by increasing the weft yarn tension, the waste length is decreased, so amount of waste can be reduced by adjusting the weft yarn tension. Also the results show that the difference between the measured lengths and the actual value is 2.09% which is an acceptable value.

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