

# Laser Spot Detection and Tracking

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**Abstract**— The aim of this paper is to accurately detect laser spots in low resolution images and track the laser spot in static background conditions. Since laser spot have many important applications in targeting and guiding smart munitions and robotics navigation, the detection and tracking of laser spots become an important research area. The accurate detection of a laser spot has been made possible with the help of the computer vision techniques. The detection process includes filtering, segmentation, feature extraction, and classification. An improved Background Subtraction and Improved Kalman filtering method was proposed in this paper. The new improved methods use some morphological operations, median filtering, and labeling algorithm. In addition, to recognize the laser spot accurately from other background noises, some features of laser spot shape and appearance were used. The software used to implement the different methods is Matlab R2013a. The results show that the proposed algorithms have better results compared to the existing Background Subtraction and Kalman Filtering methods.

**Keywords**-component; Laser Spot Detection, Laser Spot Tracking, Background Subtraction (BS), Kalman Filter (KF), Thresholding

## I. INTRODUCTION

Generally, a laser spot is defined as a small illuminated area on a surface that originated from a laser pointer. Laser pointer (or laser pen) is a small device that emits an intense beam of light over a long or narrow distance. One can use it to highlight something for example to point out important parts on a slide of presentation [1]. The typical size of a laser spot is less than 1 cm radius. The emitted laser from a tele-pointer can be found in many colors, dependent on the wavelength used. Visible color laser pointer has a wavelength ranging from 400nm to 700nm, which usually emit red, green or yellow color [2].

Laser based pointing system has been used successfully in many applications such as telemedicine [3], tele-tutoring [4], tele-surgery [5] and tele-conference [6]. The most popular usage of a laser pointer is to aid the presenter in conveying the meaning by adding basic localization and gesture information. It also allows the presenter to move freely as he can point precisely even from a distance [2].

The detecting technique suggested by several articles is to test the brightness and color value of laser dot pixels [7]. The most common way to detect the laser spot is by finding the brightest spot in the image [8, 9, 10, and 11]. Eckert and Moore [12] checks for pixels having brightness and RGB color values greater than a certain threshold which is determined initially and depends on the presentation environment; Olsen and Nielsen [13] detects the laser dot by tracking the brightest red

spot on the screen, while Kovárová, Mészáros and Zelman [14] searches in four successive frames for 5-pixel area with the biggest difference and intensity above the exact threshold.

The detection and analysis of red laser spots from RGB images were popularly used in many applications [15]. In [16], Soetedjo and Nurcahyo used a different threshold method for red laser spots. They dependent on the pixel value of the red component of the RGB image instead of the maximum intensity of the Grayscale image. In addition, they considered any component having less than 20 connected pixels as noises which need to be removed. The problem is that they couldn't represent the red color correctly since white color has also a high concentration of the red component [2].

The main problem with existing laser spot detection methods are that they might fail to detect the spot in some challenging circumstances such as lighting changes and difference in viewing angle. Image processing techniques have been used to help the users to detect and track the laser spot autonomously [2]. In addition, Jitter, which is mostly caused by uneven hand movement, is a big challenge in developing an accurate system, especially for laser interaction applications.

In this paper, we have considered detecting and tracking the laser spot in a static background. Improved algorithms of Background Subtraction and Kalman filtering methods were proposed and compared with the existing algorithms. Thresholding is used to initialize the background, detect moving objects, and update the background in real time application.

## II. OBJECT DETECTION AND TRACKING

### A. Object Detection

In Laser spot detection approaches, the laser spot should be extracted from the background image using computer vision methods [2].

The background subtraction method was tested in this paper since it is the common method of motion detection [17]. The Background subtraction method takes the difference between the current frame and the reference frame to identify the moving objects. Initializing and updating the reference frame is considered the key of this method [17].

There are some critical circumstances were the background subtraction method face problems. Some of these, as listed in [17], are: poor quality of image source, gradual variations of the lighting conditions in the scene, small movements of non-

static objects, sudden changes in the light conditions, and movements of objects in the background that leave parts of it different from the background model.

### B. Object Tracking

Object tracking is the process to track a single or multiple moving objects in a series of frames (video). The series of the image can apply to the object tracking system in two ways: first way is to get the frames directly from the camera and process it directly (real time system), the second way is to get the data as a recorded frames and do the processing for all the data [18]. In this paper, a recorded data were used. However, we develop our way to make it suitable for real time processing too.

Various techniques have been applied for object tracking such as Meanshift, Camshift, and Kalman filter. Each of these methods has many advantages and drawbacks processing. We will focus in our work on object tracking using Kalman filter to discover the ability of this method to predict and estimate the motion of the target in the image sequences.

The general block diagram of laser spot detection and tracking system is shown in figure 1.

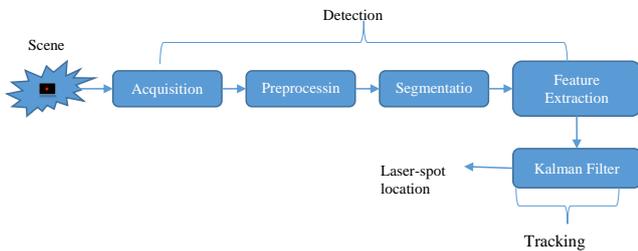


Figure 1. The General Block Diagram of Laser Spot Detection and Tracking System

### C. Object Representation

There are many different methods to define the objects. The most common methods to determine the shape of interest objects are points, primitive geometric shapes, object silhouettes and contours [19]. This paper uses a combination of first and second type of object representation, a centroid point with rectangle shape. It depends on the centroid of the object with its 2 dimensional width to calculate its corners that is required to draw the rectangle.

## III. KALMAN FILTERING ALGORITHM

Kalman filter algorithm is a recursive process which is receives one measurement (the input  $Z_k$ ) and there is just one output (Estimate,  $\hat{x}_k$ ). The whole process can be done through four internal steps as shown in the figure 2:

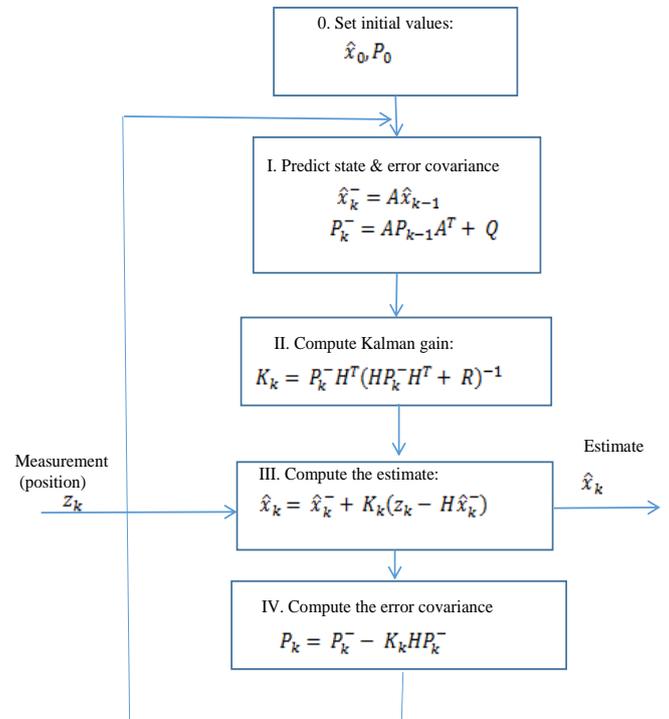


Figure 2. The Block diagram of Kalman Filtering [18]

The superscript ‘-‘ in the algorithm means nothing just prediction value for this variable, and the letter (K) means that this process is executive recursively.

There are many variables does not computed in this algorithm. In other words, We have to preset it before the process start (outside Kalman filter) by the user depending on the characteristics and the purpose of the system we are trying to modeling in kalman filter, these variables called System Models such as A, H, Q, and R. We will get a perfect result if the system model very close to our actual system which we trying to show.

Let look at these equations first:

$$x_{k+1} = Ax_k + w_k \quad (1)$$

$$Z_k = Hx_k + v_k \quad (2)$$

We can notice the system model in the equations above, the meaning of each variable is:

$x_k$  = state variable, (n\*1) column vector.

$Z_k$  = measurement, (m\*1) column vector.

A = state transition matrix, (n\*n) matrix.

H = state to measurement matrix, (m\*n) matrix.

$w_k$  = state transition noise, (n\*1) column vector.

$v_k$  = measurement noise, (m\*1) column vector.

#### IV. THE PROPOSED ALGORITHM

The proposed algorithm was implemented by the following steps:

Step (1): Calculate the Background image

The background image can be calculated using different methods. In the tested video, we have 100 frames. We started with 20 frames first to calculate the background image. Then, in order to keep the background image up to date, updating procedures were applied to recalculate the background image to adjust the changes in local and global illumination.

Step (2): Calculate the difference image

The difference image can be calculated by taking the difference between the current frame and the background image. The difference between each band from the RGB space was calculated, and then the binary image of the resultant difference image was calculated by using a threshold. Several methods have been tested in order to get better results, by using the accurate threshold to separate the foreground from the background.

To be able to get the binary image out of the difference image, a threshold value required. Manual threshold can be chosen based on trial and error. By trying different range of values, we were able to select the best threshold for the video used in this paper.

By taking the differences between the successive frames in the image series, we can easily detect any change which happened between them. The main advantage of this method is the ability to detect the change that should occur in the small time between frames. However, there are many disadvantages such as only a part of the moving object being detected because only the motion wave front will create any change, and some objects will vanish if they don't move for short time. The alternative method is to subtract a series of frames from one or more image which can be considered as a reference. This method will give a good result, but if any changes happen to the source of the light (such as intensity or position of the light) it will affect the reference image. For that reason, we can find a more accurate way to find the reference image in this specific condition, by calculating the background image for some of the frames in the series.

Step (3): Apply morphological operations

The resulted image from step (2) is the difference image between the current frame and the reference frame. This image will contain the laser spot component and many other noisy components. These noises came from different sources like environmental factors, illumination changes, or during the transmission of the video [18]. Therefore, these noisy components should be removed.

In order to remove the small noisy objects from the image, a simple median filter did a good job and improved the results. Morphological methods are used for further processing. Corrosion operation is taken to effectively filter out noise activity areas.

Step (4): Extract objects

From the resulted different binary image, we can extract the different objects depending on area threshold. The area threshold was chosen manually and estimated from the size of the object (The Laser Spot). Choosing big area threshold will pretend detecting extra positions as objects, but it makes the detecting of Laser spots in corners with small size more difficult.

Step (5): Apply Kalman filter tracking algorithm

After getting the extracted object information from step 4, we improve the position information based on kalman filter. Kalman filtering will predict the exact position of object (Laser Spot) based on pervious location information of the same object.

The last step is to locate the moving objects on the frame. All pixels which have the value 1 will be considered as foreground and the others will be considered as background. Pixels connected together will form different objects. Another threshold for area used to separate between noisy connected pixels and real objects. The area threshold was chosen manually by trial and error.

The Flowchart of the proposed algorithm is shown in figure 3.

#### V. RESULTS AND DISCUSSION

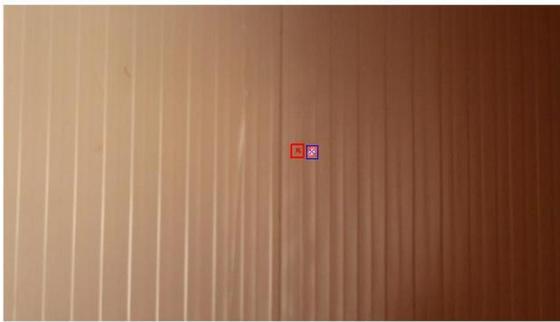
Results have been collected by testing the first 100 frames from the video. The results for correct detection and tracking of laser spot were calculated and compared between different algorithms. The evaluation used in this paper was frame based evaluation, which means object tracking compared on a frame by frame basis.

For calculation purposes, we depended on the total no. of occurrence of laser spot (96) that should be detected. We have performed many experiments with background subtraction method and Kalman Filtering method to select the variable values (threshold values and Kalman filter variable values) that gives the best results.

Four different frame results are shown in figures (4 – 7). The four algorithms tested were:

- (1) KF Algorithm: Kalman Filtering Algorithm
- (2) BS Algorithm: Background Subtraction Algorithm
- (3) Improved KF Algorithm: Improved Kalman Filtering Algorithm
- (4) Improved BS Algorithm: Improved Background Subtraction Algorithm

The results of Background Subtraction (BS) algorithms are shown using blue color, while the red color used for the Kalman filtering (KF) algorithm results.



(a)



(b)

Figure 4. Results for Frame No. 45: (a) KF and BS Algorithm Results, (b) Improved KF and Improved BS Algorithm Results



(a)

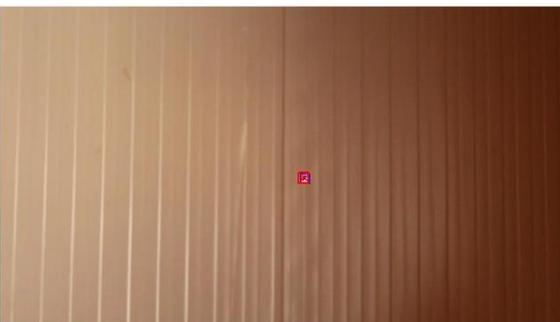


(b)

Figure 6. Results for Frame No. 55: (a) KF and BS Algorithm Results, (b) Improved KF and Improved BS Algorithm Results

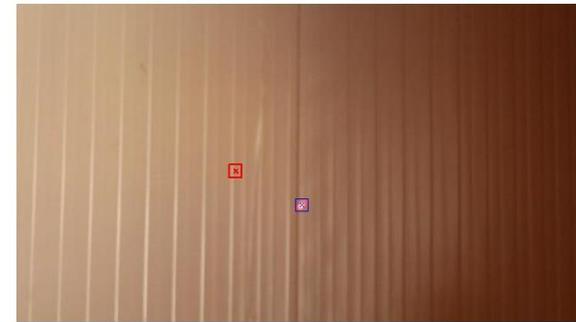


(a)

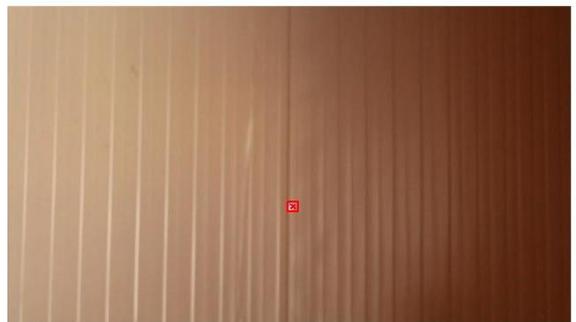


(b)

Figure 5. Results for Frame No. 50: (a) KF and BS Algorithm Results, (b) Improved KF and Improved BS Algorithm Results

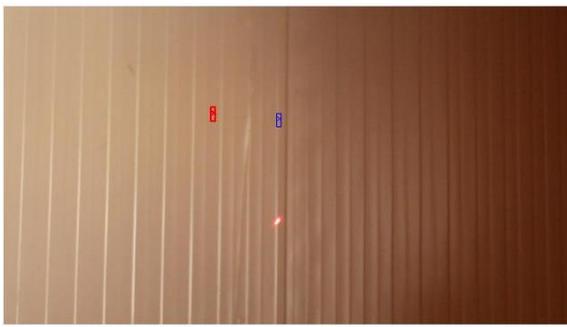


(a)

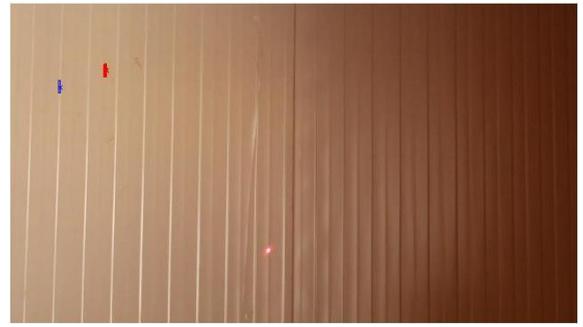


(b)

Figure 7. Results for Frame No. 60: (a) KF and BS Algorithm Results, (b) Improved KF and Improved BS Algorithm Results



(a)



(a)



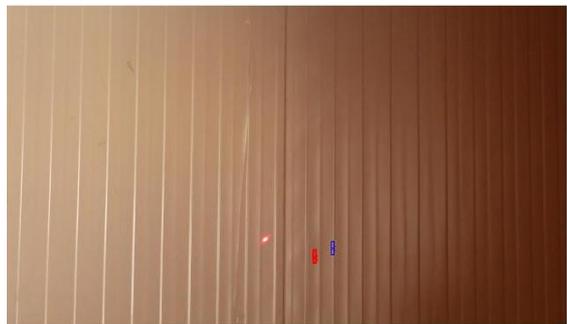
(b)



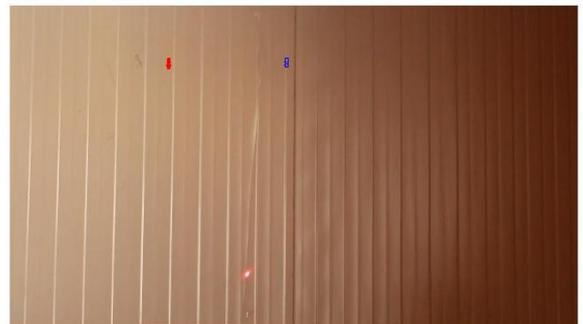
(b)

Figure 8. Results for Frame No. 65: (a) KF and BS Algorithm Results, (b) Improved KF and Improved BS Algorithm Results

Figure 10. Results for Frame No. 75: (a) KF and BS Algorithm Results, (b) Improved KF and Improved BS Algorithm Results



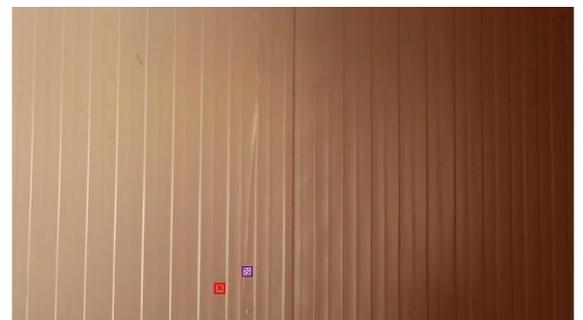
(a)



(a)



(b)



(b)

Figure 9. Results for Frame No. 70: (a) KF and BS Algorithm Results, (b) Improved KF and Improved BS Algorithm Results

Figure 11. Results for Frame No. 85: (a) KF and BS Algorithm Results, (b) Improved KF and Improved BS Algorithm Results

In figures (4, 5, 6, and 7), results for frame no. 45, 50, 55, and 60 are presented respectively. The BS algorithm detected the laser spot correctly while KF Algorithm missed tracking it due to a wrong estimation as shown in (a) of figures (4, 5, and 7). On the other hand, Improved BS and KF algorithms detected and tracked the laser spot correctly as shown in (b) of figures (4, 5, and 7).

The results for frame numbers 65, 70, 75, and 85 were shown in figures (8, 9, 10, and 11) respectively. The BS and KF algorithms were failed to detect and track the laser spot completely. On the other hand, Improved BS and KF algorithms detected and tracked the laser spot correctly. However, the improved KF algorithm were failed to locate the exact location of the laser spot as in figures (9 and 11). This failure occurred with the improved KF algorithm 7 times during the tested (100) frames.

Table 1 shows the results of the accuracy of detecting and missing laser spots using the 4 algorithms. The results clearly show that the proposed algorithms detect laser spots and track them more accurately (88.5% for the Improved BS and 81.25 % for the Improved KF) compared to the existing algorithms (between 43% and 57%).

TABLE I. COMPARISON OF NUMBER OF DETECTED AND MISSED LASER SPOTS.

Methods	Total No. of laser spots = 96			
	Detected		Missed	
	No.	%	No.	%
BS Algorithm	55	57.3 %	41	42.7 %
KF Algorithm	42	43.75 %	54	56.25 %
Improved BS Algorithm	<b>85</b>	<b>88.5 %</b>	<b>11</b>	<b>11.5 %</b>
Improved KF Algorithm	<b>78</b>	<b>81.25 %</b>	<b>18</b>	<b>18.75 %</b>

### CONCLUSION

Laser Spot detection and tracking were considered in this paper. Background Subtraction (BS) method were used for the detection part and the Kalman Filtering (KF) Algorithm for the tracking part. The results from both algorithms were compared and it has been shown that BS algorithm has better results than KF algorithm because of the non-linear motion of the laser spot. In addition, the BS algorithm had better localization for the laser spot location compared to the KF algorithm. By using median filter and some morphological operations, both algorithms had improved results compared to the existing algorithms. The results indicate that new proposed algorithms were able to detect and track objects (laser spot) more accurately than the previous mentioned algorithms. So, the detection of the laser spot had better results than tracking it in this paper.

For Future works, the proposed algorithm could be tested in dynamic background conditions. Other segmentation methods,

labeling algorithms, and noise removal techniques can be used and compared.

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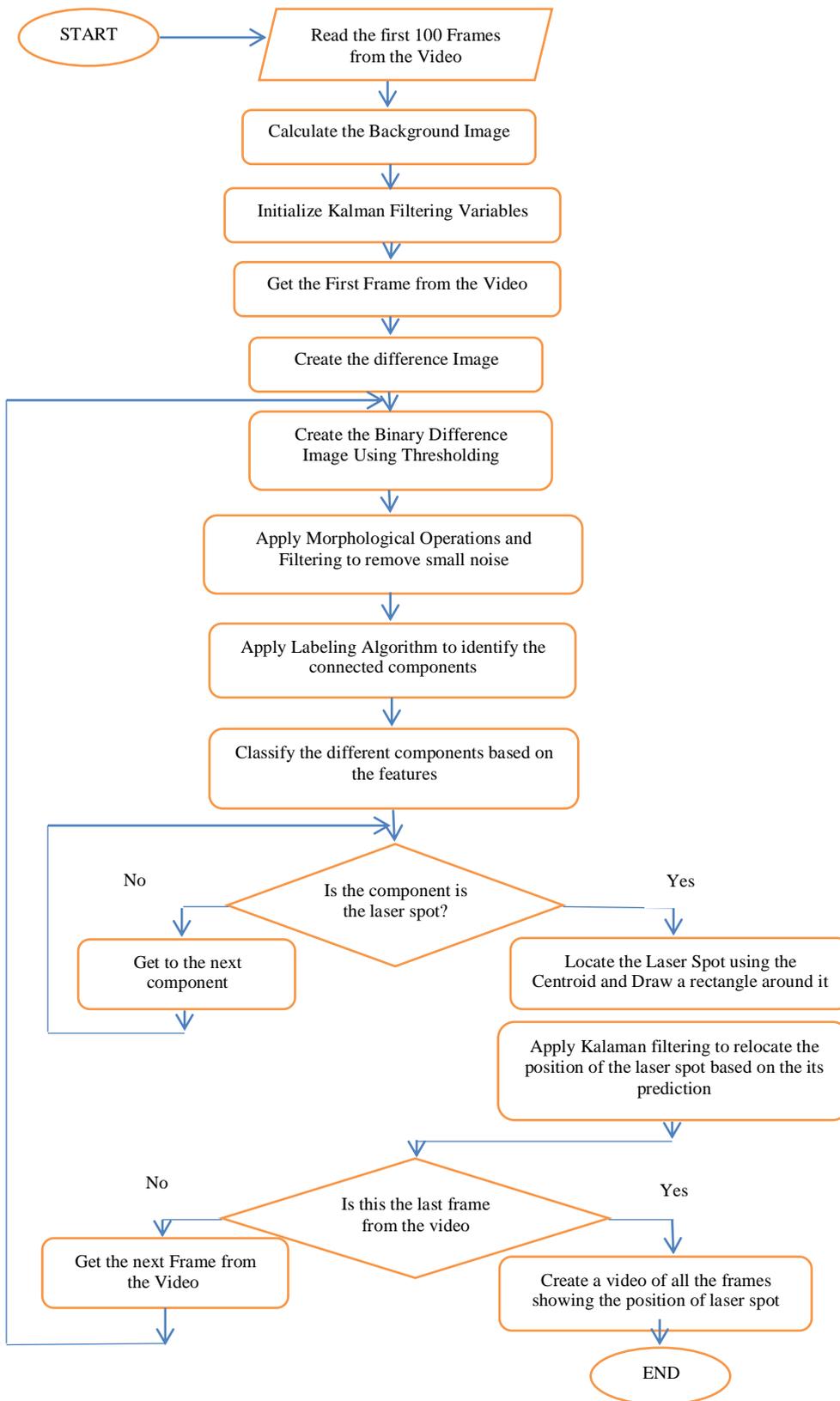


Figure 3. The Flowchart of the Proposed Algorithm