Aamish UMAR CAMERA BASED SHEET MEASUREMENT SYSTEM FOR LASER CNC MACHINES AGU 2018

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A THESIS
SUBMITTED TO THE DEPARTMENT OF ELECTRICAL & COMPUTER ENGINEERING
AND THE GRADUATE SCHOOL OF ENGINEERING AND SCIENCE
OF ABDULLAH GUL UNIVERSITY
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF
MASTER OF SCIENCE

By
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SCIENTIFIC ETHICS COMPLIANCE

I hereby declare that all information in this document has been obtained 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 materials and results that are not original to this work.

Name-Surname: Aamish UMAR
Signature :

REGULATORY COMPLIANCE

M.Sc. thesis titled Camera based automatic sheet measurement system for laser CNC machines has been prepared in accordance with the Thesis Writing Guidelines of the Abdullah Gül University, Graduate School of Engineering & Science.

Prepared By	Advisor
Aamish UMAR,	Asst. Prof. Dr. Kasım TAŞDEMİR,

Head of the Electric & Computer Engineering Program

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ACCEPTANCE AND APPROVAL

M.Sc. thesis titled Camera based automatic sheet measurement system for laser CNC machines and prepared by Aamish UMAR has been accepted by the jury in the Electrical & Computer Engineering Graduate Program at Abdullah Gül University, Graduate School of Engineering & Science.

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APPROVAL:

The acceptance of this M.Sc thesis has been approved by the decision of the Abdullah Gül University, Graduate School of Engineering & Science, Executive Board dated ….. /….. / ……….. and numbered .…………..……. .

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(Date)

Graduate School Dean
Prof. Dr. İrfan ALAN

ABSTRACT

CAMERA BASED SHEET MEASUREMENT SYSTEM FOR LASER CNC MACHINES

Aamish UMAR
M.Sc. in Electrical & Computer Engineering
Supervisor: Asst. Prof. Dr. Kasım TAŞDEMİR

January 2018

Laser CNC machines are widely utilized for cutting metal sheets of varying thickness and materials. The sheets to be cut can be of varying dimensions and be placed at any desired area of the cutting table. The operator needs to assign the starting point of the laser manually along with the dimensions of the metal sheet in order to start the cutting process. The process of assigning the starting point and dimension of sheet are time consuming and can take few minutes before every cutting process and it sums up to hours by the end of daily cutting jobs, an automated process of sheet measurement can save considerable amount of time and speed up the process.

In this thesis, a camera based system for automatic sheet measurement which includes measurement of starting point assignment, orientation, length and breadth has been developed. The algorithms have been implemented keeping in mind the importance of speed since the processing has to be done in real time and needs to be as fast as possible. The implemented algorithms can find all required parameters in about two seconds. The techniques utilized for its implementation have been discussed. The robustness of the system has been compared with other traditional methods of sheet measurement and orientation detection.

The implemented system was tested on a real laser CNC machine over a period of six months and the test results have been discussed. Also, a camera based intrusion detection system for laser CNC machine has been developed in order to make it safe for human during operation. Patent application made for the implemented system.

Keywords: Laser CNC, Image Processing, Camera, Measurement, Motion Detection

ÖZET

LAZER CNC MAKİNELERİ İÇİN KAMERA TABANLI SAC ÖLÇÜM SİSTEMİ

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Ocak 2018

Lazer CNC makineler farklı kalınlıktaki çeşitli metal levhaların kesimi için yaygın olarak kullanılmaktadır. Kesilecek levha farklı boyutlarda olabilir ve kesim platformu üzerinde herhangi bir yere yerleştirilebilir. Yerleştirilen metal levhanın boyutlarına uygun olarak, operatör kişi kesim işlemini başlatmak için lazerin başlangıç noktasını manuel olarak ayarlar. Başlangıç noktası atama ve levhanın boyutunu ayarlama işlemleri zaman alıcıdır. Her kesim işlemi için bir kaç dakika alır ve günlük olarak toplamda saatler sürebilir. Bu sebeple, otomatik levha ölçüm işlemi oldukça zaman kazandırabilir ve işlemleri hızlandırabilir.

Bu tezde, otomatik levha ölçümü için kamera tabanlı bir sistem geliştirilmiştir. Geliştirilen sistem başlangıç noktası atama, pozisyon, uzunluk ve genişlik ölçme işlemlerini de içermektedir. Bu algoritma geliştirilirken hesaplama hızı gözönünde bulundurulmuştur. Çünkü tüm işlemler gerçek zamanlı olarak çalışacağından mümkün olduğunca hızlı olmalıdır. Geliştirilen yöntem, istenen tüm parametreleri yaklaşık iki saniyede bulmaktadır. Tezde, bu gerçeklemede kullanılan teknikler tartışılmıştır. Sistemin gürbüzlüğü diğer geleneksel levha ölçüm ve pozisyon belirleme yöntemleriyle karşılaştırılmıştır.Geliştirilen sistem altı ay boyunca gerçek lazer CNC makinesinde test edilmiştir ve sonuçlar tartışılmıştır. Ayrıca iş güvenliğini artırmak için kamera tabanlı bir izleme yöntemi de eklenmiştir.

Anahtar kelimeler: Lazer CNC kesim, Görüntü işleme, Kamera, Ölçüm, Hareket algılama

Acknowledgements

I would like to express sincere appreciation to my supervisor Asst. Prof. Dr. Kasım TAŞDEMİR for his inspiring guidance, counselling and support during the course of my research and writing of this thesis. I am thankful to Asst. Prof. Dr. Mahmut KARAKAYA who helped me visualize this project and define my field of interest. I also thank Mr. Çabir ABAOĞLU general manager, Mr. Murat SERT production manager of Dener Machines company for the help and co-operation during the research and testing period.

I would also like to thank Assoc. Prof Dr. V. Çağrı GÜNGÖR head of department of graduate ECE program at AGU for his guidance and help during my graduate study at AGU.

Also I would like to thank my mother, father and sister for their support from time to time.

Lastly I would like to thank Dener Machines company Kayseri, Turkey for support during different stages of the project.

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To Myself

Chapter 1

Introduction

The laser cutting CNC machines are widely used these days for their efficiency and precision while cutting metal sheets of varying thickness and materials. The speed of cutting depends on the material to be cut, thickness of the material and the power of the laser resonator. These machines can work 24 hours a day.

The laser machine [1] has pallets where metal sheets are kept and the laser head cuts them into required designs via laser beam emitted from the laser head. The machine needs the location and orientation of metal sheet before it can start the cutting process. It takes few minutes to assign the starting point and orientation angle of sheet manually, and the total time spent assigning the starting point and orientation angle of sheet may sum up to an hour or two by the end of daily jobs done by the machine. Since the machine emits laser beam that is sufficient to cut metal sheets, therefore any human presence in the machine during cutting process can be fatal.

This thesis introduces camera based automatic sheet measurement system for laser CNC machines. The system utilizes a camera to automatically find the starting point, angle of orientation, length and breadth of the sheet in the shortest time. Sheet measurement process is completed in about two seconds by the proposed camera based sheet measurement system. An intrusion detection system has been integrated that warns the operator of any moving object presence before starting the cutting process.

1.1 Motivation

This section gives brief information about the need for a camera based automatic sheet measurement system also the need for an intrusion detection system has been explained. Figure 1.1.1 shows the Fiber Laser Machine [1] for which the systems were implemented.

Figure 1.1.1 Dener fiber laser machine

1.1.1 Sheet measurement and orientation detection

The sheet to be cut can be of varying dimensions and be located at any available area on the cutting pallet. Figure 1.1.1.1 shows several metal sheets of varying dimensions and orientation angle available on the cutting pallet. The machine cannot start the cutting process without knowing the coordinates of the starting point and angle of orientation of the metal sheet to be cut. The process of assigning the starting point can be performed in two ways:

1) It can be performed manually, the laser head is carried to the starting point and the coordinates can be fed into the machine. Dimension and

orientation of sheet are found manually (explained in more detail in the background chapter of this thesis).

2) The second method involves a laser sensor that detects the location and orientation of metal sheet automatically. The laser sensor can detect the sheet but only under some pre-defined conditions like the metal sheet must have a proper rectangular shape, specific dimensions and free of defect, also it should be kept within 200mm distance from the starting point. Dimension of sheet are found manually (explained in more detail in the background chapter of this thesis).

Figure 1.1.1.1 The Cutting Vicinity

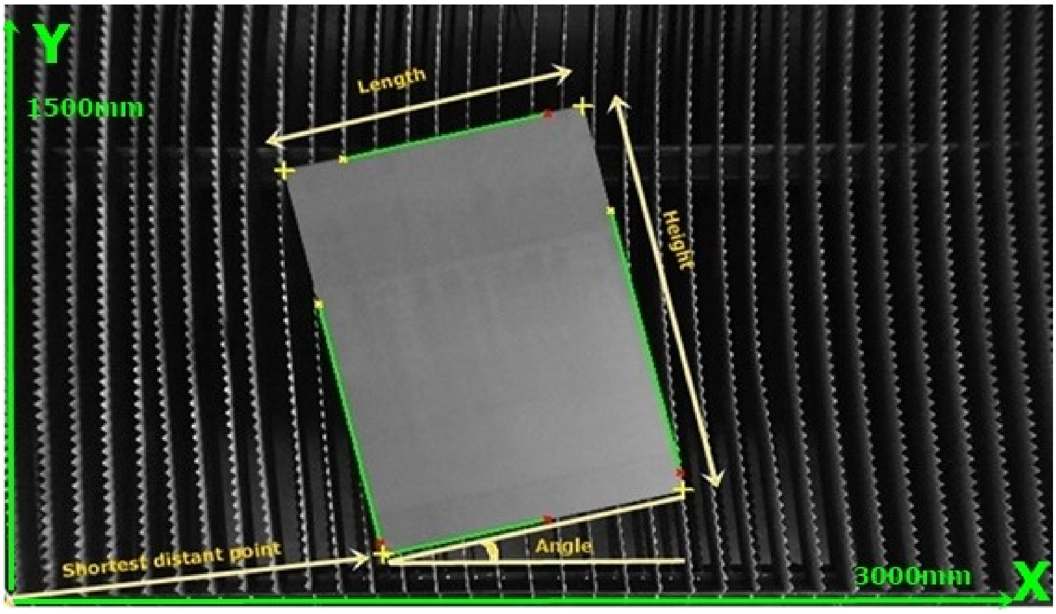


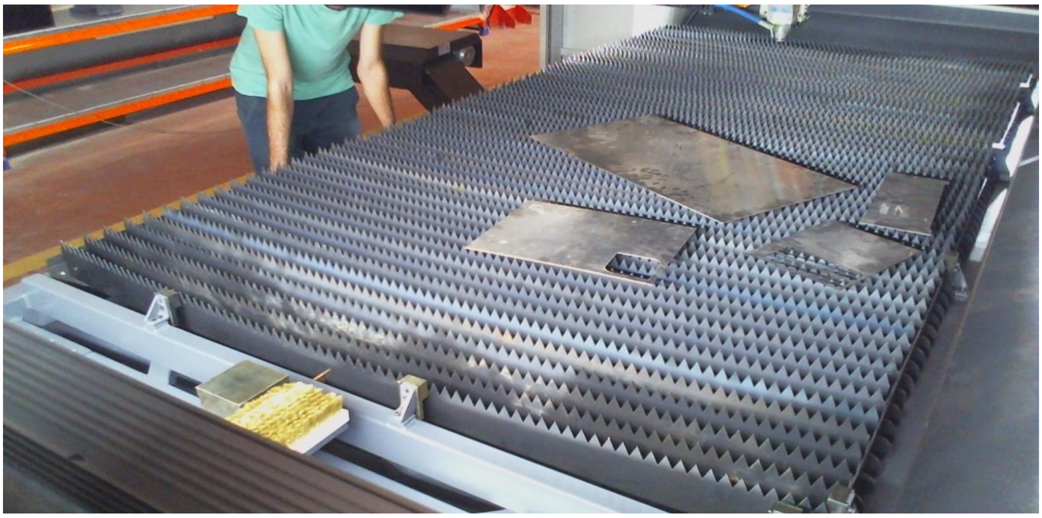
Figure 1.1.1.2 The required parameters

Figure 1.1.1.1 shows the cutting vicinity, where metal sheets are kept for cutting. Figure 1.1.1.2 shows the required parameters which include length, height, angle and the shortest distant point of the metal sheet. Starting point and orientation of the sheet are necessary to start the cutting process while length and breadth of sheet are necessary to make sure that the part to be cut will fit in the area of sheet. All required parameters mentioned above can be found automatically utilizing camera based sheet measurement system.

1.1.2 Motion detection and intrusion detection system

Figure 1.1.2.1 shows the possibilities of a human inside the machine. The laser beam utilized for cutting metal sheets can cause fatal injuries to any living being present in the machine during cutting process, therefore the machine needs an intrusion detection system to warn the user if there is a human or some moving thing present inside the machine before the cutting process starts. The use of laser sensors for intrusion detection would not be efficient enough due to the vast area inside the machine. A camera is installed in the machine for sheet measurement system. It is economical and efficient to use the same camera for human and intrusion detection system as well. The video stream from the camera is processed to detect if a human or moving object is present inside the machine.

(a)



(b)

Figure 1.1.2.1 (a) and (b) Human inside the machine

1.2 Thesis objectives

The objective of this thesis is:

1) To automate the process of sheet measurement in laser CNC machine by using a camera based system.
2) To integrate an intrusion detection system in the camera based sheet measurement system.

In this thesis, firstly the traditional systems that are being currently used in the machine for the purpose of sheet measurement are explained. Then, the need and importance of the new approach involving camera has been explained. The various image processing techniques that were utilized have been discussed in detail. Then, the accuracy of the implemented system on the machine has been investigated. The testing was conducted over a period of six months and the results achieved during the experimental process have been discussed in detail in the experimental setup and results section. Based on the results, it can be interpreted that the new system is more efficient than its traditional counterpart. It speeds up the process of sheet measurement and can detect human presence inside the machine thus saving time and preventing mishap.

1.3 Thesis outline

The rest of this thesis is structured as follows: Chapter 2 presents the similar work that has already been done in this field and the methods that are being used currently. In Chapter 3, sheet measurement program and its implementation has been explained in detail. The various techniques utilized and the challenges involved in the process, along with the benefits of using this camera based sheet measurement system have been discussed.

In Chapter 4, human and motion detection system has been discussed. The basis of the implementation of the system has been discussed. The experimental setup and results have been discussed in Chapter 5. The conclusion drawn from this work is available in Chapter 6.

Chapter 2

Background

In this chapter, the traditional methods that were being used and related work in this field have been discussed. The background and related work for the process of sheet measurement will be explained and then the human and motion detection system will be discussed.

As introduced in Chapter 1, laser cutting machines are widely used these days for the purpose of cutting metal sheets of varying thickness. The machine requires the coordinates, length, breadth and angle of orientation of the sheet in order to start the cutting operation. Traditionally this process is carried out manually by taking the laser head to the starting point and then starting the machine. The manual method is quite straightforward and the required parameters including length, breadth and starting point's coordinates are fed manually. Another traditional method involves a laser sensor attached with the laser head which detects the position of the sheet. The method involving a laser sensor can find the starting point's co-ordinate and angle of orientation but cannot find the length and breadth of the sheet. The sheet needs to have a minimum dimension of 500x500 mm and be located at a maximum distance of 200mm from the starting point otherwise the system fails.

A camera based sheet measurement system is free from above stated drawbacks, faster and automatic.

2.1 Traditional methods of sheet measurement

This section gives detail about the traditional methods of sheet measurement.

2.1.1 Manual method using the handle

This method is quite straight forward. The only thing the user does is bring the laser head to the starting point as shown in Figure 2.1.1.1 and feed it to the machine. Next bring it to the end point as shown in Figure 2.1.1.2 and feed it to the machine. This method is quite tedious and laborious since the user needs to manually check and feed the start and end point. The user should be careful while performing this process since he needs to enter the machine vicinity.

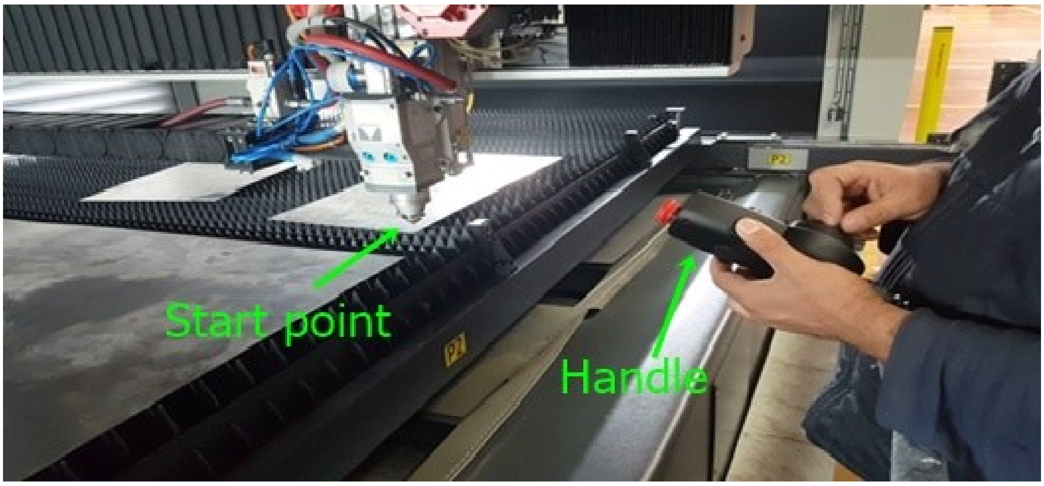


Figure 2.1.1.1 Define the start point manually

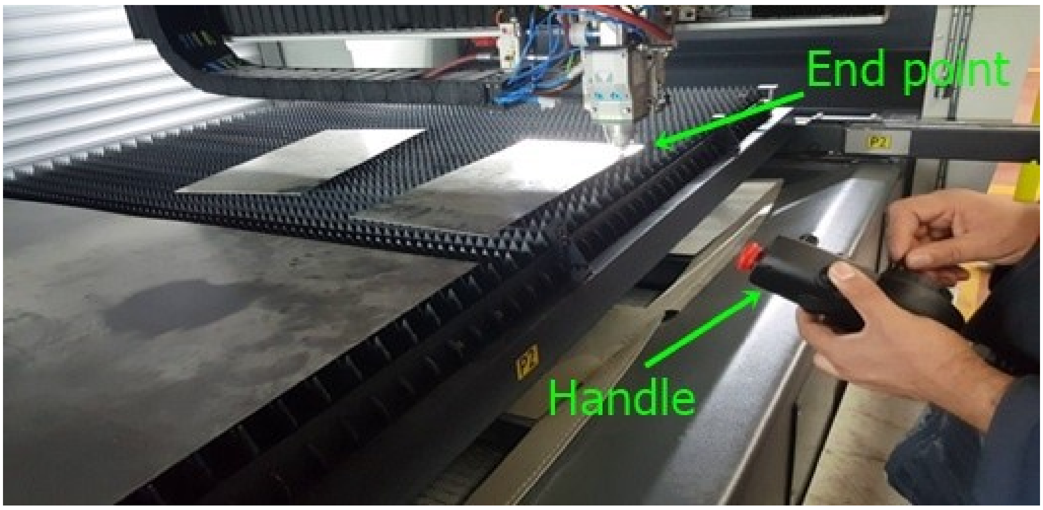


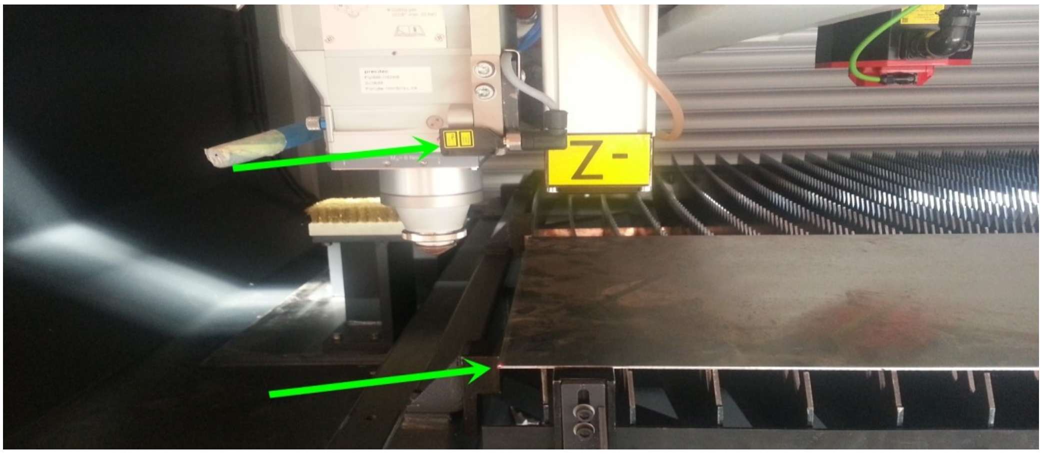
Figure 2.1.1.2 Define the end point manually

2.1.2 Automatic method utilizing laser sensor

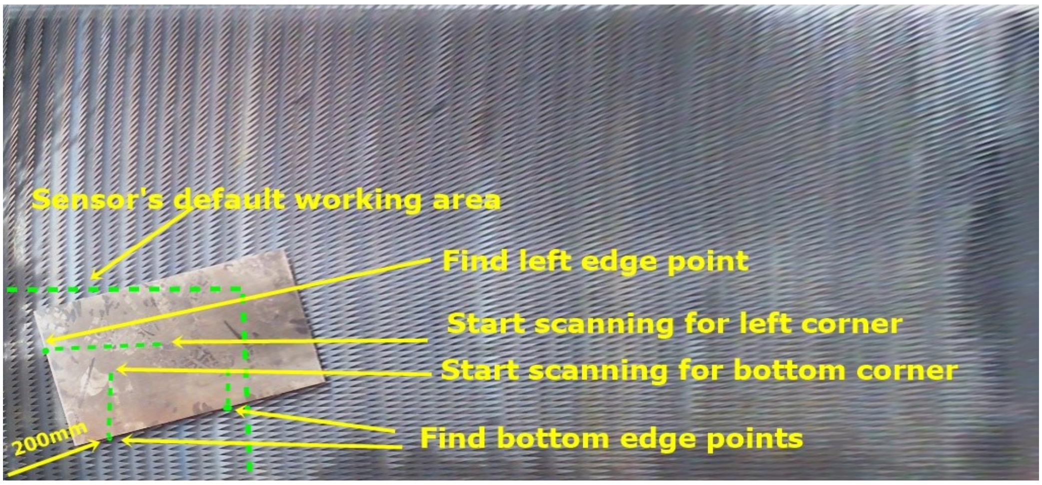
The traditional method of sheet measurement involves a laser sensor attached to the laser head. The laser sensor finds the shortest distant point and angle of orientation only. The approach used in this method is based on the corner detection. The laser sensor finds the points on the left and bottom corner of the sheet and utilize them to find the starting point and the orientation angle of the sheet. Figure 2.1.3(a) shows the laser head, the laser sensor attached along with the starting point. (b) Illustrates how the laser sensor works. The working is explained as follows:

1) It starts scanning parallel to the x axis from a predefined point, once it comes across the left corner edge the point is loaded to machine (p1x,p1y) shown in (c).
2) After that it starts scanning parallel to y axis from a predefined point shown in (b), once it comes across the bottom edge point (p2x,p2y) the point is loaded to machine and finally it scans parallel to y- axis for point (p3x,p3y) and that point is loaded to machine.
3) Now these points found in step 1 and 2 are used to find the angle of orientation (A) and starting point (X, Y) as shown in (c).

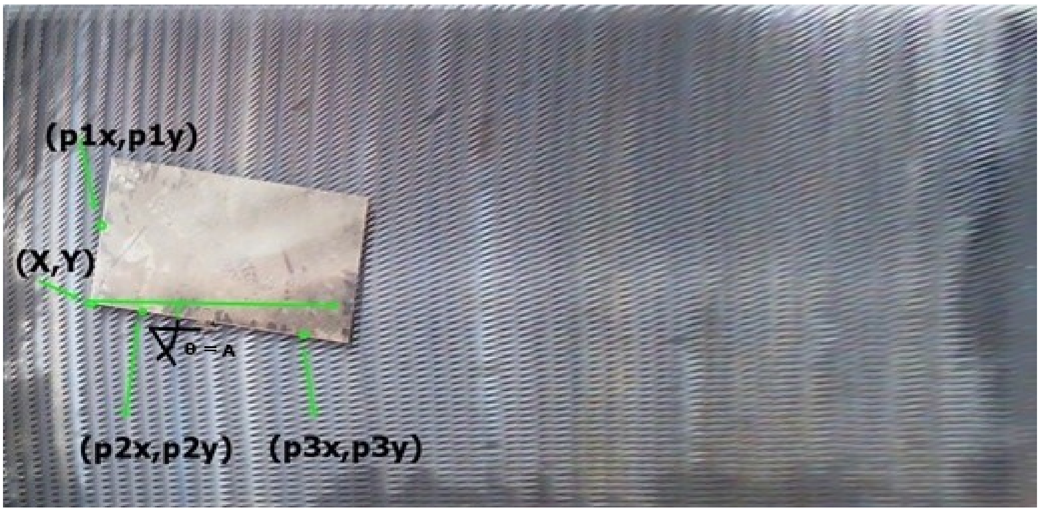
The laser sensor gives 100% accurate results. It can be understood from the working of sensor that since it scans parallel to x and y axis from predefined points and these points are kept within 200mm range from both x and y axis, therefore the sheet must be kept within 200mm from the origin (Zero X and Y coordinate of the cutting table). (Note: The points are kept within 200mm in order to minimize scanning time)



(a)



(b)



(c)

Figure 2.1.2.3(a) Laser sensor indicated by the upper arrow and the starting point indicated by the lower arrow. (b) The path of laser sensor (c) The corner points, start point and angle

The drawbacks of this method are as follows.

- It cannot find the length and breadth of the sheet.
- The sheet needs to have a minimum dimension of 500x500mm.
- The sheet can be no farther then 200mm from the origin.
- The sheet needs to be proper rectangular in shape.
- The sheet must have no holes from previous cutting
- The process is slow.
- Only single sheet must be present in the cutting vicinity.

2.2 Related works involving image processing

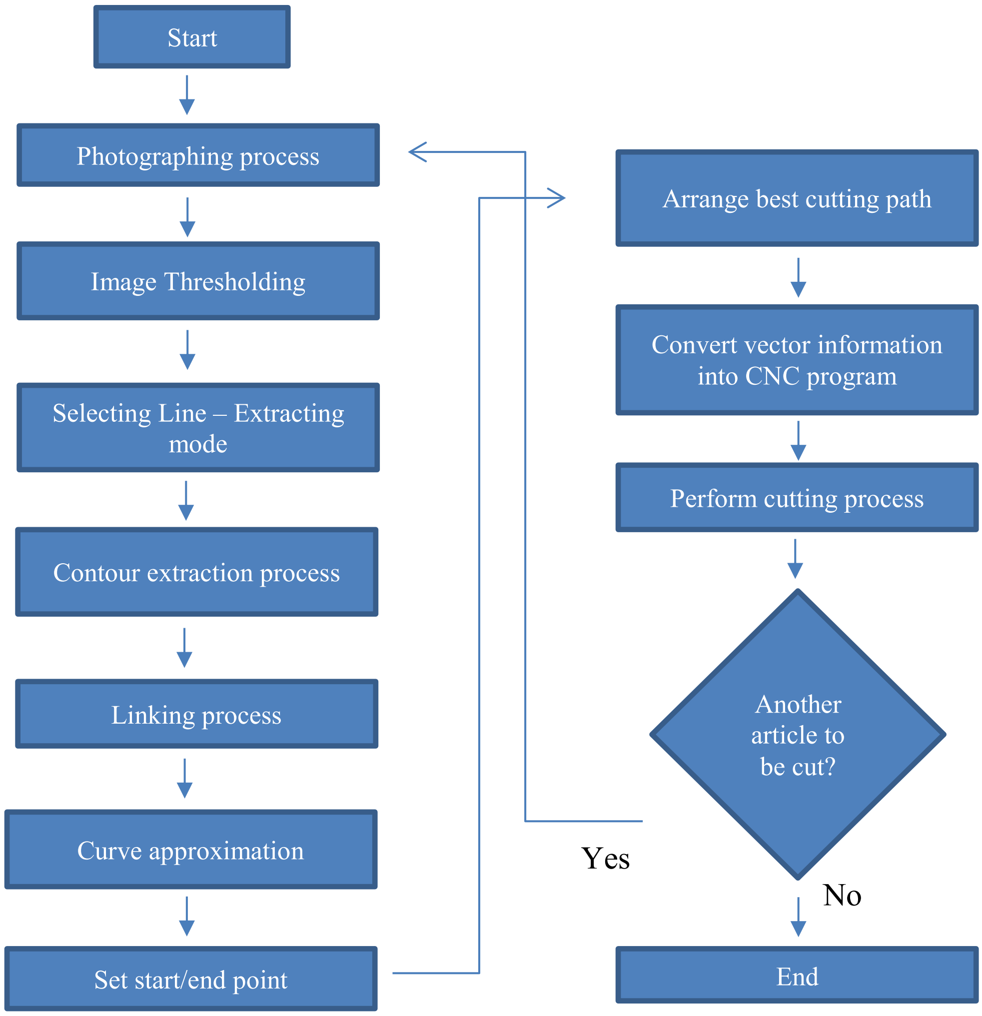


Figure 2.2.1 Steps involved in finding the best path

The various processes involved in finding the best possible path as shown in Figure 2.2.1 are explained below.

- Photographing process – This process involves a camera which takes the image of the cutting vicinity.
- Image Thresholding Process – In this step the acquired image is converted to a binary image where all pixel values above a certain value are converted to 1 while all other pixel below the specified threshold values are converted to 0.
- Selecting Line Extracting mode- In this mode the user makes a selection on what type of mode they want to choose in order to select the lines.
- Contour/Skeleton Extracting process- Contours or the outlines of the object are extracted in this process.
- Linking Process- "The pattern image is stored in the image buffer in the form of an array of pixels. For converting the image information into vector information, the characteristic points of each of the contours and skeletons must be linked in a point by order" [2].
- Curve Approximation – The curves are approximated from the image.
- Setting Starting/Terminating point – The starting and terminating points are found.
- Arranging the best cutting paths – The best cutting path is found.
- Converting the information into CNC program – The information is converted into CNC format and fed into the machine.

The patent does not define the actual machine for which it was implemented, but it can be considered as a basic background that similar type of work has been done in the past. Laser cutting machines are manufactured by many different companies hence they have their own specific design and requirement.

2.2.1 Corner detection to find the starting point

A thesis dated march, 2014 by Ismail PINAR submitted to Istanbul University, graduate school of science, department of electrical electronics engineering named image processing applications for laser cutting machines has compared corner detection methods Hough Technique [24], Haaris Technique [25] and Steerable Filter [28] to find only the starting point required by laser cutting machine. According to his thesis Hough Technique gives better results in comparison to Harris Technique and Steerable Filter for corner detection. The accuracy of corner detection with Hough Technique is 85%. The points not addressed in this thesis and the drawbacks can be stated as follows:

1. The thesis does not address any solution regarding length, breadth and orientation detection of the available sheet.
2. The cutting area covered by camera’s visibility is mere 184x138 mm, it is small in comparison to the table size which is 3000x1500 mm for a standard laser cutting machine.
3. The system is limited to rectangular sheets free from defects and kept straight (no orientation angle).

The newly implemented automatic camera based sheet measurement system eliminates all above stated drawbacks.

2.3 Related works regarding human and motion detection

There is a plethora of work has been done in the field of human and motion detection. Background subtraction principle is widely used where the frame difference between the reference and the upcoming frame is calculated in a video stream. In the next section similar work done in this field will be discussed.

2.3.1 Intensity difference method

In a paper of Belznai et al., the author has used the intensity difference between the reference frame and input frame is treated as a multi-modal probability distribution, and mode detection is performed using mean shift computation [15].

2.3.2 Background subtraction method

In a paper of Eng et al. the author has used the background subtraction process is used in the first place then a human shape model has been used for detecting a human. In simple terms they check the shape of the moving object and if its model matches to that of human it is classified as a human [16].

2.3.3 Utilizing infrared camera

In a paper of Han and Bhanu. the authors have combine the working of two separate camera one is infrared camera and the other is a normal camera, both cameras are kept in such a way that they look in same field of view. If motion is detected by the normal camera (based on background subtraction) the infrared camera checks for the thermal signature which is specific to humans and if it matches to that human the object is classified as a human [17].

2.3.4 Rectangular features method

Viola et al. This paper is restricted to pedestrian detection. A cascade of classifier is created which utilizes rectangular features of a moving human (i.e. the features of an upright human being inside a rectangular extracted region). The classifier is trained using Adaboost [20] technique [18].

2.3.5 Classifier utilizing SVM

In a paper of Dalal and Triggs. the authors divide the image into small spatial parts and finds the histogram of edge orientations over all pixels of the cell. The combine histograms of the various orientations form the feature representation. A dataset of human and non-human is created and trained using SVM classifier on the gradient histogram features from the two classes [19].

Chapter 3

Automatic Sheet measurement

3.1 Camera base automatic sheet measurement

In this chapter, the implemented sheet measurement system based on image processing is presented. The various challenges involved and how they were solved has been discussed in detail. The advantages of this system over traditional method have been discussed in detail.

As explained in section 2.1.2, traditional sensor based method of sheet measurement requires the sheet to be kept within 200mm distance from the origin point otherwise it fails to find the starting point and angle of sheet. Besides this problem, the sensor is not capable of finding the length and breadth of the metal sheet. The implemented camera based sheet measurement system eliminates the above stated disadvantages and has additional advantages.

The general working schema of the proposed method and its capabilities are as follows. First, the cutting vicinity images are taken using a camera shown in Figure 3.1.1 and the image is processed using the implemented algorithms. The camera also displays the live video stream of the cutting vicinity of the machine. This ensures that the operator can continuously monitor the cutting progress. The video stream is also processed to detect if there is a human inside the machine discussed in chapter 4 of this thesis.

The camera based system can find the length and breadth of the sheet along with the starting point in about a second regardless of the shape of the sheet. The sheets can be used without need for a proper rectangular shape and it can be located at any part of the cutting vicinity.

In the following subsections, firstly the GUI of the implemented system will be discussed then the implemented algorithms and challenges will be explained. The graphical user interface of the new system is shown in Figure 3.1.2.

Figure 3.1.1 The camera used to take the image of the vicinity.

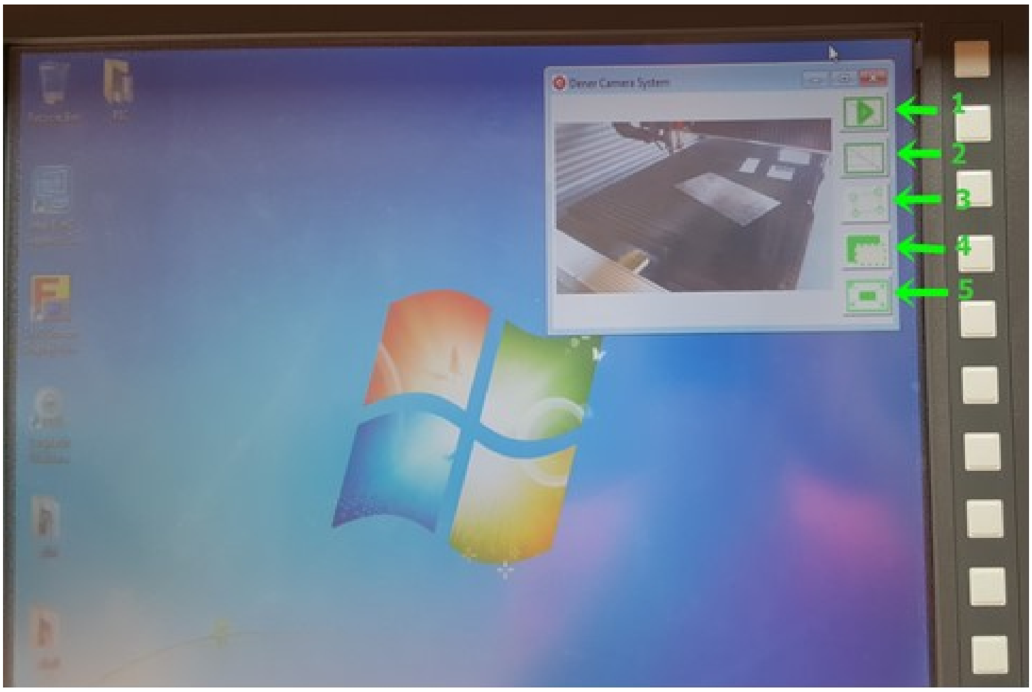


Figure 3.1.2 GUI – Sheet measurement system

Since, the system utilizes different algorithms depending on the shape of the metal sheet available in the vicinity, therefore five different buttons are used which perform their specified functions. The purpose of each button is discussed in the next section 3.1.1 the flow chart shown in Figure 3.1.3 shows the general flow of the implemented system.

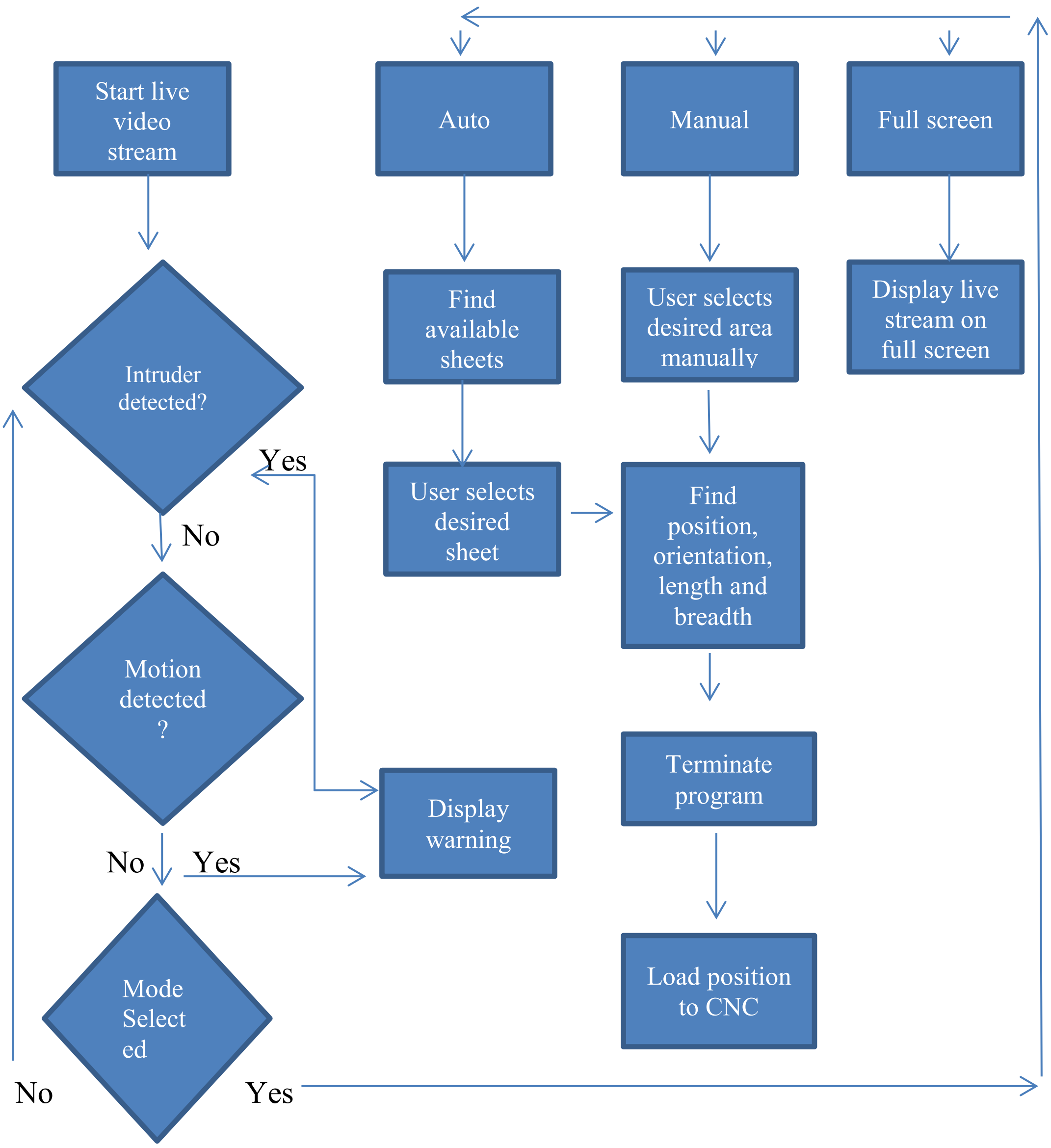
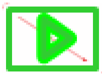
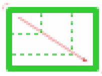
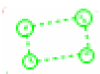
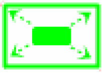


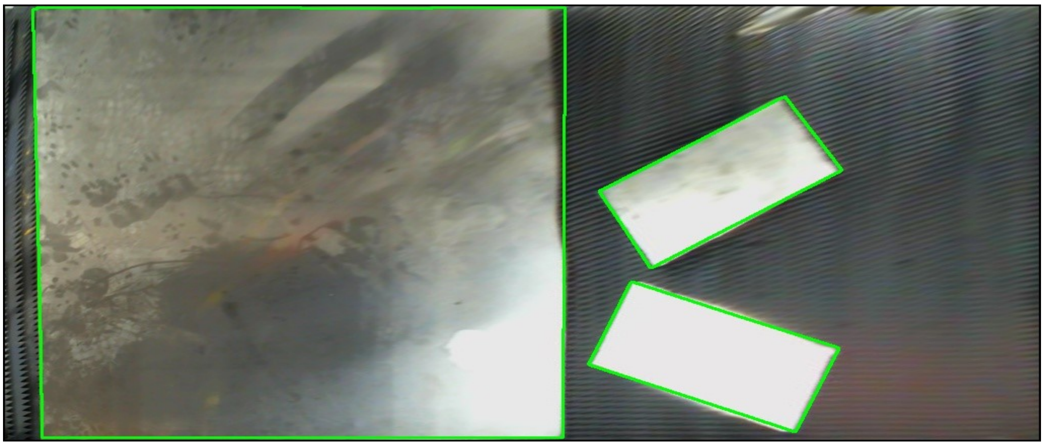
Figure 3.1.3 Flow chart of the system

3.1.1 The purpose of the buttons and the GUI

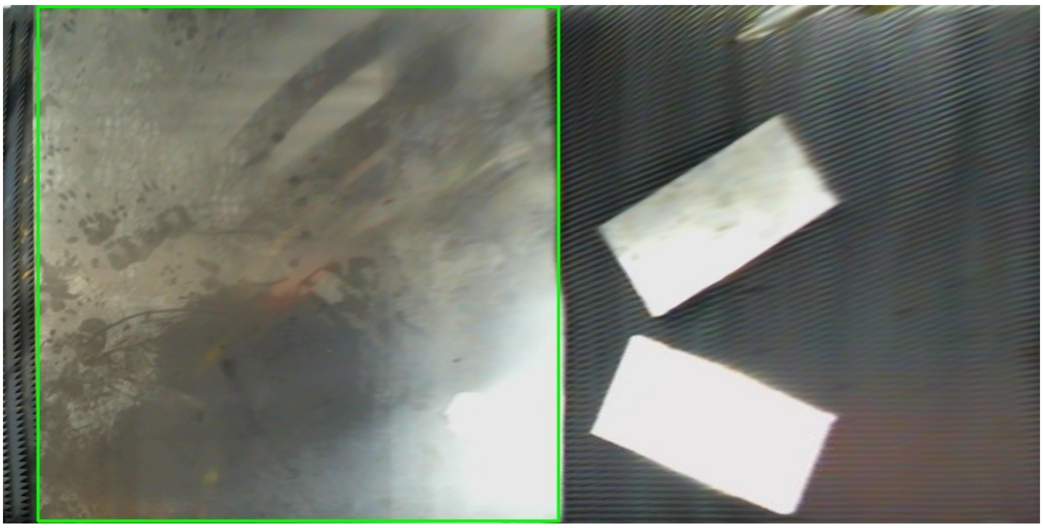
The GUI displays the live video stream, detects if there is some motion or human inside the machine and performs different actions once a button is pressed. There are five buttons available on the GUI.

-  The first button available on GUI, its purpose is to find the position of the metal sheets automatically, provided they are all rectangular in shape. All algorithms and methods utilized to implement this function are discussed and explained in section 3.2. The working is shown in Figure 3.1.4 (a) where an automatically detected sheet is shown with green lines around its borders.
-  The second button available on GUI, its purpose is to allow the user to specify a rectangular working area by dragging the mouse. When the user presses the left mouse button one coordinate of rectangle is specified and once it is released the point is used to draw a rectangle and the coordinates of this area is fed into the machine. Figure 3.1.4(b) shows how a rectangular working area is specified by dragging the mouse
-  The third button available on GUI, its purpose is to allow the user define the working area with an angle of orientation. The user simply clicks points around the sheet with or without an angle of orientation and the enclosed area is fed into machine as the working area. Figure 3.1.4(c) shows how the four points are clicked and selected around the sheet to specify an area with an angle of orientation
-  The purpose of this button is to bring the GUI on top of all other visible windows.

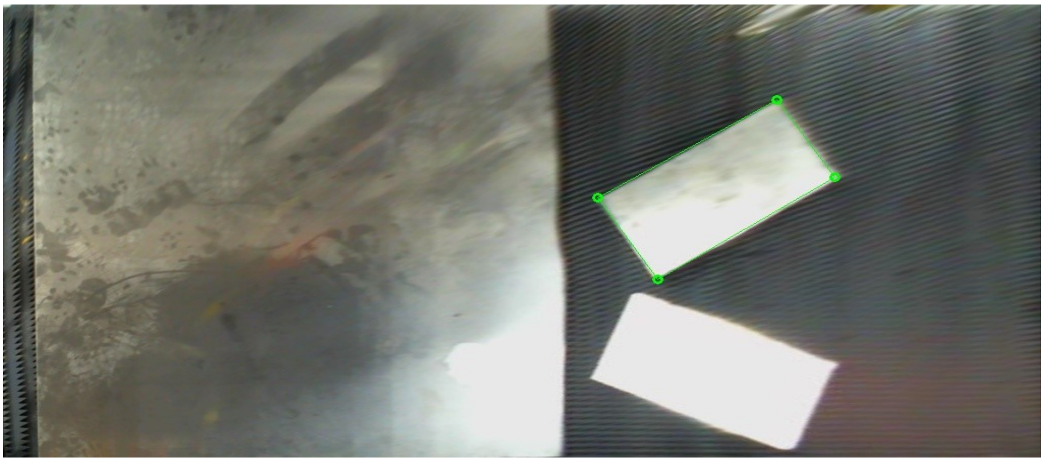
-  The purpose of this button is to maximize the window and allow the user to view the cutting process in full view. Figure 3.1 shows that the live stream video is visible on whole screen.



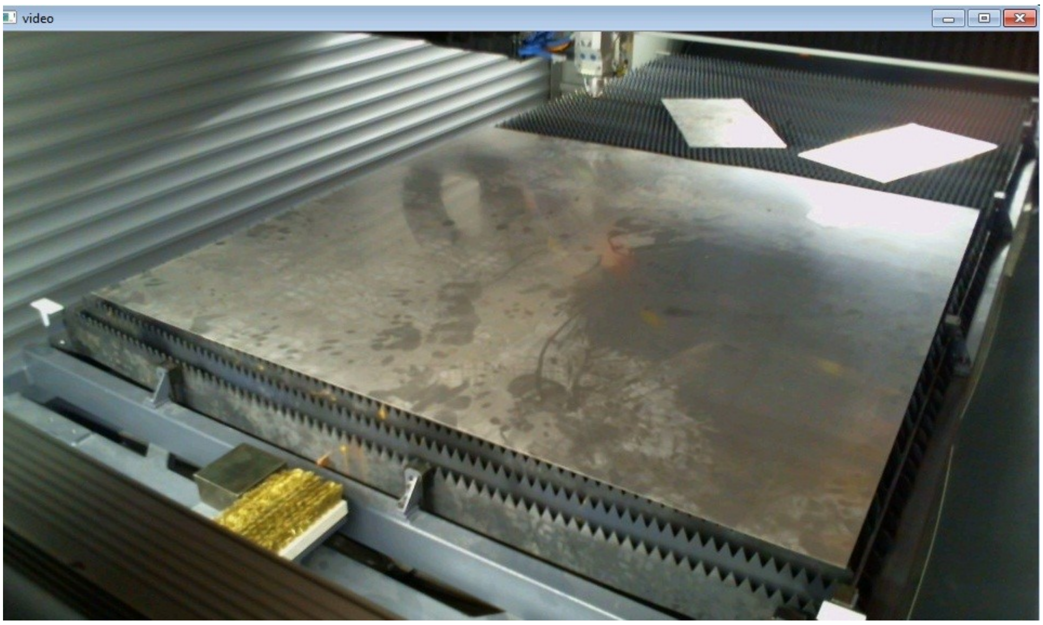
(a) Three detected automatically sheets



(b) Rectangular area selected by mouse



(c) Four points selected in left bottom sheet



(d) Full screen display

Figure 3.1.1.1 (a) Auto mode (b) Rectangle mode (c) Corner point selection (d) Full screen

3.2 Methods utilized in the implementation

This section explains the various steps and algorithms utilized to automatically find the metal sheets. All algorithms have been implemented keeping in mind that the processing should be completed in the shortest possible time. Sample image shows three visible sheets in Figure 3.2.1.

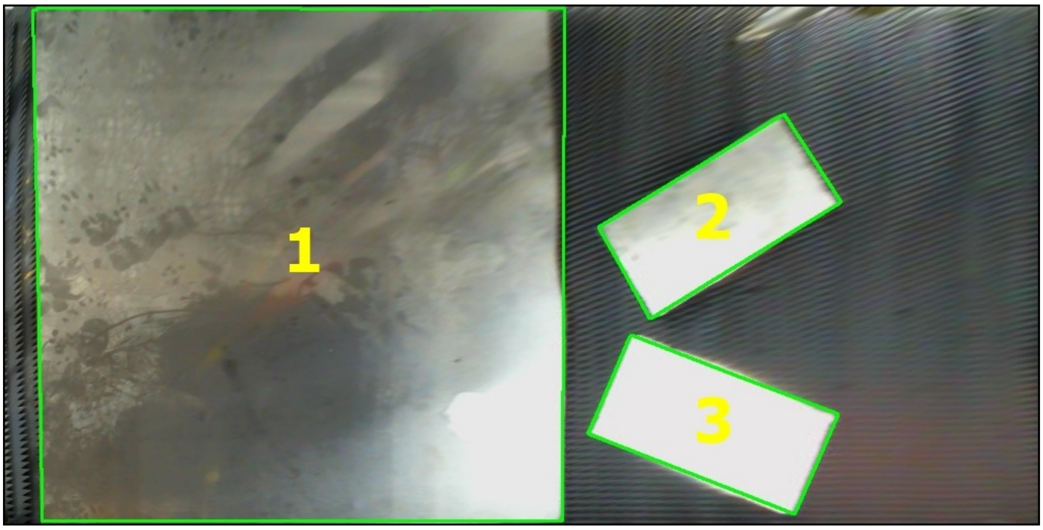


Figure 3.2.1 Three detected sheets

The methods utilized to find the sheets are as follows:

1) Perspective transformation (See Section 3.2.1)
2) Split image into channels (See Section 3.2.2)
3) Segmenting sheets (See Section 3.2.3)
4) Connected component analysis (See Section 3.2.4)
5) Contour extraction (See Section 3.2.5)

Camera has an angled view. In order to take visual measurements from the camera, first, the perspective distortions should be corrected, therefore perspective transformation is performed.

The metal sheets of different colors are easier to segment in particular color channels. For example orange colored copper sheet is more easily segmentable in red color channel, therefore image is split into channels in the second step.

The sheets need to be segmented from the cutting table, therefore the sheets are segmented using thresholding methods in the third step.

The small regions (noise) that are present in the image along with the metal sheets after thresholding is performed should be removed in order to prevent false metal sheet detections. Hence connected component analysis is performed in the fourth step.

The final step involves extracting the extreme co-ordinates (contours) of the rectangular sheets, therefore contour extraction is performed.

All the above stated steps will be explained in detail in the related subsections.

3.2.1 Perspective transformation

Image is a matrix of pixels where each pixel has a corresponding number that represents a color. Images can be translated, twisted, rotated and much more by multiplying, subtracting, adding or dividing pixels with some values. Figure 3.2.1.1 shows how an image is transformed when pixels are multiplied with a certain matrix [29].

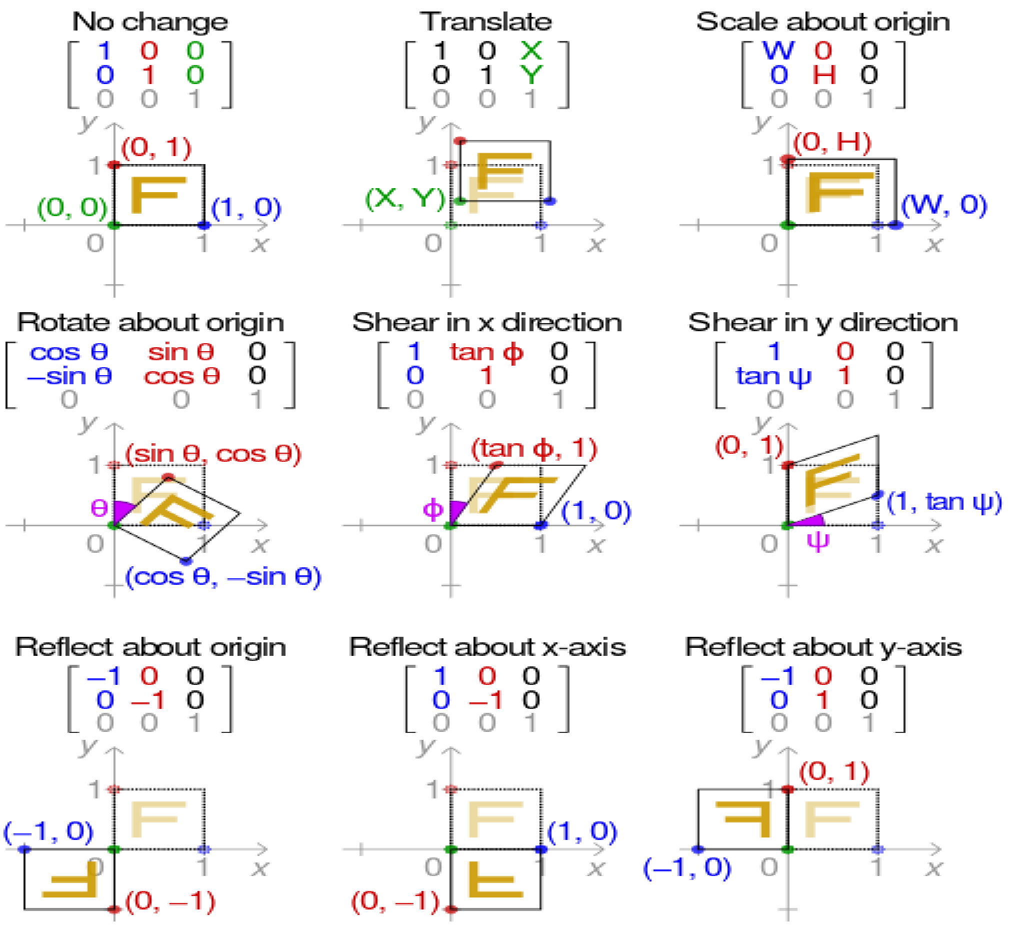


Figure 3.2.1.1 Image transformation

Perspective transformation utilizes a matrix known as projection matrix, the projection matrix consists of rotation, scale and translation coefficients. The way rotation, scale and translation manipulates an image has been shown in Figure 3.2.1.1 above. The matrix is designed in such a way that the multiplication of a 3D point with the projection matrix gives the 2D coordinate of that point on the canvas.

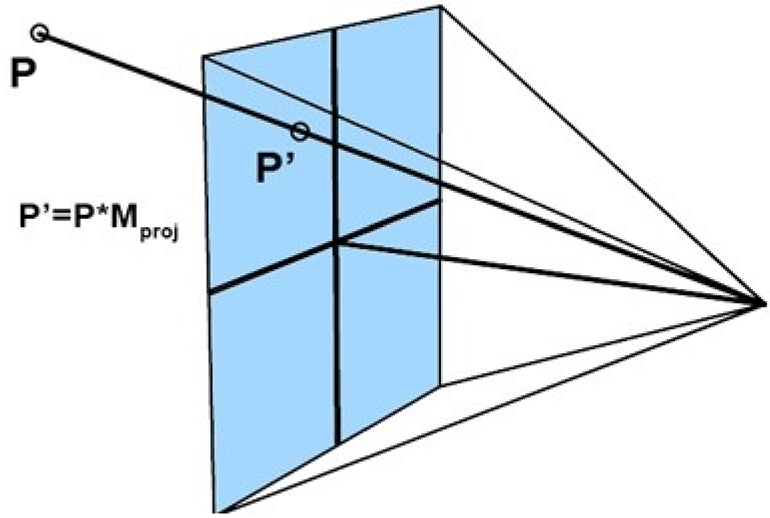


Figure 3.2.1.2 Projection of point from 3D to 2D

In Figure 3.2.1.2 P' is a point obtained by multiplying the point P with projection matrix M. All points in an image are multiplied by the matrix to obtain the new image.

The steps involved in perspective transformation are as follows.

1. 3D points Cartesian coordinates [x,y,z].
2. Implicit conversion to Homogeneous coordinates [x,y,z,w] = 1.
3. 1x4 point * 4x4 Transformation Matrix.
4. Conversion back to Cartesian coordinates [x'/w', y'/w', z'/w'].
5. Clipping to remove area outside viewing frustum.

A typical transformation matrix is shown on the next page.

$$MT = \begin{bmatrix} m_{00} & m_{01} & m_{02} & 0 \\ m_{10} & m_{11} & m_{12} & 0 \\ m_{20} & m_{21} & m_{22} & 0 \\ T_x & T_y & T_z & 1 \end{bmatrix} \quad (3.2.1.1)$$

Rotation and scale are encoded in the [3x3] matrix (green colored). Translation is encoded in the three coefficients (Tx, Ty, Tz).

Any 3D point's Cartesian coordinates can be defined as {x,y,z}, it can be understood from above that the transformation matrix is a [4x4] matrix therefore in order to be able to multiply a point P in 3D space by the transformation matrix it needs to be converted to homogeneous coordinates implicitly. A 3D point with coordinates {x, y, z} and a point with homogeneous coordinates {x, y, z, w} are equivalent as long as w = 1. The point can be written as P={x,y,z,w=1}

Now the point P can be multiplied by the transformation matrix (MT) to obtain the point P'.

$$[x'z'y'w'] = [xzyw = 1] * MT, \quad (3.2.1.2)$$

$$x' = x * m00 + y * m10 + z * m20 + (w = 1) * T_x, \quad (3.2.1.3)$$

$$y' = x * m01 + y * m11 + z * m21 + (w = 1) * T_y, \quad (3.2.1.4)$$

$$z' = x * m02 + y * m12 + z * m22 + (w = 1) * T_z, \quad (3.2.1.5)$$

$$w' = x * 0 + y * 0 + z * 0 + (w = 1) * 1 = 1. \quad (3.2.1.6)$$

The transformed point P' with homogeneous coordinates {x', y', z', w'} is converted back to 3D Cartesian coordinates {x'/w', y'/w', z'/w'}. The process is repeated for each point of the image and a new perspectively transformed image is obtained.

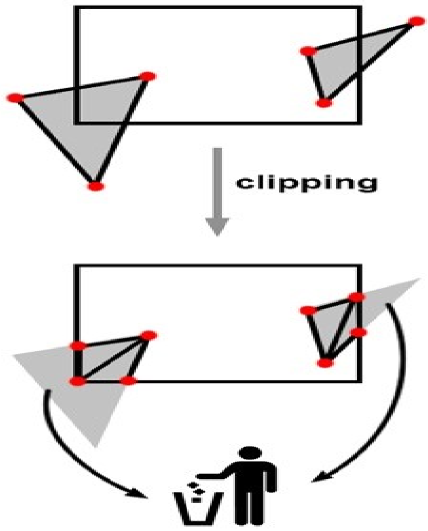


Figure 3.2.1.3 Clipping

After perspective transformation the pixels lying outside the angle of view or the desired area are eliminated by a process known as clipping shown in Figure 3.2.1.3.

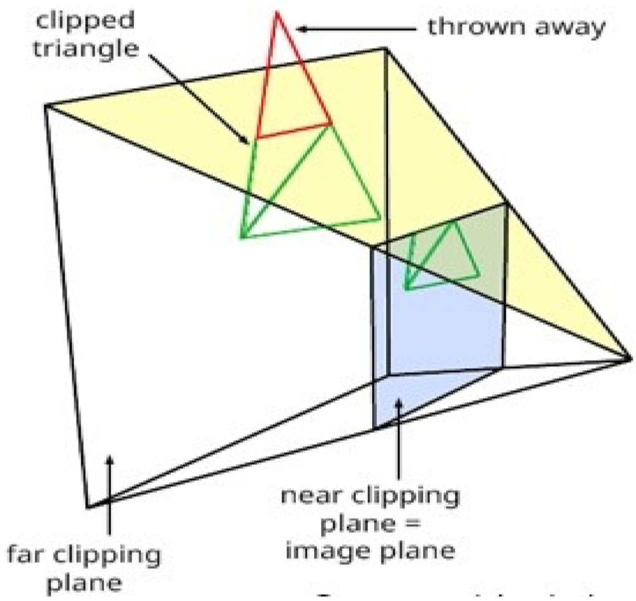


Figure 3.2.1.4 Frustum of angle of view

Figure 3.2.1.4 shows a frustum of angle of view and the objects (pixels) lying outside the frustum of angle of view are eliminated. The process can be more clearly understood from Figure 3.2.1.5 where the area surrounding the pallet (cutting table) is eliminated after perspective transformation.

The first technique applied to the image is perspective transform [3]. In perspective transform the image is transformed in such a way that it seems the image was taken from different angle (from top in this case) rather then it really was. Figure 3.2.1.5 (a) show a real image taken by the camera from the position shown in Figure 3.1.1.

Figure 3.2.1.5 also shows the point's original positions (p1, p2, p3, p4) and their final positions (c1, c2, c3, c4). Figure 3.2.1.5 (b) shows the transformed image which seems to be taken directly from the top of the pallet (cutting table). The area outside the region enclosed by (p1, p2, p3, p4) is cropped out.

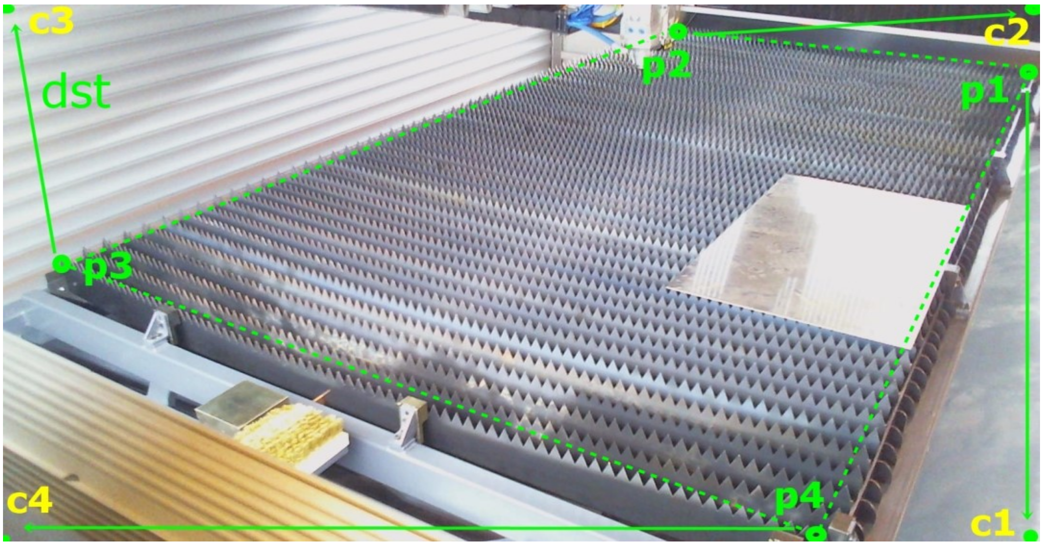
The steps involved in perspective transform are as follows:

1) Initialize the co-ordinates of required area (p1, p2, p3, p4) in this case.
2) Initialize the final position of those points (c1, c2, c3, c4) in this case.
3) Get the transformation matrix.
4) Apply perspective transform (i.e. multiply each pixel with the transformation matrix).

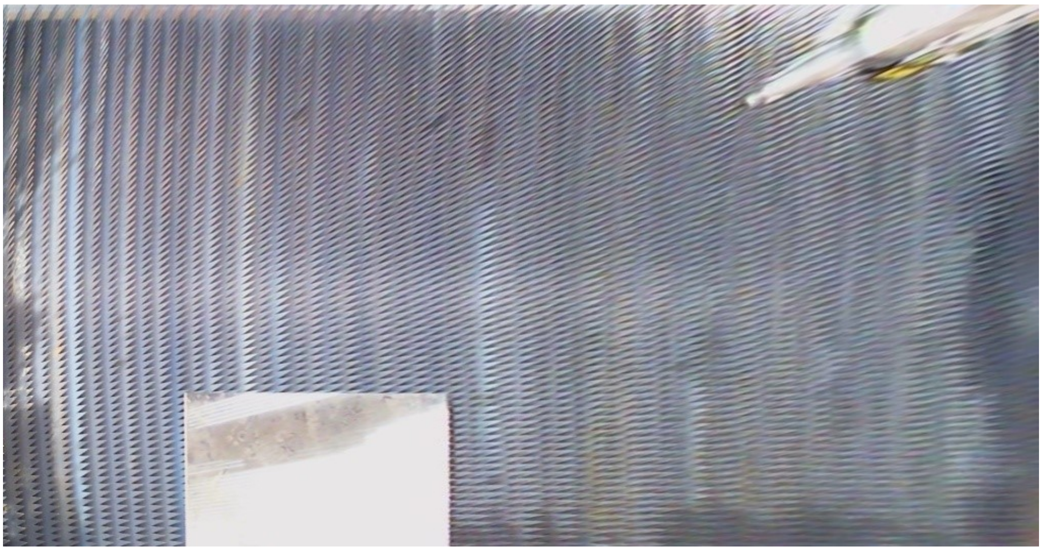
Let (I) be the image (Mt) be the transformation matrix and (Ip) be the transformed image. Pseudo code for perspective transform is as follows.

Mt = Perspectivetransform((p1,p2, p3, p4), (c1,c2,c3,c4))

Ip = I *Mt



(a)



(b)

Figure 3.2.1.5 Perspective transformation

The importance of this process is that it makes the calculation of all the required parameters shown in Figure 1.1.1.2 much easier. Also the user can get a better perspective of the original size of the sheet inside the cutting vicinity.

It also has a drawback that can be seen from Figure 3.2.1.5(b), the image becomes slightly blurred due to stretching on the right corners of the image. The metal sheets look elongated on right edges leading to false width estimation. The error in height and width calculation explained in section 5.2.2 is a result of blur on the right edge.

3.2.2 Segmentation of sheets

In this section we tried to segment the rectangular metal sheets from the background (cutting table). Ideal segmentation should result in an image that contains perfectly segmented rectangular sheets free from background (cutting table). Ideal segmentation could not be achieved by utilizing traditional methods of image segmentation. Background separation algorithms like Grab and Cut algorithm cannot be utilized due to the slow processing speed explained in section 3.3 of this thesis. Several methods of segmentation were tested and we tried to find the best method for segmenting images with different colored rectangular sheets along with different lightning conditions.

Segmentation process begins with separating the image into color channels. The image shown in Figure 3.2.2.1 is split into three channels R,G,B and later each channel is processed as a separate image. The purpose of this method is to find out different sheets with different colors at different illumination levels. This process helps to find different colored metal sheets i.e. a copper sheet orange in color would be more clearly visible in red channel. It can be seen that sheet number one is hardly visible in green and blue channels (See Figure 3.2.2.2 (a) and (b)) but highly visible in (c) red channel. (Note: The numbers 1, 2, 3 on the image are just for explanatory purpose).

Python pseudo code to split image into channels is as follows.

(B,G,R) = Splitchannel(Ip)

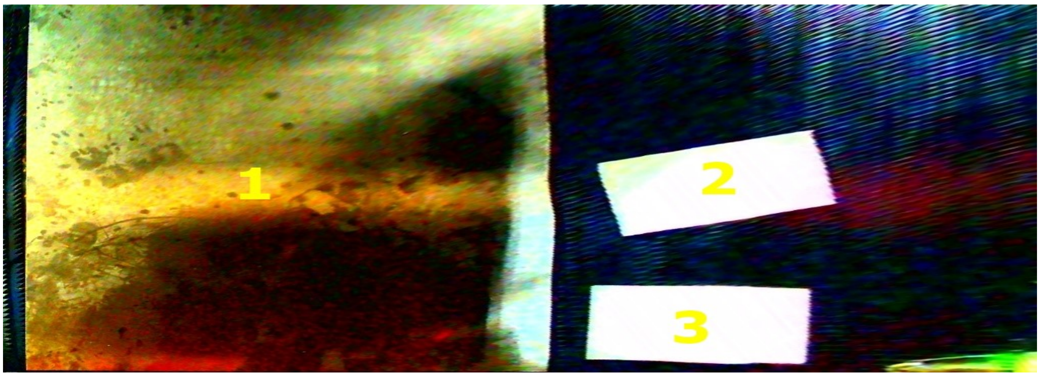
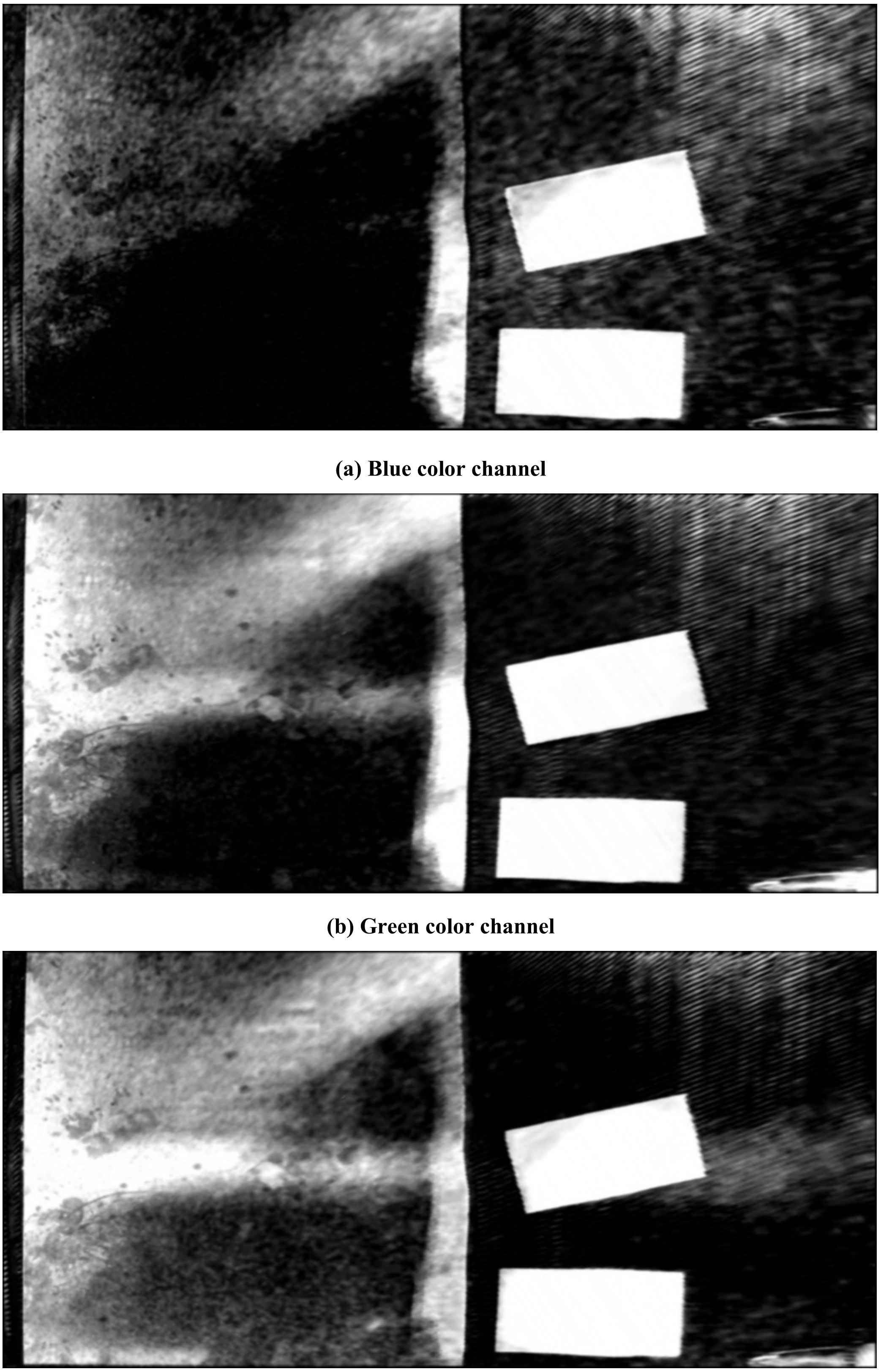


Figure 3.2.2.1 Sample image with different illumination and color levels.



(a) Blue color channel

(b) Green color channel

(c) Red color channel

Figure 3.2.2.2 Color channels

The sheets are clearly visible in separate channels i.e. sheet (2 and 3) are more clearly visible in green channel image while sheet 1 is more clearly visible in red channel image, therefore it would be much easier to segment this image via thresholding process in the next step.

The methods that were tested and failed will be discussed firstly, after that the method that gives best results will be explained. The methods that failed include single global thresholding, adaptive thresholding and Otsu's thresholding. Global thresholding with a series of thresholding values was successfully utilized to achieve the desired results.

Single global thresholding

Single global thresholding works on some parts but fails on other due to difference in lighting inside the machine. Single global thresholding is applied to a single channel image shown in Figure 3.2.2.2. Figure 3.2.2.3 shows how the sheets in one part are visible at a certain threshold level but we cannot see another available sheet in less illuminated area.

Figure 3.2.2.3 Single global thresholding

Single global thresholding does not give good result in this case because the lightning conditions are not uniform throughout the image. We can change the threshold values to reveal the sheet which is not visible but the other sheets become distorted at the same time (explained in multiple threshold heading in this section). Our aim was to achieve a properly segmented image which contains all rectangular sheet but since only two sheets were visible clearly therefor this method fails.

Adaptive thresholding

Adaptive thresholding algorithm calculates threshold value for a small region in an image. This leads to different threshold values for different regions of the image with different lighting conditions. Theoritically the algorithm should give good results for our problem since the image has varying illumination in the image.

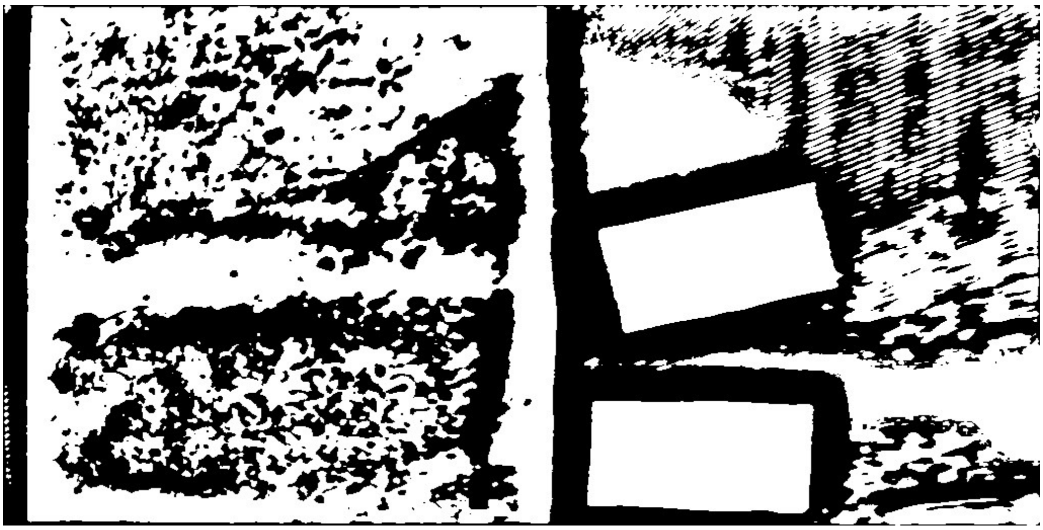


Figure 3.2.2.4 Adaptive thresholding

Adaptive thresholding was applied to image shown in Figure 3.2.2.2 (c) and the resultant image is shown in Figure 3.2.2.4. It can be seen that it would be really difficult to find the sheets [4] from the segmented region since huge background areas have been also segmented along with the rectangular sheets. It is difficult to find and infer which segmented region belongs to rectangular sheet, therefore single adaptive thresholding cannot be used in this case. Adaptive thresholding is useful thresholding different parts of an image with varying illumination but not suitable when we are interested in segmenting objects (rectangular sheets in our case) with varying lightning conditions. (Note: Adaptive thresholding has a parameter block size which decides the size of area for which threshold value should be calculated. Different values of block size were applied but desired results as stated above could not be achieved)

Otsu's method

Otsu's method [5] is one of the popular method of segmenting bimodal image (the image whose histogram has two peaks). The working of Otsu's thresholding can be understood from Figure 3.2.2.5.

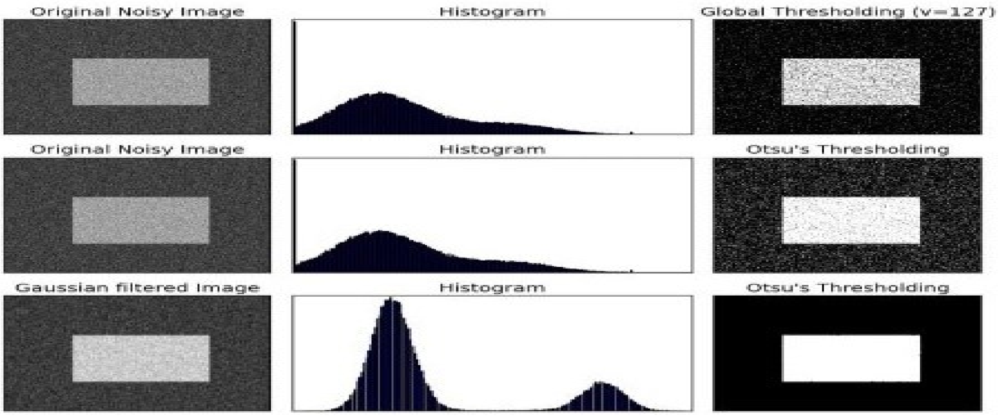


Figure 3.2.2.5 Otsu's method

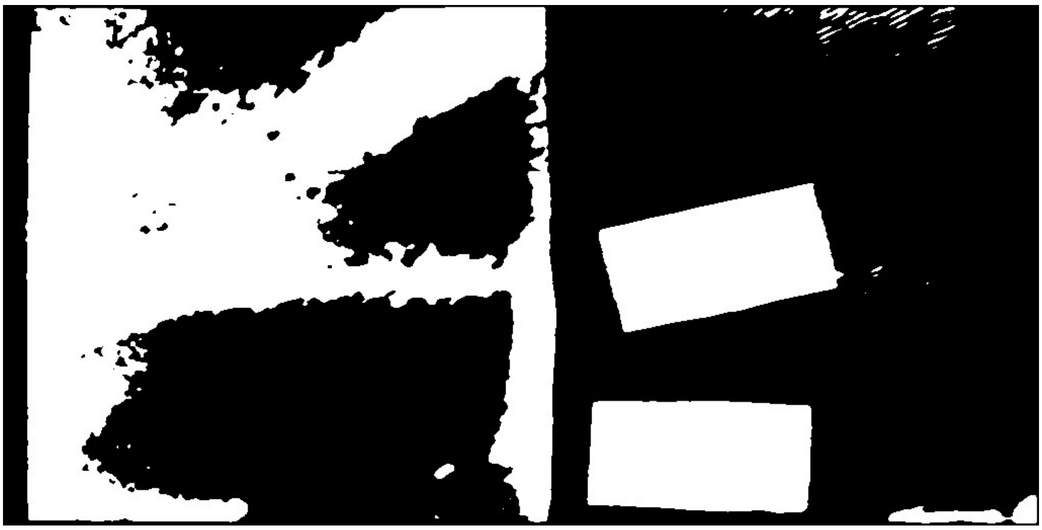


Figure 3.2.2.6 Otsu's thresholding

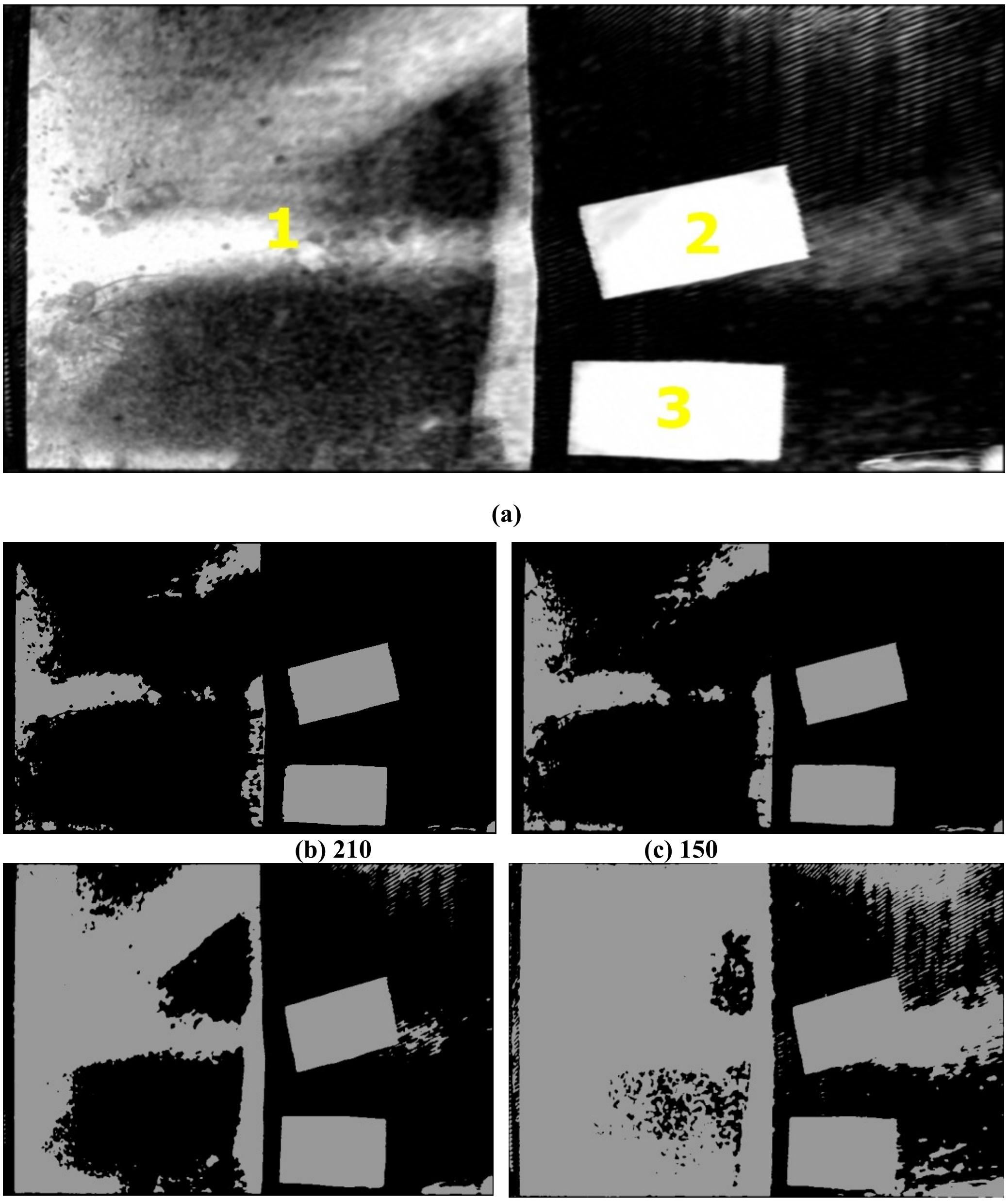
Otsu's thresholding resulted in the image shown in Figure 3.2.2.6. It can be seen clearly that two small sheets are segmented properly but the third sheet is not, therefore Otsu's method cannot be utilized either. It can be inferred that our problem has more than two threshold peak values so a different method is required which can take different threshold values into account.

Multiple Thresholding

The segmentation methods applied so far are not suitable in metal sheet segmentation because sheets can have various colors and brightness. Different thresholds can capture different sheets, therefore a segmentation method where results of multiple thresholding stages are combined is proposed in this section. A series of threshold values with a step size of ten (where image pixel values are in range of [0, 255]) are applied to each channel image in order to reveal sheets with different illumination. The value starts from 20 and goes to 210 with a step size of 10. The threshold outputs are examined individually in the next step. For each output, existence of rectangles is searched. Figure 3.2.2.7 (a) the red channel from operation in previous section has three metal sheets available. (b) Small sheets with higher illumination are revealed clearly with higher threshold values whereas the larger sheet is revealed with lower threshold value of 20, visible in Figure 3.2.2.7 (e), but the smaller sheets are not in good shape at the same time.

Pseudo code for image thresholding is as follows.

```
for i in (B,G,R)
    for l in (20, 210, 10)
        thresh(n) = threshold ( i , (l, 255)
        n = n+1
```



(a)

(b) 210 **(c) 150**

(d) 90 **(e) 20**

Figure 3.2.2.7 Application of different threshold values to red channel (a). (b) 210. (c) 150. (d) 90. (e) 20

This shows the importance of the application of different threshold values to extract sheets one by one. All values from 20 to 210 with a step size of 10 are applied to the image and whenever the extracted area satisfies the condition of it being a rectangle its co-ordinates are saved (explained in section 3.2.4). Single global threshold value for each color channel does not work in this case. In the next step connected component analysis is applied to remove unnecessary noise (small areas that are not metal sheets).

3.2.3 Connected component analysis

The purpose of this step is to eliminate the small blobs (noise) which are not metal sheets but were segmented along with the rectangular metal sheets.

Connected component analysis [21] is used to divide the image into blobs which can be accessed one by one. Each binary piece is checked and the pieces smaller than certain number of pixels are eliminated. In this case all pieces below 1000 pixels were eliminated since no sheet can be of such small size. Figure 3.2.3.1 shows the result image when connected component analysis is applied and areas below 1000 pixels are eliminated from the image shown in Figure 3.2.2.6 (b). All blobs can be accessed one by one to check if there is a rectangular metal sheet or not. Area 1 shown in Figure 3.2.3.1 is clearly not rectangular and will be eliminated after connected component analyses and the resulting image is free from noise (small blobs which are not sheets).

Pseudo code for connected component analysis is as follows.

region = CCP(thresh(n))

If region(n) < 1000

region(n) = 0

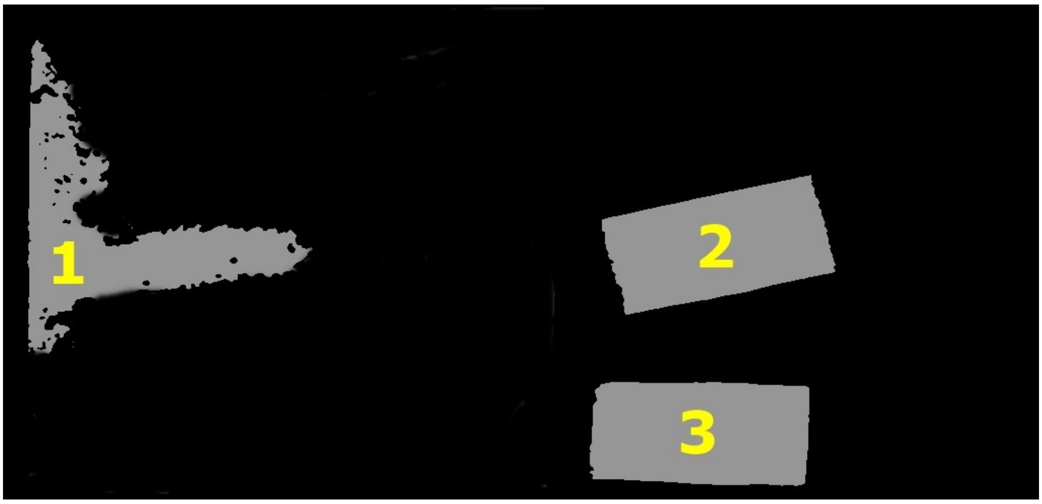


Figure 3.2.3.1 Remaining regions after removing small regions

3.2.4 Contour and corner point extraction

The process is divided into two parts:

1) Apply Canny edge detection to thresholded image
2) Polygon estimation

Figure 3.2.4.1 (a) shows extracted thresholded single sheet region after all the operations explained in the previous sections are applied. Now canny edge detection is applied and resultant image is shown in (b). Canny edge detection [22] is a very commonly used edge detection method in image processing. Canny edge detection has the following step by step working principle that results in one-pixel wide connected contours:

1) Noise reduction – Noise present in the image can lead to false edge detection, noise reduction is performed by utilizing Gaussian filter [9].

2) Finding intensity gradient of the image – Sobel kernel [19] is applied in both vertical direction and first derivatives in horizontal direction (Gx) and vertical direction (Gy) are extracted and edge gradient along with direction is found for each pixel as follows.

$$Edge\_Gradient(G) = G_x^2 + G_y^2 \qquad (3.2.4.1)$$

$$\sqrt{}Angle(\theta) = tan^{-1}(G_y/G_x) \qquad (3.2.4.2)$$

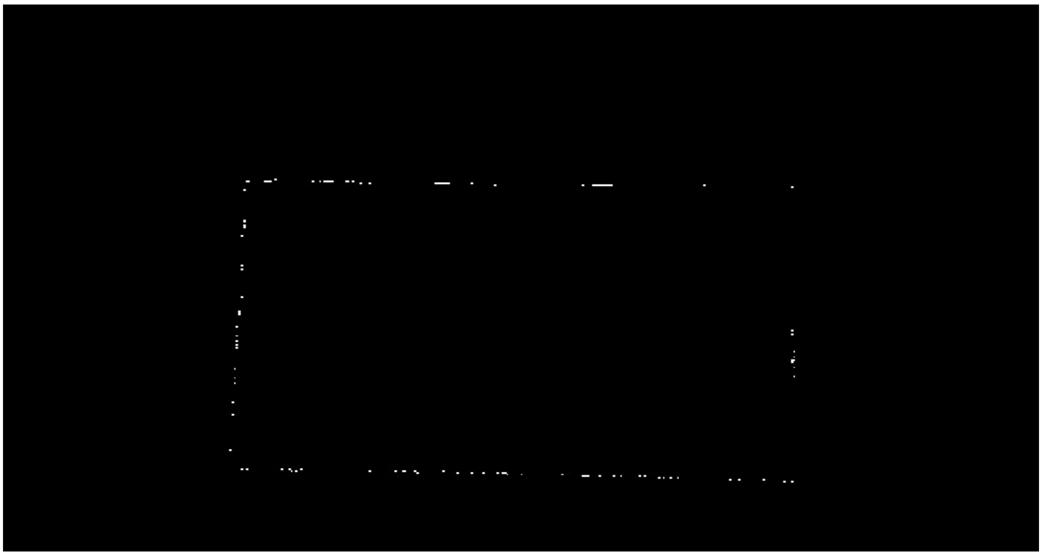
3) Non-maximum Suppression – This process is used for thinning the edges. Every pixel is checked to find if it is local maximum in its neighborhood in the direction of gradient.

4) Hysteresis Thresholding – This process is utilized to discard undesired edges i.e. the user can define if he is interested in detailed edges or just interested in main steep edges. The minimum and maximum value of intensity gradient value can be defined by the user and edges that have intensity gradient above threshold values are accepted as sure edges whereas the ones below minimum value are

rejected and those lying in between are either accepted or rejected depending on their connectivity with the neighboring pixels above maximum value of intensity gradient.

It can be seen clearly how border points are extracted using Canny edge detection in Figure 3.2.4.1(b). (Note: the image shown in Figure 3.2.4.1 is used for explanation purpose and is not extracted from image in Figure 3.2.3.1)

(a)



(b)

Figure 3.2.4.1 (a) Thresholded extracted image (b) Canny edge detection

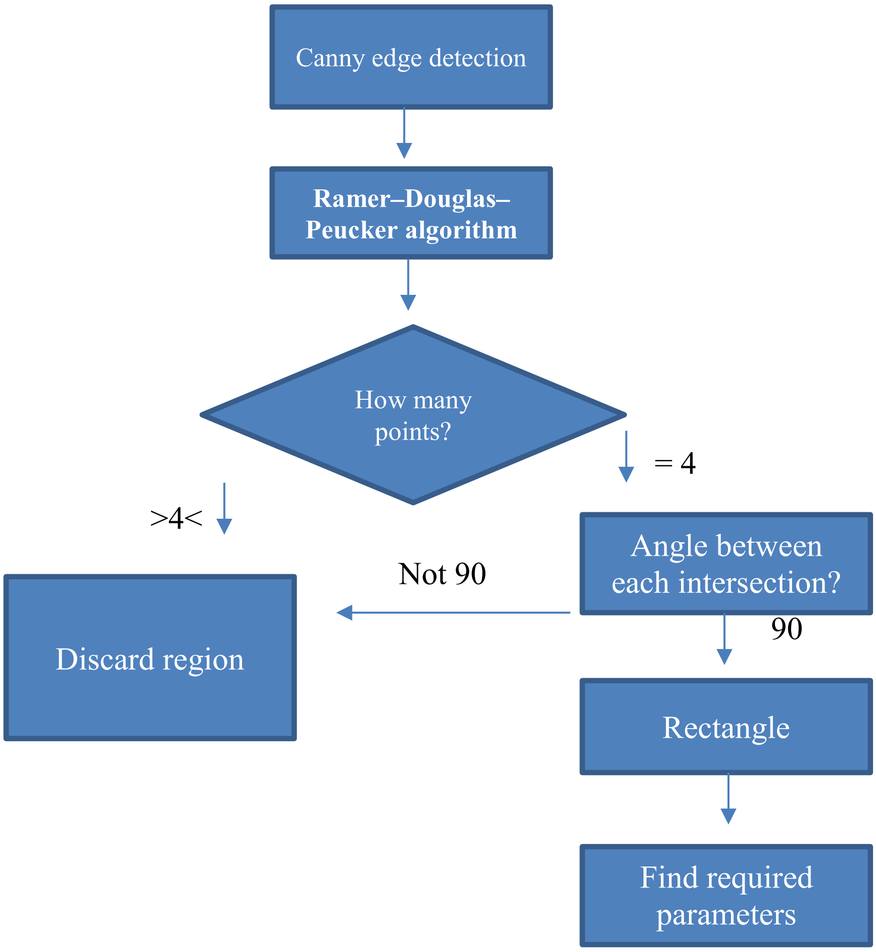


Figure 3.2.4.2 Process of rectangle estimation

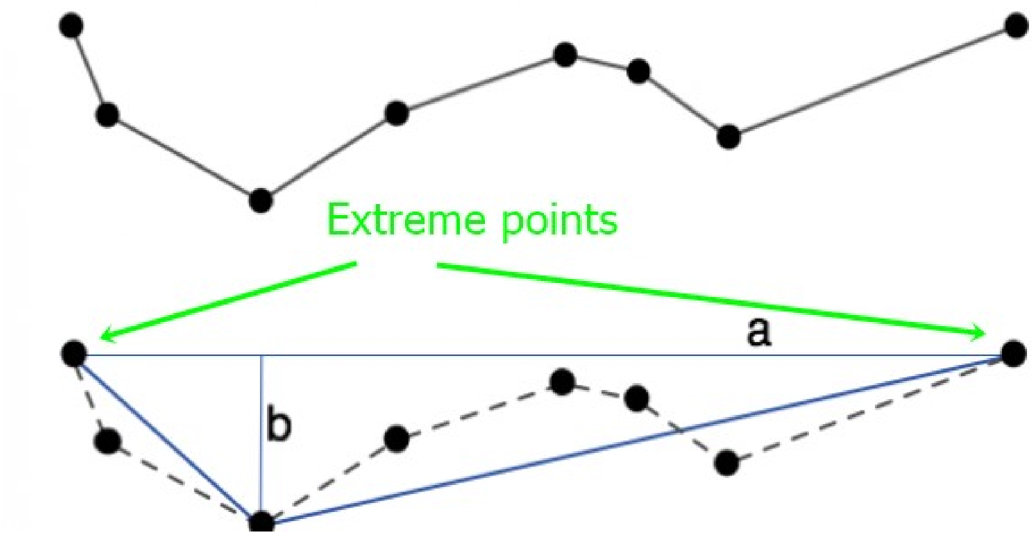


Figure 3.2.4.3 Ramer–Douglas–Peucker algorithm

The reason that other simpler methods such as thresholded gradient map is not utilized because the output from such method is a thick boundary which consists of many points while we require thin, one-pixel wide connected contours for our next step towards extracting the four corner points of a rectangular sheet.

The noise outside rectangular regions was eliminated by using connected component analysis explained in section 3.2.3. Canny edge detection gives good results and edge points are extracted, but it can be understood from Figure 3.2.3.1 that the sheets don't look like perfect rectangles hence their extracted edges cannot give perfect corner points. Moreover, the lines are broken, therefore the extracted edges from Canny edge detection need to be further analyzed in order to get the four corner points of the rectangle.

All points around the edges are extracted. Ramer–Douglas–Peucker algorithm [23] has been used to estimate lines and check if the extracted points form a rectangle. The algorithm finds the most extreme end points i.e. the top left, right and bottom left, right corner points. A straight line is drawn between extreme points and the distance between the other points is checked one by one. Figure 3.2.4.3 shows how the algorithm works, (a) is the straight line between extreme points and (b) is the perpendicular distance between the line and some other point near the line, if this distance is smaller than a predefined threshold value then the point is eliminated otherwise not.

At the end of utilizing this algorithm only four points should remain for it to be a quadrilateral. If the remaining points at the end of above process is less than or greater than four, the object is not considered as a rectangle and the object is discarded from further processing. But if the number of points is equal to four further processing is continued. Next process is to check the angle between each intersecting line (i.e. corners), if the angles are between 87-92 degrees the object is considered a rectangle and find out the required parameter i.e. starting point co-ordinates, angle of orientation, length and breadth of the sheet and other parameters explained in the introduction. (Note: the reason behind using 87-92 degrees for the corner angle is that corner angles might not seem to be 90 degrees while dealing with pixels since some estimations were made, but they are 90 degrees in reality). Figure 3.2.4.4 show the result image.

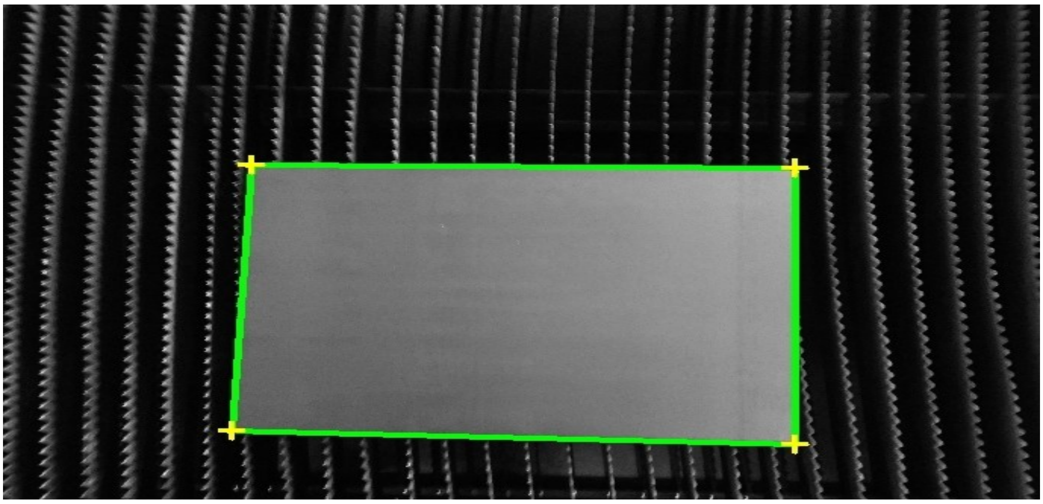


Figure 3.2.4.4 Result

The image utilized during processing is 1020x510 pixels. Size is kept small to speed up the processing and later all parameters are up scaled to 3000x1500 pixels since the cutting table size is 3000x1500 mm. System requires one second for automatic detection. Speed is very important. The reason behind Canny edge and Hough transform not being utilized will be discussed next.

Canny edge and Hough transform

Figure 3.2.4.5 (a) shows a sample image and Figure 3.2.4.5 (b) shows the result after canny edge detection is applied to the image and Figure 3.2.19 (c) shows the result image when Hough transform [11] is used for line estimation. It can be seen that canny edge along with Hough transform for line estimation is sufficient to find the edges of rectangular sheet, also the corner points can be found by extending those lines and finding their intersections. The reason why this approach fails is that Hough transform is slow it takes more time (see section 3.3.1) to process the image also it complicates the process of corner extraction when there are multiple metal sheets, reason lying in the fact that border lines of different sheets will intersect when there are multiple metal sheets in the image so it would make it difficult to find out which intersection belongs to which sheet.

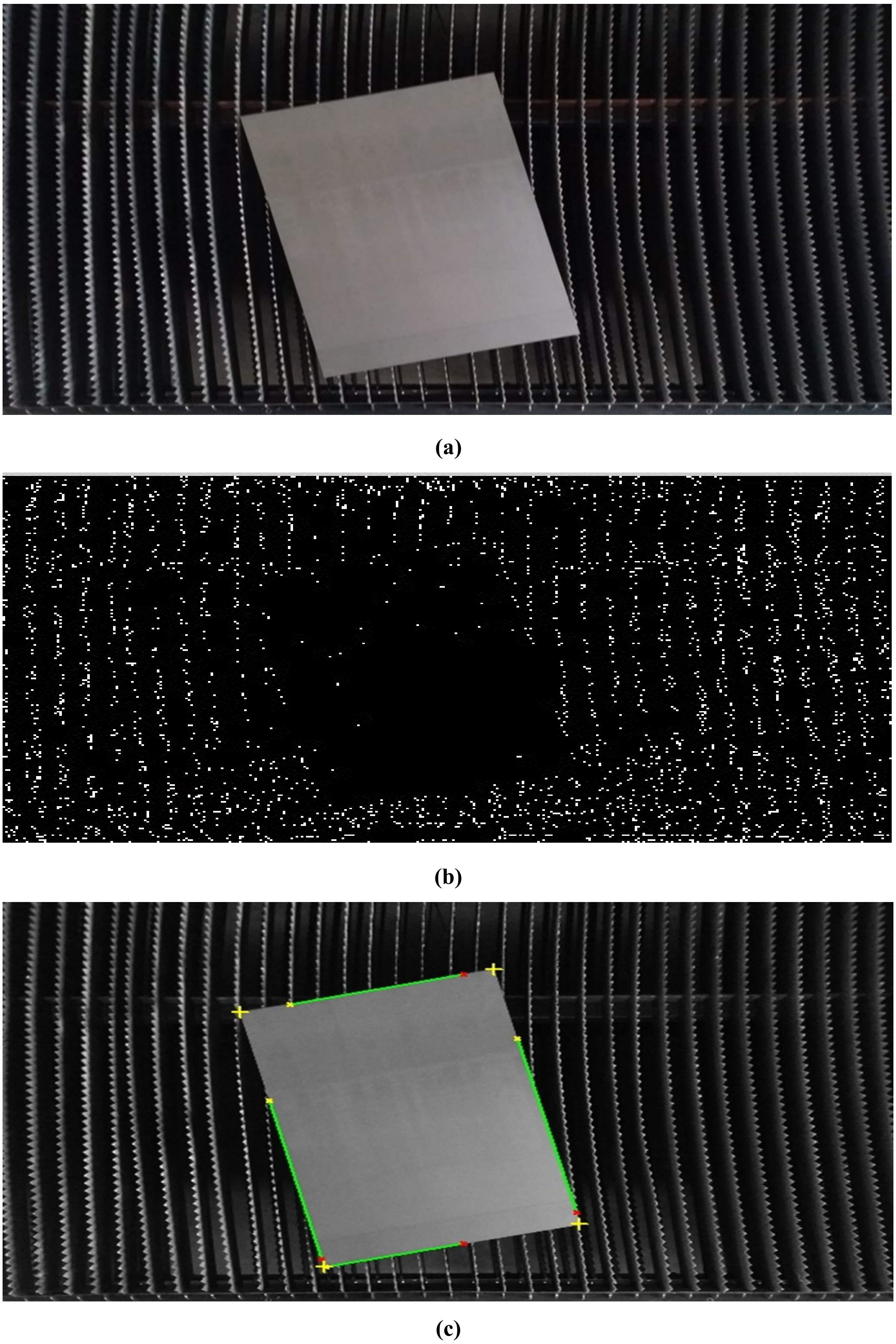


Figure 3.2.4.5 (a) Sample image. (b) Canny Edge. (c) Hough transform

Due to above stated reasons Canny edge with Hough transform is not suitable in this case.

3.2.5 Superimposed image with the rectangles found

After applying all the steps and methods stated above in the section 3.2 final result image shown in Figure 3.2.5.1 is achieved. Small yellow rectangles show the part to be cut by the machine. The size of this part is fed by the machine and is drawn on the start points.

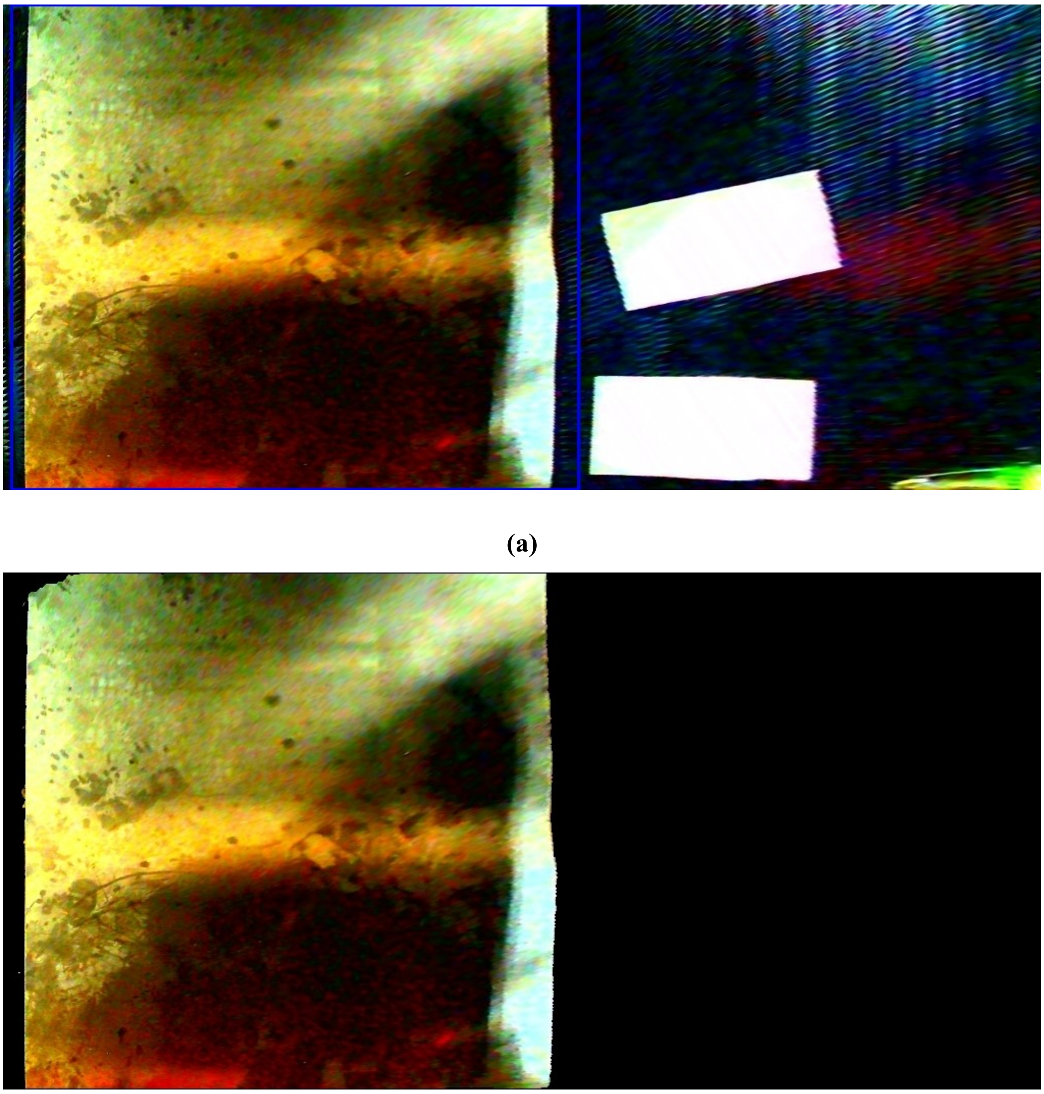
Figure 3.2.5.1 Result image

3.3 Challenges

Many different algorithms were tested before achieving the results. This section gives brief information regarding the failure of some pre implemented algorithms.

3.3.1 Grab and cut algorithm

Other segmentation algorithms like grab and cut [7] were not utilized because they were quite slow on these types of image and the image needs to be processes as fast as possible. Grab and cut took around 5 seconds to process the image shown in Figure 3.3.1 also the user needs to define a rectangular area around our foreground object (blue rectangle in this case). This type of process is not possible since a particular area cannot be predefined where the sheet will be kept. It can be located anywhere on the cutting table. The sheet can be of different size and can be located anywhere on the cutting table.



(a)

(b)

Figure 3.3.2 Grab and cut (a) extracted sheet (b)

It can be seen from Figure 3.3.2 that the metal sheet is extracted properly and can be processed very easily to find the corner points. The bounding box cannot be defined automatically also 5 seconds to process the image is quite big. Hence Grab and Cut algorithms not suitable for a laser CNC machine.

Table 3.3.1 shows the time required by the implemented algorithm utilizing (Canny edge with RDP) [23] the various steps explained in section 3.2, the time required by Grab and Cut algorithm and the time required while utilizing Canny edge with Hough Transform to perform the same task of finding the required parameters for a single sheet. It has been explained earlier why Hough Transform with Canny edge is not suitable for multiple sheets (section 3.2.4). Considering Table 3.3.1 Canny Edge with RDP [23] (the implemented system) is fastest, Hough Transform is slightly slow and has other disadvantages explained in section 3.2.4. Grab and Cut algorithm is very slow.

Method	Time (milliseconds)
Canny edge with Hough Transform	**140**
Canny edge with RDP	**130**
Grab And Cut	**5000**

Table 3.3.1 Speed Comparison

Chapter 4

Motion and intrusion detection

4.1 Motion detection

Laser cutting machines are capable of cutting metal sheets and any form of human contact with the laser beam can be fatal. The laser cutting head has the capability of rapid movement so any living being inside the machine can get some serious injuries if hit by the moving cutting head, therefore the machine needs a system (intrusion detection system) that can warn the user (operator) of any moving object presence inside the machine before the cutting process is started.

To this end, the implemented system has motion detection capability. A warning message is displayed on the screen on slightest movement inside the cutting vicinity. Figure 4.1.1 shows the warning message displayed on screen as soon as some movement is detected inside the machine.

Figure 4.1.1 Motion detection message

4.1.1 Method

Many human and intrusion detection methods have been discussed in section 2.3 of this thesis. The background subtraction method was chosen keeping in mind the processor of the windows computer associated with the laser CNC machine. The processor has limited memory and processing capability (1GB – 4GB RAM, Intel core i5 processor) with no external GPU to handle extensive video and image processing. The algorithm was implemented i.e. it utilizes minimum computer resources so that it does not interferes with the performance of other programs already running for the CNC and other interfaces associated with the laser machine.

The proposed method of motion detection is based on background subtraction [14]. The reference frame is updated every second and the absolute difference between upcoming frames is calculated as follows:

$$I_d = | I_b - I_n| \qquad (4.1.1.1)$$

Where I_d is the absolute difference between the background frame (I_b and the next frame, I_n is the nth frame. The first frame from the camera is saved as the background frame I_b and updated every two seconds i.e after two seconds I_n frame becomes the I_b frame. The frame is updated every two seconds to prevent unnecessary processing cycle loss.

If the absolute difference is greater than a threshold value a warning message is displayed on screen. The threshold values can be changed depending on requirement. The concept of background subtraction can be understood from Figure 4.1.2.

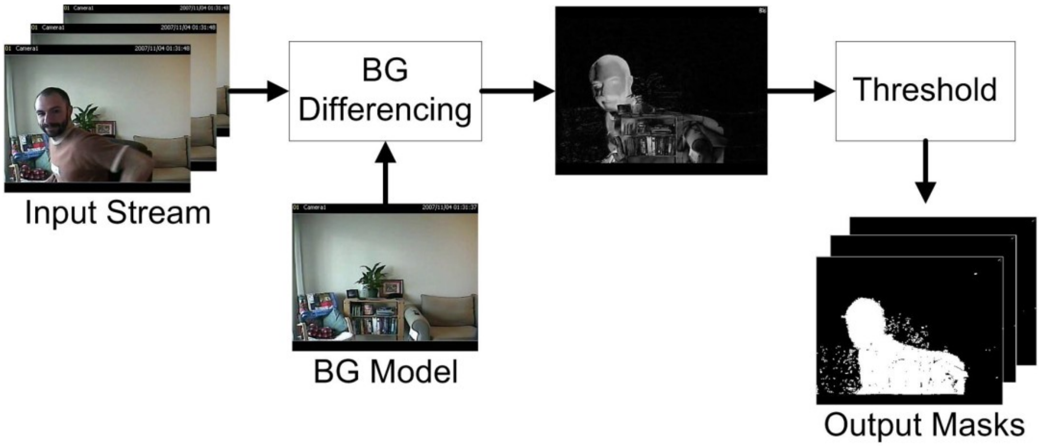


Figure 4.1.2 Background subtraction.

4.2 Intrusion detection

The machine emits laser beam to cut metal sheets and moves at a very high speed while cutting, so if a human is present inside the machine for some adjustment or any other purpose and someone presses the start cutting button it can be fatal for the person inside the machine.

To prevent any mishap, the implemented system has intrusion detection capability. Live video stream from camera is continuously processed frame by frame. If motion is detected according to the principle explained in the previous section and the motion is only in particular part of the machine it is displayed with a message "Human detected" on the main screen window. There is always a possibility that at some part detected motion might be wrongly classified as human detected but that is not important since either way the detected motion is visible with a green box on screen and any operator (human) can understand from the image if that motion is coming from a human or moving object. The messages are just for warning purpose. Figure 4.2.1 shows the warning displayed on screen once a human is detected inside the machine. The video processing is kept simple since the windows pc associated with the machine has to control the CNC and other parts of the machine and cannot be overloaded with extra processing.

(a)

(b)

Figure 4.2.1 (a) Human detection. (b) Human detection.

4.3 Challenges

The human detection system was first implemented using machine learning techniques. This problem is a classification [9] problem where the image is classified if there is a human or not, the approach is quite similar to the ones explained in the related works section. The training dataset was generated using the images taken with and without a human inside the machine. Figure

4.3.1 shows some of the dataset images with and without human inside the machine.

(a) (b) (c) (d) (e) (f)

Figure 4.3.1 (a), (b), (c) Images with human. (d), (e), (f) Images without human.

The training dataset consisted of 200 images of size 320x176 pixels each and was generated using the real images taken inside the cutting vicinity under different possible light conditions. 100 images had human and machine both while the other 100 had the machine only. From the beginning it was known that the processor associated with the CNC machine has limited processing capability and no GPU, false classification of motion detected with human detected is not important discussed in the previous section, therefore the size of the images of the dataset was kept small and also the number of images less (only 100 for each) in the dataset in order not to slow down the real time classification process and put unnecessary load on the processor of the machine. Haralick texture [10] and standard deviation between each color channel is used as feature vector. The feature vector is used to classify the frames from the live video stream in real time, therefore feature vector is kept as small as possible. This does not affects the system since a wrong classification is usually warned as motion detected and operating person can differentiate if the motion is from a human or something else.

The dataset was trained with two of the famous classification algorithms decision tree [12] and random forests [13]. Random forest gave much higher classification accuracy hence random forest classifier was used in the final implementation. Figure 4.3.2 shows the accuracy of classification with decision tree classifier. It can be seen from the Figure that the f1-score is 0.9 and a human is correctly classified as human from a test image.

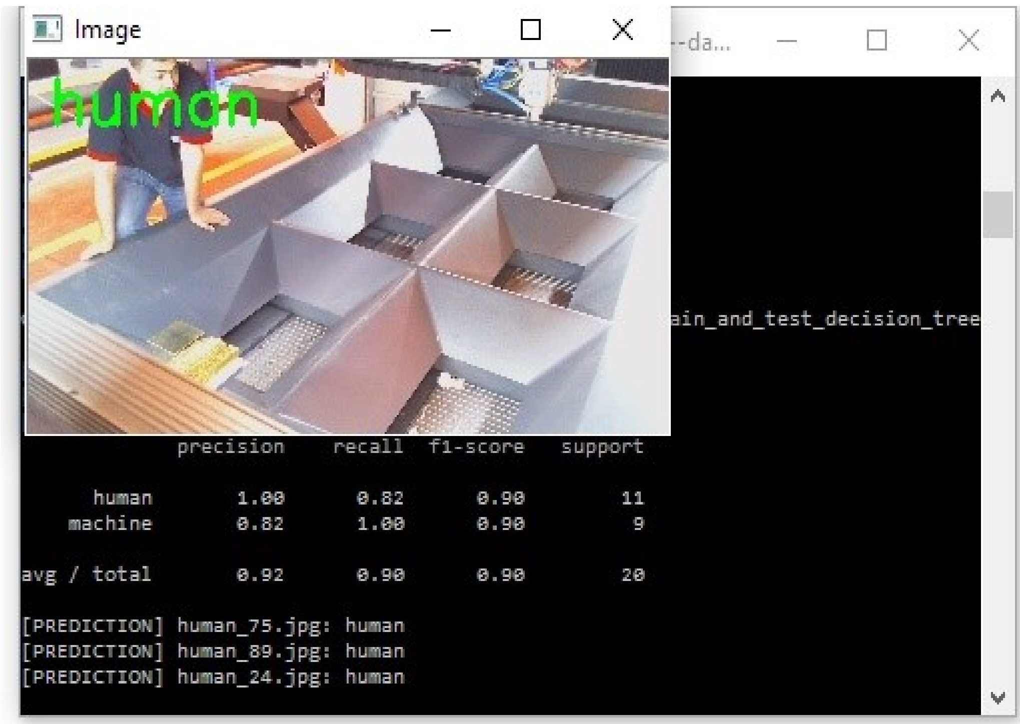


Figure 4.3.2 Classification measurements of decision tree classifier.

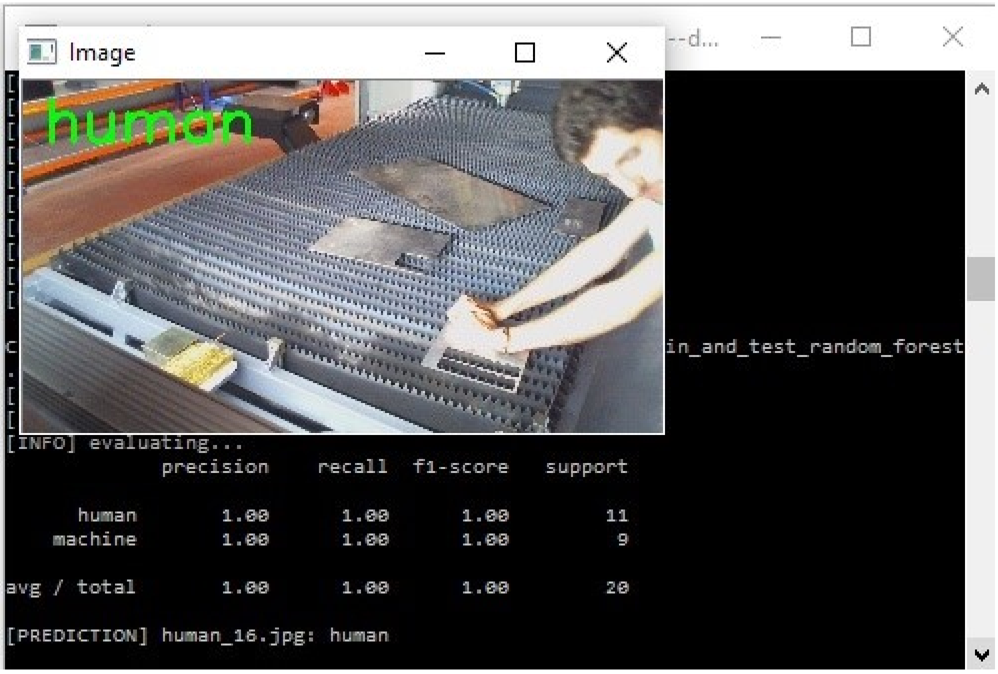


Figure 4.3.3 Classification measurements of random forest classifier

Figure 4.3.3 shows the classification accuracy of random forest classifier which is 100% on our test set which consisted of 20 images beside the dataset. (Note: 100% accuracy on dataset does not guarantees 100% accuracy on new possible images)

The above stated method failed (considerable lag was visible on screen and it did not seem like a real time classification) since the processor of windows computer associated with these type of machines do not have special graphics cards or GPU and already loaded with running the interface between user and CNC all the time. Real time video processing and classification is slow with the current processor of the windows computer and is not one on one with the video input. Classification methods involving machine learning and other processing is not suitable for laser CNC machines by us. In order to utilize them the processor needs to be upgraded which comes at an extra production cost and there is no urgent need to do so. A warning on motion detection is enough to warn the operator of the presence of any moving object inside the machine before he starts the cutting process.

Chapter 5

Experiments and results

In this chapter, the test results achieved utilizing the implemented system have been presented. This chapter is categorized as follows:

- Experimental setup of sheet measurement system.
- Results of utilizing the implemented sheet measurement system.

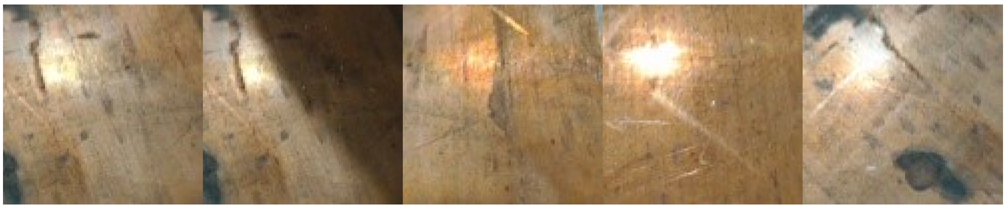
The system was directly tested on the Laser CNC machine manufactured by Dener Machines [1]. The laser sensor based system gives the most accurate results (explained in section 2.1.2). The results achieved with camera based system are compared with that of the traditional laser sensor based sheet measurement system. (Note: There was no need to present the test results of intrusion detection system since any false classification of human detection is reported as motion detected and that warning is enough to inform the operator about moving thing presence inside the machine, Motion detection works properly by checking the frame difference as discussed in chapter 4 of this thesis).

5.1 Experimental setup

Metal sheets of different materials i.e. mild steel, stainless steel, copper, aluminium and brass can be cut with the laser cutting machine. Some images of materials with different illumination has been shown in Figure 5.1.1, (a) shows mild steel, (b) stainless steel, (c) copper, (d) aluminium and (e) brass at different illumination levels.

(a) Mild steel

(b) Stainless steel



(c) Copper

(d) Aluminium

(e) Brass

Figure 5.1.1 Materials at varying illumination

It can be seen that sheets look different at different illuminations and they don’t seem to be perfectly uniform. Color can also become totally white at higher illumination. It has been explained in the previous section how the system find metal sheets of varying color and illumination.

Stainless steel is one of the most widely utilized material in the metal industry and many people buy the machine only for the purpose of cutting stainless steel. Considering the demand for stainless steel cutting the experiments were conducted on 1mm thick stainless steel rectangular piece of dimensions 750x435mm kept at different angles of orientation and different distances from the origin point of the cutting table. The experiment was performed as follows.

- Find the required points (is explained in the next section) using camera based system.
- Compare the achieved results with those of traditional laser sensor based system.

5.1.1 Required points explanation

Dener Fiber Laser Machine shown in Figure 5.1.1.1 is the industrial laser cutting machine being manufactured by CNC machine producing company Dener located in Kayseri, Turkey. The Sheet measurement system was directly tested on the Fiber laser machine. The system was tested over a period of 6 months and some of the test results have been recorded.

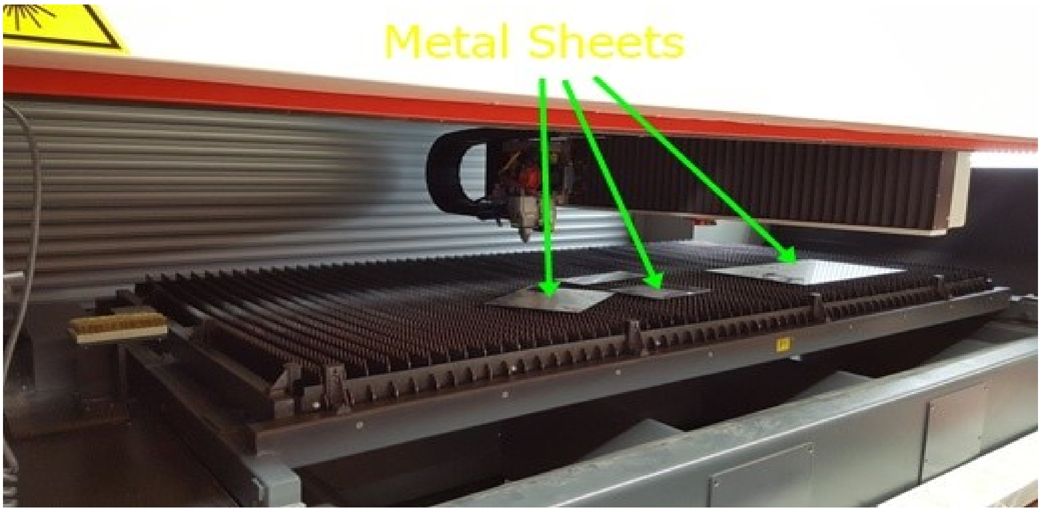


Figure 5.1.1.1 Dener fiber laser cutting machine

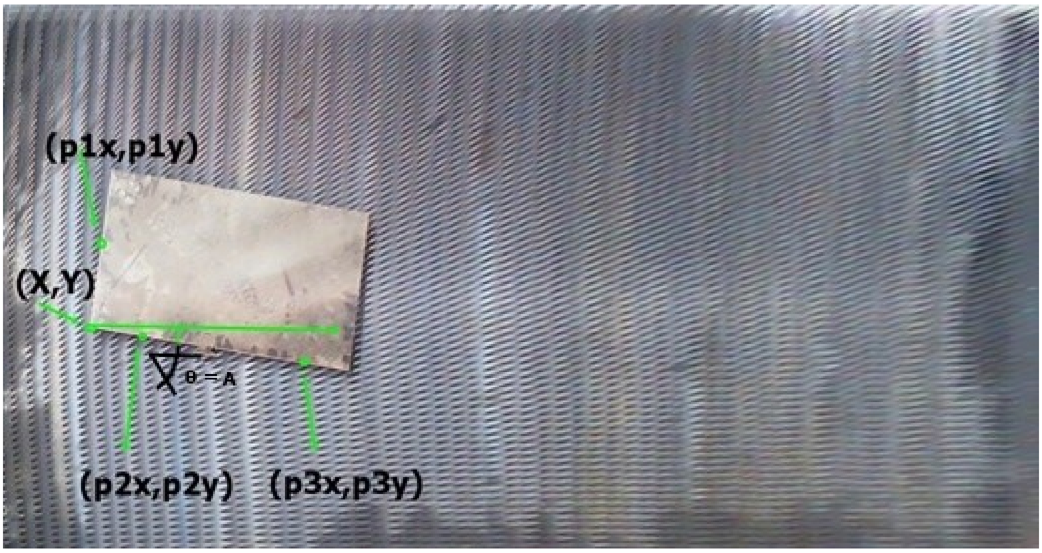
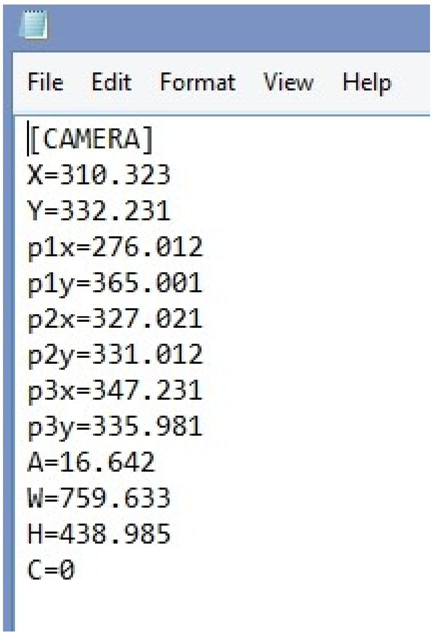


Figure 5.1.1.2 Illustration of the required points to be found using the camera system

Figure 5.1.1.2 illustrates the required points to be found using the camera system. As shown in the Figure 5.1.1.2, points p1, p2 and p3 are found using the camera based system, these points are required by the sensor in order to scan the edges and find the starting point (explained in section 2.1.2) also points (X,Y) the starting point and the angle of orientation (A) is found using the camera based system. (Note: Angle of orientation, $\theta = A$).



(a)

(b)

Figure 5.1.1.3 Illustration of a sample result found using camera based system and laser based system.

Figure 5.1.1.3 illustrates a sample result achieved by utilizing the camera based system denoted by $(p_{1,x}, p_{1,y}, p_{2,x}, p_{2,y}, p_{3,x}, p_{3,y})$ and the results achieved by utilizing laser sensor based system denoted by $(\tilde{p}_{1,x}, \tilde{p}_{1,y}, \tilde{p}_{2,x}, \tilde{p}_{2,y}, \tilde{p}_{3,x}, \tilde{p}_{3,y})$. The values denoted by px and py are the x and y co-ordinates of the points required to find the starting point (X,Y) and angle of orientation (A) with the x – axis. The length of pallet is 3000mm and breadth of pallet is 1500mm. (All results are in mm except A – angle which is in degrees). (Note : Angle of orientation $\theta = A$)

5.1.2 Error metrics

Error is calculated as absolute difference. The errors in the results from camera based system for a single image are as follows.

Error in p1x, $(E_{1,x})$ = $|p_{1,x} - \tilde{p}_{1,x}|$ = |276 – 284.9| = 8.9 mm

Error in p2y, $(E_{2,y})$ = $|p_{2,y} - \tilde{p}_{2,y}|$ = |331 – 331| = 0 mm

Error in p3y, $(E_{3,y})$ = $|p_{3,y} - \tilde{p}_{3,y}|$ = |336 – 337.4| = 1.4 mm

Error in X, (E_X) = |X – X*| = |310.3 – 297.3| = 13.0mm

Error in Y, (E_Y) = |Y – Y*| = |332.2 – 322.8| = 9.4mm

Error in A, (E_A) = |A – A*| = |16.346 – 16.149| = 0.197 degrees

Error in Height, (E_H) = |H – H*| = |438.9 – 435.0| = 3.9mm

Error in Width, (E_W) = |W – W*| = |759.6 – 750.0| = 9.6mm

The user can run the laser sensor after camera based sheet measurement. The sensor receives global working area from co-ordinates provided by camera and corrects the error. The Error within 25 mm is in the laser sensors limit and can be corrected to practically 0 by the sensor, hence in no case the error can exceed 25 mm. Width and height are excluded from this limitation that the error should not exceed 25 mm. Angle has a maximum error of 1 degree tolerance.

5.2 Results

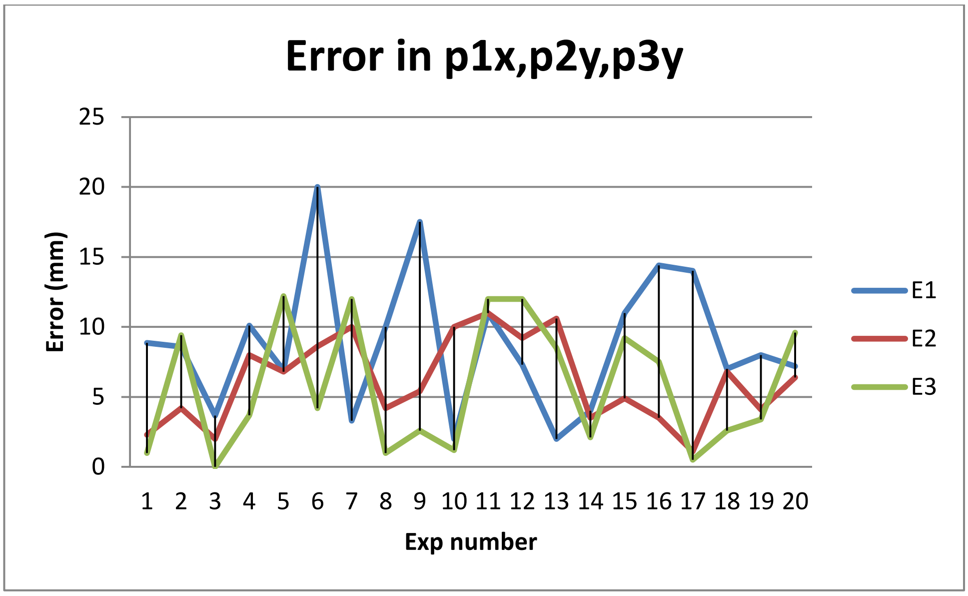
In section 5.2 the results and the error in different parameters are calculated. All calculations are based on explanations in section 5.1.1 and 5.1.2.

Tabulated results

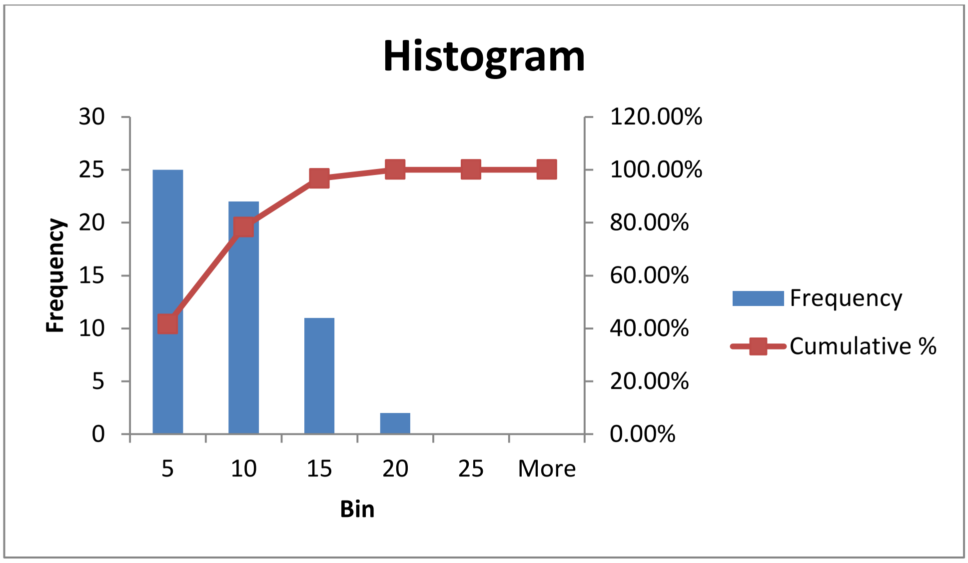
The error in $p_{1,x}, p_{2,y}, p_{3,y}$ is calculated in 20 experiments and the results are tabulated in Table 5.2.1. Maximum and minimum errors are written in bold characters.

Exp No.	$p_{1,x}$ **(mm)**	$\widetilde{p}_{1,x}$ **(mm)**	$E_{p1,x}$ **(mm)**	$p_{2,y}$ **(mm)**	$\widetilde{p}_{2,y}$ **(mm)**	$E_{p2,y}$ **(mm)**	$p_{3,y}$ **(mm)**	$\widetilde{p}_{3,y}$ **(mm)**	$E_{p3,y}$ **(mm)**
1	414	405.14	8.86	382	380.3	2.3	282	283	1
2	512	503.41	8.59	272	276.2	4.2	314	323.4	9.4
3	502	498.34	3.66	585	587	2	**682**	**682**	**0**
4	751	740.9	10.1	391	399	8	293	296.7	3.7
5	1156	1149.1	6.9	214	222.8	6.8	281	293.2	12.2
6	**1152**	**1172**	**20**	715	723.6	8.6	639	643.2	4.2
7	1243	1239.7	3.3	267	277	10	348	360	12
8	1037	1027	10	654	658.2	4.2	625	624	1
9	1553	1570.5	17.5	92	97.4	5.4	91	93.6	2.6
10	**1588**	**1590**	**2**	242	252	10	209	210.2	1.2
11	2114	2125.8	11	**261**	**272**	**11**	**254**	**266**	**12**
12	1763	1770.3	7.3	611	620.2	9.2	**653**	**665**	**12**
13	1234	1236	2	563	573.6	10.6	643	651.5	8.5
14	911	915	4	665	668.5	3.5	599	601.4	2.1
15	626	615	11	191	195.9	4.9	205	214.2	9.2
16	254	239.7	14.4	97	100.5	3.5	100	107.5	7.5
17	436	422	14	**346**	**347.1**	**1.1**	292	292.5	0.5
18	402	409	7	518	524.8	6.8	574	579.6	2.6
19	855	847	8	287	291.1	4.1	231	234.4	3.4
20	814	806.8	7.2	106	112.4	6.4	126	135.6	9.6

Table 5.2.1 Error in $p_{1,x}, p_{2,y}, p_{3,y}$



(a)



(b)

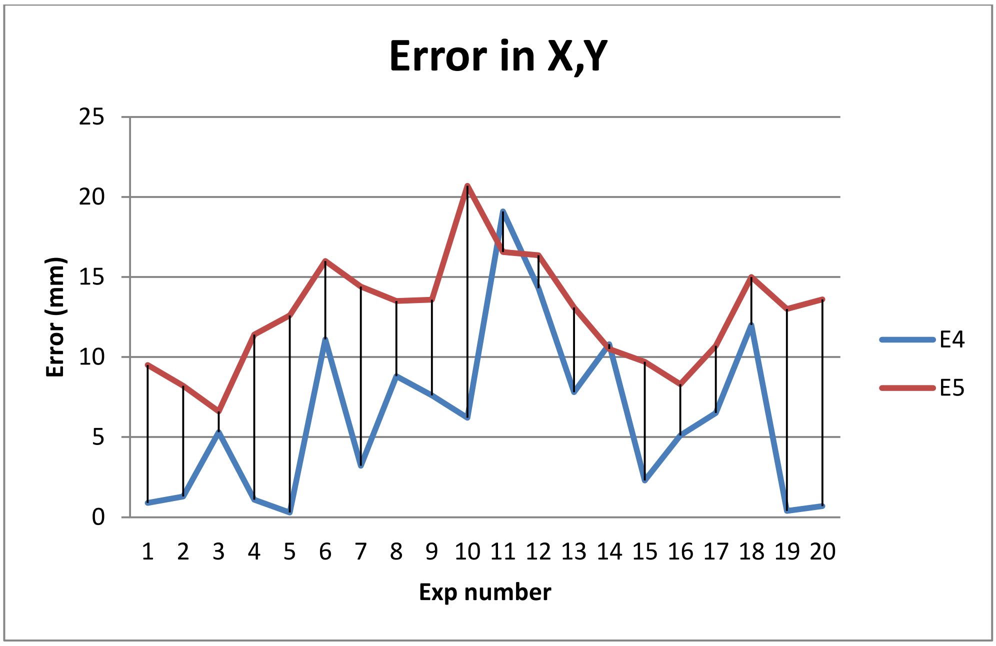
Figure 5.2.1 Error distribution of points $p_{1,x}, p_{2,y}, p_{3,y}$

It can be understood from Figure 5.2.1 (a) that the error in $p_{1,x}, p_{2,y}, p_{3,y}$ are not correlated with one another and from (b) it can be seen that more than 75% of error is below 10 mm and the highest number of points have maximum 5 mm error while no points have error between 20-25 mm.

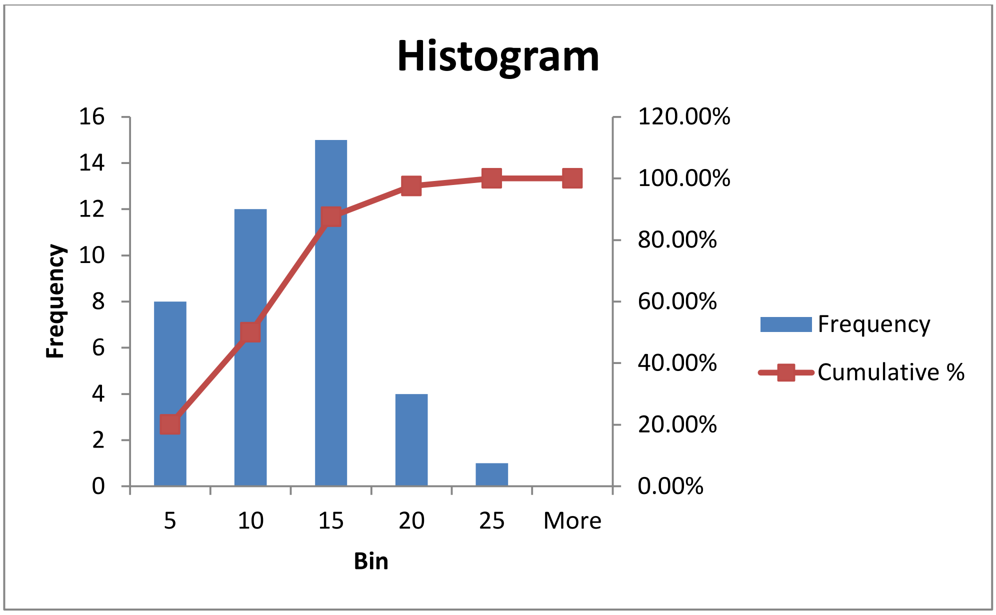
The Errors in X, Y(start point co-ordinates) and angle of orientation (A) are tabulated in Table 5.2.2.

Exp No.	X (mm)	X* (mm)	E_X degree	Y (mm)	Y* (mm)	E_y (mm)	A degree	A* degree	E_A degree
1	**391.8**	**392.7**	**0.9**	373.4	363.9	9.5	-20.23	-20.69	0.46
2	584.7	583.4	1.3	**193.7**	**185.5**	**8.2**	**9.75**	**8.77**	**0.98**
3	612.1	606.8	5.3	**478.5**	**471.9**	**6.6**	20.44	19.73	0.71
4	728.9	730.0	1.1	386.9	375.5	11.4	-20.07	-20.31	0.24
5	1243.7	1243.4	0.3	128.0	115.4	12.6	14.35	13.75	0.6
6	1172.9	1161.8	11.1	704.2	688.2	16	-16.07	-16.3	0.23
7	1343.4	1340.2	3.2	176.6	162.2	14.4	16.74	16.23	0.51
8	1055.7	1046.9	8.8	616.9	603.4	13.5	-6.72	-5.79	0.93
9	1617.7	1610.1	7.6	41.29	27.7	13.59	-0.77	-0.29	0.48
10	1616.3	1610.1	6.2	215.0	194.3	20.7	-8.29	-8.69	0.4
11	**2171.9**	**2152.8**	**19.1**	216.7	200.15	**16.55**	-1.11	-1.38	0.27
12	1847.4	1833.1	14.3	540.85	524.5	16.35	8.67	8.17	0.5
13	1336.3	1328.5	7.8	470.4	457.3	13.1	16.48	16.14	0.34
14	922.7	911.9	10.8	643.1	632.6	10.5	-13.48	-13.26	0.22
15	677.9	680.2	2.3	128.0	118.3	9.7	3.81	3.03	0.78
16	293.7	298.8	5.1	38.9	30.6	8.3	1.36	1.03	0.33
17	436.1	442.6	6.5	318.9	308.2	10.7	**-11.20**	**-11.13**	**0.07**
18	492.2	480.2	12	440.2	425.2	15	11.11	11.25	0.14
19	**861.6**	**862.0**	**0.4**	262.8	249.8	13	-11.52	-11.31	0.21
20	870.2	870.9	0.7	44.1	30.5	13.6	4.45	4.15	0.3

Table 5.2.2 Error in X, Y and A



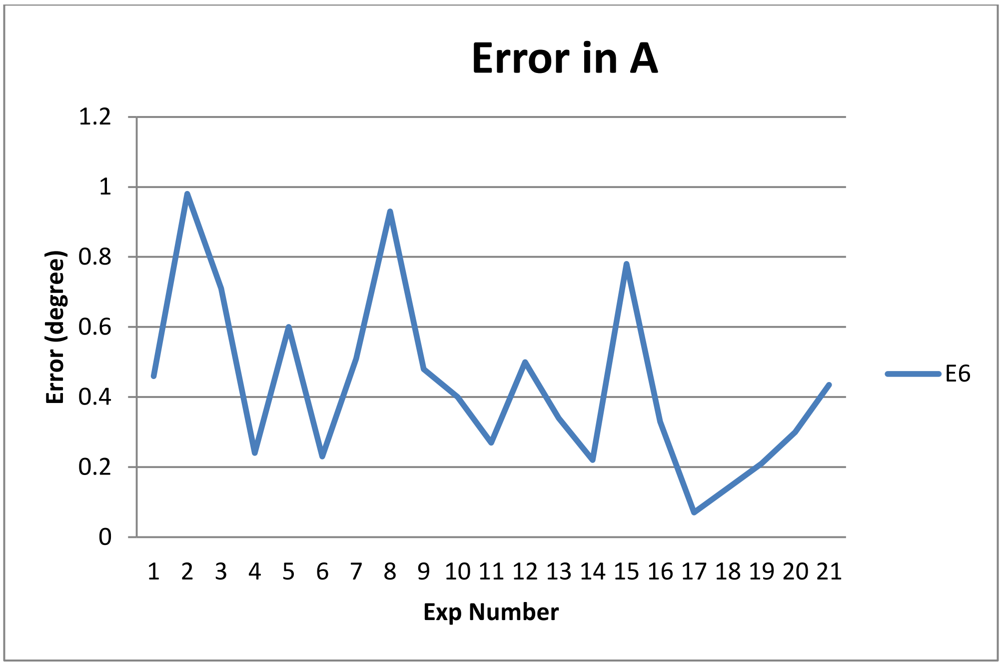
(a)



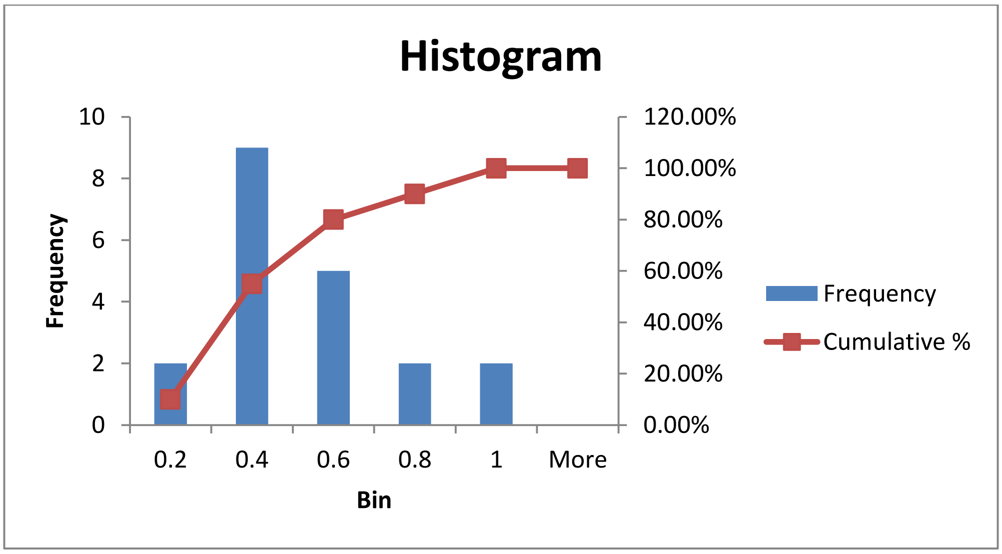
(b)

Figure 5.2.2 Error distribution of points X and Y

It can be seen from the error distribution in Figure 5.2.2(a) that the error in points X and Y is not correlated and from (b) it can be seen that most points have an error between 10-15 mm and least number of points have error between 20-25 mm.



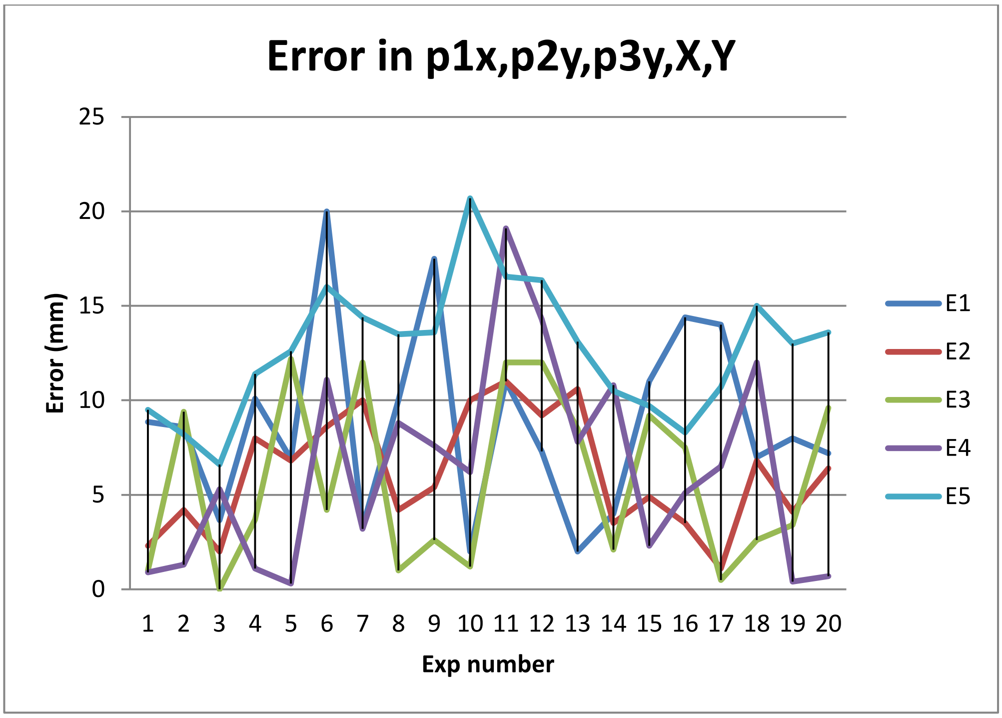
(a)



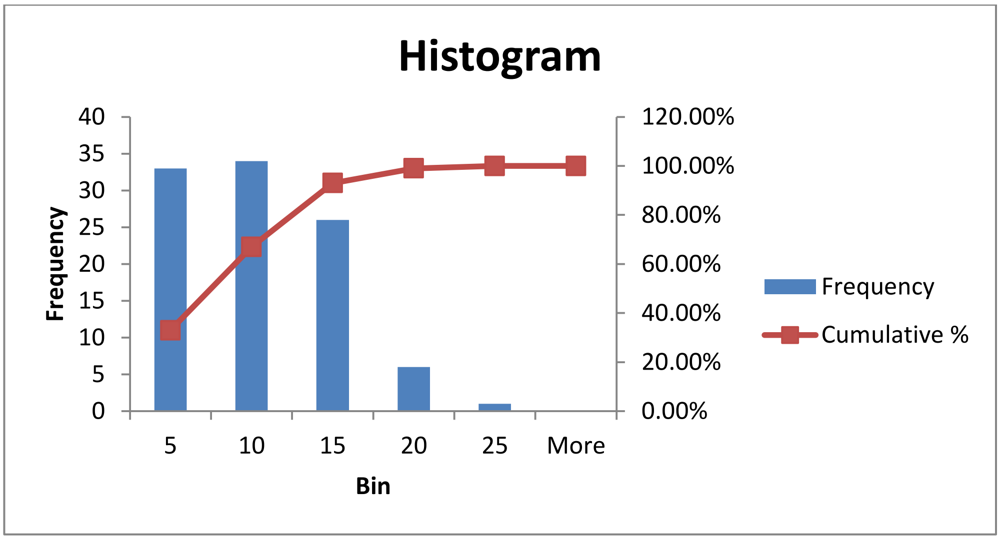
(b)

Figure 5.2.3 Error distribution of angle (A)

It can be seen from Figure 5.2.3 (b) that the maximum number of angles have error between 0.2-0.4 degrees and least number of points have error between 0.8-1 degrees.



(a)



(b)

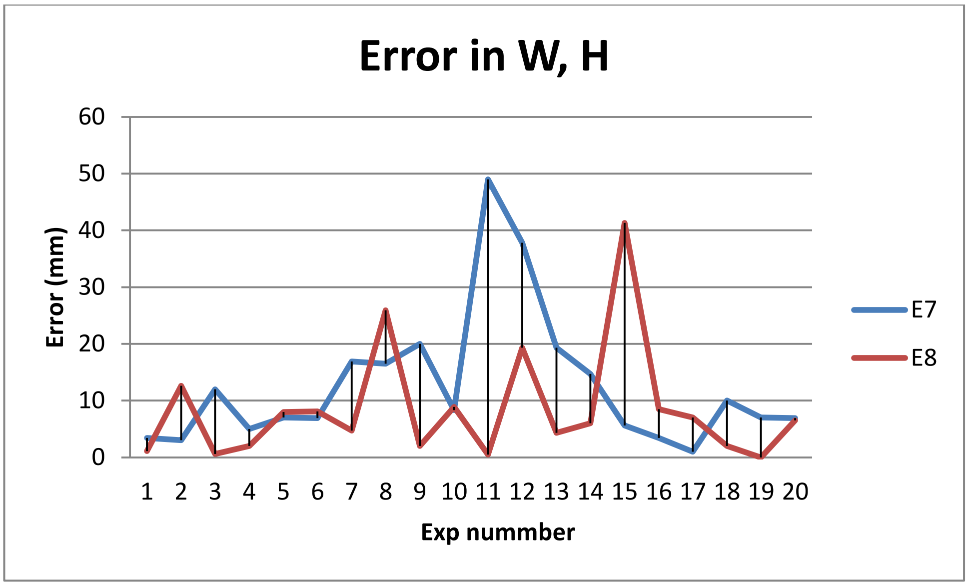
Figure 5.2.4 Error distribution of $p_{1,x}, p_{2,y}, p_{3,y}$, X, Y

From Figure 5.2.3, 5.2.4, 5.2.5 and 5.2.6 it can be clearly see that the results are not correlated to each other and there is no pattern or constant value that can be added or subtracted to decrease the error and most of the points have error 5-10 mm and least number of points have error between 20-25 mm.

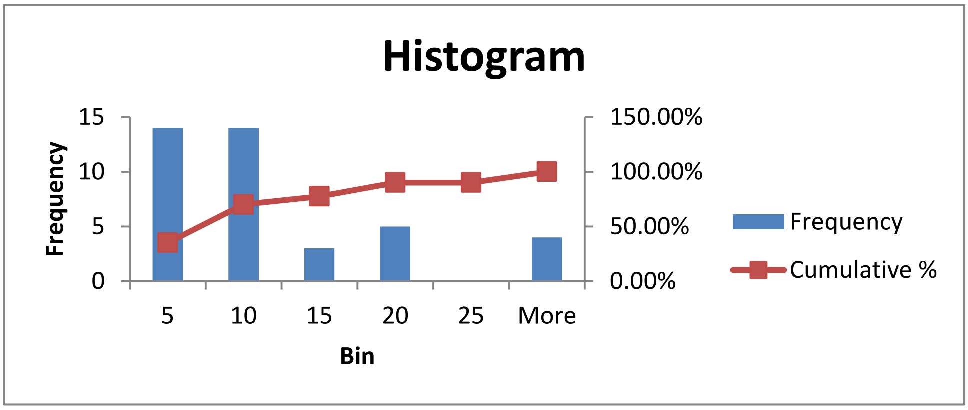
The Error in W (width) and H (Height) are tabulated in Table 5.2.3.

Exp No.	W (mm)	W* (mm)	E_W (mm)	H (mm)	H* (mm)	E_H (mm)
1	560	563.4	3.4	365	363.9	1.1
2	560	557.0	3	365	377.6	12.6
3	560	572.0	12	365	365.6	0.6
4	560	565.0	5	365	367.0	2
5	560	567.0	7	365	373.0	8
6	560	566.9	6.9	365	373.1	8.1
7	560	576.9	16.9	365	369.7	4.7
8	560	576.5	16.5	365	390.9	25.9
9	560	580.0	20	365	367.0	2
10	560	568.3	8.3	365	356.14	8.86
11	560	609.0	**49**	365	365.5	0.5
12	560	597.8	**37.8**	365	384.3	19.3
13	560	579.3	19.3	365	369.3	4.3
14	560	574.7	14.7	365	371.0	6
15	560	554.4	5.6	365	406.3	**41.3**
16	560	556.6	3.4	365	373.5	8.5
17	560	561.0	1	365	372.0	7
18	560	570.0	10	365	367.0	2
19	560	567.0	7	365	365.0	0
20	560	566.9	6.9	365	371.5	6.5

Table 5.2.3 Error in W (width) and H (Height)



(a)

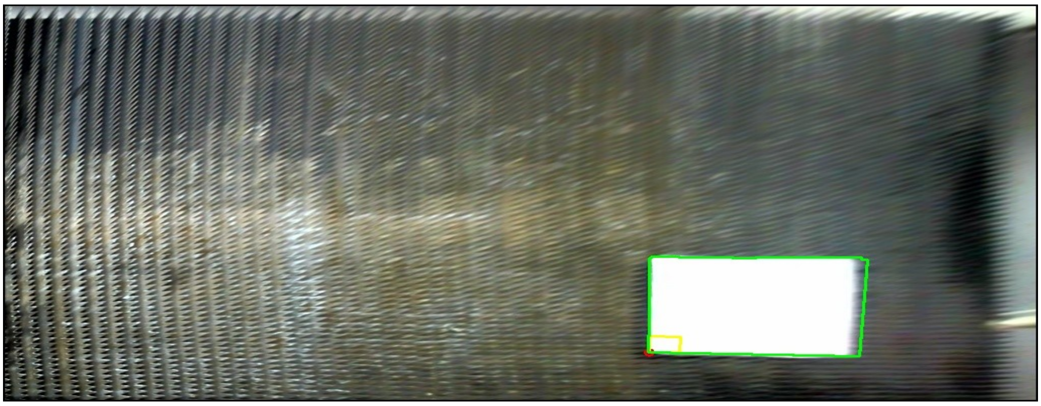


(b)

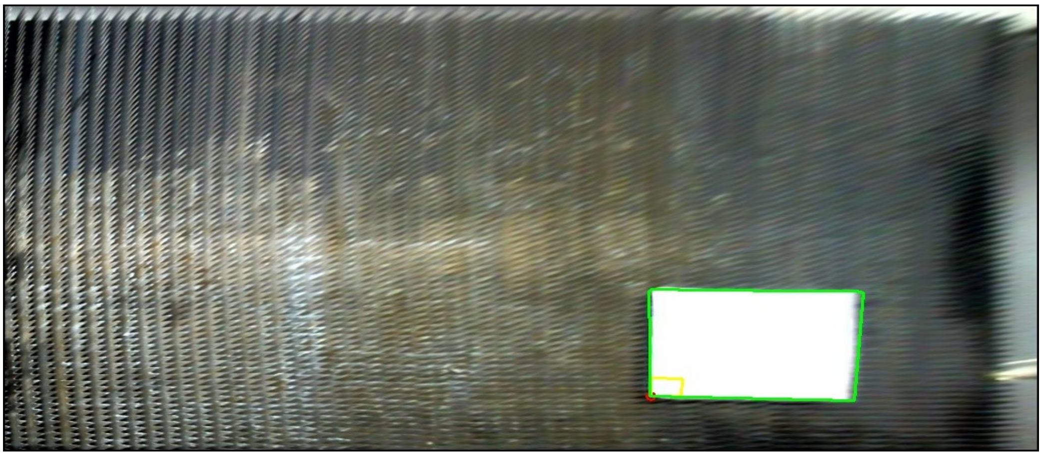
Figure 5.2.5 Error distribution of W and H

It can be seen from Figure 5.2.5 that most images have error below 10 mm while least number of images have error more than 20 mm.

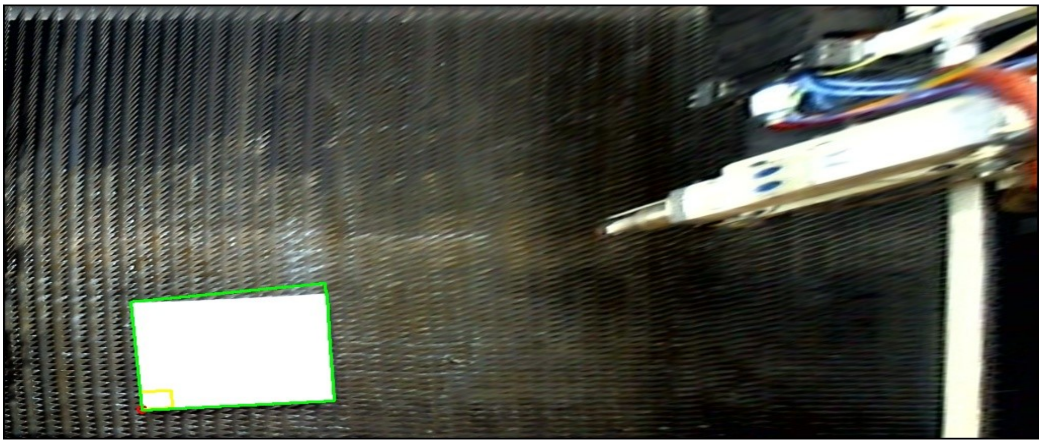
Now the reason behind absurd values in width and height from the camera system will be discussed. Figure 5.2.6(a) shows the reason behind the absurd error value in experiment 11. It can be see that width is wrongly extended due to blurring of image. This is a drawback of our method that the image gets blurred towards the right edges hence there is a chance that the height and width of the sheet be estimated wrong. The error in height needs to be minimized but it does not lead to malfunctioning of the machine since the user can understand from the image if the part to be cut (shown as yellow rectangle in the image) will fit the sheet or not. (b) Shows the error in width in experiment 12 and (c)shows the error in height in experiment number 14. The error in height and width is not bound in the 25mm limit, it should be as small as possible.



(a) 11



(b) 12



(c) 14

Figure 5.2.6 Experiment numbers that have absurd values

The minimum, maximum, mean, variance and standard deviation of errors in the points $p_{1,x}, p_{2,y}, p_{3,y,}$X, Y, A, H, W are tabulated in Table 5.2.4. It can be drawn from the results that the maximum error values are within the maximum range of 25 mm. As discussed before the error within the range of 0 – 25 mm is in the range of laser sensor and practically corrected to 0 in every case. The maximum error in point $p_{1,x}$ is 20.0 mm which is below 25 mm while the maximum error in angle of orientation (A) is 0.98 degree below 1 degree. The maximum error in height (H) is 27.8 and width (W) is 41.3 mm which needs to be minimized. The maximum limit of error in width and height is not 25 mm since the user can see the image on screen and assert if the part is bigger than the sheet to be cut.

Error	Minimum	Maximum	Mean	Variance	Standard deviation
$E_{p1,x}$	2.0mm	20.0mm	8.8mm	24.04	4.90
$E_{p2,y}$	1.1mm	11.0mm	6.1mm	9.37	3.06
$E_{p3,y}$	0.0mm	12.0mm	5.7mm	20.06	4.47
E_X	0.4mm	19.1mm	6.2mm	27.64	5.25
E_Y	8.2mm	16.5mm	12.7mm	11.59	3.40
E_A	0.07degree	0.98degree	0.43degree	0.06	0.25
E_H	1.0mm	27.8mm	12.7mm	144.93	12.03
E_W	0.0mm	41.3mm	8.4mm	101.96	10.09

Table 5.2.4 Statistics

Chapter 6

Conclusion

In this thesis, a camera based sheet measurement system has been developed. The patent application for the system was made and accepted by the patent ministry of Turkey [30] and a patent application was made to PCT [31]. The proposed camera system eliminates the existing problems related with the traditional systems of sheet measurement. The developed camera based sheet measurement system is faster and user-friendly than its traditional counterparts. The new system was integrated into a laser cutting machine and tested over a period of six months. It was found that the new sheet measurement system is accurate and reliable, but in order to achieve higher accuracy it was integrated with the traditional laser sensor based system where the laser sensor based system receives global co-ordinates from camera based system and corrects the error tending to zero (minimum acceptable value) for both starting point and angle of orientation. The system can work on rectangular sheets of any dimension with least possible error and can work with a small average error on irregular pre-utilized sheets.

Intrusion and motion detection was integrated into the sheet measurement system in order to warn the operator about any human or other moving thing presence inside the machine before he starts the cutting process.

The newly implemented systems can be improved further by eliminating the effect of image blur in the right corners of the images. Using more uniform lighting system inside the machine can be useful. There is no doubt about the system being further improved using other techniques of image processing however computational power is limited and should be kept in mind while implementing such systems. Another camera based system to monitor the cutting process and quality can be integrated into the current system. This system can be modified for sheet measurement in plasma cutting, 3D CNC cutting and many more machines.

BIBLIOGRAPHY

[1] Dener fiber laser machine, http://www.dener.com/sayfa/79/fiber-lazer.html.

[2] US4918611A, Patent number – 40918611, DOP – April 17, 1990.

[3] Ballard D.H., Generalizing the hough transform to detect arbitrary shapes. Pattern Recognition 13, pp. 111-122, 1981.

[4] Yang Y. & Yan H., An adaptive logical method for binarization of degraded document images, PR 33, pp. 787–807, 2000.

[5] Sha C., Hou J., Cui H. & Kang J., Gray Level-Median Histogram Based 2D Otsu's Method, 2016.

[6] Zhao Y., Liu J., Li H., & Li G., Improved watershed algorithm for dowels image segmentation, 2008.

[7] Carsten R., Vladimir K. & Andrew B., GrabCut: Interactive foreground extraction using iterated graph cuts, ACM Trans. Graph., vol. 23, pp. 309–314, 2004.

[8] Radhakrishna A., Appu S., Kevin S., Aurelien L., Pascal F. & Sabine S., SLIC Superpixels Compared to State-of-the-art Superpixel Methods, IEEE Transactions on Pattern Analysis and Machine Intelligence, vol. 34, num. 11, p. 2274 - 2282, 2012.

[9] Manuel W., Trimpe S., Kappler D. & Schaal S., The Feature Gaussian Filter. In IEEE Conference on Robotics and Automation, p. 6922, 2015.

[10] Zayed N. & Elnemr H. A., Statistical Analysis of Haralick Texture Features to Discriminate Lung Abnormalities, 2015.

[11] Milanfar P., On the Hough transform of a polygon. Pattern Recognition Letters, 17(2), pp. 209–210, 1996.

[12] Rokach L. & Maimon O., Decision Tree. Data Mining and Knowledge Discovery Handbook, pp. 165-192, 2005.

[13] Tin K. H., The Random Subspace Method for Constructing Decision Forests (PDF). IEEE Transactions on Pattern Analysis and Machine Intelligence. 20 (8): 832–844. doi:10.1109/34.70960, 1998.

[14] Mohan A. S. & Resmi R., Video image processing for moving object detection and segmentation using background subtraction, 2014.

[15] Csaba B., Bernhard F. & Horst B., Human detection in groups using a fast mean shift procedure. International Conference on Image Processing, 1:349–352, 2004.

[16] How-Lung E., Junxian W., A. Kam, & Wei-Yun Y., A bayesian framework for robust human detection and occlusion handling using a human shape model. International Conference on Pattern Recognition, 2004.

[17] Ju H. & Bir B., Detecting moving humans using color and infrared video. IEEE International Conference on Multisensor Fusion and Integration for Intelligent Systems, 30:228–233, 2003.

[18] Paul V., Michael J. J. & Daniel S., Detecting pedestrians using patterns of motion and appearance. IEEE International Conference on Computer Vision, 2:734–741, 2003.

[19] Navneet D. & Bill T., Histograms of oriented gradients for human detection. IEEE Computer Society Conference on Computer Vision and Pattern Recognition, pp. 1063–6919, 2005.

[20] Schapire R. E., Explaining adaboost. In Empirical Inference: Festschrift in Honor of Vladimir N. Vapnik, Springer Berlin Heidelberg, pp. 37–52, 2013.

[21] Donald G. B., Christopher T.J. & Ni M., Connected components analysis of streamed images, 2008.

[22] Ding L. & Goshtasby A., On the canny edge detector, Pattern Recognition, 34(3), pp. 721–725, 2001.

[23] David H. D. & Thomas K. P., Algorithm for the reduction of the number of points to represent a line or its caricature. The Canadian Catographer, 10(2): 112-122, 1973.

[24] Paul V. C., Hough Method and means for recognising complex patterns, US patent 3069654, 1962.

[25] Chris H. & Mike S., Combined Edge and Corner Detection, Fourth Alvey Vision Conference, pp. 147-151, 1988.

[26] Richard O. D. & Peter E. H., Use of the Hough Transformation to Detect Lines and Curves in Pictures, Comm. ACM, Vol. 15, pp. 11–15, 1972.

[27] Mahesh, Dr.M.V.Subramanyam, Corner Detection Enhancement Using Steerable filters, International Journal of Scientific & Engineering Research Volume 3, Issue 8, 2012.

[28] Engel K., Sobel operator, In Real-time volume graphics (The Eurographics Association), pp. 112–114, 2006.

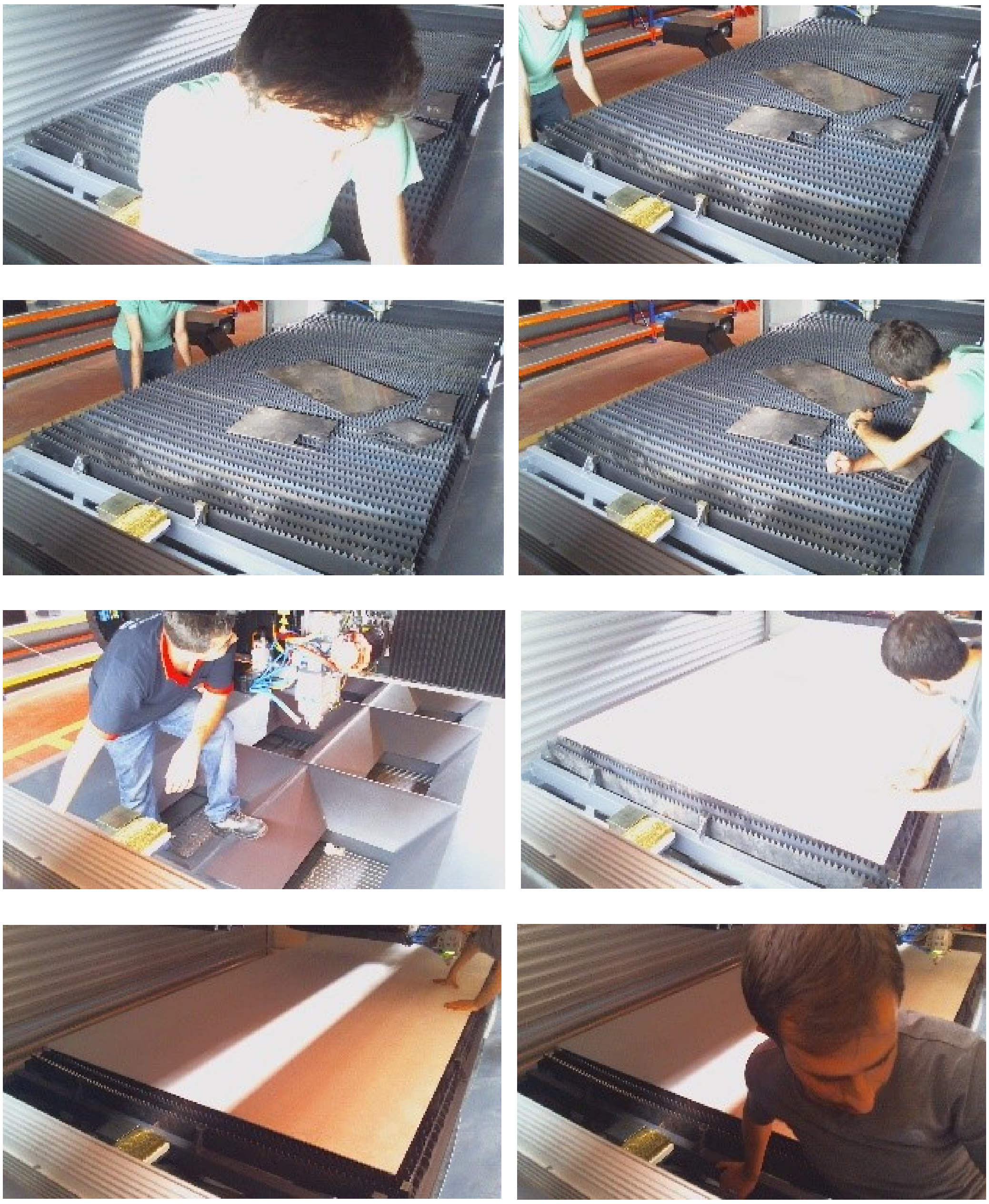
[29] Rafel C. G. & Richard E. W., Geometric spatial transformation and image registration, Digital Image Processing (3rd Edition, Pearson Education International), pp. 109 – 111, 2009.

[30] Turk Patent, Application number – 2016/16881, 2016.

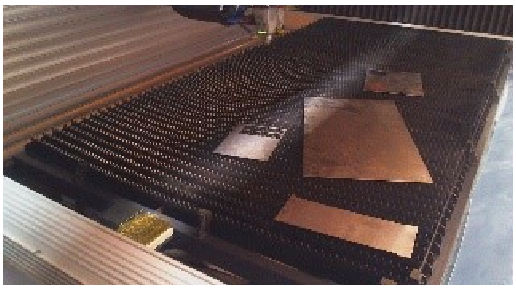
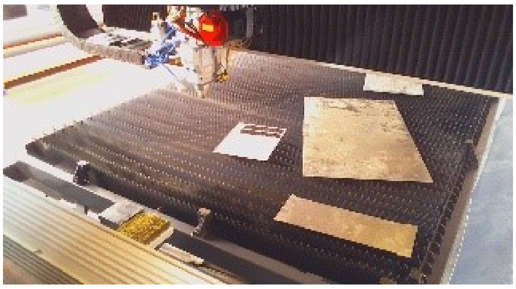
[31] Patent Cooperation Treaty, Application number – PY2017-00230, 2017.

APPENDIX A

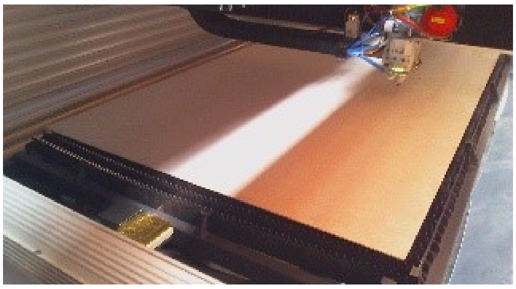
Dataset images for human detection





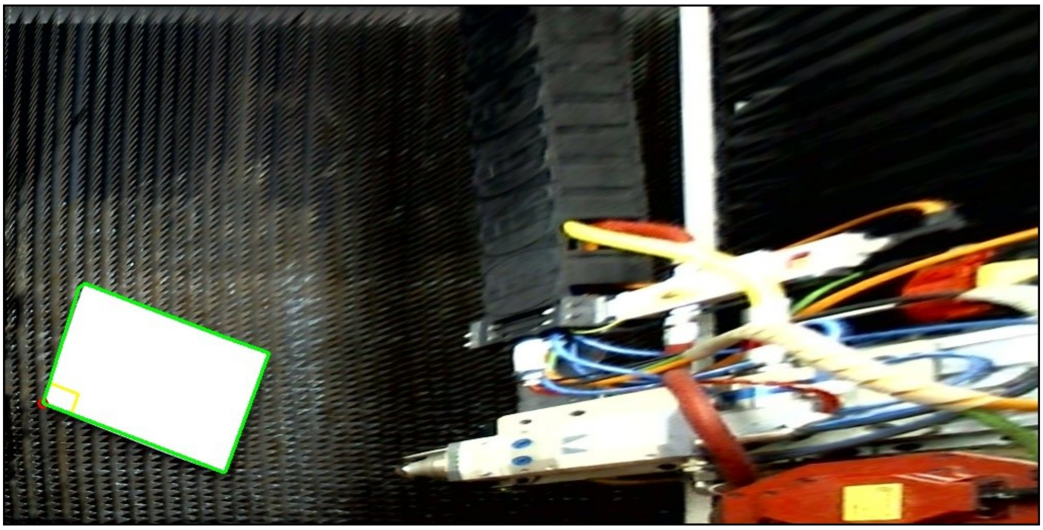








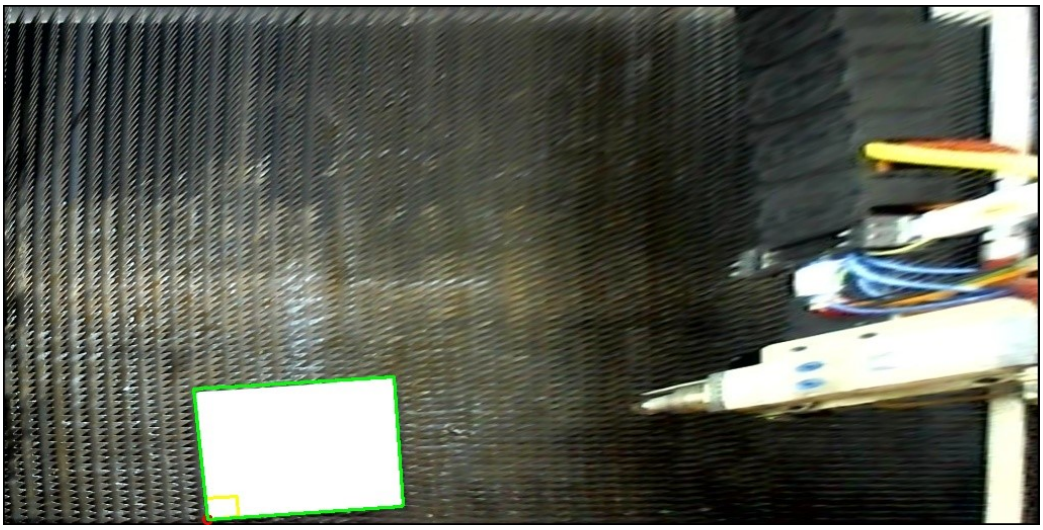

APPENDIX B

More results



CUSTOM MACRO

NO.	DATA	NO.	DATA
00550	414.0000	00562	745.0000
00551	602.0000	00563	283.0110
00552	481.0000	00564	405.1440
00553	382.0000	00565	602.0000
00554	745.0000	00566	0.0000
00555	282.0000	00567	0.0000
00556	0.0000	00568	0.0000
00557	0.0000	00569	0.0000
00558	0.0000	00570	-20.2382045393
00559	0.0000	00571	391.778859737
00560	481.0000	00572	373.488487671
00561	380.3440	00573	0.6421875



CUSTOM MACRO

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00551	281.0000	00563	135.6780
00552	954.0000	00564	806.8110
00553	106.0000	00565	281.0000
00554	1252.0000	00566	0.0000
00555	126.0000	00567	0.0000
00556	0.0000	00568	0.0000
00557	0.0000	00569	0.0000
00558	0.0000	00570	4.45163175025
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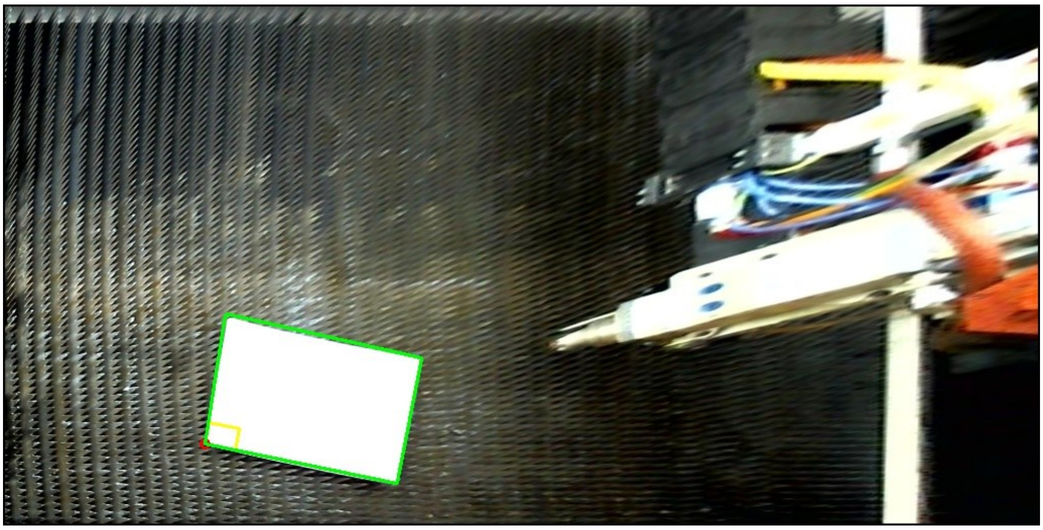
00560	954.0000	00572	44.1032815116
00561	112.4780	00573	0.6421875



CUSTOM MACRO

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00552	958.0000	00564	847.4100
00553	287.0000	00565	494.0000
00554	1236.0000	00566	0.0000
00555	231.0000	00567	0.0000
00556	0.0000	00568	0.0000
00557	0.0000	00569	0.0000
00558	0.0000	00570	-11.5210282785
00559	0.0000	00571	861.621958335
00560	958.0000	00572	262.878982406
00561	291.1440	00573	0.6421875