Development of a Two-Dimensional Plotter

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***Abstract* – Two-dimensional plotter concept has been used in many applications since a long time. Plotters are controlled by computer. Plotter is a device which do drawings according to the given coordinates. Most popular XY plotter designs are two axis manipulators, stepper motors included, and timing belt driven mechanisms are included. Main applications of plotter are CNC machine, Engraving machine and drawing machine etc. XY plotter operates in two perpendicular axes of motion in order to provide two independent movements and drawings. These type of plotting mechanisms normally use stepper motors as it is easy to achieve accuracy unlike DC motors. In drawing applications, usually image processing tools are involved to perform edge detection, noise removal and mapping etc. There are image processing software available which supports advanced processing methods such as OpenCV, Matlab. Different types of plotters are being used commonly such as cutting plotters, XY writers, electrostatic plotters, drawing machines etc.**

Keywords – Plotter; Robotics; Drawing Robot; Image Processing

I. INTRODUCTION

Robotics can be described as part of technology that attached with the design, production, operation and robotic applications and software systems for feedback control, data processing. Any robotic system is a combination of mechanical, electrical and software component. First introduction of the term 'Robotics' were done by Isaac Asimov in his Liar in 1942: science fiction. The term 'Robot' can be described as a device which combines electronic, mechanical with computer software programs to control to do specific tasks. A robot arm is an end effector of robotic system that can be programmed to get the similar performance of human.

Focusing of the robotic 2D plotter, it is capable of producing drawings in any shape and size. Plotters that attached a vertical pen draws on a surface of paper and the pen acts as manipulator. Unlike raster graphics, 2D plotters are vector graphics devices. Mechanical movement of the pen could produce complex shapes, also text drawings. SCARA robot used to make a drawing robot that plots the input graphics given from computer. It is an XY (two-dimensional) plotter. Currently available plotters are Cartesian, cylindrical and spherical robots. Applications of Cartesian robots are handling operations, assembly operations, welding operations. It has three prismatic joints and those axes are collide with Cartesian coordinator. For applications like assembly operations, spot welding spherical robots are being used. It forms a cylindrical coordinate system.

Similarly, spherical robots are used to form a polar coordinate system. There is another type of plotters called articulate robots in which the links between joint are attached with universal rotary joints. Processing and handling data using digital devices has speed up the development process in many applications.

Along with such environment, different suggestions for output devices which capable of representing the images/ diagrams as information came into account. For those kind of applications, two-dimensional plotter was basically using for creating diagrams since it gives a better understanding of the drawing. CNC machine, plotter machine, printer and engraving machine are few applications of x-y plotter mechanism.

Regarding the features of X-Y plotter, acquisition of visual data and processing is called 'Image Processing'. The input image is expressed as a continuous function of x,y variables and if it varies with time, third variable (t) can be added. The function of image represents the brightness of points in the image.

II. LITERATURE REVIEW

Pen plotters on a paper by moving the pen manipulator. Basically, plotters can draw art and text, the only constraint is it works slowly as two axis movement of the pen. It is not possible to draw solid shapes only the edges. XY plotter usually runs in two perpendicular motions ('X' & 'Y'). The difference between plotter and printer is plotters can draw lines whereas printers generates images using ink.

A. Image Processing

Image processing used to apply edge detection methods, contour drawing methods in order to use for another purpose. This term strongly related with processing and enhancing the images such as;

- Error correction during acquisition
- Prevention the variations of human visual system

The task of image processing can be summarized as" process of inputting an image and getting a modified image". By using image processing techniques, the final quality of the image will be enhanced. The goal of applying image enhancement techniques is to use the modified image for another specific reason. Therefore, applying enhancement

techniques should be problem-focused and not considered as universal methods. The main three functions of image processing are grey-scale image formation, sharpening the image and smoothing the image. When applying image processing to two dimensional images, basically it identifies important features in the image and characteristics that describes the object will be extracted.

Following the feature vector is consisted of object characteristics.

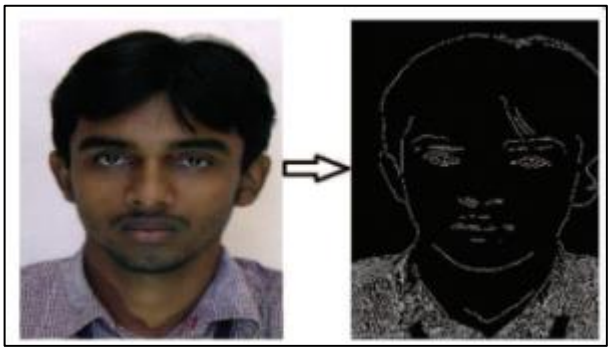

Fig 1: Output of Canny edge detection

B. Projects

USB XY Plotter – To enable a fast and strong connection between computer and plotter, parallel port was used in earlier days. This project discusses the transformation from series/ parallel ports to USB port. These plotters could draw only straight and diagonal lines. Also, these were not as powerful as which available in the market. A GUI interface was created that make the user able to enter 2D vectors. The ability of the pen to move in Z direction was not possible and it causes to draw unnecessary lines in the drawing. As a conclusion, as the gear ratios of two motors are different the errors in X and Y directions are not the same. The speed of USB connection was not enough to achieve the goal.

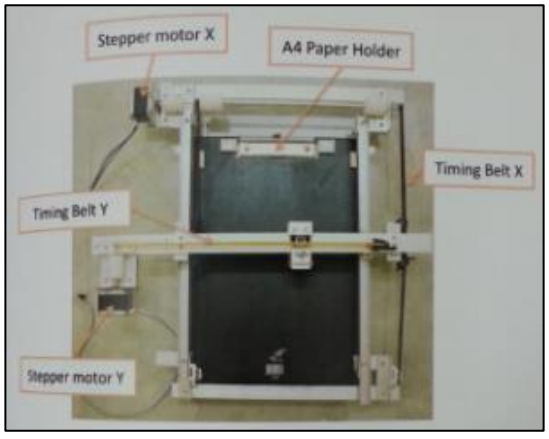

Fig 2: USB XY Plotter

Robotic 2D Plotter - In a similar project done by Dr. M Shivakumar, Stafford Michahail, Ankitha Tantry H, Bhawana C K, Kavana H, Kavya V Rao in Mysore, India named" Robotic 2D plotter", they were using two servo motors for perpendicular axis control and one servo to move the pen in Z direction. The commands for the robot is given by ATMega 8 microcontroller on Arduino board. (Shivakumar, et al., April 2014)

Microcontroller based X-Y Plotter - The main advantage is that capability to tool replacement according to the application (CNC machine, Laser cutting machine, Painting robot and Engraving machine). The microcontroller they were using in this project was MSP430 and PWM driver circuit with timer circuit. Two stepper motors for the X and Y axis driving. (Dayana & Gunaseelan, April 2014)

Drawing Robot - Another related project was "Drawing Robot" done by Ferran Alet and Maria Bauza in 2015. The main challenge of this was to identify what lines to choose for drawing. What it was capable in image processing are: converting the RGB image to Gray Image. And while setting a threshold value, obtained Binary Image to find the edges. Considering simple images in drawing, it has few colours and would lose little information in converting RGB image to Binary image. For coloured images, threshold value should be adjusted as its change of intensity in colours can be different. Therefore, they found out the best way to represent an image using its edges. Only the long lines are considered, and others can be ignored. They analyzed the image of a text every digit that has a boarder goes around it. Further, they have created a special algorithm to avoid duplicated drawings.

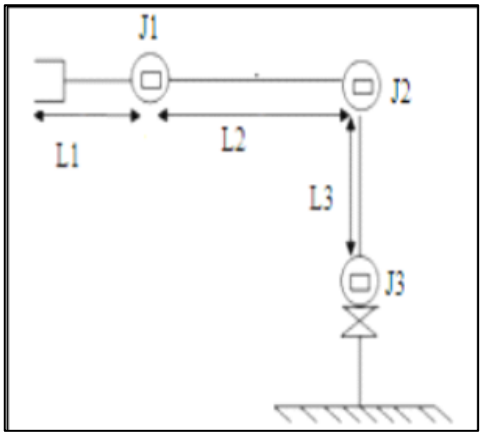

Fig 3: Robotic arm design

A force-controlled Portrait drawing robot – "A Force controlled Portrait Drawing Robot", a project done by Shubham Jain, Prashant Gupta, Vikash Kumar, Kamal Sharma in India is limited only to draw basic shapes. Mainly two sections are involved with drawing robot. In first step, capturing image of a human face and applying image processing techniques to extract important features of the drawing. After processing the image, those details are transmitted to a robotic arm as 3-Dimensional coordinates in

order for drawing. The image processing procedure involves extracting important features and after that send those to robot arm. At the beginning, pre-processing of image is required. That image after pre-processing is used for edge detection. The edges contain the important features of the image. The Canny Edge detector find the real and localized edges without the effect of noise. Even after the image processing is done, some processing needs to be done before sending them to robot. (Jain, Gupta, Kumar, Sharma, 2015)

- Branch Removal - There should not be any branches in an edge, the robot can draw directly that edge from one end to the end of the edge to other. To address this, the branch points were identified and removed.
- Removal of small objects - The edges which contains small number of pixels were ignored from the output therefore the noise effect can be eliminated.

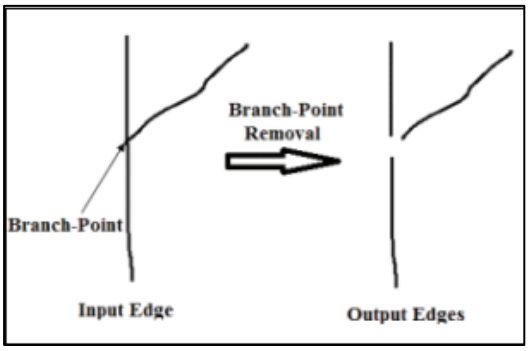

Fig 4: Removal of Branch points

High Accuracy A3 size X-Y Plotter - The A3 size XY plotter was developed by Machida in 1987 was contained the features of high speed, high acceleration and high resolution for a reasonable cost. The specialty of this plotter is low vibration stepper motor control system, high stiffness mechanism, specific velocity control system and new coil pen manipulator that provide user a fine quality drawing output. According to Machida, the weakness of this XY Plotter is it allows only connection using RS-232C serial interface or 8-bit parallel interface.

Computer controlled X-Y Plotter - Dominic Tighe explains that XY plotter is a device which controlled by computer, by manipulating the motion of one or few pens over a sheet of paper allowing a computer-controlled diagrams. Tighe introduced a special feature that help the blind people to read which this plotter cut out polystyrene shapes (punch out Braille) that able blind people to feels. The Braille is yielded by replacing pens with a punch and placing the sheet of paper on a polystyrene support. The resulted punched Braille is read by reversing the paper. (Tighe, 1987) All the Braille should be written in reversed order as it enables reading using Tighe's Braille. He had been developed an algorithm to enable the direct translation of words to Braille.

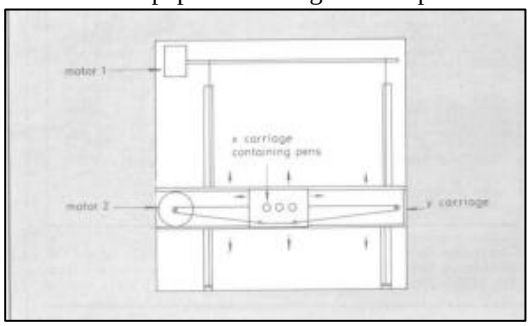

Fig 5: Tighes designed plotter

III. METHODOLOGY

The methodology section presents the understanding of mechanical design, software implementation and project structure.

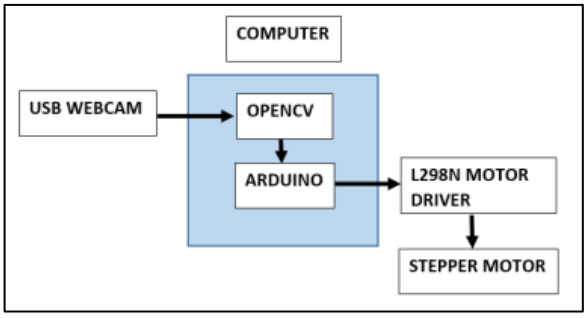

Fig 6: Block diagram of X-Y Plotter

A. System Overview

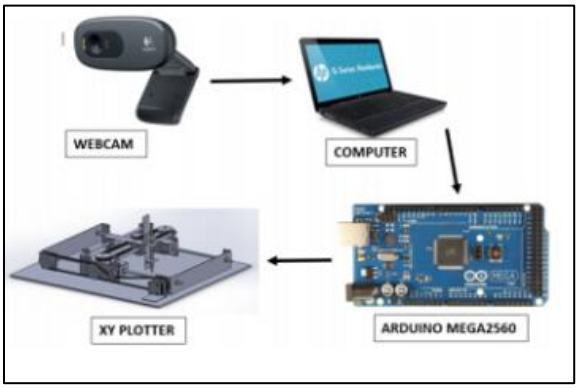

Fig 7: Project Overview

The input image will be taken from USB webcam and processed through a computer using OpenCV to obtain pixel coordinates, convert them to map coordinates. Those will be sent to the Arduino microcontroller and after to the stepper motors. The microcontroller of the project is Arduino Mega 2560 in plotting. To drive the pen manipulator on X and Y directions two stepper motors used. Also, 12V solenoid actuation is used to move the pen manipulator in z direction. The linear motion of X and Y directions will be done through linear bearings. Following figure represents the overview of the project.

Mainly XY Plotter consists of two sections:

- XY Plotter mechanical structure and stepper motor controlling
- Image processing and Serial communication

The image taken is analyzed by image processing techniques and edge pixel coordinates are retrieved. Those pixel coordinates are transferred to Arduino Mega through serial communication. The following flow diagram describes the entire process step by step.

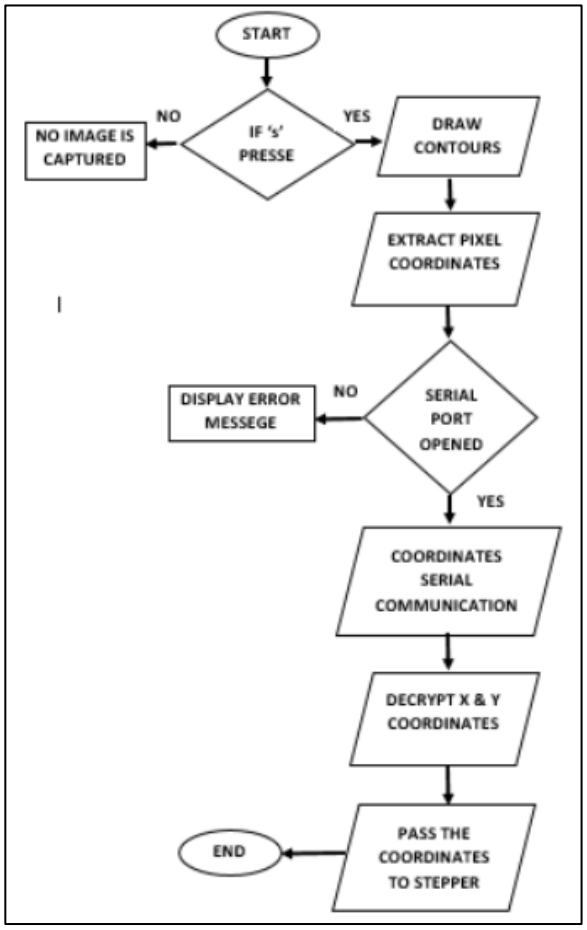

Fig 8: Project Flow chart

B. Mechanical Design

This chapter covers the mechanical structure of the plotter, software design and schematic design.

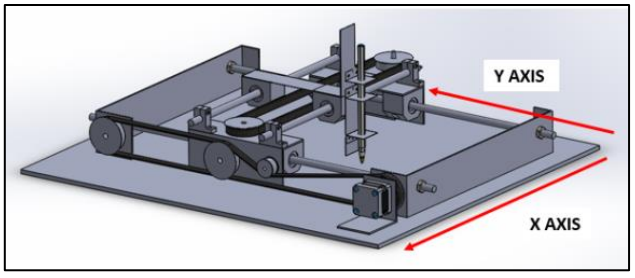

Fig 9: CAD model of XY Plotter

The above CAD model shows main components of the plotter. The following table summarizes the operation of each and every component of mechanical structure. After doing a considerable amount of research based on mechanical structure, below present a comparison between few possible alternatives.

- **Linear Motion**: To achieve linear motion, it is possible to use either lead screw mechanism or belts. But speaking with the speed that can achieve with lead screws is comparatively slow. Also, it is required to use powerful stepper motors to accelerate and expensive motor drives too. There is a maximum speed for lead screw to drive. In terms of accuracy, lead screws wins as unlike belt drive depending on the pitch size higher accuracy can be achieved.
- **Z direction movement**: There are various methods available for Z direction motion such as use stepper motor, servo mechanism, dc solenoid mechanism. Among them the method I selected was dc solenoid mechanism. Easy to control, not expensive made me realized to select this option.

C. Electrical Design

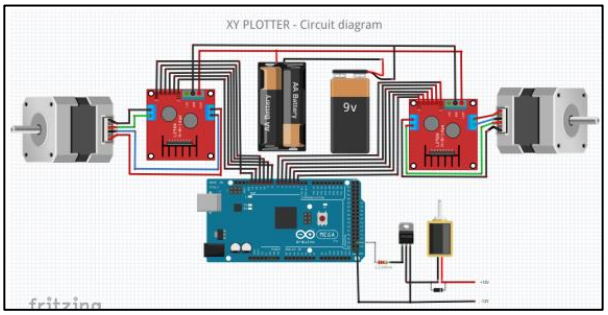

Table 4: Circuit Diagram

Table 3: Mechanical components and operation

Component	Operation
X axis motor	Plotter operation in x direction
Y axis motor	Plotter operation in y direction
Gear wheels	Guide the belt for moving
Linear bearing	Guide the circular rods
Timing Belt	Support the pen manipulator movement
DC Solenoid	Moves pen in z direction
Pen manipulator	Plotting
Rod support bearing	Keep the rods stable
Base	Support the entire structure

Electrical circuits, motors and motor drivers which used in the project are descriptively explained in this section. The main electrical components associated with the project are Stepper motor driver, AC-DC converter, Arduino controller, Solenoid control circuit etc. Using AC-DC converter, 230VAC input is converted to two 12VDC outputs. The current rating of the power supply is 15A.

D. Image Processing

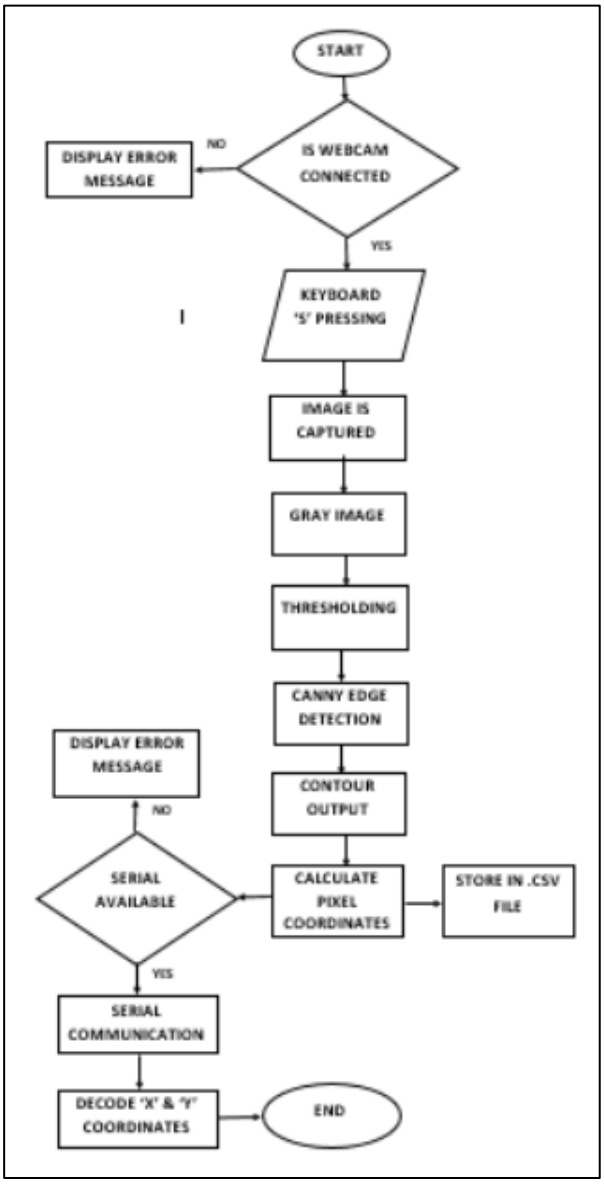

Fig 14: Image processing flow chart

As the above flowchart describes, the pixel coordinates of the edges of the captured image will be stored in separate arrays. Through serial communication, all the coordinates are transmitted. Since serial communication operates one char by char, encryption before transmission is applied and extraction of X & Y coordinates after transmission is necessary. OpenCV is stands for 'Open Source Computer Vision Library'. OpenCV has C++, C and Python interfaces running on various platforms such as Windows, Linus, Android. It has libraries in it that we can directly use. In my project, few images generated such as RGB image, Grayscale image and Binary image. First of all, the live video stream will open. We can set the background cleared before image is captured. When the user pressed 's' on the keyboard, it captures the image and save it for post processing. Next RGB image is converter into grayscale image using 'RGB2GRAY' function. To convert RGB to Gray image, first single pixel has three values: R (Red), G (Green) and B (Blue). To combine these three values into one single value, we average the R, G and B values. After getting corresponding one-pixel value, it is between 0 - 255 where 0 value is for black colour and 255 is for white colour. As the next step, we get the binary image. We set a threshold value between 0 & 255.Each pixel in the image is compared with the threshold value. Therefore, pixel values less than threshold value considered black while pixel values greater than threshold value considered white color. This 'threshold' helps to separate an image into white and black pixels only. After getting the binary image, canny edge detection is applied to identify the edges. Canny image is then used to find contours and draw contours of the image. These contour lines will be stored in a vector. Vector contains the pixel coordinates of the edge which is used for plotting. Contour lines will change its color if it breaks the contour line. These coordinates of the contour line are printed on the

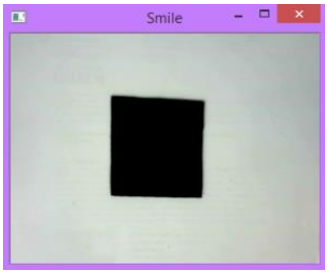

Fig 13: Video stream

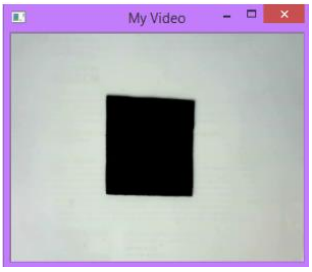

Fig 13: RGB image

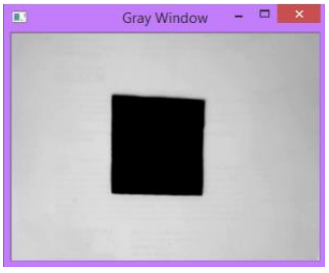

Fig 13: Grayscale image

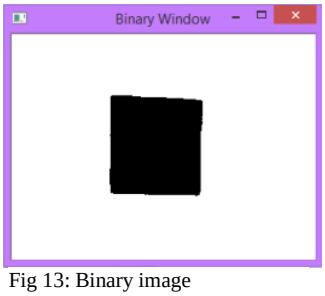

Fig 13: Binary image

OpenCV console. Next, calculated X and Y coordinates are sent through Serial communication as the following figure shows. X and Y coordinates are enveloped with two symbols and separated from another two symbols. Those are

for decrypt X and Y separately after receiving from Arduino. While sending coordinates to Arduino, it will be saved in a .csv file for plotting using MATLAB software. The following figure is snapshot of X & Y coordinates stored in excel file. For plotting in MATLAB software, the above coordinates can be transferred. Excel data is transferred to MATLAB software. By doing so, we have the advantage of verifying the input image.

IV. TESTING AND RESULTS

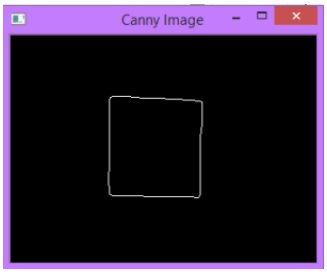

Fig 18: Canny image

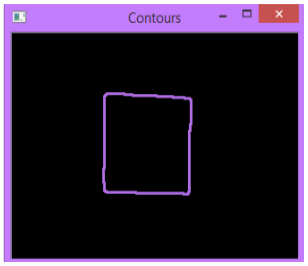

Fig 18:Contour image

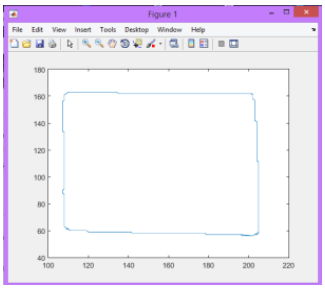

Fig 18: MATLAB file

	A	B
1	X_values	Y_values
2	197	56
3	196	57
4	179	57
5	178	58
6	142	58
7	141	59
8	120	59
9	119	60

Fig 18: Excel file

This section compares experimental and theoretical data. Results also included and calculating the overall system error is done.

A. *Position Control & Mapping*

Mapping ratio analysis

The image pixel resolution of the webcam image is 320 (pixel) x 240 (pixel). The dimensions of drawing area is 155 (mm) x 155 (mm).

Y direction analysis

Mapping ratio = (165/320) (*mm/px*) = 0.515625

X direction analysis

Mapping ratio = (160/ 240) (*mm/px*) = 0.666667

Theoretical average mapping ratio = ((0:515625+0:666667)/ 2) = 0.591146 (mm/ pixel)

B. *Error Calculations*

Y axis error calculation

Total distance of Y axis = 165 mm
Total no. of steps for Y axis = 66
Distance for single step = 2.5 mm

Experimental distance for 10 steps = 26 mm
Experimental distance for single step = 2.6 mm
Percentage Error for Y axis = (2:6 2- :6 2:5) ∗ 100 = 3.846%

X axis error calculation

Total distance of Y axis = 160 mm
Total no. of steps for Y axis = 64
Distance for single step = 2.5 mm

Experimental distance for 10 steps = 25.65 mm
Experimental distance for single step = 2.565 mm
Percentage Error for X axis = (2:565 2:565 -2:5) ∗ 100 = 2.53411%

Total error percentage for system = 6.38011%

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