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Machining A Component Using Vision Based 3-Axis Cartesian Robot

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Abstract

Manufacturing systems can be improved by the amalgamation of the intelligent control systems along with vision and image processing systems. This paper describes the machining of a component using vision based 3-Axis Cartesian robot. The main objective is to detect the profile of the object from the input image and determine its dimension for machining on the work piece. A web camera is used to capture the image of the object, a morphological image processing algorithm is developed to extract the profile and dimensions and finally a microcontroller based system is designed for controlling the end milling operation in X, Y, Z directions. The prototype is successfully designed, developed, tested and validated in real time for high speed machining.

Keywords: Cartesian Robot Manipulator, Computer Numerical Control, Matrix Laboratory, Charged Coupled Device, Automatic Computer Aided Design, Graphical User Interface.

Introduction

Removal of undesired material from the work piece to produce final shape of the product is known as machining. CNC machines are regarded as the most suitable machines for industrial purpose because of their stiffness and surface accuracy. Yet these are expensive and require a large amount of floor space. Machining by industrial robots can be a better option over CNC machining as it gives more flexibility. With the change of tool, it can perform various operations and is easily reprogrammable. But the only major disadvantage of robots in machining is its low stiffness. Industrial robots are efficient enough for machining operations like milling, drilling, broaching, grinding etc.

A Cartesian robot or linear robot is an industrial robot having three sliding or prismatic joints whose three principal axes are linear and are at right angles to each other i.e. in X, Y, Z directions. The simplest application is used in milling and drawing machines. The designed Cartesian coordinate robot uses four perpendicular slides to construct the x, y and z axes. Two perpendicular slides are in x axis for forward and reverse movement, one slide is in y axis for left and right movement and the fourth slide is in z axis to control the depth i.e. up and down movement. By moving the four slides relative to one another, the robot is capable of milling operation within a rectangular work envelope.

End milling is a special kind of milling process similar to drilling operation with the advantage of machining in all directions including axial direction. End milling by robots offer numerous advantages over CNC machining in terms of flexibility and affordability. Basically for this operation, robot takes the input dimension to make the desired profile on the work piece which is often erroneous. A Sensor based compensation method can offer higher position accuracy but they are very difficult to implement on an existing robot manipulator. Even though a sensor installation is possible, the final system cost becomes expensive because of the sensor cost. This makes the sensor based methods more suitable for high accuracy discrete processes such as drilling; thus it is a need to introduce a practical vision based method to improve the machining for complicated as well as simple profiles. This paper describes the generation of profile without taking the manual dimensions. The robot takes the image of the profile to be generated, extracts the dimensions and machines accordingly.

Industrial robots generally deviate from the desired path because of low stiffness and strong forces. Olof et al., [1] described that this problem can be solved by implementing a continuously modifying robot trajectory stiffness model. The feed rate also can be tuned by adjusting the weights. This simulation can be designed by MATLAB Simulink. The implementation was done in various milling processes and materials to observe the parameters of machining and the performances. Hui Zhang et al., [2] presented the critical issues and the means to improve robotic machining performances compared with CNC machines. The setup of a milling test was developed with a fixed spindle on the robot arm and the work piece was fixed on a steel table. The cutting force was regulated in spite of the variance of depth of cut when the force control was activated, resulting a great reduction of machine cycle time. The different conditions that limit the robots in robotic machining applications are proposed by Claudiu et al., [3]. KUKA KR240-2 equipped with a HSM Spindle was considered for the dynamical behavior analysis. The self-excited frequencies were determined and the dynamical vibration of the structure was studied. Jianjun Wang et al., [4] proposed a constant joint stiffness model, which accounts for the tool center point deflection and minimization of its computation time. A PI control strategy was developed for the adjustment of cutting feed rate based on measured cutting force resulting a minimized cycle time with optimized material removal rate. Another similar work of Jianjun Wang et al., [5] presented a practical method to compensate the robot deformation caused by the machining force. This model implemented feed forward compensation scheme to the robot controller to compensate the deformation of aluminum sheets.

Sabri and Ray-long [6] also developed a three dimensional cutting force dynamics of end-milling operation. A self-tuning PI control proposed by Jianmin He [7] can be effective for regulating cutting forces during the robotic machining process. A self-tuning PI control with anti-windup scheme was developed for the force regulation. The developed system showed a satisfactory control performance and system stability throughout the end milling process by the robot ABB IRB 6400. Jean et al., [8] studied and highlighted the influence of the geometric configuration of the robot arm of KUKA KR_240_2on the overall stiffness of the system. This study described the robotic machining vibrations in various directions of movement in milling process. Zengxi and Hui [9] developed a real-time compensation algorithm based on a robot stiffness model and force control scheme to overcome the reasons of low surface quality in robotic machining processes and also analyzed the stiffness properties of robot structure. This proposal resulted a much better surface without extending the process cycle time. John et al., [10] studied the pros and cons of penetration of industrial robots in the field of machining. According to them industrial robot technology could provide an excellent base for machining as it's both flexible and cost efficient unlike CNC machines. However they lack positional accuracy and the stiffness.

Xuecai et al., [11] proposed an approach based on polynomial approximation to calibrate and verify the relationship between distance accuracy and positioning accuracy for robotic manipulators. Distance error of a PUMA 560 industrial robot can be compensated by utilizing singular value decomposition. Taj Mohammad et al., [12] developed Kinematics and Dynamics model for a CRM interfaced a 3-axis controller. The developed model and controller were programmed in C++ language. A. Altintas [13] described the actuation of both the 3-axis cylindrical and Cartesian coordinate robot manipulators by the stepper motors and a GUI with a programming page driven from MATLAB program are developed for programming and controlling the designed robot manipulators. Stepper motors, unipolar type with two phases, can be run at different drive modes. Linear motions of the Cartesian robot were performed with the ball-screw nut systems whereas rotary motion in cylindrical robot design is realized with a timing belt. Naife A. Talib [14] described the effect of cutting speed and feed rate on tool life at constant depth of cut with no cooling fluid. Kenneth and Melvin [15] proposed an algorithm for straight line and circular interpolation without involving complex trigonometric formulae for Programming in numerical control and adaptive numerical control.

Anayet et al., [16] studied the characteristic features produced by machining processes like shaping, end milling, and horizontal milling. An automated system was developed to classify machined plates into three categories. The process developed is very economical and simple technique and requires a metallurgical microscope of reasonable magnification and computing facilities for completing the analysis. Othman and Amirasyid [17] proposed an image-processing approach for the detection of chatter involved in a turning process by evaluating the surface roughness of a turned work piece. Chatter is detected by first establishing the correlation and comparison between the surface roughness and the vibration level. The arithmetic average of gray level was computed along with variance, mean, and optical roughness parameter of the intensity distributions was calculated. A second-order histogram or co-occurrence matrix of the images was used to analyze the surface texture.

Elias et al., [18] surveyed on industrial vision system involving most contemporary software and hardware tools like image sensors, software and hardware technology, vital issues and directions for designing and developing industrial vision system. Xiaoyan et al., [19] composed a system involving two parallel line scan CCD cameras, a wide field illumination to overcome the vibration of tinplate and neural network based software. The images of tinplate were captured by cameras to detect the defects such as pinholes, scallops, dust and scratches and their features were extracted. Alexandru and Theodor [20] presented a numerical control tool path generation strategy based on image models for design part and cutting tool. It involved pixel-based simulation of the milling process with tool engagement control for arbitrarily geometry, to reduce the machining time and tool wear.

The objective of the present work, derived from above literature review concludes that by implementation of vision system in robot machining can make it more robust in operation as well as it can improve the cost effectiveness of the operation. A three axis Cartesian robot with vision application is proposed here for the end milling operation. This paper is to poses a stabilized robot model as it leads to reduce machining errors due to structural deformation as much as possible, and hence 3-axis Cartesian robot is selected which is considerably having higher kinematical stiffness than other type of robot configurations. So high stiffness robot design is to be developed for analyzing the process of machining errors, and with the results obtained a real-time compensation algorithm based on a robot stiffness model and force control scheme is to be introduced without extending the process cycle time. And a robot vision implementation makes it more feasible as the robot captures the image of the profile is to b machined on the work piece and determines the profile as well as the dimension satisfactorily.

The methodology which is used for identifying the problem statement first and then need of the project to be identified, followed by developing the design of 3-axis Cartesian Robot is made using Solidworks 2013. A web camera is interfaced to capture the image of the object, morphological operations are implemented to detect the profile of the image and appropriate image processing using MATLAB 2013a is done to measure the dimension of the profile detected. The micro controller board is developed using Arduino Atmega162v and respective driver circuits, with integrated software to communicate with PC which takes the input dimension from the image to machine the profile on the desired work piece. The Cartesian robot is controlled online by a Personal Computer through Microcontroller board acting as intermediate communicator. The Microcontroller gets feedback from the image and providing data to controlling software to machine the profile. Simultaneously it receives operating signal from software and provides controlling signals to 3-axes motors of the robot.

System Design and Development

Firstly the overall view of the three axes Cartesian robot was designed in AutoCAD 2013 including all the parts such as base, frame, driving mechanism and the motors. It depicts the rough idea of the parts involved, parts quantity, and their varieties in brief. Figure 1 shows the AutoCAD model of the Cartesian robot with its all components like motors, lead screw, cross rail, guide rail, supporting frame, end mill tool, base, bearing and the control unit.

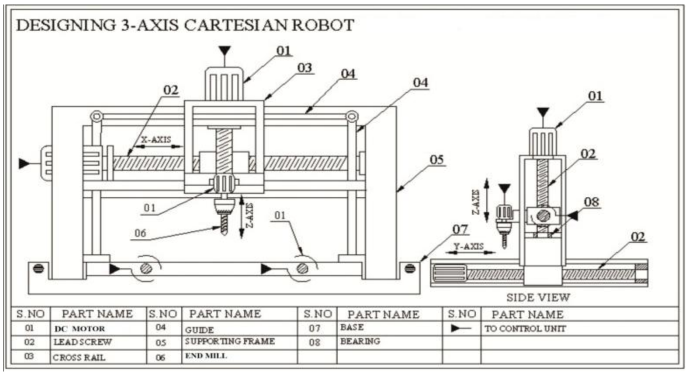


Figure 1: Design of a Cartesian Robot for End Milling Operation

Modeling and analysis of the Cartesian Robot

The Robot Model was done in Solidworks 2013.Figure 2 shows isometric view of Cartesian robot considering manufacturer's manual and analytical data from the obtained experimental data of making different types of cuts in different types of woods no force over than 31N was observed, and cuts with forces greater than 27N resulted in unacceptably bad surface finish, so maximum of 50N cutting force was opted and applied to all the axis movements for the software analysis. The final developed model of Cartesian robot is shown in Fig. 2.

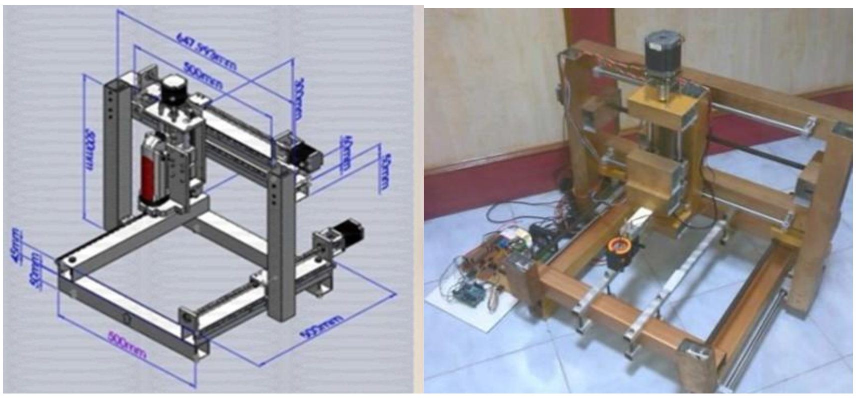


Figure 2: Isometric and developed Model of the Cartesian robot

The Cartesian robot is designed in such a way that the end effecter moves through 300 mm workspace coverage in X-axis and Y-axis. The Z-axis movement is constrained to 150 mm workspace coverage.

Solidworks2012 Analyzed Reports for X-Axis, Y-Axis, and Z-Axis Frames
Figure 3-4 are the representation of Solid works 2012 analyzed plots for X, Y, Z-Axes Frame for its respective simplified model and Table 1-3represent mesh information for X-Axis, Y-Axis and Z-Axis respectively.

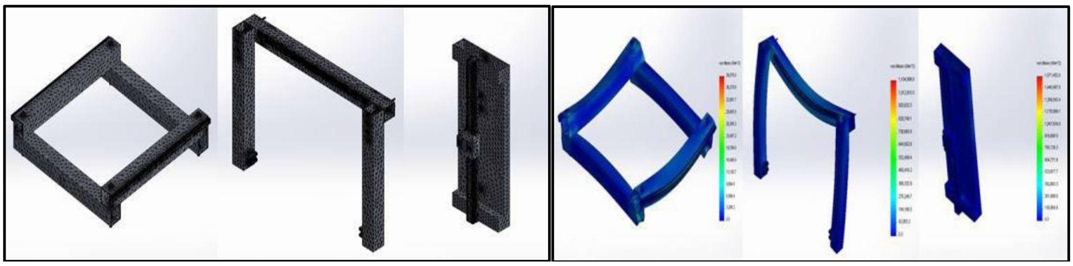


Figure 3: Mesh Details &Von Mises Stress Plot for X, Y, and Z Axes Respectively

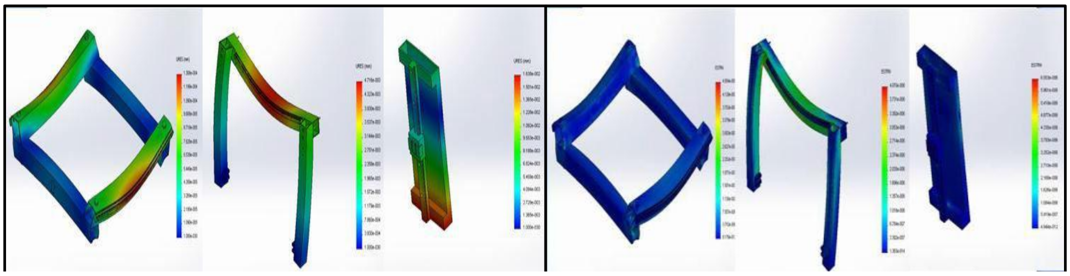


Figure 4: Resultant Displacement &Equivalent Strain Plot for X, Y, and Z Axes Respectively

Table 1: Mesh Information for X-Axis

Mesh type	Solid Mesh
Mesher Used:	Curvature based mesh
Jacobian points	4 Points
Maximum element size	18.445 mm
Minimum element size	3.68901 mm
Mesh Quality	High
Remesh failed parts with incompatible mesh	On

Table 2: Mesh Information for Y-Axis

Mesh type	Solid Mesh
Mesher Used:	Curvature based mesh
Jacobian points	4 Points
Maximum element size	16.5414 mm
Minimum element size	3.30827 mm
Mesh Quality	High
Remesh failed parts with incompatible mesh	On

Table 3: Mesh Information for Z-Axis

Mesh type	Solid Mesh
Mesher Used:	Curvature based mesh
Jacobian points	4 Points
Maximum elementsize	8.25962 mm
Minimum element size	1.65192 mm
Mesh Quality	High
Remesh failed parts with incompatible mesh	On

Calculation and Selection of Motor

The input torque has several different components. The largest is the torque required to overcome gravitational and cutting forces. Once those forces were estimated by experimentation they were input into Eq. (1)

$$\tau\ external = \frac{(Fgravity + Fcutting)\ell}{2\pi\eta} \quad (1)$$

After consultation with manufacturer catalogue, an efficiency of 90% was used. Then external major torque component is that due to friction from the pre-loaded ball nut is given as in Eq. (2) as above. The sum of the external torque and the torque due to pre-loading is the required continuous torque of the motor. The intermittent torque requirement is the sum of the continuous torque and the acceleration torque. The acceleration torque is found with Eq. (3) and the maximum operating speed of the motor was calculated with Eq. (4) as follows:-

$$\tau\ pre\text{-}\ load = \frac{\ell Fpre - load}{40\ \pi\sqrt{}\ (\tan(\beta))} \quad (2)$$

$$\tan(\beta) = \frac{\ell}{\pi dball - circle} \quad (3)$$

$$\omega = \frac{2\pi x}{\ell} \quad (4)$$

These calculations were performed for the three axes and the results are summarized in Table4 as follows:-

Table 4: Calculated Motor Torque details of all 3 axes

	Y-Axis	Z-Axis	X-Axis
External Torque	4.95Nm	0.18Nm	0.11Nm
Pre-Load Torque	1.69Nm	0.08Nm	0.09Nm
Continuous Torque	6.64Nm	0.25Nm	0.20Nm
Acceleration Torque	1.26Nm	0.05Nm	0.02Nm
Intermittent Torque	8.61Nm	0.30Nm	0.21Nm
Maximum Operating Speed	952.2rpm	3808.8rpm	1904.4rpm

After considering all stress, strain, torque and material deformations the robot frame and structure were developed. A variety of materials have been used in the building of Robots. Its frame materials need to have some strength in order to support the weight of the gantry and the cutting head as well as withstand forces resulting from the milling process.

The properties that were gathered include the modulus of elasticity, yield strength, and density. The ratio of the modulus of elasticity to density was calculated to give an indication of stiffness and the ratio of yield strength to density was found to give a strength value relative to weight. The structure of the robot is made up of Mild Steel for self-weighting and base stiffness, and rest with aluminum for its light weight and rigidity.

Programming and Interfacing

The program for Arduino is developed in MATLAB 2013a and the code was debugged, compiled and then uploaded to Atmega8 Arduino Board for image processing and Cartesian movement for end milling operation. The Arduino is programmed in such a way that it has a continuous communication with interfacing circuits and Cartesian robot controller software. It simultaneously gets data from software and machines the received data. The Cartesian robot controller software is designed in such a way that the robot can be controlled either manually or automated. The start and end points of end effecter to move is initialized. Whether the radius is given or not defines the linear or circular interpolation to be used. The spindle speed can also be controlled through software. There is a provision for displaying the current motor direction by one LCD.

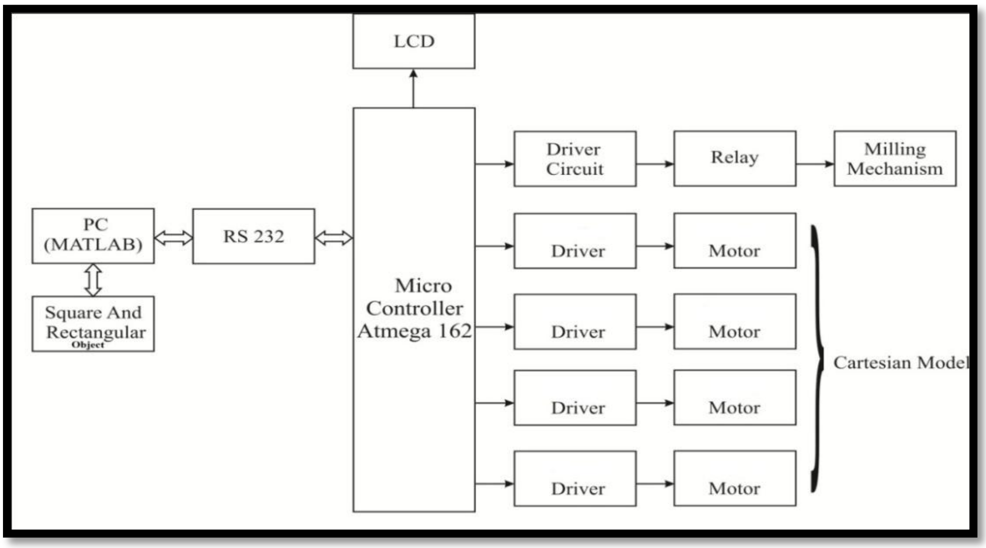


Figure 5: Block Diagram of Electronics Components

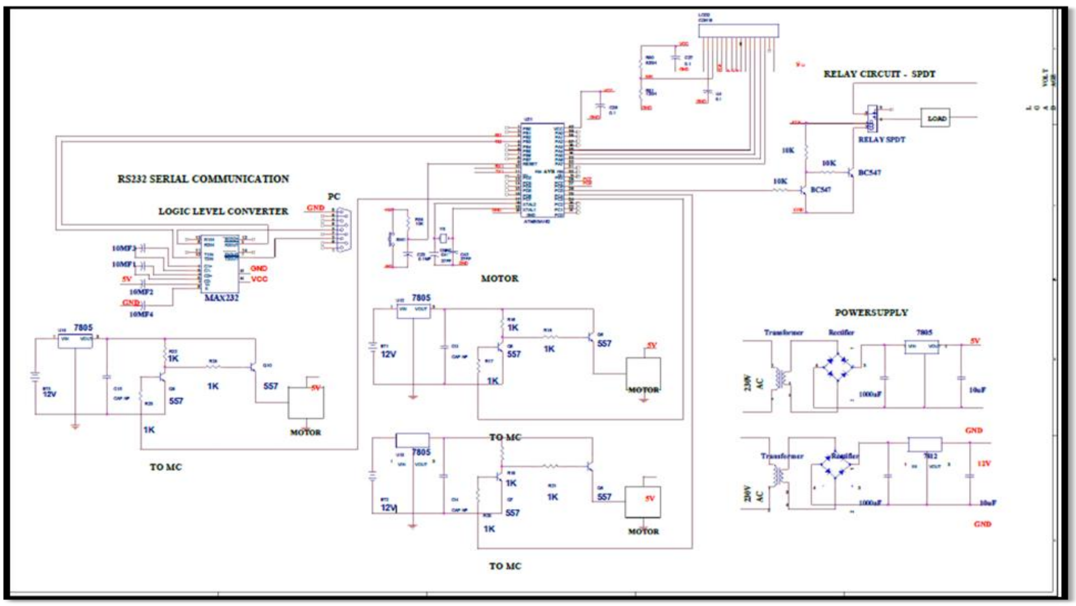


Figure 6: Circuit Diagram of Cartesian Robot Control

Shape Perception and Dimension Extraction by Image Processing

The image of the object captured by the camera consists of various noises hence it needs to be filtered and resized according to the desirable conditions. The image is processed using MATLAB 2013a to detect the shape and the dimension of the object. The image processing basically involves two major operations:-

Morphological Operation

It is a collection of techniques that deals with the shape or morphology of features in an image. Basically it aims to remove the imperfections of the image. It relies only on the relative ordering of pixel values, not on their numerical values, especially suited to the processing of binary images. This technique probes an image with a small shape or template called a structuring element and the structuring element is positioned at all possible locations in the image and it is compared with the corresponding neighborhood of pixels.

Gradient Operation

An image gradient is a directional change in the intensity or color in an image. It is used to extract information from images. It is a 2D vector with the components given by the derivatives in the horizontal and vertical directions. The gradient vector points in the direction of largest possible intensity. The length of the gradient vector corresponds to the rate of change in that direction. Mathematically

$$\Delta f = (\partial f/\partial \chi) .X + (\partial f/\partial y). Y \qquad (5)$$

$(\partial f/\partial \chi)$ is the gradient in the x direction and $(\partial f/\partial y)$ is the gradient in the y direction. The gradient direction can be calculated by the formula:

$$\theta = \text{atan2}\left((\partial f/\partial y), (\partial f/\partial \chi)\right) \qquad (6)$$

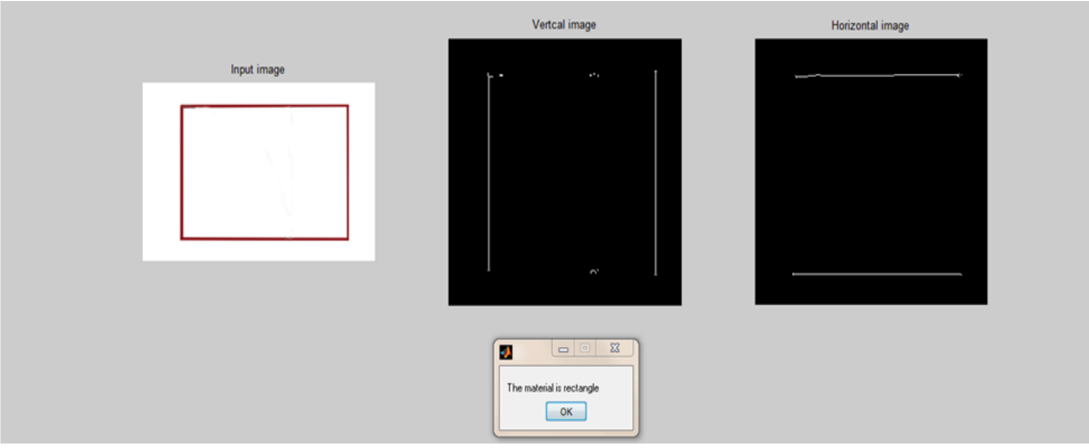
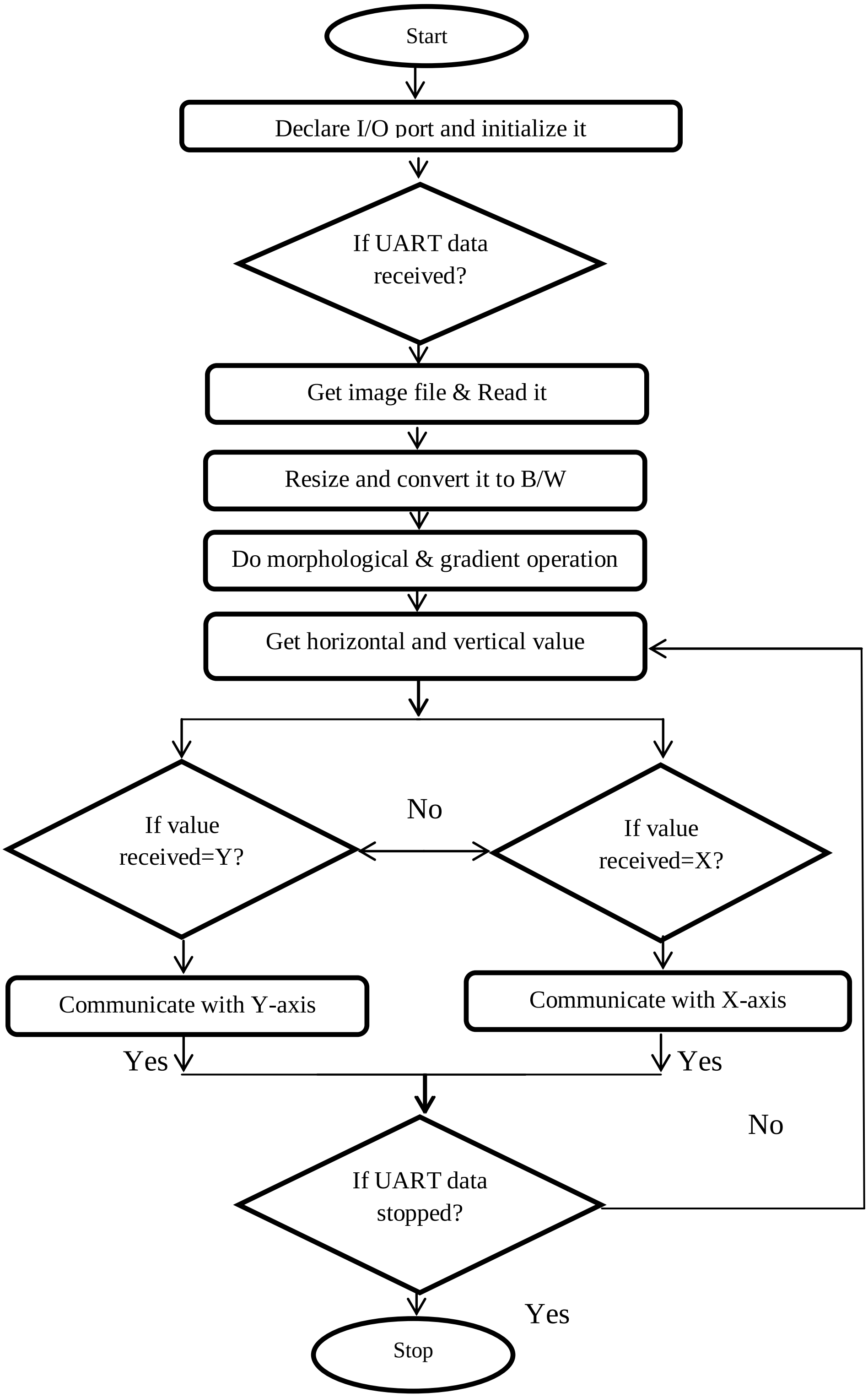


Figure 7: Matlab O/P for shape perception along with vertical and horizontal length

Flow Chart of Working Mechanism



Algorithm for end milling operation

1. Home position (X1, Y1, Z1), the right top most point is defined.
2. Variables to be initialized such as to set the current relative position (X2, Y2, Z2) of the tool to (0, 0, 0). This effectively sets the current tool position to the starting point.
3. Web Camera is fitted properly considering the height distance and the light intensity and other noise conditions to capture the image of the profile.
4. The captured image is given as an input and this image is processed by MATLAB for filtration and enhancement.
5. Image is resized to required dimensions, horizontal and vertical pixels are computed to get the dimension and predict the image profile by doing morphological and gradient operations.
6. When horizontal length data is received, Y-axis motor is activated to move from left to right and when the vertical length data is received, X- axis motor is activated to move forward and reverse.
7. With the dimension extracted from the image, the machining is done successfully by moving the tool in respective directions.

Results and discussions

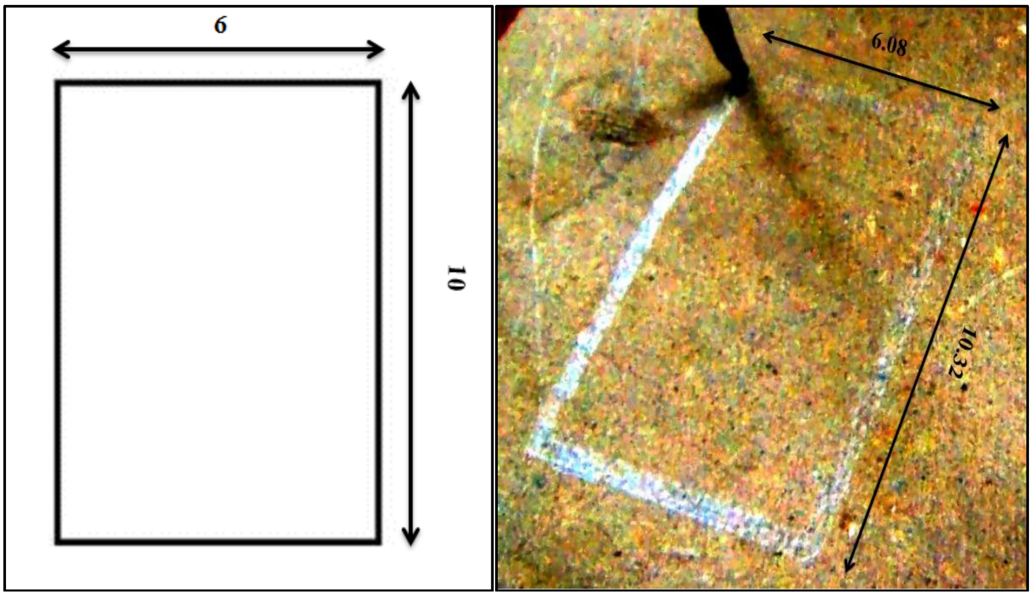


Figure 8: Input and Output image with respective dimensions

The machining is carried out by taking various images of various dimensions and the machined part dimensions were noted down for percentage error analysis. The above figure 8 depicts the input image given to the system and the output image taken after machining the part.

Table 5: Input and Output dimensions with error percentage

Input Dimensions(cm)		Output Dimensions (cm)		% Error	
Horizontal	Vertical	Horizontal	Vertical	Horizontal	Vertical
6	10	6.08	10.32	1.3	3.2
7.5	12	7.64	11.68	1.8	2.6
8	8	7.81	7.81	2.3	2.3
10	12	10.33	11.74	3.3	2.1
15	20	14.68	20.45	2.1	2.2

The above table 5 compares the input and output dimensions observed from the machining. There is a variation of dimension is observed because of the change of the light intensity and the height of the camera capturing the images. At optimal height and optimal light intensity this experiment provides an error percentage ranging from 1- 5%.

Conclusion

Cartesian robots are the simplest of all stationary robots to build by own. Theoretically, one can buy components needed and assembled to make a Cartesian robot. FESTO, EPSON, BOSCH are a few of the manufacturers of Cartesian robots. Although programming is not an easy task yet a Cartesian robot could be programmed manually. Lastly because of their relative simplicity, Cartesian robots are cheaper than other ones. Now coming to the cons, the work envelope is not ideal. Also, the possibilities of tool orientation are very limited. Though it is possible to make a Cartesian robot with a fourth rotary axis but still it lacks the movement needed for operations like welding.

Taking these issues into consideration a conclusion can be drawn that a typical robot of Cartesian type can be the cheapest solution for simple machining operations and pick and place operations. For example - gluing, sorting, soldering &palletizing etc. With the application of robot vision makes it more robust and cost effective as it doesn’t include any complex sensor or high end software.

References

[1] Olof Sornmo, Bjorn Olofsson, Anders Robertsson, Rolf Johansson., 2012, “Increasing Time-Efficiency and Accuracy of Robotic Machining Processes Using Model-Based Adaptive Force Control,” 10th IFAC Symposium on Robot Control., pp.543-548.

[2] Hui Zhang, Jianjun Wang, George Zhang, Zhongxue Gan, Zengxi Pan, Hongliang Cui, Zhenqi Zhu., 2005, “Machining with Flexible Manipulator: Toward Improving Robotic Machining Performance,” International Conference on Advanced Intelligent Mechatronics., pp. 1127-1132.

[3] Bisu Claudiu1, Cherif Mehdi, Gerard Alain And Knevez Jean, Yves.,2011 “Dynamic behavior analysis for a six axis industrial machining robot,” Advanced Materials Research, Vol. 423., pp. 65-76.

[4] Jianjun Wang, Hui Zhang, Zengxi Pan., 2006, “Machining with Flexible Manipulators: Critical Issues and Solutions,” Industrial Robotics: Programming, Simulation and Application, pp. - 515-536.

[5] Jianjun Wang, Hui Zhang, Thomas Fuhlbrigge., 2009, “Improving Machining Accuracy with Robot Deformation Compensation,” International Conference on Intelligent Robots and Systems, pp. 3826-3831.

[6] Sabri Ceaankunt, Ray-Long Tsai., 1990 “Position Error Compensation of Robotic Contour End-Milling,” International Journal of Machine Tools and Manufacture, Vol. 30, pp. 613–627.

[7] Jianmin He, Zengxi Pan, Hui Zhang.,2007, “Adaptive Force Control for Robotic Machining Process,”American Control Conference, pp. 1-6.

[8] Jean-Yves Knevez, Mehdi Cherif, MironZapciu, Alain Gerard., 2010, “Experimental Characterization Of Robot Arm Rigidity In Order To Be Used In Machining Operation,” 19th International Conference on Manufacturing System, pp. 153-156.

[9] Zengxi Pan, Hui Zhang., 2009,“Improving robotic machining accuracy by real-time compensation,” ICCAS-SICE International Joint Conference, pp. 4289-4294.

[10] John Pandremenos, Christos Doukas., 2011, “Machining With Robots: A Critical Review,” 7th International Conference on Digital Enterprise Technology, pp. 28-30.

[11] Xuecai Zhou, Qixian Zhang, William A. Gruver, GongliangGuo.,1994, “Distance and Positioning Accuracy for Robotic Manipulators,” Intelligent Robots and Systems and Advanced Robotic Systems and the Real World, pp. 1399-1404.

[12] Taj Mohammad Khan, Muhammad Arshad, Ahmad Choudhry., 2005, “Modeling and Control of Cartesian Robot Manipulator,” 9th International Multitopic Conference, pp. 1-4.

[13] A. Altintas., 2010, “A New Approach to 3-Axis Cylindrical and Cartesian Type Robot Manipulators in Mechatronics Education,” Electronics and Electrical Engineering, pp. 151-154.

[14] Naife A. Talib., 2010, “Studying The Effect Of Cutting Speed And FeedRate On Tool Life In The Turning Processes,”Diyala Journal of Engineering Sciences, pp. 181-194.

[15] Kenneth, Melvin Goldberg., 1983, “XY Interpolation Algorithms”, Robotics Age, pp. 22-25.

[16] Anayet U. Patwari, Muammer D. Arif, Md. S. I. Chowdhury, N. A. Chowdhury., 2012, "Identifications of Machined Surfaces Using DigitalImage Processing," International Journal of Engineering, pp. 213-218.

[17] Othman O. Khalifa, AmirasyidDensibali, WaleedFaris., 2006, "Image processing for chatter identification in machining processes,"International Journal of Advanced Manufacturing Technology, pp. 443–449.

[18] Elias N. Malamas, Euripides G.M. Petrakis2, MichalisZervakis, Laurent Petit, Jean-Didier Legat., 2003, "A Survey on Industrial Vision Systems, Applications andTools,"Journal of Image and Vision Computing, vol. 21, pp. 171-188.

[19] Xiaoyan Deng, Xiaojuan Ye, Jinsheng Fang, Chun Lin, Lei Wang., 2010, "Surface Defects Inspection System Based on Machine Vision,"International Conference on Electrical and Control Engineering, pp. 2205-2208.

[20] Alexandru Dumitrache N, Theodor Borangiu., 2012, "Image-Based Milling Tool Paths with Tool Engagement Control For Complex Geometry," Engineering Applications of Artificial Intelligence, pp. 1161–1172.