Australian Journal of Basic and Applied Sciences, 11(5) April 2017, Pages: 126-132

AUSTRALIAN JOURNAL OF BASIC AND APPLIED SCIENCES

ISSN:1991-8178 EISSN: 2309-8414
Journal home page: www.ajbasweb.com

Three Degree of FreedomDelta Robot, Design, Control, and Implementation for Educational Purposes

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ARTICLE INFO

Article history:
Received 18 January 2017
Accepted 28 March 2017
Available online 1 May 2017

Keywords:
Delta, Parallel robots, computer control, Workspace, Kinematics

ABSTRACT

Computer control labsat Palestine Polytechnic university consists of different control plants including 3DOF linear systems, also single, and double inverted pendulums. For the educational need of applying control techniques on parallel robots; Delta robot is to be implemented. A 3DOF Delta robot is implemented to provide 3 translational motions in xyz directions. The design itself is considered to fit well in lab environment and support future educational use. Different design issues are also tackled including choosing the right dimensions of connecting links, end effecter, and robots upper plate and choosing the appropriate joints. Independent joint control technique was used to move end effector to a desired position. Robot is first modeled through SOLIDWORKS computer aided design software. Further, Different analysis are done including design, and workspace analysis. Delta robot is then provided with different interacting elements including keypad, LCD display, and computer GUI; so students can interact easily with the robot. Design elements are made available openly for students to reach and work through so they can understand, interact, and apply knowledge and techniques on the robot.

INTRODUCTION

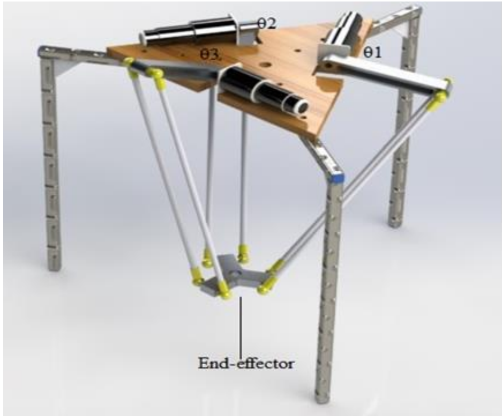
Delta robot is a parallel robot. It is a closed loop chain mechanism characterized by high rigidity, speed, and accuracy. The use of delta robot is becoming increasingly popular in the fields of machining, packaging and more applications summarized byMerlet (2006). Delta robot consists of 3 chains, end effector and base as shown in
Fig. 1. Each chain includesone active revolute and two passive universal joints. The base has the motors mounted on it and thus motors weight have no effect upon moving parts. The three chains connect the end effector and the base.

Delta robot was first designed in early 90s by a research team at EPFL, Switzerland by Staicus&Carp-Ciocardia (2003). It was designed to manipulate light small objects at high speeds. Which was an increasing demand of industry at the time. Three rotating motors are controlled to move the end effector in the x, y and $z$axes. Motors are mounted uniformly around robot's center as shown in Figure1. One of Delta robots design feature is end effector always maintain a parallel position to the base as shown by Alashqar (2013). Different previous studies were considered when delta robot was implemented including the work of Stan *et al*. (2011). and Mohsen *et al*. (2013).

This paper presents an educational delta robot which was originally designed and implemented by undergraduate students in the mechanical engineering department at Palestine Polytechnic University (PPU).

To Cite This Article: Humam Abu-Alkebash, Abdallah Bader, IyadHashlamon., Three Degree of FreedomDelta Robot, Design, Control, and Implementation for Educational Purposes. ***Aust. J. Basic & Appl. Sci.,*** *11(5): 126-132, 2017*

This educational delta robot is explored from different aspects including mechanical design, sensors, microcontrollers and possible control techniques. Some experiments are shown too. The robot is actuated using DC servo actuators connected directly to the active revolute joints. Each actuator has an attached encoder for joint position measurements. A three axes accelerometer is mounted on the end effector. The control and data acquisition hardware are mainly based on microcontroller.



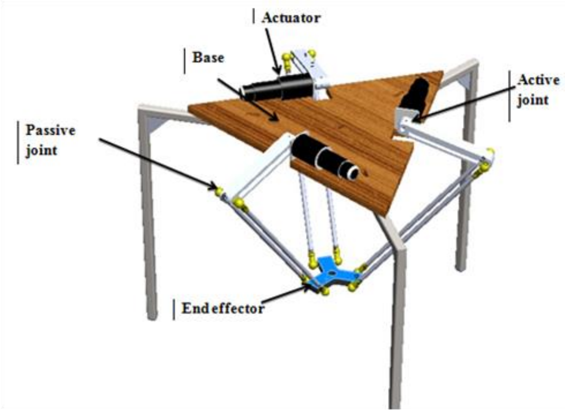


Fig. 1: 3D CAD model for delta robot

MATERIALS AND METHODS

Delta Robot for Educational Purpose:

For the availability of different open source information on delta robot at PPU; delta robot was built to be an educational platform for different levels of higher studies including bachelor and master level of mechatronics. Available open source information including kinematics, CAD, dynamic models, control algorithms, programming codes, and different analysis of delta robot makes it a great value of being an educational platform. This means students can apply different knowledge and engineering techniques on such a platform,including applying different control techniques and understand different design concepts. This educational platform gives the students the chance to test and validate different applications using SimMechanics tool box through MATLAB combined with SOLIDWORKS. SimMechanics provides a detailed description of delta robots mechanics extracted from MATLAB; thus input torques can be applied on active joints. This means different controller designs can be tested in a simulation environment before applying on the actual hardware.

Furthermore, the Delta robot was equipped with Arduino MEGA ADK microcontroller, current sensor, Ethernet shield and 3-axes accelerometer. A graphical user interfaceGUI was built for more interacting options through computer. Where students can enter different positions and observe how delta robot moves through different set of locations. And to be more realistic, a keypad is attached with an LCD so that the students can interact with delta robot for commanding and observing the data. Different buttons are added including, a start, stop, and emergency buttons.

Mechanical Design and Hardware:

The robot was first modeled through SOLIDWORKS CAD software. Where drawings are available for students to learn several design concepts; including designing for workspace, checking for reachability, applying new dimensions, and applying different materials. The robot is composed of a fixed wooden plate (base),supported by three stands.End effector and connecting links are made from aluminum for its relative light weight and high strength.

The base shape is triangle, each side is 555 $[mm]$ and thickness 20 $[mm]$ as inFig. **2**. The base is fixed to the three legs made by steel as shown in**Error! Reference source not found.**. The width of the leg is 300 $[mm]$ and the height is$550[mm]$. The cross section of the steel structure is square with dimension$20x20$ $[mm^2]$.

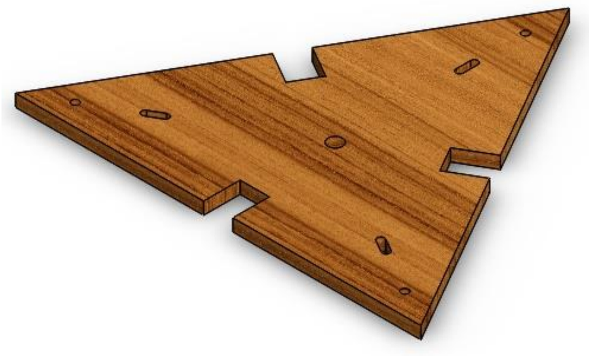


Fig. 2: Base

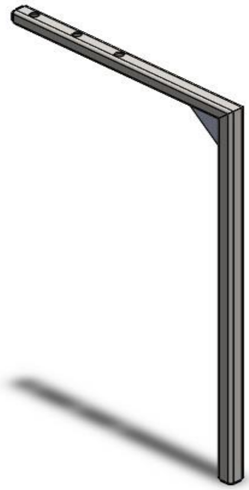


Fig. 3: Structure

The upper links, lower links and the end–effector all are Aluminumwith dimensionsas in Fig. 4, Fig. 5 and Fig. 6 respectively. The mass of upper and lower links are 190 $[g]$ and 55 $[g]$ respectively. The end-effector has a mass of 196 $[g]$**.** The bearings are ball bearings made from aluminum and each bearing has a mass of 24 $[g]$ as in Fig. 7. The final robot after assemble is shown in
Fig. 8 and the real robot is shown in Fig. 9.

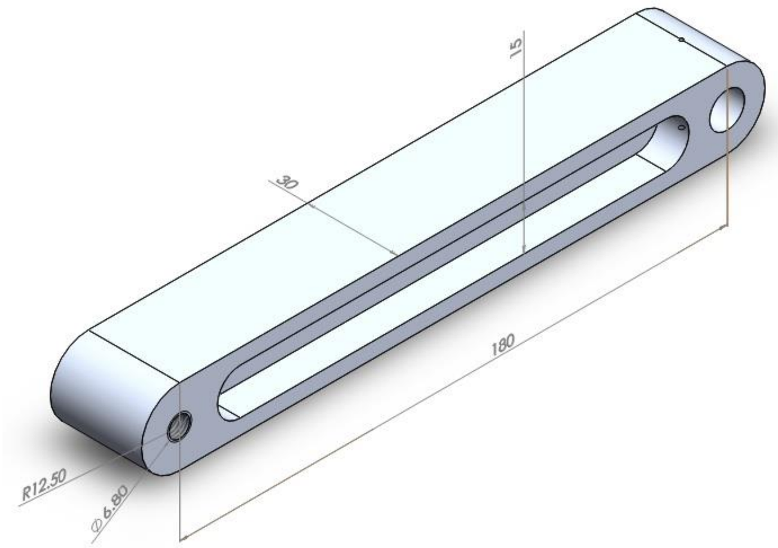


Fig. 4: Upper link

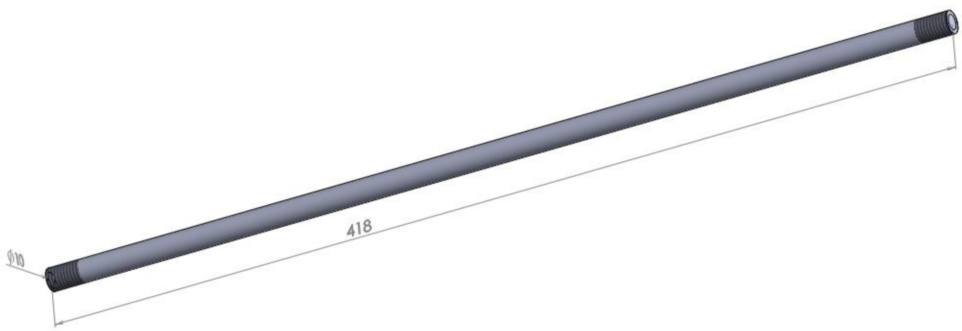


Fig. 5: Lower link.

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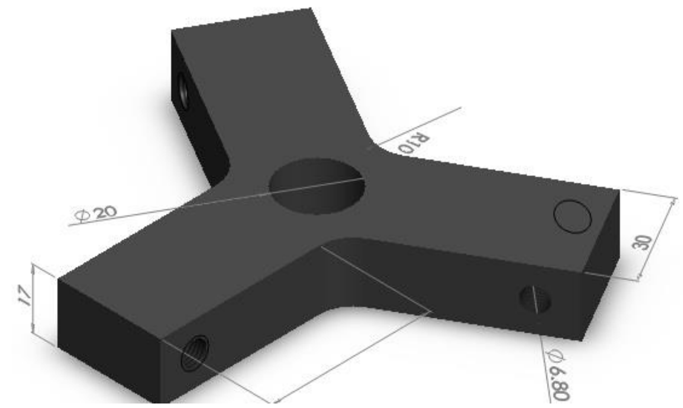

Fig. 6: End-effector

Fig. 7: Ball joint bearing

Fig. 8: Delta robot after assembly

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Fig. 9: Real Design for 3DOF Delta Robot at PPU

Workspace:

Delta robot workspace is shown inFig. **10**. There are different elements that limits delta robot's workspace including, lengths of connecting links, and the presence of singularities, discussed by Lopez *et al*. (2005).

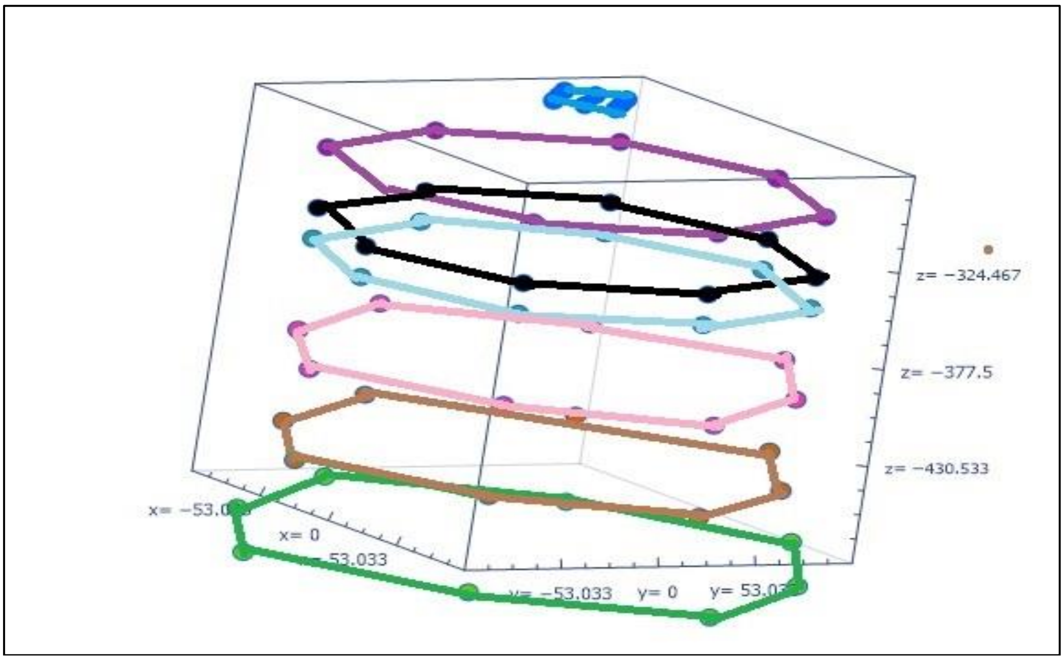


Fig. 10: Workspace of delta robot in xyz directions

Controller:
The control can be in the joint space or in the task space, therefore, forward and inverse kinematics are required and obtained using the same procedure as in Alashqar (2013). For demonstrating task space motions, feedback control technique was applied upon each motor independently considering two states of which are angular speed and angle of each active joint. GUI was made to operate in software environment to make it easier for user to enter new positions of end effector through keyboard and to monitor new positions of end effector. The control in this paper is in the joint space, the desired position is entered in the task space, then it is transformed into angles through inverse kinematics equations, each motor is then controlled to reach the new desired angle. Feedback control was applied upon each motor to reach the desired angle. Overall controller design is shown in Fig. 11.

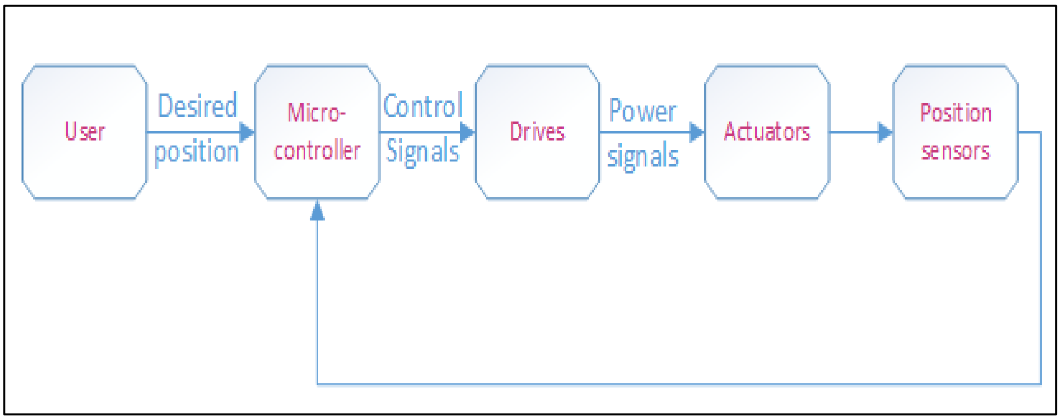
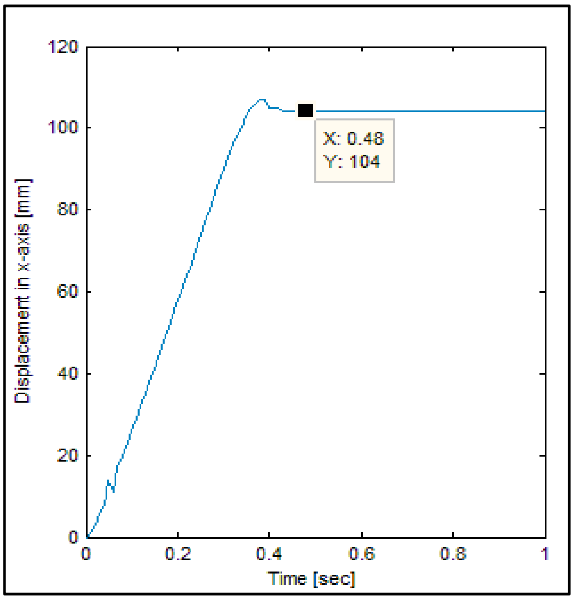


Fig. 11: Overall control block diagram for delta robot

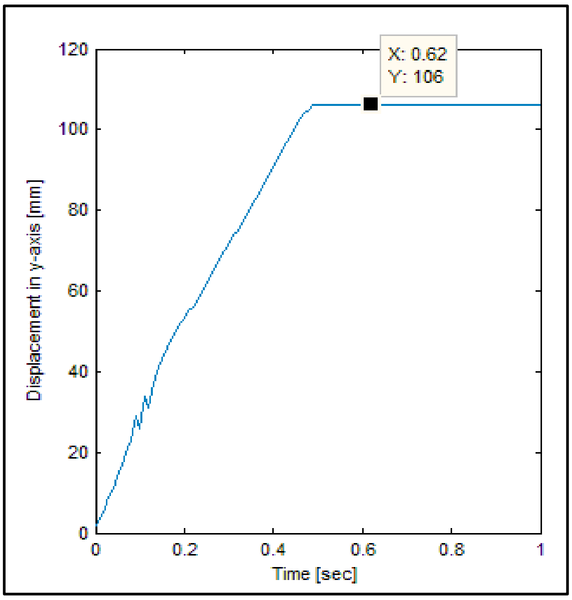
RESULTS AND DISCUSSION

Step displacement in xyz directions are commanded from a starting position of (0,0,-333) referred to the center of the fixed base, the case at which each active joint angle is zero; upper links are horizontal. Step inputs of $100[mm]$are applied in each xyz directions.

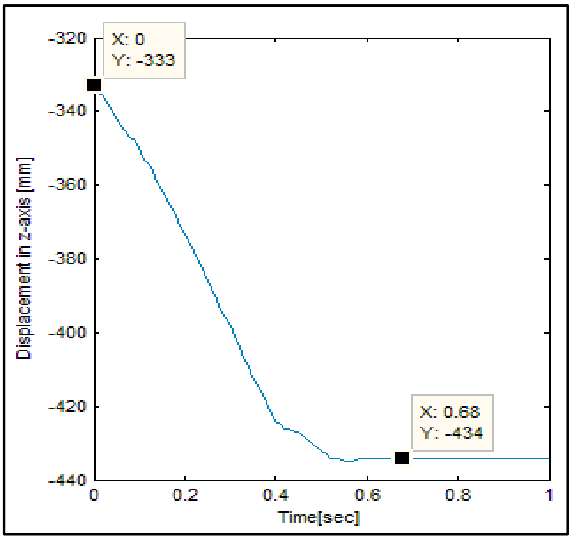
Fig**. 12** shows experimental results in each xyz directions. These results were acquired through encoders then transformed to xyz positions through forward kinematics.



(a)



(b)



(c)

Fig. 12: Experimental displacement response for step inputs in $\boldsymbol{x\ axis}$ (a), $\boldsymbol{y\ axis}$ (b), $\boldsymbol{z\ axis}$ (c)

Results show step response of motion in each xyz directions. A settling time of roughly 0.5 sec was observed for displacing end effector $100[mm]$. Results are taken for a desired final position. Delta robot is observed to be very stable, rigid, and accurate. The robot is used for various educational uses including introducing students on closed chain robots, interacting with robot by setting new desired positions and observing the location of new positions, also exploring different design concepts while checking open source made available information and tools, including CAD model, different control algorithms, software codes, and hardware.

Conclusion:

Delta robots is very adequate for an educational platform. The availability of different analysis of delta robot makes it easy to work with and develop on educational bases for undergraduate level of studies, and applying different knowledge and advanced control techniques for graduate levels of studies.

ACKNOWLEDGEMENT

We would like to thank the Deanship of Graduate Studies and Scientific Research at Palestine Polytechnic University for their financial support.

Presented delta robot is originally a graduation project at Palestine Polytechnic University undertaken byHumam Abu-Alkebash, Omar Abu-Alfeilat and SufyanAl-Sharawi. Supervised by Dr. IyadHashlamoun.

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