Effect of Link Length Ratio on the Workspace of A Delta Robot

Swapnil S. Jogal, K. Jayarajan, Aqleem Siddiqui

Abstract— Delta robot design has attracted a great interest in industry and in academia. The aim of this paper is to study the effect of link length ratio on the vertical reach of a delta robot. Link length ratio is defined as the ratio of the length of a link attached to the motor at the base plate to the total length of links between the base plate and the moving plate. Based on the study, the optimum link length ratio is obtained for maximum depth of workspace. The study makes use of inverse kinematic algorithm. Workspace is plotted using MATLAB.

Index Terms— Delta Robot, Inverse kinematics, Link length ratio, Workspace.

I. INTRODUCTION

Delta robot is a spatial parallel robot. In a three-degree of freedom delta robot, a movable platform is connected to a fixed base plate through three independent kinematic chains. Kinematic chain comprises of an active link and a passive parallelogram link connected together. The active link is coupled to an actuator at the base and the passive link is connected to the moving platform. The three kinematic chains keep the movable platform parallel to the base plane, while moving in 3D space.

The foundation for parallel robot was laid down in 1947 by Gough. He established the basic principles of a mechanism with a closed-loop kinematic structure that allows positioning and orientating a moving platform. He built a prototype of this machine in 1955. Since then, the Stewart platform has also been used for other applications such as milling machines (Aronson, 1996), pointing devices (Gosselin and Hamel, 1994), and an underground excavation device (Arai, 1991). A three degree of freedom parallel manipulator was designed by Clavel (1988) and others at the Swiss Federal Institute of Technology. A new parallel manipulator that eliminated the need for the spherical joints was invented by Tsai (1997).

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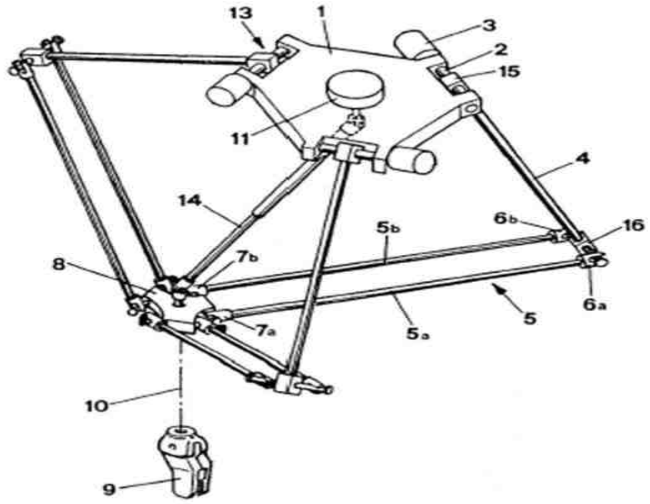

1- Base element	9- Working element
2- Shaft	10- End-effector joint
3- Fixed parts	11- Fixed motor
4- Arm	12- Control system
5a, 5b- Linking bars	13- Actuator
6a, 6b- Revolute joints	14- Telescopic arm
7a, 7b- Revolute joints	15- First extremity
8- Movable element	16- Second extremity

Fig 1. Delta robot parts [5]

Parallel structures such as the Delta robot possess a number of advantages, compared with serial manipulators. Delta robot can transport products with high precision from the acceptance location to the target location. They generally have a higher rigidity and smaller mobile mass than their serial counterparts. Thus, they can move a heavier payload relative to the components of body mass. The structure of a Delta robot also makes it stiffer in perpendicular direction to the travelling plate (e.g. resistive against vibration perpendicular to the travelling plate). The major drawback of the parallel robots is their limited range of motion, compared to that of a serial robot.

However, with a system structure as the Delta robot this limitation has partially been resolved.

The set of parallelograms (Fig 1) in a delta robot restricts the output link to remain at a fixed orientation with respect to an input link. However, it allows the output link to move in three-dimensional space. The input links of the three parallelograms are mounted on rotating levers via revolute joints. The revolute joints of the rotating levers can be actuated using rotational (DC or AC servo) motors or using linear actuators. Finally, a mechanism is used to transmit rotary motion from the base to an end-effector mounted on the mobile platform.

In a delta robot, the mass of links can be reduced by mounting the actuators on the base. This allows the mobile

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platform to achieve large accelerations up to 50 times the gravity (g) in experimental environments and 12g to 15g in industrial applications[5]. There are two kinds of Delta Robot: high-speed robot (objects that weigh up to 1 kg) and robots to handle heavy objects. Both of them have a low inertia structure[5].

A. Kinematics of a delta robot

Kinematics is the science of motion which treats motion without regard to the forces which causes it. Within the science of kinematics one studies the position, velocity, acceleration, and all higher order derivatives of the position variables (with respect to time or any other variable(s)). Hence, the study of the kinematics of manipulators refers to all the geometrical and time-based properties of the motion.

Generally the robots are designed for the payload they handle and the workspace they possess. To estimate the workspace the study of kinematics is essential. The kinematic analysis of a delta robot includes the study of inverse kinematics, forward kinematics and singularity analysis. In parallel manipulators inverse kinematics is simpler compared to direct kinematics. Please refer [7] for inverse kinematics.

II. LINK LENGTH RATIO ANALYSIS

In a delta robot, the maximum vertical reach depends on the total length of one kinematic chain, i.e., sum of the lengths of active link and the parallelogram link. However, the vertical stroke or the topmost point the movable platform can reach depends on the ration of link lengths. Link length ratio is a ratio of the length of a link attached to the motor at the base plate to the sum of length of links in kinematic chain present between the base plate and the moving plate.

The selection of link length ratio helps in determining the workspace. We have studied the effects of link length ratios on the workspace of a delta robot.

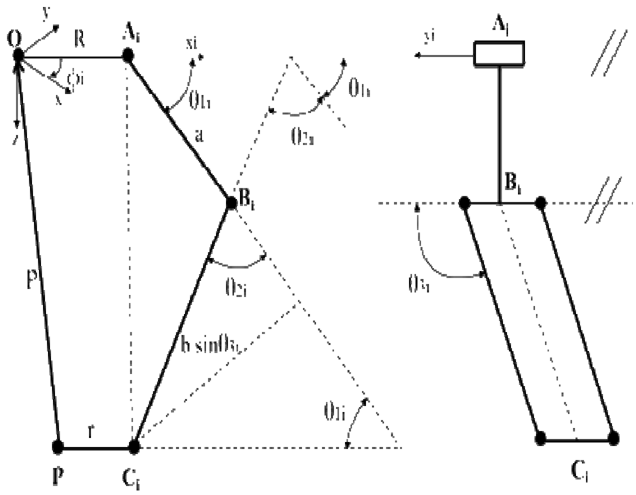

Fig 2. Description of the joint angles

The workspaces are plotted in the XZ plane and YZ plane for the various link length ratios.

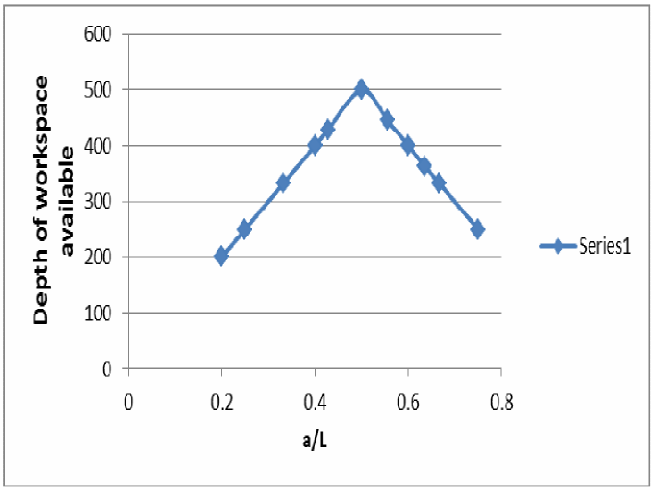

Fig 3. Link length ratio versus depth of workspace available

The shape in the figure 4 and figure 5 are like an inverted dome. The inner portion of the workspace is void dome shaped space up to the depth of 250 mm from the base plate.

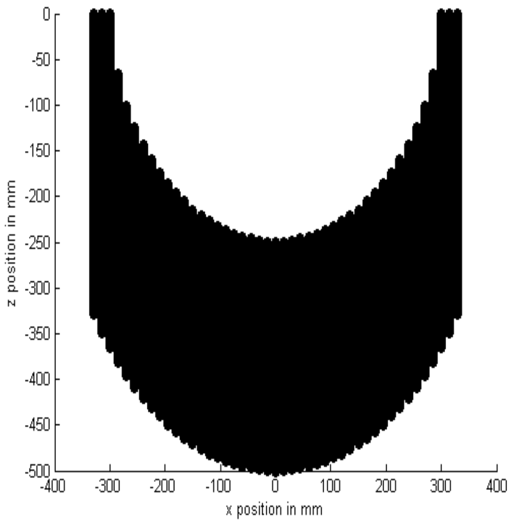

Fig 4. Workspace in XZ plane for link length ratio 0.25

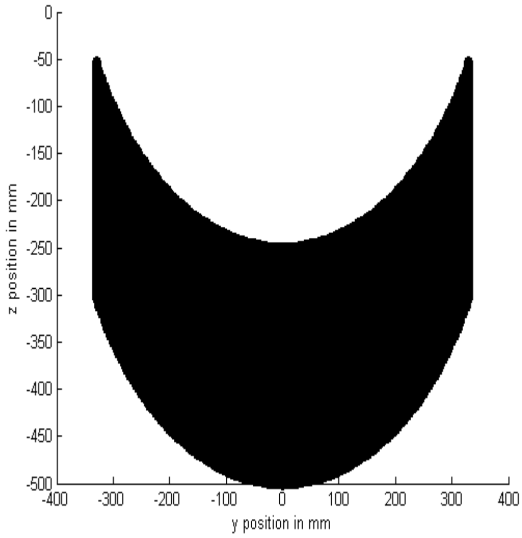

Fig 5. Workspace in YZ plane for link length ratio 0.25

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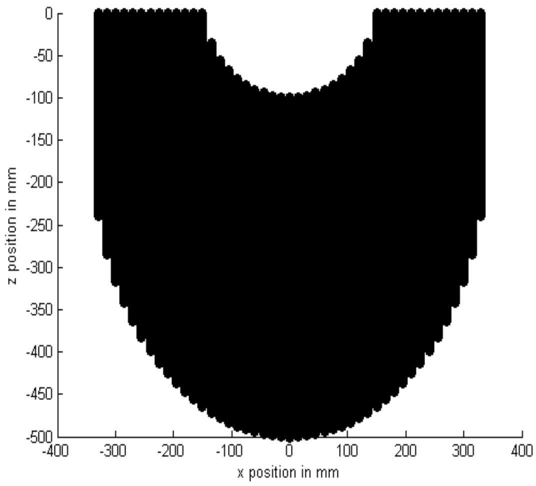

Fig 6. Workspace in XZ plane for link length ratio 0.4

The shape of the workspace in XZ plane in the figure 6 is like a bullet head with an empty dome shaped in the middle of the workspace till the depth of 100 mm. The YZ plane workspace shown in the figure 7 is like an ellipsoid with a part of circular arc emptied from the middle up to 100 mm depth from the origin.

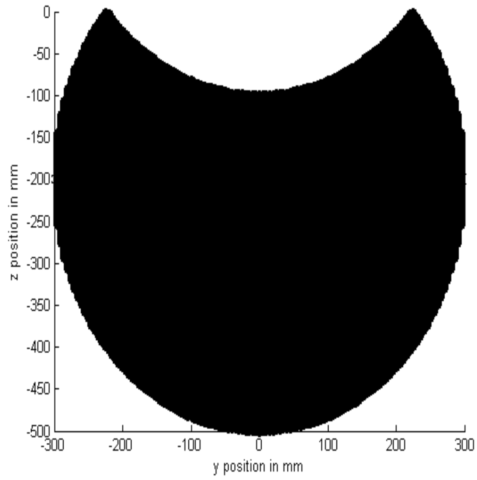

Fig 7. Workspace in YZ plane for link length ratio 0.4

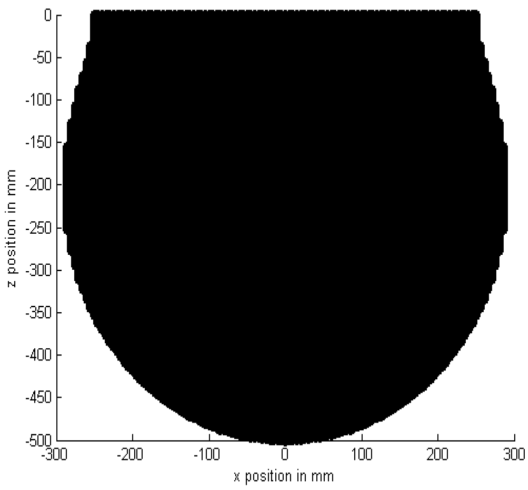

Fig 8. Workspace in XZ plane for link length ratio 0.5

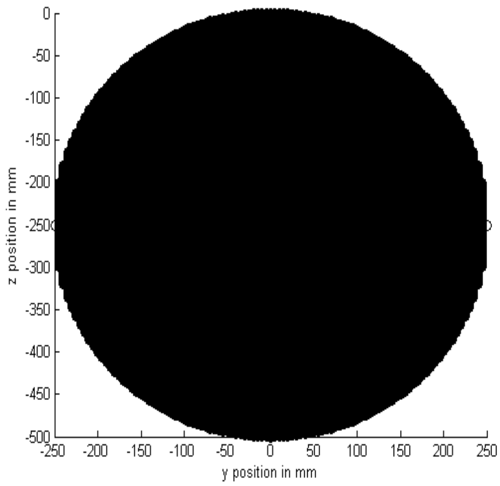

Fig 9. Workspace in YZ plane for link length ratio 0.5

The workspace plotted in the figure 8 and figure 9 is for link length ratio 0.5. It has great importance if maximum depth is the objective. The link length ratio 0.5 becomes optimum link length ratio.

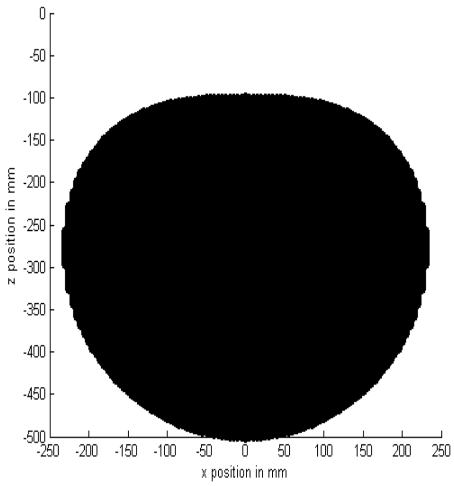

Fig 10. Workspace in XZ plane for link length ratio 0.6

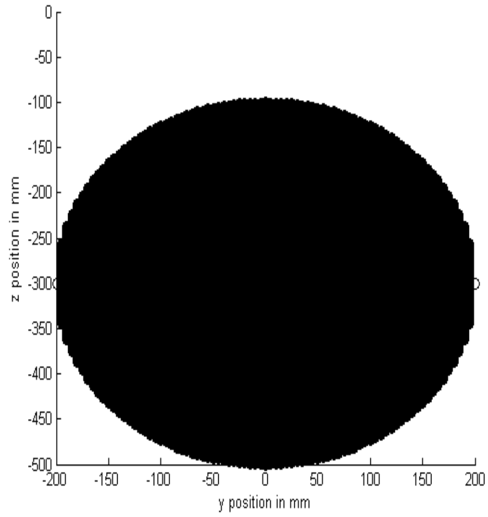

Fig 11. Workspace in YZ plane for link length ratio 0.6

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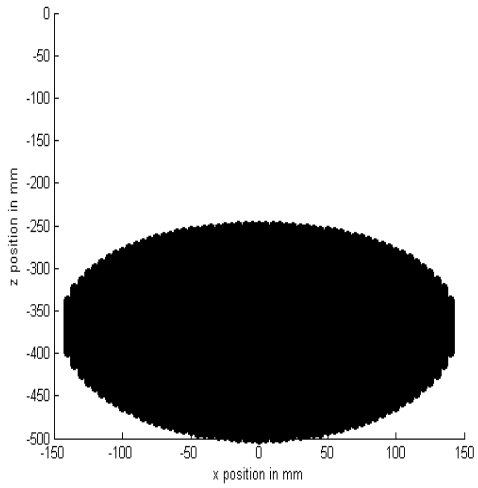

Fig 12. Workspace in XZ plane for link length ratio 0.75

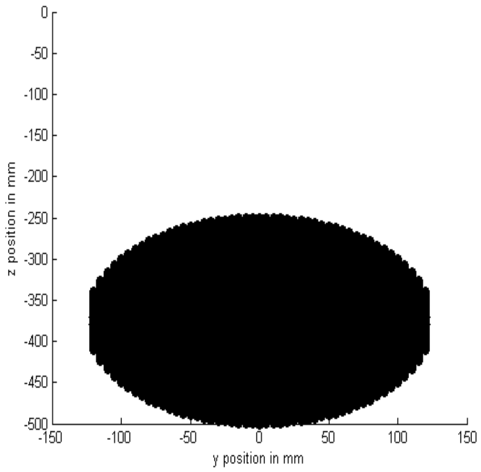

Fig 13. Workspace in YZ plane for link length ratio 0.75

The area of workspace in the XZ and YZ plane goes on decreasing as the link length ratio increases. From the above workspace plots we observe that a link length ratio of 0.4 gives maximum diameter to the workspace.

III. CONCLUSION

We have observed that when the link length ratio is small, the delta robot has a hollow workspace. Therefore, the height of the workspace, when measured along the axis of the delta robot is small for smaller link ratios. As the link length ratio increases, the size of the cavity decreases and the cavity disappears at link length ratio of 0.5. So, at link length ratio of 0.5, full height is available for the workspace. Again, as the link length ratio increases further, the top most boundary of the workspace starts shifting downwards.

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