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Forward Kinematics of 3 Degree of Freedom Delta Robot

Mahfuzah Mustafa, Rosita Misuari, Hamdan Daniyal

***Abstract*--Delta robot is a type of parallel robot. It consists of three arms connected to universal joints at the base. In this project, 3 Degree of Freedom delta robot use of parallelograms in the arms, this maintains the orientation of the end effectors. The development of the Delta robot corresponds to the current requirement of having a robot able to transfer amount of light object in the least time. In this paper involves forward kinematics calculation using S-S (Spherical-Spherical) join pair and compared with real position of Delta robot.**

***Index Terms*--Delta robot, Forward Kinematics, Parallel robot, S-S pair joint, 3 DOF.**

I. Introduction

ROBOT is an electro-mechanical device that can perform preprogrammed tasks. Robotics is the science and technology of robots, their design, manufacture and application. Robots are good for repeatedly task because the tasks can be accurately defined and must be performed the same every time, with little need for feedback to control the exact process. The robots have a various capabilities and share the features of a mechanical and structure under some form of control. Any tasks involve the motion of robot, while the study of the motion can be divided to two categories that are kinematics and dynamics. There are so many types of robot that used in various field. One of the most familiar robots is Delta robot. Delta or Parallel robot was designed by Reymond Clavel in 1988. In 1999, Dr. Clavel is presented with the Golden Robot Award, sponsored by ABB Flexible Automation for his innovation work on the Delta robot [1]. A parallel robot is made up of an end-effector with *n* degree of freedom, and of a fixed base, linked together by at least two independent kinematics chains. Actuation takes place through *n* simple actuator [2].

Research in parallel robots documented in the literature dates back to the year 1938, when Pollard [3] patented his mechanism for car painting. Reymond Clavel is the professor at Swiss Federal Institute of Technology, Lausanne. The direct drive DELTA parallel robot designed by R. Clavel and co-workers at Swiss Federal Institute of Technology, Lausanne is capable of sustaining acceleration better than $500m/s^2$ [4].In the early 80's, he comes up with the brilliant idea of using parallelograms to build a parallel robot with three translational and one rotational degree of freedom [5]. The delta robot consists of three arms connected to universal joints at the base [6]. Parallel manipulator shows better stiffness, positioning accuracy and load carrying capacity than serial manipulators [7].The workspace is defined as the range of allowable end-effector position [8]. Usually, the Delta robot the working envelope is in cylindrical workspace. The workspace of the parallel link manipulator is much smaller than that of the serial link manipulator, since the links interface with each other in orientating motion.

In [9], the author describes method to solve direct kinematics of parallel manipulator. The technique used iterative method with kinematics Jacobian, iterative method with Euler's angles Jacobian matrix, reduced iterative scheme and polynomial method apply to six DOF with six manipulators for both SSM and TSSM. Jacobian matrix is the best real-time method, although it is slower than the iterative method with the Euler's angles Jacobian matrix. The reduced iterative scheme is poorly convergent as soon as the estimate of the orientation angle is not exact. The polynomial method is the slowest method. It can be used only for the design problem for which the speed of the algorithm is less important. Kinematics characteristics of a 3-DOF parallel robot are studied through Square Jacobian matrix of the parallel robot is got by the velocity polygon vector function method and differential relations of the motion platform axes [10]. The method in [11], mobility of the manipulator is analyzed based on the reciprocal screw theory. Then, the inverse position kinematics solution is derived in closed-form, the forward position kinematics problem is solved through Newton iterative method, the velocity kinematics analysis is performed, and the singularity configurations including three kinds of conventional singularities and the constraint singularity are derived

II. Forward Kinematics

This project deals with forward kinematics calculation of Delta Robot and compare with developed Delta robot. Delta Robot or Parallel Robot forward kinematics calculation is different than serial because movement three servo motors in same time. In this paper, we are using S-S pair joint constraint [12] for forward kinematics calculation. Delta robot developed using RCTS (*Robotic Construction & Training System*) which consists three servo motors as three degree of freedom and

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three translational that is X, Y, and Z axis. The conservation of the orientation is covered by three pairs of parallel bars. The joints of the parallel bars are spherical, so each bar can turn around its longitudinal axis. The working envelop of the Delta robot operate typically in a cylindrical workspace.

The position vector of the end-effector of 3 DOF parallel manipulator can be obtained by using the S-S pair joint constraint. Assuming that all the rotary joints are at the vertices of a triangle where b is the distance of the rotary joint from origin of Base. The S-S joint pair constraint can be obtained by formula below:

$$^{Base}S_1 = (b - l_1\cos\theta_1, 0, l_1\sin\theta_1)^T \tag{1}$$

$$^{Base}S_2 = (-\frac{b}{2} + \frac{1}{2}l_2\cos\theta_2, \frac{\sqrt{3b}}{2} - \frac{\sqrt{3l_2}}{2}\cos\theta_2, l_2\sin\theta_2)^T \tag{2}$$

$$^{Base}S_3 = (-\frac{b}{2} + \frac{1}{2}l_3\cos\theta_3, -\frac{\sqrt{3b}}{2} + \frac{\sqrt{3l_3}}{2}\cos\theta_3, l_3\sin\theta_3)^T \tag{3}$$

III. Result

In this result illustrated three different angles for each θ. For all Forward kinematics analysis used $\alpha = 0^0$, b = 76.2mm and $l_1 = l_2 = l_3$ = 182.0 mm. In order to get the position of the end effector of the 3 DOF Delta robot and coordinate frames, Denavit and Hartenberg (D-H) [13] proposed a convention to determine the coordinate mechanism.

A. *Forward kinematics analysis for $\theta_1 = \theta_2 = \theta_3 = 45°$*

For position of all joints at θ = 45°, all actuated joint going down about 45° as shown in Fig. 1 . Note that z-axes for Base S_1 pointing out of the paper. According to the frame as shown in Fig. 2, there are no parallel axes among X, Y and Z axes for frame Base S_1,this condition also apply for Base S_2 and Base S_3 since it had same value of θ. Table 1 shown position of X, Y, Z axes for Base S_1, Base S_2 and Base S_3

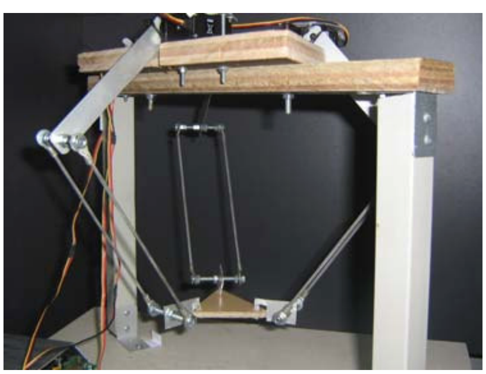

Fig. 1. Position for $\theta_1 = \theta_2 = \theta_3 = 45°$

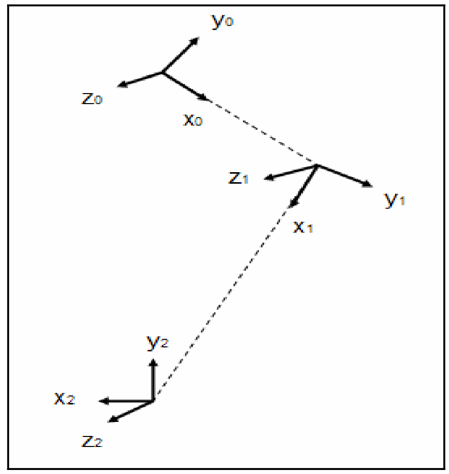

Fig. 2. Frame of Base S_1 for $\theta_1 = 45°$

Table 1. Coordinates of X, Y and Z axis for $\theta_1 = \theta_2 = \theta_3 = 45$

Base S_1 (mm)	X	- 53.1
	Y	0
	Z	129.3
Base S_2 (mm)	X	91.2
	Y	- 46.1
	Z	129.3
Base S_3 (mm)	X	91.2
	Y	158.1
	Z	129.3

B. *Forward kinematics analysis for $\theta_1 = \theta_2 = \theta_3 = -45°$*

For position of all joints at θ = -45°, all actuated joint going up about 45° as shown in Fig. 3. Note that all z-axes are pointing out of the paper. According to the frame as shown in Fig. 2, there are no parallel axes among X, Y and Z axes for frame Base S_1, this condition also apply for Base S_2 and Base S_3 since it had same value of θ. Table 2 shown position of X, Y, Z axes for Base S_1, Base S_2 and Base S_3

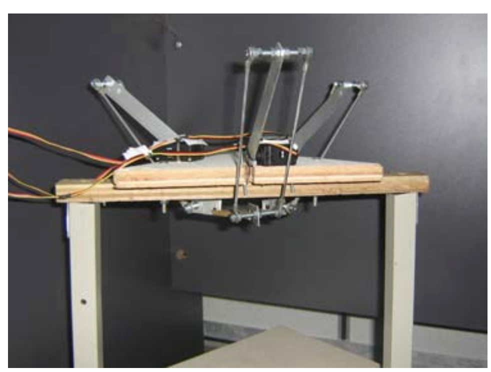

Fig. 3. Position for $\theta_1 = \theta_2 = \theta_3 = -45°$

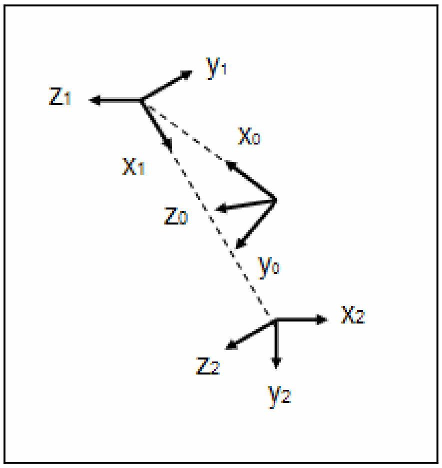

Fig. 4. Frame of Base S_1 for θ_1 = -45°

Table 2. Coordinates of X, Y and Z axis for $\theta_1 = \theta_2 = \theta_3$ = -45°

Base S_1 (mm)	X	- 53.1
	Y	0
	Z	129.3
Base S_2 (mm)	X	91.2
	Y	-46.1
	Z	129.3
Base S_3 (mm)	X	91.2
	Y	158.1
	Z	129.3

C. Forward kinematics analysis for θ_1 = 45°, θ_2 = 0°, θ_3 = -45°

For position of all joints at θ_1 = 45°, θ_2 = 0°, θ_3 = -45° as shown in Fig. 5. Note that all z-axes are pointing out of the paper. According to frame as shown in Fig. 6, there are parallel axis between y_o and y_1 but not for the rest axes among X,Y and Z axes for frame Base S_1 Base S_2 and Base S_3. Table 3 shown position of X, Y, Z axes for Base S_1, Base S_2 and Base S_3

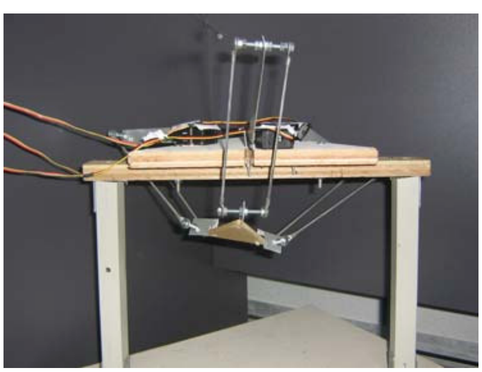

Fig. 5. Position for $\theta_1 = 45^0$ θ_2 = 0° θ_3 = - 45°

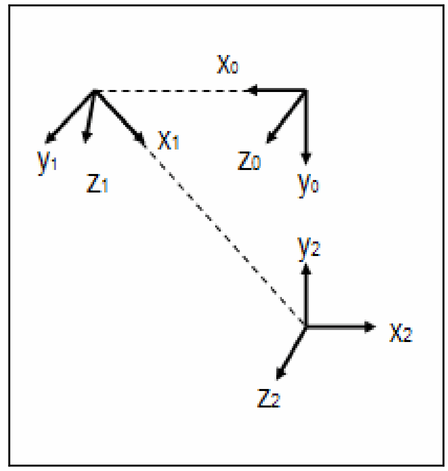

Fig. 6. Frame of Base S_2 for θ_2 = 0°

Table 3. Coordinates of X, Y and Z axis for $\theta_1 = 0$, θ_2 = 45°, θ_3 = -45°

Base S_1 (mm)	X	- 53.1
	Y	0
	Z	129.3
Base S_2 (mm)	X	91.2
	Y	- 46.1
	Z	129.3
Base S_3 (mm)	X	91.2
	Y	158.1
	Z	129.32

IV. Conclusion

In this paper, we have illustrated Forward kinematics solution for 3 DOF Delta robot using S-S pair joint. This Forward kinematics calculation for $\theta_1 = \theta_2 = \theta_3$ =45°, $\theta_1 = \theta_2 = \theta_3$ =-45° and θ_1 = 45°, θ_2 = 0°, θ_3 = -45°. In conclusion, the position or translation of X, Y and Z axis of developed Delta robot same as the forward kinematics calculation

V. Acknowledgment

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VII. Biographies

Mahfuzah Mustafa was born in Johor Bahru, Johor. She received her Diploma in Electronics in 1998 from Universiti Teknologi Malaysia in Malaysia. She then continued her study in B. Eng. (Hons) Computer System and Communications in Universiti Putra Malaysia, Malaysia which was awarded the degree in 2002. Knowing that her interest more in mechatronics, she then started her Master in Electrical Engineering (Mechatronics) at University College of Technology Tun Hussein Onn (KUiTTHO) in Malaysia and was attached at Georg-Simon-Ohm-Fachhocshule Nürnberg, Germany in 2004 to do her Master project thesis which supported by her employer, University College of Engineering & Technology Malaysia (KUKTEM). She is now working as academic staff at Universiti Malaysia Pahang (UMP) and member of Control Focus Group in Faculty of Electrical & Electronics, UMP.

Rosita Misuari was born in Lahad Datu, Sabah, She is student from Faculty of Electrical & Electronics Universiti Malaysia Pahang (UMP) and will be graduated in B. Eng. (Hons) Electrical (Electronics) on 2008. She is currently doing her practical training and was offered work as Electrical Engineer at Usrahlite Engineering (M) Sdn. Bhd. Her special fields of interest included robotics and electrical.

Hamdan Daniyal received the B.Sc (Hons) degree in Electrical-Electronics Engineering from Universiti Teknologi Malaysia (UTM), Johor, Malaysia in 2002, and the M.Eng (Mechatronics) degree from Kolej Universiti Teknologi Tun Hussein Onn (KUiTTHO), Johor, Malaysia in 2004. He is currently continuing his study in PhD degree at University of Western Australia (UWA), Perth, Australia in Electrical Engineering while attached as a lecturer at University Malaysia Pahang (UMP), Pahang, Malaysia. His research interests include control systems which emphasis on nonlinear controls in various applications such as power electronics & drives, motor controls, mobile & industrial robotics, and automotive.

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