Journal of Manufacturing Engineering, March 2010, Vol. 5, Issue 1, pp 11-16

AN EXPERIMENTAL STUDY ON 3 – DOF TRIPOD PARALLEL MANIPULATOR

*Arockia Selvakumar A[1], Sivaramakrishnan R[2] and Kalaichelvan K[2]

[1]Department of Mechanical Engineering, Sri Venkateswara College of Engineering, Pennalur, Sriperumbudur – 602105
[2]Department of Production Technology, MIT Campus, Anna University, Chennai- 600044

ABSTRACT

Parallel manipulators are more suitable for applications in which the requirements for accuracy, rigidity, payload to weight ratio and load distributions are more important than the need for large workspace. The aim of this paper is to perform the modeling and dimensional synthesis of a 3 - DOF tripod parallel manipulator. The model was modeled and analyzed by considering the payload and working conditions. The designed model was modeled and simulated by using ADAMS®. The concept involved in this paper is based on the transformation of motion between screw pair and the spherical pair through the links. The links are connected to the screw pair, which is actuated by stepper motors. A set of kinematic equations was formulated for the parallel manipulator. An algorithm was written in C for interfacing it with the computer. The values obtained by experimental method were further compared with the analytical method and ADAMS. Dimensional synthesis of parallel manipulator was carried out by considering the parameters like link length and moving platform radius. The dimensional synthesis was taken in to account for determining the suitable dimensions of mechanisms by logical approach.

Key words: *Tripod, Parallel manipulator, Kinematic Synthesis*

1. Introduction

The science and technology of robotics originated with the spirit of developing mechanical systems, which would carry out tasks normally ascribed to human being. Generally, robot manipulators are classified in to serial type (open loop chains) and parallel type (closed loop chains). Open loop manipulators have the advantage of sweeping large workspaces and dexterous maneuverability like human arm but their load carrying capacity is rather poor due to cantilever structure consequently to satisfy the strength requirements, the links become bulky which leads to vibration at high speed. Though possessing large workspace their precision positioning capability is rather poor due to the cantilever structure [2].

In last two decades, considerable improvements in the field of robotics are the parallel manipulators for its high load carrying capacity, superior positioning capability with greater rigidity which serial manipulators fail to posses. The interesting thing about parallel manipulator is that the degrees of freedom of these varies up to 6 having the end effector connected and several links actuated in parallel [1].

The concept involved in this paper is based on the transformation of motion between screw pair and the spherical pair through the links. In the tripod type parallel manipulator the lead screws are kept in a vertical manner so that it is possible to achieve a maximum angular tilt of moving platform to 60°[6]. The movable platform of the parallel manipulator can be tilted to required angle by giving suitable pulses to the stepper motors which actuates the links connecting the movable platform. In the new design each and every component (Lead screws, moving platform, links and joints) is designed for carrying a payload of 70N and is fabricated for angular drilling machine.

2. Parallel Manipulator

A mechanism is called parallel if it consists of internally closed kinematic loops [2]. A parallel manipulator typically consists of moving platform that is connected to a fixed base by several links or legs. Generally, the number of links is equal to the number of degrees of freedom such that every link is controlled by one actuator and all the actuators can be mounted at or near the fixed base [6].

A schematic diagram of a 3 DOF parallel manipulator is shown in Fig. 1 consisting of an upper platform which houses the driving mechanism of the gripper, three extensible links and base platform [5].

*Corresponding Author - E- mail: aselvakumar@svce.ac.in

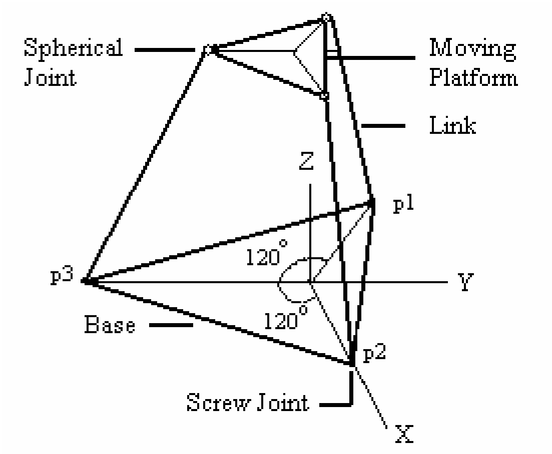


Fig.1 Schematic Diagram of 3 DOF Parallel Manipulator

2.1 Mobility equation

The degrees of freedom of the closed chain manipulators are mainly dependent on the number of links or legs, which connect the moving platform and the fixed platform [4].

In this paper work, the links are connected to the moving platform by means of spherical joints on one end and the other end to half nuts by means of pin joints (Turning pair). Since the half nuts are mounted on the lead screws, which are coupled to the stepper motors, when the screw is actuated, the nut translates over the screw, which in turn actuates the links. For finding the degrees of freedom of the parallel manipulator the mobility equation shown in equation (1) was used.

$$F = 6\,(n-g-1) + \sum_{i=1}^{j} f_i \qquad (1)$$

For this Tripod mechanism n=8 (3 Rigid links + 3 nuts + 1 movable platform+1 base or fixed platform), g = 9 and f_i = 3 for each spherical joint and 1 for each revolute joints and for a screw joint. Application of equation 1 yields the degrees of freedom F = 3. The 3 – DOF's are rotation about x - axis and y - axis and translation along z - axis.

3. Kinematic Analysis

Kinematics deals with the relative motion of the body excluding the forces acting on it. There are two types of kinematics direct or forward kinematics and backward or inverse kinematics [1]. Mapping from Cartesian space to joint space is referred as inverse or reverse or backward kinematics. Forward kinematics the joint variables are given, and the position and orientation of the moving platform are to be found. The forward transformation finds the corresponding Cartesian configuration to a given set of joint angles. For inverse kinematics the position and orientation of moving platform are given and the joint angles are to be found. The inverse kinematic transformation finds the joint angle that corresponds to the position [3].

From Fig. 2, kinematics of single link movement can be formulated from the equation (2) to (11),

$$L_1 = 1.5\, r \qquad (2)$$

$$X = L_1 + L \cos\theta \qquad (3)$$

$$Y = L \sin\Phi \qquad (4)$$

$$V = Y + L_1 \sin\theta \qquad (5)$$

$$a = L_1 \cos\theta \qquad (6)$$

$$b = L_1 \sin\theta \qquad (7)$$

$$c = X - L_1 \cos\theta \qquad (8)$$

$$\cos\theta_1 = \frac{c}{L} \qquad (9)$$

$$\tan\theta_1 = \frac{(V-D)}{c} \qquad (10)$$

$$D = V - (c \tan\theta_1) \qquad (11)$$

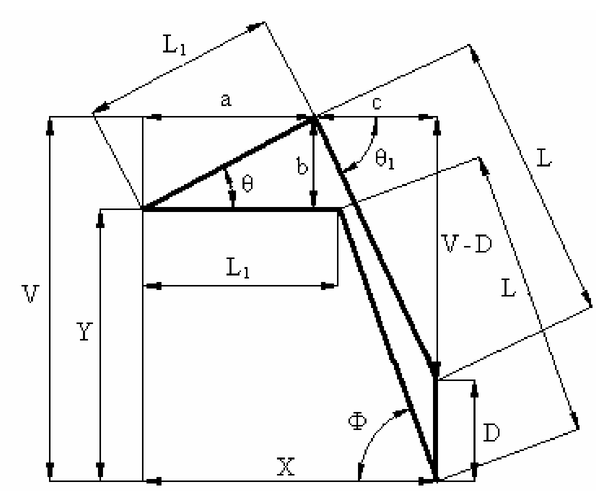


Fig. 2 Single Link Synthesis of Tripod

4. Kinematic Synthesis

Kinematic syntheses normally are of three categories: Type synthesis, number synthesis and dimensional synthesis. The dimensional synthesis is taken into account for the determination of suitable dimensions of mechanisms by logical approach [6]. By varying the link lengths and radius of moving platform the synthesis was performed in Analytical method and ADAMS.

4.1 Experimental method

An experiment was conducted for finding out the angle of tilt of the moving platform for the displacement of nut 50 mm (Experimental setup is shown in Fig. 3. The parameters are Link Length 300 mm, radius of moving platform 90 mm)

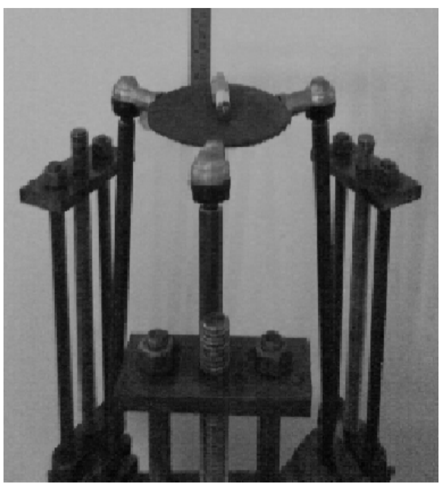


Fig. 3 Experimental Setup of Tripod Parallel Manipulator

A laser torch is mounted to the center of the movable platform and a laser light is projected on vertical wall at a point ‘A’, which is at a predetermined distance ‘OA’ from the point of laser source. When the platform is tilted by the actuation of link the laser beam get deflected to some other point ‘B’ on the wall. The steady state positions of the laser beam on the vertical wall before and after the actuation were tracked and the distance is considered to be X. Angle of tilt of the platform is measured from the orientation of the source, and is explained in the Fig. 4. From the fig. 4, the movable platform rotates at an angle of θ which is measured as

$$\theta = \mathrm{Tan}^{-1}\,(AB / OA) \qquad (12)$$

Where OA is fixed predetermined distance, AB is vertical height

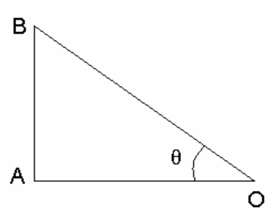


Fig. 4 Determination of Rotation Angle

4.2 Analytical method

A software program was written in C language for finding the displacement of nut for the 3 - DOF parallel manipulator. The software program was written based on the algorithm formulated [7]. The tilt of the moving platform obtained by actuating the links was obtained from algorithm. In analytical method in order to verify the displacement of the nut, angle of tilt of platform is given as the input. Once the input is given, the software calculates the linear displacement of nut and the number of rotation of screw, which will be useful for giving the pulses to the stepper motor.

4.3 ADAMS method

The manipulator model was created in the ADAMS software package by building the physical attributes of the elements or parts in the mechanical systems that has rigid bodies, point masses, flexible bodies and constrains. The working model was simulated by actuating one of the links. The results are obtained for the displacement of 50 mm of the nut and the respective angle of rotation of the moving platform.

5. Modeling and Simulation

The model (Fig. 5) has been built by building the physical attributes of the element or parts in the mechanical system using the rigid bodies and constraints. Constraints define how parts are attached to one another and how they are allowed to move relative to each other. Constraints restrict the relative movement between parts and represent idealized connections. After creating the model or at any point in the modeling process, one can run tests of model to ensure that it was created correctly and to verify in system characteristics.

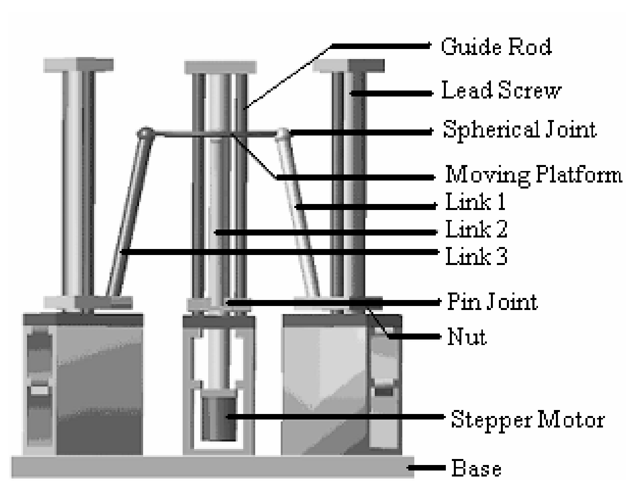


Fig. 5 ADAMS Model of Tripod

6. Results and Discussion

6.1 Experimental analysis

The kinematic analysis and synthesis of the 3-DOF parallel manipulator of tripod type have been carried out and the results were verified by experimental method, analytical method and by ADAMS. The results are shown in Table 1. The result of the experimental method shows that, for a linear displacement of 50 mm of the nut, the moving platform has tilted to an angle of 20.52°. The experimental results are to be checked through the analytical results. The results obtained by analytical methods are calculated from the kinematic equations mentioned in (2) to (11).

By analytical method, it is found that for the same nut displacement of 50 mm, the angle of tilt obtained is found to be 20.98 °. By comparing both the results obtained from experimental methods and analytical method, there is an error of 0.46°.

ADAMS results are compared with the experimental results, the result shows small variation in the angle of tilts of moving platform 0.21° is due to arresting the motion of other two links while simulating the model. Also the error may be due to fixing the exact co-ordinates in the working grids of ADAMS package. Since values obtained from analytical results are closely matching with ADAMS results, the values obtained from them are considered to be the correct value.

6.2 Synthesis

The link length and the radius of moving platform are considered to be the important parameters, which will play the important role in increasing or decreasing the tilt of moving platform. From table 2, the results shows that when the radius of moving platform is increased for the constant link length of 200 mm, the angle of tilt of the moving platform is decreased from a maximum of 26.67° for a radius of 50 mm to a minimum of 12.64° for a radius of 150 mm.

Similarly it is also found in ADAMS that the angle of tilt of the moving platform is decreased from a maximum of 26.46° for a radius of 50 mm to a minimum of 12.29° for a radius of 150 mm. From table 3, it is found that when the link length is increased for the constant moving platform radius of 90 mm, the angle of tilt of the moving platform is increased from a minimum of 19.49° for a link length of 100 mm to a maximum of 20.98° for a link length of 300 mm. Similarly it is also found in ADAMS that the angle of tilt of the moving platform is increased from a minimum of 18.98° for a link length of 100 mm to a maximum of 20.73° for a link length of 300 mm.

By comparing the results of analytical method with ADAMS from table 2 and 3, the result shows that the deviation is 0.67 to 2.77%. The deviation may be due to fixing the exact co-ordinates in the working grids of ADAMS package.

Table 1: Results of Angle of Tilt of Moving Platform by Three Methods

Displacement of NUT (mm)	Angle of tilt of moving platform (Degree)		
	Experiment	Analytical	ADAMS
10	4.10	4.21	4.11
20	8.17	8.35	8.11
30	12.15	12.46	12.18
40	16.29	16.54	16.38
50	20.52	20.98	20.73

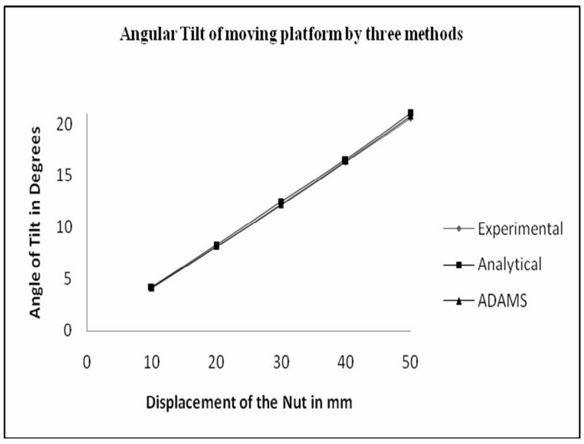
Table 2: Influence of Radius of Moving Platform over Angle of Tilt of Moving Platform

Radius of moving platform (mm)	Angle of tilt of moving platform (Degree)		
	Analytical	ADAMS	% Deviation
50	26.67	26.46	0.78
75	21.86	21.31	2.51
100	17.73	17.61	0.67
125	14.78	14.52	1.76
150	12.64	12.29	2.77

Table 3: Influence of Link Length on Angle of Tilt of Moving Platform

Length of link (mm)	Angle of tilt of moving platform (Degree)		
	Analytical	ADAMS	%Deviation
100	19.49	18.98	2.61
150	20.27	19.97	1.48
200	20.63	20.30	1.59
250	20.84	20.68	0.76
300	20.98	20.73	1.19

Fig. 6 Comparison of Moving Platform Angle of Tilt



by Experimental, Analytical and ADAMS

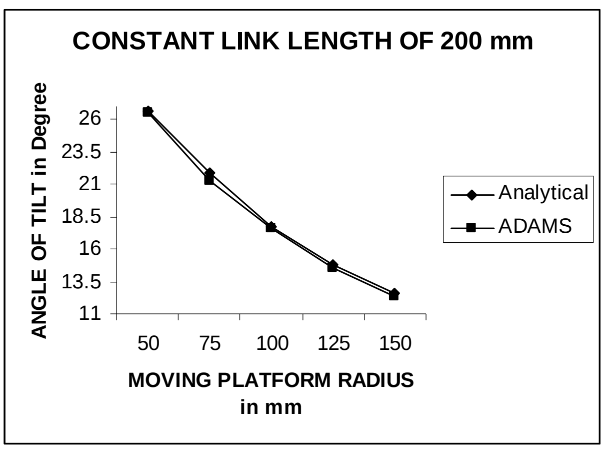


Fig. 7 Effect of Radius of Moving Platform over Angle of Tilt of Platform

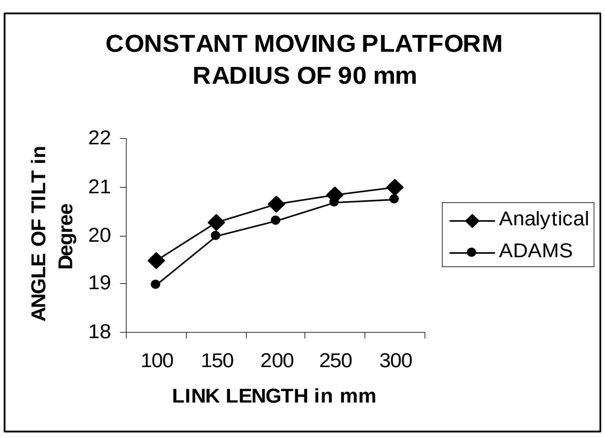


Fig. 8 Effect of Link Length on Angle of Tilt of Moving Platform

7. Conclusion

The Tripod parallel manipulator has been successfully fabricated and analyzed for position kinematics and dimensional synthesis. This manipulator can be used in place of machine tool table for machining purposes like angular drilling and inclined holes on components and contour milling using end milling cutters. The following conclusions are made based on the experimental method, analytical method and ADAMS,

1. The Kinematic analysis carried out for links actuation individually, the results shows that the angle of tilt of moving platform of experimental values are closer with the analytical and ADAMS Values.
2. It is found that the link lengths and the radius of the moving platform influences the angle of tilt obtained in the moving platform.
3. If the link lengths are increased the angular tilt of moving platform gets increased for constant moving platform radius.
4. If the radius of moving platform is increased the angular tilt of moving platform is decreased for constant link length and vice versa.

The above synthesis results also reveal that, for getting the maximum angular tilt there should be an optimum link length otherwise connectivity will not be achieved between the links and moving platform.

References

1. *Collins C L (2002), "Forward Kinematics of planar Parallel Manipulators in the Clifford Algebra of P2", Mechanism and Machine Theory, Vol.37, (8), 799-813.*

2. *Fanghella P and Galleti C (1990), "Kinematics of Robot Mechanisms with Closed Actuating Loops", The International Journal of Robotics Research, Vol.9, (3), 19-24.*

3. *Jim Wook Kim and Park J C (2000),"Direct Kinematic Analysis of 3-PRS Parallel Mechanisms", Elsevier Publications, Mechanism and Machine Theory, Vol.35, 1121 - 1134.*

4. *Luc Berar, Jeorge Angles, 2000,"The Kinematics of a parallel manipulator under Joint – Sensor Redundancy", IEEE Transactions of Robotics and Automation, Vol.16, (1), 12-19*

5. *Meng – Shiun Tsai, Ting-Nung Shiau, 2003, "Direct Kinematic Analysis of a 3 –PRS Parallel Mechanism", Mechanism and Machine Theory, Vol.38, (1), 71-83.*

6. *Sivaramakrishnan R, Kalaichelvan K, and Dhanraj R (2000), "Kinematics and Construction of 3-DOF Parallel Manipulator", Proceeding of International Conference on Intelligent Flexible Autonomous Manufacturing Systems (IFAMS 2000), 789-795.*

7. *ArockiaSelvakumar A and Sivaramakrishnan R, (2009), "Modelling, Simulation and Synthesis of 3 – DOF Tripod Parallel Manipulator", Proceedings of 2nd International Conference on Recent Advances in Material Processing Technology (RAMPT '09), 318 – 323.*

Nomenclature

Symbol	Meaning	Unit
θ	Angle of tilt of moving platform	Degree
F	DOF of the Mechanism	No Unit
f_i	Number of Degrees of freedom of i^{th} Joint	No Unit
g	Number of joints	No Unit
Φ	Initial angle between the link and the fixed platform	Degree
Y	Initial height from the center point of fixed platform to moving platform	mm
X	Horizontal Distance from Spherical joint of Pin Joint	mm
r	Moving platform radius	mm
D	Displacement	mm
L	Link Length	mm