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Experimental investigation on position analysis of 3 – DOF parallel manipulators

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Abstract

Parallel manipulators (PMs) have been the subject of study, of much robotic research during the past three decades. A parallel manipulator (PM) is a closed loop kinematic chain mechanism, that is connected to the base via multiple independent chains. The scope of this research work is to perform the position analyses of the three degrees of freedom PMs (TRIPOD and TRI-GLIDE). The present work has been planned to model the parallel manipulators using the screw joints for very accurate positioning. Experiments were conducted for the position analysis and the angular tilt of the mobile platform along x-axis and y-axis and they were found by actuating the links of the manipulators. In order to confirm the results obtained by the experimental method, ADAMS was used for solving the kinematic problems involved. The Tri-Glide and Tripod manipulators were created in ADAMS based on the fabricated models. The models were simulated for the displacement of the nut and the angle of tilt / rotation of the mobile platform about the x and y axes. The results obtained by the three methods are discussed and analyzed. In a conventional drilling machine, drilling an angular hole requires special fixtures for each specific angle. In the present work, the parallel manipulator mechanisms have been modified to an angular drilling machine, for performing angular drilling operations.

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Keywords: Manipulator; tripod; triglide; position anlysis; ADAMS

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1. Introduction

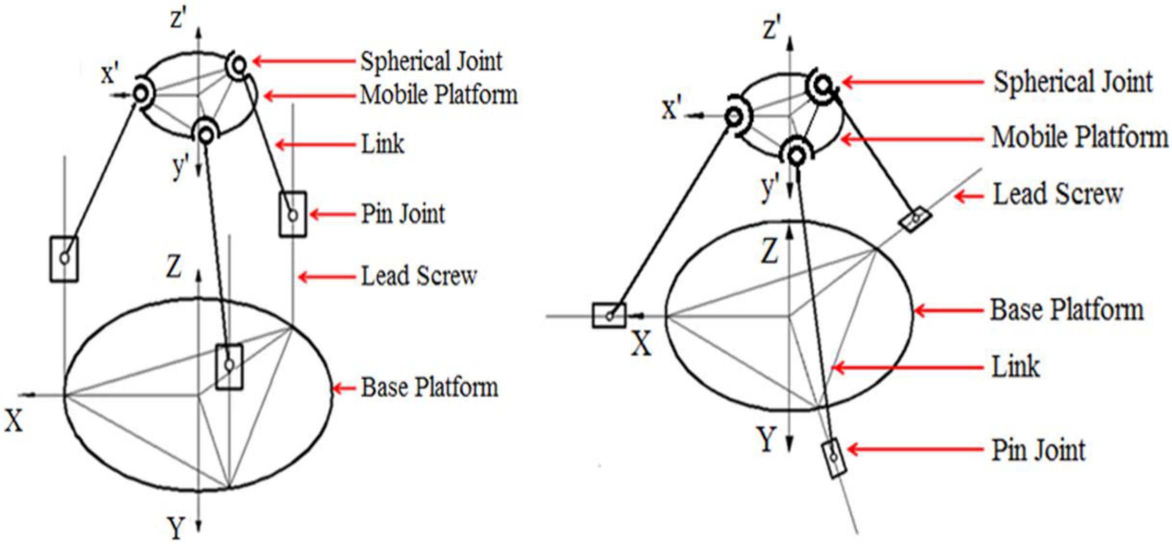
The introduction of industrial robots was the beginning of a new era in many fields, especially in the manufacturing industry. Eventually, serial manipulators became an invaluable tool for a broad range of applications. As the science of machine and mechanisms develop and the need for higher precision, robustness, stiffness and load-carrying capacity arise, the PMs begin to show up. In the 90s, the Stewart-Gough Platform, and PMs in general became a popular research topic. Industries always thrive for higher quality and more economical processes. Xin-Jun Liu et al proposed two degrees of translational freedom and one degree of rotational freedom parallel manipulator with three non identical chains. They used MATLAB for workspace simulation [7]. Yangmin Li and Qingsong Xu investigated the kinematics and inverse dynamics of a general 3-PRS parallel mechanism. The proposed model is simulated in MATHEMATICA software and the animation results were obtained from MATLAB software [8]. Yangmin Li and Qingsong Xu presented an optimal kinematic design of a 3-PRS spatial parallel manipulator, the simulated results provided the basis for the optimization of the manipulator [9]. Sadjadian and Taghirad proposed the kinematic modeling of a 3-DOF redundant parallel manipulator. The derived model was verified through a simulation example using a sample trajectory in the task space of the hydraulic shoulder manipulator [6]. Ng et al presented the design and development of a 3-legged micro Parallel Kinematic Manipulator (PKM) for positioning in micro-machining and assembly operations. The hybrid micro PKM was developed and calibrated based on the simulated workspace [4]. Yangmin Li and Qingsong Xu proposed a new 3-PRC (Prismatic – Revolute – Cylindrical) translational parallel manipulator with fixed actuators. Finally, the obtained results were compared with the simulation results [10]. Abdelhakim Cherfia et al presented a geometrical model of a constrained parallel robot with a PPP passive segment, to provide pure translational motion and the theoretical results were verified with the simulation results [1]. Ciprian - Radu Rad et al suggested two methods of forward kinematics of a 3 - DOF RPS parallel manipulator for medical purposes, and the methods were implemented in the MATLAB/SIMULINK [2].

Yi Lu et al proposed the kinematic analysis of two novel 3-UPU I and 3-UPU II PKMs, their analytical calculation was verified by using a simulation tool [11]. Most existing PKM can be classified into two main families. The PKM of the first family generally called as “hexapods”. In this first family, a hybrid architecture with a 2-axis wrist mounted in series to a 3-DOF tripod positioning structure (the TRICEPT from Neos Robotics) also found. The second family of PKM has been more recently investigated. In this category the HEXAGLIDE which features six parallel and coplanar linear joints is found. This PKM has three vertical (non coplanar) linear joints. A hybrid parallel/serial PKM with three parallel inclined linear joints and a two-axis wrist is the GEORGE V [5]. Dan Zhang et al addressed that since machining operation requires five axes at most, new configurations with less than six parallel axes would be more appropriate. Development on new configurations is mainly on three axes PKMs. Examples include Tri-Glide and Tripod [3].

From the literatures, the existing PKM structures Tripod and Tri-Glide are considered for the study. In conventional drilling machine, drilling an angular hole requires special fixtures for each specific angle. In this present work, the Tri-Glide and Tripod parallel manipulators mechanisms have been modified to an angular drilling machine for performing angular drilling operation. The mobile platform of the Tri-Glide and Tripod were used as worktable to attain the required angular tilt. In the first type, the lead screws are kept or placed horizontally (Glide type), and in the second type the lead screws are kept vertically (POD type). This study is carried out to find the parallel configuration, which will give a better MP tilt for the smaller linear displacement of the nut. At first, the architectural description and mobility of the PMs are briefly given. Secondly, the experimental models are illustrated. Later, the modelling and simulation of PMS using ADAMS package is discussed. Finally, a study is carried out based on the experimental and simulation results.

2. Architectural description

Figure 1 show the 3-PRS Tripod and Tri-Glide PMs, which depict the various names of the linkage assembly. These mechanisms typically consist of a circular plate, referred to as the MP. This MP is connected to a base platform (BP) through links. The link is connected to a revolute joint at the bottom end, and a spherical joint at the other end. The revolute joint is attached to the nut, which is mounted on the guide way. The guide way consists of a lead screw and two guide rods. The mobility of the MP is accomplished by the screw and nut pairs on the guide ways.



(a) Tripod (b) Tri-Glide

Fig. 1. parallel manipulators

2.1. Mobility equation

The degrees of freedom of the PM are mainly dependent on the number of links which connect the MP and the BP. In this work, the links are connected by spherical joints to the MP at one end, and the other end is connected by pin joints to the nuts. Nuts are mounted on the lead screws which are actuated by the stepper motors. The mobility of the mechanism is calculated by Equation (1).

$$DOF = \lambda\,(N - J - 1) + \Sigma^{n}_{i=1}\ F_i \tag{1}$$

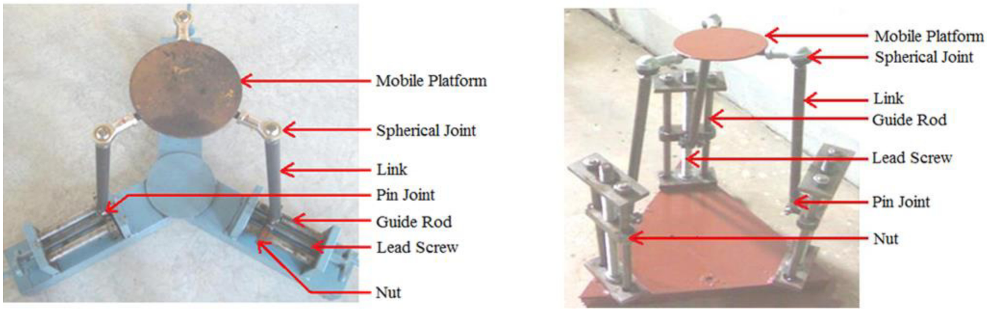
λ= 6 for the spatial PM, F_i = 1 for the Revolute joints and Prismatic joints and F_i = 3 for the Spherical joints. For the proposed mechanisms, N=8 (3 links, 3 nuts, 1 MP and 1 BP), J=9 and F_i = 15. Therefore, the given mechanisms have 3-DOF. The 3-DOF of the PMs are 1) the rotation about the x axis, 2) rotation about the y axis and 3) translation along the z axis.

3. Experimental models

The experimental models of the Tripod and the Tri-Glide PMs are built, and are shown in Figures 2 and 3. The models are made of the same geometrical size of the simulation models. Each link is actuated at various positions to get various MP tilts.

(a)Tri-Glide (b) Tripod

Fig. 2. one link arrangement of PMs



(a) Tri-Glide (b) Tripod

Fig. 3. prototype model of PMs

3.1. Methods used in position analysis

An experiment was carried out for the position analysis by actuating one of the links at a time. A laser torch is mounted on the center 'C' of the MP, and the laser light is projected on the vertical screen at a point 'A', which is at a predetermined distance 'AC' from the point of the laser source. When the MP is tilted by the actuation of the link, the laser beam gets deflected to some other point 'B' on the vertical screen. The angle of tilt of the MP is measured from the orientation of the source. From Figure 4, the MP tilt angle (α) is measured from the Equation (2).

$$\alpha = \tan^{-1}(AB / AC) \tag{2}$$

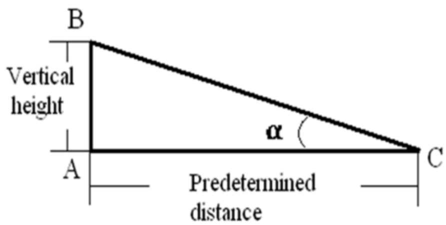
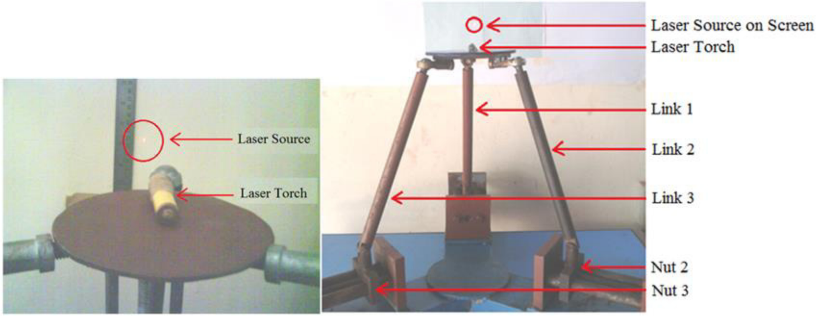


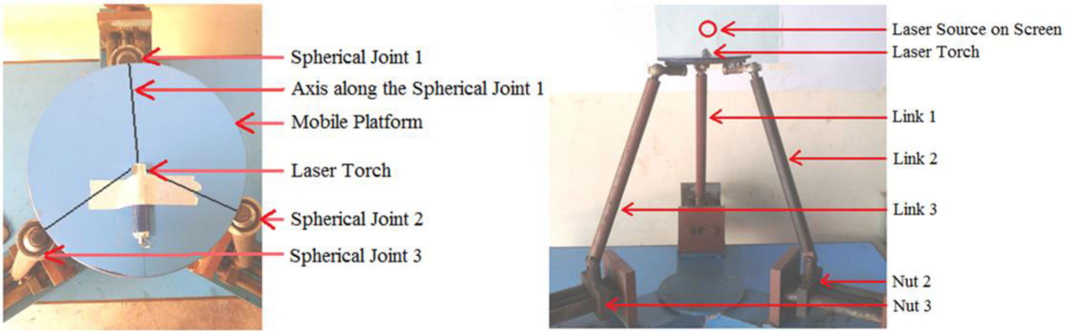
Fig. 4.calculation of angle of tilt of the MP

Figure 5 show the experimental setup of laser torch on PMs. The Laser torch is placed on the MP in such a way that the laser torch axis is aligned with one of the joint axis from the MP. The experimental procedures of actual experiments are shown in Figures 6 to 8. In initial position all the links are placed in same distance in such a way that the nut positions are same in the lead screws. Similarly, at the final position any one or two links are actuated and the other link or links are kept constant. Due to the various positions of nut, the MP is tilted. The tilt is measured from the positions of laser source.



(a) Tripod (b) Tri-Glide

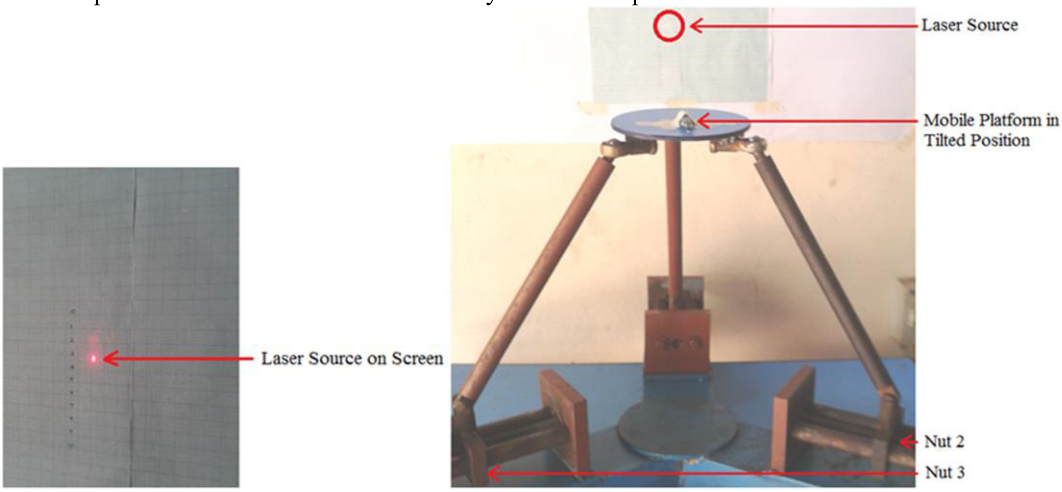
Fig. 5. experimental setup with laser torch



(a) Positioning of laser torch (b) Initial position of PM

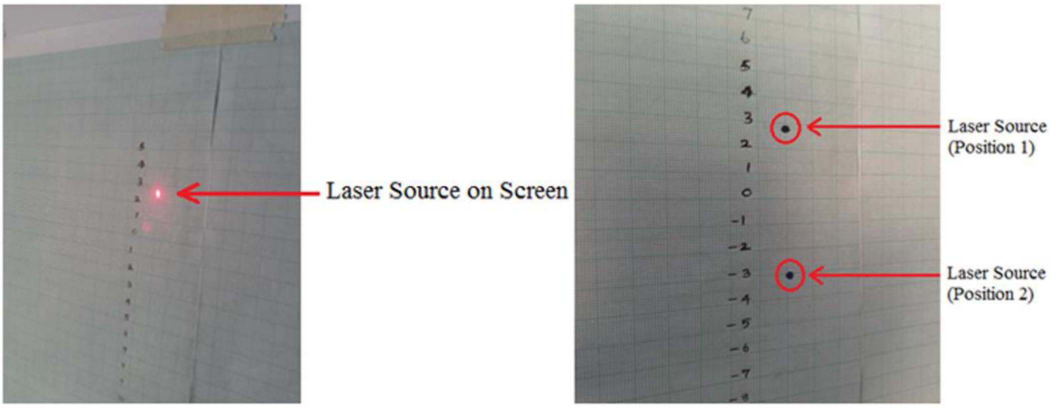
Fig. 6. PM with laser torch

In Figure 3.24, the link1 is kept constant and the links 2, 3 are actuated. In initial position all the links are placed in same distance in such a way that the nut positions are same in the lead screws.



(a) Laser source on screen at initial position (b) Final position of PM with laser torch

Fig. 7. positions of laser source

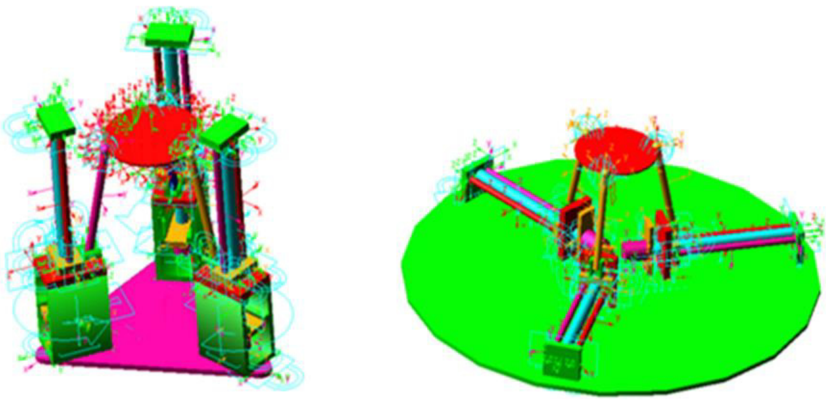


(a) Laser source on screen at final position (b) Laser source positions on screen

Fig. 8. laser sources on screen

3.2. ADAMS model

The manipulator models are constructed in ADAMS by building the physical attributes of the elements, or the parts in the mechanical systems that have rigid bodies, point masses, flexible bodies and constraints. The working models are created using ADAMS, as shown in Figure 9. The models are simulated for the nut displacement of 50 mm and the angles of tilt of the MP about the X and Y axes are obtained from the simulation graphs.



(a) Tripod (b) Tri-Glide

Fig. 9. Various constraints of ADAMS models

4. Results and discussions

The kinematic analysis of the 3-DOF PMs has been carried out and the results are verified by experiments, analyses and the software package ADAMS. The Experimental models of the Tripod and Tri-Glide (B) PMs are fabricated with a Link length of 300 mm, MP radius of 90 mm and the initial angle of θ=70°. Table 1 shows the predetermined distance (AC) from the point of the laser source to the vertical screen, and various vertical heights of the laser beam on the vertical screen (AB), to calculate the Tripod MP tilt by the experimental method.

Table 1. Tripod results of the angle of tilt of the MP for the nut displacement of 90 mm by experimental method.

Actuation Link	Predetermined distance (AC) from the point of the laser source to the vertical	Vertical height of the laser beam on the vertical screen(AB) in	Angle of tilt of the MP (degrees)

Number	screen in mm	mm (Average of 5 Trials)			
		About the X axis	About the Y axis	About the X axis α	About the Y axis β
1	195	135	0	34.69	0
2	195	57	114	16.29	30.31
3	195	56	114	16.02	30.31

Table 2. Results of the angle of tilt of the MP for the nut displacement of 90 mm by experimental and ADAMS methods

Actuation Link Number	Angle of tilt of MP (degrees)			
	Experiment		ADAMS	
	About the X axis α	About the Y axis β	About the X axis α	About the Y axis β
1	34.69	0	35.25	0
2	16.29	30.31	16.58	30.51
3	16.02	30.31	16.58	30.51

From Table 2, the Tripod PM result shows, that for the 90 mm linear displacement of the nut, the MP has tilted to an angle of 34.69° about the x axis by the actuation of link 1 in the experimental method. Similarly, by the derived single link movement kinematic equations (analytical method), it is found that the angle of tilt about the x axis is 35.95°. The angle of tilt of the MP about the x axis from the ADAMS simulation is found to be 35.25°. From the above results, the experimental method shows a deviation of 3.5% (for the x axis MP tilt) when compared with the analytical method. The ADAMS results are compared with the experimental results. It is found that it has a maximum deviation of 3.5%. Since the values obtained from the experimental and ADAMS methods have minimum deviation from the analytical results, the values are considered to be closer.

Table 3 shows the predetermined distance (AC) from the point of the laser source to the vertical screen, and the various vertical heights of the laser beam on the vertical screen (AB) to calculate the Tri-Glide (B) MP tilt by the experimental method. The Tri-Glide (B) PM result shows, that for a 90 mm linear displacement of the nut, the MP has tilted to an angle of 30.72° about the x axis by the actuation of link 1 in experimental method. Similarly, by the derived single link movement kinematic equations (analytical method), it is found that the angle of tilt about the x axis is 31°. The angle of tilt of the MP about the x axis from the ADAMS simulation is found to be 30.98°. From Table 4, the experimental method shows a deviation of 0.9% (for the x axis MP tilt), when compared with the analytical method. The ADAMS results are compared with experimental results. It is found that it has a maximum deviation of 3.54%. Since the values obtained from the experimental method and ADAMS have a minimum deviation from analytical results the values are considered to be closer. The ADAMS simulation results of the Tripod and Tri-Glide PMs for the Link actuation 2 are shown in Figure 10. Similarly, the other simulation results are obtained.

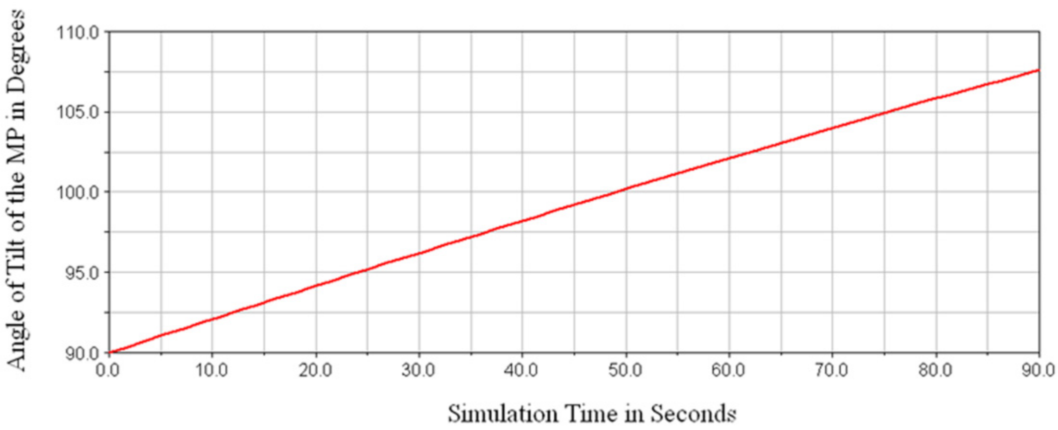
Table 3. Tri-Glide (B) results of the angle of tilt of the MP for the nut displacement of 90 mm by the experimental method.

Actuation Link Number	Predetermined distance ‘AC’ from the point of the laser source to the vertical screen in mm	Vertical height of the laser beam on the vertical screen in mm (Average of 5 Trials)	Angle of tilt of the MP (degrees)

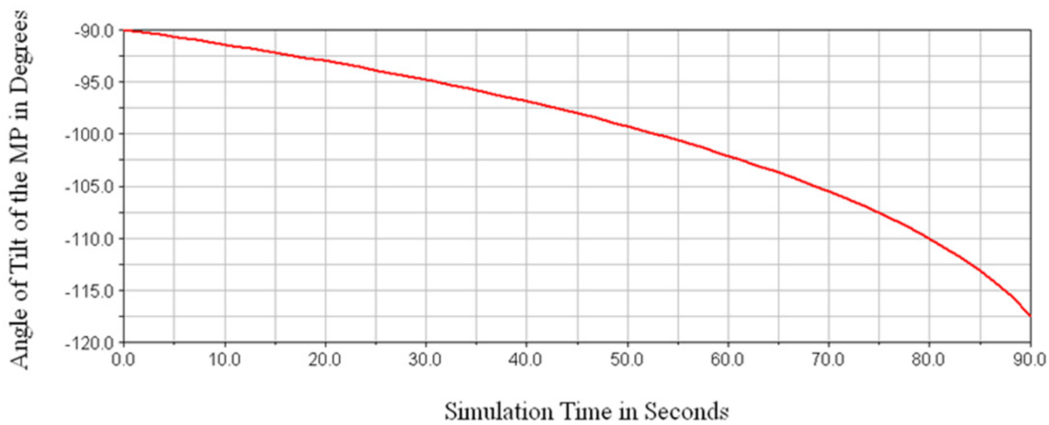
		About X axis	About Y axis	About X axis α	About Y axis β
1	249	148	0	30.72	0
2	249	64	129	14.41	27.38
3	249	64	128	14.41	27.20

Table 4. Results of the angle of tilt of the MP for the nut displacement of 90 mm by experimental and ADAMS methods.

Actuation Link Number	Angle of tilt of MP (degrees)			
	Experiment		ADAMS	
	About the X axis α	About the Y axis β	About the X axis α	About the Y axis β
1	30.72	0	30.98	0
2	14.41	27.38	14.92	27.48
3	14.41	27.20	14.92	27.48



(a) Tripod – x axis



(b) Tri-Glide – y axis

Fig. 10. PMs MP tilt for link actuation 2

5. Conclusions

In the kinematic study, position analysis is carried out for the Tripod and Tri-Glide PMs, the experimental method shows a deviation of 3.5% (for the x axis MP tilt) when compared with the analytical method for the Tripod PM. The ADAMS results are compared with the experimental results (for the x axis and y axis MP tilt) and it is found that it has a maximum deviation of 3.5%. From the Tri-Glide (B) PM results, the experimental method shows a deviation of 0.9% (for the x axis MP tilt) when compared with the analytical method. The ADAMS results are compared with the experimental results, and it is found that the ADAMS has a maximum deviation of 3.54%. The deviation occurs due to the resisting force developed against link movement, particularly in the extreme positions; so that, the link requires more force to reach the maximum angle of tilt of the MP. While simulating the PM at extreme positions, the link struggling to attain the required position is observed.

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