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Linear Translation Motion of a Stewart Platform with Solid Works Modelling and Matlab Simulation

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Abstract

The solid work modelling of a Stewart Platform for linear translation motions has been performed in this paper. The sinusoidal motions with different amplitudes of three linear translation motions as surge, sway and heave have been studied with solid works modelling. The inverse kinematic modelling of Stewart platform is done in this paper. The piston motions for the linear translation motions have been framed with inverse kinematic modelling. The piston motions from the solid work modelling and inverse kinematics model-ling have been illustrated and portrayed in this paper. The maximum range of the platform motions have also been found out and tabulated which can be implemented in real time. The maximum possible ranges are 100 mm amplitude of surge motion, 90 mm amplitude of sway motion and 100 mm amplitude of heave motion with the available piston stroke length of 150 mm.

Keywords: *Stewart Platform, Linear Motion, Solid Work Modelling, Inverse Kinematics, Matlab Simulation*

1. Introduction

In the modern manufacturing and industrial applications robotic manipulators have a great role. So it is an interesting research filed in different types of robotic manipulators. Parallel Manipulator has one fixed and another moving platform. This manipulator has three fundamental translation and three fundamental rotational motions along three major principle axis. The parallel manipulator can carry higher load compared to serial manipulator due to its higher rigidity and inertia [1]. The power consumption in parallel manipulator is less compare to that of serial manipulator because of less moving masses. But the workspace formed by the serial manipulator is more compare to that of parallel manipulator. This manipulator can be used as Flight Simulator [2] for the training purpose of the pilots before going to the real time experiences. Radio-telescope stabilization [3] can be achieved with this parallel manipulator. In modern industry the real time automation performances in Laser cutting, welding, drilling [4-5] can be reached with this manipulator. Vasfiet al. (2011) [6] show the realization for steering functions operated by two or three DOF joysticks.

Kinematic modelling is used to find out the kinematics characteristics of the moving platform and each actuator motion [7-8]. The inverse kinematic modelling technique is useful [9-10] to find out the corresponding motion of each

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actuator. The individual motion of the actuator can be used for real time applications [11] and their precise control [11-12]. Dasgupta et al. (2000) [13-14] present simulation and control of SP with linear motor. The dynamic analysis, kinematic analysis have been presented. Real-time control [15-16] of this platform is another challenging research works in the modern industrial application field. The modern controllers [17-18] have been used to control precisely [19-20] for the real time motions for different applications.

In this work the inverse kinematics equations have been formulated and the corresponding simulation results with help of Matlab have been depicted. The platform motion study has been also performed in Solid-works modelling and the corresponding piston motions have been shown. The different amplitudes of sinusoidal motions of surge along x axis, sway in y axis and heave along z axis have been considered. The piston motions for each type of motion have been depicted from the Matlab and also from the Solid-works. The maximum range of the platform motions have also been found out and tabulated which can be used in real time applications. The Stewart Platform is described in the next section. The inverse kinematics modeling has been framed in the section 3 and results and discussion has been given in the section 4 followed by the concluding section.

2. Description of Stewart Platform

The Fig.1 of a parallel manipulator has been adopted from Mintu Ghosh et al. (2020).

Fig. 1 represents a 3-D view of Stewart Platform or Parallel Manipulator with “F” fixed platform and “M” moving platform. There are six linear actuators which are connected by moving platform and fixed platform. The cylinder-piston arrangement has one cylinder C and actuated piston which can move to and fro direction to make the motion of the platform. Each cylinder has respective bottom point denoted by Band the corresponding top points denoted by T. The bottom and top points have been connected by spherical joints. Each piston has the maximum displacement as 150 mm. So the neutral pose of the platform is considered with each piston motion of 75mm.

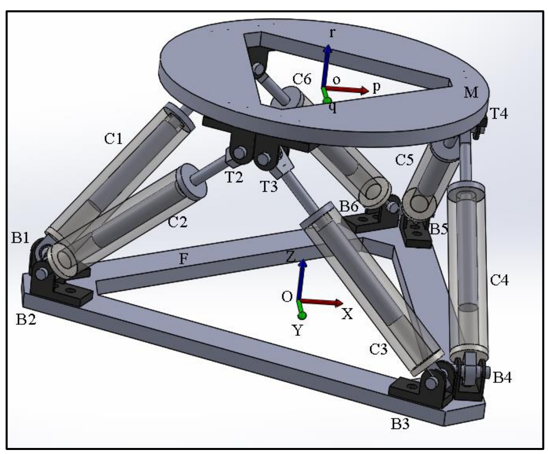


Fig. 1. Parallel Manipulator with six linear actuators

The *OXY* plane is passing through the plane where the all bottom points lie. The vertical axis has been denoted by the *Z* axis. The corresponding *opq* plane is in the middle horizontal plane of the top platform. The vertical distance at neutral pose has been taken as 474mm. The bottom points and top points coordinates are required for the motion study. So these points have been extracted in the Solid-works modeling with help of the corresponding dimensions of cylinder-piston arrangement provided by the Dasmahapatra et al.(2016) [11]. The corresponding bottom points B in Table 1 and the top points T in Table 2 have been tabulated.

Table 1. Bottom coordinate at neutral pose.

	X (mm)	Y (mm)	Z(mm)
B1	287.88	-597.37	0
B2	373.40	-547.99	0
B3	-661.27	-49.37	0
B4	-661.27	49.38	0
B5	287.88	597.37	0
B6	373.40	547.99	0

Table 2. Top coordinate at neutral pose.

	X (mm)	Y (mm)	Z(mm)
T1	-158.24	340.00	-85
T2	-215.33	-307.04	-85
T3	-215.33	-307.84	-85
T4	-158.24	-340.00	-85
T5	373.57	-32.96	-85
T6	373.57	32.96	-85

3. Inverse Kinematics Modelling

The inverse kinematic [9] modelling has been illustrated in this section for finding out the piston motions. These formulations has been taken for the simulation study in Matlab simulation.

The coordinate OXYZ is the stationary coordinate system. In this coordinate system, the bottom points have been represented as

$$\mathbf{x}_{Bi}=(x_{Bi} \quad y_{Bi} \quad z_{Bi})^T\,\hat{\mathbf{e}}_O, \tag{3.1}$$

and top points have been denoted as

$$\mathbf{x}_{Ti}=(x_{Ti} \quad y_{Ti} \quad z_{Ti})^T\,\hat{\mathbf{e}}_O. \tag{3.2}$$

The coordinate opqr is the moving coordinate system. In this coordinate system, top points have been designated as

$$\mathbf{p}_{Ti}=(p_{Ti} \quad q_{Ti} \quad r_{Ti})\hat{\mathbf{e}}_o. \tag{3.3}$$

The platform pose has been denoted as

$$q=(d^T \ \theta^T)^T=(x_o\, y_o\, z_o\, \alpha\ \beta\ \ \gamma)^T \tag{3.4}$$

where d = Translation & θ = Rotation.

The overall rotational matrix has been defined as **R** which is the multiplication of rotational matrix R_α along x axis, R_β in y axis and R_γ along z axis. Each rotational matrix has been given as

$$R=R_\gamma R_\beta R_\alpha \tag{3.5}$$

$$R_\alpha = \begin{bmatrix} 1 & 0 & 0 \\ 0 & c\alpha & s\alpha \\ 0 & -s\alpha & c\alpha \end{bmatrix} \tag{3.6a}$$

$$R_\beta = \begin{bmatrix} c\beta & 0 & -s\beta \\ 0 & 1 & 0 \\ s\beta & 0 & c\beta \end{bmatrix} \tag{3.6b}$$

$$R_\gamma = \begin{bmatrix} c\gamma & s\gamma & 0 \\ -s\gamma & c\gamma & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{3.6c}$$

$$\text{and } R^T = R_\gamma{}^T R_\beta{}^T R_\alpha{}^T = \begin{bmatrix} c\beta c\gamma & -c\beta s\gamma & s\beta \\ c\alpha s\gamma + s\alpha s\beta c\gamma & c\alpha c\gamma - s\alpha s\beta s\gamma & -s\alpha c\beta \\ s\alpha s\gamma - c\alpha s\beta c\gamma & s\alpha c\gamma - c\alpha s\beta s\gamma & c\alpha c\beta \end{bmatrix} \tag{3.7}$$

The length of the piston has been formulated [14] as

$$l_i = \sqrt{(\mathrm{p}_{Ti}^T \mathrm{R} + \mathrm{d}^T - \mathrm{x}_{Bi}^T)(\mathrm{R}^T \mathrm{p}_{Ti} + \mathrm{d} - \mathrm{x}_{Bi})} \tag{3.8}$$

Here T_i = represents spherical joint at top position & B_i = represents spherical joint at bottom position.

4. Results and Discussions

In this section the simulation results for the piston motion by Inverse kinematics modelling in Matlab software has been given. The motion study of the platform has been also done with help of Solid-works modelling in this section. The basic three linear as surge, sway and heave motion have been studied. The individual piston motions extracted from the inverse kinematics equation in Matlab and the motion study in Solid-works have been depicted in this section. The range of motion of the platform motions with available piston motions have been also tabulated in this section.

4.1 Surge Motion Tracking for 100 mm displacement of top moving platform

The motion study of surge motion in Solid-works have been represented in the Figs. 2(a-c). In surge motion top moving platform has been displaced along X-axis in positive & negative direction also. Fig. 2(a) shows top platform and piston displacement for 100 mm linear displacement of top moving platform along positive X-axis direction. Fig. 2(b) shows top platform and piston displacement for 100 mm linear displacement of top moving platform along negative X-axis direction. Fig. 2(c) shows top platform and piston displacement at neutral position.

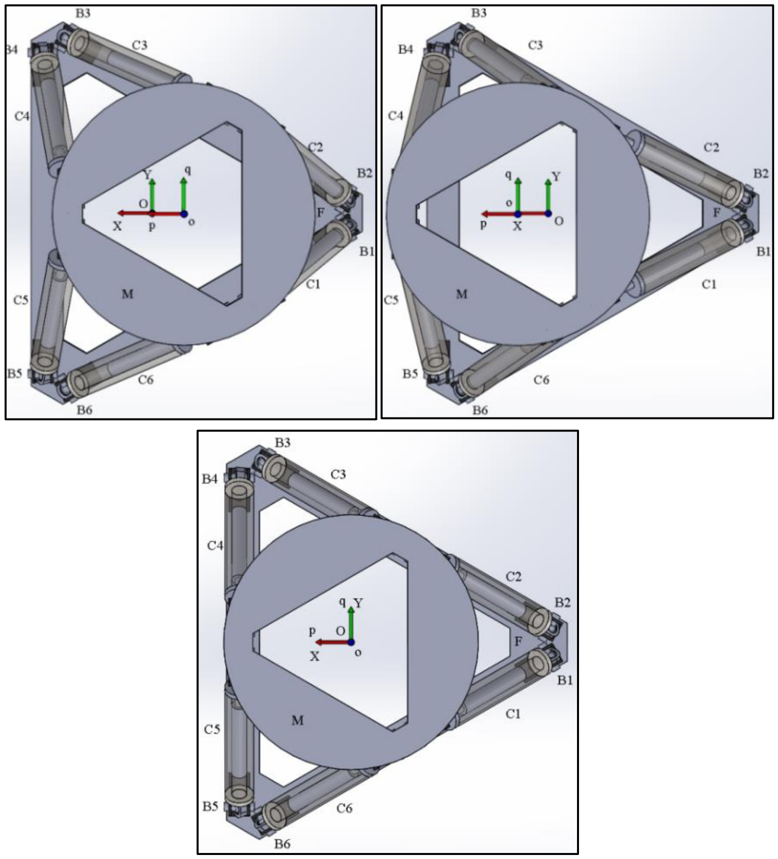


Fig. 2. Top platform position (a) with positive 100 mm surge from the neutral position (b) with negative 100 mm surge from the neutral position (c) at neutral position.

The surge motion results have been depicted in Figs 3 (a-c). The demand of the moving platform has been shown in the Fig. 3(a). The actuator displacements extracted from the solid works modelling have been depicted in the Fig. 3(b). The actuator displacements found in Matlab have been revealed in the Fig. 3(c). The Solid-works motion results in Fig. 3(b) and Matlab simulation results in Fig. 3(c) show the same results in piston displacements. So it can be said that Solid-works motion study of this sinusoidal motion has been validated with the Matlab simulation results which have been extracted by the inverse kinematics formulations. It can also be revealed from the Figs. 3(b) and 3(c) that the pistons 1 and 2 have been extended up to 147.58 mm initially whereas pistons 3and 6 have been retracted up to 10.51 mm. There is very low amplitude of motions in piston 4 and 5.

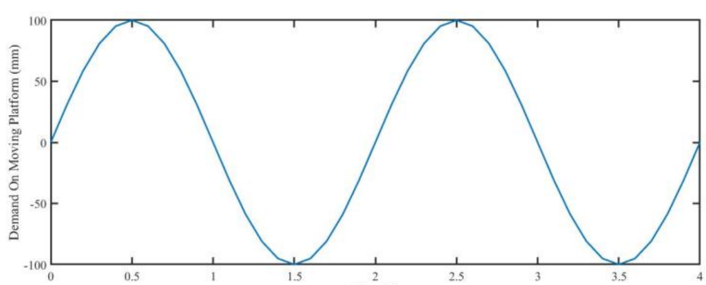


Fig. 3a. Demand of moving platform for 100mm amplitude and 0.5Hz frequency sinusoidal type Surge motion.

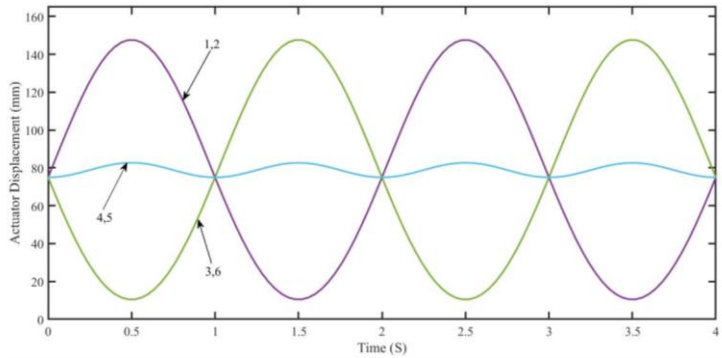


Fig. 3b. Solid-works Modelling results of each piston motion for the platform demand in Fig.3a.

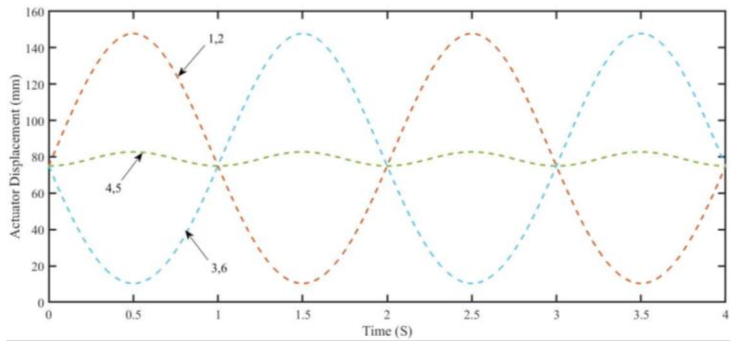
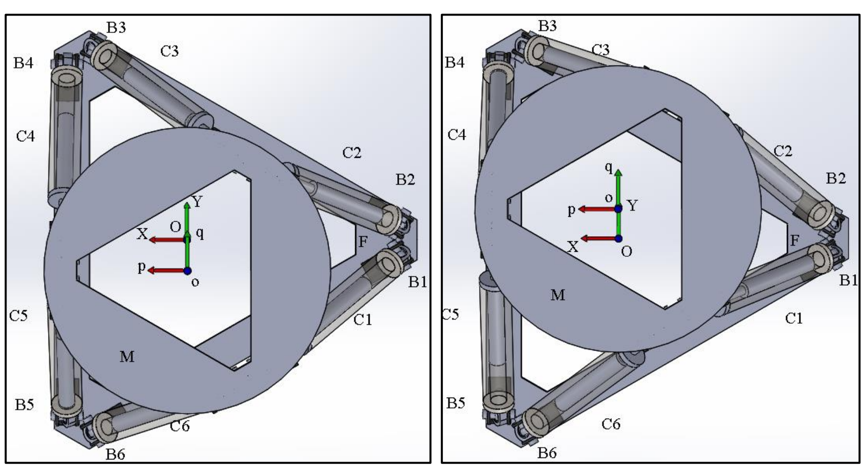


Fig. 3c. Matlab Simulation results of each piston motion for the platform demand in Fig.3a.

4.2 Sway Motion Tracking for 90 mm displacement of top moving platform

The motion study of sway motion in Solid-works have been represented in the Figs. 4(a-c). In sway motion top moving platform has been displaced along Y-axis in positive & negative direction also. Fig. 4(a) shows top platform and piston displacement for 90 mm linear displacement of top moving platform along positive Y-axis direction. Fig. 4(b) shows top platform and piston displacement for 90 mm linear displacement of top moving platform along negative Y-axis direction. Fig. 4(c) shows top platform and piston displacement at neutral position.



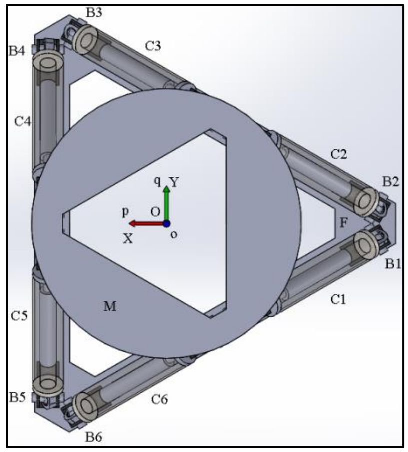


Fig. 4. Top platform position (a) with positive 90 mm sway from the neutral position (b) with negative 90 mm sway from the neutral position (c) at neutral position.

The sway motion results have been depicted in Figs 5 (a-c). The demand of the moving platform has been shown in the Fig. 5(a). The actuator displacements extracted from the solid works modelling have been depicted in the Fig. 5(b). The actuator displacements found in Matlab have been revealed in the Fig. 5(c). The Solid-works motion results in Fig. 5(b) and Matlab simulation results in Fig. 5(c) show the same results in piston displacements. So it can be said that Solid-works motion study of this sinusoidal motion has been validated with the Matlab simulation results which have been extracted by the inverse kinematics formulations. It can also be revealed from the Figs. 5(b) and 5(c) that the pistons 1, 3 & 4 have been extended up to 115.81 mm, 115.77 mm, 148.70mm respectively initially whereas pistons 2, 5 & 6 have been retracted up to 44.68 mm, 5.88 mm, 44.72 mm respectively.

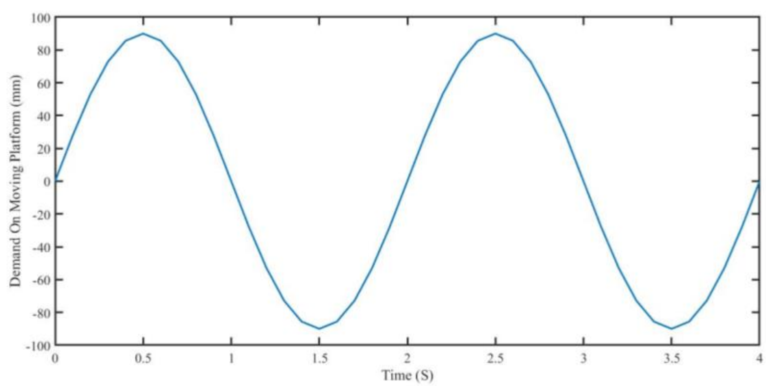


Fig. 5a. Demand of moving platform for 90 mm amplitude and 0.5Hz frequency sinusoidal type Sway motion.

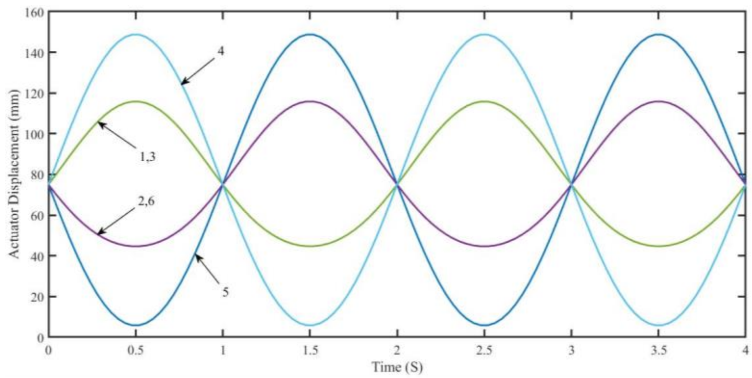


Fig. 5b. Solid-works Modelling results of each piston motion for the platform demand in Fig.5a.

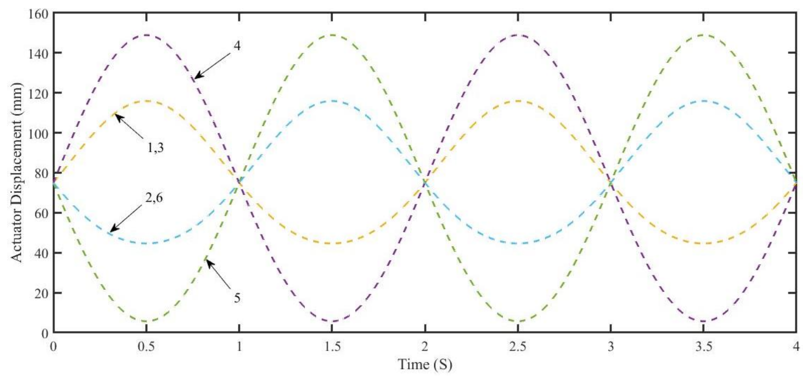
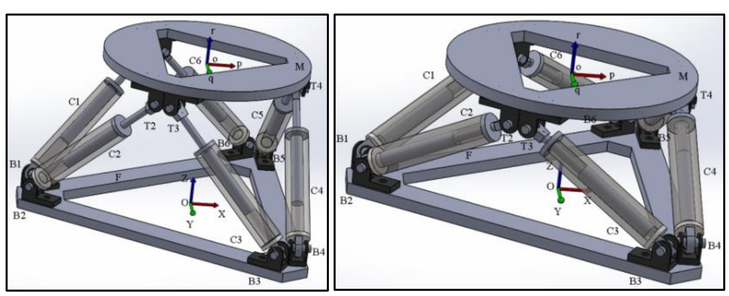


Fig. 5c. Matlab Simulation results of each piston motion for the platform demand in Fig.5a.

4.3 Heave Motion Tracking for 100 mm displacement of top moving platform

The motion study of heave motion in Solid-works have been represented in the Figs. 6(a-c). In heave motion top moving platform has been displaced along Z-axis in positive & negative direction also. Fig. 6(a) shows top platform and piston displacement for 100 mm linear displacement of top moving platform along positive Z-axis direction. Fig. 6(b) shows top platform and piston displacement for 100 mm linear displacement of the top moving platform along negative Z-axis direction. Fig. 6(c) shows top platform and piston displacement at neutral position.



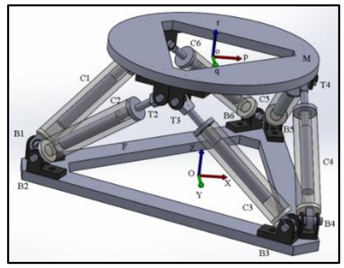


Fig. 6. Top platform position (a) with positive 100 mm Heave from the neutral position (b) with negative 100 mm Heave from the neutral position (c) at neutral position.

The heave motion results have been depicted in Figs 7 (a-c). The demand of the moving platform has been shown in the Fig. 7(a). The actuator displacements extracted from the solid works modelling have been depicted in the Fig. 7(b). The actuator displacements found in Matlab have been revealed in the Fig. 7(c). The Solid-works motion results in Fig. 7(b) and Matlab simulation results in Fig. 7(c) show the same results in piston displacements. So it can be said that Solid-works motion study of this sinusoidal motion has been validated with the Matlab simulation results which have been extracted by the inverse kinematics formulations. It can also be revealed from the Figs. 7(b) and 7(c) that the pistons 1-6 have been extended up to 139.64 mm initially whereas pistons 1-6 have been retracted up to 20.23 mm.

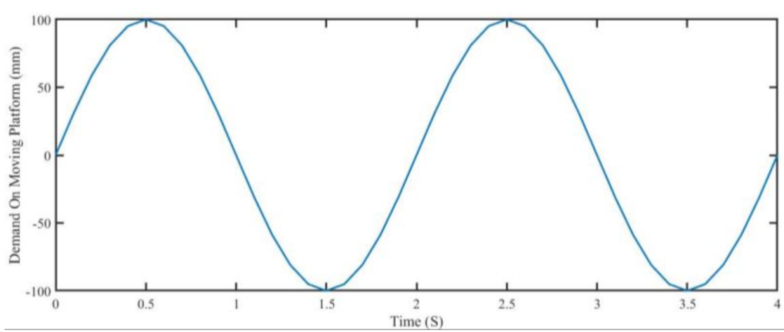


Fig. 7a. Demand of moving platform for 100mm amplitude and 0.5Hz frequency sinusoidal type Heave motion.

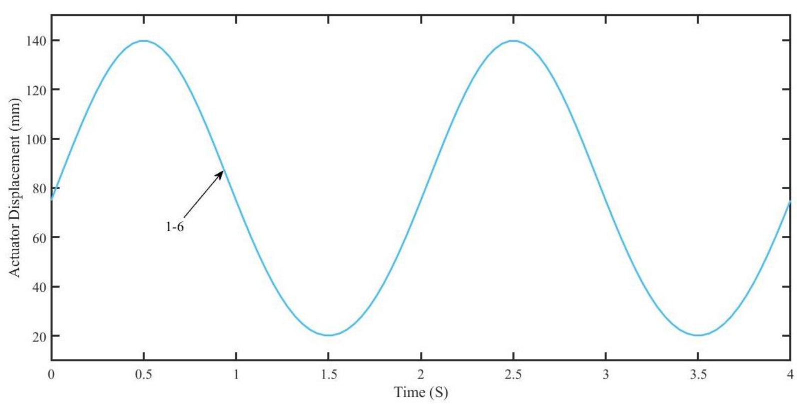


Fig. 7b. Solid-works Modelling results of each piston motion for the platform demand in Fig.7a.

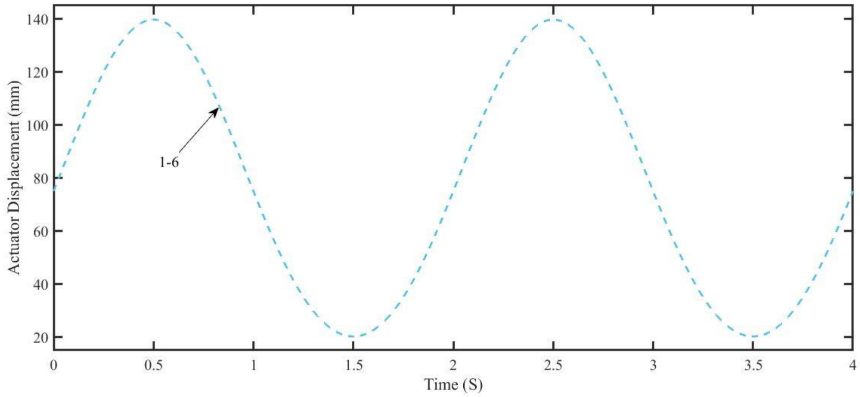


Fig. 7c. Matlab Simulation results of each piston motion for the platform demand in Fig.7a.

The maximum possible motion of the moving platform have been tabulated in Table 3. From this table it can be revealed that surge and heave motion can be done maximum 100mm in positive and negative direction whereas sway motion can be done 90mm in positive and negative direction. For the surge motion it can be revealed that the similar type of motion of the actuators 1-2, 3-6 and 4-5. In the sway motion the similar type of motion of the actuators 1-3, 2-6 but there is no similarity of 4 and 5 actuators. In case of heave motion all the actuators 1 to 6 are in same motions to create the pose of the heave motion. In this paper the graphical representation for the sinusoidal type surge motions in Figs. 2-3, sway motions in Figs. 4-5 and heave motion in Figs. 6-7. The corresponding figures in Figs. 2 to 7 have been done with help of solid works modeling and inverse kinematics modeling in Matlab Simulink environment. The piton position for different step responses in positive and negative directions of surge, sway and heave motions have been reflected in the Table 3. The initial position of each piston is 75mm and any the piston extension has been defined as more than 75mm whereas the retraction of the piston is considered here as less than 75mm. So it can be said from the Table 3 that there is extension of piston 1-2 and retraction of 3-6 in case of positive surge motion. For the negative surge motion there is extension of piston 3-6 and retraction of 1-2. In case of piston 4-5 there is no such change in motion for both of positive and negative surge motions. For positive sway motion the piston 1, 3 and 4 in extension mode whereas the retraction motion has been done in case of piston 2, 5 and 6. In negative sway motion piston 2, 5 and 6 are in extension motion and piston 1, 3 and 4 in retraction motion. So the motion of the piston in positive sway are in opposite to that of negative sway motion. All the piston are in same motion for the heave motion. So that there are extension motion of each piston for positive heave motion and retraction motion of each piston for negative heave motion.

Table 3. Range identification of piston position for linear demand on top platform for Sinusoidal demand.

Top Platform Demand	Top Platform Demand in mm	Piston Position (mm)					
		1	2	3	4	5	6
Surge Positive	+25	92.48	92.48	58.01	75.48	75.48	58.01
	+50	110.43	110.43	41.57	76.93	76.93	41.57
	+75	128.80	128.80	25.72	79.34	79.34	25.72
	+100	147.58	147.58	10.51	82.69	82.69	10.51
Surge	-25	58.02	58.02	92.48	75.47	75.47	92.48
	-50	41.59	41.59	110.44	76.91	76.91	110.44

Negative	-75	25.74	25.74	128.82	79.30	79.30	128.82
	-100	10.54	10.54	147.60	82.64	82.64	147.60
Sway Positive	+25	85.35	65.45	85.34	95.07	55.27	65.46
	+50	96.49	56.75	96.46	115.47	35.93	56.77
	+75	108.35	48.93	108.32	136.16	17.01	48.97
	+90	115.81	44.68	115.77	148.70	5.88	44.72
Sway Negative	-25	65.45	85.35	65.46	55.27	90.07	85.34
	-50	56.75	96.49	56.77	35.93	115.47	96.46
	-75	48.93	108.35	48.97	17.01	136.16	108.32
	-90	44.68	115.81	44.72	5.88	148.70	115.77
Heave Positive	+25	90.34	90.34	90.34	90.34	90.34	90.34
	+50	106.25	106.25	106.25	106.25	106.25	106.25
	+75	122.69	122.69	122.69	122.69	122.69	122.69
	+100	139.64	139.64	139.64	139.64	139.64	139.64
Heave Negative	-25	60.27	60.27	60.27	60.27	60.27	60.27
	-50	46.20	46.20	46.20	46.20	46.20	46.20
	-75	32.84	32.84	32.84	32.84	32.84	32.84
	-100	20.23	20.23	20.23	20.23	20.23	20.23

5. Conclusions

Sinusoidal motion of three basic linear motions as surge, sway and heave have been studied in both of Matlab simulation and Solid-works modelling. The amplitude of the linear motions for positive and negative direction have been taken as 25mm, 50mm, 75mm, 90mm and 100mm. The maximum possible range of the moving platform motions have been examined with the available piston stroke length of 150mm. The maximum possible range of the 0.5Hz sinusoidal type surge motion is with 100mm amplitude, sway motion with 90mm amplitude, heave motion with 100mm amplitude. From this study it has been observed that the piston motion of each actuator is same for heave motion either in positive or negative directions. But in surge and sway motions there are some pairing between different actuators to make the desirable pose of the moving platform. One remarkable observation from this study can be revealed that there is minor change in motion of the piston 4 and 5 in surge motion either in positive or negative directions.

It can also be concluded from this research work that the Solid-works motion results and Matlab simulation results are exactly identical to each other. So the Solid-works motion study has been validated with the Matlab simulation results which have been extracted by the inverse kinematics formulations. So this Solid-works modelling can be successfully used as simulation study for the parallel manipulator-Stewart Platform. The real time work can be done to make low cost 6-DOF Stewart Platform with low cost electric linear actuator controlled by precise controllers such as Sliding Mode Controller-SMC, Fuzzy –SMC, Fuzzy-PID, Adaptive Fuzzy SMC.

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