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Modeling of Gough Stewart Robot Manipulator Inverse Kinematics by Using MSC ADAMS Software

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Abstract:

The Gough Stewart Robotic manipulator is a parallel manipulator with six-degree of freedom, which has six equations of inverse and forward with six variables. This paper model of the Gough Stewart has been built into the MSC ADAMS software and its motion based on the inverse equations of the Stewart. Then compare the obtained results from the software with the results, which obtained from theoretical model.

Key words: Robot, Gough-Stewart, MSc. ADAMS, Kinematics, Inverse analysis.

1- Introduction:

Parallel manipulators are mechanisms where all the links are connected to the ground and the moving platform at the same time [1]. The Stewart platform manipulator is a fully parallel kinematic linkage system that has major mechanical differences over typical serial link robots [2]. The manipulating structure now known as the Stewart platform has its origin in the design by Stewart of a 6-DOF mechanism to simulate flight conditions by generating general motion in space [3]. For a 6-DOF Stewart platform, the complexity of the forward kinematics has to be compared with that of the direct kinematics of the serial robot and, on the contrary, inverse kinematics are as Gough-Stewart easy as the forward kinematics of a serial robot arm [4].

Parallel mechanisms (PMs) have become a large field of investigation during the past several decades because of their many attributes, including large load capacities, high stiffness and stability, and good dynamic performance. However, PMs are only one type of closed-loop spatial mechanisms and their architectural nature limits their application [5].

2- Gough Stewart Model:

A Gough-Stewart parallel manipulator typically consists of a moving platform and a fixed base that are connected together by six links. Because of the closed-loop architecture, not all of the joints can be independently actuated. In general, the number of actuated joints is equal to the number of degrees of freedom of the manipulator [6].

In this paper, the model of the manipulator consists of the fixed base and moving platform, six linear actuators which are connected to the base by universal joints (have two degrees of freedom) and connected with the moving platform by a ball joint (have three degrees of freedom) as shown in fig (1).

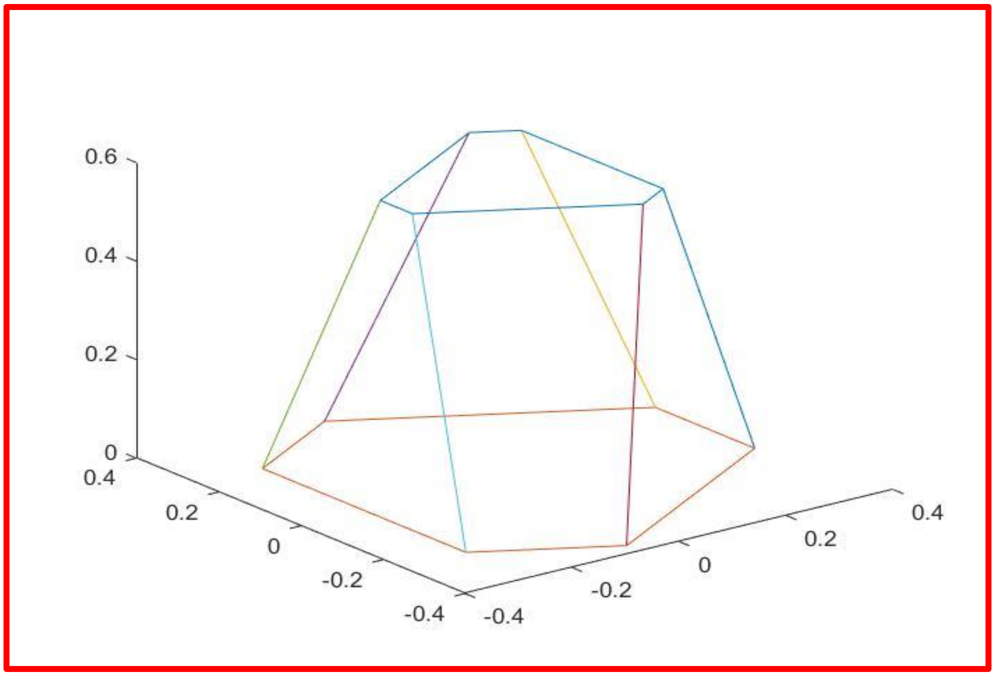


Fig (1): The mechanism of the Stewart.

2.1- Inverse Kinematics Analysis:

The tables 1 and 2 show coordinates of the base and moving platform as shown in fig. (2) and fig (3), respectively and the length of each linkage at initial conditions equal to (0.625 m).

Table: the coordinates of the base of the Gough-Stewart

Base Coordinates			
Point No	X	Y	Z
1	355	121	0
2	-73.5	367.5	0
3	-281.5	247.5	0
4	-281.5	-247.5	0
5	-73.5	-367.5	0
6	355	-121	0

Table2: the coordinates of the moving platform of the Gough-Stewart

Moving Platform Coordinates			
Point No	X	Y	Z
1	144.5	172.5	600
2	77	211.5	600
3	-221.5	39	600
4	-221.5	-39	600
5	77	-211.5	600
6	144.5	-172.5	600

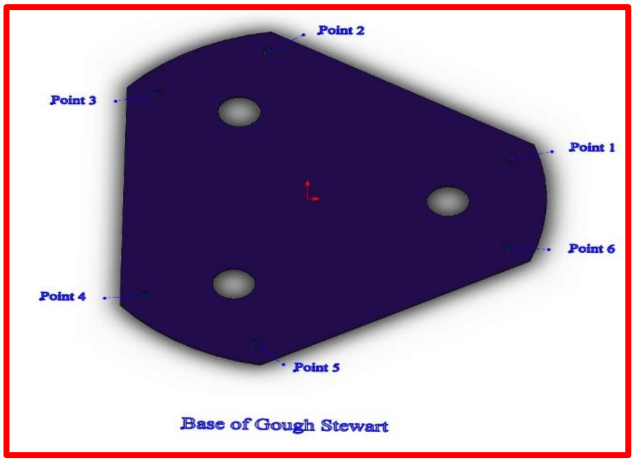


Fig (2): Fixed base of the Stewart

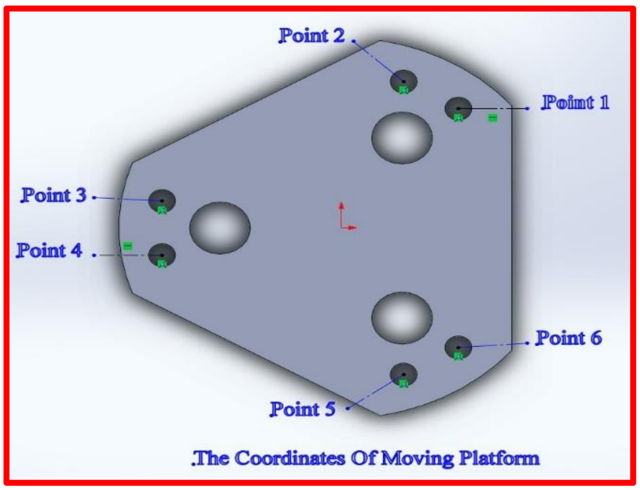


Fig (3): The moving platform of the Stewart

Inverse kinematics is the calculation of the links length, in order to satisfy a position and orientation of the moving platform center. It is commonly used for trajectory generation [7]. To find the inverse kinematics of the Stewart based on the geometry of the Gough-Stewart manipulator, which shown in Fig. (4), the lengths of all links are function of the position and orientation of the moving platform center, the inverse analysis is expressed as in the equations below.

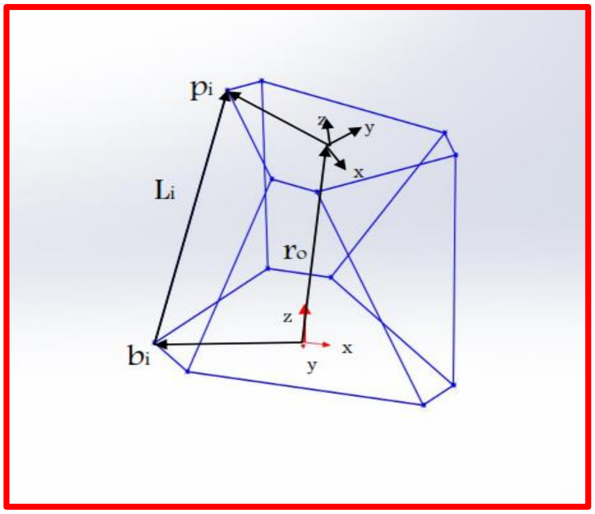


Fig (4): Description of the Stewart.

$$L_i = {r_o}^G + R_L^G . {P_i}^L - {b_i}^G \text{ [8]} \qquad \dots (1)$$

i = 1 … 6

$${r_o}^G = [X \quad Y \quad Z]^T$$

$$R_L^G = R_z(\gamma).R_y(\beta).R_x(\alpha) = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix}$$

$${P_i}^L = [p_{xi} \quad p_{yi} \quad p_{zi}]^T$$

$${b_i}^G = [b_{xi} \quad b_{yi} \quad b_{zi}]^T$$

Where:

L_i: is the length of i linkage.

${r_o}^G$: The coordinates of moving platform in the Global Coordinate system.

R_L^G: Rotation matrix of the local Coordinate system relative to Global coordinate system.

${P_i}^L$: The coordinates of i joint of with i link moving platform in the local coordinate system.

${b_i}^G$: The coordinates of i joint of fixed platform with the I link in global coordinate system.

a_{11}=$cos(\gamma)\ cos(\beta)$

a_{12}=$cos(\gamma)\ sin(\beta)\ sin(\alpha)$-$sin(\gamma)\ cos(\alpha)$

a_{13}=$cos(\gamma)\ sin(\beta)\ cos(\alpha)$+$sin(\gamma)\ sin(\alpha)$

a_{21}=$sin(\gamma)\ cos(\beta)$

a_{22}=$sin(\gamma)\ sin(\beta)\ sin(\alpha)$+$cos(\gamma)\ cos(\alpha)$

a_{23}=*sin(γ) sin(β) cos(α)-cos(γ) sin(α)*

a_{31}=*-sin(β)*

a_{32}=*cos(β) sin(α)*

a_{33}=*cos(β) cos(α)*

The length of i linkage can be obtained from the equation below which is derived by square equation (1.1):

$$L_i . {L_i}^T = \left[{r_o}^{G^T} . {r_o}^G + {b_i}^{G^T} . {b_i}^G + {P_i}^{L^T} . {P_i}^L + 2. {P_i}^{L^T} . R_L^G . {b_i}^G - 2. {b_i}^{G^T} . R_L^G . {P_i}^L - 2. {P_i}^{L^T} . {b_i}^G\right] \quad \ldots\ldots (2)$$

From above equation the change in length of i linkage present in the following equations:

$$q_i = \Big(\Big(X + \big((cos(\gamma) * cos(\beta)\big) * p_{xi}\Big) + \Big(\Big(\big(cos(\gamma) * sin(\beta) * sin(\alpha)\big) - \big(sin(\gamma) * cos(\alpha)\big)\Big) * p_{yi}\Big) + \Big(\Big(\big(cos(\gamma) * sin(\beta) * cos(\alpha)\big) + \big(sin(\gamma) * sin(\alpha)\big)\Big) * p_{zi}\Big) - b_{xi}\Big)^2 + \Big(Y + \big((sin(\gamma) * cos(\beta)\big) * p_{xi}\Big) + \Big(\Big(\big(sin(\gamma) * sin(\beta) * sin(\alpha)\big) + \big(cos(\gamma) * cos(\alpha)\big)\Big) * p_{yi}\Big) + \Big(\Big(\big(sin(\gamma) * sin(\beta) * cos(\alpha)\big) - \big(cos(\gamma) * sin(\alpha)\big)\Big) * p_{zi}\Big) - b_{yi}\Big)^2 + (Z + ((-sin(\beta)) * p_{xi}) + ((cos(\beta) * sin(\alpha)) * p_{yi}) + ((cos(\beta) * cos(\alpha)) * p_{zi}) - b_{zi})^2)^{0.5} - L_i \quad \ldots (3)$$

3- MSC ADAMS software:

ADAMS full simulation package is a powerful modeling and simulating environment that lets build, simulate, refine, and ultimately optimize any mechanical system. ADAMS full simulation package [9].

3.1- Build the model:

The model of Stewart done in this software by design the base and moving platform in solid works and the imported here to complete the six linkage between them. Finally, insert the joints (universal, prismatic, and ball) as shown in fig (5).

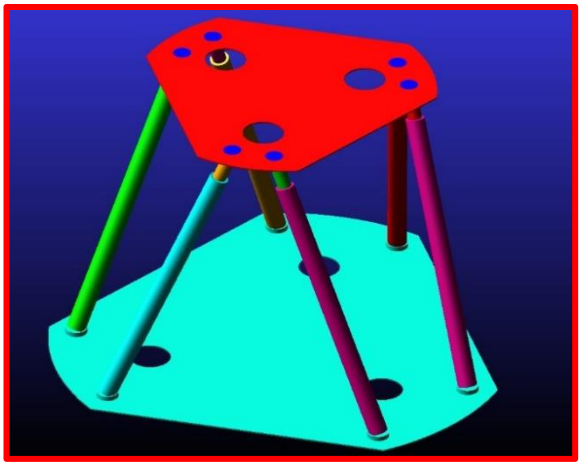


Fig (5): The Model in ADAMS

3.2- Insert the Equation of motion:

In this step, the equations (q_i) inserted into the prismatic joints to get the motion.

3.3- Simulation the model:

The simulation of the model done after insert the equation of motion for each prismatic joint.

3.4- MSC ADAMS results:

Finally, the ADAMS results include the length of the linkages at five positions, which explained in figures.

4- Results and discussion:

In this section three positions and three orientations (X, Y, Z, α, β, γ) shown in the table (3), which represent five position in the workspace in the workspace of the manipulator used to calculate the length of the linkages at each position by substituted in the inverse equations to get these lengths, which represented the theoretical calculation.

Then substituted these position and orientation in MSC ADAMS to obtain the length of the linkages to compare with the length obtain from inverse equations.

Figure (6, 7, 8, 9, 10, and 11) shows the Stewart model in the MSC ADAMS. The first figure shows the model at initial condition where the initial length equal to (0.625 mm) and the other five explained the model at five position as shown in table (3) by insert the position (X, Y, and Z) and orientation (α, β, and γ) in MSC.ADAMS model at each point.

Figures (12, 13, 14, 15, and 16) explained the lengths of the linkages at the period of the simulation at the five points, where any figure include the lengths of the six linkage at any time during simulation.

After calculation, the lengths of the linkages in theoretical and MSC.ADAMS at the five points the difference between them explained in the figures (17, 18, 19, 20, and 21), there are difference between the theoretical and ADAMS calculation.

Always the lengths of the linkages in ADAMS is smaller than from theoretical due to the ADAMS software take the type of materials and friction in calculation, while do not appear in inverse equation lead to these difference.

Table (3): the positions and orientations at points

Position and Orientation	Position 1	Position 2	Position 3	Position 4	Position 5
X	-0.1464	0.03853	0.04422	0.1324	0.115
Y	-0.9921	-0.02765	-0.02775	-0.05686	-0.1754
Z	0.8173	0.6285	0.624	0.7485	0.7464
α	-0.03709	0.2658	0.3004	0.1673	0.02394
β	0.8312	0.5569	0.4933	0.4337	1.51
γ	0.7613	0.8985	0.8316	1.133	1.414

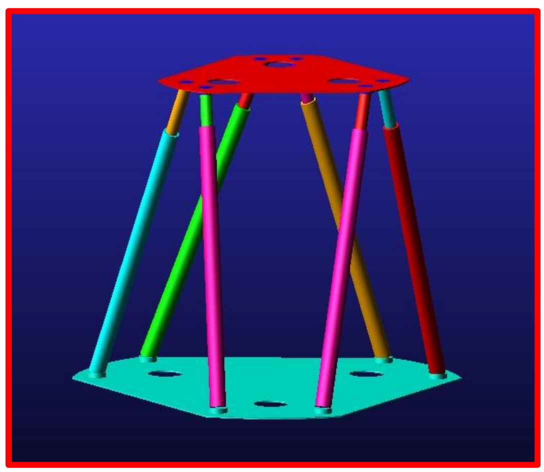


Fig (6): Stewart at initial condition

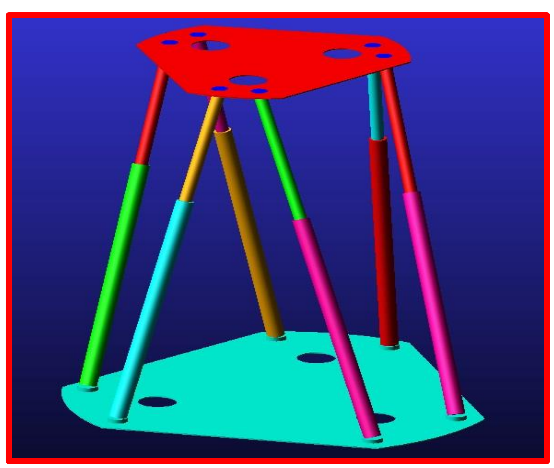


Fig (7): Stewart at Position 1.

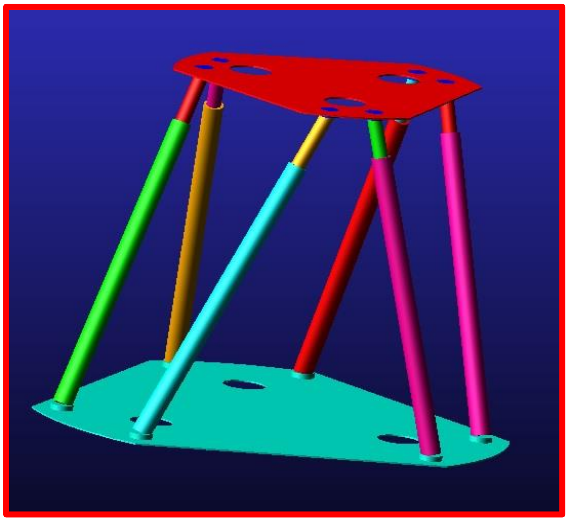


Fig (8): Stewart at Position 2.

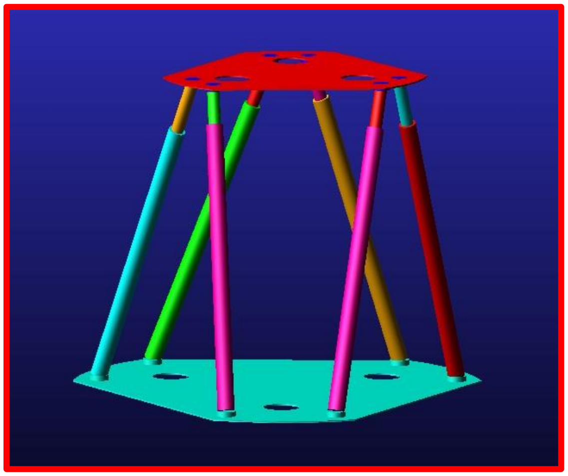


Fig (9): Stewart at Position 3.

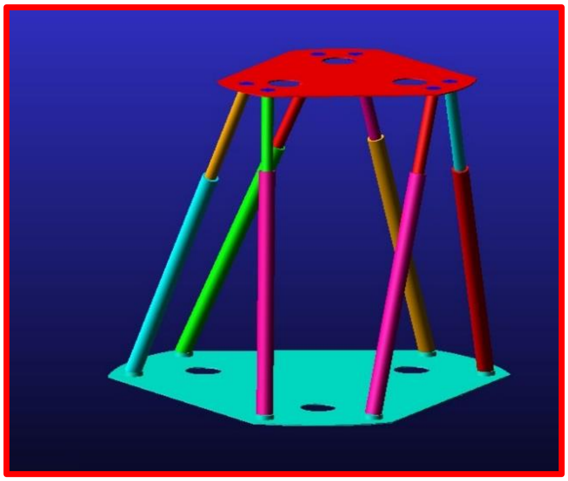


Fig (10): Stewart at Position 4.

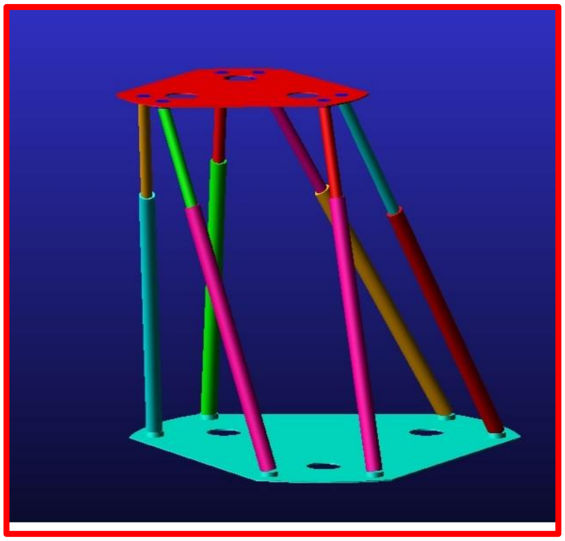


Fig (11): Stewart at Position 5.

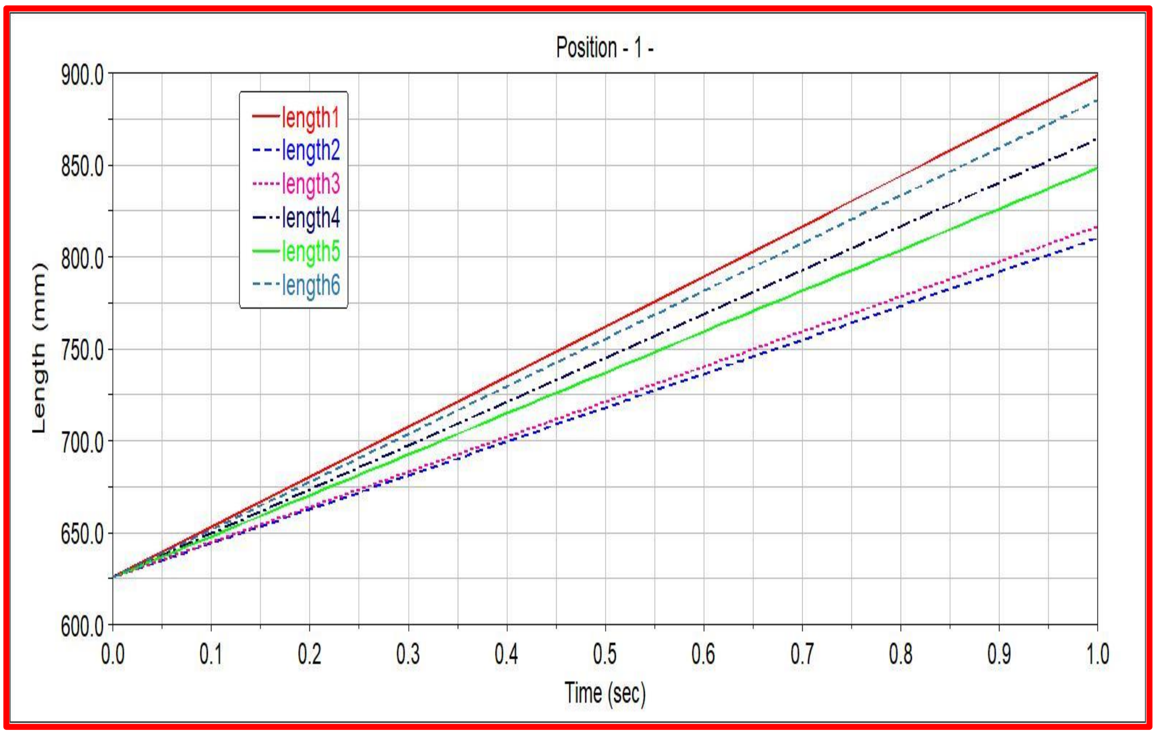


Fig (12): Stewart linkages length Position 1.

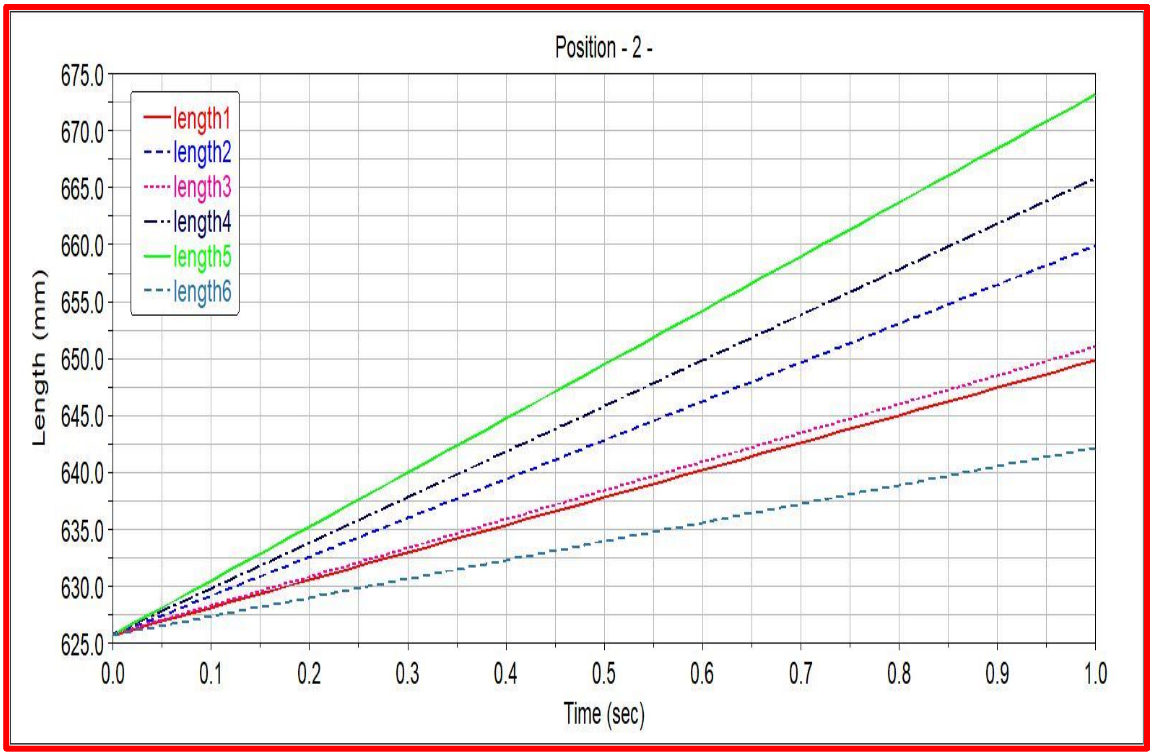


Fig (13): Stewart linkages length Position 2.

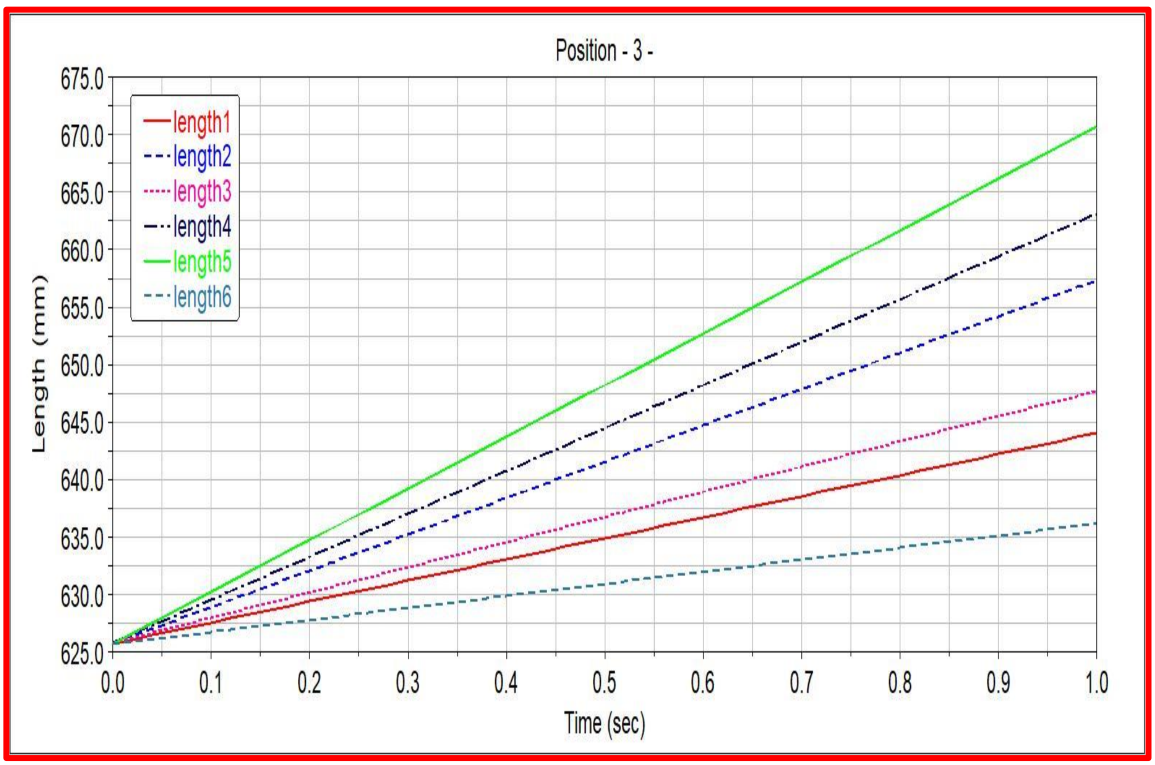


Fig (14): Stewart linkages length Position 3.

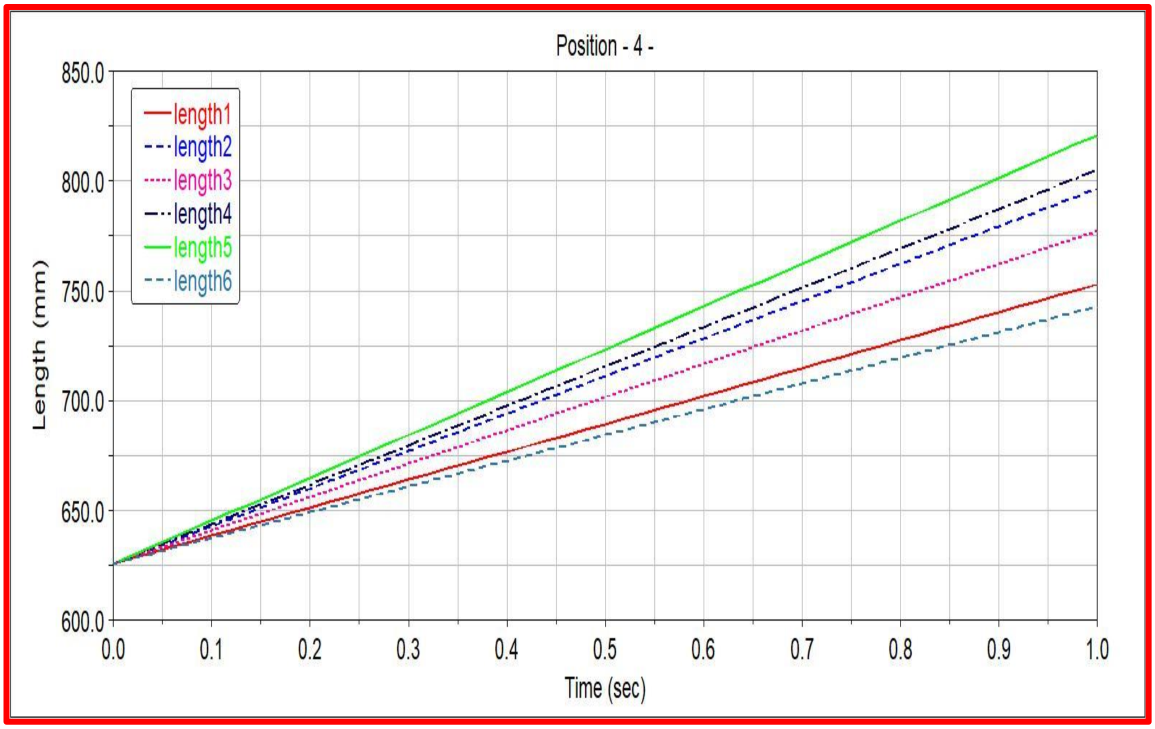


Fig (15): Stewart linkages length Position 4.

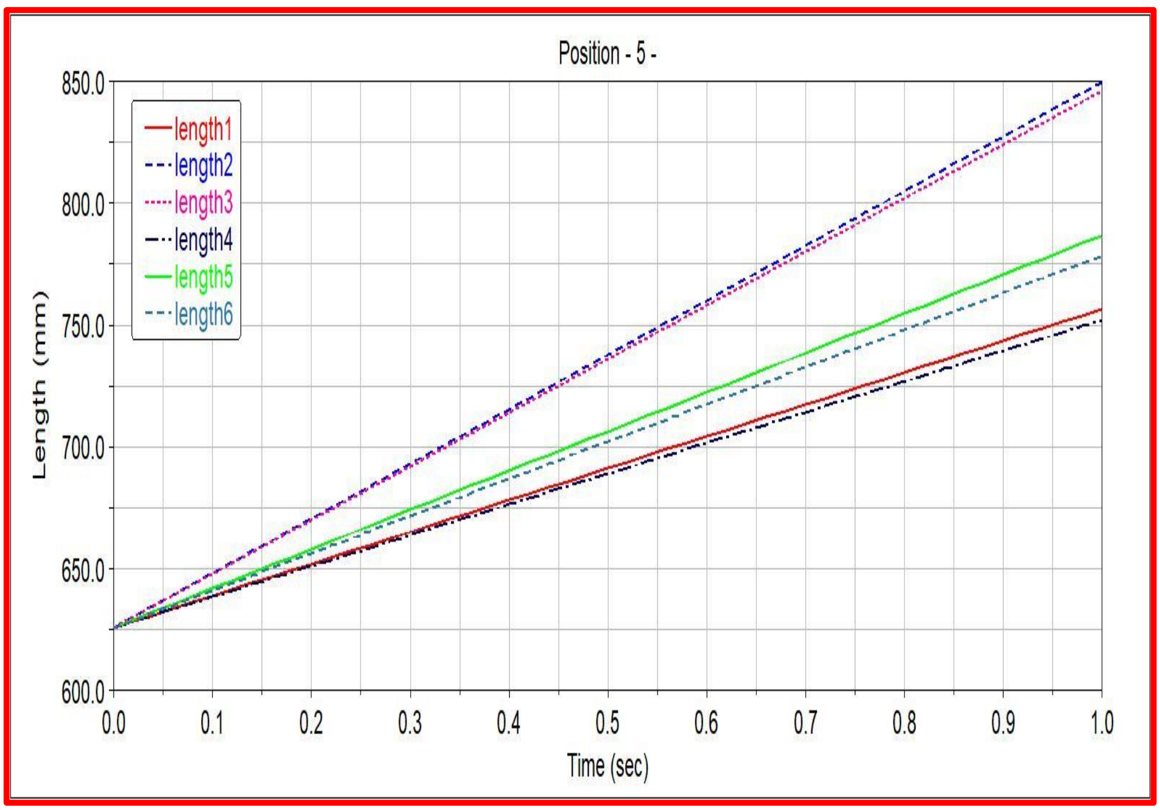


Fig (16): Stewart linkages length Position 5.

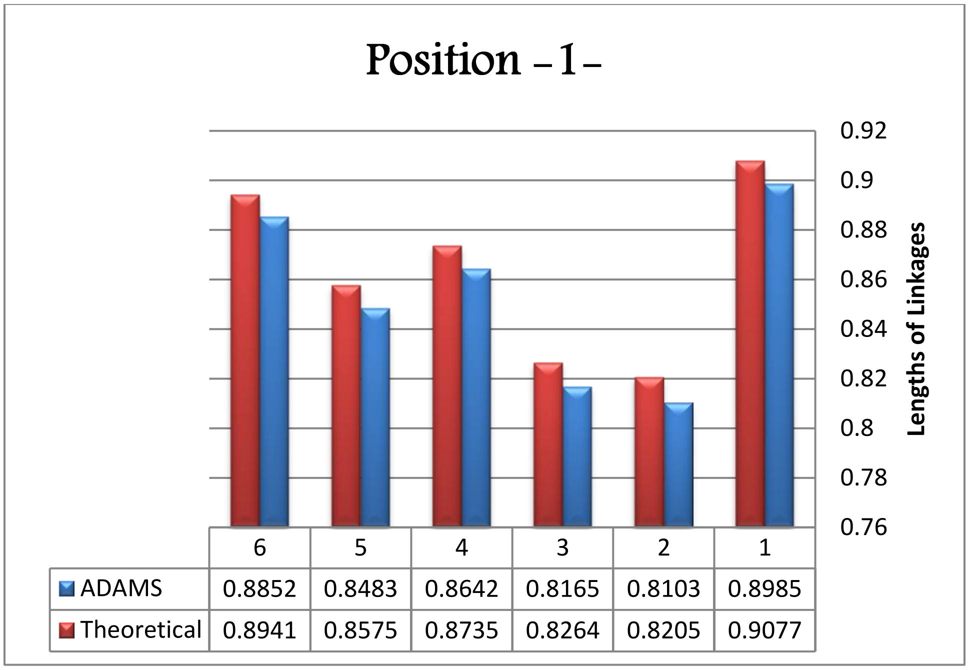


Fig (17): Stewart linkages length.

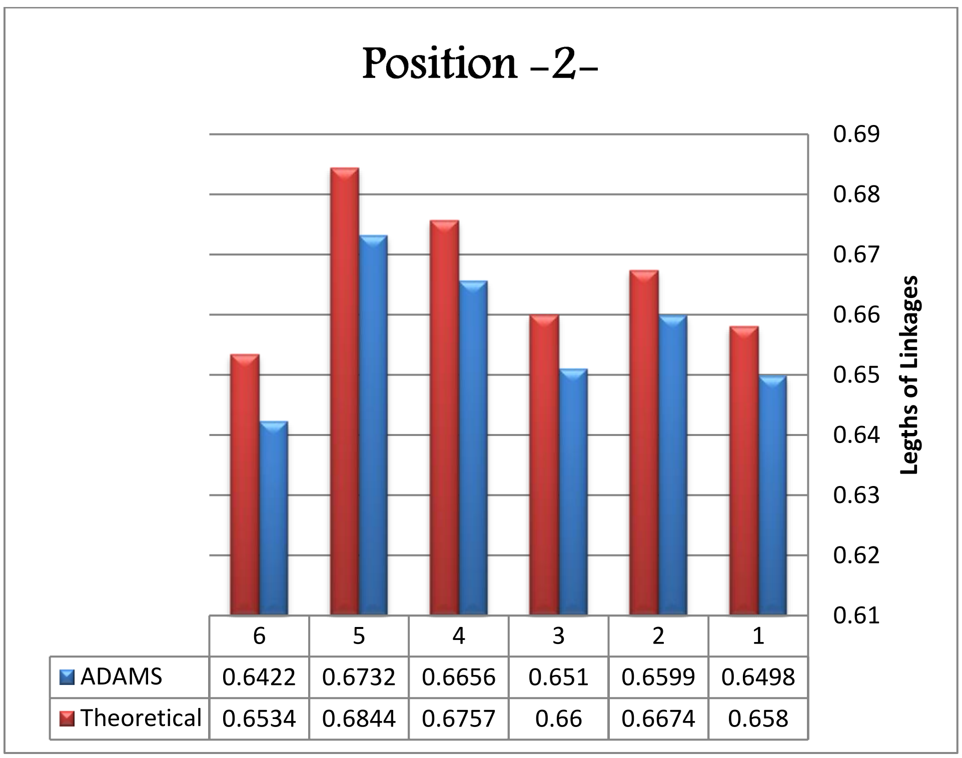
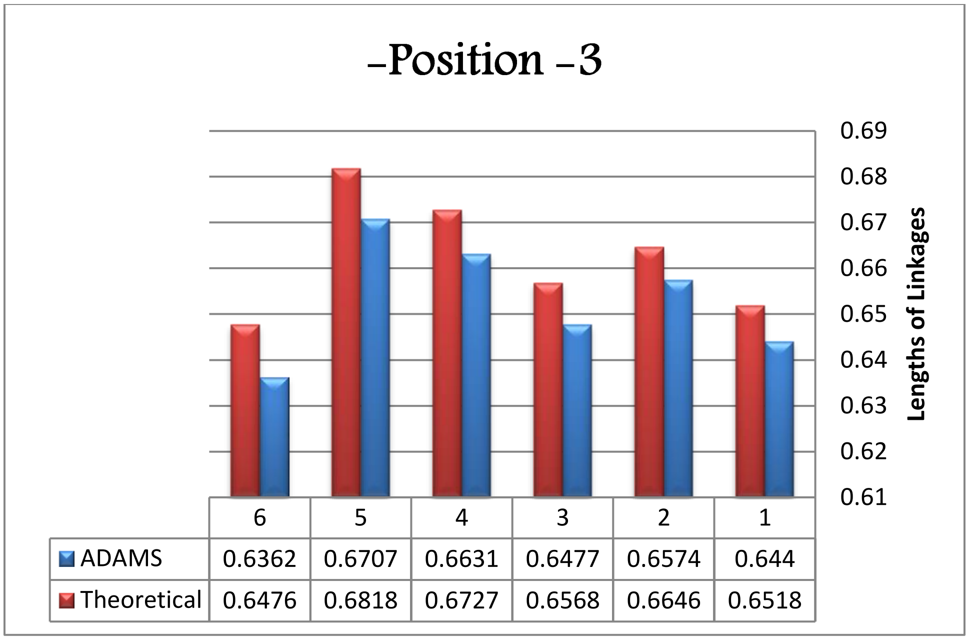
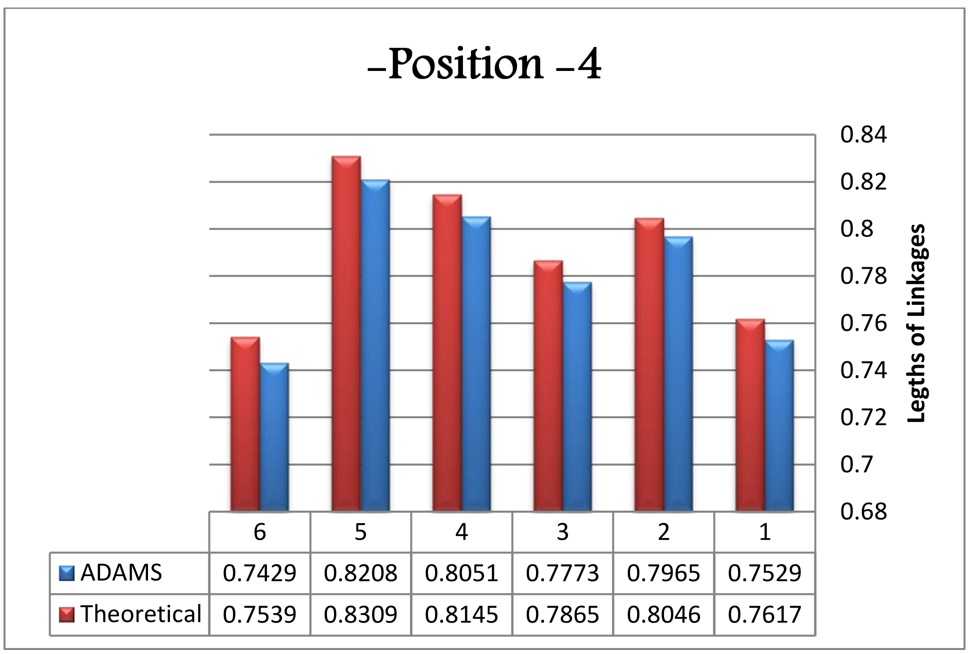


Fig (18): Stewart linkages length.



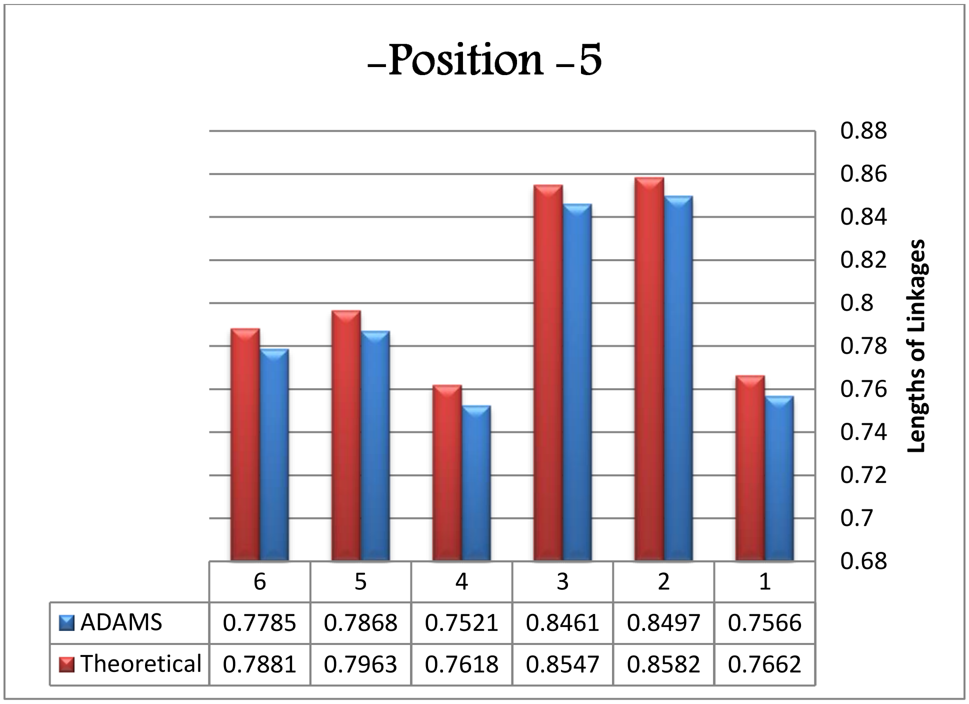
	6	5	4	3	2	1
ADAMS	0.6362	0.6707	0.6631	0.6477	0.6574	0.644
Theoretical	0.6476	0.6818	0.6727	0.6568	0.6646	0.6518

Fig (19): Stewart linkages length.



	6	5	4	3	2	1
ADAMS	0.7429	0.8208	0.8051	0.7773	0.7965	0.7529
Theoretical	0.7539	0.8309	0.8145	0.7865	0.8046	0.7617

Fig (20): Stewart linkages length.



	6	5	4	3	2	1
ADAMS	0.7785	0.7868	0.7521	0.8461	0.8497	0.7566
Theoretical	0.7881	0.7963	0.7618	0.8547	0.8582	0.7662

Fig (21): Stewart linkages length.

5- Conclusion:

This work explained how to calculate the lengths of the linkages of the Gough-Stewart robot manipulator by using the inverse equation and ADAMS software. At point (1) the lengths change in theoretical (45.232, 31.28, 32.224, 39.76, 37.2, and 43.056) percentage from initial length (0.625m), while in ADAMS at same points (43.76, 29.648, 30.64, 38.272, 35.728, and 41.632) percentage from initial length. In addition, with respect to the other points, there are a difference between the theoretical and ADAMS, due to the software deals with the model as an actual model by including the type of materials and the friction between the different parts of the model.

6- Reference:

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نمذجة كينماتك العكسية والأمامية للكووف ستيوورت باستخدام البرنامج (MSC ADAMS)

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الخلاصة

كووف ستيوورت هو روبوت متوازي له ست درجات حرية، وله ست معادلات كينماتك مع ست متغيرات. في هذا البحث تم نمذجة معادلاته باستخدام البرنامج (MSC ADAMS)بالاعتماد على المعادلات الكينيماتكية له. في هذا البحث تم بناء نموذج للستيوورت وتم تحركيه بالاعتماد على معادلات الحركة العكسية له. وبعد ذلك يتم مقارنة النتائج المحصلة من البرنامج مع النتائج النظرية والتي تم احتسابها.

الكلمات المفتاحية: انسان الي، كووف ستيوورت، برنامج ادمز، كينماتك، التحليل العكسي.