Control Law for Rover Arm Having 6 Degrees of Freedom

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Abstract*—the purpose of this research is to design a remote controlled mechanism and build a five degree of freedom rover arm for mounting on spacecraft for use during exploration of heavenly bodies. The design is modeled on PTC Creo 2.0 and involves structural analysis performed on ANSYS. A simplified Matlab based algorithm is developed and verified on MapleSim. This code is then implemented and hardware interfacing is done on the Arduino. A three DoF rover arm and its one DoF baseand two DoF mobile base are manufactured using Aluminum 2024. The motors and actuators selected and off the shelf items are mounted for movement control of links. A complete framework of remote control module can be incorporated for various other applications such as ensuring safety of personal lives while handling explosives, radioactive materials, chemicals etc and salvaging goods from fire our flood ridden areas/buildings.

***Keywords*—degree of freedom; rover; control; remote**

I. INTRODUCTION

Rover is an exploration vehicle designed to move across the surface of earth, other planets and other celestial bodies. Rovers examine more territory and collect data pertaining to the properties of the exploratory celestial body.

II. LITERATURE REVIEW

With huge advancement of technology in all field of science in general and robotics in particular these past few decades the use of robot and rovers to do dangerous task which would put personnel in danger is increasing day by day.

Robots and rovers have vast number of applications in fields like space exploration, munitions disposal, military and micro surgery etc.

Robotics Mechanics and Control [1]explains the science and engineering of robotic manipulations and manipulators very clearly and efficiently. Kinematics is used to transform angles into position and vice versa with the help of transformation matrices. There is a huge amount of work done on this particular field. Mulder in *A minimum effort control algorithm for a cooperating sensor driven intelligent multi-jointed robotic arm* [2] has generated an algorithm for minimum effort control algorithm required for multiple DoF robotic arms. Robot can be controlled through different mediums such as IFI, Bluetooth, infrared and radio signals.

III.METHODOLOGY

In this research we implemented a control scheme on the actuators through MATLAB algorithm formation. Rotation matrixes are calculated for forward kinematics. A transformation matrix is formed by multiplying the entire rotation matrix. The inverse of this matrix is taken to get the equation in terms of inverse kinematics.

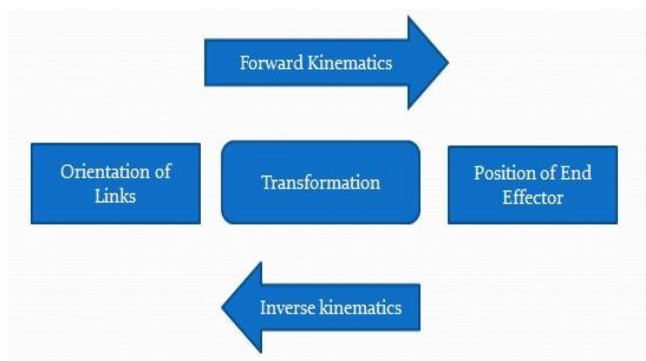

Figure 1 Kinematics Analysis

Forward Kinematics is simply to find the position of end effector of arm using transformation matrix given the orientation of links whereas the inverse kinematics is simply the opposite; to find the orientation of link using the transformation matrix.[3]

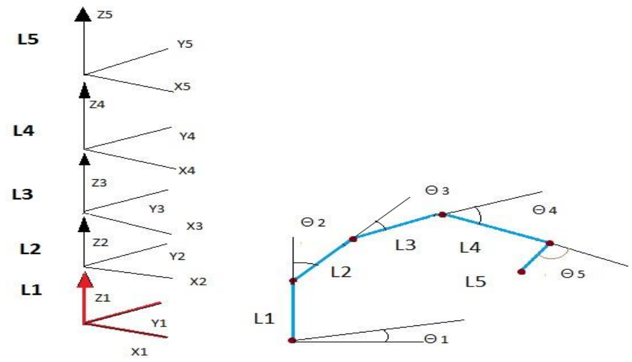

Fig.2 Static Analysis of the Rover Arm

The joint variables are calculated through DH method

S.No	DH Parameters			
i	$\alpha_{(i-1)}$	$a_{(i-1)}$	d_i	
1	0	16.2	0	0
2	45	22.5	15.91	
3	150	22.5	22.5	120
4	45	17.5	17.5	
5	0	2.54	0	

TABLE I. DH PARAMETERS FOR ROVER ARM

Following rotation and transformation matrices are used to transform frames.

$$R_x = \begin{matrix} \cos\theta_x & \sin\theta_x & 0 \\ -\sin\theta_x & \cos\theta_x & 0 \\ 0 & 0 & 1 \end{matrix}$$

Where x= 1,2,3,4 and

$$R_5 = \begin{matrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{matrix}$$

$$T_1 = \begin{matrix} \cos\theta_1 & \sin\theta_1 & 0 & 0 \\ -\sin\theta_1 & \cos\theta_1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{matrix}$$

$$T_2 = \begin{matrix} \cos\theta_2 & 0 & \sin\theta_2 & 0 \\ 0 & 1 & 0 & 0 \\ -\sin\theta_2 & 0 & \cos\theta_2 & l_1 \\ 0 & 0 & 0 & 1 \end{matrix}$$

$$T_3 = \begin{matrix} 1 & 0 & 0 & 0 \\ 0 & \cos\theta_3 & \sin\theta_3 & 0 \\ 0 & -\sin\theta_3 & \cos\theta_3 & l_2 \\ 0 & 0 & 0 & 1 \end{matrix}$$

$$T_4 = \begin{matrix} 1 & 0 & 0 & 0 \\ 0 & \cos\theta_4 & \sin\theta_4 & 0 \\ 0 & -\sin\theta_4 & \cos\theta_4 & l_3 \\ 0 & 0 & 0 & 1 \end{matrix}$$

$$T_5 = \begin{matrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & l_4 \\ 0 & 0 & 0 & 1 \end{matrix}$$

We multiply all the transformation matrices.

$$Transformation = [T_1][T_2][T_3][T_4][T_5]$$

Frames are transformed as such

$$\begin{bmatrix} X_b \\ Y_b \\ Z_b \\ 1 \end{bmatrix} = Transformation \begin{bmatrix} X_5 \\ Y_5 \\ Z_5 \\ 1 \end{bmatrix}$$

Now the above matrix is the desired matrix. It is actually converting our last frame i-e frame [5] into the base frame [B]. We can use this matrix to calculate the position of frame [5] i-e actually the position of end effector in our case with respect to the base frame. The structural design was modeled on PTC Creo.

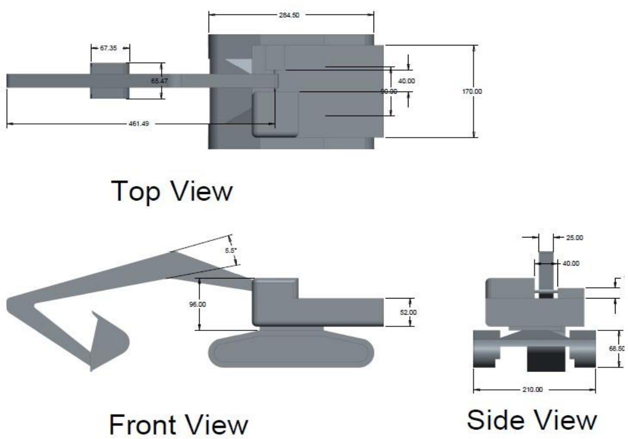

Fig.3 PTC Creo 3-D Model

The MATLAB algorithm has been verified through MapleSim. The workspace has also been designed in form of all feasible points by the manipulator.[4]

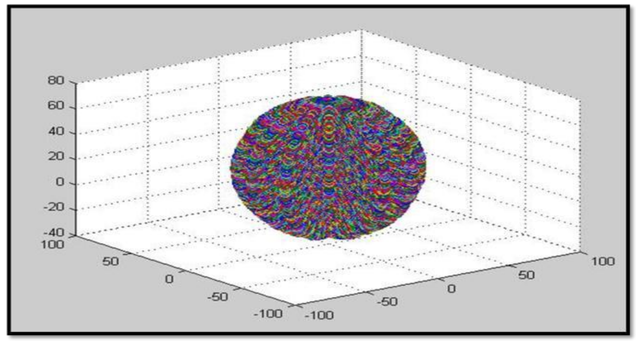

Fig. 4 Workspace without constraints

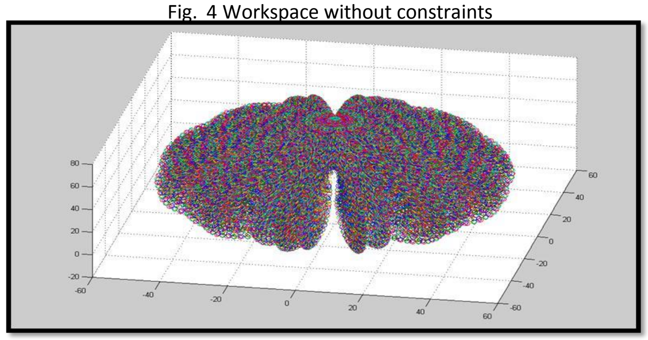

Fig.5 Workspace with contraints

IV. RESULTS

The designing and implementation of the control scheme for remotely controlling the rover arm holds a lot of significance. The type of controller used in the control scheme is PID controller.

The transfer function for all servo motors is

$$\frac{w(s)}{V(s)} = \frac{\left(\frac{K_T}{R_A f_M + K_E K_T}\right)}{1 + \left[\frac{R_A (J_M + J_L)}{R_A f_M + K_E K_T}\right] s} s$$

After inputting all the values we get the following transfer function:

$$\frac{w(s)}{V(s)} = \frac{31.71870506}{1 + 0.01430095442s}$$

Following response is achieved through this above mentioned transfer function for step input.

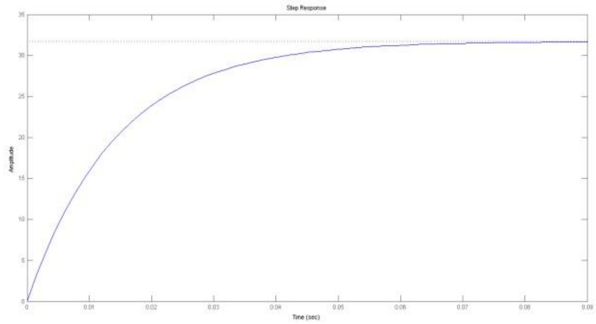

Fig.6 Response to Step Command

The controller designed for this transfer function is:

$$C = 0.010082 * \frac{1 + 0.032s}{1 + 0.53s}$$

This gives the following result

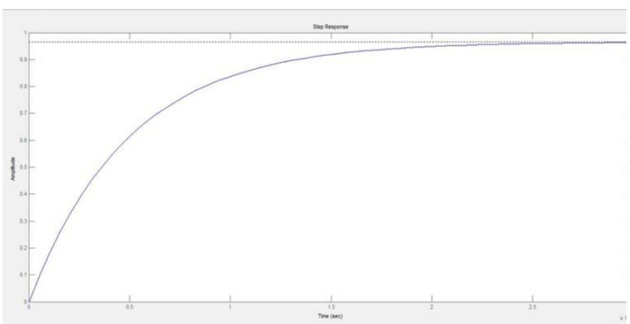

Fig.7 Response to Step Command With Application of Controller

Furthermore, the stress analysis to check out the limitations of the structure on Ansys was also done. The strain energy and total deformation is found out using a load of 250N at the end of the bucket.

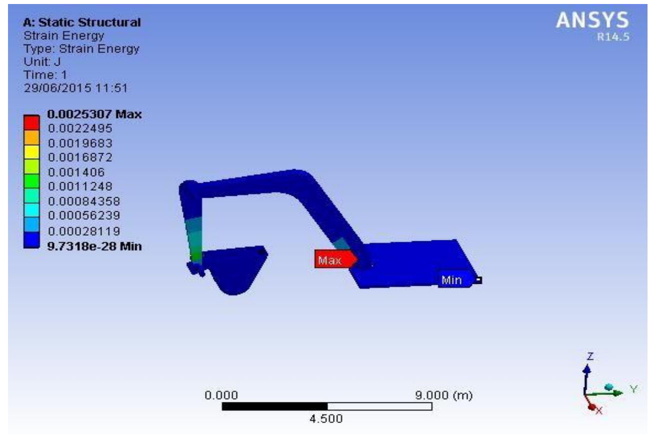

Fig 8 Strain Energy

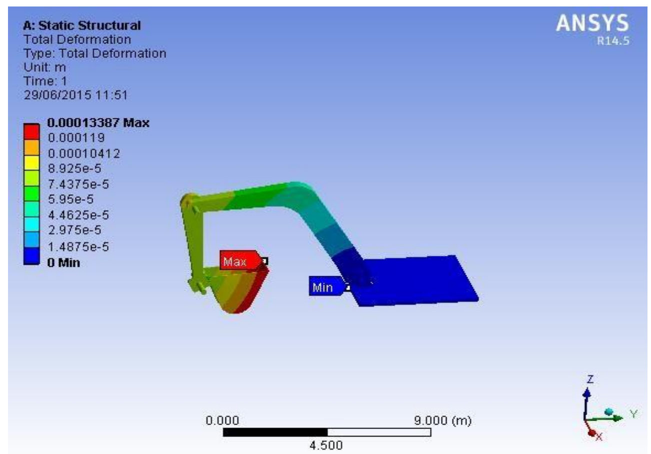

Fig 9 Total Deformation

The Forward and inverse kinematics was verified through MapleSim. The values that were obtained from MATLAB through the trasformation matrix are:

$$\begin{bmatrix} 16.5 \\ -5.3 \\ -1.5 \\ 1 \end{bmatrix}$$

The similar values were obtained from MapleSim for the same set of values of angles.

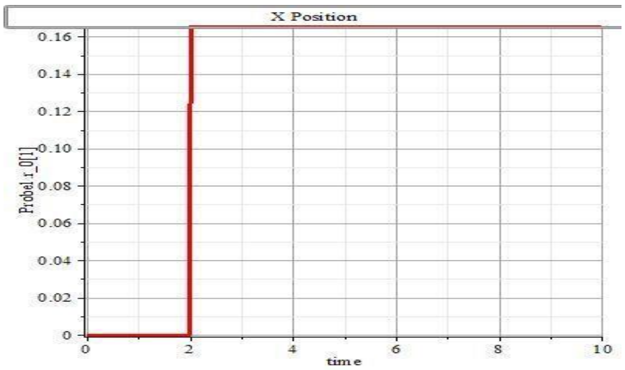

Fig. 10 X-Position

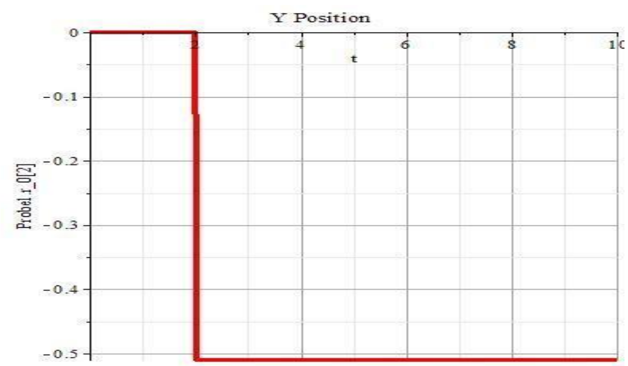

Fig. 11 Y-Position

Fig. 12 Z-Position

V. APPLICATIONS

Following are some of the advantageous uses of rovers:

1. Rovers are mostly used to explore the surface crust of the heavenly body.

2. Rovers can be used to collect soil samples, explore the terrain of the planet under exploration.

3. Rovers can be operated in danger zones such as fires, floods and toxic dumps without endangering the personnel operating it.

4. Bomb squads and law enforcement agencies also us such rovers to defuse the bombs and explosives so that safety of the crew is ensured

VI. CONCLUSION

A six DoF RC rover arm is designed and manufactured. A model with one DoF base rotation (yaw-motion), three DoF shoulder, elbow and wrist joint (pitch) and a mobile platform (translation) is designed on PTC Creo. Kinematics is done using transformation matrix and DH Table, and verified through MATLAB and MapleSim. Inverse kinematics and workspace is done with or without constraints on MATLAB. The inverse kinematics enables the intelligence of the rover arm and workspace defines the reach of the rover arm and the singularities. Arduino MEGA2560 controller is used for implementing the PID control for each motor. The coding is done in Arduino and MATLAB.

The six DoF rover arm is basically a stepping stone into advanced and further complicated robotics interlinked with aerospace industry

Further work in this field can be to mobilize the rover arm on a moveable base. Moreover the control of the rover arm can be linked to the movement of a human arm. In such case sensors are placed on the arm of a person. These sensors notes the movement of muscles and joints of the human arm and then transfer that same movement to the actuators of the rover arm that is to be controlled.

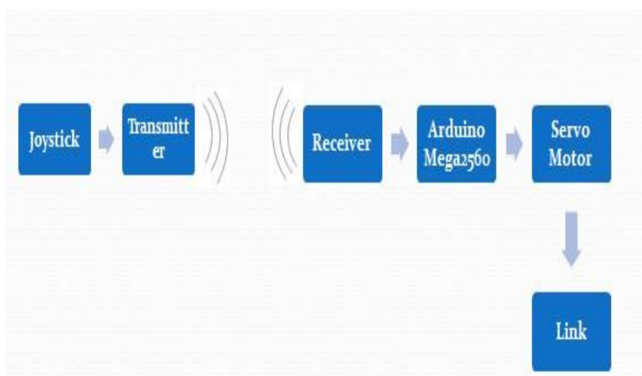

Fig. 13 Remote Control Flowchart

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