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Robotic Arm Technology Development for Research and Mars Exploration

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Abstract: ***NASA and other space organisations are working incessantly to create future generation Mars rovers for the assistance of astronauts and to explore the Martian surface. Rovers are required to explore Mars and gather all the requisite details and signs of any life on the planet. To make all this easy a rover should be equipped with a strong and flexible arm which should be capable of performing just like a human arm. It helps the rover to do various tasks like collecting and deploying specific tools, turning knobs, flipping switches, opening and closing drawers, writing message on the keyboard and collecting soil samples to test pH moisture and other compositions to be performed on-board and off-board. This paper explains the design, functioning and mobility of the arm, it is a uniquely designed four bar manipulator which gives 6 degrees of freedom to the end effector. The working of the end effector and wrist is also explained scrupulously. The arm has been designed, analysed and fabricated. Its was found easy to be operated remotely and gave much precise motion. This robot manipulator is found to be advantageous in remote manual operation where the operator needs to understand the view and then manipulate accordingly. The manipulator is mechanically constraint to suppress the change in orientation of the gripper and hence providing a stable camera feed to the operator. Where as in other jointed arm manipulators the camera feed is stabilized electronically. The simple and profound addition of the mechanical components aid to the actuator coding part.***

Key words: — Mars exploration; Martian Soil; Planetary Robotics; Autonomy.

I. INTRODUCTION

Rudra-SRM Mars Rover is working on Mars rover designs from past 6 years. The rover can perform tasks which will help the astronauts like the accumulation of tools and objects by means of a robotic arm mounted on the rover and deploying them at the given GPS coordinates. The robotic arm comprises of a manipulator to position the gripper and a YAW-PITCH-ROLL system (wrist) to orient the end effector. Various End Effectors are manufactured to perform different tasks like gripping, digging and sensing. During the R&D phase, the team focused on designing an arm, simple and efficient, with many industrial applications like grinding, welding, spray painting etc. The manipulator and the wrist are actuated electrically using 6 actuators in all. The concept design was brought down to the CAD model using CATIA. The analysis of the manipulator and wrist parts was done on ANSYS to know the static and dynamic performance and the durability of this robotic arm.

Figure 1: CATIA model of ARM

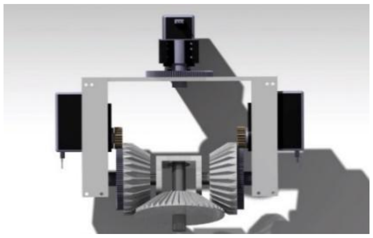


Figure 2: CATIA model of yaw-pitch-roll

II. MECHANISM

The mechanism [1] of this manipulator is a four-bar [2] which lets to orient the gripper parallel to the base. The arm has a detachable and a compact YAW, PITCH, and ROLL system that gives additional three degrees of freedom to the manipulator.The arm is a jointed arm configuration (T-R-R-R-R-T) [3] which connects two parallelograms in a way such that on a minimal actuation of the electric actuators we get maximum actuation of the end effector. The arm can turn an angle greater than 360^{o} around the fixed vertical axis. The gripper is a power screw mechanism that converts the actuator's rotary motion to a linear one and further to parallel motion of the two claws of the same. The entire arm uses 7 electrically driven actuators, 5 rotary and 2 linear. The heavy weighted instrument on the arm is placed near the axis of the base to avoid any stresses developed on arm due to self-weight hence maintains the center of gravity of the arm on near the rotational axis of the arm.

III. MANIPULATOR

The robotic arm is mounted on a turning base consisting an external gear of module 2 and diameter 150 mm and the link fixtures, all centred on a hollow shaft. The Turntable rotates in a broad race radial bearing to counter both axial and radial load of the arm. The two links of the arm connect each other with the help of Mild Steel shafts constrained by triangular plates. The effective length of the 1st link is 500 mm and that of the 2nd link is 350 mm. The four-bar mechanism of the arm allows the gripper to perform tasks easily by mechanically constraining the end-effector to hold the default position. One of the electric linear actuators is mounted on the turntable to give the first revolute motion to the end-effector while the second is mounted on the first link and linked to the second link of the manipulator. Both the linear actuators have a stroke length of 100 mm each.

IV. WRIST

The wrist is compact and is fabricated using aluminum and MC nylon (MC901) actuated by three servo motors. The servo motors best suits for the Y-P-R due to its torque management, precision and lightness as compared to other comparable precision motors. One servo is used with a gear ratio 6:1 which is responsible for the yaw motion of the gripper and the other two motors having a gear ratio of 3:1 are responsible for pitch and roll motion. The complete Y-P-R system is bolted on a 6:1 reduced servo motor gear which gives 180^{o} rotation to the Y-P-R system which acts as the yaw of the end effector. This servo may also provide roll motion when pointing to the ground, to lift and twist heavy objects. The assembly includes two bevel gears [4], screwed to the servo motor gears placed parallelly facing each other, meshed to the third bevel gear larger in diameter particularly for torque increment and reduced rpm which are two keys to an accurate orientation. Two collinear aluminum shafts coaxial to the servo's driven gears, sits in a bearing on one end. Third shaft transverse to the other two shafts passes through the third bevel gear and sits in the third bearing. The bearing hub is a specifically designed aluminum part which encapsulates three bearings, holding the three shafts and keeping the bevel gears in mesh. The gripper is bolted to the third front-facing bevel gear. The two servo motors are calibrated to give pitch and roll motion to the gripper. When both the actuators are given actuation in the same direction, a roll is procured while actuating in different directions pitch is produced. The mightiest advantage of this wrist is we can combine roll and pitch motion by varying the rpm of the servo actuators to obtain smooth and continuous trajectory to the end-effector.

V. GRIPPER

For this arm different end effectors are manufactured to solve the purpose of gripping, digging, sensing, typing and scanning its own parts using a camera feedback. Gripper [5] is designed, considering, the aid it will provide to the Martian astronauts such as collecting rocks samples to analyze it either onboard or off-board, or else it can grasp and deliver tools to aid the astronauts. A 12V D.C. motor, coupled with the power screw [6] by means of a custom designed coupler transfers the rotational motion of the D.C. motor to the linear motion of the power screw. Based on the direction of rotation of the motor the fingers open and close to load/unload. The gripper is designed to grab objects up to 70 mm in diameter picking up maximum loads up to 5kg between the fingers (25 mm thick) with uniquely designed contour to allow maximum contact with the object. On 360-degree actuation of the D.C. motor gripper receives 2mm of linear actuation to move the fingers by 4.5mm each. Two parallel four-bars are applied for the actuation of fingers. A 3-Dimensional model of the gripper mechanism is shown in figure 2. The linkages 1,2,3 and 4 provide the parallel motion which is being actuated by the coupler moving linearly due to the lead screw mechanism.

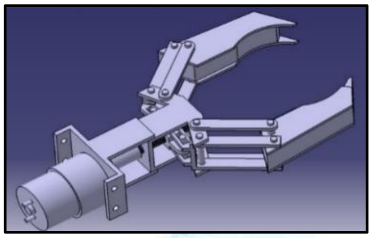
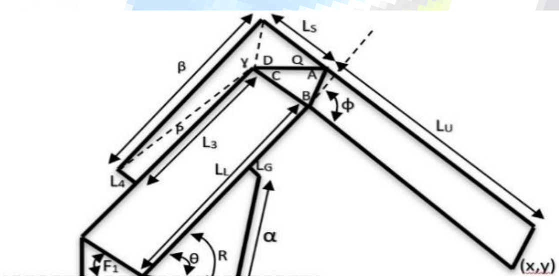


Figure 3: Catia model of gripper

VI. MATHEMATICAL MODEL



α = Length of actuator 1

β= Length of actuator 2

ϕ= Angle between the two links

θ= Angle of lower links with the horizontal

L_L= Length of lower links

L_U= Length of upper links

L_S= Length between actuator 2 and pivot points of upper links

The angle of the upper links due to actuation of β:

$\text{Cos}\ \phi = x^2+y^2-(L_L{}^2+L_U{}^2)/(2L_LL_U)$

Change in the angles due to actuation of α:

$\text{Tan}\ C= [y\ (L_L + L_U \cos\phi) + (x\ L_U \sin\phi)]/\ [x\ (L_L + L_U \cos\phi) - (y\ L_U \sin\phi)]$

Length of Actuators for given angles:

$$\alpha = \sqrt{(L_L^2) + (L_U^2) - 2(L_L)(L_U)\cos R}$$

$\lambda = \sqrt{L_S^2 + b^2 - 2L_S b \cos Q}$

{where,Q = π - A -θ - B - F_1+ϕ}

$\beta = \sqrt{\lambda^2 + L_S^2 - 2\lambda L_S \cos\gamma}$

{where,γ = π - S - P +θ + F_1 + C}

VII. TORQUE CALCULATIONS

The torque of the servo (785-HB) used for pitching the gripper is 13.3 kg-cm. The gear reduction of the servo is 3:1 and further the gear reduction in the bevel gear transmission is 38:23.T_s = given motor torque, T_{sg1} = after 1st gear reduction, T_{sg2} = torque after 2nd gear reduction, T_{sf} = final torque obtained.

a. Torque requirements for roll

T_s = 13.2 kg-cm

On spur gear reduction of 3:1,

T_{sg1} = 13.2 x 3 / 1 = 39.6 kg-cm

On bevel Gear reduction of 38:23,

T_{sg2} = 39.6 x 38 / 23 = 65.4 kg-cm

As the two servo motors actuate in opposite direction (giving the roll motion), so the total torque given by the wrist for roll will be two times. Therefore, T_{sf} = 65.4 x 2 = 130.8 kg-cm = 12.8N-m

b. Torque requirements for pitch

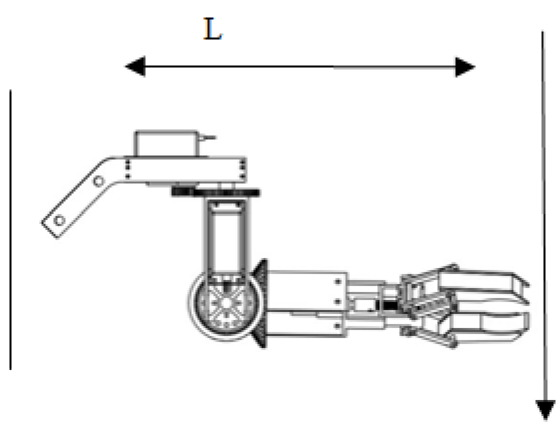
T_s = 13.3 kg-cm

After gear reduction of 3:1

T_{sg1} = 13.2 x 3 / 1 = 39.6 kg-cm

Pitch is provided by two identical servos

T_{sf} = 39.6 x 2 = 79.2 kg-cm = 7.8 N-m



Consider a mass 'm' to be picked up by the gripper. Let the length between the axis of servo's driven gear axis and the point of application ofweight on the gripper be 'L'.

('L' value will vary according to the gripper length, 'g' is the acceleration due to gravity).

Now the mass that the gripper can lift in pitch is,m = $T_{sf(pitch)}$ / (L x g)

VIII. STRESS ANALYSIS

The robotic arm was analysed on ANSYS for the total deformation and Von Mises (equivalent stress) of the manipulator and the wrist. Static load of 80N was applied on the two links of the arms for deformations. The results obtained showed maximum deflections of 0.45, 0.92 and 1.24mm respectively for the three configurations. The YPR was given a load of 50N. Results showed a maximum deflection of 0.3mm in the positions of the servo plates.

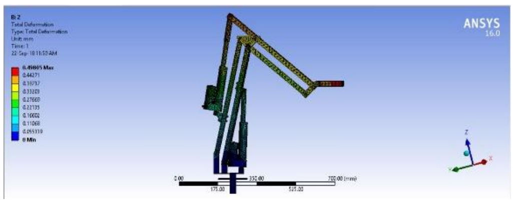


Figure 4: Analysis of Total deformation(Fully Contracted) –Manipulator

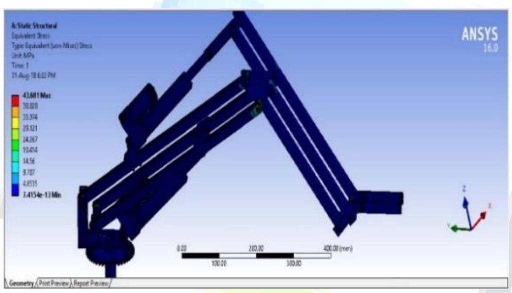


Figure 5: Analysis of Total deformation(Partially Opened)-Manipulator

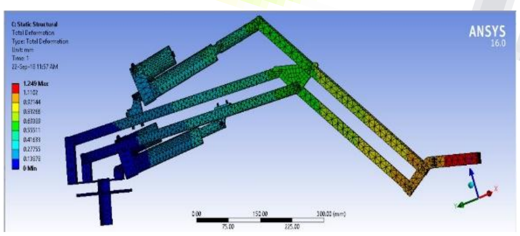


Figure 6: Analysis of Total deformation(Fully Extended) –Manipulator

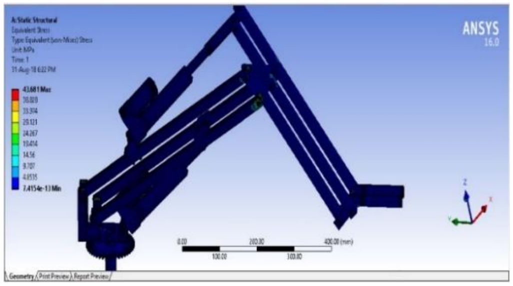


Figure 7: Stress Analysis-Manipulator

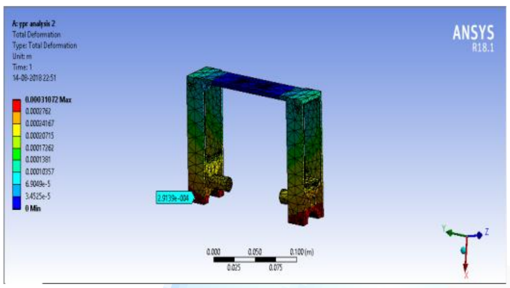


Figure 8: Analysis of Total deformation-Wrist

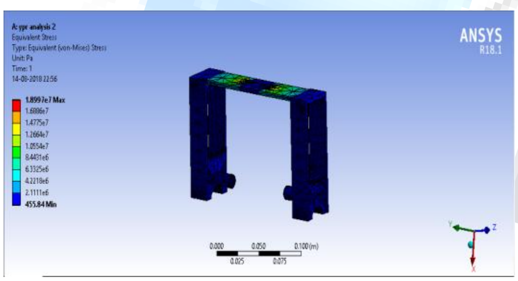


Figure 9: Stress Analysis-Wrist

IX. FABRICATION

The robotic arm was manufactured using aluminium alloy 6061 box channels of cross-section 20x20 mm. The length of link 1 is 500 mm and that of link 2 is 350 mm incorporating two four-bars with the first inversion. The two links connect by means of two parallel aluminium plates of thickness 5 mm, the plates have been cut in the form of a triangle to meet the design requirements, the plates are having three holes to accommodate the box channels of the arm using the mild steel shafts of 8 mm.Two electric linear actuators are being used to provide the motion to the links, the stroke of each actuator is approximately 100mm.

Part	L4CT4P
Stroke	4”
Input	12VDC
Average speed	0.5”/second
Dynamic load	110lbs
Static load	500lbs

Table 1: Specifications of Linear Actuator [7].

The YPR was fabricated using an aluminium block which was milled to get the desired product. The bevel gears were fabricated using MC Nylon (MC901). Shafts for the Y-P-R system held between the bearing and the servo motor is has a diameter of 9mm are hollow, restricting the gears to mesh.
Major parts of the gripper were fabricated by milling aluminium blocks. Links for four-bar were made using mild steel. Fingers were cut out of Stainless Steel Plate and spaced by 3D printed spacers. The connections to the four bars were made by means of 4mm Mild Steel shafts.

Figure 10: Fabricated Manipulator

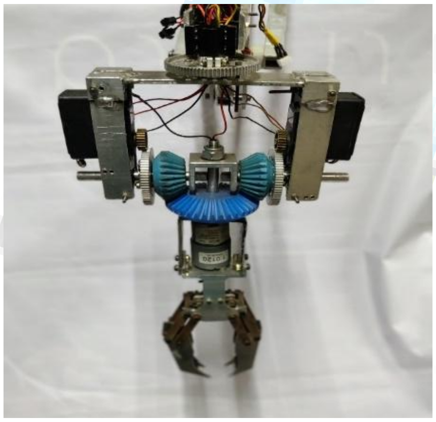


Figure 11: Fabricated Wrist

X. SCOPE

1. For space exploration as it has potential uses in on lunar and mars surface for assistance of astronauts in performing autonomous robotic operations.
2. Arm can be used in automobile industries where assembly of certain parts is required with precision. The precise motion of the arm lets open a a wide field in welding, painting and line conveyor assembly.
3. For applications in such places where humans are restricted such as electrical grids or deep mine where there is a hazard of poisonous gasses.
4. Agricultural use viz. for collecting and testing soil samples.

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