

Reconfiguration of Joint Locked Redundant Space Manipulator

Singirala Navya Sree¹, Vijay Kumar Dalla², Vamshi Kadali³, Addetla Girish Kumar⁴

M.Tech Scholar, Dept. of Mechanical Engineering, Vidya Jyothi Institute of Technology, Aziz Nagar,
Hyderabad, India

ABSTRACT: This Project presents the elimination of redundancy in 6 DOF planar space robot using the reconfigurable robots. As we know, space robots are hired to handle extreme conditions in outer space. But this likely result in collapsing of the robot, because of various failures. Which ultimately inclines us in installation of reconfigurable robots for them to function with ease. Such Robots are equipped with sensor and actuator. To optimize the functioning of the robot, at any time, only two joints are actuatable while the rest are held inactive temporarily in order to prevent the undesired movement through a Proportional Derivative (PD) controller. The implementation of the inactive joints will happen when the healthy joints get locked due to actuator failure. The proposed reconfigurable robot can provide much easier and more effective solution to maneuver in a small volume. The results of simulation and the animation validate two case studies. Each one of those includes motion planning of space robot when one joint suffers joint locked failure at some stage in manipulation and its reconfiguration. For the dynamic model analysis of the system and generating the system equations, symbol shakti *Bond graph technique* has been utilized.

KEYWORDS: Space robot, reconfiguration, hyper-redundancy, joint locked failure.

I. INTRODUCTION

Whenever we highly rely on robots for maneuvering in risky environments, reconfigurable manipulators are quite necessary. The manipulator employed in rough environments should every often be reconfigured to fulfill the demand of specific task with that environmental constraints. As we notice mostly in space exploration, it is necessary to engage with a single versatile and cost effective robot with the capability to perform multiple tasks. Such reconfigurable robots reduces active human intervention in case of any failure and will highly be able to self-configure itself. In this way, tolerance capability in a robot can be enhanced.

From the past few decades, this reconfigurable robots were used in ground applications a lot, but only a few were used in space robot application. Some among this robots were discussed here. Fukuta and Kawauchi in [1990], introduced the original reconfigurable robot to add flexibility to the robotic manipulator. Further the idea was developed in [Paredis and Khosla, 1995].

The moto of this paper is to propose a single versatile space robot that is capable of tolerating catastrophic joint failures. te catastrophic joint failure. The curiosity that how a space robot [Saha, 1996, Kumar et al., 2013] works in congested and narrow space with faulty joint encourages us to make strategy for smooth trajectory planning with faulty joint. Various researches as reported are mainly based on modular design approach and used in ground robot.. The remaining paper structure is classified as follows. Section 2 deals with a model of the 6 DOF planar hyper-redundant space manipulator using bond graph. It includes a model of a free-floating base. Section 3 describes reconfiguration of the 6 DOF robot and PD controller. Section 4 discusses the accommodation of actuator fault considering two cases of joint locked failure. Section 5 represents simulation and animation results. And section 6 deals with concluding remarks and future scope.

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: www.ijirset.com

Vol. 7, Issue 10, October 2018

II. MODEL OF 6DOF PLANAR HYPER-REDUNDANT SPACE MANIPULATOR

The modelling of a six DOF planar robot includes both translational and rotational dynamics for the links. It starts with an assumption that all the links of the space robot and the base of it are made up of rigid bodies. As in here the robot has only single arm and revolute joint which has an open kinematic chain. Fig 1 shows an illustrative representation of the planar space robot. This figure has 2 frames where frame 1 is {A} absolute frame and {v} is for vehicle frame which is located near the center of mass of our space robot. This again is divided into 6 frames where the root of the manipulator has frame {1} and consecutively the other frames like {2}, {3}, {4}, {4}, {5}, {6} are located at the 2nd, 3rd, 4th, 5th, 6th joint angles of manipulator. At the tip of the manipulator is frame {7}.

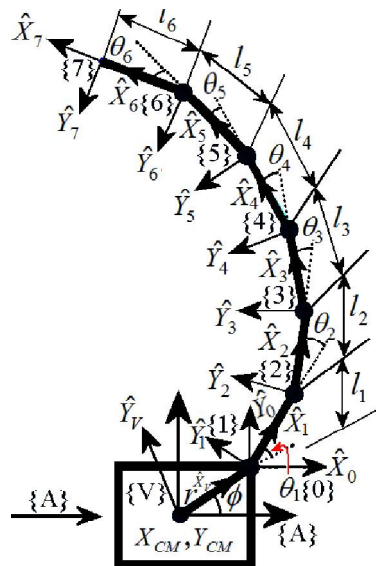


Figure:1 Illustrative representation of space robot with multi joints

Let X_{CM} , and Y_{CM} are the space robot's CM co-ordinates concerning the Absolute frame {A}. Let ϕ speaks to the revolution of the casing {V} regarding the outline {A}. Let $\theta_1, \theta_2, \theta_3, \theta_4, \theta_5$ and θ_6 demonstrate 1st, 2nd, 3rd, 4th, 5th, 6th joint points of manipulator, individually. Kinematic relations are shown regarding the tip position and introduction as:

$$X_{tip} = X_{CM} + r c(\phi) + l_1 c(\theta_{\phi 1}) + l_2 c(\theta_{\phi 12}) + l_3 c(\theta_{\phi 123}) + l_4 c(\theta_{\phi 1234}) + l_5 c(\theta_{\phi 12345}) + l_6 c(\theta_{\phi 123456}) \quad (1)$$

$$Y_{tip} = Y_{CM} + r s(\phi) + l_1 s(\theta_{\phi 1}) + l_2 s(\theta_{\phi 12}) + l_3 s(\theta_{\phi 123}) + l_4 s(\theta_{\phi 1234}) + l_5 s(\theta_{\phi 12345}) + l_6 s(\theta_{\phi 123456}) \quad (2)$$

$$\theta_{\phi 1} = \phi + \theta_1, \theta_{\phi 12} = \theta_{\phi 1} + \theta_2, \theta_{\phi 123} = \theta_{\phi 12} + \theta_3$$

Where, $\theta_{\phi 1234} = \theta_{\phi 123} + \theta_4, \theta_{\phi 12345} = \theta_{\phi 1234} + \theta_5,$

$$\theta_{\phi 123456} = \theta_{\phi 12345} + \theta_6.$$

$$\theta_{tip} = \theta_{\phi 123456} = \phi + \theta_1 + \theta_2 + \theta_3 + \theta_4 + \theta_5 + \theta_6 \quad (3)$$

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: www.ijirset.com

Vol. 7, Issue 10, October 2018

Here, $s(\)$ and $c(\)$ speak to $\sin(\)$ and $\cos(\)$, individually. The angular velocities and tip translational can be assessed with help of equations 1, 2 and 3 as follows.

$$\begin{aligned} \dot{X}_{tip} = & \dot{X}_{CM} - r\dot{\phi}s(\phi) - l_1(\dot{\theta}_{\phi 1})s(\theta_{\phi 1}) - l_2(\dot{\theta}_{\phi 12})s(\theta_{\phi 2}) \\ & - l_3(\dot{\theta}_{\phi 123})s(\theta_{\phi 123}) - l_4(\dot{\theta}_{\phi 1234})s(\theta_{\phi 1234}) \\ & - l_5(\dot{\theta}_{\phi 12345})s(\theta_{\phi 12345}) - l_6(\dot{\theta}_{\phi 123456})s(\theta_{\phi 123456}) \end{aligned} \quad (4)$$

$$\begin{aligned} \dot{Y}_{tip} = & \dot{X}_{CM} + r\dot{\phi}c(\phi) + l_1(\dot{\theta}_{\phi 1})c(\theta_{\phi 1}) + l_2(\dot{\theta}_{\phi 12})c(\theta_{\phi 2}) \\ & + l_3(\dot{\theta}_{\phi 123})c(\theta_{\phi 123}) + l_4(\dot{\theta}_{\phi 1234})c(\theta_{\phi 1234}) \\ & + l_5(\dot{\theta}_{\phi 12345})c(\theta_{\phi 12345}) + l_6(\dot{\theta}_{\phi 123456})c(\theta_{\phi 123456}) \end{aligned} \quad (5)$$

$$\dot{\theta}_{tip} = \dot{\theta}_{\phi 123456} = \dot{\phi} + \dot{\theta}_1 + \dot{\theta}_2 + \dot{\theta}_3 + \dot{\theta}_4 + \dot{\theta}_5 + \dot{\theta}_6 \quad (6)$$

III. RECONFIGURATION

These redundant robots have the preferred stance that they have joints more than the required DOF. The additional number of joints can be utilized for reconfiguration of robots on the off chance that when the activated joint fails. If there should be an occurrence of considered 6 DOF planar space robot, let number of dynamic and passive joints be 2 and 4, individually. Accepting that at once single disaster happens, the conceivable reconfiguration mixes will be ${}^2_6C_2 = 15$. These 15 likely reconfiguration mixes are given in Table 1. A couple of them are represented underneath. Accepting that joints 1 and 4 are dynamic while others are passive.

Elements are utilized to demonstrate translational and the rotational inertia of the space robot system. The R element represents to the damping in the joints. In this Figure 3, X_v and Y_v indicate the body-settled coordinates and the modelling of space robot is done in a non-inertial frame. The rotation of the base of the robot is about Z-axis. For a planar case, where, where, $\omega_x = 0$, $\omega_y = 0$ and $\omega_z = 0$, the net force acting up on manipulator can be given as [Merzoukiet al. 2013, Kumar et al.,2011] .

Here, joint 1 and joint 4 are impelled active while others are kept inactive through the PD controller. Manipulating redundancy, one can stimulate any joint according to particular prerequisite. To control joint movement, PD control is utilized as appeared in Fig. 3. The control law for the actuator at the joint is given as,

Where, τ is the joint torque, θ_d is the coveted position of joint and θ_a is the actual position of the joint, $\dot{\theta}_a$ is the actual joint angular velocity and K_p and K_d are proportional and the subordinate gain parameters, separately. PID controllers are utilized to deliver the remedied effort for a given error signal. The correct signals are sent to each joint of the manipulator as torque (τ) signal through the Jacobian.

IV. ACCOMMODATION OF ACTUATOR FAULT

Currently, assume one of the joints got failed due to sealed joint, at that point other joint should be worked for a satisfactorily motion planning. For this, one of the PD locked joints is opened and activated.

Along these lines, we contemplate the reconfiguration idea in the accompanying two cases. These are:

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: www.ijirset.com

Vol. 7, Issue 10, October 2018

4.1 Case I: When joint 1 got failed at $t \geq 4$ s, joint 2 is opened to keep proceed wanted movement planning.

Assuming that at first, joints 1 and 4 are activated to perform the desired tip movement as discussed about in section 3. Accepting that during manipulation (at $t \geq 4$ s) joint 1 endures serious joint locked failure. Along these lines, the robot can't perform the desired movement with it. Thus, one more joint is required to be actuated along with joint 4.

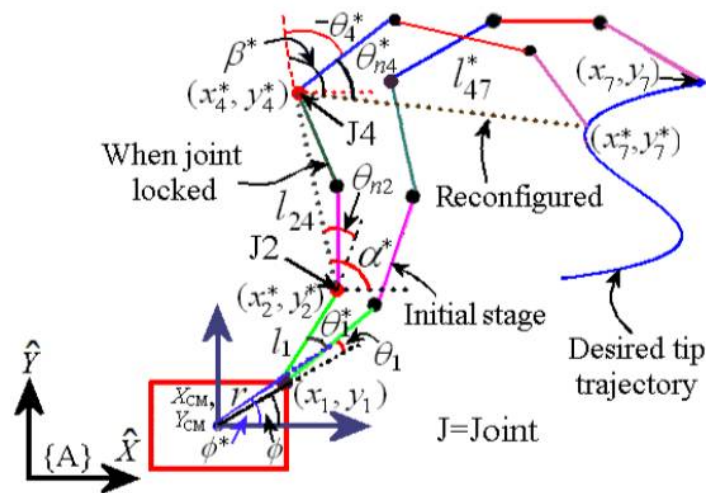


Fig. 2: Case 1: Schematic of the reconfigured space robot at the point when joint 1 got failed. Here, joints 2 and 4 are currently dynamic.

For this, assume joint 2 is unconstrained. Henceforth, joints 2 also, 4 are currently dynamic. The schematic of reconfigured space robot is appeared in Fig. 4. For this, Equations 7 and 8 get altered as,

$$X_{tip}^* = X_{CM}^* + r\alpha(\phi^*) + l_1\alpha(\theta_{\phi_1}^*) + l_{24}\alpha(\alpha^*) + l_{47}\alpha(\beta^*) \quad (25)$$

$$Y_{tip}^* = Y_{CM}^* + rs(\phi^*) + l_1s(\theta_{\phi_1}^*) + l_{24}s(\alpha^*) + l_{47}s(\beta^*) \quad (26)$$

$$l_{24} = \sqrt{(x_4^* - x_2^*)^2 + (y_4^* - y_2^*)^2},$$

$$\text{Where, } l_{47} = \sqrt{(x_7^* - x_4^*)^2 + (y_7^* - y_4^*)^2} \quad (27)$$

$$\alpha^* = \phi^* + \theta_1^* + \theta_{n2}, \beta^* = \alpha^* - \theta_4^* - \theta_{n2}$$

It is eminent that the superscript "*" with factors means the parameter's values at $t \geq 4$ s which are known by the sensors utilized in model as appeared in Figure 3. The joint factors α^* and β^* of the reconfigured robot can be assessed similarly as Equations 15 to 18.

Presently let us consider the case that joint 4 becomes inactive and joint 5 is activated. Consequently, joint 2 and 5 will be activated while others will be inactive. This case is delineated in the following area.

The Jacobian for cases I and II, can be assessed in the equivalent design as specified in section 3 and bond graph model can be drawn for the equivalent, i.e., the cases I and II. The end-effectors following execution relies on the moment setup of the space robot controller. Determination of healthy actuator must guarantee workspace reachability. In the case of during the task, the manipulator faces peculiarity issue then quickly other healthy must be made dynamic guaranteeing workspace reachability.

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: www.ijirset.com

Vol. 7, Issue 10, October 2018

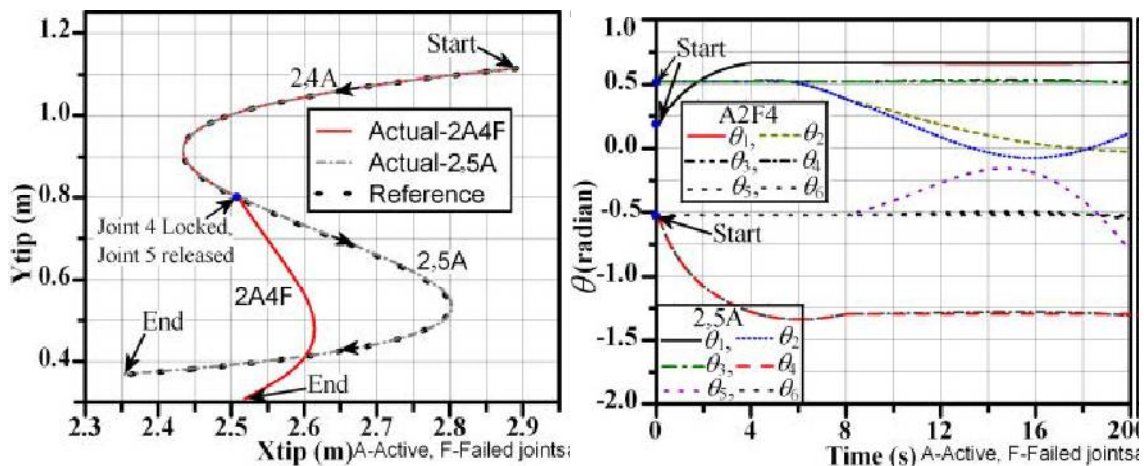
V. SIMULATION AND ANIMATION RESULTS

The proposed reconfiguration of space manipulator due to joint locked failure disappointment has been thought to be approved through simulation and activity results. The reproduction is done for 20 seconds for the two cases I and II as in section 4. As a kind of perspective input direction to the robot tip, a B-spline bend of "S" formed tip direction is considered. Give a B-spline a chance to bend with four control points is built for tip direction following. The reference tip relocation conditions is given as:

$$X_{tip} = p_{x0}(1 - t/t_f)^3 + 3p_{x1}(t/t_f)(1 - t/t_f)^2 + 3p_{x2}(t/t_f)^2(1 - t/t_f) + p_{x3}(t/t_f)^3 \quad (31)$$

$$Y_{tip} = p_{y0}(1 - t/t_f)^3 + 3p_{y1}(t/t_f)(1 - t/t_f)^2 + 3p_{y2}(t/t_f)^2(1 - t/t_f) + p_{y3}(t/t_f)^3 \quad (32)$$

Where, $(P_{x0}, P_{y0}) \dots (P_{x3}, P_{y3})$ are four control purposes of a curve comparing to X and Y directions and t is time and t_f is add up to travel time. The reference tip velocity conditions can be found by time subordinate of equations 31 and 32



desired tip trajectory. And when the manipulator got reconfigured, it imparts the desired tip trajectory. In future scope, the present work will be extended for obstacle avoidance as well as extending this strategy for three dimensional case in the workspace

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: www.ijirset.com

Vol. 7, Issue 10, October 2018

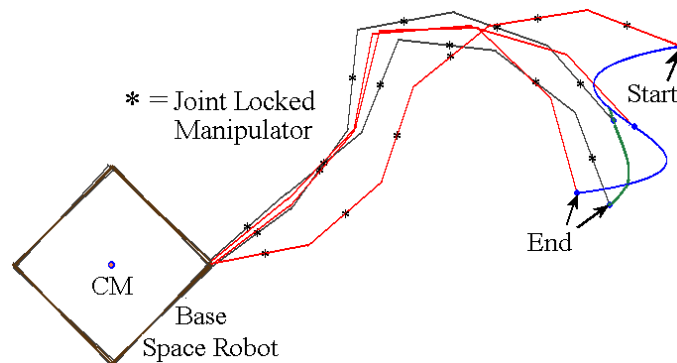


Figure 3. Motion planning of the 6 DOF planar space robot when joint 1 got failed at $t = 4$ s, joint 2 is made active to achieve desired trajectory (Joints 2 and 4 are active), (a) Tip trajectory (b) Joint rotation and (c) Animation result

VI. CONCLUSION

Here, a methodology has been actualized for reconfiguration of space robot obliging actuators. It merits specifying that at once just two joints were actuatable though others were kept passive intentionally. These joints were incidentally locked through the PD controller and can be opened at whatever point required. These joints come to assume their critical role in special cases, for example, joint locked failure, manipulator in a narrow and congested place obstruction avoidance, and so on. In this paper, we tended to the reconfiguration of 6 DOF planar space robot within the sight of joint locked failure. To show the robot manipulators, need to change their design with a specific end goal to meet the requests of a particular task inside the limitations of the environment. Two cases of the joint failures are completely explored. Each case comprises of the robot with one healthy and one locked joint during manipulation and reconfigured robot with both healthy joints all through the manipulator. The recreation and the movement results approved that when the robot is in healthy condition, it gives the required motion planning. What's more, when the robot encounters joint locked failure, it ends up unfit to track the desired tip direction. Furthermore, when the controller got reconfigured, it confers the coveted tip direction. In future degree, the present work will be stretched out for obstruction evasion and additionally broadening this system for three dimensional case in the workspace.

REFERENCES

1. Aghili, F, 2004 A Conceptual Design for Reconfigurable Manipulators, the CDEN/RCCI Design Conf, Montreal, QC , Canada(2004)
2. Castano A.Alberto, B., and Will P. m. 2002 , The Conro Modulus for Reconfigurable Mechatronics ,IEEE/ASME Transcations, 7.3(2002).403-409.
3. Kumar A Pathak PM and Sukavanam N. 2011 Reduced Model Based Control of Two Link Flexible Space Robot, Intelligent Control and Automation 2, 112-120.
4. Merzouky and R.,Samantary and A.K.Pathak, P.M and OuldBouman B.2013. Intelligent Mechatronic systems: Modelling Control and Diagnosis ISBN: 978-1-4471-4627-8 (print),Springer.