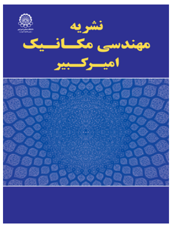

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Design, Modeling and Control of a Hybrid Climbing Robot in Manipulation Mode Using Feedback Linearization Control Method

V. Boomeri, H. Tourajizadeh*

Mechanical Engineering Department, Faculty of Engineering, Kharazmi University, Tehran, Iran.

ABSTRACT: In this paper, design, modeling and control of a grip-based planar climbing robot is performed which is consist of a triangular plate and three actuating legs. This robot is extremely applicable for many applications in which a human operator should climb through a truss infrastructure and implement some manipulations on the relevant installations. A grip-based climbing robot is designed which has three legs and grippers for climbing through the truss and infrastructures and is able to perform manipulating tasks by locking two legs and its corresponding grippers. This robot is a kind of hybrid robot which has two phase of climbing and operating modes. The control is performed for the operational phase using Feedback Linearization (FBL) in order to overcome the disturbances of operation. Overall kinematics and kinetics of the robot is modeled. All of the modeling are verified by conducting some analytic and comparative simulation scenarios in the MATLAB and the results are also compared with ADAMS software to investigate the correctness of modeling and simulations. Also by the aid of the proposed climbing robot, it is possible to climb and perform a complete operational task through trusses and infrastructures with the best status of safety and accuracy.

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1- Introduction

By developing metallic bridges, telecom and electricity masts, truss shaped structures like scaffolds used in constructive industry and astronomy technology such a rocket lunch station the demand of locomotion on such these infrastructures is seriously felt. By consideration of dangers for working on such these structures for workers, climbing robots are designed to ascend mentioned structures in order to do tasks including manipulating, maintenance, contractions (riveting and welding) and periodic inspections. ROMA II [1] for climbing walls, Climbot [2] and Shady3D [3] and Libra [4] for climbing trusses, PCR [5] a parallel robot and 3Dclimber [6] for climbing poles and pipes with circular area. In this paper design and modeling (kinematics and dynamic modeling) of a hybrid three limbed climbing robot is explained and at the end the designed robot is controlled by feedback linearization method which results show well control during manipulation.

2- Distinct Characteristics of Designed Robot

The basic characteristics: 1- For climbing infrastructures against gravity 2- Planar movement. 3- Grip-based Climbing robot 4- Hybrid mechanism. 5- Five Degree of Freedoms (Dofs) robot by neglecting grippers Dofs. 6- High stability because of two point gripped as support. 7- Redundant Dofs for best maneuvering through complex profiles. 8- High stiffness by parallel part configured by 2 linear jacks. 9- Less and logical loads on supports by well distribution of total load on pair of gripper grasped the terrain simultaneously. The inspiration for designing this climbing robot is monkey movement on trees which can balance himself by grasping two point of a branch by his legs or tail or hands and by other hand or leg is seeking for new point to grab as new support. The configuration of robot is as Fig. 1(a) .Series of such this movements (grabbing and seeking for new point to grab) form a locomotion on tree. Here we consider seeking for new point to grab as a manipulating task and modeling with control is considered in this phase by knowing that a chain of manipulations movement constitutes locomotion Fig. 1(b).

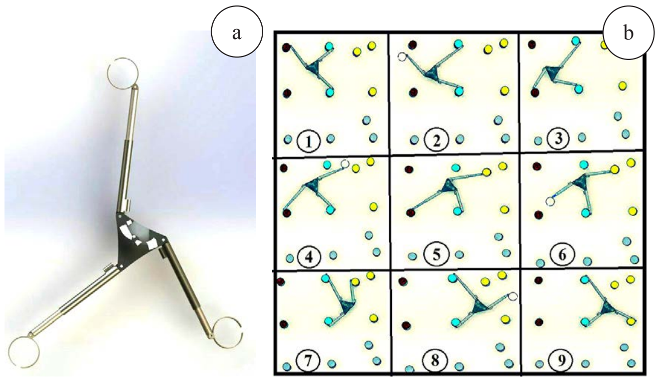

Fig. 1. (a). Robot shape-(b). Robot locomotion steps

*Corresponding author's email:tourajizadeh@khu.acir

3- Kinematics and Dynamics Modeling

Kinematics of the system can be defined by establishing the relation between the active joint space movement and the end-effector workspace motion:

$$\begin{bmatrix} v_x \\ v_y \\ \omega_z \end{bmatrix} = J\left[\dot{\theta}_1,\dot{\theta}_2,\dot{d}_2,\dot{\theta}_3,\dot{d}_3\right]^T \tag{1}$$

while x,y,w are the workspace displacement of the end-effector and $\theta_1,\theta_2,d_2,\theta_3,d_3$ are the active joint space of the robot. J is the Jacobean matrix of the system and its elements can be provided by extracting the geometrical relations of the robot components.

Dynamics of the system is also extracted using Lagrange method and the resultant dynamic equation of the system can be defined as follow where D is the inertia matrix, C is Coriolis matrix and g is gravitation vector of the system. τ and f are the input torque and force of the actuators.

$$\begin{bmatrix} \tau_1 \\ \tau_2 \\ f_1 \\ \tau_3 \\ f_2 \end{bmatrix} = D(\theta_1,\theta_2,d_2,\theta_3,d_3)_{(5\times5)} \begin{bmatrix} \ddot{\theta}_1 \\ \ddot{\theta}_2 \\ \ddot{d}_2 \\ \ddot{\theta}_3 \\ \ddot{d}_3 \end{bmatrix} + C(\theta_1,\theta_2,d_2,\theta_3,d_3,\dot{\theta}_1,\dot{\theta}_2,\dot{d}_2,\dot{\theta}_3,\dot{d}_3)_{(5\times5)} \begin{bmatrix} \dot{\theta}_1 \\ \dot{\theta}_2 \\ \dot{d}_2 \\ \dot{\theta}_3 \\ \dot{d}_3 \end{bmatrix} + g(\theta_1,\theta_2,d_2,\theta_3,d_3)_{(5\times1)} \tag{2}$$

4- Control Design

Feedback linearization is employed here for controlling the operational tasks of the robot manipulator. Considering the extracted dynamic equation of the system, the required input of the actuators can be defined as:

$$\tau = D(\mathrm{q})(\ddot{q}_d - K_v\dot{e} - K_p e) + C(\mathrm{q},\dot{q})\dot{q} + g(\mathrm{q}) \tag{3}$$

where d denotes the desired value of the parameter, this input results in the following error dynamics through which the proper gain of pole placement procedure can be extracted:

$$\mathrm{D(q)}(\ddot{e} + K_v\dot{e} + K_p e) = 0 \rightarrow \ddot{e} + K_v\dot{e} + K_p e = 0 \tag{4}$$

5- Simulation and Result Verification

Desired Value of the joint space is:

$$\begin{aligned} &\theta_1 = 0.004t^2 + \theta_1(0)(\mathrm{rad}); \theta_2 = -0.01t^2 + \theta_2(0)(\mathrm{rad}); \\ &d_2 = 0.0004t^2 + \mathrm{d}_2(0)(\mathrm{m}); \theta_3 = 0.02t^2 + \theta_3(0)(\mathrm{rad}); \\ &d_3 = -0.1\sin(0.625\,\mathrm{t}) + \mathrm{d}_3(0)(\mathrm{m}) \end{aligned} \tag{5}$$

The extracted workspace of the manipulator velocity along y using kinematics and its comparison with ADMAS is shown in Fig. 2 which shows good compatibility:

Table 1. Parameters of robot

Parameter	Symbol	Value	Unit
Cylinder length	L_1	0.1	m
Piston length	L_2	0.1	m
Distance between two supporting grippers	Le	0.4	m
Chassis triangle side	b	0.2	m
Mass of the robot components	m_i	2	kg
Moment of inertia of the robot components	I_i	0.001	kg.m^2
Chassis mass	M_G	4	kg
Moment of inertia of the chassis	I_G	0.004	kg.m^2

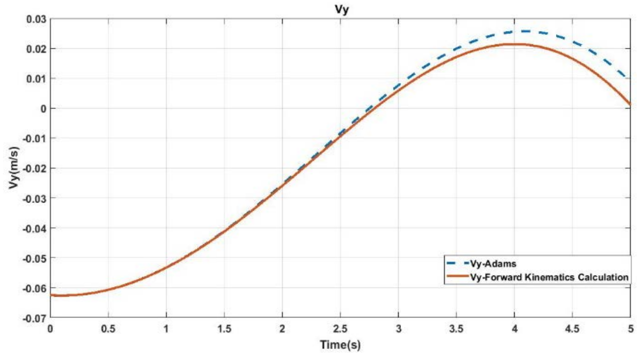

Fig. 2. Forward kinematics compared with MSC-Adams simulation

Required motor torque (motor 2) using dynamics and its comparison with ADAMS is as Fig. 4.

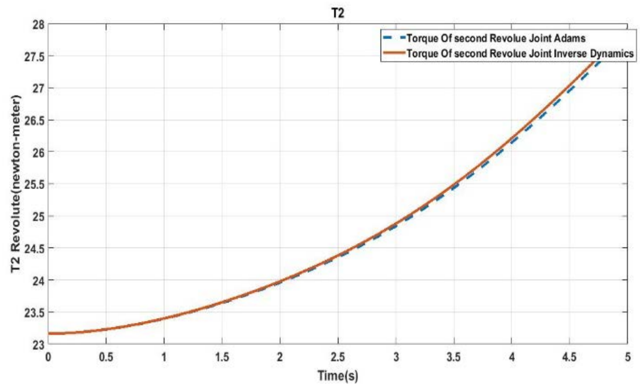

Fig. 3. 2nd motor torque by inverse dynamics compared with MSC-Adams simulation

In order to verify the designed controller the following desired workspace is considered:

$$\begin{aligned} &V_x = -0.002t^3 + 0.01t^2(\mathrm{m/s}) \\ &V_y = -0.00288t^3 + 0.0144t^2(\mathrm{m/s}) \\ &\dot{\phi}_z = -0.014t^2.\sin(2t) + 0.07t.\sin(2t)(\mathrm{rad/s}) \end{aligned} \tag{6}$$

Following disturbance is implemented to check the efficiency of the designed controller:

$$\tau_{dis\,1} = 3\sin(10\,t); \tau_{dis\,2} = 3\sin(10\,t)$$
$$f_{dis\,1} = 1.5\sin(5\,t); \tau_{dis\,3} = 0.5\sin(10\,t + \frac{\pi}{2}) \qquad (7)$$
$$f_{dis\,2} = 0.1\sin(10\,t)$$

Considering proper controlling gain results in the following joint space movement and its comparison with open loop system for joint 2 Fig. 4 shows comparison between controlled and non-controlled system under disturbances:

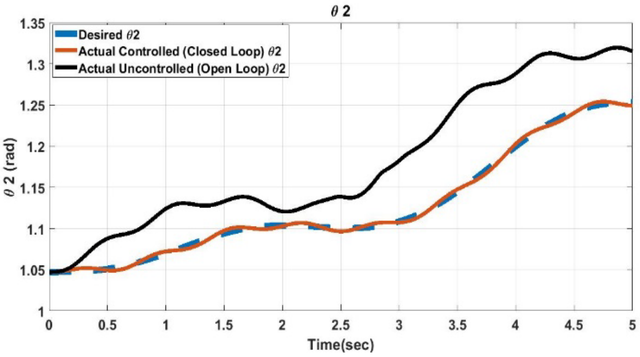

Fig. 4. Comparison between controlled and non-controlled system for 2nd revolute joint

It can be seen that the open loop system diverges from the desired value of the joint space path while the designed controller can track the path successfully with a great compatibility.

6- Conclusion

In this paper, for the tasks like movement on scaffold and maintenance with high mobility, a new planar grip based robot was designed. According to its functionality by inspiration of monkey's movement on trees the robot was designed. This robot with 2 locomotion and manipulation phases was made by combination of serial and parallel mechanism (non-fully parallel) which is called hybrid. Kinematic and dynamic modelling of the manipulation phase was performed with 5 DOFs joint space and 3 DOFs workspace. Feedback linearization controller was designed and implemented on the robot to neutralize the destructive effect of operational disturbances. In order to verify the efficiency of the robot design and the proposed controller, some comparative and analytic simulation scenarios was prepared and also the results was compared with ADAMS. It was shown that not only the robot is able to move successfully through the trusses but also is able to do an operational task with the least amount of error.

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