Design and Development of 3-DOF RPR Planar Parallel Robot

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Abstract— Use of parallel mechanism as a robot manipulator is an emerging technology in the field of robotics. This paper represents the kinematic modeling and synthesis of three degree of freedom planer parallel mechanism. Use of a parallel mechanism as a robot manipulator has its own potential merits like, high structural rigidity, good dynamic performance, high load carrying capacity and precision positioning. Forward kinematic analysis is essential for evolution of the work volume of the robot and design of the feedback control system design. While the inverse kinematic analysis is essential for synthesis of robot manipulator and design of continuous control system. This paper also includes the development of the working model of the 3-DOF parallel planer robot. Because of precise positioning capability this manipulator can be used for generation of the planer profiles, welding and cutting on planer geometry.

Keywords— *Optimal kinematic design; Local mobility index; Force manipulability*

I. INTRODUCTION

Majority industrial robots are serial mechanism based. This type of cantilevered structure has less rigidity and poor dynamic performance. Also the end effector positioning accuracy is poor due to cumulative error at each joint. So the serial mechanism based robot manipulators are not preferred for high speed and high precision tasks.

The parallel mechanism based robot manipulators are away from these kind of problems due to their truss-like structure. They are having very good dynamic performance and high positioning accuracy.

Good amount of research work is there focusing the kinematic analysis of parallel manipulators. Very first, the idea of using the manipulation capability of parallel mechanism can be used as robot manipulator was suggested by Hunt [1]. Hunt [2] also found out different possible arrangements of parallel mechanisms which can be used as robot manipulator. Yang and Lee [3] checked the feasibility of using parallel mechanism as robot manipulator from kinematic point of view. Mohamed and Duffy [4] presented forward kinematics of parallel mechanism with passive joint variables, while Prajapati et al. [5] presented the inverse analysis of parallel manipulator by symbolic approach, which increases the computational complexity.

This paper presents the forward and inverse kinematic analysis and the same is used for developing the working model of the 3-DOF planer parallel robot. For actuating this robot, three 12 V, 0.3 amp stepper motors of 3.1

torque along with the controller circuit is used. Plywood sheet of 8 mm thickness is used as base. The bolt & cylinder assembly forms the 3 telescopic links of planar robot. Voltage of 5 V to the controller is provided through power circuit & 12 V to motor is provided through adapter. The working of the robot is executed and the work volume of it is also evaluated.

II. 3-DOF PLANER PARALLEL ROBOTS

Conventionally, revolute joints are labeled as *R*, while prismatic joints labeled as *P* and the actuated joints are underlined.

A moving platform, within the plane, will have three degrees of freedom, two translations along the x and y axes, and rotation through an angle θ about the z axis, perpendicular to the plane. A fully parallel robotic structure possesses three independent kinematic chains, actuated by three actuators. As one of the ends each of these chains must be linked to the ground, and the other end to the moving platform. So, there will be three attachment points on the ground and three on the moving platform. One can therefore consider, still in a general manner, a triangular moving platform.

A chain can be described by the sequence of these three joints, from the base upwards. The chains can present the following sequences: RRR, RPR, RRP, RPP, PRR, PPR, PRP, and PPP. The sequence PPP is excluded as the joints motion must remain independent.
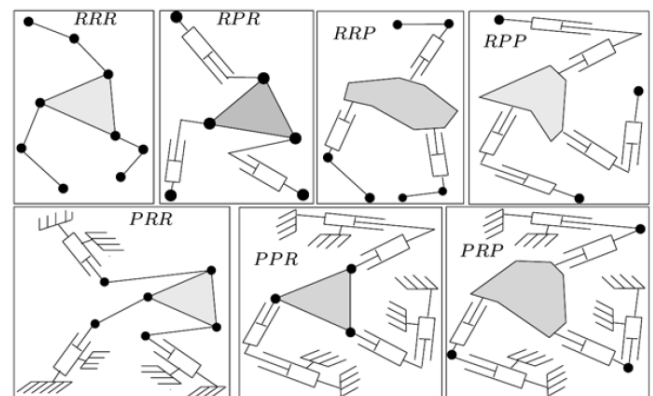

Fig. 1. Different configurations of 3-DOF planer Manipulator

A simple exchange of the base and the moving platform, the robots of the *RRP* type become equivalent to *PRR*, and the *RPP* equivalent to *PPR*. The actuated joint can be any of the three. Generally, placing the actuator on the end effector is avoided in order to lighten the weight of the moving equipment.

III. KINEMATIC ANALYSIS

The manipulator considered here is symmetric and composed of three identical legs connecting the fixed base to the end-effector triangle as shown in Fig. 2. Each leg is of RPR design, with two passive revolute joints and an active prismatic joint in-between.
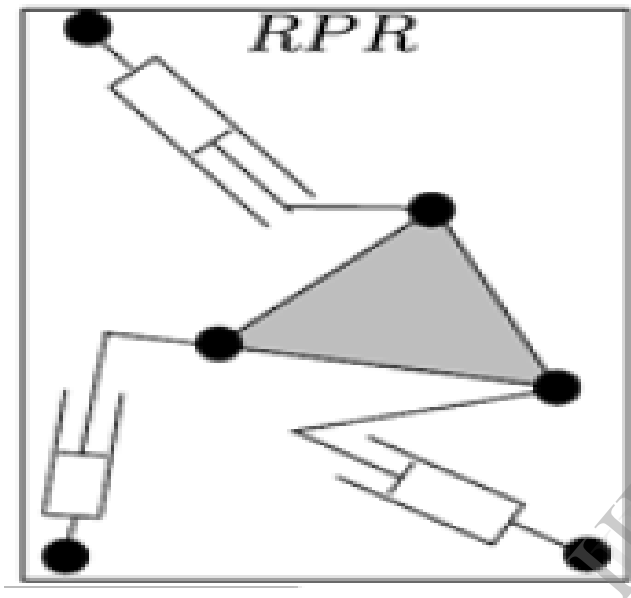

Fig. 2. RPR configuration of 3-DOF planer Manipulator

The 3-RPR kinematic diagram is shown in Figure 3. The three grounded passive revolute joints are located on the base triangle at Ai and the three moving passive revolute joints are located on the moving triangle at C_i, where i =1,2,3. The active prismatic joint variables are the total lengths L_i, giving the length between passive revolute joints. The moving frame {H} is at the triangle centroid and the base frame {B} is shown in Fig. 2. The Cartesian variables are the triangle link pose   . The Grubler mobility equation predicts this device has three degrees of freedom, by counting eight rigid links connected by 9 one-dof joints. q_i are passive intermediate joint angles which are not required for hardware control, but which may be calculated for computer simulation and/or velocity and dynamics calculations.

IV. INVERSE KINEMATICS

The inverse kinematics consists in establishing the value of the joint coordinates corresponding to the end-effector configuration. Establishing the inverse kinematics is essential for the position control of parallel robots. There are multiple ways to represent the pose of a rigid body through a set of parameters X. The most classical way is to use the coordinates

in a reference frame of a given point C of the body, and three angles to represent its orientation.

The inverse kinematic problem of the 3-DOF parallel manipulator is to calculate the required prismatic joint lengths   for given desired cartesian pose
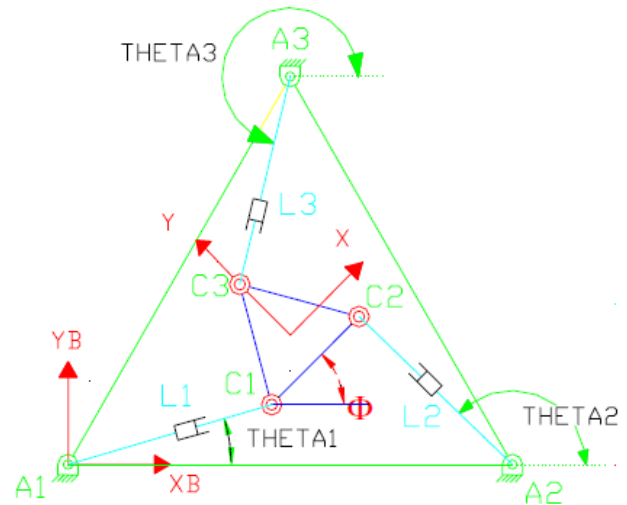.

Fig. 3. Kinematic arrangment of 3-DOF planer Manipulator

There is a duality with serial manipulators. Generally the inverse kinematics is straight-forward, while the forward kinematics problem is difficult, which is opposite the case for serial manipulators. For the 3-*RPR*, since we are given the pose *X*, we can easily calculate moving revolute locations C_i and then the inverse pose solution is simply finding the vector lengths L_i between C_i and A_i, i = 1, 2, 3. For each *RPR* leg, the following vector loop closure equation may be written:

$$^B C_i = \, ^B P_H + \, ^B R_H \times \, ^H C_i = \, ^B, \qquad i = 1, 2, 3 \quad (1)$$

where,   and $^B R_H$

Calculate $^B C_i =$ for given X and known robot geometry and then the solutions are found using the Euclidean norm in (2):

$$, i = 1, 2, 3 \qquad (2)$$

The intermediate passive joint angles θ_i are

$$\theta_i = \tan^{-1} 2\left(^B C_{iy} - \, ^B A_{iy} \right) / \left(^B C_{ix} \right) \qquad (3)$$

V. FORWARD POSE KINEMATICS

The forward poseproblem is to calculate the Cartesian pose
.   for given prismatic joint lengths
. This problem requires the solution of coupled nonlinear equations. The same vector loop closure equations (1) is applied and rewritten as, for, i =1, 2, and 3:

$$\begin{Bmatrix} L_i c\theta_i \\ L_i s\theta_i \end{Bmatrix} = \begin{Bmatrix} x \\ y \end{Bmatrix} + \begin{bmatrix} c\varphi & -s\varphi \\ s\varphi & c\varphi \end{bmatrix} \begin{Bmatrix} ^H C_{ix} \\ ^H C_{iy} \end{Bmatrix} - \Bigg\{ \qquad (4)$$

Equation (4) includes all unknowns   and one passive unknown θ_i. One approach to solve this problem is to apply the numerical Newton Raphson method. First, since θ_i is not required, we can square and add the x and y component equations in (4) to eliminate θ_i. The result is three equations coupled and nonlinear in the unknowns X. Solution details are not given here. θ_i can be found after X is known using (3). This forward pose problem is equivalent to finding the assembly configurations of a four bar linkage with input/output links L_1, L_2 and an RR constraining dyad of length L_3. By itself the four-bar linkage has infinite assembly configurations because it has one-dof. RR dyad A_3C_3 constrains the mechanism to a statically determinate structure of 0-dof. Point C3 defines a four bar coupler curve which is a tricircular sextic (sixth-degree algebraic curve) that has a maximum of six intersections with the circle of radius L_3 centred at A_3.

VI. WORK SPACE ANALYSIS

Parallel manipulators motions can be restricted by different factors: mechanical limits on passive joints, self-collision between the elements of the robot, limitations due to the actuators and singularity varieties that may split the workspace into separate components. The main problem with the workspace representation of parallel robots is that the limitations on the dof are all usually coupled. Hence for robots having more than 3 dof there will be no possible graphical illustration of the robot workspace. A graphical representation of the workspace of parallel robots will be possible only for 3 dof robots. For robots within more than 3 dof, workspace representation will be possible only if we fix $n - 3$ pose parameters. According to which types of parameters are fixed or to the constraint we impose on the parameter, we will obtain different types of workspace.

All possible locations of the operating point C of the robot, which can be reached with a given orientation is shown in the Fig. 4.
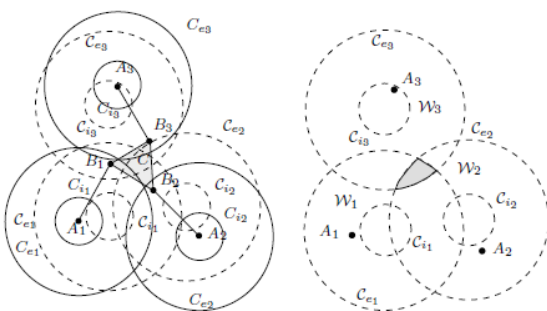

Fig. 4. Work space of 3-DOF planer Manipulator

VII. DEVELOPMENT OF 3-DOF RPR ROBOT

The following components were used for the development of the 3-RPR planer parallel robot. A stepper motors with high torque were used as an actuator to actuate a prismatic joint to change the link length. Ball bearings were used to generate revolute joint on the Platform Overall dimensions of 100mm X 100mm X 6mm. The prismatic joint is composed of a screw

pair between a threaded cylinder and a bolt. Both have turning as well as sliding motion with respect to each other. Beam coupling is made up of MS solid rod with one end connected to bolt through lock nut arrangement and another end is connected to motor shaft. A sensor-3 axis linear accelerometer module 3G is used to sense motion or tilt (in case of non-moving) in 3 axis. 12V adapter is used as power source for operating the 3 stepper motor along with driver circuit, 5V is provided via the power circuit for operating the ATMEGA16 controller. The complete assembly is as shown in the Fig. 5.
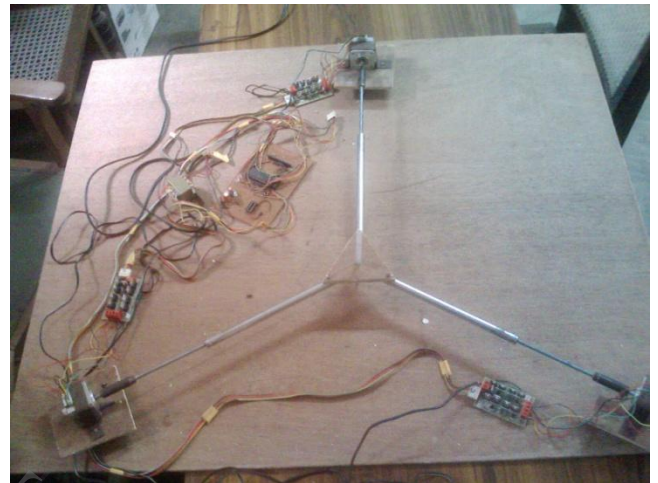

Fig. 5. Assembly of 3 DOF Planer Parallel Robot

VIII. CONTROLLING THE MOTOR WITH CIRCUIT

To execute the 3 DOF Planer Parallel Robot, ATMEGA16 is used as a controller. The 5 pins of the controller named B5, B6, B7, RESET, and VCC & GND are used for giving input to the controller i.e. feeding data to controller. Data is fed to the controller in form of the programmable logic with help of the loader form computer through a male bug strip + 5 V form the power circuit is given to the VCC and ground connection to the GND pin. Stepper motors are to be connected to the controller ATMEGA16. Driver circuit of the stepper motors, performers the function equivalent to the motor IC. It energizes the coils of the stepper motor according to the logic fed to the controller. Thus according to the controller signal, the driver circuit using the 12 V DC power energizes .The coils of the stepper motor according to the program fed .Thus considering the rotation of the motor. First Motor is connected to the port D3, D4, D5 and D6 of ATMEGA16 controller. Second Motor is connected to the port C7, C6, D0 and D1 of ATMEGA16 controller. And the third Motor is connected to the port D7, B4 and B3, B2 of ATMEGA16 controller.

IX. CONCLUSIONS

In this paper different possible configurations of 3 DOF planer parallel mechanisms are presented. Having potential benefits like, structural rigidity, positional accuracy and good dynamic performance of the parallel mechanisms over the serial mechanisms, the parallel mechanisms can be used as robot manipulators. The forward kinematic analysis and inverse kinematic analysis of the RPR configuration of the 3 DOF planer parallel mechanism is presented. And the same is

implemented for preparing a working model of the 3 DOF planer parallel robot. The end effector can trace any track within the work volume based on the program commands. This planner robot can be used for industrial applications like arc welding, gas cutting etc. for planner geometry.

REFERENCES

[1] K. H. Hunt, "Kinematic geometry of mechanisms", Clarendon Press, Oxford, 1978.

[2] K. H. Hunt, "Structural kinematics of in-parallel-actuated robot-arms, Journal of Mechanisms, Transmissions and Automation in Design, Vol. 105(4), pp. 705-712, 1983.

[3] D. C. H. Yang and T. W. Lee, Proceedings of "IEEE International Conference on Robotics and Automation, 1, 345-350 (1987)

[4] M. G. Mohamed and J. Duffy, "A direct determination of the instantaneous kinematics of fully parallel robot manipulators", Journal of Mechanical Design, Vol. 107(2), pp. 226-229, 1985.

[5] J. M. Prajapati, L. N. Patel, A. Verma, "Inverse dynamic analysis of robot manipulator having parallel mechanism – Stewart platform, by symbolic approach", International conference on emerging mechanical technology – macro to nano, Birla Institute of Technology and Science, Pilani, India, ISBN 81-904262-8-1, Vol. 1. pp. 239-242, 2007.