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Stiffness Analysis of 3-RPS Parallel Manipulator

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***Abstract:** In many applications, the moving platform of a parallel manipulator is in contact with a stiff environment, and applies force to the environment. As the Jacobian transpose is a projection map between the applied force to the environment and the actuator forces causing this moment. In this section, we focus our attention on the deflections of the manipulator's moving platform that are the result of the applied moment to the environment. This deflection is the function of the stiffness and the force applied, therefore the stiffness has the direct impact on positional accuracy of the manipulator. In this paper we study the stiffenss analysis by analytical method and numerical method. The analytical model for the 3 RPS parallel kinematic manipulator is derived by putting the unit vectors of the fixed base, actuators, fixed leg and the moving platform into final jacobian matrix. For the case study, the perfectly rigid links are considered and main sources of compliance come from the compliance of the actuators.*

***Keywords:** Parallel manipulator, platform, stiffness, environment, jacobian, deflection, actuator.*

I. INTRODUCTION

Stiffness is one of the fundamental performance specification in designing of the parallel manipulators. Higher stiffness is needed in high accurate and application involving larger loads and forces. High speed machine tools needs high speed machining and accurate movement of the moving platform. Stiffness of the planner and special manipulator firstly investigated by Huang [1] in which he shows the relation between the joint forces and torques with the end effector by the jacobian matrix. Stiffness of the different type of parallel manipulator is found in literature [2, 3] e.g. Planar, shoulder manipulator and Stewart platform. Stiffness model of tripod based parallel mechanism were developed in [4] by the method of equivalent stiffness for linear connected springs in series. They decomposed the structure into two substructures. One of them is the machine frame structure and other is the actual mechanism structure. They combined the whole stiffness of the manipulator by principle of virtual work and linear superposition techniques. The stiffness matrix for the 3PUU type manipulator was derived by [5].They derived the stiffness by considering the actuator and constraints imposed by passive joint. They also consider the compliance subject to involved legs and the actuators in the final stiffness matrix. Both Xu, Q. and Y. Li investigated the stiffness and mobility of the 3 PRC type manipulator approach based on screw theory by considering the actuator and constraints [6]. Stiffness modeling for over-constrained type manipulator is developed by Pashkevich, et al.,[7] they generate the translational and rotational compliance by replacing the mechanism link into a 6-DOF virtual springs. The presented model was applied to the 3PUU and PRPR mechanism.

II. STIFFNESS ANALYSIS OF PARALLEL MANIPULATOR

Let $\tau = [\tau_1, \tau_2, \dots\dots, \tau_n]$ is the vector of actuators joint torque or force and the joint deflection $\Delta q = [\Delta q_1, \Delta q_2, \dots\dots, \Delta q_n]$.τ and Δq can be related by n×n diagonal matrix.

Let $x = diag[k_1, k_2, \dots\dots, k_n]$ so the relation will become as.

$$\tau = x\Delta q$$

It is known that the joint deflection Δq is related to end effector deflection Δx by the jacobian matrix.

$$\Delta q = J\Delta x$$

Where $\Delta x = [\Delta p_x, \Delta p_y, \Delta p_z, \Delta\emptyset, \Delta\psi, \Delta\theta]$

We know that the $F = [f, n]$ is the vector of output force and moment, which is related to the joint torque τ by jacobian matrix as.

$$F = J^T\tau \text{ we get}$$

$$F = J^T x\, J\, \Delta x$$

Here $K = J^T x\, J$ called as the stiffness matrix for the parallel manipulator. However the stiffness matrix is symmetric positive semidefinite, and it depends upon the manipulator configuration. When all the actuators are the same type, the stiffness constant will also be same as $k = k_1 = k_2 = \cdots\dots = k_n$ then

$$K = k\, J^T x\, J$$

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III. ANALYTICAL MODEL

The analytical model of for the 3 RPS parallel kinematic manipulator is derived by putting the unit vectors of the fixed base, actuators, fixed leg and the moving platform into final jacobian matrix $J = J_a J_r$. Where $J = J_q{}^{-1} J_x$ and

Φ, ψ, θ are the Euler Angles

To find the jacobian matrix J_a we need to put unit vector of J_x and J_q

$$J_q = \begin{bmatrix} I_{10}.d_{10} & 0 & 0 \\ 0 & I_{20}.d_{20} & 0 \\ 0 & 0 & I_{30}.d_{30} \end{bmatrix}$$

d_{i0} is the position vector of the i^{th} linear actuator

$$J_x = \begin{bmatrix} I_{10}^T & (b_1 \times I_{10})^T \\ I_{20}^T & (b_2 \times I_{20})^T \\ I_{30}^T & (b_3 \times I_{30})^T \end{bmatrix}$$

b is the moving platform radius

The unit vector I_{i0} for $i = 1,2,3$ $\quad I_{i0} = L_i - d_i d_{i0}$

L_i is the vector of each limb

d_i is the linear displacement of the ith actuator

d_{i0} is the unit vector of linear actuator

$$L_i = q_i - a_i$$

a is the fixed base platform radius

$$J_r = \begin{bmatrix} \frac{\partial P_x}{\partial P_z} & \frac{\partial P_x}{\partial \psi} & \frac{\partial P_x}{\partial \theta} \\ \frac{\partial P_y}{\partial P_z} & \frac{\partial P_y}{\partial \psi} & \frac{\partial P_y}{\partial \theta} \\ 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \\ \frac{\partial P_\phi}{\partial P_z} & \frac{\partial P_\phi}{\partial \psi} & \frac{\partial P_\phi}{\partial \theta} \end{bmatrix}$$

IV. SIMULATION RESULTS

Table.1 Architecture parameters for 3 PRS manipulator

Parameters	
g	400mm
h	200mm
α	30^0

The architecture parameters for 3RPS manipulator is shown in table.1 and stiffness constant is taken to be 19500 N/m for each of the linear actuator. A MATLAB program is written to find the maximum and minimum stiffness of the general 3RPS mechanism. The results are shown in Fig.1 and Fig.2. Let we take P_Z = 0.59 M from configuration -1 and corresponding values for ψ and θ are 0.751 and 0.089 respectively. The results shows the value of maximum stiffness at this points, is equal to be 14625 N/m and minimum stiffness is equal to 96.95 N/m

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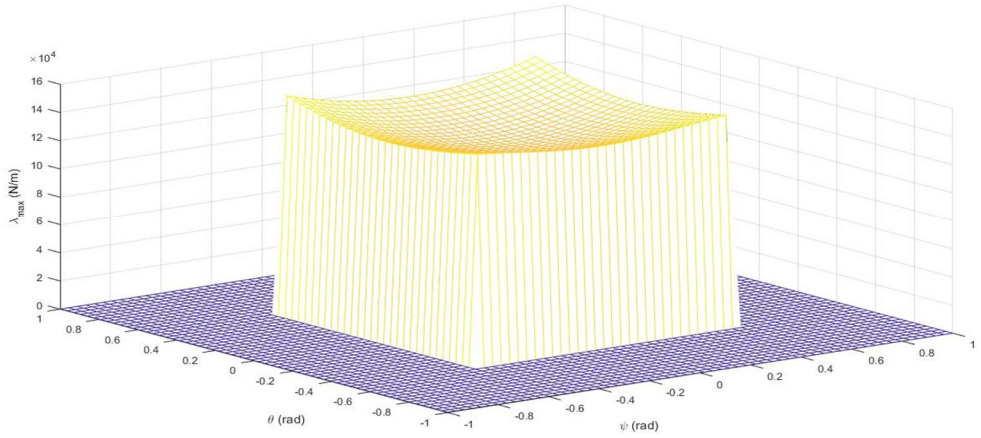


Fig. 1 Maximum stiffness of 3RPS mechanism at height P_Z = 0.59m

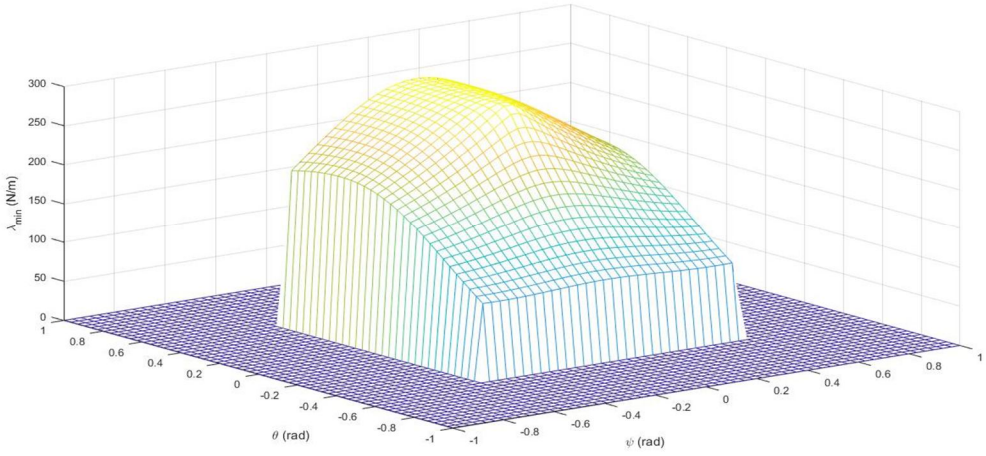


Fig. 2 Minimum stiffness of 3PRS mechanism at height P_Z =0.59m

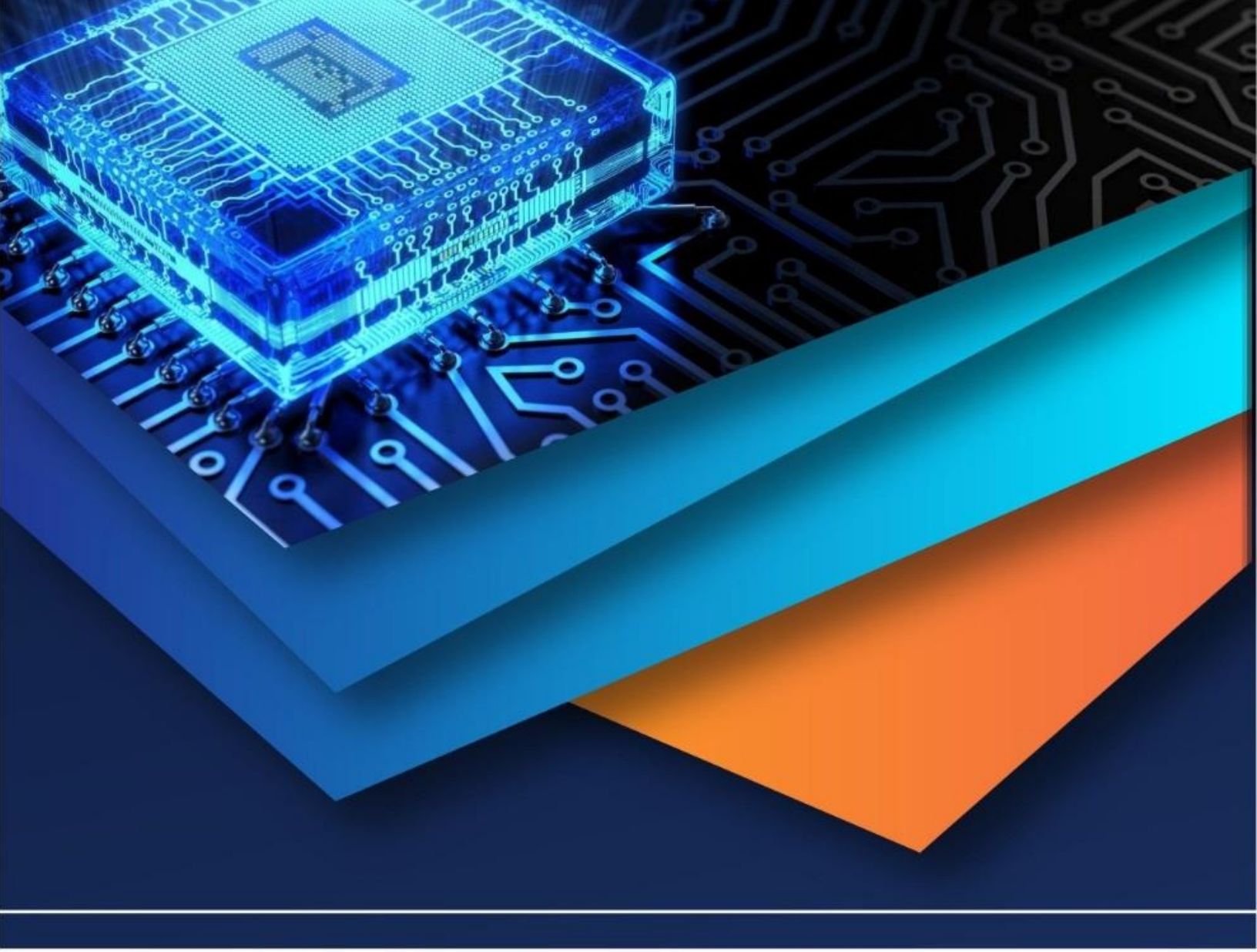
V. CONCLUSIONS

Stiffness analysis of the 3RPS manipulator is derived and solved by numerical method. The minimum and maximum eigenvalues of the stiffness matrix are commonly used performance indices. These values can be used to estimate the stiffness of the 3 RPS manipulator.

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