Methodology Development of Design of a Hybrid Parallel Robot

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Abstract

This paper addresses a new method for the design and modeling of a hybrid parallel robot involving two parallel kinematic mechanisms that are serially connected. The design includes a tripod mounted on the moving plate of a hexapod in order to gain a larger overall work volume whilst retaining sufficient overall stiffness for flexible, accurate, and automated gripping and jigging applications such as the assembly of large aerospace components. Different configurations are analyzed and compared in order to identify the most optimum structural architecture in terms of stiffness and workspace. The theoretical model is supported by the simulation results using SOLIDWORKS, SOLIDSIMULATION and MATLAB software tools. Experimental results were obtained by exerting a known force to the tripod, here acting as the end effecter, that causes displacement along the actuator. The actual displacement was then determined by receiving data from a set of strain gauge sensors that are connected to the body of the actuators.

1 Methodology

The 6 UPU-3UPR configuration of hybrid parallel robot is investigated in order to increase the workspace while stiffness of the model remains in suitable level for industry application such as jigs and fixture in aerospace area. The considered characteristics of desired robot lead the investigation about the stiffness and workspace of hybrid parallel robot in comparison with the conventional model of parallel robot such as the tripod and the hexapod. In following study the inverse kinematic of the hybrid model is developed. The developed kinematic model is used to find the actuator size and workspace of robot. In developed model the possible position and orientation of end-effector are searched to check limitation of the system. The stiffness model of hybrid parallel robot is developed by using identified stiffness matrix of the hexapod and the tripod. The finite element analysis of the robots are investigated and compared.

2 Kinematic Mapping

The motions of the end effecter for 6 DOF base is calculated by developing the transformation matrix containing all possible rotation and translation motions as given in Equation 1.

$$T = T_r \times \left(R_\theta \times R_\emptyset \times R_\varphi\right) \tag{1}$$

Therefore, the second position of the end effecter is obtained by using the transformation matrix. The platforms are considered to be rigid bodies throughout this paper, thus all points on the platforms move along the same path motions.

Firstly, the initial positions of the center point of platform A will need to be identified, together with the linear motions in x, y and z directions, and the desired orientation with reference to the fixed position of the centre point of platform B, as given in

Transformation matrix is used, as shown in Equation 2.1.a .

$$[T] = \begin{bmatrix} c\phi c\psi & -c\phi s\psi & s\phi & 0 \\ c\Theta s\psi + c\psi s\Theta s\phi & c\Theta c\psi - s\phi s\psi & -c\phi s\Theta & 0 \\ s\Theta s\psi - c\Theta c\psi s\phi & c\psi s\Theta + c\Theta s\phi s\psi & c\Theta c\phi & 0 \\ L & M & N & 1 \end{bmatrix} \quad (2.1.a)$$

$$L = s\psi((mc\Theta + ns\Theta) + c\psi(lc\phi - s\phi(nc\Theta - ms\Theta)) \quad (2.1.b)$$

$$M = c\psi(mc\Theta + ns\Theta) - s\psi(lc - s\phi(nc\Theta - ms\Theta)) \quad (2.1.c)$$

$$N = ls\phi + c\phi(nc\Theta - ms\Theta) \quad (2.1.d)$$

Where, l, m and n are linear motions along x, y and z respectively.

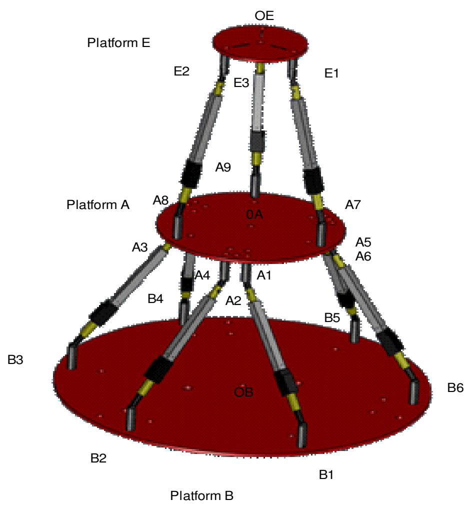

Figure 1: CAD Model for Kinematic

3 Workspace limitation analysis

The developed parametric transformation matrix is capable of illustrating all of the vector motions in space without any limitations due to the actuators and joints, as shown in Figure 1.

Based on the geometrical dimensions and maximum stroke of the actuators, the parameters are obtained as follow:

In order to define the joint limitation, the angles between the actuators and the base platform are obtained and compared with the maximum joints motion range as follows:

$$A_iB_i \cdot U_x = |A_iB_i| \times cos\ (\alpha_{Bi}) \quad i \in \{1 \dots 6\} \quad (3.a)$$

$$A_iB_i \cdot U_y = |A_iB_i| \times cos\ (\beta_{Bi}) \quad i \in \{1 \dots 6\} \quad (3.b)$$

$$B_iA_i \cdot \left(U_x \times {}_B^AT\right) = |B_iA_i| \times cos\ (\alpha_{Ai}) \quad i \in \{1 \dots 6\} \quad (3.c)$$

$$B_iA_i \cdot \left(U_y \times {}_B^AT\right) = |B_iA_i| \times cos\ (\beta_{Ai}) \quad i \in \{1 \dots 6\} \quad (3.d)$$

Where, α_{Ai} and β_{Ai} are the joints' angles with their own X-axis and Y-axis respectively. Moreover, the parameters in equation are defined as: $U_x = (1 \quad 0 \quad 0 \quad 1)$ and $U_y = (0 \quad 1 \quad 0 \quad 1)$.

However, the angles of revolute joints are obtained using equation 4.a,

$$E_jA_i \cdot \left(U_x \times {}^A_BT\right) = |A_iB_i| \times cos\ (\alpha_{Ei}) \quad i \in \{7 \dots 9\}, j \in \{1 \dots 3\} \tag{4.a}$$

$$E_jA_i \cdot \left(U_x \times {}^A_BT\right) = |A_iB_i| \times cos\ (\alpha_{Ei}) \quad i \in \{7 \dots 9\}, j \in \{1 \dots 3\} \tag{4.b}$$

Where, α_{Ej} (j=1, 2, 3) are the angles of the joints connecting to platform E after a particular motion, and u_{2X} is the xis of the revolute joints in a particular pose and orientation.

Where, B is the positions of joints on lower platform an alpha is angle between actuator and platform.

The maximum translation motion in x and y are assumed the same as that in z axis. The lengths of the actuators and their angles with respect to the base plate are calculated for each motion in order to verify the motion profile.

4 Stiffness of Hybrid Parallel Robot

In this section the stiffness of the hybrid parallel robot is investigated through the comparison of different models. The derived formulation is based on the stiffness matrix of the tripod and the hexapod. Here, all matrices are assumed invariable:

$$F = K \times U \tag{5}$$

Where, the parameters are defined as: $F = [F_x \quad F_y \quad F_z]^T$, $U = [U_x \quad U_y \quad U_z]^T$ and K is stiffness matrix.

The Stiffness of the hexapod and the tripod are derived using equations derived by equation 15. The displacement of the hybrid system is equivalent to the sum of the hexapod and the tripod displacements. In order to calculate the equation for the displacement, an inverse matrix of the system stiffness is multiplied and as a result, displacement of system is as follow:

$$U = u_H + u_T \tag{6.a}$$

$$U = {K_H}^{-1} \times F + {K_T}^{-1} \times F \tag{6.b}$$

The obtained formulae for the hexapod and the tripod are substituted in the equation 7. Therefore, the stiffness of the system is obtained as follows:

$$K^{-1} = {K_H}^{-1} + {K_T}^{-1} \tag{7}$$

4.1 FEA simulation of the models

Finite Element simulations were performed in order to analyze and compare structural stiffness of a number of different configurations of the parallel hybrid robot. Initially, the stiffness of the tripod and the hexapod are obtained separately. The material, mesh size, exerted force, and the pose are identical for all of the models in this simulation in order to compare the effect of size and joint positions in the different configurations as shown in Figures 2 and 3. The material throughout is Aluminum 7075-T6, with a force of 100N exerted to the end-effecter. The FE mesh size of 3.048mm was used.

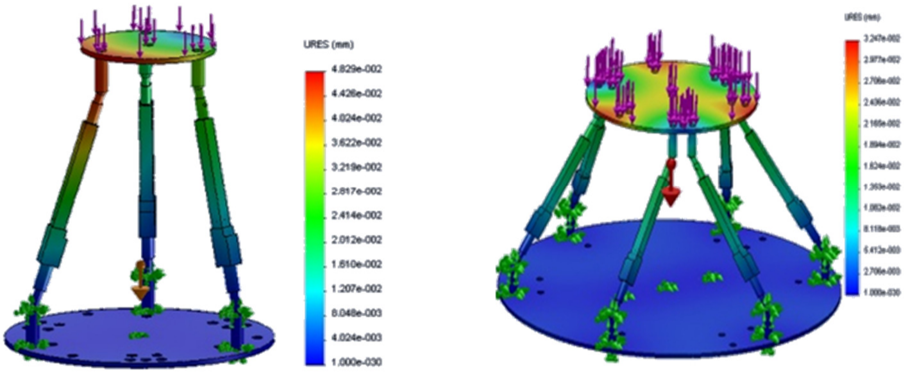

Figure 2: Tripod with D=50, 25 Cm and Tripod With D= 25-12.5cm In Left And Right Hand Side Respectively

The results show that the 3-3 configuration is stiffer than 6-3, while the actuators' displacement is reduced in the 6-3 model.

However four symmetrical configurations based on the lower joints' positions of the tripod are considered and simulated for comparison purposes. These are 6-3-N-3, 6-3-M-3 models as shown in Figures 3.

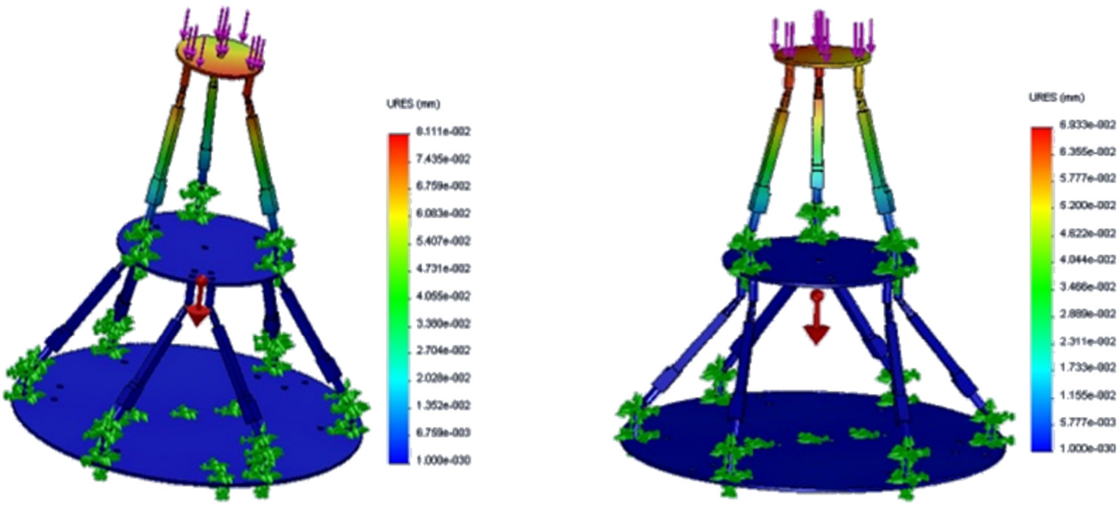

Figure 3: The 6-3-M-3 and the 6-3-N-3 Deformation FEA Analysis