Design and Evaluation of 3 Link Parallel Manipulator

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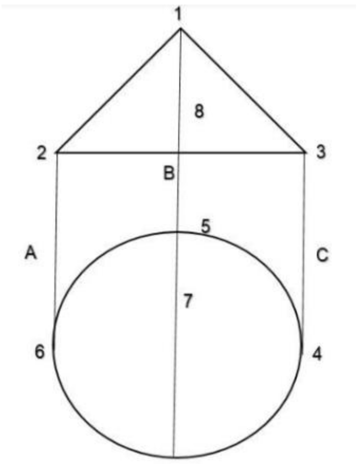
ABSTRACT:

In Industrial ergonomics a manipulator is a lift assist device used to help workers lift, maneuver and place articles in process that are too heavy, too hot, too large or otherwise too difficult for a single worker to manually handle. Manipulators are of two types, Parallel and Series manipulator. In a Parallel manipulator several links are used to control a single platform. The subject of this paper is to study Kinematic analysis and Design synthesis of a 3 link Parallel manipulator and to determine the movement of the end effector and workspace of a 3 link parallel manipulator with identical links. The designing is done using CREO and numerical analysis is done using Freudenstein approach.

KEYWORDS: Parallel manipulator, Freudenstein approach, CREO Parametric.

1.1 INTRODUCTION

Parallel Robot (Manipulator) is a mechanical system which is made up of links and joints to support a moving platform using actuators. The main aim of this paper is to design and analyze a 3 DOF parallel manipulator. In this design we focused on maximizing the work volume and minimizing the singularity. To achieve that three identical links are designed to enlarge work volume by reducing the links interference. This study analyzed the Kinematic analysis, both inverse and forward, dimensional synthesis and velocity analysis.



1 ,2,3,4,5,6 Pin Joints

A, B, C – 3 Identical Links

7 – Base Platform

8 – Top Platform

Figure 1.1 3- (PRR) Link Parallel Manipulator

Figure 1.2 Designed 3 Link Parallel Manipulator

1.2 DESIGN ANALYSIS

Parallel Manipulator has multiple kinematic chains which are formed by using links and joints that connect the Base Platform (BP) and Top Platform (TP) where one is actuated and others are passive. Three identical links are designed to enlarge work volume by reducing the links interference which is of three degrees of freedom.

The advantages of identical links are in 3 DOF parallel manipulator are,

- Identical links are easy to design and beneficial in controlling the manipulator.
- The more number of links increase the difficulty in singularity analysis and also affects the workspace of the mechanism.

1.3 MOBILITY EQUATION

The Grubler-Kutzbach mobility equation is used to calculate degrees of freedom of the mechanism.

$$DOF = 3(N - J - 1) + F_1$$

For the proposed mechanism

$N = 8$ (3 links, 3 nuts, 1BP, 1TP)

$J = 9$

$F_1 = 9$ (3 prismatic joints and 6 pin joints)

Therefore, $DOF = 3(8-9-1) + 9 = 3$ (1.1)

1.4 DIMENSIONAL SYNTHESIS

The dimensional synthesis of 3 Link parallel manipulator determines the most suitable structure that provides the maximum workspace.

The geometrical parameters of the manipulator are taken into account while doing dimensional synthesis like as the length of Link(K), radius of TP (a) and the angle ($\boldsymbol{\theta}$) between the BP(base platform) and link.

In the synthesis the distance moved by the nut is calculate by changing the angle of tilt of the top platform (TP). Freudenstein approach states that the sum of all components along x and y axis should be equal to zero in equilibrium condition.

As per Freudenstein approach

For x axis

a cos**α** + R sin**ϴ** - X = 0 (1.2)

For y axis

a sin**α** + Z = Rcos**ϴ** + C (1.3)

From (1.2)

ϴ = $\sin^{-1}$[X - a cos**α**/C] (1.4)

From (1.3)

C = a sin**α** + Z - C cos**ϴ** (1.5)

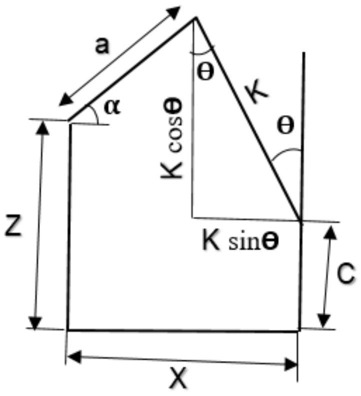


Figure1.2 Single link moment of 3 PRR Mechanism.

1.5 KINEMATIC ANALYYSIS

The Kinematic analysis used to find the range of movement of the given mechanical system. Here it determines the position velocity and acceleration of mechanical elements of the 3 DOF parallel manipulator.

Inverse Kinematics

The inverse kinematics of the manipulator uses kinematic equations to determine the joint parameters that provide a desired position for the end effectors. From the figure a - Top platform radius, A- base platform(BP) radius and C_j vertical distance in z direction j=1,2,3. The TP vertices are denoted as T_j in the top reference frame O' - x'y'z' is located at the centre of TP vertices T_1 and T_2. The BP vertices are denoted as B_j with fixed reference frame O-xyz located at the center of B_1B_2.

The length of 3 identical links is 'R'. For inverse kinematics the end effector position is considered to be known. The orientation is given by rotation matrix R_b and position by column matrix (C')R.

$$(C')R = \begin{pmatrix} x \\ y \\ z \end{pmatrix} \qquad (1.6)$$

$$R_b = \begin{pmatrix} cos\alpha & 0 & sin\alpha \\ 0 & 1 & 0 \\ -sin\alpha & 0 & sin\alpha \end{pmatrix} \qquad (1.7)$$

The coordinates of the TP are

$$T_1 = \begin{pmatrix} 0 \\ -a \\ 0 \end{pmatrix},\ T_2 = \begin{pmatrix} 0 \\ a \\ 0 \end{pmatrix},\ T_3 = \begin{pmatrix} -a \\ 0 \\ 0 \end{pmatrix} \qquad (1.8)$$

The coordinates of BP are

$$B_1 = \begin{pmatrix} 0 \\ -A \\ C1 \end{pmatrix},\ B_2 = \begin{pmatrix} 0 \\ A \\ C2 \end{pmatrix},\ B_1 = \begin{pmatrix} -A \\ 0 \\ C3 \end{pmatrix} \qquad (1.9)$$

The TP vertices in the reference frame O-xyz are written as

$$(T)_A = R_b(T)_a + (C)'_A(T)_A \qquad (1.10)$$

$$(T1)_A = \begin{pmatrix} cos\alpha & 0 & sin\alpha \\ 0 & 1 & 0 \\ -sin\alpha & 0 & sin\alpha \end{pmatrix} \begin{pmatrix} 0 \\ -a \\ 0 \end{pmatrix} + \begin{pmatrix} 0 \\ y \\ z \end{pmatrix} \qquad (1.11)$$

$$(T2)_A = \begin{pmatrix} cos\alpha & 0 & sin\alpha \\ 0 & 1 & 0 \\ -sin\alpha & 0 & sin\alpha \end{pmatrix} \begin{pmatrix} 0 \\ a \\ 0 \end{pmatrix} + \begin{pmatrix} 0 \\ y \\ z \end{pmatrix} = \begin{pmatrix} 0 \\ y+a \\ z \end{pmatrix} \qquad (1.12)$$

$$(T3)_A = \begin{pmatrix} cos\alpha & 0 & sin\alpha \\ 0 & 1 & 0 \\ -sin\alpha & 0 & sin\alpha \end{pmatrix} \begin{pmatrix} -a \\ 0 \\ 0 \end{pmatrix} + \begin{pmatrix} 0 \\ y \\ z \end{pmatrix} = \begin{pmatrix} -acos\alpha \\ y \\ asin\alpha \end{pmatrix} \qquad (1.13)$$

The above equations (1.9) to (1.13) are substituted in equation (1.14) to find the vertical distance of links in any position.

$$R = \| T_A - B_A \| \qquad (1.14)$$

The distance moved by three nuts are calculated as a function of the end effector position and orientation from equations (1.15) to (1.17)

$$C_1 = z \pm \sqrt{K^2 - y^2 - [-A - (y - a)]^2} \qquad (1.15)$$

$$C_2 = z \pm \sqrt{K^2 - y^2 - [A - (y + a)]^2} \qquad (1.16)$$

$$C_3 = (a\, sin\alpha + z) \pm \sqrt{K^2 - y^2 - [-A + (acos\alpha)]^2} \qquad (1.17)$$

Forward Kinematics

Forward kinematics refers to the use of the kinematic equations of a robot to compute the position of the end-effector from specified values for the joint parameters. For the proposed model with prismatic actuators, the inputs C_1, C_2, C_3 are given. The unknown position and orientation of the TP are described by (C)'R and the TP angleα.

From equation (1.17)

$K^2 = [- A + a\cos\alpha]^2 + y^2 + [C_3 - a\sin\alpha + z]^2$ (1.18)

By simplifying the equation

$[K^2 - y^2 - a + A^2 - z - C_3{}^2]x^2 + [4az - C_3]x + [K^2 - y^2 - a - A - z - C_3{}^2] = 0$ (1.19)

Where $x = \beta/2$, equation (1.19) leads to

$ix^2 + jx + k = 0$ (1.20)

It can be solved by

$$x = \frac{-i \pm \sqrt{j^2 - 4ik}}{2i} \quad (1.21)$$

From the above equations (1.19) to (1.21)

$\alpha = 2\ \tan^{-1} x$ (1.22)

The equation provides the angle of TP as the function of the joint angles.

1.6 VELOCITY ANALYSIS

By differentiating the inverse kinematic equations with respect to time the velocity analysis of parallel manipulator is solved.

From (1.15),(1.16),(1.17), $\dot{C}\ \dot{x}\ \dot{y}\ \dot{z}$

$(z - C_1)\dot{C}_1 = (-a+y+A)\,\dot{y} + (z - C_1)\dot{z}$ (1.23)

$(z - C_2)\dot{C}_2 = (a+y-A)\,\dot{y} + (z - C_2)\dot{z}$ (1.24)

$((a\ \sin\alpha + z) - C_3)\,\dot{C}^3 = y\ \dot{y} + (a\ \sin\alpha + z - C_3)\ \dot{z} + [Aa\ \sin\ \alpha + (z - C_3)a\cos\alpha)\dot{\alpha}$ (1.25)

The equations (1.23),(1.24),(1.25) are in the form of

$$\begin{pmatrix} z - C_1 & 0 & 0 \\ 0 & z - C_2 & 0 \\ 0 & 0 & a\ sin\alpha + z - C_3 \end{pmatrix} \begin{pmatrix} \dot{C}_1 \\ \dot{C}_2 \\ \dot{C}_3 \end{pmatrix} =$$

$$\begin{pmatrix} (-a + y + A & (z - C_1) & 0 \\ (a + y - A) & (z - C_2) & 0 \\ y & (a\ sin\alpha + z - C_3) & [Aa\ sin\alpha + (z - C_3)a\cos\alpha] \end{pmatrix} \begin{pmatrix} \dot{y} \\ \dot{z} \\ \dot{\alpha} \end{pmatrix} \quad (1.26)$$

From the above equation (1.26) we can write

$C\dot{u} = D\dot{v}$

Where

$$C = \begin{pmatrix} z - C_1 & 0 & 0 \\ 0 & z - C_2 & 0 \\ 0 & 0 & a\ sin\alpha + z - C_3 \end{pmatrix}$$

$$D = \begin{pmatrix} -a + y + A & (z - C_1) & 0 \\ (a + y - A) & (z - C_2) & 0 \\ y & (a\,sin\alpha + z - C_3) & [Aa\,sin\alpha + (z - C_3)a\cos\alpha] \end{pmatrix}$$

$$\dot{u} = \begin{bmatrix} \dot{C}_1 \\ \dot{C}_2 \\ \dot{C}_3 \end{bmatrix} \text{ And } \dot{v} = \begin{bmatrix} \dot{y} \\ \dot{z} \\ \dot{\alpha} \end{bmatrix}$$

CONCLUSION

The design synthesis, kinematic analysis, velocity analysis of a 3 link parallel manipulator is derived. From the study it is found that for shorter linear displacement is beneficial to get maximum tilt of top platform about one axis. To get the maximum compound angle the 3 link parallel manipulator is better.

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