Project on
Mechanical Design Methods in Robotics

Submitted by:

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1.Manipulator Design Specification

For the above-mentioned specifications, I analysed multiple parallel manipulator configurations. Upon multiple testing and analysis, I have chosen the **3-RRR parallel manipulator system.**

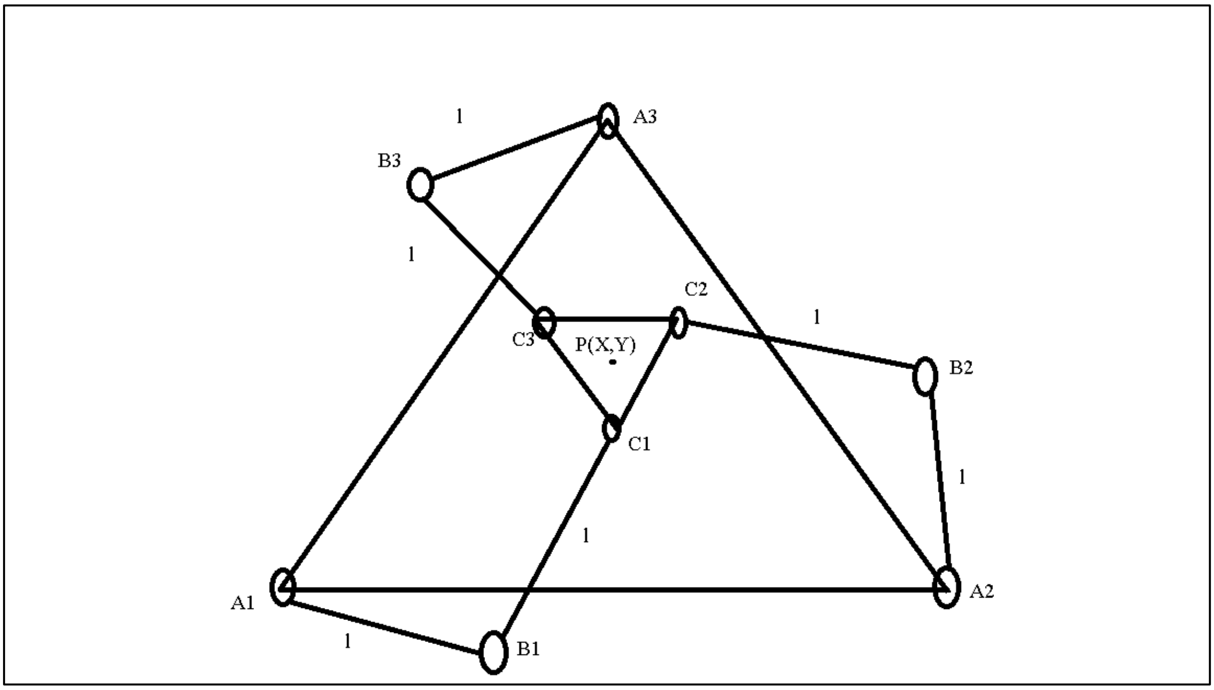

Figure 1.1: 2-D schematic of the manipulator

In the above figure, we have a fixed platform A1A2A3 in the form of an equilateral triangle. 3 RRR serial manipulators are connected to the corners of the fixed platform namely A1B1C1, A2B2C2 and A3B3C3. They connect the fixed platform with the moving platform (End-effector) C1C2C3. The cartesian position of the end-effector is depicted by point P (X,Y) which is geometrically placed at the centroid of the Moving platform.

The manipulation of the moving platform is the result of corresponding manipulation of the revolute joints of the limbs.

2.Detailed CAD Design of the Manipulator

For the CAD design of the proposed 3 RRR parallel manipulator, I have used the ***CATIA V5 2013*** tool for the corresponding design and assembly. The following figure shows the fixed platform for the manipulator mounting.

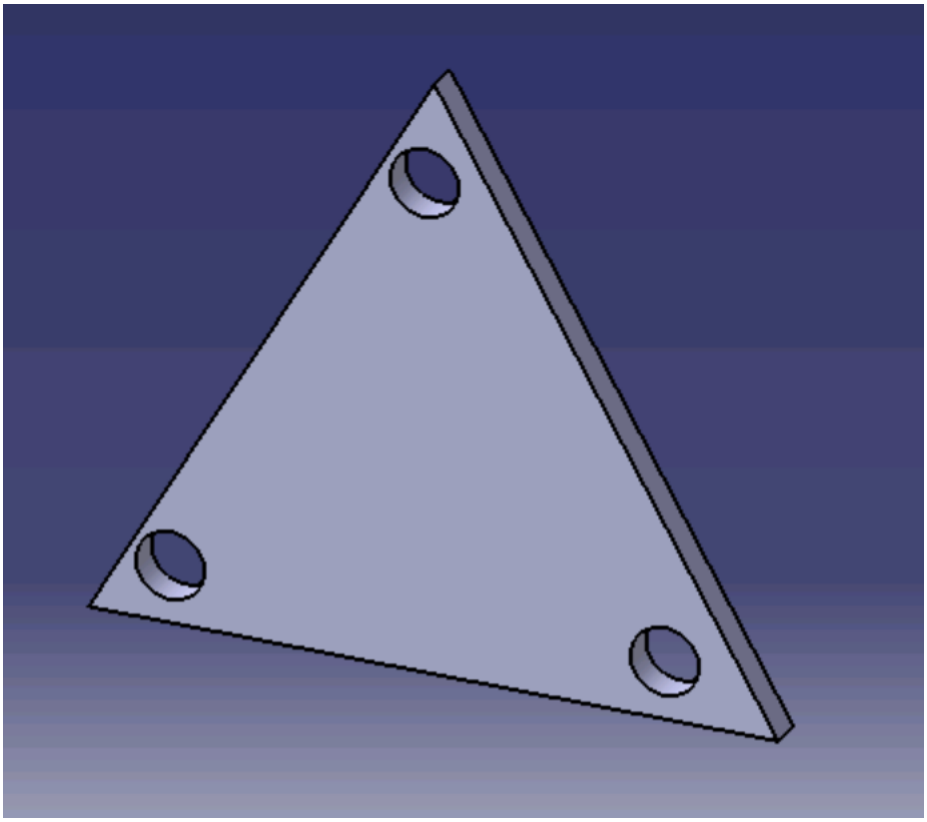

Figure 2.1: Fixed platform

To replicate the first revolute joint R1, a revolute hinge has been created as shown in the figure.

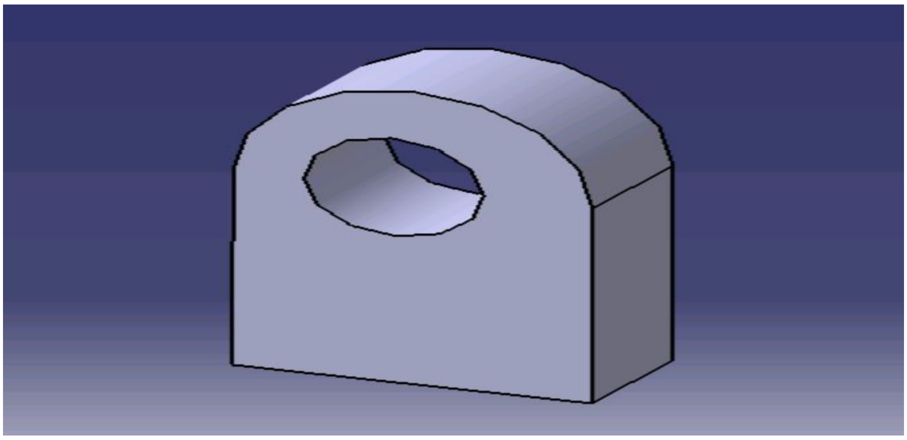

Figure 2.2: R1 hinge

The arms used for the end-effector actuation consist of 2 limbs connected by the second revolute joint R2. The part of the limb actuation system is as shown in the figure.

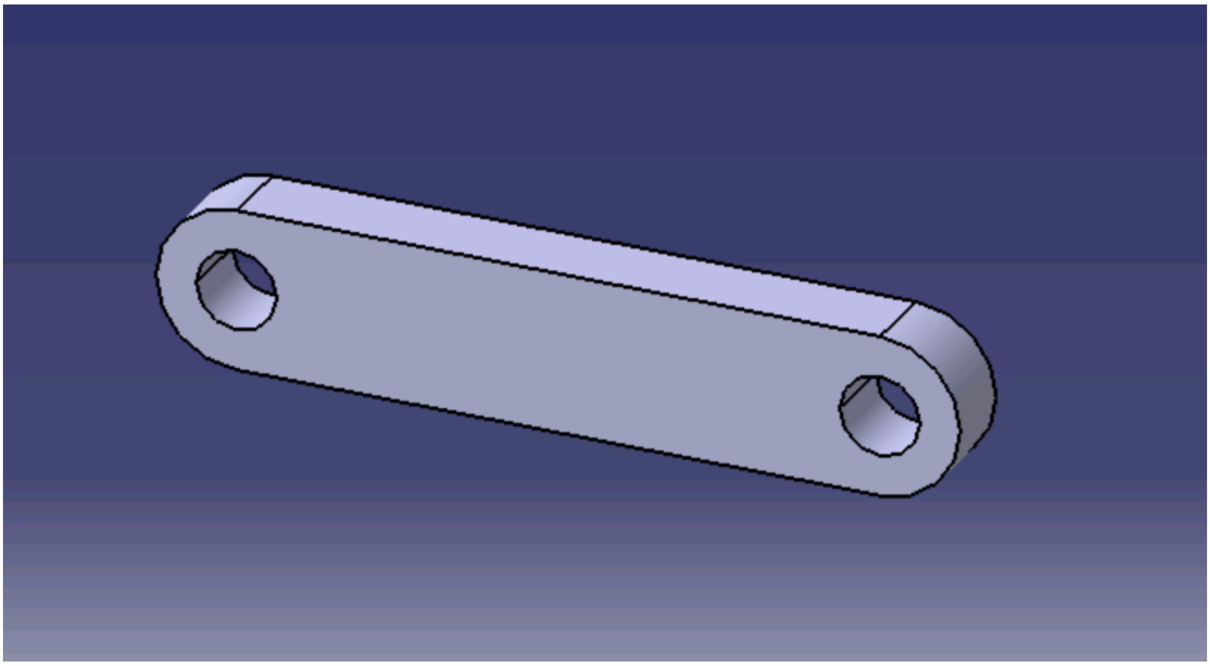

Figure 2.3: Manipulator limb

The following figure shows one of the three actuating arm system.

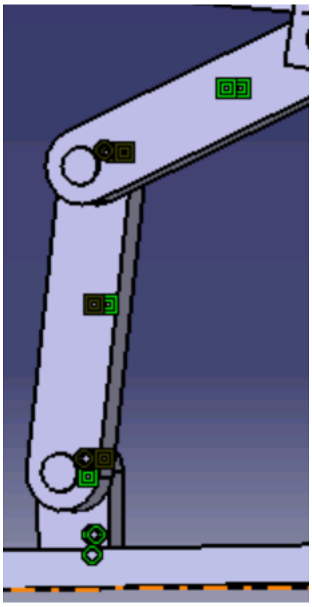

Figure 2.4: Serial actuator system

The actuation system is connected to the end-effector (moving platform) by the third revolute joint which is replicated by another hinge as shown in the following figure.

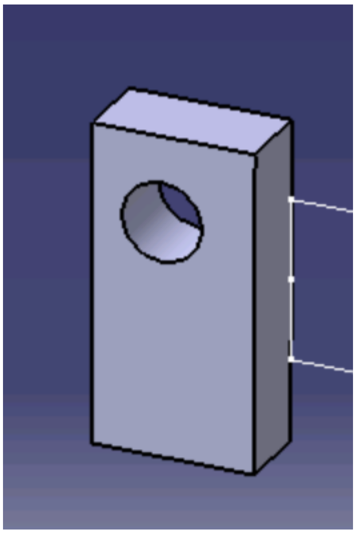

Figure 2.5: R3 hinge

The above shown hinge connects the moving platform with the actuation system thus completing the manipulator assembly.

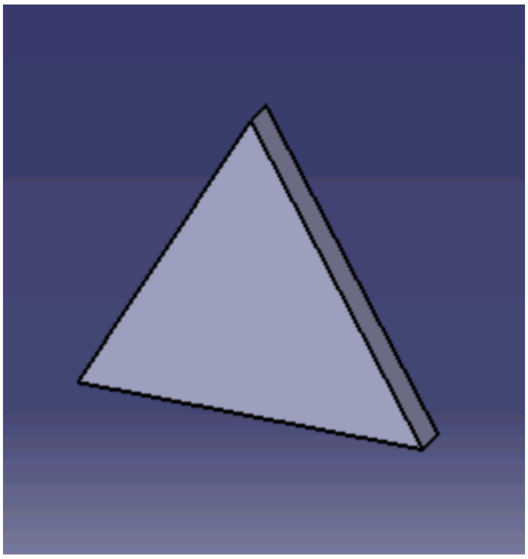

Figure 2.6: Moving platform (End-effector)

The following figure depicts the completed assembly of the 3 RRR parallel manipulator.

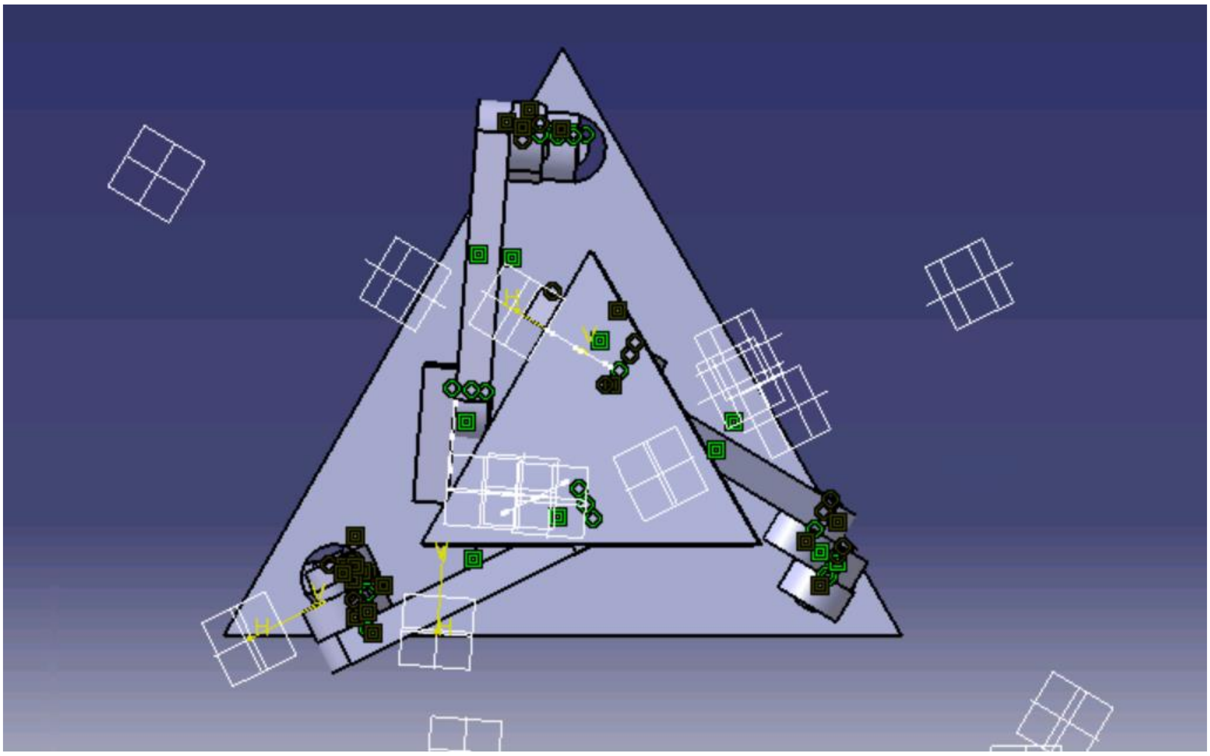

Figure 2.7: Top view of the manipulator

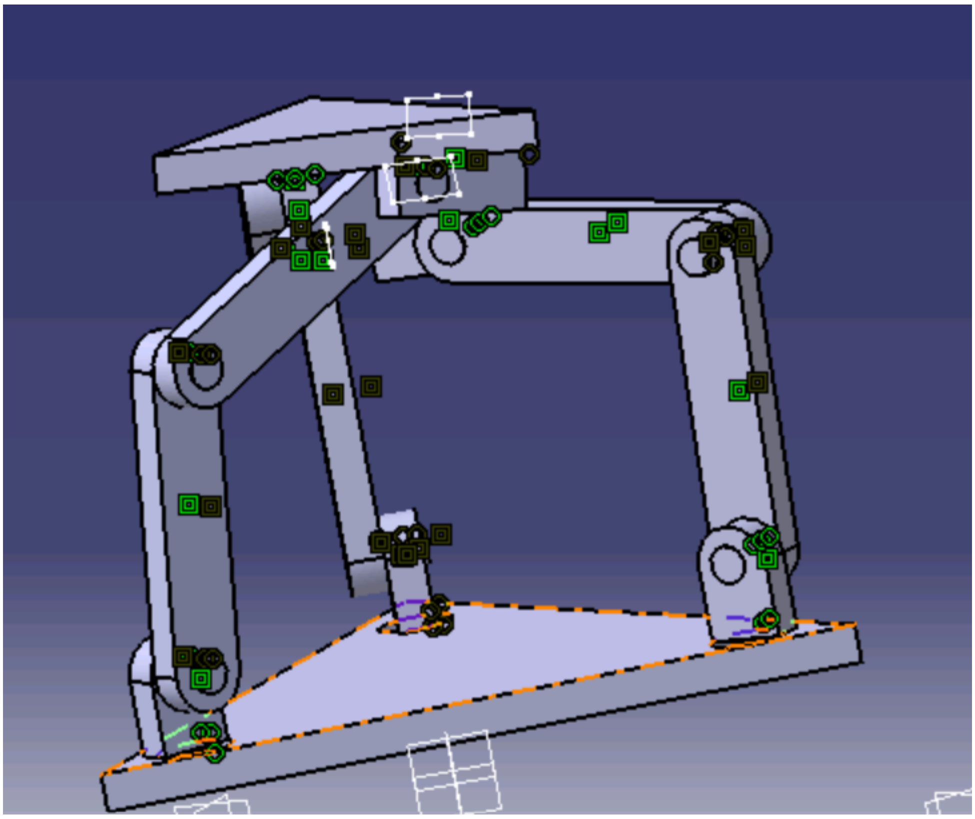

Figure 2.8: Isometric view of the manipulator

I have selected Aluminium as the material for the manipulator. The following figure depicts the manipulator with the corresponding material finish.

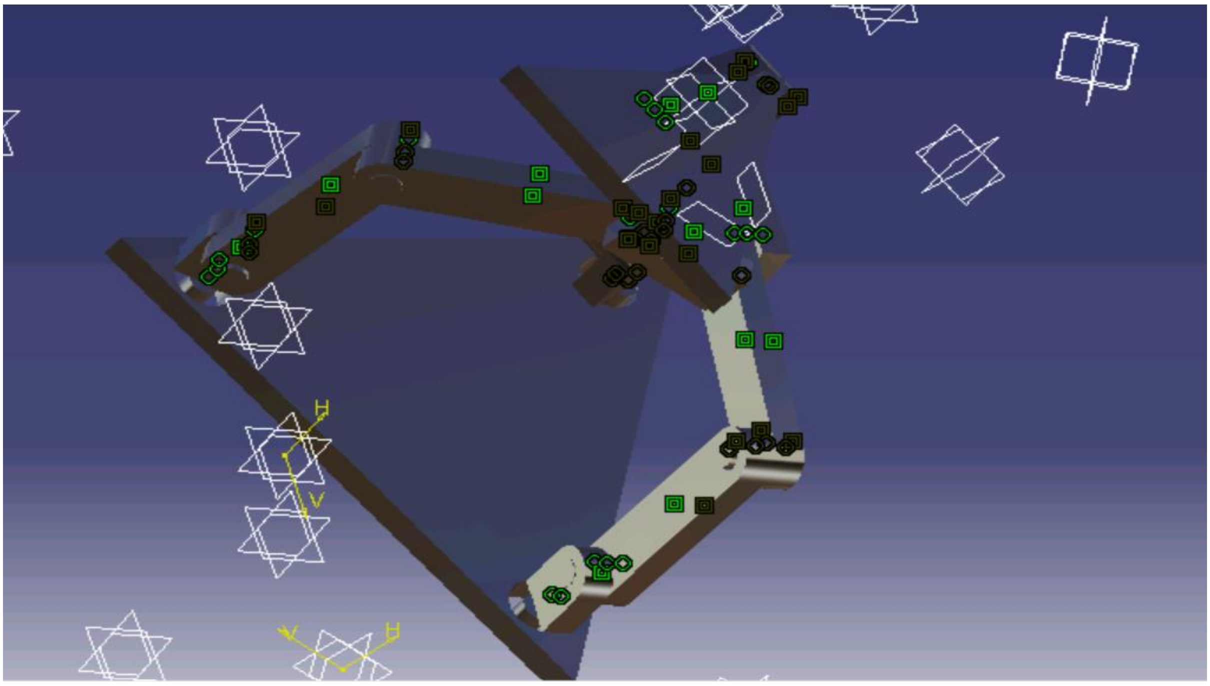

Figure 2.9: Manipulator with the material finish

3.Kinematic Analysis

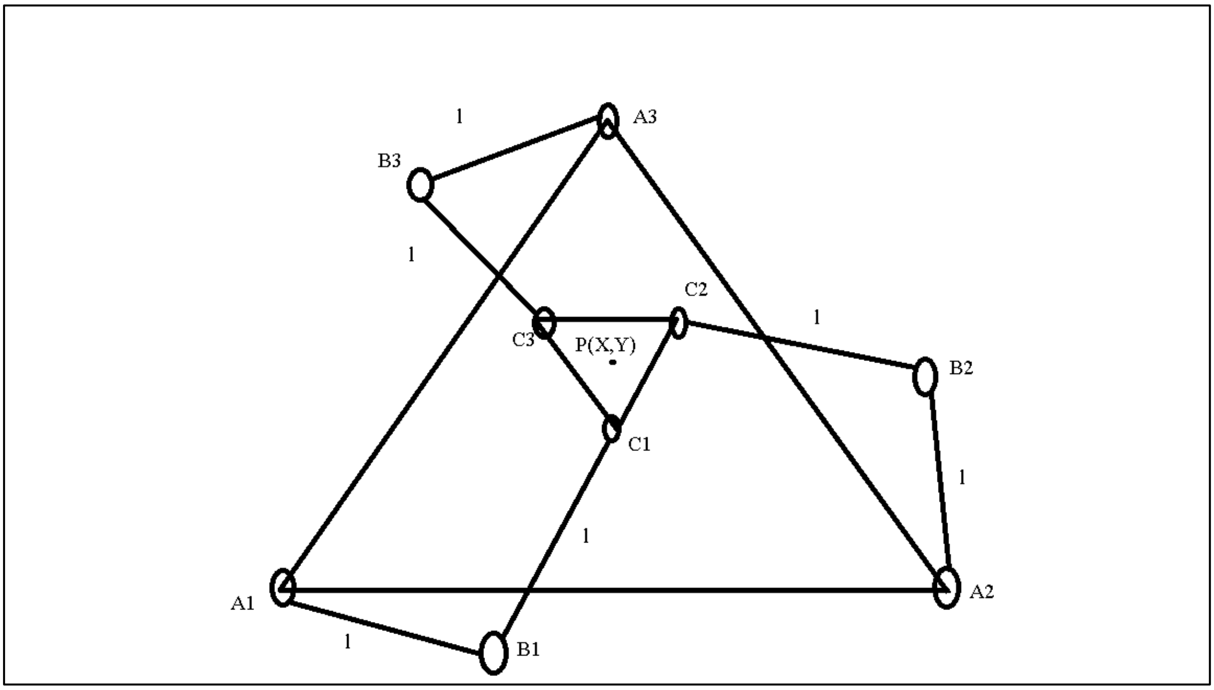

Figure 3.1: 2-D schematic of the manipulator under analysis

The relationship between the cartesian locations of the joint and the end-effector can be mathematically summarised with the Straight-line equation between 2 points.

$$(Xf-Xi)^2+(Yf-Yi)^2 = r^2$$

Here,

(Xf,Yf) : Final cartesian coordinates

(Xi,Yi) : Initial cartesian coordinates

r : Distance between the 2 points

By applying the above solution to the existing manipulator system, we get,

$$(Cix - Bix)^2 + (Ciy - Biy)^2 = l^2$$

i = 1,2,3

Constraints:

Magnitude of $C_1C_2 = C_2C_3 = C_3C_1 = r$

Loop Closure equation:

We consider O as the origin for the manipulator space.

$$OP = OA_i + A_iB_i + B_iC_i + C_iP$$

By converting the above equation onto the vector form, we get,

$$\vec{P} = R\vec{h}_i + l\vec{u}_i + r\vec{w}_i$$

By differentiating the above equation with respect to time we get,

$$\dot{\vec{P}} = \vec{O}_2 + l\vec{u}_i\dot{\alpha}_i\vec{E} + l\vec{v}_i(\dot{\alpha}_i + \dot{\beta}_i)\vec{E} + r\vec{w}_i(\dot{\alpha}_i + \dot{\beta}_i + \dot{\gamma}_i)\vec{E}$$

$$\text{Consider, } \dot{\varphi} = \dot{\alpha}_i + \dot{\beta}_i + \dot{\gamma}_i$$

Multiplying both sides of the equation with $\vec{v}_i^{\,T}$

$$\vec{v}_i^{\,T}\dot{\vec{P}} = l\vec{u}_i\dot{\alpha}_i\vec{v}_i^{\,T}\overrightarrow{E} + l\vec{v}_i\vec{v}_i^{\,T}(\dot{\alpha}_i + \dot{\beta}_i)\vec{E} + r\vec{w}_i\vec{v}_i^{\,T}\dot{\varphi}\,\vec{E}$$

By converting the above equation onto matrix form, we get,

$$\begin{matrix} \vec{v}_1^{\,T} & -\vec{v}_1^{\,T} r\vec{w}_1\overrightarrow{E} \\ \vec{v}_2^{\,T} & -\vec{v}_2^{\,T} r\vec{w}_2\overrightarrow{E} \\ \vec{v}_3^{\,T} & -\vec{v}_3^{\,T} r\vec{w}_3\overrightarrow{E} \end{matrix} \;\text{x}\; \begin{matrix} \dot{\vec{P}} \\ \dot{\varphi} \end{matrix} = \begin{matrix} l\vec{w}_1\vec{v}_1^{\,T}\vec{E} & 0 & 0 \\ 0 & l\vec{w}_2\vec{v}_2^{\,T}\vec{E} & 0 \\ 0 & 0 & l\vec{w}_3\vec{v}_3^{\,T}\vec{E} \end{matrix} \;\text{x}\; \begin{matrix} \dot{\alpha}_1 \\ \dot{\alpha}_2 \\ \dot{\alpha}_3 \end{matrix}$$

$$\text{Forward Jacobian Matrix, A} = \begin{matrix} \vec{v}_1^{\,T} & -\vec{v}_1^{\,T} r\vec{w}_1\overrightarrow{E} \\ \vec{v}_2^{\,T} & -\vec{v}_2^{\,T} r\vec{w}_2\overrightarrow{E} \\ \vec{v}_3^{\,T} & -\vec{v}_3^{\,T} r\vec{w}_3\overrightarrow{E} \end{matrix}$$

$$\text{Inverse Jacobian Matrix, B} = \begin{matrix} l\vec{w}_1\vec{v}_1^{\,T}\vec{E} & 0 & 0 \\ 0 & l\vec{w}_2\vec{v}_2^{\,T}\vec{E} & 0 \\ 0 & 0 & l\vec{w}_3\vec{v}_3^{\,T}\vec{E} \end{matrix}$$

Upon further calculations, it is found that the inverse conditioning numbers for both the Forward and Inverse Jacobian matrices are greater than 0.1 throughout the workspace.

4.Singularity Analysis

4.1 Parallel Singularity check:

A manipulator has parallel singularity if Determinant of the forward Jacobian matrix A is 0.

Here, Forward Jacobian Matrix, A = $\begin{matrix} \vec{v}_1{}^T & -\vec{v}_1{}^T r\vec{w}_1\overrightarrow{E} \\ \vec{v}_2{}^T & -\vec{v}_2{}^T r\vec{w}_2\overrightarrow{E} \\ \vec{v}_3{}^T & -\vec{v}_3{}^T r\vec{w}_3\overrightarrow{E} \end{matrix}$

In this case, the determinant of the matrix is 0 if $\vec{v}_i$ is parallel to $\vec{w}_i$ or $\vec{v}_1, \vec{v}_2$ and $\vec{v}_3$ are parallel to each other, thus stating the corresponding Parallel singularity condition.

4.2 Serial Singularity check:

A manipulator has serial singularity if Determinant of the inverse Jacobian matrix B is 0.

Here, Inverse Jacobian Matrix, B = $\begin{matrix} l\vec{w}_1\vec{v}_1{}^T\vec{E} & 0 & 0 \\ 0 & l\vec{w}_2\vec{v}_2{}^T\vec{E} & 0 \\ 0 & 0 & l\vec{w}_3\vec{v}_3{}^T\vec{E} \end{matrix}$

In this case, the determinant of the matrix is 0 if either of $\vec{u}_i$ (i.e., $\vec{u}_1$ or $\vec{u}_2$ or $\vec{u}_3$) is parallel to $\vec{v}_i$, thus stating the corresponding Serial singularity condition.

References

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2. Patel, Ketankumar & Nayakpara, Vinit & Patel, Yogin & Patel, Yashavant. (2013). Workspace and singularity analysis of 3-RRR planar parallel manipulator.
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4. Pickard, Joshua & Carretero, Juan. (2015). Design Optimisation of the 3-RRR Planar Parallel Manipulator via Wrench Capability Analysis.