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Topological Characteristic Analysis of 4-RUUMulti-operation ModeParallel Mechanism Based on Position and Orientation Characteristic Set

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Abstract: The topological structure of the mechanism is characterized by the inherent topological invariant, which reflects the structure, kinematics and dynamics of the mechanism. Based on the theoryof position and orientation characteristic (POC) method, the topology structure character of the three operation modes of the 4-RUU PM are analyzed. According to the singularity of the 4-RUUPM, it is showingthat the mechanism's topological structure and its corresponding DOF can be changed in the process ofmovement bytransition throughthe singular positions of the mechanism.

Keywords: PM；4-RUU；POC method；Topological characteristic analysis

I. INTRODUCTION

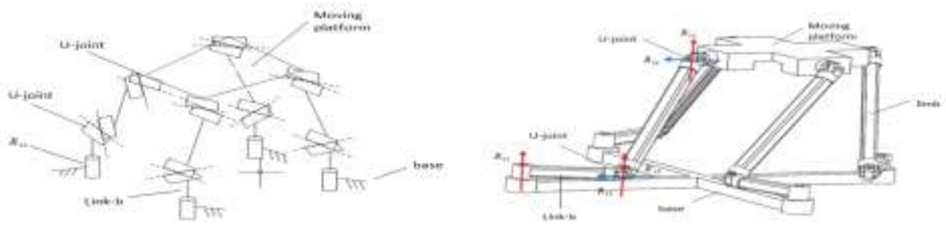
The PM has been widely concerned and studied for thereasons that it has the characteristics of simple structure, high rigidity, high bearing capacity, high positioning accuracy and easy to control compared with serial structure, and it is widely used in the field of motion simulator, industrial robots, medical devices,micro- and nano-manipulator [1]. In the process of work, the configuration and DOF of the kinematic pair axis are fixed, which can't meet the special needs of the multi-function and multi-task. As a result of the existence of the singular position of multi-operation mode PM in the position space, there are many kinds of operation modes, and the different operation modes can also be converted to the other. So the PM with multi-operation mode can meet the above requirements. In this paper, we mainly study about the 4-RUU PM.

4-RUU is an over-constrained PM,it has beenproventhat 4-RUU mechanism has three operation modes with Study's kinematic mapping of the Euclidean group se(3) dual quaternion method by LatifahNurahmi, Stéphane Caro etc[3], and the singularity conditionsof the mechanism is analyzedwith Jacobian matrix[6]. The singularity conditions of the 4-RUU mechanism are analyzed with Grassmann-Cayley algebra by Semaan Amine, Mehdi Tale Masouleh, St´ ephane Caro[4]. In this paper, the characteristics of 4-RUU PM are analyzed based on the POC method[2], and the DOF, independent displacement equation and POC set of 4-RUU PM are solved respectively. Threeoperation modes are analyzed[5]. Three transition configurations modes of three operation modes are given.

II. 4-RUU MANIPULATOR ARCHITECTURE

2.1 4-RUU Architecture

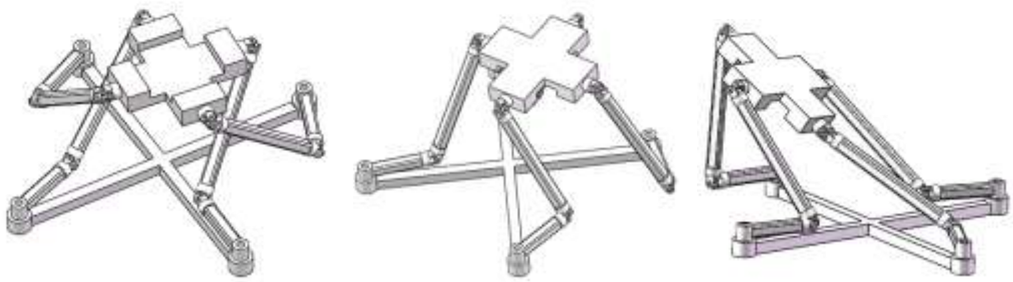
The 4-RUU PM is shown in Figure.1, the mechanism sketch of the 4-RUU PM is shown in Figure.1.a, 3d model is shown in Figure.1.b, which is composed of a moving platform, a base and four identical branches. Each branch is composed of five R-joints such that the second and the third, as well as the fourth and the fifth, are built with intersecting and perpendicular axes. Thus they are assimilated toU-joint.The R-joint axis are denoted by R_{ij} (i=1,…4,j=1,…5),***i*** represents theithbranch, and ***j***represents thejth R-joint of the ithbranch, $R_{i1} // R_{i3}$, $R_{i2} // R_{i4}$.



2.2 Three operation modes of 4-RUU

Three operation modes as shown in Figure 2, the first and second kind of operation mode,the moving platform is parallel to base, the moving platformshave four DOF and can realize three-dimensional transition motion and rotation around the axis of the platform in the vertical direction, but the two operation modes of the corresponding moving platform flip 180 degrees. The third operation mode, the moving platform has only two DOF and the moving platform is no longer parallel to the base, only two dimensional rotations can be realized.Without consideringassembly transition, the first and third operation modes, the second and third operation modes can be converted by singular positions. Three operation modes of 4-RUU areshown in Figure 2.

Mode 1 Mode 2 Mode 3



III. ANALYSIS OF 4-RUU TOPOLOGICAL CHARACTERISTICS

3.1The POC set of the first operation mode of 4-RUU

1) The topological structure of the PM limb

$$SOC\left\{-R_{i1} // \overbrace{R_{i2}^{U} \perp R_{i3}^{U}} // \overbrace{R_{i4}^{U} \perp R_{i5}^{U}}\right\} (i=1\sim 4)$$

2) Selectingthe center of the moving platform for O 'point

3) The POC sets of each branch end

$$\mathrm{MS}=\begin{bmatrix} t^1(\perp(R_{i1},\rho_{I1})) \\ r^1(//\ \mathrm{R}_{i1}) \end{bmatrix} \cup \begin{bmatrix} t^2(\perp \rho_{i2}) \\ r^2(//\ \diamond(\mathrm{R}_{i2},\mathrm{R}_{i3})) \end{bmatrix} \cup \begin{bmatrix} t^2(\perp \rho_{i4}) \\ r^2(//\ \diamond(\mathrm{R}_{i4},\mathrm{R}_{i5})) \end{bmatrix}$$

$$=\begin{bmatrix} t^3 \\ r^2(//\ \diamond(\mathrm{R}_{i2},\mathrm{R}_{i3})) \end{bmatrix}$$

4) The number of independent displacement equation ξ_{L1}

$$\xi_{L1} = \dim.\{M_{b1} \cup M_{b2}\} = \dim.\left\{\begin{bmatrix} t^3 \\ r^2(// \diamond(\mathrm{R}_{12}, \mathrm{R}_{13})) \end{bmatrix} \cup \begin{bmatrix} t^3 \\ r^2(// \diamond(\mathrm{R}_{22}, \mathrm{R}_{23})) \end{bmatrix}\right\}$$

$$= \dim.\left\{\begin{bmatrix} t^3 \\ r^3 \end{bmatrix}\right\} = 6$$

5) The DOF of the sub PM composed of the first and second branch

$$\mathrm{F}_{(1\text{-}2)} = \sum_{i=1}^{6} f_i - \sum_{j=1}^{1} \xi_{Li} = 10 - 6 = 4$$

6) The POC set of the sub PM composed of the first and second branch

$$\mathrm{M}_{\mathrm{P}a(1-2)} = M_{b1} \cap M_{b2} = \begin{bmatrix} t^3 \\ r^2(// \diamond(\mathrm{R}_{12}, \mathrm{R}_{13})) \end{bmatrix} \cap \begin{bmatrix} t^3 \\ r^2(// \diamond(\mathrm{R}_{22}, \mathrm{R}_{23})) \end{bmatrix}$$

$$\begin{bmatrix} t^3 \\ r^1(// (\diamond(\mathrm{R}_{12}, \mathrm{R}_{13}) \cap (\diamond(\mathrm{R}_{22}, \mathrm{R}_{23})) \end{bmatrix}$$

7) The number of independent displacement equations ξ_{L2}

$$\xi_{L2} = \dim.\{M_{Pa(1-2)} \cup M_{b3}\}$$

$$= \dim\left\{\begin{bmatrix} t^3 \\ r^1(// (\diamond(\mathrm{R}_{12}, \mathrm{R}_{13}) \cap (\mathrm{R}_{22}, \mathrm{R}_{23})) \end{bmatrix} \cup \begin{bmatrix} t^3 \\ r^2(// \diamond(\mathrm{R}_{32}, \mathrm{R}_{33})) \end{bmatrix}\right\}$$

$$= \dim.\left\{\begin{bmatrix} t^3 \\ r^2(// \diamond(\mathrm{R}_{32}, \mathrm{R}_{33})) \end{bmatrix}\right\} = 5$$

8) The DOF of the sub PM composed of the first three branches

$$\mathrm{F}_{(1\text{-}2\text{-}3)} = \sum_{i=1}^{9} f_i - \sum_{j=1}^{2} \xi_{Li} = 15 - 11 = 4$$

9) The POC set of the sub PM composed of the first three branches

$$\mathrm{M}_{\mathrm{P}a(1-2-3)} = M_{\mathrm{P}a(1-2)} \cap M_{b3} = \begin{bmatrix} t^3 \\ r^1(// (\diamond(\mathrm{R}_{12}, \mathrm{R}_{13}) \cap (\mathrm{R}_{22}, \mathrm{R}_{23})) \end{bmatrix} \cap \begin{bmatrix} t^3 \\ r^2(// \diamond(\mathrm{R}_{22}, \mathrm{R}_{23})) \end{bmatrix}$$

$$= \begin{bmatrix} t^3 \\ r^1(// (\diamond(\mathrm{R}_{12}, \mathrm{R}_{13}) \cap (\mathrm{R}_{22}, \mathrm{R}_{23})) \end{bmatrix}$$

10) The number of independent displacement equations ξ_{L3}

$$\xi_{L3} = \dim.\{M_{Pa(1-2-3)} \cup M_{b4}\}$$
$$= \dim\left\{\begin{bmatrix} t^3 \\ r^1(//\ (\Diamond(\mathrm{R}_{12},\mathrm{R}_{13}) \cap (\mathrm{R}_{22},\mathrm{R}_{23})) \end{bmatrix} \cup \begin{bmatrix} t^3 \\ r^2(//\ \Diamond(\mathrm{R}_{32},\mathrm{R}_{33})) \end{bmatrix}\right\}$$
$$= \dim.\left\{\begin{bmatrix} t^3 \\ r^2 \end{bmatrix}\right\} = 5$$

11) The DOF of 4-RUU PM

$$\mathrm{F} = \sum_{i=1}^{20} f_i - \sum_{j=1}^{3} \xi_{Li} = 20 - 6 - 5 - 5 = 4$$

12) The POC set of the 4-RUU PM

$$\mathrm{M_{pa}} = \sum_{i=1}^{4} \begin{bmatrix} t^3 \\ r^2(//\ \Diamond(\mathrm{R}_{i2},\mathrm{R}_{i3})) \end{bmatrix} = \begin{bmatrix} t^3 \\ r^1(//\ R_{11}) \end{bmatrix}$$

3.2 The POC set of the second operation mode of 4-RUU

The solving process of the second modes of operation is the same with the first operation mode, and the output result is the same

$$\mathrm{M_{pa}} = \sum_{i=1}^{4} \begin{bmatrix} t^3 \\ r^2(//\ \Diamond(\mathrm{R}_{i2},\mathrm{R}_{i3})) \end{bmatrix} = \begin{bmatrix} t^3 \\ r^1(//\ Z) \end{bmatrix}$$

3.3 The POC set of the third operation mode of 4-RUU

Using the same mothed, we obtain the DOF and POC setof the third operation mode of 4-RUU.In the third operation model the three-dimensional translation is Non independent elements.

1) The DOF of 4-RUU PM

$$\mathrm{F} = \sum_{i=1}^{20} f_i - \sum_{j=1}^{3} \xi_{Li} = 20 - 6 - 6 - 6 = 2$$

2) The POC set of the 4-RUU PM

$$\mathrm{M_{pa}} = M_{pa(1-2-3)} \cap M_{b4} = \begin{bmatrix} t^3 \\ r^2 \end{bmatrix} \cap \begin{bmatrix} t^3 \\ r^3 \end{bmatrix} = \begin{bmatrix} (t^3) \\ r^2 \end{bmatrix}$$

3.4 Thetransition configurations of three operation modes

There exist common configurationswhere the 4-RUU PMcan switch fromone operationmode to another operationmode. These configurations are well known as transition configurations.The geometrical conditions of switchingfirst operation mode to third operating modes fulfill the condition $b_1 // b_3$,$b_2 // b_4$,$l_1 // l_3$,$l_2 // l_4$; second operation mode converted to third operation modes is b_1, b_2, b_3, $b_4$pointing to the center of the base platform at the same time;to switch from the first operation mode to the second operation mode cannot be done directly, which must through the third operation mode for excessive, which is shown in Figure 3.

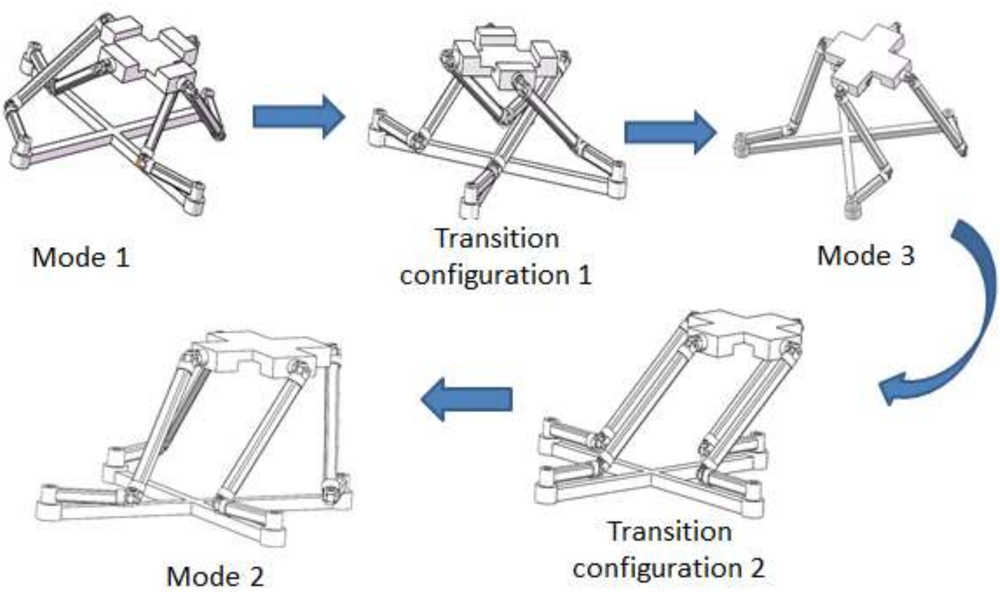


Figure 3 Transition from model to mode2

IV. CONCLUSION

In this paper, the characteristics of the 4-RUU PM are analyzed by using the POC method, and the DOF, independent displacement equation and POC set of the 4-RUU PM are studied respectively. Three operation modes of 4-RUU PM are analyzed. It is shown that the singular position of the mechanism can change the structure of the mechanism and the corresponding DOF in the motion process. It issignificant for multi-operation mode PMto meet the special needs of the multi-functions and multi-tasks, using the configuration and the freedom degree of the kinematic pair in the working process.

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