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Design of an active reconfigurable 2R joint

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Abstract. The increasing flexibility requirements in the manufacturing processes has led to the development of novel reconfigurable mechanisms to be implemented in machine heads and tables. This is the case of the reconfigurable parallel manipulators which are also used in a wide variety of applications. These mechanisms include often in their kinematic chains active or reconfigurable joints. In this paper, a 2R active reconfigurable joint is presented. As well as carrying out the kinematic characterization of the joint, a demonstrative prototype has been also built.

Keywords: parallel manipulator, active joint, reconfigurable, kinematics.

1 Introduction

When developing a parallel manipulator with the reconfiguration ability, different strategies can be used to fulfill the adaptability requirements [1]. One of the approaches used is varying the dimensions or the configuration of the base platform or end-effector platform [2]. In other cases, the reconfigurability is achieved by blocking actuators or joints. In [3] passive lockable revolute joints are implemented in order to operate in the six-dimensional space avoiding the singularities. In [4] is presented a reconfigurable parallel mechanism for pick and place operations that can provide pure translation motion and pure rotation motion patterns. It implements lockable universal joints in the 3-CPU kinematic structure. In [5] the proposed parallel manipulator changes its degrees of freedom by using selective actuation. Depending on the actuation, spherical, translational or hybrid motion types can be obtained. Also, the robot provides spatial motion when it is fully actuated. Another strategy is to use joints able to change the orientation of their axes. In [6] a novel joint, called Hook (rT) joint, is presented. A manipulator, based on reconfigurable revolute joints (rR), which has two possible motion modes, is proposed in [7]. Finally, another possible way to obtain reconfigurability is to develop special joint designs, which can change the motion type. As an example, in [8] variable joints, which combine rotation and translation (RP-joints) are described.

In this paper, the authors present a 2R active reconfigurable kinematic joint designed to be implemented in future designs of reconfigurable parallel manipulators. In Section 2 the proposed design is described and in Section 3 the kinematics of the joint are studied in deep. Finally, the developed joint prototype and the future works is presented.

2 Design description

The joint proposed in this paper (see Fig. 1) consists of a central ball with two perpendicular slots crossing the sphere. The red cranks (in red) define one of the rotations. The blue cranks actuate an intermediate link to control the second rotational degree of freedom (see Fig. 2). Although only one input crank is needed to control each degree of freedom, in order to balance the loads in the mechanism two symmetrically opposed cranks have been used. In the case of the red ones, the same input command can be used for the two actuators. However, for the blue ones the two motors will be actuated in a synchronized way following the relationship obtained in Section 3.3 of this paper. Also, the redundancy of the blue cranks is needed in order to avoid the two singularities detailed in Section 3.4.

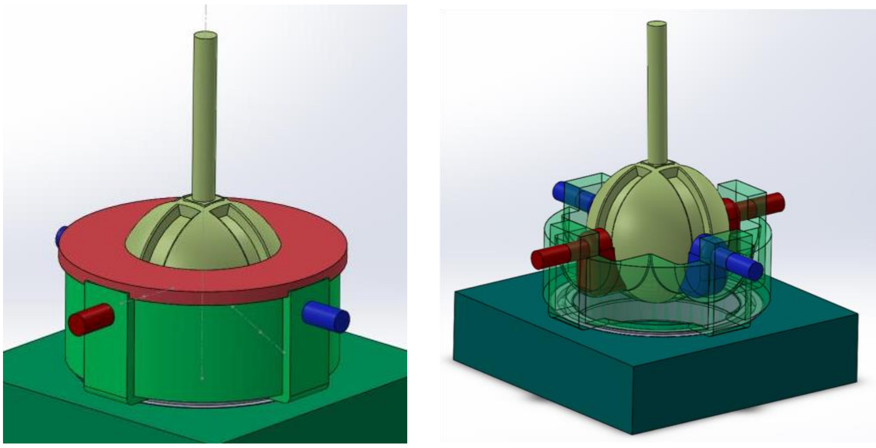

Fig. 1. The active reconfigurable 2R joint.

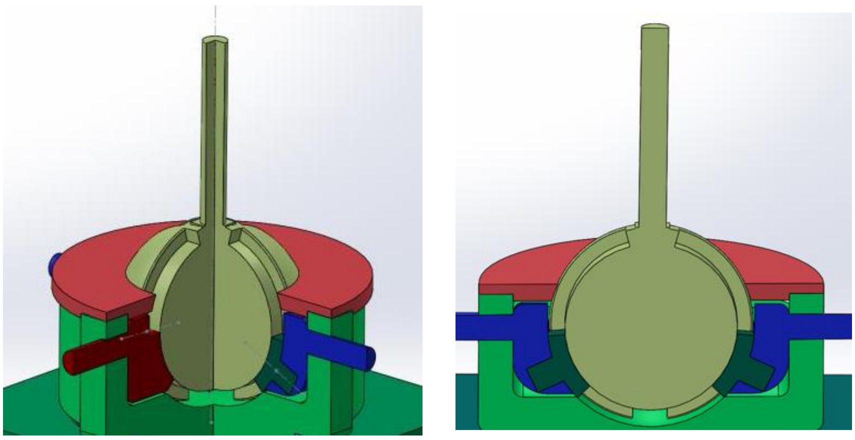

Fig. 2. Section of the joint.

Kinematically, the proposed joint corresponds to a spherical five bar linkage [9]. The design proposed in this paper, tries to increase the load carrying capacity of the joint compared to those based on a classic linkage. Thus, the contact area between the central ball and the base part allows a good distribution of the load.

The proposed joint can be simultaneously actuated in order to actively control the two rotational degrees of freedom. Additionally, the red cranks can be blocked in any angles becoming a reconfigurable revolute joint.

3 Kinematic analysis of the joint

3.1 Direct position problem

Consider a joint with a central ball of radius R being the input angles α for the red crank and β for the blue crank. The red crank defines directly the orientation of the red plane (see Fig. 3) being $\boldsymbol{n}_\alpha$ its normal vector,

$$\boldsymbol{n}_\alpha = \begin{Bmatrix} 0 \\ -\cos\alpha \\ \sin\alpha \end{Bmatrix} \tag{1}$$

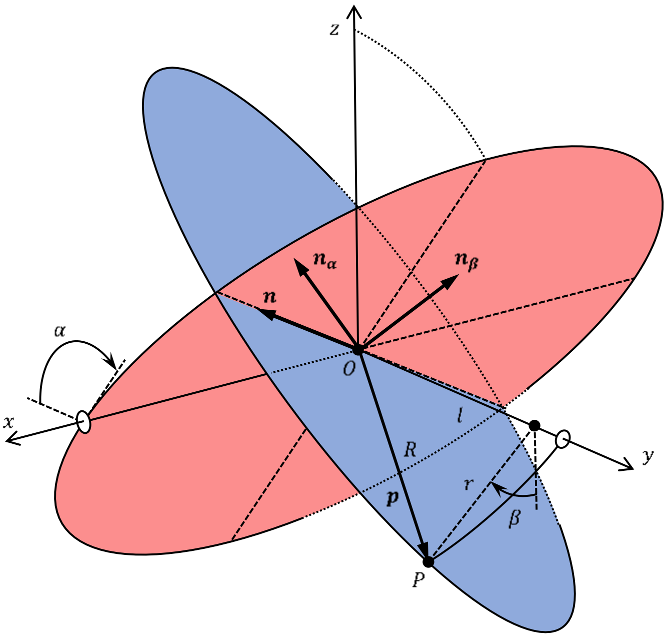

Fig. 3. Position parameters of the joint.

The blue plane is perpendicular to the red one and contains point P that defines the location of the revolute joint connecting the blue crank to the intermediate link. The position vector of point P is,

$$\boldsymbol{p} = \begin{Bmatrix} r\sin\beta \\ l \\ -r\cos\beta \end{Bmatrix} \tag{2}$$

Being r the length of the crank and $l = \sqrt{R^2 - r^2}$. So, the normal vector of the blue plane, $\boldsymbol{n}_\beta$, can is obtained as,

$$\boldsymbol{n}_\beta = \boldsymbol{n}_\alpha \times \boldsymbol{p} = \begin{Bmatrix} r\cos\alpha\cos\beta - l\sin\alpha \\ r\sin\alpha\sin\beta \\ r\cos\alpha\sin\beta \end{Bmatrix} \tag{3}$$

Finally, the vector $\boldsymbol{n}$ that defines the orientation of the joint's axis is,

$$\boldsymbol{n} = \boldsymbol{n}_\alpha \times \boldsymbol{n}_\beta \tag{4}$$

Which normalized has the form,

$$\boldsymbol{n} = \begin{Bmatrix} \frac{-r\sin\beta}{\cos\alpha(r\cos\alpha\cos\beta - l\sin\alpha)} \\ \tan\alpha \\ 1 \end{Bmatrix} \tag{5}$$

3.2 Inverse position problem

In this case, the components of vector $\boldsymbol{n} = (u \quad v \quad 1)^T$ are known. Thus, the possible values for the red input, can be directly calculated as,

$$\alpha = \tan^{-1} v \tag{6}$$

To obtain the values for the blue input, the following equation has to be solved,

$$(ur\cos^2\alpha)\cos\beta + r\sin\beta = ul\sin\alpha \tag{7}$$

By making the following change of variable,

$$\tan\varphi = u\cos^2\alpha \tag{8}$$

the solution for the blue input is obtained,

$$\beta = -u\cos^2\alpha + \cos^{-1}\left(\frac{\text{ul}\sin\alpha\cos(u\cos^2\alpha)}{r}\right) \tag{9}$$

3.3 Relationship between the inputs $\boldsymbol{\beta}$ and $\boldsymbol{\beta'}$

As explained, the two blue cranks should be actuated in a synchronized way. In this section, the relationship between the input angle β of one crank (see Fig. 3) and the input angle β' of the symmetrical crank is obtained.

The equation of the blue plane as a function of the two input angles α and β (see Fig. 3) is,

$$x + \frac{r\sin\beta\tan\alpha}{r\cos\beta - l\tan\alpha}y + \frac{r\sin\beta}{r\cos\beta - l\tan\alpha}z = 0 \tag{10}$$

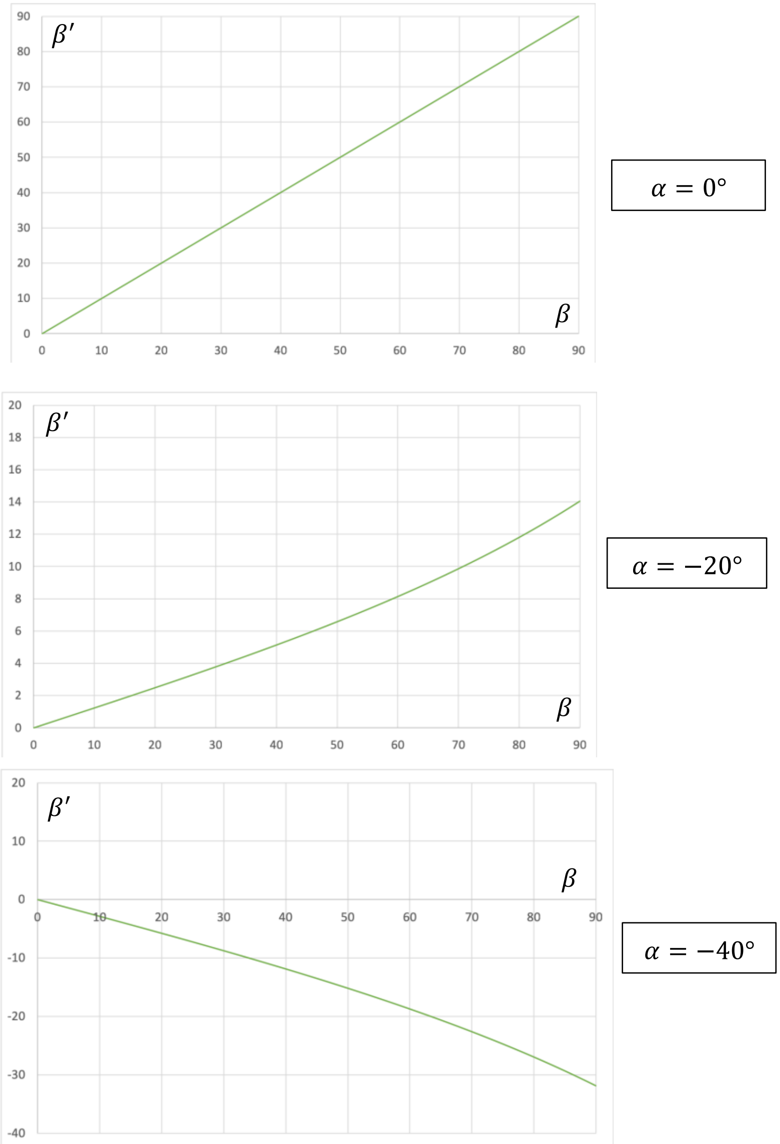

Fig. 4. Relationship between β and β' (*R=30mm*; *r=12,67mm*)

Intersecting the plane with.

$$\begin{cases} x^2 + z^2 = r^2 \\ y = -l \end{cases} \tag{11}$$

we obtain the following equation,

$$(1+m^2)z^2-(2mn)z+(n^2-r^2)=0 \tag{12}$$

being,

$$m=\frac{r\sin\beta}{r\cos\beta-l\tan\alpha}$$
$$n=\frac{rl\sin\beta\tan\alpha}{r\cos\beta-l\tan\alpha} \tag{13}$$

Finally, β' is obtained as,

$$\beta'=\tan^{-1}\left(\sqrt{\left(\frac{r}{z}\right)^2-1}\right) \tag{14}$$

In Fig. 4 the relationships between β and β' for different values of α are shown.

3.4 Singularities

The condition for singularity is,

$$\alpha=\tan^{-1}\left(\frac{r}{l}\right) \tag{15}$$

When Eq. 15 is verified for $0<\alpha<\pi/2$ the joint cannot be actuated from the blue crank with input angle β. In the case that Eq. 15 is verified in the range $0<\alpha<-\pi/2$, the joint cannot be actuated from the blue crank with input angle β'.

4 Prototype

A demonstrative prototype of the joint has been manufactured using 3D printing (see Fig. 5).

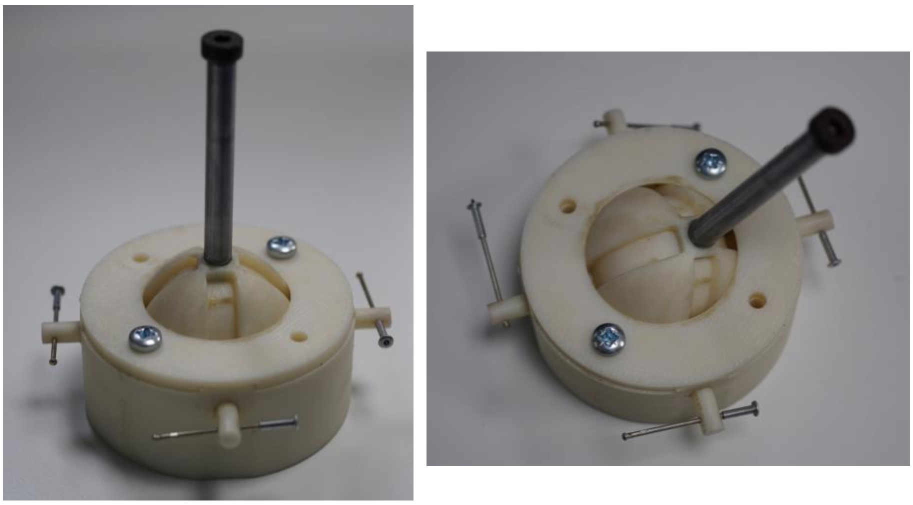

Fig. 5. Joint prototype (*R=30mm*; *r=12,67mm*)

We have verified the functionality of the design concept proposed in this paper and its good load-carrying capacity. However, for high accuracy applications, the wear inherent to this design will produce clearances that will be difficult to compensate.

5 Conclusion

In this paper, a 2R joint based on the actuation of a central ball has been presented. The joint design is compact with good load capacity. The two rotational degrees of freedom are redundantly actuated to obtain a good balance on the load transmission and to avoid two possible singularities. Additionally, the joint can be used as a reconfigurable revolute joint with the ability of varying its revolute axis. The direct and inverse kinematics of the joint have been solved in closed form obtaining simple mathematical relations.

Currently we are working in evolving the joint design in order to simplify the mechanism components and the actuation scheme, to avoid possible singularities in the workspace and to increase its reliability and durability.

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