A Family of New Parallel Architectures with Four Degrees of Freedom

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Abstract

This paper describes a novel parallel kinematic chain with 4 DOF. Three of the freedoms of the platform are rotational and only one is translational.

1. Introduction

There has been an increasing interest in parallel mechanisms with fewer than six DOF that are neither planar nor spherical. It is hoped that such mechanisms can perform successfully many tasks that have so far required 6-DOF platforms and achieve lower device and operational costs, due to simplified designs involving fewer links and actuators.

In flight and motion simulation, rotational freedoms play a major role, while translations are of lesser importance. However, one translational freedom, the heave, is of great significance in flight simulation [1]. Hence, if one were to choose a subset of the platform freedoms for the purposes of flight simulation, a natural choice would be to keep three rotations and only one translation. It can be expected, therefore, that the architectures proposed herein can be used in the design of new flight and motion simulators.

2. Description of the Mechanism

The base and the mobile platform are connected by $m \geq 2$ serial subchains (legs), each with five revolute joints. One such subchain, together with the base and the mobile platform, is shown in Fig. 1. The first three joints (counting from the base) in each serial subchain form a 3R spherical chain, i.e., their axes intersect in one fixed point, O, the *rotation centre* common to all serial subchains. The remaining fourth and fifth revolute joints in each leg form a planar 2R chain, i.e., the two revolute axes are parallel. Moreover, these last two joint axes in each serial subchain are also parallel to a chosen plane in the moving platform (the *platform plane*). It is also required that the m axes of the fifth joints (the joints on the mobile platform) are not all parallel, i.e., at least two of the m planar 2R subchains have different planes of motion (Figs. 2 and 3).

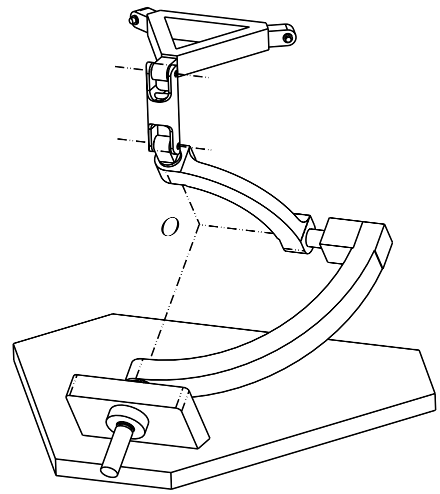

Figure 1: A 5R serial subchain

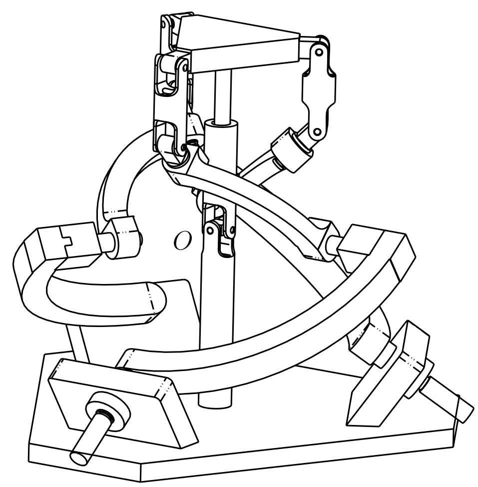

Figure 2: A variant of the mechanism

3. Mobility and Actuation Schemes

It may be easier to visualize the four degrees of freedom if we consider the inverted mechanism, i.e., if the mobile platform is assumed fixed and we consider the relative movement of the base of the mechanism. It is clear that the spherical part of the mechanism and, in particular, the common centre of intersection of the spherical revolutes, O, is attached to the mobile platform by m planar 2R chains. Each 2R chain restricts the rotation centre, O, to a plane perpendicular to the mobile platform. Since we have postulated that these m *heave planes* are not all identical and since their intersection is not empty (the mechanism has at least one configuration), they must all intersect in one straight line (*the platform axis*) perpendicular to the platform plane and, therefore, the rotation centre is restricted to move along this line. Hence, the possible motion of the base with respect to the mobile platform is composed of a translation perpendicular to the platform plane followed in series by a spherical wrist at O (Fig. 4).

Returning to the original kinematic chain, it is now clear that the mobile platform can rotate arbitrarily about a point fixed in the base (the rotation centre O) and translate along a direction fixed in the platform (the platform axis) and perpendicular to the platform plane.

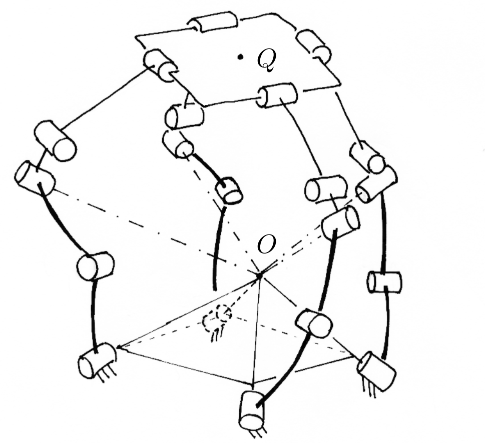

Figure 3: The parallel architecture with four 5R legs.

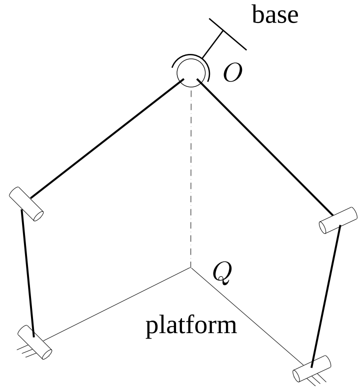

Figure 4: The inverted mechanism.

From a purely geometric point of view the mechanism may have any number of legs not smaller than two. Since it is desirable to have the actuators at the base it is natural to have four serial subchains (Fig. 3). To avoid excessive link interference and increase the orientational workspace, one of the four serial subchains can be designed with only 4 DOF, namely the three rotational and one translational freedoms of the platform, and placed in the middle between the other three legs. Such an architecture can be seen in Fig. 2, where the middle leg is an RRC chain. The mechanism can also be made with only three 5R legs as long as, in addition to the three base joints, any one other joint is actuated. We emphasize that the degree of freedom of the mechanism is determined only by (any) two 5R legs (with different heave planes); the addition of extra 5R chains or 4-DOF chains like the one in Fig. 2 does not affect the mobility. Thus, the mechanism in Fig. 2 will have the same 4-DOF with or without the middle leg, with or without the third or an extra fourth 5R chain. With only two 5R legs we have a single-loop chain with 10 joints and 4 DOF and the Grübler-Kutzbach mobility criterion is satisfied. With additional legs the mechanism is overconstrained and the formula is violated.

4. Kinematic Analysis

The pose of the mobile platform is described by $(\mathbf{R}, h)$, where $\mathbf{R}$ is the orthogonal rotation matrix giving the orientattion of the platform and h is the directed distance between O and Q along the platform axis.
It can be shown that h determines the locations with respect to the platform of the last three axes of each serial subchain. Once these are known, the problem reduces to the inverse kinematics of a general spherical parallel manipulator [2]. As a result, the inverse kinematics for each 5R subchain has a maximum of four solutions and the inverse kinematics of the mechanism as a whole has 64 solutions at most (for a version with four legs).
The relationship between the instantaneous motion of the platform, the output twist, $\boldsymbol{\xi} = (\boldsymbol{\omega}, \mathbf{v})$, and the input joint velocities can be derived from the twist equations of the serial subchains using a modification of the meth od of reciprocal screws [3]. An input-output velocity equation of the following type is obtained:

$$\mathbf{Z}\begin{bmatrix} \boldsymbol{\omega} \\ v_z \end{bmatrix} = \boldsymbol{\Lambda}\dot{\boldsymbol{\theta}}\,,$$

where v_z is the projection of the velocity of the platform centre onto the platform axis, $\dot{\boldsymbol{\theta}}$ is the vector of the four input joint velocities, while $\mathbf{Z}$ and $\boldsymbol{\Lambda}$ are 4×4 Jacobian matrices. The matrix $\boldsymbol{\Lambda}$ is diagonal, while the rows of $\mathbf{Z}$ are the reciprocal wrenches for each leg. The above equation can be used for the singularity analysis of the mechanism [3, 4].

5. Conclusions

In this paper, we presented a family of new 4-DOF parallel architectures. The proposed mechanisms make it possible to supplement an orientational parallel structure with a translational motion fixed in the mobile frame, which is ideal for motion simulation.

References

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