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A key point dimensional design method of a 6-DOF parallel manipulator for a given workspace

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ABSTRACT

This paper presents a new method of dimensional design for a 6-PSS parallel mechanism according to a given workspace. A symmetrical description has been found to describe the 6-D workspace concisely for the dimensional design. Many key point characteristics have been found and verified by the kinematic analysis and the method of Lagrange multipliers. Furthermore, the direct relations between the given workspace and the manipulator's geometrical parameters have been derived. The proposed design method which is based on these key point characteristics has very high efficiency and accuracy. Additionally, the avoiding of the complex analysis of the manipulator's workspace and the dimensionless derivation make the possibility of wide use of this method.

1. Introduction

The interest for parallel manipulators arises from the fact that they have better load-carrying capacity, better stiffness, and better precision than serial manipulators [1–4]. Thus the research on designing parallel manipulators has become a hot topic in the international robotic research area [5–9]. The design of parallel manipulators is a challenging problem in the machinery product design process. The type synthesis is for designing the configuration for manipulators [10–12]. And then the geometrical parameters of manipulators should be determined by the dimensional design. Because the types of parallel mechanisms are almost unlimited, the dimensional design must be based on a certain type of mechanisms. The parameter design methods presented in reference [13,14] are based on 6-DOF Gough-type manipulators and 3-DOF parallel manipulators, respectively.

Generally, one of the most important design objectives is to let the manipulator work in a given workspace. Therefore, the dimensional design of parallel manipulators for a given workspace is an important problem, which has not gained too much interest. So far, there are mainly two ways to design the geometrical parameters of parallel manipulators according to a given workspace. The first one uses many points to describe the given workspace and then check whether the manipulator with certain parameters fits the design requirements at each point [15–17]. The other one establishes a function between the parameters and the workspace boundaries of the manipulator, then make sure that the given workspace is within the manipulator's workspace boundaries [18–22]. Based on several key points that we have found in this study, this paper attempts to explore a new way of dimensional design for a new 6-DOF parallel manipulator according to a given workspace. This design method is fast and its result is accurate.

In our previous work, a new type of 6-DOF parallel mechanism with an orthogonal '3-3'-PSS configuration has been proposed. Compared with the traditional 6-SPS parallel manipulators, this '3-3'-PSS parallel manipulator allows higher isotropy of the manipulator's performance, larger rotation range of the moving platform and less body inertia.

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To begin the design, the required workspace should be clearly described. Because the 6-dimensional workspace cannot be represented graphically in a human-readable way and there are no general way to analytically determine the boundaries of the 6-D workspace for 6-DOF parallel manipulators, most literatures [23–27] divide the 6-D workspace into position workspace and orientation workspace. The position workspace refers to a space that the manipulator's moving platform can reach with a certain orientation. And it can be easily depicted. The orientation workspace is the collection of all the orientations that the moving platform can achieve at a certain point. However, due to the complexity of the rotating angles, the orientation workspace is difficult to be determined and represented. Considering the symmetry of our parallel manipulator, a concise way of describing the 6-D workspace is found for the dimensional design.

The paper is organized as follows. Section 2 introduces the modeling of the design problem and the kinematics analysis. Section 3 shows how the key point characteristics are found. The design method and its application are discussed in Section 4. Finally, concluding remarks are presented in Section 5.

2. Modeling of the design problem and kinematic analysis

The architecture of the new '3-3'-PSS parallel manipulator is shown in Fig. 1, which is composed of a moving platform, a fixed base, and six supporting limbs with identical geometrical structure. The limbs are numbered from 1 to 6. Each limb connects the fixed base to the moving platform by a prismatic joint, a spherical joint B_i and a spherical joint A_i in series. A linear actuator actuates the prismatic joint of each limb along a fixed rail. Between the joint B_i and joint A_i is a rigid link of length L_i (i=1,…,6).

The three linear actuators of the limbs 1, 2, and 3 are arranged with their axes located in a horizontal plane P_B, and the angles between each of their axes are 120° while these axes do not intersect at one point. The distances between these axes and the symmetry axis of the manipulator are the same, and here we use the parameter a to represent this distance. The other three linear actuators of the limbs 4, 5, and 6 are arranged with their axes vertically. The centers of the joints $A_1 \sim A_6$ of the moving platform are distributed symmetrically on a circle of radius a. The center of this manipulator is at the intersection of the plane P_B and the symmetry axis of the manipulator, on which attached a fixed Cartesian reference coordinate frame $O\{x, y, z\}$. The fixed frames y-axis and z-axis are in the plane P_B, and its x-axis coincides with the symmetry axis of the manipulator. A moving frame $O'\{x', y', z'\}$ is attached on the moving platform at point O' which is the center of the circle that points $A_1 \sim A_6$ located on. Considering the fact that the manipulator is axisymmetric, let point O' coincides with point O when the moving platform is at the initial position. Thus the workspace of the manipulator is also axisymmetric with respect to the fixed frame O.

Before designing the geometrical parameters of the manipulator, the required workspace should be clearly described. As can be seen from the previous discussion, concisely describing the required 6-D workspace is a challenging problem. In this research, for the orientation description of the moving platform, only the pointing vector (showed in Fig. 2) rather than the rotation about its symmetry axis is concerned. In fact this has the same situation for many machine tools. Based on this, we use a special set of Euler angles to represent the orientation of the moving platform. The moving platform first rotates about the fixed x-axis by an angle-φ, then about the fixed z-axis by an angle θ, and finally about the fixed x-axis by the angle φ (Fig. 2). And we can simply write the rotation matrix for this case as:

$$\mathbf{R} = Rot(x,\varphi)Rot(z,\theta)Rot(x,-\varphi) = \begin{bmatrix} c\theta & -c\varphi s\theta & -s\varphi s\theta \\ c\varphi s\theta & s^2\varphi + c^2\varphi & -c\varphi s\varphi + s\varphi c\theta c\varphi \\ s\varphi s\theta & -c\varphi s\varphi + c\varphi c\theta s\varphi & c^2\varphi + s^2\varphi c\theta \end{bmatrix}, \quad (1)$$

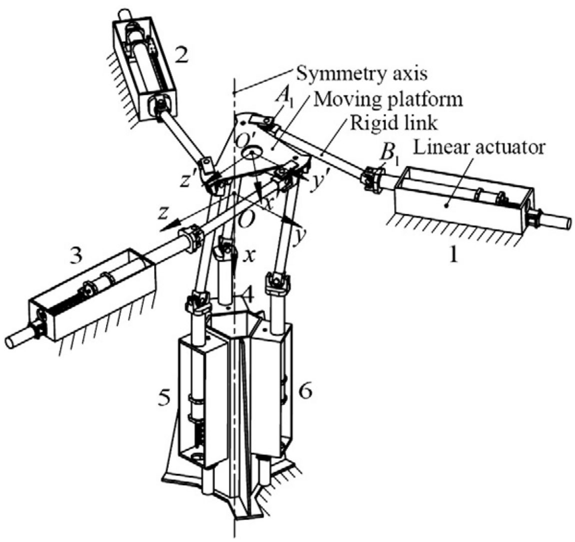

Fig. 1. The configuration of the proposed '3-3'-PSS parallel manipulator.