Computer Aided Geometric Design 63 (2018) 122–134

Contents lists available at ScienceDirect

Computer Aided Geometric Design

www.elsevier.com/locate/cagd

Operation mode analysis of 3-RPS parallel manipulators based on their design parameters

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ARTICLE INFO

Article history:
Available online 17 May 2018

Keywords:
Study's kinematic mapping
3-RPS
Parallel manipulator
Operation modes

ABSTRACT

It is known that a 3-RPS parallel manipulator with an equilateral triangle base and an equilateral triangle platform has two operation modes (Schadlbauer et al., 2014) whereas a 3-RPS cube manipulator with a cube shaped base and an equilateral triangle platform has only one operation mode (Nurahmi et al., 2014). This behavior is indeed a result of the difference in the architectures of these manipulators. Therefore, this paper deals with the operation mode analysis of 3-RPS parallel manipulators based on their design parameters. Study's kinematic mapping is exploited to derive the constraint equations of the manipulators under study. A linear combination of the constraint equations independent of the joint variables is compared with a general quadric in the 7-dimensional projective space $\mathbb{P}^7$ to obtain some relations between the design parameters of 3-RPS manipulators with coplanar revolute joints, such that those manipulators have two operation modes. Some special cases and a numerical example are considered to emphasize the proposed approach and highlight the contributions of the paper.

1. Introduction

The 3-RPS parallel manipulator is a three degree-of-freedom (DOF) spatial mechanism, initially proposed by Hunt (1983). This manipulator allows one pure vertical translation and two rotations about axes parallel to the horizontal plane, but since those axes do not remain fixed when the manipulator moves, the two rotations generate two parasitic horizontal translations. The mechanism is composed of three identical limbs connecting its base to its moving platform. Each limb consists of a revolute joint, a prismatic joint and a spherical joint mounted in series.

Several arrangements of the joints are possible, e.g. the R-joint axes in the base frame can be tangential to a circle, parallel or intersect at a common point.

Several research works have dealt with the kinematic analysis of the 3-RPS parallel manipulator. Huang and Fang (1995) described the constraints of the manipulator using screw theory. The number of solutions to the inverse kinematics was first published by Nanua et al. (1990) and Tsai (1999), Self-motions were investigated by Schadlbauer et al. (2013) in which

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https://doi.org/10.1016/j.cagd.2018.05.003
0167-8396/

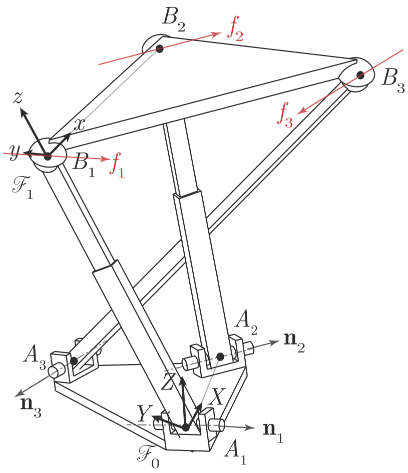

Fig. 1. Architecture of a 3-RPS parallel manipulator with coplanar revolute joints.

a spatial 3-RPS Manipulator was considered with R-joints tangential to the base circum-circle. Workspace and joint space analysis using quaternions was done by Chablat et al. (2014), and more special configurations of the 3-RPS manipulator like the 3-RPS cube manipulator as well as the synthesis of design parameters with respect to specific operation modes were both investigated by Nurahmi et al. (2014; 2015). Moreover, a complete algebraic analysis of the 3-RPS parallel manipulator was published, using Study's kinematic mapping in Schadlbauer et al. (2014) and in Schadlbauer et al. (2012). Gallardo et al. (2008) analyzed the kinematics of the 3-RPS parallel manipulator by using screw theory.

The motion capabilities of the 3-RPS parallel manipulator were exploited in telescope applications studied by Carretero et al. (1997) and in machine tool heads, investigated by Hernández et al. (2008).

The application for medical purposes like human machine interactions were investigated in Verde et al. (2009), including the control of the manipulator with PID controllers.

The subject of this paper is about the determination of some conditions on the design parameters of 3-RPS manipulators with coplanar revolute joint axes for those manipulators to have two operation modes.

The paper is organized as follows: Section 2 presents the architecture and parameterization of 3-RPS manipulators with coplanar revolute joint axes. Section 3 expresses their constraint equations as a function of Study parameters and independently of joint variables. Section 4 deals with the operation mode analysis of the manipulators under study and gives some conditions on their design parameters to lead to two operation modes. The operation modes of three 3-RPS parallel manipulators with coplanar revolute joints defined based on the foregoing conditions on design parameters are analyzed in Section 5 as illustrative examples. Some discussions and conclusions are given in Sec. 6.

2. Manipulator architectures

The investigated spatial parallel manipulator shown in Fig. 1 consists of a moving platform connected to a fixed base with three limbs. Each limb is composed of a revolute joint, a prismatic joint and a spherical joint mounted in series.[1] The three prismatic joints are actuated. Fig. 2 represents a RPS limb. The base of the 3-RPS manipulator is specified by 3 base-points A_1, A_2 and A_3 in the fixed frame $\mathscr{F}_0$. The fixed frame is defined such that A_1 is the origin of the coordinate frame, A_2 is along the x-axis and A_3 is an arbitrary point in the XY-plane. B_1, B_2 and B_3 are the vertices of the triangular moving-platform, B_1 is the origin of the moving-platform frame $\mathscr{F}_1$, B_2 is along the x-axis of $\mathscr{F}_1$ and B_3 lies in the xy-plane.

The ith revolute joint axis of direction $\mathbf{n}_i$ is perpendicular to the direction of the ith prismatic joint, namely,

$$\mathbf{n}_i \cdot \overrightarrow{A_iB_i} = 0, \quad i = 1, 2, 3 \tag{1}$$

3. Kinematic modeling

To derive the constraint equations of the 3-RPS parallel manipulators with coplanar revolute joint axes, the homogeneous coordinates of point A_i and vector $\mathbf{n}_i$ are firstly expressed in frame $\mathscr{F}_0$ while that of the point B_i are expressed in frame $\mathscr{F}_1$:

$$^0\mathbf{a}_1 = (1, 0, 0, 0), \quad ^0\mathbf{a}_2 = (1, a_{12}, 0, 0), \quad ^0\mathbf{a}_3 = (1, a_{13}, a_{23}, 0), \tag{2}$$

[1] A revolute, prismatic and a spherical joint are denoted by R, P and S respectively.