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On the position analysis of a new spherical parallel robot with orientation applications

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ABSTRACT

In this paper, we propose a new spherical parallel robot for celestial orientation, and rehabilitation applications (TV satellite dish, tracking systems, solar panels, cameras, telescopes, table of the machine tools, ankle, shoulder, wrist and etc.). The proposed robot can completely rotate about an axis. After describing the robot and its inverse position analysis, using the genetic algorithm, the dimensional optimization to maximize the workspace of the robot is performed. The workspace analysis shows that the proposed robot has a relatively large workspace. Also, singularity analysis represents that the manipulator is a singularity-free workspace. It is a great advantage of the proposed robot. Next, an optimal approach is proposed for solving the direct position problem of the robot. According to the geometry of the robot, two coupled trigonometric equations are obtained through using a special form of Rodrigues' rotation formula. Next, the two coupled equations are transformed to a 8-degrees polynomial using the Sylvester's Dialytic elimination method. Finally, a numerical example for the robot with an asymmetric structure is given with eight real solutions. Therefore, the polynomial being minimal and the proposed approach is optimal. This greatly decreases computational time, which is necessary for dynamics, control and simulation.

1. Introduction

The spherical movement of a rigid body around an optional point allows variable orientation of a rigid body. A fully spherical parallel manipulator (SPM) is a developed parallel manipulator that its moving platform has pure rotational movement around a fixed spherical joint. There are several usages of SPM, mentioned in the papers. Radio telescopes, surgical instruments, rehabilitation equipment, TV satellite dish orientation, sun tracker, solar panels, cameras, satellite antenna, radar tracking systems, as well as a table of the machine tools.

A lot of mechanisms for these tasks have serial architecture. Lately, the mechanisms with parallel architecture started to impose, taking into account their characteristics: high stiffness, kinematic accuracy, the advantageous ratio between payload and its own weight.

Several parallel mechanisms are proposed for orientation of a rigid body. Campsite and Visa present a hybrid mechanism with 2-dof, which are used for orientation of solar panels and satellite [1,2]. The synthesis of 2-dof spherical fully parallel mechanisms is performed by Vertechy and Parenti-Castelli [3] and Gallardo introduced a family of spherical parallel manipulators with a simple architecture [4]. A Stewart platform prototype for a radio antenna orientation is proposed in Ref. [5]. An original technological solution of equivalence in the spherical joints in order to allow significant rotations in radio antenna for the Stewart Platform applications is presented in Ref. [6]. Itul and Pisla present kinematics and dynamics of a 3-dof parallel mechanism for TV satellite antenna orientation or sun tracker [7–9]. Meschini presents a parallel mechanism for a satellite antenna with double reflector. The mechanical system of the mechanism consists of two platforms which are connected through six extensible legs. A reflector for signaling is mounted on each platform [10].

Alici and Shirinzadeh are introduced 3(SPS)-S SPMs [11]. Each kinematic chain has spherical (S), prismatic (P) and spherical (S) joints. The moving platform connected to the fixed platform by a spherical joint. Innocenti and Parenti [12] and Wohlhart [13] and Vertechy and Parenti [14] have investigated on the 3(UPS)-S SPM. Bonev presents a methodology for the analytical determination and representation of the workspace boundaries of symmetrical spherical parallel mechanisms [15]. The methodology is based on an intuitive orientation representation which has proven to be very useful for the analysis of symmetrical parallel mechanisms.

Enferadi and Akbarzadeh investigate the forward position analysis of a novel spherical star triangle (SST) parallel

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manipulator [16]. Chebbi, Affi and Romdhane present analytical method for the forward kinematic problem of spherical 3-(UPU) PM [17]. Boudreau and Turkkan solved the forward position of parallel manipulators with the genetic algorithm. They used inverse kinematics problem to optimize their method [18]. Zheng, Bin and Luo present a hybrid serial–parallel manipulator that is based on two kinds of 3-UPU parallel mechanisms with six degrees of freedom. The motion of the hybrid serial–parallel mechanism can be decoupled to pure translation and pure spherical rotation. They also obtain a closed-form solution for direct position problem of the hybrid manipulator [19]. Also, some studies have addressed the forward position problem for different parallel manipulator architectures [20–24]. They showed that the forward position analysis of these mechanisms can be solved in echelon form (finding all possible solutions of the forward position analysis). Also, some relevant kinematic analysis of a 3(RRRS)-S parallel wrist with orientational actuators and without intersecting revolute axes are investigated in Ref. [25].

This paper is organized as follows. In Section 2, we describe a new 3(RSS)-S fully spherical robot. Then, in Section 3, we define coordinate frames and rotation matrices. This is important for kinematics analysis of the robot. Solving the inverse kinematics problem is performed in Section 4. This analysis is required to workspace optimization. In Section 5, the dimensional optimization to maximize the workspace of the robot is performed using the genetic algorithm (GA). The optimization process is performed with joint constraints and without joint constraints. In Section 6, an innovative method is presented for solving the direct kinematics problem of the robot based on the geometry of the manipulator. We show the proposed approach is optimal. In the last section, a numerical example for the robot with symmetric structure is given. This example has eight real solutions. Therefore, the polynomial being minimal and the proposed approach is optimal.

2. Description of the 3(RSS)-S parallel robot

The 3(RSS)-S fully spherical robot consists of a fixed platform connected to the moving platform by a non-moving spherical joint at the center of the moving platform that is called fixed spherical joint and three similar legs. Each leg has Revolute (R), Spherical (S) and Spherical (S) joints that are actuated with a motor. See Figs. 1 and 2. For the infinite rolling motion of the moving platform, three revolute joints are considered on a single an axis. This axis is defined along O_iS. The proposed robot similar to any spherical parallel manipulator orients a rigid body in the desired direction, but in the proposed manipulator, if we rotate all of the motors simultaneously, we can rotate the rigid body around a vertical axis (the z_B axis in Fig. 2), unlimitedly. The unit vector $\mathbf{u}_i$ defines along O_iA_i. Rotation of the each motor is specified by angle θ_i. This angle is measured from the axis x_B. The fixed distance between the spherical joint (A_i) and the motor axis is denoted by a_i. The unit vector $\mathbf{e}_i$ is defined along the intermediate link A_iB_i. The length of the link is defined by l_i. The unit vector $\mathbf{v}_i$ defines along SB_i. The fixed distance between the fixed spherical joint, S, and the upper spherical joint, B_i, is denoted by b_i. Also, it is assumed that all of the $\mathbf{v}_i$ vectors are on a plane. Furthermore, the fixed distance between the fixed spherical joint, S, and each of the revolute joint, O_i, is equal to h_i. The unit vector $\mathbf{w}_i$ is defined along SA_i. The unit vector $\mathbf{m}_i$ is defined perpendicular to the plane A_iB_iS. Therefore, the unit vector $\mathbf{m}_i$ is perpendicular to the unit vectors $\mathbf{w}_i$ and $\mathbf{e}_i$. The unit vector $\mathbf{n}$ is defined perpendicular to the moving platform and the unit vector $\mathbf{v}_i$. Therefore, the unit vectors $\mathbf{w}_i$, $\mathbf{m}_i$ and $\mathbf{n}$ can be defined as

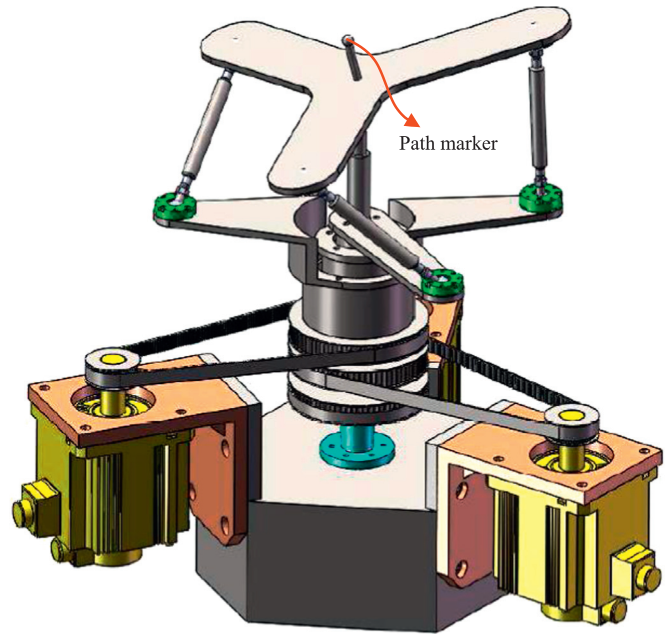

Fig. 1. Schematic representation of a 3(RSS)-S fully spherical robot.

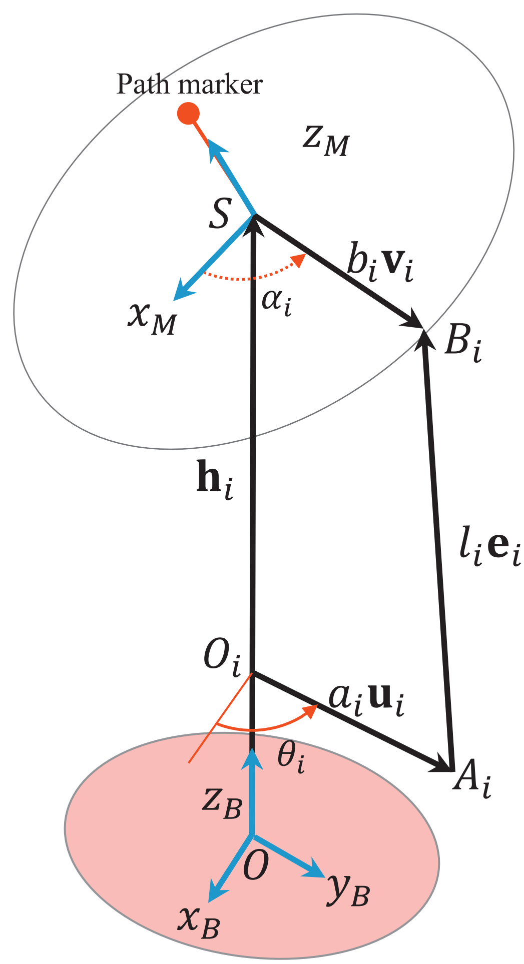

Fig. 2. Geometry of one typical kinematic chain.

$$\mathbf{w}_i = \frac{\mathbf{h}_i - a_i\mathbf{u}_i}{\|\mathbf{h}_i - a_i\mathbf{u}_i\|} \quad \text{for } i = 1, 2, 3 \tag{1}$$