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Research paper

Type synthesis of 1T2R parallel mechanisms with parasitic motions

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ABSTRACT

Finite motion analysis and type synthesis of parallel mechanisms with parasitic motions are great challenges in the fields of mechanisms and robotics. This paper proposes a finite screw based approach to handle this problem by taking one translational and two rotational (1T2R) parallel mechanisms with parasitic motions as examples. Firstly, 1T2R finite motion of the moving platform is categorized into four cases whose finite motions are described by finite screw analytically and then the reasons for producing parasitic motions are explored in this process. Based on this, available limbs are obtained algebraically by deriving formulas formed by triangle screw product. Finally, the assembly conditions among limbs, fixed base and moving platform are acquired in an analytical manner, leading to synthesize 1T2R parallel mechanisms with parasitic motions systematically. This paper solves a long-term problem that describes and analyzes finite motions of parallel mechanisms with parasitic motions and synthesizes their topology structures.

1. Introduction

One translational and two rotational (1T2R) parallel mechanisms draw great interest and attention from academia and industry in the past thirty years [1–6]. They are integrated serially to a two-degree-of-freedom (DoF) rotating head or X/Y long guide ways to form 5-DoF hybrid kinematic machines that have been applied successfully in machining and assembly of large and complex components [7,8]. Tricept Series and Ecospeed Series are their representatives [9,10]. The former is composed of a 1T2R Tricept parallel mechanism and a 2-DoF serial rotating head, while the latter includes a 1T2R Sprint Z3 parallel mechanism and two X/Y long guide ways. Although the DoF number and type of two parallel mechanisms are identical, the geometric distributions of axes of two rotations within prescribed workspace are different. For Tricept parallel mechanism, the two rotational axes are orthogonal and intersecting at one point just like a universal joint [11]. And a series of Tricept-like parallel mechanisms have been proposed by means of type synthesis based on instantaneous motion [12,13] and finite motion analyses [14–16]. But for Sprint Z3 parallel mechanism, its two rotational axes are changeable instantaneously in prescribed workspace [17], resulting in great difficulties to describe its finite motion and synthesize topological structures of new parallel mechanisms with the same finite motion characteristic [18,19].

The Sprint Z3 parallel mechanism is composed of fixed base, moving platform and three identical PRS limbs (P is the prismatic joint, R and S denote revolute and spherical joint, respectively) [2]. Its studies can be dated back to 1983 when Hunt proposed a similar mechanism that consists of fixed base, moving platform and three identical RPS limbs [1]. In 2000,

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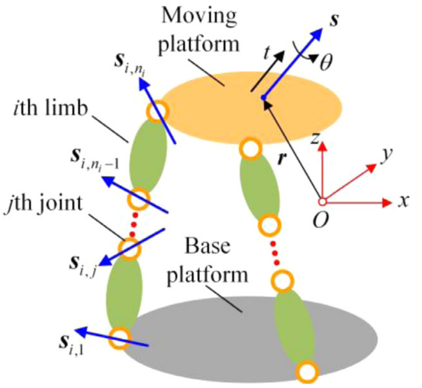

Fig. 1. Schematic diagram of a parallel mechanism.

Carretero and Gosselin demonstrated Sprint Z3 parallel mechanism would produce two translations along *x* and *y* axes and one rotation about *z* axis besides the excepted motions in terms of one translation along *z* axis and two rotations about *x* and *y* axes [20]. The additional and unwanted motions are referred to as parasitic motions and could be expressed as functions of the 1T2R motions [20,21]. For a long period, the researchers considered the parasitic motions make kinematic analysis and control strategy complex and affect accuracy of parallel mechanisms [22]. In order to solve this problem, Carretero and Gosselin proposed a nonlinear optimization method to design Sprint Z3 parallel mechanism for the purpose of minimizing the parasitic motions [20]. Li compared the parasitic motions of Sprint Z3 parallel mechanism with different limb arrangements and found that the parasitic motions are related to geometrical arrangements of limbs and the location of three spherical joints [23]. Inspired by this, Li and Hervé carried out type synthesis of 1T2R parallel mechanisms without parasitic motions and obtained many new mechanisms [16]. However, the three limbs of these new mechanisms are usually distributed as 'T' shape and the centers of the joints producing three rotations with their axes intersecting at one point are collinear, leading to this type of 1T2R parallel mechanisms without parasitic motions are with intuitively poor performance in terms of stiffness and accuracy.

With the success of Ecospeed Series in machining of large aerospace component with complex surface, Sprint Z3 parallel mechanism again attracts interest from academia. Considering the instantaneously changeable rotational axes, the methods on instantaneous motion level focus on the rotational axes in the home configuration and propose some new parallel mechanisms by replacing the PRS limbs with other kinematic equivalent limbs [24–26]. On the other hand, the parasitic motion results in great difficulties to type synthesize by means of the existing finite motion based methods [27–30]. As the prerequisite of type synthesis, great efforts have been made to carry out motion description and analysis of Z3-like parallel mechanisms. Schadlbauer revealed the global properties of this type of mechanisms by employing study-parametrization of the special Euclidean group SE(3) [31]. Wu developed a new kinematic model as the exponential submanifolds for mechanism analysis and synthesis [32]. However, the finite motion could not be described in an algebraic manner and the 1T2R mechanisms with different types of parasitic motions could not be synthesized till now. If we want to settle the difficulties, the following efforts will be made: (1) explore the reason for producing parasitic motions and formulate the coupled relation between parasitic motions and expected motions analytically in the finite motion level; (2) obtain limb structures generating these complicated motions and the assembly conditions among limbs, fixed base and moving platform.

Based on these, this paper proposes a finite screw based approach to describe and analyze finite motions of 1T2R parallel mechanisms with parasitic motions and synthesize their topology structures. Having outlined in Section 1 the state-of-art of 1T2R parallel mechanisms with parasitic motions, the remainder of this paper is organized as follows. In Section 2, the finite screw and its applications in finite motion description and calculation are given. In Section 3, 1T2R finite motion is categorized into four cases whose finite motions are described by finite screw analytically and then the reason for producing parasitic motions is explored. Based on this, available limbs generating 1T2R motions and parasitic motions are obtained in Section 4 algebraically by deriving formulas formed by triangle screw product and finite screws. In Section 5, the assembly conditions among limbs, fixed base and moving platform are acquired in an analytical manner, leading to synthesize 1T2R parallel mechanisms with parasitic motions systematically. The conclusions are drawn in Section 6.

2. Finite screw

In this section, finite screw [33–35] is introduced to describe finite motions of parallel mechanisms, open-loop limbs and kinematic joints in an analytical and algebraic way. Herein, the finite motion of an open-loop limb can be denoted as screw triangle product of finite motions of kinematic joints. The finite motion of the moving platform for a parallel mechanism is represented by calculating the intersection of finite motions of open-loop limbs.