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A new forward kinematic algorithm for a general Stewart platform

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ABSTRACT

In this paper, a new forward kinematic algorithm based on dual quaternion for a six-degree-of-freedom (DOF) general Stewart Platform is proposed. The algorithm is established after taking into account the pose parameters of joints and the D–H parameters of each branch chain, which yields a precise mathematic model with a total of 174 geometric parameters. The validity of the algorithm is tested using an inverse kinematic algorithm of a general serial manipulator. The forward kinematic algorithms for the 6-6R and 6-2RP3R mechanisms can be expressed by a unified mathematic model. The proposed algorithm can solve the difficult problem of forward kinematics for the unsolved 6-6R parallel manipulator and can also be applied to error analysis, error synthesis, kinematic calibration, stiffness analysis and the accurate kinematic simulation by analysing the effect of geometric parameters on the platform.

1. Introduction

Forward kinematics and inverse kinematics are essential research issues in robotics. The forward kinematic solutions of the 6R serial manipulator, which can be represented by a product of a series of matrices, are comparatively easy. However, the research of inverse kinematics has experienced two stages. In 1968 (i.e., the first stage), Pieper solved the inverse kinematic problem for simple 6R robot manipulators for which the last three axes intersect at one point [1]. From the 1970s to 1980s (i.e., the second stage), the more difficult problem of the inverse kinematic solutions for the general 6R serial manipulator with arbitrary structure parameters attracted many researchers. Many scholars significantly contributed to the inverse kinematic problems of general 6R robot manipulators. Specifically, the 7R problem has been regarded as one of the most difficult problems in kinematics. Liao Qizheng first advanced a complex mathematical method to solve the 7R problem [2]. Subsequently, a number of simpler, faster and more robust algorithms have been developed [3].

Stewart introduced parallel manipulators in 1965 [4]. The forward kinematic solution for a parallel manipulator is more complex than the inverse kinematic solution because of the coupling between the branch chains.

Fig. 1 shows a general parallel manipulator. It consists of a base platform, B, a moving platform, P, and six branch chains. The base platform is fixed to the ground, while the moving platform is capable of moving within its workspace and is connected to the fixed platform via six legs, each of which is regarded as a six-DOF serial manipulator. Until recently, this parallel manipulator was so complex that only its topological structure was accessible. Thus, it requires further research [5].

The research of forward kinematics of the Stewart platform has experienced four stages.

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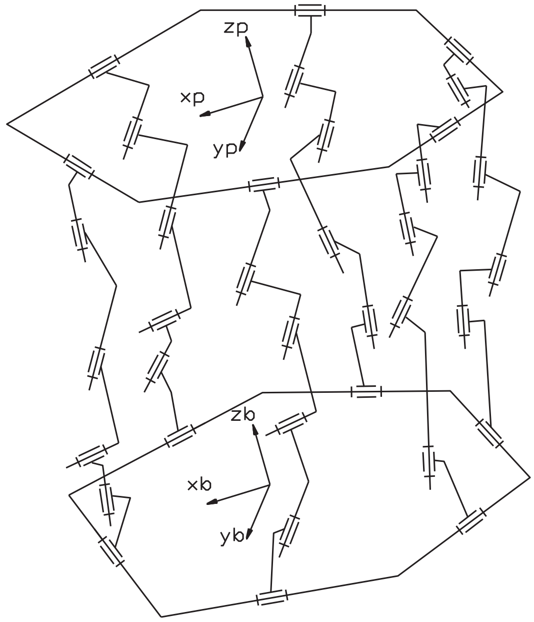

Fig. 1. Manipulator of the general 6-6R parallel.

The first stage: special configuration manipulators. A_i and B_i $(i = 1\ldots6)$ denote the joint points on the base platform and mobile platform, respectively. The special configuration is obtained through combining some joint points on the Stewart platform, which simplifies the forward kinematic problem. W. Lin, Griffis and Duffy solved the forward kinematic problem of 4–4 parallel manipulators [6]. In 1990, Innocenti obtained the forward solution of 4–6 Stewart platform parallel manipulators using a numerical method [7]. Researchers have proposed many approaches for variable types of Stewart manipulators, such as 3–6, 4–4, 4–5, 4–6 and 5–5 [8] Stewart manipulators.

The second stage: plane parallel manipulators with joints fixed to a plane on the two platforms shown in Fig. 2. Nanua made progress in 1990 using an algebraic elimination method [9]. In 2002, Dhingra derived the unitary 20-order algebraic equations for Stewart parallel manipulators on a Groebner Basis [10].

The third stage: plateau parallel manipulators. Plateau parallel manipulators with joints that are arbitrarily fixed on the two platforms are more complicated than the plane parallel manipulators, because the six chains are expressed as 6 links, and both ends of the links are considered to be spherical joints. The plateau parallel manipulator has 42 geometric parameters, namely the lengths of the six links and the three-dimensional parameters of 12 points. In 1996, Husty deduced a 40-order polynomial for the forward kinematic solution of plateau parallel manipulators [11]. In 1998, Diemair obtained the 40 groups of real solutions for the plateau parallel manipulators [12]. In addition, many other researchers studied forward kinematics with various methods: Merlet [13]; Sreenivasan and Waldron [14]; Wampler [15]; Sika et al. [16]; Ku [17]; Bonev and Ryu [18]; P.K. Jamwal [19]; Antonio Morell [20]; Huang, Liao, and Wei [21] and Gan, Liao, and Dai [22]. To date, the plateau parallel manipulator is the most mature Stewart platform.

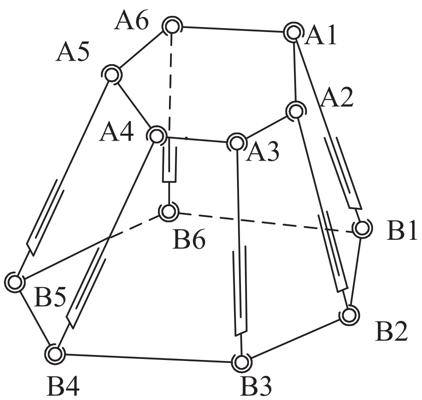

Fig. 2. Diagram of the Stewart platform.