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Dimension optimization of an orientation fine-tuning manipulator for segment assembly robots in shield tunneling machines

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ABSTRACT

This study focuses on the dimension optimization of a three-DOF orientation fine-tuning manipulator for segment assembly robots in shield tunneling machines. An index is introduced to evaluate the effectiveness of the motion/force transmissibility of the manipulator. The orientation capability of the manipulator is analyzed, and the corresponding indices for orientation capability are then defined. On the basis of performance atlases, the process of determining optimum geometric parameters is presented for the purpose of high orientation capability and good motion/force transmissibility.

1. Introduction

In underground space development, shield tunneling machines are widely used in subway tunnels, channel tunnels, and other kinds of tunnels. As one of the key sub-devices in a shield tunneling machine, a segment assembly robot is used to automatically form the segment lining. Since a segment usually weighs heavily, it is difficult to precisely achieve its required pose. This will seriously hamper the efficiency of segment assembly and considerably slow down the advancing speed of the shield tunneling machine.

A few studies on segment assembly robots in shield tunneling machines have been conducted. Wada [1] presented a segment erection robot that assembles segments and forms tunnel walls to prevent rock mass from collapsing. A seven-degree-of-freedom (seven-DOF) serial automatic segment assembly robot introduced in [2] had already found use in a 600-m-long tunnel construction site. Another serial robot manipulator [3] that has a linked structure with seven-DOF was studied for segment assembly in a shield tunneling machine. Precision analysis of position and attitude of a serial segment erector with six degrees of freedom was investigated in [4]. A parallel link robot, the so-called Stewart platform, was used for the assembly of segments of a shield tunnel excavation system [5]. However, serial and parallel robots each present disadvantages. Serial robots poorly handle stiffness and load capacity, while parallel robots present the disadvantage of limited workspace and poor dexterity. Considering the requirement of high assembly accuracy in heavy segments, serial robots undergo many technical problems when used in segment assembly. Meanwhile, as the diameter of the shield expands, parallel robots cannot be well extended to applications that require large workspaces.

Our study focuses on a three-DOF spherical parallel manipulator which can be used as an orientation fine-tuning manipulator for segment assembly robots in shield tunneling machines. Various types of structures have been proposed for spherical three-DOF parallel robots. One of the most popular structures is the 3-SPS-1-S manipulator (Fig. 3(a)), in which S and P represent spherical and prismatic joints, respectively. The forward kinematics of this manipulator was studied in [6]. Several studies [7–9] investigated the singularity of the manipulator and presented the computation and representation of singular loci. A systematic method for obtaining the singular loci of the manipulator was also addressed [10]. Recursive relations in kinematics and dynamics of the spherical 3-UPS/S parallel mechanism were investigated in [11], and a recursive matrix approach in dynamics modeling of spherical robots was developed [12]. The topology optimization of the 3-SPS-1-S manipulator was studied in [13] to determine its design parameters based on the *global conditioning index* (GCI) [14], which denotes the condition number of the Jacobian matrix over the entire workspace. In the design of parallel manipulators, the *local conditioning index* (LCI) [15] and GCI are the two most commonly used performance indices for the evaluation of dexterity. However, a recent study [16] found serious inconsistencies when these indices were used for the design of mixed-DOF parallel manipulators (those having both translational and rotational DOFs). In [17], the LCI was ineffective when applied to a planar parallel manipulator with only translational DOFs. We therefore believe that LCI and GCI should be carefully used in the design of the parallel orientation fine-tuning manipulator.

Being counterparts of serial robots, parallel robots are always good at motion/force transmission but not dexterous manipulation. A transmission index is hereby introduced in this paper to evaluate the effectiveness of the motion/force transmissibility of the orientation

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