Mechanism and Machine Theory xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Mechanism and Machine Theory

journal homepage: www.elsevier.com/locate/mechmt

Reconfiguration analysis of a 4-RUU parallel manipulator

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ARTICLE INFO

Available online xxxx

Keywords:
Parallel manipulators
Operation modes
Reconfigurability
Schoenflies motions
Primary decomposition

ABSTRACT

This paper deals with the characterization of the operation modes of the 4-RUU parallel manipulator with an algebraic approach, namely the Study's kinematic mapping of the Euclidean group *SE(3)*. As the 4-RUU parallel manipulator is an over-constrained manipulator, it can be decomposed into two 2-RUU parallel manipulators. The manipulators are described by a set of constraint equations and the primary decomposition is computed. By combining the results of primary decomposition from two 2-RUU parallel manipulators, it reveals that the 4-RUU parallel manipulator has two Schönflies modes (4-*dof*) and one lower dimension operation mode (2-*dof*). The singularity conditions are obtained by deriving the determinant of the Jacobian matrix of the constraint equations with respect to the Study parameters in each operation mode. It is shown that there exist singular configurations in which the manipulators may switch from one operation mode to another operation mode. All the singular configurations are mapped onto the joint space, i.e., the actuated joint angles, and are geometrically interpreted. Eventually, the 4-RUU parallel manipulator may switch from the 1st Schönflies mode to the 2nd Schönflies mode, or vice versa, via the 2-*dof* third mode that contains self-motions.

1. Introduction

To the best of the authors knowledge, the notion of operation mode was initially introduced by Zlatanov et al. in [1] to explain the behaviour of the three degree-of-freedom (3-*dof*) DYMO robot which can undergo a variety of transformation when passing through singular configurations. In [2], the author analysed the types of operation modes and the transition configurations of the 3-RER[1] Parallel Manipulator (PM) based upon the Euler parameter quaternions. Walter et al. in [3] used the Study's kinematic mapping to show that the 3-UPU PM built at the Seoul National University (SNU) has nine different operation modes. Later in [4], the authors revealed five different operation modes of the 3-UPU PM proposed by Tsai in 1996 [5]. By using the same approach, Schadlbauer et al. in [6] found two distinct operation modes of the 3-RPS PM proposed by Hunt in 1983 [7]. Later in [8], the authors characterized the motion type in both operation modes by using the axodes. The self-motions of this manipulator were classified in [9]. Another PM of the 3-RPS family is the 3-RPS Cube PM and was proposed by Huang et al. in 1995 [10]. Nurahmi et al. in [11,12] found that this manipulator has only one operation mode in which the 3-*dof* general motion and 1-*dof* Vertical Darboux Motion occur inside the same operation mode.

Accordingly, a general methodology for the type synthesis of reconfigurable mechanisms has been proposed and several new reconfigurable mechanisms have been generated. In [13,14], the authors proposed a general method based upon the screw theory to synthesize a PM that can perform two operation modes. In [15], a novel 1-*dof* single-loop reconfigurable 7-R mechanism

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[1] R, P, E, U, S denote revolute, prismatic, planar, universal and spherical joints, respectively.

http://dx.doi.org/10.1016/j.mechmachtheory.2015.09.004
0094-114X/

with multiple operation modes based upon the Sarrus mechanism, was proposed. The following year, the reconfiguration analysis of this mechanism based on the kinematic mapping and the algebraic geometry method was presented in [16].

By using the theory of the displacement groups, the lower-mobility PM with multiple operation modes and different number of *dof* were presented in [17]. Refaat et al. in [18] introduced a family of 3-*dof* PM that can exhibit two 1T1R modes by using Lie-group theory. In [19], Gogu introduced several PM with two 2T1R modes. In [20], a new joint was presented and added in the manipulator architecture hence it allows the moving platform to change the motion types. By adding a *rTPS* limb which has two phases, a new metamorphic parallel mechanism is introduced in [21]. The link-coincidence-based geometric-constraint method is proposed in [22] to obtain reconfigurable mechanisms which originated from carton folds and packaging dated back to 1996. At the same year, Wohlhart in [23] showed mechanisms that changed mobility through singularities.

In [24], Li and Hervé investigated several PMs with two distinct Schönflies modes. The Schönflies motion contains three independent translations and one pure rotation about an axis of fixed direction, namely 3T1R. The authors continued in [25] to present the systematic approach to synthesize the iso-constrained parallel Schönflies motion generators with two identical 5-*dof* limbs.

The type synthesis of the 3T1R PM with four identical limb structures was performed in [26], which leads to a kinematic architecture with four revolute actuators, namely the 4-RUU PM. In [27], eight solutions of the direct kinematics were enumerated by using the linear implicitization algorithm. Amine et al. in [28,29] investigated the singularity conditions of the 4-RUU PM by using the Grassmann–Cayley Algebra and the Grassmann Geometry. It is shown that the 4-RUU PM is an over-constrained manipulator and it shares some common properties among the constraint wrenches.

By using an algebraic description of the manipulator and the Study's kinematic mapping based upon [30], a characterization of the operation modes of the 4-RUU PM is discussed in more details in this paper. Due to the unique topology of the RUU limb that comprises two links with one revolute actuator attached to the base, the actuated joint angle always appears in every constraint equation. This kinematic issue does not allow computation of a primary decomposition because the constraint equation changes for every joint inputs. As a consequence, the 4-RUU PM is decomposed into two iso-constrained 2-RUU PM. The constraint equations of each 2-RUU PM are initially derived and the primary decomposition is computed. It turns out that the 2-

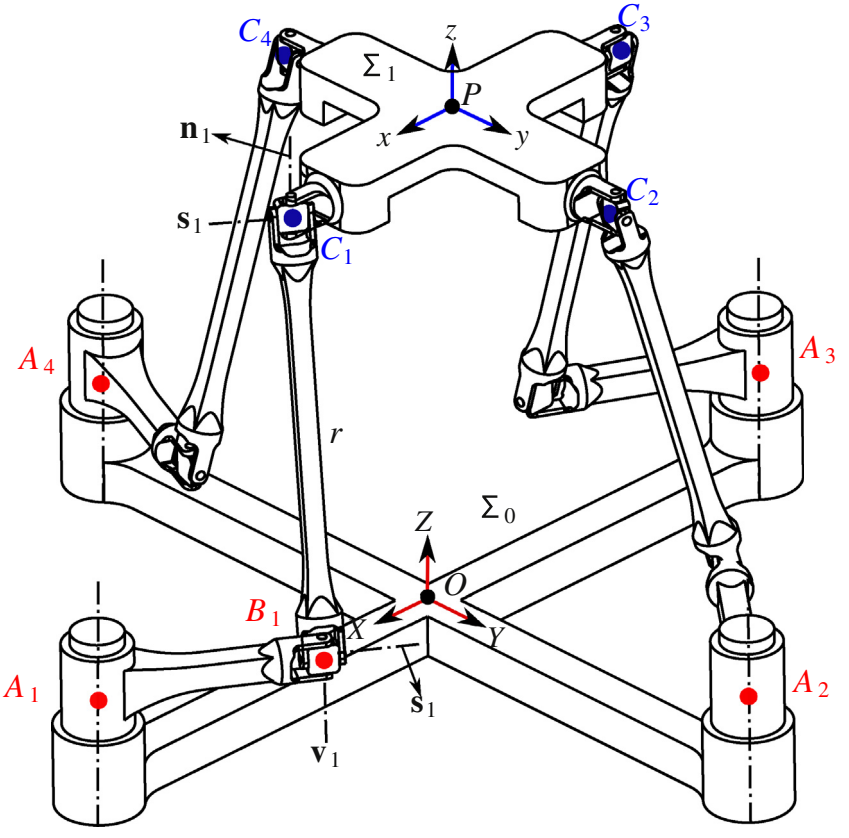

Fig. 1. The 4-RUU PM.

Please cite this article as: L. Nurahmi, et al., Reconfiguration analysis of a 4-RUU parallel manipulator, Mech. Mach. Theory (2015), http://dx.doi.org/10.1016/j.mechmachtheory.2015.09.004