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Type Synthesis of 3-DOF multi-mode translational/spherical parallel mechanisms with lockable joints ☆

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ABSTRACT

A 3-DOF (degrees-of-freedom) multi-mode translational/spherical PM (parallel mechanism) with lockable joints is a novel reconfigurable PM. It has both 3-DOF spatial translational operation mode and 3-DOF spherical operation mode. This paper presents an approach to the type synthesis of translational/spherical PMs with lockable joints. Using the proposed approach, several 3-DOF translational/spherical PMs are obtained. It is found that these translational/spherical PMs do not encounter constraint singular configurations and self-motion of sub-chain of a leg during reconfiguration. The approach can also be used for synthesizing other classes of multi-mode PMs with lockable joints, multi-mode PMs with variable kinematic joints, partially decoupled PMs, and reconfigurable PMs with a reconfigurable platform.

1. Introduction

To develop reconfigurable manufacturing systems with a short changeover time, multi-mode PMs (parallel mechanisms) (also PMs with multiple operation modes or disassembly-free reconfigurable PMs) have received much attention from researchers since 2007 [1–8]. Multi-mode PMs have the following characteristics: a) Fewer actuators are needed for the moving platform to realize at least two motion patterns; and b) Less time is needed in reconfiguring the PM since there is no need to disassemble the PM in the process of reconfiguration. During the past ten years, a number of multi-mode PMs have been proposed [1–8] and a systematic approach [4,8] has been developed for the design of multi-mode PMs that have no lockable joint[1]. Fig. 1 shows a 3-DOF(degrees-of-freedom) multi-mode PM developed by the first author's team at Heriot-Watt University, which is called DIRECTOR (DIsassembly-free REConfigurable parallel manipulaTOR). The DIRECTOR has two 3-DOF operation modes: Operation Mode 1 — PPR equivalent mode — in which the moving platform rotates about an axis parallel to Y-axis that translates along the O-YZ plane, and Operation Mode 2 — E equivalent mode — in which the moving platform undergoes planar motion or rotates about an axis parallel to X-axis that translates along the O-YZ plane. It is composed of two PRU legs and one PUU leg. Here and throughout this paper, R, P and U denote a revolute joint, prismatic joint and universal joint respectively. As pointed out in [8], multi-mode PMs without lockable joint must pass through constraint singular configurations when switching from one operation mode to another. Brakes and timing belts are used to ensure the DIRECTOR passes through the constraint singular configurations.

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[1] A lockable joint in this paper refers to a joint that can be locked by a physical stopper attached to the joint itself.

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Nomenclature

A joint	Lockable revolute joint that is locked in all the operation modes except operation mode A a multi-mode PM (parallel mechanism)
B joint	Lockable revolute joint that is locked in all the operation modes except operation mode B of a multi-mode PM
m	Number of joints in a leg of a multi-mode PM
m_A	Number of joints in a leg of PMs with a mono-operation mode associated with mode A of a multi-mode PM
m_B	Number of joints in a leg of PMs with a mono-operation mode associated with mode B of a multi-mode PM
m_c	Number of non-lockable joints in a leg of a multi-mode PM
R joint	Revolute joint
R̀ joint	R joints within the same leg are parallel
Ŕ joint	R joints within the same leg are parallel but are not parallel to the axes of the Ř joints
Ř joint	R joints within a PM meet at one point
R^u joint	R joints whose axes are parallel to the axes of R joints within the same leg and meets the intersection of the axes of the Ř joints with a multi-mode PM in a transition configuration
ζ	Wrench
ζ_0	Wrench of 0-pitch (constraint force)
ζ_∞	Wrench of ∞-pitch (constraint couple)

In addition, the first author of this paper also proposed a reconfigurable 3-5R PM with a Bricard-linkage-based reconfigurable moving platform (Fig. 2), which was investigated in detail in [9]. The mechanism (Fig. 2(a)) is composed of three 5R legs connecting the Bricard-linkage-based reconfigurable moving platform to the base. In each leg, the axes of the intermediate three R joints (2, 3 and 4), have parallel axes. The axes of the first joints (1) in all the legs meet at one point. The axis of the fifth joint (5) in each leg is coaxial with the axis of one R joint (6) of the Bricard linkage. By locking one R joint of the Bricard-linkage-based reconfigurable moving platform at different positions, the relative locations of the fifth joints in all the legs may vary. This leads to that the moving platform can undergo several 3-DOF motion patterns including spatial translation (Fig. 2(b)), spherical motion (Fig. 2(c)), planar motion (along three different planes), zero-torsion motion and general 3-DOF motion. Fig. 2(d) shows a prototype of this mechanism built in 2010 [9]. The use of reconfigurable platform makes it possible for a PM to transit from one operation mode to another without passing through constraint singularities.

A systematic study has also been made on metamorphic mechanisms [11] and metamorphic PMs [10,12,13,16]. For example, metamorphic PMs have been proposed by using reconfigurable U joint [10,12] and the variable axis joints [13]. These PMs are in fact kinematically redundant PMs. To realize the mobility change, these PMs must go through configurations in which a sub-chain of a leg is in self-motion.

Meanwhile, reconfigurable PMs with lockable joints have been proposed [14–16]. In [17], a systematic method has been developed for the construction of single-loop mechanisms with two operation modes from two single-loop overconstrained mechanisms by sharing different number of common joints. However, no systematic method has been proposed for the type synthesis of multi-mode PMs with lockable joints for two specified motion patterns.

In this paper, the approach to the type synthesis of multi-mode PMs without lockable joints [4,8] and single-loop mechanisms with two operation modes [17] will be further developed for synthesizing multi-mode PMs with lockable joints. During reconfiguration, such multi-mode PMs may avoid both constraint singular configurations, which multi-mode PMs without lockable joints suffer [4,8], or self-motion of a sub-chain, which the metamorphic PMs using reconfigurable joints or variable-axis joints [12,13] encounter.

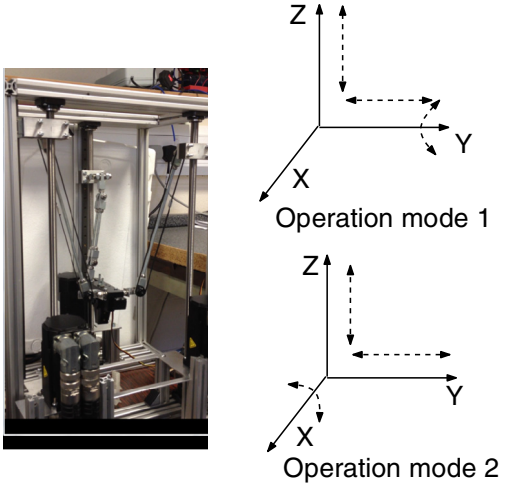

Fig. 1. DIRECTOR — a 3-DOF multi-mode PM.

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