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Research paper

Structural synthesis of a class of two-loop generalized parallel mechanisms

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ABSTRACT

The conventional parallel mechanism (CPM) is characterized by connecting serial kinematic limbs or chains to the moving platform or linkage. The mobility and motion pattern of the CPM may be further constrained by adding a coupling sub-chain to serial kinematic chains. That will result in a new class of mechanisms called generalized parallel mechanisms or GPMs for short. While the systematic mobility analysis and structural synthesis of GPMs are more challenging and have rarely been studied, the application of the coupling sub-chain possesses the potential for enhanced functionality and performance. This paper proposes a novel approach for synthesizing two-loop mechanisms with coupling sub-chains that form the basic building blocks for GPMs. The screw theory based constraint synthesis method is advocated. Examples are enumerated to demonstrate the feasibility of the proposed approach.

1. Introduction

A parallel mechanism is a multi-loop mechanism with several independent serial kinematic limbs connecting from the moving platform to the fixed base [1–3]. To reduce the total amount of floating weights, the actuated joints in the connecting chains are often placed at or near the base. Such conventional parallel mechanisms (CPMs) have been focused on in the research during the past decades. In recent years, however, significant research attention has been drawn to a new class of parallel mechanisms that are characterized by coupling sub-chains [4–6] or configurable platform [7,8]. They are called *generalized parallel mechanisms* (GPMs) and possess the potential for more tailored functionality or improved performance [9,10]. As the structural synthesis of GPM is much more complex than that of CPM, the current research focus has been on the two-loop mechanism, which is the basic building block of GPM [4,11]. It should be mentioned that the two-loop mechanisms proposed in this paper are two longitudinal loop mechanisms. This paper aims at developing a systematic approach for the structural synthesis of 2-DOF and two-loop mechanisms.

In general, to design a novel mechanism, structural synthesis and dimensional synthesis are two significant processes. In the creative design process of parallel manipulators, the structural synthesis is the essential step and received much attention in the past decades [12–15]. As for CPMs, Gogu [16] investigated the linear transformation to synthesize parallel manipulators. Huang and Li [17] explored parallel mechanisms with identical limbs using screw theory method. Fang and Tsai [18] proposed 4-DOF (degrees of freedom) and 5-DOF serial kinematic limbs to synthesize symmetrical parallel mechanisms. Kong and Gosselin [19] extended virtual chain approach to constructing 3T1R parallel manipulators. Hervé [20] and

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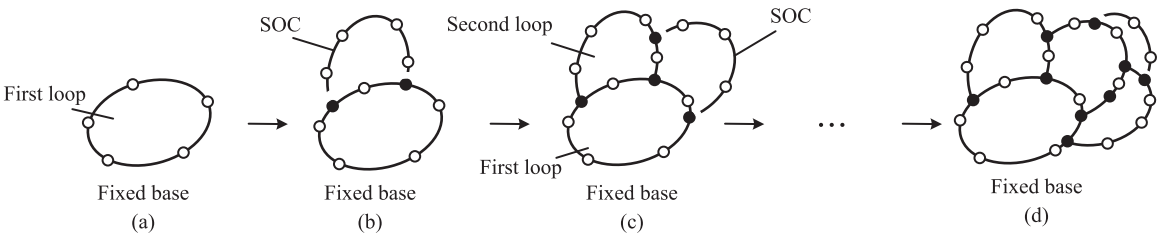

Fig. 1. Generating GPMs by assembling appropriate SOCs.

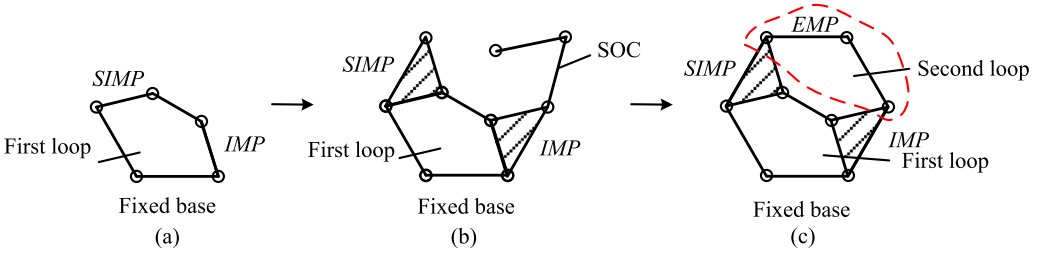

Fig. 2. The planar two-loop mechanism.

Li et al. [21] proposed several parallel mechanisms by displacement group. Yang et al. [22] presented a kind of characteristic set and equations to create parallel manipulators. In the process of synthesizing parallel mechanisms, Gao et al. [23] put forward the novel concept of G*f* set. By using the motion synthesis and kinematic mapping approach, Zhao et al. [24] designed planar mechanisms.

In recent years, the structural synthesis of GPMs has received much attention and efforts. Parallel mechanisms with coupling sub-chains or configurable moving platform have been synthesized for specified output motion [8,25] and possess the potential for higher accuracy and stiffness of the overall parallel mechanism. Based on chain groups, Campos, et al. [26] investigated the use of Assur groups for constructing generalized kinematic limbs and manipulators. Ding et al. [4,11] explored the mobility analysis method of two-layer and two-loop (TLTL) mechanisms, and synthesized novel hybrid parallel mechanisms with various DOFs. By using the embedment methodology, Shen et al. [27] presented several 6-DOF hybrid manipulators. Zeng and Fang [6] developed the displacement group theory for synthesizing spatial multi-loop manipulators and proposed the novel manipulators with deployability and kinematotropic property. For the sake of obtaining agile underwater stereo vision, Zoppi and Molfino [25,28] designed and analyzed a 3-DOF flexible parallel-hybrid mechanism. The complete set of mechanism solutions was presented by Bałchanowski [29] to synthesize spatial mechanisms.

This paper proposes a systematic structural synthesis approach for the 2-DOF two-loop mechanisms. This paper is organized as follows. Section 2 details the method for designing GPMs by adding appropriate serial kinematic chains. Section 3 gives the screw theory of closed-loop mechanisms and identifies mutual constraints between different loops. It then describes in detail the procedure for synthesizing two-loop mechanisms. Section 4 presents the constraint synthesis and virtual work based method for various kinematic legs and single-loop mechanisms. This method is then used to deduce various combinations of kinematic limbs and general single-loop mechanisms. Finally, some representative 2-DOF and two-loop mechanisms are constructed to demonstrate the feasibility of the proposed method.

2. A generative approach to the synthesis of GPMs

Based on screw theory, structural synthesis of GPMs can be realized by synthesizing different single-loop mechanisms from the end moving platform to the base [11]. According to the displacement subgroup method, the spatial multi-loop detachment method and the configuration cards method for displacement subsets [6] are developed for designing and analyzing coupling sub-chains. In addition, the GPMs derived by constructing parallel mechanisms with configurable platforms offer the higher accuracy than CPMs [8].

A GPM can be generated by starting with a single-loop mechanism and then adding several open kinematic chains on the top of one another [30]. Thus, a *V* independent closed-loop GPM is decomposed into a *V*-1 closed-loop mechanism with an additional serial open chain (SOC) on the top of it, as shown in Fig. 1. In this scheme, a two-loop mechanism, which will be used as the basic building block of GPMs, can be obtained by assembling one SOC to a single-loop mechanism. Taking the planar two-loop mechanism as an example, the process to construct GPMs can be described in detail. The mechanism in Fig. 2(a) is a planar five-bar closed-loop mechanism with 2-DOF, in which, *IMP* and *SIMP* respectively represent the first and second intermediate moving platforms of GPMs, and *EMP* is the end moving platform. After arranging one appropriate SOC on the five-bar closed-loop mechanism, a two-loop mechanism with 2-DOF can be derived, as shown in Fig. 2(c). In this way, the coupling sub-chain can be effectively determined. Similarly, more mutual constraints and less passive joints