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A new family of reconfigurable parallel mechanisms with diamond kinematotropic chain

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ABSTRACT

This paper focuses on a diamond kinematotropic chain which is integrated in the construction of a new family of reconfigurable parallel mechanisms. The branch transition of the planar diamond kinematotropic chain is analyzed and the equivalent kinematic joints corresponding to each motion branch are identified. Kinematic limbs that can provide a constraint force and a constraint couple are enumerated based on screw theory. Sixteen reconfigurable limbs which are capable of decoupling the constraint force and the constraint couple in the reconfigured configurations are constructed by integrating the diamond kinematotropic chain. A family of reconfigurable parallel mechanisms having three identical kinematic limbs is structured by connecting the platform to the base with reconfigurable limbs. The platform of each reconfigurable parallel mechanism has ability to perform variable motion modes such as 3 T, 2T1R, 2R1T and 3R. One of the reconfigurable parallel mechanisms is sketched as example and the actuation scheme for the mechanisms in this family is discussed.

1. Introduction

In the past decades, researchers have made great contributions to the study of traditional parallel mechanisms which usually have fixed mobility. However, with the development of science and technology, mechanisms with changeable mobility are expected in certain production to meet various task requirements. This leads to the new development of reconfigurable mechanisms including metamorphic mechanisms and kinematotropic linkages with variable topological configurations [1].

Metamorphic mechanisms [2,3] are a type of mechanical assembly with changeable mobility resorting to topological structure variation. Since proposed in 1998 [4], this kind of mechanisms has attracted substantial interest in the field of mechanisms and robotics. Parise et al. [5] developed ortho-planar metamorphic mechanisms that can perform structural change in orthogonal planes. Liu and Yang [6] presented three metamorphic ways for changing the topological structures of a metamorphic mechanism. Dai and Jones [7] introduced matrix representation for the topological changes of metamorphic mechanisms and formulated the matrix operations between different configurations. Yan and Kuo [8] presented the topological representations and characteristic analysis of topological variable joints. Wang and Dai [9] investigated the theoretical foundation of metamorphic mechanism and presented a metamorphic equation for representing the configuration change. Using five-bar spherical linkage as a metamorphic palm, Dai et al. [10–12] presented a novel multi-fingered robotic hand which has high dexterity and versatility. Zhang et al. [13] presented a new metamorphic kinematic pair and its evolved metamorphic parallel mechanism and investigated the topological reconfiguration together with mobility change. Gan et al. [14–16] presented a new joint coined as the rT joint and put forward a general procedure for mobility-change-aimed metamorphic parallel mechanism construction. Li et al. [17] presented a systematic structure synthesis methodology of single-driven metamorphic mechanisms based on augmented Assur groups.

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Comparing with the metamorphic mechanisms, kinematotropic linkages are a type of mechanisms characterized by the continuous variations in the positions of their variables and the resulted changes in the permanent finite mobility [18]. Starting from the mid-1990s, a number of kinematotropic linkages have been synthesized and their bifurcated motion characteristics were analyzed. Galletti and Fanghella [19] derived four basic single-loop kinematotropic linkages through a systematic approach based on the theory of the displacement groups. Subsequently, the study progressed to the method for identifying multi-loop kinematotropic mechanisms, which led to the identification of several multi-loop mechanisms [20]. Fanghella et al. [21] presented several parallel mechanisms that can change their group of motion constructed with the kinematotropic linkages. Gogu [22,23] analyzed the branching singularities in kinematotropic parallel mechanisms.

As aforementioned, the reconfigurable mechanisms have been extensively studied. However, very few reconfigurable parallel mechanisms with ability either to alter motion mode or to perform mobility change are presented [24]. Kong et al. [25] proposed a general method for type synthesis of parallel mechanisms with multiple operation modes. The kinematotropic linkages have different motion characteristics in different motion branches, it casts light in the direction of constructing reconfigurable parallel mechanisms by integrating kinematotropic linkages as subchains in the kinematic limbs. In this paper, the planar diamond single-loop chain with kinematotropic property is focused and the motion characteristics of this chain in different motion branches are analyzed. Kinematic limbs that can provide a constraint force and a constraint couple are enumerated based on screw theory. Sixteen reconfigurable limbs are constructed by integrating the diamond kinematotropic chain. A new family of reconfigurable parallel mechanisms is constructed with the reconfigurable limbs. One of the reconfigurable parallel mechanisms is sketched as example to illustrate its ability of performing variable motion modes. Finally, the actuation scheme for the mechanisms in this family is discussed.

2. Diamond kinematotropic chain

A planar four-bar parallelogram is a close chain with four links connected end to end by revolute joints, as shown in Fig. 1. Link 1 has the same length with link 3, link 2 has the same length with link 4, which determine the close chain has an important characteristic, that is, links 1 and 3 always have the same orientation and so are links 2 and 4. Based on this characteristic, the planar four-bar parallelogram has been used to design some distinct parallel mechanisms [26,27].

If the lengths of all the four links are equal, the four-bar parallelogram becomes a planar diamond chain. As Galletti and Fanghella mentioned in [19], the planar diamond chain is a single loop chain with kinematotropic property. In the special position as shown in Fig. 2(b), all the links are coincident with each other: the axis of revolute joint *B* is coincident with axis of joint *D*. This special position is called as a singular position. The mechanism can separate two branches of motion: by rotating joint *B*, the diamond chain will change to branch 2 as in Fig. 2(c), while by rotating joint *A*, the chain evolves into branch 1 as in Fig. 2(a). Two motors should be mounted to joints *A* and *B* respectively to actuate the diamond chain switching between different motion branches. Therefore, the chain is redundantly actuated in branch 1, only the motor mounted to joint *B* is active in branch 2 since joint *A* is locked. Fig. 3 shows the solid model of the diamond kinematotropic chain.

The relative motion between link 1 and link 3 are different with the kinematotropic chain in different motion branches: it is obviously a rotational motion in branch 2, while in branch 1, it is not clear and should be analyzed.

As shown in Fig. 4, when the kinematotropic chain is in branch 1, the instantaneous move direction of joints *D* and *C* is perpendicular to link 2(4), which determines that link 3 has an instantaneous translational motion in the direction perpendicular to link 2(4), the chain can be regarded as a virtual prismatic joint with changeable direction.

Therefore, the diamond kinematotropic chain can be regarded as different kinematic joints in different motion branches. Based on this property, the kinematotropic chain can be integrated into the design of reconfigurable limbs.

Reconfigurable limbs that are capable of providing different constraints are usable in the construction of reconfigurable parallel mechanisms. In this paper, the constraints considered are pure force and pure couple that are two particular forms of constraint. In 2002, Fang et al. [28] identified the limb structures that can provide a constraint force or a constraint couple, namely,

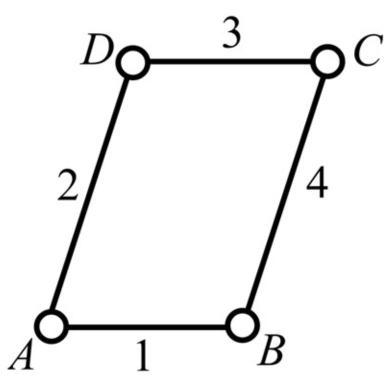

Fig. 1. Planar four-bar parallelogram.