Mechanism and Machine Theory 131 (2019) 152–171

Contents lists available at ScienceDirect

Mechanism and Machine Theory

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

Research paper

The isomorphic design and analysis of a novel plane-space polyhedral metamorphic mechanism

Rugui Wang[a,*], Yifeng Liao[a], Jian S Dai[b,*], Huiqing Chen[a], Ganwei Cai[a]

[a] College of Mechanical Engineering, Guangxi University, Nanning 530004, PR China
[b] Center for Robotics Research, King's College London, University of London, Strand, London WC2R 2LS, UK

ARTICLE INFO

Article history:
Received 9 January 2018
Revised 17 July 2018
Accepted 24 September 2018

Keywords:
Metamorphic mechanism
Isomorphism
Shape evolution
Screw theory
Workspace

ABSTRACT

This paper introduces the concept of isomorphism into the study of metamorphic mechanisms and presents the design of the isomorphic metamorphic mechanism, in which the structure is the same but the shape topology is different. A novel plane-space polyhedral metamorphic mechanism governed by the edge forming principle is developed. This mechanism is able to achieve the structural transformation between plane topology and space topology, and it has broad prospects for engineering application. The polyhedral metamorphic mechanism can be evolved into isomorphic mechanisms, like the spherical metamorphic mechanism and conical metamorphic mechanism, according to the scale relation between links. The evolution principle and movement conditions of the isomorphic mechanism are analyzed. The position and velocity of joints of novel plane-space isomorphism metamorphic mechanism and the workspace of these mechanisms are compared and analyzed using screw theory, and the configuration expanded analysis of novel plane-space metamorphic mechanism is performed. Finally, potential engineering applications are listed. The research results provide a reference for the reasonable choice of application configuration for such mechanisms.

© 2018 Elsevier Ltd. All rights reserved.

1. Introduction

In 1995, Dai and Rees discovered the metamorphic mechanism while studying the structure of various paper crafts and wrapping boxes, and it was formally proposed in 1998 [1] at the twenty-fifth session of the ASME mechanism and robotics biennial conference. Research on the design and analysis of the metamorphic mechanisms has greatly progressed since then. For instance, Li [2, 3] proposed a method in synthesizing a metamorphic mechanism and presented a distinguishing method for kinematic chain isomorphism of the metamorphic mechanism. In 2005 Dai [4] presented the topology of variable mobility-configurations of metamorphic mechanisms, and described transformations using matrix operations. In 2007, Wang [5] discussed the constitution and description of metamorphic mechanisms and built a series of metamorphic equations based on the fundamental characteristics of metamorphic mechanisms. In 2009, Dai [6] presented a novel robotic hand, Matahand, by introducing a metamorphic palm that generates reconfigurable motion. Li [7,8] presented the equivalent resistance gradient model of metamorphic mechanisms, and the associated design method. After 10 years of development, scholars all over the world have achieved much in the design and analysis of metamorphic mechanisms [9–18]. However,

* Corresponding authors.
E-mail addresses: rugui.wang@kcl.ac.uk (R. Wang), jian.dai@kcl.ac.uk (J.S. Dai), 794668743@qq.com (H. Chen), cganwei@gxu.edu.cn (G. Cai).

https://doi.org/10.1016/j.mechmachtheory.2018.09.017
0094-114X/© 2018 Elsevier Ltd. All rights reserved.

innovation in the related topic of structural configuration theory and method still need to be further studied. That limits the progress of metamorphic mechanisms, moreover, it inhibits wide application in engineering.

Isomorphism is a common term in chemistry and mathematics. It is even mentioned in art design [19, 20]. It explains geometrical entities that have the same structures but different shapes. Introducing the concept of isomorphism into the study of metamorphic mechanisms, researching the problems about the isomorphic design and analysis of the polyhedral metamorphic mechanism, that to say, when the metamorphic mechanism keeps the same structure but acquires a different shape topology, a different geometry is formed. On this basis, the related design and theoretical analysis of such metamorphic mechanisms are carried out. As a result, isomorphism generates a greater diversity in configurations of metamorphic mechanisms, allowing it to meet varied requirements in engineering, and thus promote development of production and technology.

Applying the principle of metamorphic mechanisms and the method of edge forming of polyhedrons, this paper presents a novel plane-space polyhedral metamorphic mechanism. Analyzing the appearance evolution principle of the mechanism then makes it to evolve into many shapes. Subsequently, the evolved spherical mechanism and conical mechanism are studied. The screw method is applied to analyze the position and velocity of polyhedral mechanisms, spherical mechanisms, and conical mechanisms. The similarities and differences of these mechanisms in kinematics are obtained by comparative analysis. Finally, the novel plane-space polyhedral metamorphic mechanism is expanded. It provides information for the reasonable selection of engineering mechanisms.

2. Shape evolution of the mechanism

Normally the mechanism corresponding to a packaging carton is developed by looking the edges, the creases of the paper, as the joints of the mechanism, and the connecting paperboards of the carton as the links of the mechanism [21–23]. However, the edges of the carton is regarded as the links of the mechanism and the corner tips of the carton as its joints, which is called the method of edge forming of polyhedron in this paper. Inspired by origami and artworks of the packaging, a novel plane-space polyhedral metamorphic mechanism on the basis of paper folding and the method of edge forming of polyhedron has been developed, as shown in Fig. 1.

In Fig. 1, a_1 is length of the bottom link, b_1 is length of the side link, c_1 is length of the metamorphic straight link, d_1 is the length of the metamorphic triangle side link, and d_{d1} is the length of the metamorphic triangle bottom link. Here c_1 is equal to d_1, so the metamorphic triangle is isosceles. In the polyhedral metamorphic mechanism shown in Fig. 1(b), the six joints A on the bottom and six joints C on the top of the mechanism are all revolute joints, and the six joints B on the side link is the spherical joints. The axial direction of the joint A of the bottom is the tangential direction of the circle of the six revolute joints A. During the working process of polyhedral metamorphic mechanism, the motion of each link of the mechanism is interrelated with each other. As shown in Fig. 2, in the process of the mechanism from the plane state to the final closed state, the motion trajectory of each link is fixed. Therefore, in practical engineering applications, three revolute joints are used to instead of the spherical joint B, as shown in Fig. 1(c), (d) and (e).

This novel metamorphic mechanism can be transformed from plane state to space state. It has advantages in precision and control. Its four working states are shown in Fig. 2.

When the mechanism is being transformed from the plane state to the first state, the metamorphic straight link c_1 gradually merges into the metamorphic triangle side link d_1. When they merge completely, the mechanism is in the second working state. While the mechanism is changing configuration, the side link b_1 is unable to move inwards. Suppose the rotation angle of the side link b_1 is θ_{b1}, called the metamorphic angle. When transforming the second working state to the third working state, the top merging angle is labeled θ_{d1}.

As shown in Fig. 3, the metamorphic angle θ_{b1} is affected by the metamorphic triangle bottom link d_{d1}. When d_{d1} changes, θ_{b1} will change, and the top merging angle θ_{d1} is similarly affected by metamorphic triangle side link d_1. When d_1 changes, θ_{d1} will change.

Setting $a_1 = 100$mm, $b_1 = 95$mm, the range of d_{d1} is [0, 109]. Then the relationship between d_{d1} and θ_{b1} is shown in Fig. 4.

One of the middle sections $A_zB_zC_zD_z$ of the mechanism is set as the solid line in Fig. 5.

If b_1 and d_1 satisfy the following relation

$$d_1 = 2a_1 \sin\left[\frac{\pi}{4} - \arcsin\left(\frac{b_1}{2a_1}\right)\right] \tag{1}$$

Then, as shown in the dotted line of Fig. 5, the middle section of the mechanism is tangent to a circle of radius a_1. As shown in Fig. 6, if all of the links use the arc links, then the mechanism evolves into a spherical mechanism.

The working state diagram of the spherical mechanism is shown in Fig. 7.

When θ_{b1} and θ_{d1} change, it does not just evolve into a spherical mechanism, but also can evolve into other shapes. When θ_{d1} is 0°, the polyhedral metamorphic mechanism can evolve into the conical metamorphic mechanism, as shown in Fig. 8. The spherical metamorphic mechanism and the conical metamorphic mechanism have the same structures with the polyhedral metamorphic mechanism, that is to say, the type of joints and the relationship among their joint directions in those three metamorphic mechanisms are the same. The type of mechanism depends on the outline of links and the relationship among their link lengths.

Download English Version:

https://daneshyari.com/en/article/11023532

Download Persian Version:

https://daneshyari.com/article/11023532

Daneshyari.com