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Design of a type of deployable/retractable mechanism using friction self-locking joint units

Xilun Ding, Xin Li *

School of Mechanical Engineering and Automation, Beihang University, 37 Xueyuan Road, Beijing, 100191, China

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ABSTRACT

To develop a new type of deployable/retractable mechanism, the joint friction effect is considered in this paper. Several types of mechanisms with self-lock and unlock functions are presented as design units. These units can be constructed in parallel, in series, or in both ways to form a type of large deployable mechanisms. The self-locking and unlocking conditions of the designed units are analysed, and a new type of deployable mechanism, which can be extended and retracted along a straight line, is designed with the proposed unit constructing method. The relationship between the unit constraint matrices at various configurations is presented. During the moving process, the topology structure of the deployable mechanism is variable, including changes of the joint direction and the joint number. A cable driving prototype with only one motor is built, and relevant simulations are conducted to verify the design method. The results demonstrate that the joint units perform perfectly and that a larger dimension deployable mechanism can be established.

1. Introduction

Mechanism topology configurations are often changed to satisfy various task requirements. Such mechanisms are known as the mechanisms with variable topologies (MVTs) [1,2]. The mobility of the MVTs may be accordingly variable due to the change of the joint types. A joint of this type is known as a variable kinematic joint or a variable joint by Yan and Kuo [3]. These researchers illustrated several types of joints, such as variable kinematic type and variable motion orientation type. Dai and Jones [4] analysed the mobility of metamorphic mechanisms. These researchers established mechanism models of artefacts to study their topology structures and mobility, with the metamorphic phases being completed by fixing a link or gluing flaps. However, this approach makes the inverse change difficult. Gan et al. [5] presented two types of joints that can be used to construct metamorphic parallel mechanisms. Balli and Chand [6,7] proposed a method for the synthesis of five-bar motion with variable topology between the extreme positions. The MVTs and metamorphic mechanisms have been studied using many methods, including the matrix representation method [8] and the topological graph method [9–11]. Pucheta et al. [12] analysed the topological constraints for metamorphic changes using the graph theory based method. The synthesis method has been successfully applied to design a family of low-voltage circuit breakers. Li and Dai [13] proposed a modularised structure synthesis method of single-driven metamorphic mechanisms based on the developed augmented Assur groups. However, in such mechanisms, the frictional effects are not taken into consideration for the following reasons. Generally, the degree of freedom of a mechanism is not affected by friction. In addition, using the topology method, the mechanism dimensional parameters are always removed, as well as the friction. However, if two links are in the self-locking state due to friction, then they can be observed to be an integral link. This approach should also agree with the form of

* Corresponding author. Tel.: +86 10 8233 9055.
E-mail addresses: xlding@buaa.edu.cn, li.xin@buaa.edu.cn (X. Li).

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MVTs. The model of the self-locking drive mechanisms has been studied by Oledzki [14], and four possible cases of drives were given. Leonesio and Bianchi [15] studied the self-locking conditions in closed loop mechanisms.

The MVTs and metamorphic mechanisms are used for many tasks, such as an operating mechanism for a spacecraft hatch [16]. Furthermore, relevant designs include the FAST mast for the International Space Station [17], the Deployable Optical Telescope [18], the Extendable and Retractable Mast [19], the Sula Boom for the Cibola Flight Experiment Satellite [20], the CFRP Boom and the DLR Boom [21]. New designs can be proposed by using the self-locking joint, which should improve the performance of the deployable mechanisms.

In this paper, the self-locking conditions of several joints are analysed. Next, methods of unlocking the joints are studied. According to the self-locking and unlocking conditions and the topological analysis, the self-locking joints are designed to construct a new type of deployable and retractable mechanisms. To verify our method, relevant simulations are conducted.

2. Straight-line self-locking and unlocking mechanism design

Before we discuss the detailed configurations of self-locking mechanisms, a common example is presented to introduce several design requirements.

Fig. 1 shows a type of gate lock. To open a locked gate, the door handle should be turned along axis A first. The D.O.F. of the gate is changed from 0 to 1. There are two independent motions (unlocking and open), for which two actuators are usually required to operate the gate automatically. It is possible to reduce an actuator. Additional constraints on a novel deployable mechanism design are proposed as follows.

(a) The mechanism should be self-locking when fully deployed. The unlocking force should be apparently smaller than the payload.
(b) It is better not to deploy the device by using self-locking transmission mechanisms because the transmission efficiency is always low.
(c) Only one actuator is used to control the deployment, locking, unlocking and retraction process.
(d) No reliance on singularity configurations, such as at the dead point of a planar four-bar mechanism. The singularity is sensitive to the relative positions of the particular links.

Friction is an inevitable phenomenon to address in the mechanical design, but it could be used to fulfil the requirements listed above via elaborative designs. A classical friction model is as shown in Fig. 2.

The coefficient of friction between the block and ground is μ, and the vertical angle of the exerted force F_1 is θ. The self-locking of the block is achieved whenever $\mu > \tan\theta$. With the help of F_2, the block can be unlocked because the angle of the resultant force is actually changed.

Based on this knowledge, several mechanisms meeting the presented requirements could be constructed, and their self-locking and unlocking conditions will be given in the following section. In this section, a floating type (E and F move with B) mechanism is constructed, as shown in Fig. 3.

In Fig. 3, if a proper joint friction is taken into consideration for joint 4, in the ideal situation, the mechanism will remain locked regardless of how large F_1 is unless the force F_2 is applied. Because the unlocking parts will move with B after being unlocked, the mechanism is called as a floating unlocking mechanism.

Correspondingly, another type of unlocking mechanism is also designed, as shown in Fig. 4. If an extra force is exerted on link G, then the mechanism will be unlocked. This mechanism is named the fixed unlocking mechanism because link G is hinged to the fixed frame.

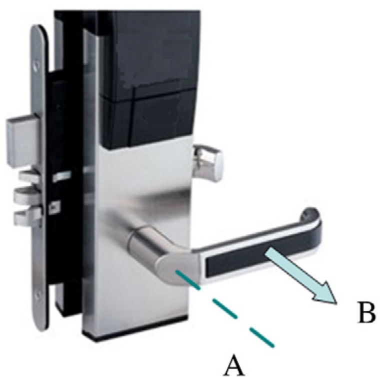

Fig. 1. A gate lock.