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Research paper

Reconfigurable deployable polyhedral mechanism based on extended parallelogram mechanism

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ABSTRACT

This paper dealt with the construction of a novel class of reconfigurable deployable polyhedral mechanisms (RDPMs). A parallelograms mechanism was designed by considering layers of links and size of revolute joints, and extended parallelogram mechanisms (EPaM) were constructed for the first time by inserting angulated elements and scissor-like elements into the parallelogram mechanism. The detailed parameters and magnification ratios of two kinds of EPaMs were calculated. A method was then proposed for constructing RDPMs based on EPaMs. The proposed method can provide more modular linkages for RDPMs, and all polyhedra constituted by regular polygons can be used to construct RDPMs. The obtained RDPMs can be reassembled by increasing or decreasing the number of basic elements to change the sizes beyond their deployment capacity. A prototype of reconfigurable deployable hexahedral mechanism based on EPaMs was fabricated to verify the feasibility of this class of RDPMs, and three reconfigurable deployable hexahedral mechanisms in three sizes based on the prototype were reassembled and tested.

1. Introduction

Deployable mechanisms, which are also known as deployable structures [1,2], have received much attention from many researchers due to their potential application in architecture and space exploration. The general design method of deployable mechanisms based on scissor-like was pioneered by Pienro's work on the movable theatre [3] and was further developed by Escrig [4]. Deployable mechanisms can be in different geometric shapes such as plane [5], cylinder [6], prism [7] and polyhedron [8–18] etc. Recently deployable polyhedral mechanisms (DPM) preserving polyhedral shape during deployment have become one of the research focuses in deployable mechanisms. They are usually synthesized by inserting modular linkages into the faces of regular or irregular polyhedra (platonic polyhedrons, semiregular polyhedrons and even Johnson solids). Hoberman [8] constructed the Hoberman sphere and other inventions based on angulated element, which later was generalized by You and Pellegrino [9]. Wohlhart [10–12] synthesized zig-zag linkages, regular polyhedral linkages and twisting towers using Nuremberg scissors, planar link groups and double rotor connecters respectively. Wei et al. [13] proposed a single-plane-symmetric 8-bar linkage and synthesized a class of semiregular and Johnson DPMs. Kiper et al. [14] proposed a synthesis method for constructing Fulleroid-like DPMs base on the principle of Cardan motion. Kovács et al. [15] constructed expendable polyhedral structures to imitate the reversible expansion of viruses. Wei et al. [16] created a class of

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Nomenclature

RDPM	reconfigurable deployable polyhedral mechanism
AEs	angulated elements
SEs	scissor-like elements
DSCM	double slider-crank mechanism
SSCM	single slider crank mechanism
PaM	parallelograms mechanism
EPaM	extended parallelogram mechanisms
RDHM	reconfigurable deployable hexahedral mechanism
l	side length of a polygon constructed by EPaM
l_{max}	maximum value of side length of a polygon constructed by EPaM
l_{min}	minimum value of side length of a polygon constructed by EPaM
L	distance between two adjacent revolute joints
GE_{max}	maximum value of the length of link GE
OE_{max}	maximum distance between points O and E
OE_{Dmin}	minimum distance between points O and E in the DSCM mode
OE_{Smin}	minimum distance between points O and E in the SSCM mode
OG_{max}	maximum value of the length of crank OG
R_{Dm}	magnification ratio of EPaMs in the DSCM mode
${R_{Dm}}^O$	magnification ratio of RDPMs in the DSCM mode
${R_m}^O$	magnification ratio of RDPMs
R_{Sm}	magnification ratio of EPaMs in the SSCM mode
${R_{Sm}}^O$	magnification ratio of RDPMs in the SSCM mode
w	diameter of revolute joints
θ	interior angle of the polygon constructed by EPaM
γ	included angle of the AE
γ_1	included angle of AE-1 in 2-AEs-EPaM
γ_2	included angle of AE-2 in 2-AEs-EPaM

expandable structure for spatial objects which were constructed by connecting a series of parallelogram mechanisms. Gosselin and Gagnon-Lachance [17] constructed a new type of one-DOF expandable mechanism using one-DOF planar linkages and spherical joints, and they also carried out detailed mechanical design to reach high expansion ratio [18].

In order to increase the adaptability of DPM as parallel manipulators with multiple operation modes [19,20], several reconfigurable deployable polyhedral mechanisms (RDPM) have been proposed recently. The term "deployable" refers to the scaling ability of the mechanisms. When a deployable mechanism is defined as "reconfigurable", the mechanism normally can change assembly modes or motion modes during operation without disassembly and reassembly. Wei and Dai [21] constructed a group of reconfigurable deployable platonic mechanisms using variable revolute joints, which can transform themselves between Fulleroid-like linkage type and the star-transformer linkage type. Li et al. [22,23] proposed a method of constructing reconfigurable deployable platonic mechanisms based on reconfigurable angulated elements. Especially, Wohlhart [24] constructed a class of reconfigurable mechanisms named "Cupola Linkages" based on double shields modules. Double shields modules can switch between double slider crank mechanisms and single slider crank mechanism, so that the "Cupola Linkages" is reconfigurable. However, the "Cupola Linkages" lacks of detailed mechanical design and expandability. In this paper, we designed parallelograms mechanism (PaM) by considering layers of links and size of revolute joints, and proposed extended parallelograms mechanism (EPaM) by inserting angulated elements (AEs) and scissor-like elements (SEs) into PaM. A family of RDPMs based on PaM and EPaM was synthesized. The proposed method can provide more modular linkages for RDPMs and increase the expandability of the RDPMs. The expandability mainly consists of two aspects: (1) We can design RDPMs using different modular linkages; (2) We can reassemble RDPMs by increasing or decreasing the number of AEs and SEs to change the size beyond their deployment capacity. The obtained RDPMs can have bigger magnification ratios and can be reassembled to different sizes to meet a variety of application requirements.

This paper is organized as follows: In Section 2, an n-parallelograms mechanism is built by arranging double slider crank mechanism circumferentially. Two kinds of extended parallelogram mechanisms with AEs and SEs are constructed in Section 3. A method for constructing EPaM-based RDPM is illustrated in Section 4. In Section 5, a prototype is fabricated to verify the proposed method. Section 6 concludes the paper.

2. n-parallelograms mechanism

In this section, n-parallelograms mechanism was designed and investigated. A double slider-crank mechanism (DSCM) consists of two identical cranks, two identical links and a slider (Fig. 1(a)). When two cranks coincide with each other, the