Mechanism and Machine Theory 120 (2018) 1–29

Contents lists available at ScienceDirect

Mechanism and Machine Theory

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

Research paper

Type synthesis of deployable single-loop overconstrained linkages based on Bennett linkages

Hongwei Guo[a], Xiaoke Song[a,*], Lifang Li[b], Zongquan Deng[a], Rongqiang Liu[a,*], Jinsong Geng[c]

[a] State Key Laboratory of Robotics and System, Harbin Institute of Technology, China
[b] Laboratory for Space Environment and Physical Sciences, Harbin Institute of Technology, China
[c] Harbin Engineering University, China

ARTICLE INFO

Article history:
Received 28 December 2016
Revised 24 August 2017
Accepted 17 September 2017

Keywords:
Type synthesis
Bennett linkage
Deployable mechanism
Symmetry
Screw theory

ABSTRACT

In this study, a series of spatial single-loop overconstrained linkages (SLOLs) is synthesized using Bennett linkages as the basic units. A set of 5R and 6R single-loop kinematic chains is constructed by combining Bennett linkages. The motion screw equations of these kinematic chains are obtained. Using screw theory their mobility is analyzed. Linkages with zero joint offset are constructed to create mechanisms with excellent deployability. The deployability of the SLOLs with symmetric configurations and their relationship with Bricard linkages are investigated. The symmetry of the obtained linkages is evaluated, and several linkages with line symmetry and plane symmetry are generated. Results show that a part of the synthesized linkages has excellent deployability and can serve as the units of deployable mechanisms. Intersections exist between the Bennett-based SLOLs and Bricard linkages.

© 2017 Elsevier Ltd. All rights reserved.

1. Introduction

Overconstrained linkages refer to the linkages that do not satisfy the Kutzbach–Grübler criterion. A single-loop overconstrained linkage (SLOL) has been the focus of mechanism research since Bennett proposed the Bennett linkage in 1903 [1]. Numerous 5R and 6R SLOLs have been synthesized based on the Bennett linkage. The synthesized methods can be divided into three kinds: (1) one joint of two Bennett linkages are collinear, then the joint is fixed, the rest six joints construct a 6R SLOL; (2) several Bennett linkages are summated, one link of these Bennett linkages has identical geometric parameters, and they are overlapped. The joints at one end of the link are fixed, at other end are merged to one joint, then a new SLOL is obtained; (3) one Bennett-based linkage is syncopated from another Bennett-based SLOL, in this method part of the links are overlapped, then the common joints and links are eliminated, the rest construct a new SLOL. Using the first method, Bennett [2] proposed the Bennett 6R hybrid linkages. Using the second method, Myard [3] constructed a plane-symmetric 5R SLOL by combining two Bennett linkages with a link twist of $\frac{\pi}{2}$, Goldberg [4] created the Goldberg 5R and 6R linkages by combining multiple Bennett linkages, Wholhart [5] constructed the Wholhart 6R linkage by combining two Goldberg 5R linkages, Waldron [6] proposed the Waldron hybrid 6R linkage. Chen and You constructed several 5R and 6R SLOLs by the second method [7,8] and third method [9]. Aside from the Bennett-based linkages, SLOLs have another major category, that

* Corresponding authors.
E-mail addresses: xiaoke0379@163.com (X. Song), liurq@hit.edu.cn (R. Liu).

http://dx.doi.org/10.1016/j.mechmachtheory.2017.09.013
0094-114X/© 2017 Elsevier Ltd. All rights reserved.

is, the Bricard-related linkages, which were proposed by Bricard [10] in his study on a mobile octahedron. Moreover, Baker summarized the Bennett-based SLOLs systematically and obtained their loop equations [11-13]. Chen described the existing SLOLs in her thesis [14].

As the two major categories of SLOLs, Bennett-based linkages and Bricard-related linkages both have restrictions on the geometric parameters. The research on the relevance between these two categories is limited. Song et al. [15] proposed a reconfigurable linkage between the line-symmetric Bricard linkage and the Bennett linkage. He also constructed a reconfigurable mechanism that can be reconfigured among five types of SLOLs [16]. However, these studies focused on specific linkages, the relevance of the two categories for general linkages was not examined.

An SLOL can move only when it follows specific geometric requirements, but it features excellent deployability compared with planar linkages. SLOLs have been the focus of studies on deployable mechanisms, and many researchers have paid considerable attention to this field. Gan and Pellegrino [17,18] first proposed the SLOLs that can be folded to a tight bundle and deployed to a plane polygon. Chen et al. [19,20] studied the deployability of plane-symmetric and three-fold symmetric Bricard linkages. Viquerat et al. [21] studied the deployability of a plane-symmetric Bricard linkage. These studies showed that the three-fold Bricard linkage can be folded completely and deployed to a plane triangle or plane hexagon and the plane-symmetric Bricard can be deployed to a rectangle given specific geometric parameters.

However, the existing studies on the synthesis of SLOLs focus on new geometric configurations, and the verification of the synthesis methods is conducted through prototyping. Furthermore, the theories to analyze the mobility of new configurations are limited. Deployable mechanisms are one industrial application of SLOLs. The deployability analysis of SLOLs created through type synthesis remains inadequate. Screw theory can be used to analyze the mobility of overconstrained mechanisms. Huang et al. proposed [22,23] a modified Kutzbach–Grübler criterion and analyzed numerous overconstrained linkages, they also analyzed the order of Bennett-based SLOLs [24] and proposed two theorems to analyze the mobility of SLOSs [25]. In this study, we proposed a series of Bennett-based SLOLs using the second synthesis method. The screw motion equations of these SLOLs are obtained, the singular states of the SLOL are also analyzed based on the screw motion equation. Then, the mobility of the obtained SLOLs is analyzed by screw theory. Subsequently, the relationship between the symmetric 6R linkages and Bricard-related linkages is studied, and the deployability of the symmetric 6R linkages is analyzed. Finally, the symmetry of the obtained linkages is analyzed, and the appropriate configurations for deployable mechanisms are selected.

This paper is organized as follows: In Section 2, the Bennett linkage is introduced briefly. In Section 3, a series of 5R, 6R SLOLs are synthesized using Bennett linkage as the basic units. In Section 4, the deployability of symmetric linkages is analyzed, and the obtained linkages are selected based on their symmetry. In Section 5, a conclusion is given.

2. Bennett linkage

The geometry of the Bennett linkage is shown as below:

As a SLOL, Bennett linkage should follow the below geometric constraints:

$$\begin{cases} a_1 = a_3 = a, a_2 = a_4 = b \\ \alpha_1 = \alpha_3 = \alpha, \alpha_2 = \alpha_4 = \beta \\ R_i = 0 (i = 1, 2, 3, 4) \\ \left|\frac{a}{\sin\alpha}\right| = \left|\frac{b}{\sin\beta}\right| \end{cases} \tag{1}$$

where $\alpha_i (i = 1, 2, 3, 4)$ denotes the twist of link i, a_i denotes the length of link i, R_i denotes the joint offset.

For the revolute variables, they follow the following condition:

$$\begin{cases} \theta_1 + \theta_3 = 2\pi, \theta_2 + \theta_4 = 2\pi \\ \tan\frac{\theta_1}{2}\tan\frac{\theta_2}{2} = \frac{\sin\frac{\beta+\alpha}{2}}{\sin\frac{\beta-\alpha}{2}} \end{cases} \tag{2}$$

In Bennett linkage, define θ_1 as θ, θ_2 as φ, we have $AC = \sqrt{a^2 + b^2 + 2ab\cos\varphi}$, $BD = \sqrt{a^2 + b^2 + 2ab\cos\theta}$. Define $AC = 2l$, $BD = 2m$, then Bennett linkage satisfies the following screw motion equation [26],

$$m(\$_A - \$_C) = l(\$_B - \$_D) \tag{3}$$

3. Type synthesis of SLOLs based on Bennett linkages

As a 4R SLOL, Bennett linkage can be used to constructed 5R, 6R SLOLs. In this section, we combine multi Bennett linkages, overlap the links with same parameters, then eliminate the overlapped links, fix part of the coincident joints, and translate the rest coincident joints to the single joints, then a new 5R or 6R kinematic chain is obtained. Using screw theory to analyze the mobility of the kinematic chain, the chain with one DOF is the SLOL, which we want to construct. The detailed process is shown as blow.

Download English Version:

https://daneshyari.com/en/article/5018716

Download Persian Version:

https://daneshyari.com/article/5018716

Daneshyari.com