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Kinematic synthesis of over-constrained double-spherical six-bar mechanism

Omar W. Maaroof [a,*], Mehmet İsmet Can Dede [b,1]

[a] Department of Mechatronics Engineering, Mosul University, 41002 Mosul, Iraq
[b] Department of Mechanical Engineering, İzmir Institute of Technology, 35430 İzmir, Turkey

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ABSTRACT

The main problem in the synthesis of any mechanism is the fact that the objective function of the mechanism, which will be synthesized, should be found and simplified by using appropriate algebraic method. Finding objective function and calculation process can become complicated especially when the number of design parameters is increased for the over-constrained mechanisms. A new technique for solving the kinematic synthesis of over-constrained double-spherical six-bar mechanism is developed and applied in this work. Interpolation approximation is used during synthesis procedure. A numerical example for the kinematic synthesis procedure is given to validate the theory in application.

1. Introduction

One of the main problems in kinematic synthesis is finding the function generation, which describes a relation between input and output of the mechanism with a desired function complying with the constraint conditions. Several mathematical methods including algebraic method, complex numbers method, vector method, quaternion and bi-quaternion methods, matrix and screw methods, and computer-aided-design (CAD) based methods have been developed and applied in order to solve for the kinematic synthesis problem. The kinematic synthesis problem becomes harder to solve for when the number of design parameters is increased especially for the over-constrained mechanisms.

Spherical mechanisms hold a transition position between the planar and spatial linkages, hence there is still an ongoing interest in solving for the kinematic synthesis of these mechanisms. Many studies have been conducted based on the limit positions of the input and output links. The design of spherical four-bar linkages for four specified orientations were was proposed by Ruth and McCarthy [1], where they described a CAD software solution procedure for spherical four-bar linkages that is based on Burmester's planar theory [2]. Cervantes-Sanchez and Medellin-Castillo [3,4] proposed a classification scheme and an improved motion analysis for spherical four-bar linkages. Shih-Hsi Tong and C.H. Chiang [5] discussed the syntheses of planar and spherical four-bar path generators, wherein they based the syntheses on the geometrical relations between the pole of the coupler and the joints of the mechanism.

Function generation synthesis of four-bar spherical linkage has been widely studied. Function generation for the entire motion cycle for spherical four-bar linkages has been discussed in [6]. Denavit and Hartenberg [7] presented the synthesis procedure for three precision points in the function generation of spherical four-bar mechanism. Zimmerman [8] proposed a different algorithm for the same mechanism for four precision points. Polynomial approximation is used for three, four and five precision points in the work of Murray and McCarthy [9], Alizade [10], and Alizade and Kilit [11], respectively for the spherical four-bar mechanism.

* Corresponding author. Tel.: +964 770 2044149.
E-mail addresses: omarmaaroof@uomosul.edu.iq (O.W. Maaroof), candede@iyte.edu.tr (M.İ.C. Dede).
[1] Tel.: +90 232 750 6778.

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Furthermore, Alizade and Gezgin [12] proposed a new function generation synthesis method for spherical four-bar mechanism with six independent parameters. They applied interpolation approximation, least-square approximation and Chebyshev approximation and evaluated the error magnitudes of the approximations. Furthermore, several researchers made significant contributions in this field and many mathematical techniques have been developed for the synthesis and analysis of spherical four-bar mechanisms [14–17].

Double-spherical six-bar mechanism is not a new mechanism and researchers have identified simple constraints to have the mechanism move. Some have named the mechanism as double-Hooke's-joint linkage [19] or 6R double-spherical over-constrained mechanism [20] and worked on the analysis of the mechanism. In the study of N. Makhsudyan et al. [13], the comparative analysis and synthesis of six-bar mechanisms are discussed for two serially connected spherical four-bar linkages and two serially connected planar four-bar linkages. However, they placed the input and output axes of the spherical linkages parallel and the construction parameters of the first spherical and planar mechanism are selected by the authors and not determined by the kinematic synthesis procedure.

The objective of this study is the function generation synthesis of double spherical six-bar mechanism. A passive revolute joint is inserted into the mechanism between the intersections of the joint axes of the two spherical four-bars. The passive joint's rotation axis is aligned with the line drawn from one intersection point to the other one. The objective functions for the first and the second spherical four-bar are determined. The objective function of the double-spherical six-bar mechanisms is defined. However, the objective function of the first spherical four-bar linkage is selected independent of the whole mechanism's function between the input and the output. Four precision points are selected by using equal spacing for the first spherical four-bar linkage and the double-spherical six-bar mechanism. Interpolation approximation method is used for designing the six construction parameters for the mechanism and the results are tabulated.

The next section of this paper provides the theory for the synthesis of six-bar mechanisms. Structural synthesis of double-spherical six-bar mechanism is explained through the analogy between various planar and spatial six-bar mechanisms. Later, the kinematic synthesis procedure for function generation of the double-spherical six-bar mechanism is explained. Objective function determination and interpolation approximation methods are then complemented by a numerical example to validate the theory presented in this paper. Finally, discussions on the developed methodology and the results are given in the last section.

2. Structural synthesis of six-bar mechanisms

This section consists of the analogy between the structural syntheses of six-bar mechanisms. The first step in the design of new robot manipulators is structural synthesis, which is the fundamental concept in mechanism design. In this section, structural synthesis of three 6R spatial closed-loop serial robot manipulators is considered.

The mobility of a robot mechanism describes the number of actuators needed to define the location of end-effectors. It is important that the mobility or the degrees of freedom (DoF) of robot manipulators ($M > 1$) indicates the number of independent input parameters to determine all the possible configurations of robot manipulators.

If links are connected in a loop by four single-DoF joints and the joints are configured so that the links move in parallel planes, the assembly is called a planar four-bar linkage [7]. If the linkage has four revolute joints with axes angled to intersect in a single point, then the links move on concentric spheres, and thus, the assembly is called a spherical four-bar linkage.

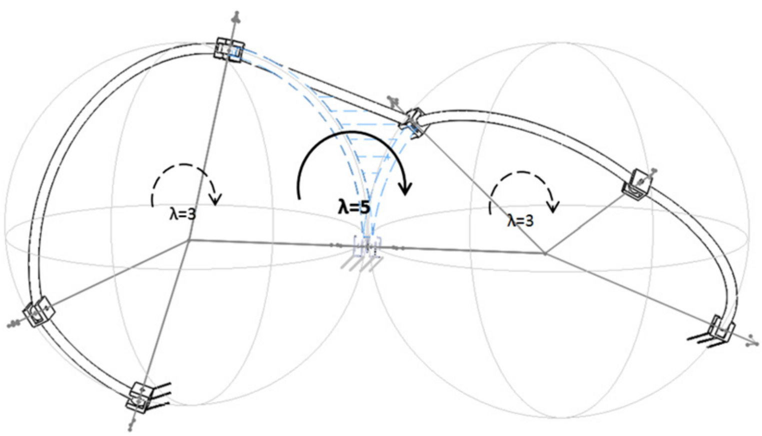

Fig. 1. (*RRR*)(*RRR*) double-spherical six-bar mechanism.