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Motion generation of spherical four-bar mechanism using harmonic characteristic parameters

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ABSTRACT

In an earlier work, we presented a method to address the path generation problems associated with spherical four-bar mechanism. In this paper, we seek to extend this approach to the synthesis of spherical four-bar linkages for motion generation. Through harmonic analysis, the output characteristics of a spherical four-bar mechanism is observed to be dependent on the rigid body rotation angle operator $\mu_p(t)$. Subsequently, a database that contains 221,968 sets of basic rotation angle dimensional types for a spherical four-bar mechanism was constructed. The theoretical formulas to calculate the actual dimension and installation parameters of spherical four-bar mechanism are deduced from the harmonic parameters for position output and the harmonic parameters for the rigid body rotation angle operator. On the basis of the theoretical formulas and the numerical atlas database, the motion generation problem for a spherical four-bar mechanism was solved. Finally, two examples are provided to demonstrate the validity of this method.

1. Introduction

Dimensional synthesis is an important field of research for studying spatial mechanisms. This paper examines the problems associated with the dimensional synthesis for a spherical four-bar mechanism for motion generation using a Fourier series. According to the definition given by Sandor and Erdman [1], motion generation or rigid body guidance requires that a rigid body be guided through a prescribed motion sequence. The difficult motion generation problem regarding coordinated position guidance synthesis was studied by Avilés et al. [2]. Several methods have been developed to solve the traditional motion generation problem. Bagci [3] proposed an approach to treat two prescribed positions in the motion generation problem for a spherical four-bar mechanism using inversion, pole, and overlay techniques. By using the least-squares method, an alternate set of mechanism constraint equations were formulated by Lee [4,5]. From this, the synthesis of two or more phases for prescribed rigid body positions was realised. Based on the classical Burmester theory, Ruth and McCarthy [6] developed a computer-aided design software system to provide a convenient means to design a spherical four-bar linkage to guide a body through four specified orientations. Shirazi [7] proposed computer modelling and geometric construction of a Burmester curve for four prescribed positions during motion generation in a spherical mechanism. Based on a set of successive points on the instantaneous screw axis, Russell [8] selected several specified joint axes to represent the coupler body positions. The positions were incorporated into the constraint equation, allowing motion generation for adjustable RRSS mechanisms. This method was later extended to synthesising a spatial RRSS mechanism to achieve phases for the precise rigid body positions [9]. In general, rigid body guidance synthesis at several precise positions can be realised using an analytical method. However, the literature available on the large number of prescribed position problems is limited. Based on four-dimensional

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Notation

α, γ, β, ξ, θ_{p0}	The length of each link of spherical four-bar mechanism.
θ_p	The angle between BC and BP.
α_i, γ_i, β_i, ξ_i, θ_{pi}, and θ_{p0i}	The optimal parameters of skewed angle of the revolution axis.
θ_1	Input angle.
θ'_1	The initial angle of the driving crank.
ω	The angular velocity of the driving crank.
θ_x	The rotation angle between the y' axis and the y axis.
μ	The rotation angle output.
μ_{pq}	The angle between the spherical arc PQ and BP.
μ_p	The angle between the great circle of the sphere and BP.
j	Imaginary unit.
n	The term of the Fourier series.
c_n, c_n'	The nth amplitude term of the RBRAO.
ϕ_n, ϕ_n'	The nth initial phase angle term of the RBRAO.
D_n, D'_n	The nth amplitude term of the prescribed coupler curve $\boldsymbol{r}_p$ projected onto the x axis and the y–z plane.
ζ_n, ζ'_n	The nth initial phase angle term of the prescribed coupler curve $\boldsymbol{r}_p$ projected onto the x axis and the y–z plane.
c_n''	The nth amplitude term of the function $\mu_p(t)$.
ϕ_n''	The nth initial phase angle term of the function $\mu_p(t)$.
D_n''	The nth amplitude term of the prescribed rotation angle.
ζ_n''	The nth initial phase angle term of the prescribed rotation angle.
π	Ratio of the circumference to its diameter.
δ	The hamming distance.
T_n	The RAHCPDT in the numerical atlas database.
T'_n	The RAHCPDT of the prescribed rigid body rotation angle.
T''_n	The RAHCPDT of every set of optimal parameters.

Euclidean space, a mathematical model of the distance between the spatial locations and the orientations for a candidate design sphere was given. By calculating the minimised distance, a finite set of desired spatial locations can be realised for the spherical mechanism [10]. Alizade [11] presented a method for the approximate motion synthesis of spherical linkages. Through analysis of four poses of motion generation for an RR dyad, the objective function was obtained. Then, the nonlinear terms of the function were transformed into linear terms. A solution to synthesis problems was obtained by Chebyshev using equal spacing. A framework for approximating the algebraic motions of spherical mechanisms using rational B-Spline spherical motions was presented by Ge and Larochelle [12]. Then, by representing the motion as algebraic curves and rational B-Spline curves in image space, the approximation was transformed into a curve approximation problem. This enabled the mechanism motion approximation from a computational geometric viewpoint to be studied. By using the small-crank mechanism theory, descriptions for the follower angular displacement in terms of the input crank angle can be obtained [13]. Then, the follower displacement can be expressed as a linear combination of simple harmonic functions of the first and second harmonics of the crank angle. Based on these approximate equations, function generation for spherical 4R mechanisms was proposed. Jiménez and Álvarez [14] described a system using a set of geometric constraints and introduced design requirements through a set of functional constraints. By minimising an objective function, the design parameter values

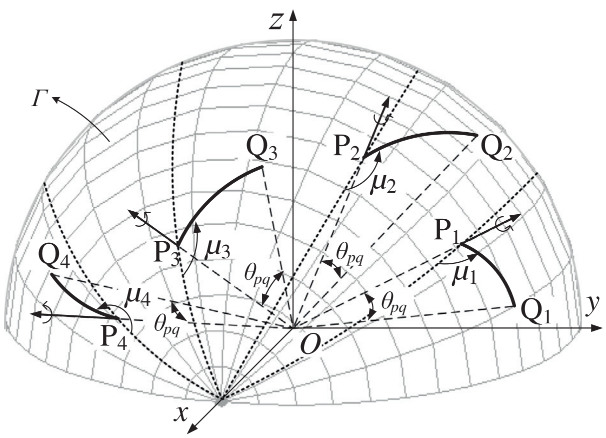

Fig. 1. Definition of position and rotation angle of a rigid body arc PQ.