Mechanism and Machine Theory 121 (2018) 28–41

Contents lists available at ScienceDirect

Mechanism and Machine Theory

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

Research paper

Non-integer-period motion generation of a planar four-bar mechanism using wavelet series

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ARTICLE INFO

Article history:
Received 26 May 2017
Revised 11 October 2017
Accepted 19 October 2017

Keywords:
Motion generation synthesis
Numerical atlas
Planar four-bar mechanism
Wavelet coefficients
Fuzzy identification

ABSTRACT

In this paper, on the basis of the theory of the Haar wavelet series, the early proposed method, which is used to solve the problem of planar four-bar path synthesis, is extended to motion generation synthesis of a planar four-bar mechanism. By analysing the wavelet coefficients between the rigid-body rotation angle and the connecting rod rotation angle of its corresponding basic dimensional type, the internal relationships are determined. Based on this finding, an output feature parameters database of planar four-bar motion generation including 101,408 sets of the basic dimensional type was established. Using the fuzzy identification method and theoretical formulas to compute the actual size and installing positions parameters of a planar four-bar mechanism, the synthesis of a planar four-bar motion generation mechanism can be achieved using the established numerical atlas, fuzzy identification method and theoretical formulas.

1. Introduction

In general, dimensional synthesis includes function synthesis, path synthesis and motion generation synthesis. Motion generation (or rigid body guidance) is more difficult than the other two types of synthesis. Motion generation requires that a point of guidance-line passes through the given points; on the other hand, it also requires a guidance-line that meets the required rotation angle of the rigid body. Motion generation synthesis is an important aspect of four-bar linkage design with practical significance in engineering fields. Numerous methods have been proposed to handle the planar four-bar motion generation mechanism. For example, an essential dimensional synthesis method of the four-bar motion generation mechanism is the numerical atlas method, which has been studied for years [1]. Hrones and Nelson [2] introduced an atlas including almost 10,000 curves for the four-bar mechanism, however, the efficiency and accuracy of the method were not adequate. Recently, with the prevalence of computer technology, the atlas method has gradually replaced the traditional atlas method for the dimensional synthesis of mechanisms. Nie et al. and Mullineux [3,4] studied the synthesis problem of planar and spatial mechanisms using the numerical atlas method. On the basis of the Buchberger algorithm, the synthesis method of planar four-bar rigid-body guidance was given by Li [5]. Aviles [6] presented a method which can achieve the appropriate synthesis of a planar mechanism. Then, the synthesis for several types of mechanisms and kinematics (function generation, path generation, motion generation, and the blending of the three types) was enabled. By using kinematic mapping, a general algorithm combining both types and dimensional synthesis for planar motion generation mechanisms

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https://doi.org/10.1016/j.mechmachtheory.2017.10.013
0094-114X/

Notation

i	imaginary unit
j	the wavelet decomposition series ($j=4,5$ or 6)
L_P	the length of link *DP*
L_Q	the length of link *DQ*
L_β	the length of *OA*
PQ	guidance-line of rigid body
θ_P	the angle between link *DP* and link *CD*
θ_Q	the angle between link *DQ* and link *CD*
γ (RBRA)	the angle between link *PQ* and *x*-axis
θ_2 (CRRA)	the angle between link *CD* and link *AB*
L_1, L_2, L_3, L_4	the length of link *AD, CD, BC*, and *AB*
L_1', L_2', L_3', L_4'	the mechanism's basic dimensional type
θ_1	the input angle
θ_t ($\theta_t=\omega t$)	a function of time parameter t
ω	the angular velocity of the driving crank
θ_1'	the initial angle
θ_4	the angle between link *AB* and *x*-axis
θ	the design interval
$\Delta\theta$	the scanning interval.
δ	the similarity of the required RBRA and the generated CRRA
ϕ	the scaling function of Haar wavelet
ψ	the wavelet function of Haar wavelet
$y_c^{(0)}$	the wavelet approximation of the CRRA
$w_c^{(n,l)}$	the *n*th-level *l*-th wavelet detail of the CRRA
$y_r^{(0)}$	the wavelet approximation of the RBRA
$w_r^{(n,l)}$	the *n*th-level *l*-th wavelet detail of the RBRA
$y_P^{(0)}$	the wavelet approximation of rigid body positions generated by objective mechanism
$w_P^{(n,l)}$	the *n*th-level *l*-th wavelet detail of the rigid body positions generated by objective mechanism
$y_P'^{(0)}$	the wavelet approximation of rigid body positions generated by the MBDT
$w_P'^{(n,l)}$	the *n*th-level *l*-th wavelet detail of rigid body positions generated by the MBDT

was developed by Hayes [7]. The constraint force design was presented by Yoon [8] as a new method, which allows for the topology optimization of a planar rigid body mechanism. By using a coupler-angle function curve, a new computer method that approximates synthesis for a four-bar path mechanism was presented by Yu [9]. A method for synthesizing a rigid-body passing through five prescribed positions was presented by Myszka et al. [10] and Zhao et al. [11]. An N-pose motion synthesis approach with expandable solution space for planar linkages was proposed in [12]. Liu and Lin [13] proposed a practical method for the synthesis of a rigid-body guidance mechanism by dividing the guidance task into path and pose generation independently. The synthesis of planar four-bar motion generation was realized by a guidance-line rotation method in [14]. Sancibrian et al. [15] presented a synthesis approach based on optimization in which the location of the centrode is included in the objective function. A unified synthesis method for simultaneously determining the type and dimension of a planar four-bar linkage system is proposed to solve body guidance synthesis problems in [16]. By using different evolution, the dimensional synthesis for planar mechanisms was realized in [17].

The Fourier series method is a widely used tool for the integral period in the numerical atlas method. Fourier series theory was first introduced by Meyer Zur Capellen [18] to analyse the comprehensive problem of planar linkage mechanisms. Ge et al. [19,20] used the Fourier descriptor to realize the synthesis problem of planar path synthesis and planar motion approximation. According to the Fourier series theory, the unified model of planar, spherical and spatial motion for linkage mechanism dimensional synthesis was established by Sun and Chu [21]. Freudenstein [22] as an earlier scholar explored the uses of Fourier transform to solve linkage mechanism synthesis, continued by Fanhang et al. [23] together with McGarva [24]. Chu and Cao [25] used fast Fourier transform for connecting rod curves synthesis of planar four-bar mechanism, and Sun [26] used this theory for the problem of rigid body guidance synthesis and achieved an effective solution to the rigid body guidance synthesis of a spherical four-bar mechanism.

Based on the previous studies [18–26], the Fourier series could be a proper method for integer period dimensional synthesis. However, in many conditions, more attention is given to non-integer-period dimensional synthesis than integer period dimensional synthesis. So non-integer-period dimensional synthesis is more noteworthy. However, the Fourier series cannot describe the non-integer periodic synthesis well because of this limitation. It is not a great solution for the synthesis of the non-integer-period rigid body guidance, while as an original method, the wavelet was first introduced in the geology field