



Research paper

Kinematic chains isomorphism identification using link connectivity number and entropy neglecting tolerance and clearance

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ABSTRACT

It has always been a challenge for the researchers to detect isomorphism of the kinematic chains since this leads to the most critical and intolerable problem of duplicate structures. In order to avoid duplication among the kinematic chains, there has always been a need to develop an easy, reliable and efficient method. In the present paper, an attempt has been made by involving two new invariants i.e. power and efficiency (neglecting link tolerance and joint clearance) for detecting the isomorphism among the kinematic chains. The invariants are calculated on the basis of entropy, which refers to the average information concept taken from the information theory. The validity and reliability of this method is demonstrated with the help of several simple joints kinematic chains (taken from the references given) of single and multi-degree of freedom (dof) to verify the results. The proposed method is very simple and reliable in the identification of isomorphism and also provides a freedom to decode a particular link.

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1. Introduction

Isomorphism decides structural similarity between kinematic chains and if not identified, causes duplicate structures. Therefore, the identification of isomorphism is an essential step to reduce time and effort. Many researchers of repute have contributed in this area [1–40]. Uicker and Raicu [1] discussed about the advantage of link-link form of incidence matrix over link-joint form of incidence matrix and represented a kinematic chain by a set of characteristic coefficients of the characteristic polynomial of the link-link square symmetric matrix of the chain. The authors used these identification codes to identify isomorphism. Mruthyunjaya [2–4] developed a fully computerized methodology for structural synthesis of kinematic chains, applied to several cases for which solutions were either fully or partially available. This was to check the reliability of the computer program and to derive new and complete collection of ninety seven 10-link, 3 dof simple joints kinematic chains. Despite the examples of co-spectral graphs in graph theoretic literature it was believed that for closed kinematic chains without singular links and/or without any over constrained sub-chains, the characteristic polynomials are most likely to be unique. Examples of 10 links, 1-dof, non-isomorphic chains by Mruthyunjaya and Balasubramanian [5] having co spectral graphs, however, belies the hopes.

Ambekar and Agrawal [6] proposed minimum code for kinematic chains with simple joints. They utilized upper triangular portion of adjacency matrices of kinematic chains to generate binary sequences and finally binary codes. The main

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advantage of this method is its decodability, but the main disadvantage is the computational complications when applied to large kinematic chains. Agrawal and Rao [7] proposed link-link variable characteristic matrix for representing a kinematic chain. The determinant of this matrix, called variable characteristic polynomial, is claimed to provide a powerful set of identification numbers for single as well as multi-loop kinematic chains with revolute pairs.

The Hamming number approach [8–10] is introduced for isomorphism identification, but the counter examples also are found against them. Chu and Cao [11] proposed link's Adjacent-Chain Table (ACT) method to identify isomorphism and number of inversions of kinematic chains. The authors opine that the proposed method is much simpler than the traditional methods of matrix. Yadav et al. [12,13] presented a sequential three-step test for isomorphism and proposed a link-link distance matrix approach. Yadav et al. [14] proposed linkage path code for the detection of isomorphism of planar kinematic chains with simple joints and turning pairs. Hwang and Chen [15] proposed an algorithm for the synthesis of all kinematic chains with two inversions. Some unconventional methods, such as genetic algorithm and artificial neural network approach as mentioned by the authors [16,17], are also introduced to pursue the issue.

Rao [18] discussed about Fuzzy numbers to investigate isomorphism among kinematic chains and inversions. But the main problem with this method is that secondary Fuzzy string is required when number of links goes on increasing and also calculation becomes so complicated that it is almost impossible to handle the situation. Chang et al. [19] proposed comparison of eigenvalues and eigenvectors of adjacent matrices for isomorphism identification.

He et al. [20] proposed the method of eigenvectors and eigenvalues of adjacency matrices to detect isomorphism through computation of eigenvectors and eigenvalues as well as some permutation operations (some modifications in the existing methods). Sarkar and Khare [21] proposed the concept of flow path, i.e. flow of motion between links in kinematic chains and mechanisms considering all the paths through which motion can be transmitted from the input to the output link. The authors rejected the concept of shortest path. This idea behind this was that if only the shortest route was considered, effect of other links that contribute significantly in the transmission of motion from input to output link is completely neglected. Cubillo and Wan [22] discussed necessary and sufficient conditions of the eigenvalues and eigenvectors of adjacent matrices of isomorphic chains and also they revised the theory published by Chang et al. [19] about mechanism kinematic chain isomorphism using adjacent matrices. The main advantage of this method is its easy computer execution.

Butcher and Hartman [23] proposed an algorithm to enumerate and classify planar simple joints kinematic chains using the hierarchical representation of Fang and Freudenstein. Rajesh and Linda [24] established the reliability of the existing spectral techniques i.e. characteristic polynomial and eigenvector approaches for isomorphism detection by determining the number of pairs of non-isomorphic chains, up to 14 links and one, two, and three dof.

Ding and Huang [25] developed a program for the automatic sketching of topological graphs of kinematic chains. They obtained a characteristic adjacency matrix of canonical perimeter topological graph by labeling vertex coordinates on perimeter topological graphs. After that they obtained characteristic representation code and this code has been used in the development of the program. Ding and Huang [26] proposed two basic loop operations based on the array representation of loops in topological graphs of kinematic chains.

Ding and Huang [27,28] extended their previous work done [25] to identify the isomorphism of kinematic chains after some modifications. Yang et al. [29] proposed a method to establish a necessary condition for identifying the isomorphism by comparing the calculation of incident matrices. Ding et al. [30] proposed an automatic method to synthesize the whole family of planar 1-dof kinematic chains with different links, and the corresponding atlas databases containing all the classified topological graphs.

Ding et al. [31] proposed an automatic method for getting a complete atlas database of 2-dof kinematic chains up to 15 links by first transforming the kinematic structure into a graph based representation and then an approach for the generation of all non-fractionated topological graphs of 2-dof kinematic chains using contracted graphs as well as a method for synthesizing all the fractionated topological graphs through the combination of corresponding 1-dof kinematic chains are addressed. Ding et al. [32] proposed the bicolor topological graph and the bicolor contracted graph to represent the topological structures of multiple joint kinematic chains. Then, the characteristic number string of bicolor topological graphs is proposed and used to efficiently detect isomorphism.

Ding et al. [33] proposed an automatic method to synthesize and classify all the kinematic structures of planar 3-dof closed loop mechanisms or robots up to 16 links. They addressed contracted graphs and topological graphs in a unique way to detect isomorphism. Zeng et al. [34] proposed the Dividing and Matching Algorithm, based on first dividing all the vertices into groups and then matching them for isomorphism identification. Yan and Chiu [35] presented a comprehensive literature review on the number synthesis of kinematic chains of mechanisms in which they introduced various terminology and definitions regarding kinematic chains of mechanism and also various methods for number synthesis have been presented and discussed.

Ding et al. [36] proposed an algorithm to obtain the characteristic number string of topological graphs with two multiple joints to enhance the efficiency of isomorphism identification. Ding et al. [37] proposed a method to automatically synthesize the complete set of planar non-fractionated kinematic chains with up to six independent loops in which they synthesized and classified the kinematic chains according to their planar and non-planar characteristics and derived constraint equations from the contracted graphs and used these equations to synthesize topological graphs of kinematic chains. Also they developed an algorithm to obtain the simplified characteristic codes of topological graphs for isomorphism identification.

Varadaraju and Mohankumar [38] focused on a method suitable for identification of isomorphism of kinematic chains with revolute and especially prismatic pairs. The authors used a method similar to hamming number technique to get a

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