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Research paper

A new atlas for 8-bar kinematic chains with up to 3 prismatic pairs using Joint Sorting Code

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ABSTRACT

It is important for designers of mechanical systems to visualize as many kinematic structures of mechanisms as possible. In this paper, a systematic methodology is proposed to generate all solutions of planar 8-bar kinematic chains (KCs) with up to 3 prismatic (P) pairs. First, a totally automated technique is developed to enumerate all available configurations of prismatic pairs for each KC. Second, Joint Sorting Code (JSC) is introduced for the first time to represent all KCs. Then a Kinematic Chain Structural Matrix (KCSM) is generated for all KCs to solve the problem of isomorphism. Finally, all results are evaluated by considering rules of P-joints assignment introduced by Ref. [1]. A vc++ code has been developed for enumeration, codes generation and isomorphism detection processes. The proposed methodology produces a new atlas for 8-bar chains that contains 16 groups and 48 subgroups. It contains 108, 426 and 816 KCs with 1P, 2P and 3P-joints respectively. The presented technique can be extended to single degree-of-freedom (DOF) planar n-bar chains with simple joints.

1. Introduction

Traditional conceptual design of mechanisms depends mainly on experience of designers. Synthesis of all feasible topologies of kinematic chains helps designers to visualize and select the appropriate chain for a specific task. Structural synthesis techniques should be simple, completely automated and should not produce isomorphic or rigid structures. Generation of planar kinematic chains usually assume that all pairs are revolute (R). However, prismatic pairs are essentially used in many applications of planar mechanisms.

In the few last decades, generation of kinematic chains that contain P-joints has a little work. Martin [1] presented a method to enumerate and codify solutions of type synthesis of linkage mechanisms with R and P-joints. A method to P-joint assignment was introduced. Dharanipragada [2] used split hamming string as a reliable and simple test for isomorphism among KCs with P-pairs. A computer program in PYTHON was applied successfully on a single DOF simple-jointed planar six-bar chains (up to all possible seven prismatic pairs) and eight-bar KCs (up to all ten P-pairs). Kang et al. [3] found that mechanisms with R-joints were a main concern so far but planar mechanisms with general joints including P-joints cannot be synthesized. However, they proposed a new concept of double-springs that can be used to connect a finite number of ground rectangular rigid blocks that discretize a given synthesis domain. Mitsi et al. [4–6] used R-joints and P-joints in position analysis of Assur group of classes 3 and 4. All possible configurations of Assur group, for a given position of its external joints, were determined. Five new kinds of class-three Assur group with two or three prismatic joints were

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investigated. Myszka and Murray [7] identified arrangements of five task positions for one-dimensional set of (R-P) dyads that are particularly useful in design situations using a P-joint.

Most structural synthesis techniques have been developed to generate *KCs* with R-pairs. Rao [8] developed a direct method for the generation of *n*-link Φ-DOF chains from *(n – 2)*-link and *f*-DOF chains using Hamming number technique. A new method was presented by Rao et al. [9] which did not require test for isomorphism using loop assortment and matrix representation. Ding and Huang [10] proposed an original theory of loop analysis which was applied to type analysis, isomorphism identification of KCs.

Kim et al. [11,12] used unified planar linkage consisting of rigid blocks connected by stiffness-varying zero-length springs and formulated the synthesis problem as iterative design optimization problem. Zongquan et al. [13] obtained vertex assortment according to the given DOF and link connection property of planar closed chain mechanisms. A method of adding sub-chains was proposed to solve isomorphism problem. Addition method with 2 links and 3 pairs was introduced by Nie et al. [14] for type synthesis of planar closed KCs. This method was applied to synthesize all KCs with up to 12 links and some KCs with 13 links or 14 links. Ding et al. [15] proposed an automatic approach for establishing complete atlas database of 2-DOF KCs up to 15 links using graph based representation. Yan and Chiu [16] provided an enumeration algorithm for constructing various atlases of generalized KCs based on link assortments, Robinson's method, generating function of planar blocks, Euler's formula, and graph theory. A systematic method for synthesis of KCs with one multiple joint and 3-DOF planar closed loop KCs was proposed by Ding et al. [17,18]. The whole families of multiple joint KCs with up to 16 links and all possible DOF were synthesized. A complete atlas database with valid KC classified for planar 3-DOF closed loop mechanisms up to 16-link was established. An improved method for systematic construction of generalized KCs was presented by Yan and Chiu [19] based on cut-links and nonplanar graph checking algorithms. The atlases of generalized KCs comprising up to 16 links were constructed. Ding et al. [20,21] introduced an improved algorithm to obtain the characteristic number string of topological graphs with two multiple joints to enhance the efficiency of isomorphism identification. A complete set of planar non-fractionated simple joint mechanisms with up to 19 links was synthesized.

Many researches have been investigated to solve the problem of isomorphism. Yang and Ding [22] proposed computer-aided method to automatically synthesize non-isomorphic mechanisms from the corresponding planar non-fractionated simple joint KCs. A matrix representation of KCs was introduced by Agrawal and Rao [23] to develop a unique mathematical expression for a KC. Yang et al. [24] used genetic algorithm and local search algorithm to detect isomorphism of KCs. A new method, based on theoretic approach for isomorphism detection, using Joint–Joint matrices was presented by Hasan et al. [25]. New algorithms, based on graph theory and combinatorial analysis, were developed by Pucheta and Cardona [26]. Ding and Huang [27–29] proposed perimeter loop, maximum perimeter degree sequence, and perimeter topological graph for isomorphism identification of KCs. Therefore, atlas database of KCs was established. Marin et al. [30] developed a multivalued neural network that enables a simplified formulation of graph isomorphism problem. Zeng et al. [31] proposed dividing and matching algorithm to detect whether the adjacency matrices of two graphs can be adjusted to be equivalent by changing the order of vertices. A satisfactory solution to isomorphism detection was developed by Singh [32] using Hamming method. Kamesh et al. [33] presented a new concept, net distance, based on graph theory to be a quantitative measure to assess isomorphism in planar KCs.

In this work, a complete automated algorithm is proposed to obtain all available 1-DOF 8-bar chains with up to 3P-joints. However, the proposed algorithm will be discussed in three main stages: (1) assignment of P-joints, (2) generation of codes and (3) evaluation of KCs.

2. Assignment of P-joints

It is well known that traditional atlas of 1-DOF 8-bar chains, presented by Tsai [34], contains sixteen topologies. All topologies are assumed to have R-pairs. In the proposed methodology, some of these R-pairs should be replaced by P-joints. Therefore, all possible configurations of P-joints assignment should be enumerated.

2.1. Topological analysis of 8-bar KCs

A kinematic chain should be analyzed to identify its topological characteristics. Types of links, types of joints, number of links and number of joints should be identified. Generally, for a kinematic chain, the total number of independent loops and the peripheral loop are given by relation (1) indicated in Ref. [35].

$$x = \frac{n + 1 - f}{2} \tag{1}$$

Where: x: total number of independent loops including peripheral loop

n: number of links
f: degree of freedom (DOF)

Each KC in Fig. 1 has 8-links and 10 revolute (R) joints. Hence, each chain has 4 independent loops including peripheral loop. For example, chain-1 has three independent loops namely loop-1, loop-2 and loop-3 in addition to a peripheral loop L_P as shown in Fig. 2. A detailed configuration of each loop is illustrated in Table 1.