ANALYSIS OF STRUCTURAL CHARACTERISTICS OF PLANAR KINEMATIC CHAIN TO APPLY GRADIENT CONCEPT

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ABSTRACT

Every machine is a mechanism or combination of mechanisms. Kinematic characteristics of kinematic chains depends on link assortment, type of loop, type of joints and their topology. Different mechanisms give different motion characteristics because of difference in connectivity. An attempt has been made to reveal the characteristics of kinematic chains on the basis of topology. A unique concept is proposed to grade the kinematic chains on the basis of kinematic characteristics. The proposed method is able to reveal kinematic characteristics such as angular velocity, and mechanical advantage based on their topology and compare kinematic chains. Kinematic chains are directly used for writing the distance matrix. The concept has great potential and can be used to study symmetry and parallelism which are useful in structural synthesis and platform-type robots respectively. An analysis of structural characteristics of planar kinematic chain is done here so that the concept of gradient method can be applied.

Keyword: - *Isomorphism, kinematic chains, parallelism, symmetry, mechanisms*

1. INTRODUCTION

There are few major problems in creating distinct planar kinematic chains one of them is the detection of isomorphism. Much time and effort has been spent to developing a reliable and computationally efficient and effective technique. Structural analysis and synthesis is very much important to design the mechanisms. Identifying isomorphism between kinematic chains is a necessary step in the kinematic mechanism synthesis. Undetected isomorphism outcomes in duplicate solutions and excessive effort, and incorrectly identified isomorphism reduces probable candidates for new mechanisms. The study of mechanisms begins with the iron age when people started making simple machines.

Now a days mechanisms are encountered in all places from a nano-mechanical devices to the space shuttle. Due to the great requirement for a new mechanisms, automated design of mechanisms from a specified set of functional requirements is beneficial. In the duration of conceptual design phase some of the functional requirements can be converted into structural requirements of the mechanisms.

The structural studies of kinematic mechanisms are generally divided into two categories, these are structural synthesis and structural analysis. The structural synthesis of kinematic chains comprises enumerating all possible kinematic chains having a specified number of links, degrees of freedom and types of joints. One of the very important steps in this method is the detection of degenerate kinematic chains using Gruebler's degrees of freedom equation. Whereas in structural analysis, the main problems are isomorphism detection and identification of kind of mobility. Researchers in the mechanisms community follow different strategies to specify the non-isomorphic kinematic chains. However, most of the existing techniques are not computationally efficient and hence simply generation of non-isomorphic kinematic chains with fewer links is possible. Furthermore there are several differences in the results found by researchers in the mechanisms community.

Hence there is a need for an efficient, effective and reliable method for the synthesis of kinematic chains and a re-examination of the present results on kinematic synthesis to validate the present methods. This forms the primarily objective of this work.

In the structural analysis of planar kinematic chains one common error is to assume that the graph of a planar kinematic chain is a planar graph. It is pointed out recently that the main and important cause for this is the misuse of the term ‘planar’. In the mechanisms it means to lie in one or more parallel planes, but in graph theory it means to lie on a single plane. A number of algorithms for structural analysis, including the algorithms for degeneracy testing, isomorphism testing and mobility type identification, work under the assumption that the graph of a planar kinematic chain is a planar graph.

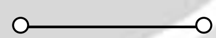
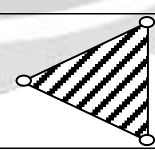
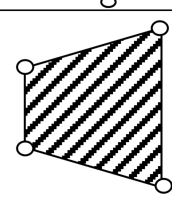
Mechanisms are generated by the designer’s knowledge, intuition, skill, information and experience. This approach however neither confirm the identification of all the feasible design options, nor does it essentially lead for an optimum design. During the conceptual design stage, some functional requirements of a desired mechanism can be converted into structural characteristics that can be engaged for systematic enumeration of mechanisms. The kinematic structure of a mechanism has the essential information as regards connectivity of different links with different kind of joints. Depending upon the number and kind of links, joints and their connectivity, the kinematic chains differ resulting in different output.

In the initial stage of mechanism design, it is very useful to find out all the distinct kinematic chains of the required number of links and degree of freedom in a logical way. When this is accomplished, each mechanism structure can be now, drawn and evaluated with respect to remaining functional requirements. This results in a class of possible mechanism that can be subjected to dimensional synthesis, kinematic and dynamic analysis, design optimization, and design detailing.

1.1 Links, Joints, and Loops

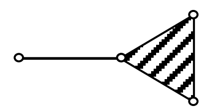
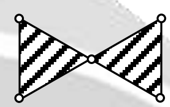
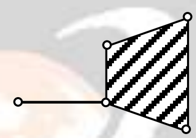
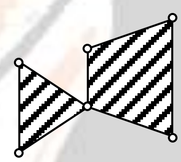
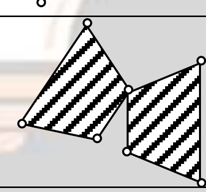
Link: A link can be defined (assumed) as a rigid body which has at least two nodes which are the points in which the other links can be attached. If a link has y nodes, then it is called y-nary link. Each link in a mechanism is represented by a polygon whose vertices represents the joint. Specially, a binary link is shown by a line with the two end vertices, a ternary link is shown by a cross-hatched triangle with the three vertices, a quaternary link is shown by a cross- hatched quadrilateral with the four vertices, and so on. Table -1 represents different types of links.

Table -1: Different types of Links

Binary Link	
Ternary Link	
Quaternary link	

Joint: A joint can be defined as a connection between the two or more links (at their nodes point), which allows some motion between the connected links, Table -2 Represents the different types of joints.

Table -2: Different Types of Joints

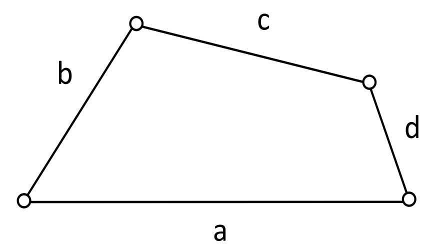
Links Used	Type of Joints
Two Binary Link	
One Binary Link & One Ternary Link	
Two Ternary Link	
One Binary Link & One Quaternary link	
One Ternary Link & One Quaternary link	
Two Quaternary link	

The term lower pair describes the joints with the surface contact between two elements of a pair and the term higher pair describes the joints with point or line contact between two elements of a pair. The revolute (R) and the prismatic (P) joints are the only joints which are useful in a planar mechanism have a pairs and that pairs are lower pairs.

Loop: A loop of a kinematic chain can be defined as path or circuit where one can travel from one joint and back to its traverse at least from joints.

1.2 Kinematic Chain: A kinematic chain can be defined (assumed) as an assembly of links and joints and the interconnection between them is in a manner to give a controlled output motion in response to a given input motion. Kinematic chain can be open type or closed type. When a kinematic chain makes a closed loop, it is then known as closed kinematic chain otherwise it is an open kinematic chain. A simple example of an open kinematic chain is an industrial robotic manipulator, like PUMA.

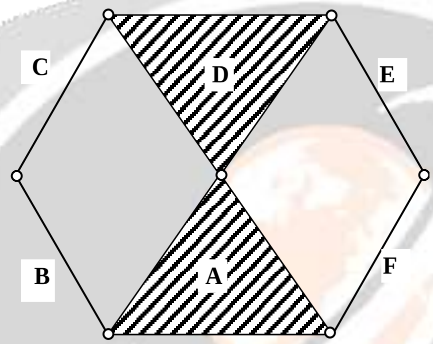
A simple closed kinematic chain contains only binary links, each link connecting from each other as represented in figure -1.



a, b, c, d - Binary Links

Fig -1: A Simple Closed Kinematic Chain

Also there may be a compound closed kinematic chain which contains ternary and higher-order links with binary links, each connecting with two or more than the other two links, as represented in figure -2.



A, D - Ternary Links. B, C, E, F - Binary Links

Fig -2: A Compound Closed Kinematic Chain

Further, kinematic chain can be categorised as planar and spatial kinematic chains. A planar kinematic chain comprises of links connected by joints so that all the points on the links are capable of moving in the parallel planes. Whereas spatial Kinematic chain has their links performing planner motions that are not parallel to each other.

2. LITERATURE SURVEY

The various literature survey details given below:

A.C. Rao [1] recommended usefulness of the fuzzy logic to check isomorphic chains and inversions. Fuzzy membership is given to the every link of a kinematic chain which improves a fuzzy vector in relation with fits for every link, on the basis of their adjacency. In other words, for every link separate vectors for first adjacency, second adjacency and so on are projected. Numerical measures to calculate the numerous individual chains with the similar number of links and degrees of freedom (d.o.f.) for the chain properties like symmetry, parallelism and mobility are projected. Fuzzy entropy is applied with the intention of evaluating the chains for the purpose of mobility.

Chang et al [2] introduced a new method based on Eigen vectors and Eigen values to identify isomorphism between kinematic chains. Kinematic chains are firstly represented by Adjacent Matrices. By calculating the Eigen values and related Eigen vectors of the Adjacent Matrices, the isomorphic chains can be recognized.

J. P. Cubillo and J. Wan [3] suggested a different method for identifying isomorphic chains. With this innovative procedure, it is only important to relate Eigen values and numerous Eigen vectors of adjacent matrices of isomorphic kinematic chains to recognize the isomorphism between kinematic chains.

S.C. Sarkar & Khare [4] proposed a concept for detecting the isomorphism and outcome for uncertainty in 10 link kinematic chain, by means of a theory of directed graph. In that case, flow of motion between links is expected considering all the possible paths for motion conduction as a substitute of only the shortest path.

A. Srinath and A.C. Rao [5] offered a technique which is based on the correlation concept for detection of the isomorphic chains with its inversions. Correlation between the two links shows the number of links typically connected to them. The method uses for adjacency matrix to find out the correlation matrix.

A. C. Rao and D. Varada Raju [6] proposed the concept of Hamming distance for the structural synthesis of kinematic chains. The Hamming code of the link is a row of the adjacency matrix related with a link. There are number of places where the Hamming codes for the two links vary is called as the Hamming distance between two links. The Hamming matrix is nothing but the matrix of the same size as the adjacency matrix when the i j^{th} entry relates to the Hamming distance between the links i and j. Link hamming number is nothing but the sum of the parallel row of the Hamming matrix. Similarly the chain Hamming number is the sum of the complete link Hamming numbers. The concatenation of the chain Hamming value and the whole link Hamming strings prepared in the decreasing order is known as the chain Hamming string.

T. S. Mruthyunjaya and H. R. Balasubramanian [7] suggested a vertex-vertex degree matrix where ith and jth entry are the sum of degrees of links i and j respectively when i and j are adjacent and which is equal to 1. All the 10-link kinematic chains with up to 3 degrees of freedom, the characteristic polynomial of that matrix effectively and efficiently recognized.

W. M. Hwang and Y. W. Hwang [8] suggested a very straight forward approach for the computer-aided structural plan of planar kinematic chains with very simple-simple joints, which comprises of efficient development of possible slender link adjacency matrices, recognition of degenerate chains and recognition of isomorphism between kinematic chains. Based upon the planned algorithm, a computer program is prepared so that the catalogues of planar kinematic chains with the known number of links and degrees of freedom can be synthesized.

Huafeng Ding and Zhen Huang [9] proposed some new concepts, for example, the maximum perimeter degree sequence, the perimeter topological graph and the perimeter loop, in addition with the method to find out the perimeter loop is also engaged. There after based upon the perimeter topological graph and various policy for relabeling their vertices canonically, a one-to-one explanatory method, the canonical adjacency matrix set of kinematic chains, is planned. One more characteristic of this concept is that in the canonical adjacency matrix set the element number is compacted, generally only one. Subsequently, an efficient and effective way to identify isomorphic chains is specified.

Renbin Xiao et al [10] suggested a new method for isomorphism detection based upon the two novel evolutionary approaches—ant algorithm (AA) and artificial immune system (AIS). Main features of the two evolutionary approaches which are noticed that it's efficient, robust, effective and general purpose algorithms for isomorphism detection despite their nondeterministic polynomial (NP) tough nature.

Gloria Galán-Marín et al [11] designed a unique multivalued neural network that permits a simplified formulation for the problem of graph isomorphism problem. In order to make improvement in the performance and presentation of the model, a supplementary constraint on the degree of combined vertices is imposed. The resulting distinct neural algorithm converges quickly under any set of primary conditions and does not need the parameter to be tuned.

A. C. Rao [12] presented a genetic algorithm for checking isomorphism between kinematic chains and to select the best frame and input links. The computational effort involved is less and the concept is unique as it satisfies both the necessary and sufficient requirements. Fitness of a binary string corresponding to a link is indicative of its design parameters. Consequently the fitness of a chain shows the number of design parameters active in motion generation. Kinematic chains are compared for function generation on the basis of the 'fitness' of first generation and second generation 'fitness,' etc., in that order.

Fei Yang et al [13] proposed a new method in which incident matrices is used to identify the isomorphism of topological graphs is proposed in this paper. The technique of obtaining the necessary condition for identifying the isomorphism is developed by comparing the calculation of incident matrices. In addition, it can be automatically implemented by programs.

Huafeng Ding and Zhen Huang [14] attempted a paper to solve the problem by finding an entirely different representation of graphs. First, the perimeter loop of a graph is traced from all the loops of the graph obtained by a new algorithm. From the perimeter loop a related perimeter graph is derived, which renders the forms of the graph canonical**.** Then canonical perimeter graph can be obtained by relabelling the perimeter graph, adjacency matrices of a graph reducing from thousands to several or even only one.

Huafeng Ding et al [15] offered an automatic approach to synthesize the entire family of the kinematic chain of 2- and 3-DOF fractionated planar kinematic structure. Isomorphism free algorithms for the combination of two or three non-fractionated topological graphs are recommended first. Then depending upon the algorithms and the atlas databases of the topological graphs of non-fractionated mechanisms, a common approach for the generation of fractionated topological graphs and the related atlas database for 2 and 3-DOF fractionated planar kinematic chains is suggested.

Kehan Zeng et al [16] recommended an algorithm called the Dividing and Matching Algorithm (DMA). Firstly, the vertices of each graph are divided by the degree. Then, vertex connection properties in a sub-graph and between sub-graphs are explored. According to the result expanded square degree and the correlation degree are planned, based on which, the Dividing Vertex Algorithm (DVA) is established to divide vertices into sets. Yet, it is proved that only the vertices from the corresponding sets among two graphs are possible to be matched, which escapes exhaustive search. Eventually, a backtracking process is employed to match the vertices among corresponding sets by calling up DVA repeatedly. DMA detects whether the adjacency matrices of two graphs can be adjusted to be equivalent by altering the orders of vertices. Justifications for the reliability of every part of DMA are given.

Eric A. Butcher and Chris Hartman [17] presented an algorithm to structurally classify planar and exhaustively enumerate simple-jointed kinematic chains using the hierarchical representation of Fang and Freudenstein in which all isomorphic chains are automatically eliminated in the enumeration procedure such that isomorphism testing on the final set of chains is eliminated.

S. Shende and A.C. Rao [18] dealt with the problem of detection of isomorphism which is as often as possible experienced in structural synthesis of kinematic chains. A fresh method which includes all necessary features of graph, easy to calculate and reliable, is proposed. Summation Polynomials are used instead of Characteristic Polynomials. The advantage is that they are easy to calculate. The coefficient and exponents of Summation Polynomials are extremely informative and from them important & valuable information regarding topology of kinematic chains can be expected. It is capable of identifying isomorphism in all kinds of planar kinematic chains i.e. chains of single degree or multi degree of freedom and multiple jointed chains.

E.R. Tuttle [19] presented a fully automated, mathematically rigorous procedure that produces all planar, non-fractionated, pin-jointed kinematic chains having 2-6 non-dependable loops and 1, 2 or 3 degrees of freedom. Moreover it also addresses the isomorphism problem and the elimination of rigid sub-chains. The computer programs can be run on any personal computer; more than 6 million kinematic chains and 100 million inversions have been produced.

Schmidt C. Linda and Harshawardhan Shetty [20] investigated the critical fact of Isomorphism detection in structural synthesis of mechanism. A Graph Theory has been connected to the structural analysis to recognize graph isomorphism, while generating new mechanisms. Linear time algorithm is presented here for isomorphism identification with its sentence structure rules.

J.N. Yadav et al [21] extended their work of Isomorphism identification through Distance Concept with personal computer. Another invariant, called the Arranged Sequences of Total Multiplicity Distance Ranks of all the Links **(**ASTMDRL), has been created for a binary chain. These invariants are derived from the connection interface variety of the considerable number of joints in a chain and are taken into consideration, with a view to upgrade the separating capacity of the new invariant. On the basis of this invariant, a computer aided method has been created for identifying Isomorphism between planar binary chains. However these strategies are complicated, difficult to put on and fail to reliably detect uniqueness or take excessive time for determining isomorphism of a kinematic chain.

3. CONCLUSIONS

The study was focused on the structural characteristics of planar kinematic chain and the methodology applied to find that characteristics. It is always challenging to find the best, easy, economical and efficient method to find the structural characteristics of a planar kinematic chain. The analysis of structural aspects of kinematic chains is very important for the invention and innovation point of view for mechanisms. Structural synthesis as well as analysis basically involves the study of the following:

1. Determination of all the feasible structurally different kinematic chains with a given number of links and degree of freedom i.e. testing of isomorphism.
2. Determination of all the feasible structurally different mechanisms that can be derived from kinematic chain i.e. detecting the inversions.
3. Determination, in the case of multi degree of freedom kinematic chains, whether the particular chain has total, partial and/or fractional freedom.
4. For a particular mechanism determining all the possible locations for giving input motion.

The gradient concept is very easy, economical, reliable and computationally efficient to find the structural characteristics of a planar kinematic chain and it can help the researchers to improve their quality of research as well as it can reduce the time taken also.

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