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CONCEPTUAL MECHANICAL ENGINEERING DESIGN

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Abstract: *This paper presents a new method for the identification of isomorphism among given kinematic chain [KC]. The suggested method is based on a physical connectivity matrix [PCM] of a given KC. Two structural invariants namely Sum of Absolute characteristic Polynomial Coefficients [SACP], and Maximum Absolute Value of Characteristic Polynomial Coefficients [MACP] have been calculated from PCM. These structural invariants have been used as the composite identification numbersof thekiematic chains and mechanisms . This study is very much helpful for designer to select the best possible mechanism kinematic chains to perform the specified task at the conceptual stage of design.*

***Keywords**: Kinematic Chain; Physical Connectivity Matrix; Sum of Absolute characteristic Polynomial Coefficients; Maximum Absolute Value of Characteristic Polynomial Coefficients.*

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1. INTRODUCTION

The conceptual design of mechanisms is a very important stage in the kinematic synthesis of mechanisms. A mechanism is a planar kinematic chain with one link. Many researchers in mechanism design have worked on the number, type, and structural synthesis of kinematic chains and few of them are [1–27]. Many design methodologies have been presented during the past 50 years for the conceptual design of mechanisms. Motives behind these studies range from the desire for an orderly classification system, to studies of mechanism degree of freedom to the hope of identifying the mechanisms. Methods for the recognition and identification of a given mechanism's kinematic structure can be divided into two main categories, graphical methods based on the visual inspection of various forms of simplified systematic diagrams and numerical methods, many of which are based on the theory of graphs. Many of these studies have been used successfully in practical applications

The usual approach is to identify the non-isomorphic, or feasible, mechanisms, from kinematic chains, based on inspection or observation .However, no efficient generalized method is known which will characterize the given mechanisms by inspection. Therefore, in this paper, a modifiedmethod to identify distinct mechanism from a given simple jointed kinematic chain is proposed.

2. IDENTIFICATION OF ISOMORPHISM AMONG THE KCS:

Theorem: Two similar square symmetric matrices have the same characteristic polynomial

Proof: Let the two KC are represented by the two similar matrices A and B such that $B = P^{I}AP$ for an invertible matrix P, taking into account that the matrix λI commutes with the matrix P and

$|P^{-I}| = |P|^{-I}$. Since the determinant of the product of two square matrices equals the product of their determinants. We have

$|B-\lambda I| = |P^{-I}AP - \lambda I| = |P^{-I}(A-\lambda I)P| = |P^{-I}|\,|(A-\lambda I)|\,|P| = |A-\lambda I|$

Hence, D(λ) of 'A' matrix = D(λ) of 'B' matrix.

D(λ) = Characteristic polynomial of the matrix.

It means that if D(λ) of two PCM representing two KC is same, their structural invariants 'SACP' and 'MACP' will also be same and the two KC are isomorphic otherwise non-isomorphic chains.

3. CHARACTERISTIC POLYNOMIAL OF [A] MATRIX

D(λ) Gives the characteristic polynomial of [A] matrix. The monic polynomial of degree n is given by equation.

$| (A-\lambda I) | = \lambda^n + a_1\lambda^{n-1} + a_2\lambda^{n-1} + a_1\lambda^{n-2} +$ ------------------- $a_{n-1}\lambda + a_n$

Where; n = number of simple joints in kinematic chain and 1, a_1, a_2, a_{n-1}, a_n are the characteristic polynomial coefficients.

The two important properties of the characteristic polynomials are

(a) The sum of the absolute values of the characteristics polynomial coefficients (SACP) is an invariants for a [A] matrix. i.e.

$|1| + |a_1| + |a_2| +$ -------------------$|a_{n-1}| + |a_n| =$ invariant

(b) The maximum absolute value of the characteristics polynomial coefficient (MACP) is another invariant for a [A] matrix.

4. METHODOLOGY

Let a square symmetric matrix A of size (n×n),where ‘n’ is the number of joints in a kinematic chain,be defined as;

$$A = \{a_{ij}\}_{nxn} \quad \text{---------------------------------------(1)}$$

where

$$a_{ij} = \{ \text{minimum path distance between joint i and joint j} \}$$
$$= 0, \text{ otherwise}$$

5. STRUCTURAL INVARIANTS [SACP] AND [MACP]

The characteristic polynomial is generally derived from (0,1) adjacency matrix. Many researchers have reported co-spectral graphs (the non-isomorphic KC having same Eigen spectrum derived from (0,1) adjacency matrix).But the proposed [SACP] matrix has additional information about the types of links existing in a mechanism KC. It has been verified that the characteristic polynomial and characteristic polynomial coefficients of [SACP] matrix are unique to clearly identify the mechanisms and even KC with co-spectral graphs. The proposed [SACP] matrix provides distinct set of characteristic polynomial coefficients of the kinematic chain with co-spectral graph also. Here the new composite invariants [SACP]. [$SACP_{max}$] of the [SACP] matrix are proposed and are obtained by using software MATLAB.

6. ILLUSTRATIVE EXAMPLES:

Example-1

Considering Stephenson's Six Bar 1 Degree of Freedom KC (Figure 1) and Watt's Six Bar 1 DOF KC (Figure 2)

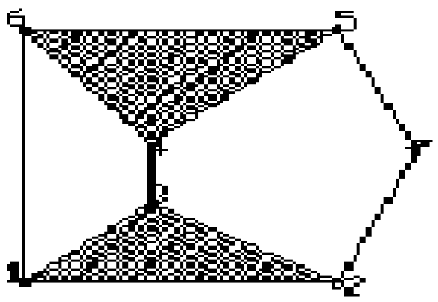

Figure 1

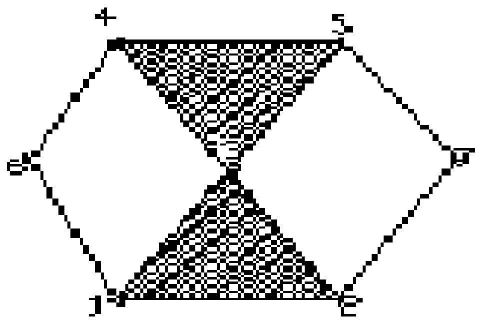

Figure 2

Using MATLAB,

From Path Matrix Method:

$$\mathbf{A1} = \begin{bmatrix} 0 & 1 & 1 & 2 & 2 & 1 & 2 \\ 1 & 0 & 1 & 2 & 2 & 2 & 1 \\ 1 & 1 & 0 & 1 & 2 & 2 & 2 \\ 2 & 2 & 1 & 0 & 1 & 1 & 2 \\ 2 & 2 & 2 & 1 & 0 & 1 & 1 \\ 1 & 2 & 2 & 1 & 1 & 0 & 2 \\ 2 & 1 & 2 & 2 & 1 & 2 & 0 \end{bmatrix} \quad \mathbf{A2} = \begin{bmatrix} 0 & 1 & 1 & 2 & 2 & 1 & 2 \\ 1 & 0 & 1 & 2 & 2 & 2 & 1 \\ 1 & 1 & 0 & 1 & 1 & 2 & 2 \\ 2 & 2 & 1 & 0 & 1 & 1 & 2 \\ 2 & 2 & 1 & 1 & 0 & 2 & 1 \\ 1 & 2 & 2 & 1 & 2 & 0 & 3 \\ 2 & 1 & 2 & 2 & 1 & 3 & 0 \end{bmatrix}$$

For [A1] :SACP = 863.0000 , MACP = 352.0000

For [A2] :SACP = 928.0000 , MACP = 393.0000

The two results are different, hence both the kinematic chains are non-isomorphic

Example-2

Considering two 10 Bar 1 DOF KCs Figure 3 and Figure 4

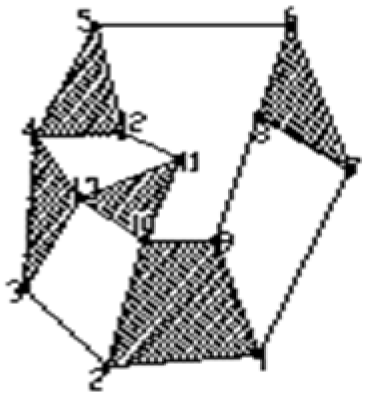

Figure 3

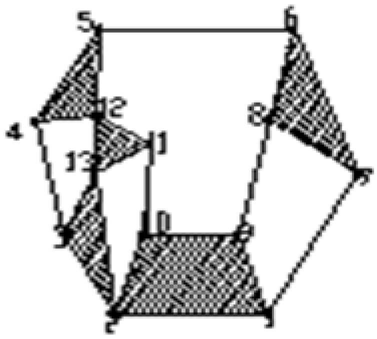

Figure 4

From Path Matrix Method:

$$
A3 = \begin{pmatrix}
0 & 1 & 2 & 3 & 3 & 2 & 1 & 2 & 1 & 2 & 3 & 4 & 3 \\
1 & 0 & 1 & 2 & 3 & 3 & 2 & 3 & 2 & 1 & 2 & 3 & 2 \\
2 & 1 & 0 & 1 & 2 & 3 & 3 & 4 & 3 & 2 & 2 & 2 & 1 \\
3 & 2 & 1 & 0 & 1 & 2 & 3 & 3 & 3 & 2 & 2 & 1 & 1 \\
3 & 3 & 2 & 1 & 0 & 1 & 2 & 2 & 3 & 3 & 2 & 1 & 2 \\
2 & 3 & 3 & 2 & 1 & 0 & 1 & 1 & 2 & 3 & 3 & 2 & 3 \\
1 & 2 & 3 & 3 & 2 & 1 & 0 & 1 & 2 & 3 & 4 & 3 & 4 \\
2 & 3 & 4 & 3 & 2 & 1 & 1 & 0 & 1 & 2 & 3 & 3 & 3 \\
1 & 2 & 3 & 3 & 3 & 2 & 2 & 1 & 0 & 1 & 2 & 3 & 2 \\
2 & 1 & 2 & 2 & 3 & 3 & 3 & 2 & 1 & 0 & 1 & 2 & 1 \\
3 & 2 & 2 & 2 & 2 & 3 & 4 & 3 & 2 & 1 & 0 & 1 & 1 \\
4 & 3 & 2 & 1 & 1 & 2 & 3 & 3 & 3 & 2 & 1 & 0 & 2 \\
3 & 2 & 1 & 1 & 2 & 3 & 4 & 3 & 2 & 1 & 1 & 2 & 0
\end{pmatrix}
$$

$$
A4 = \begin{pmatrix}
0 & 1 & 2 & 3 & 3 & 2 & 1 & 2 & 1 & 2 & 3 & 4 & 2 \\
1 & 0 & 1 & 2 & 3 & 3 & 2 & 3 & 2 & 1 & 2 & 2 & 1 \\
2 & 1 & 0 & 1 & 2 & 3 & 3 & 4 & 3 & 2 & 2 & 2 & 1 \\
3 & 2 & 1 & 0 & 1 & 2 & 3 & 3 & 4 & 3 & 2 & 1 & 2 \\
3 & 3 & 2 & 1 & 0 & 1 & 2 & 2 & 3 & 3 & 2 & 1 & 2 \\
2 & 3 & 3 & 2 & 1 & 0 & 1 & 1 & 2 & 3 & 3 & 2 & 3 \\
1 & 2 & 3 & 3 & 2 & 1 & 0 & 1 & 2 & 3 & 4 & 3 & 3 \\
2 & 3 & 4 & 3 & 2 & 1 & 1 & 0 & 1 & 2 & 3 & 3 & 4 \\
1 & 2 & 3 & 4 & 3 & 2 & 2 & 1 & 0 & 1 & 2 & 3 & 3 \\
2 & 1 & 2 & 3 & 3 & 3 & 3 & 2 & 1 & 0 & 1 & 2 & 2 \\
3 & 2 & 2 & 2 & 2 & 3 & 4 & 3 & 2 & 1 & 0 & 1 & 1 \\
4 & 2 & 2 & 1 & 1 & 2 & 3 & 3 & 3 & 2 & 1 & 0 & 1 \\
2 & 1 & 1 & 2 & 2 & 3 & 3 & 4 & 3 & 2 & 1 & 1 & 0
\end{pmatrix}
$$

For [A3] : SACP = 7.5562e+007 , MACP = 3.5648e+007

For [A4] : SACP = 7.5562e+007 , MACP = 3.5648e+007

The two results are same, hence **Isomorphism is satisfied.**

5. CONCLUSIONS

To identify the isomorphism, a simple, efficient and reliable method is proposed. By this method, the isomorphism of mechanisms kinematic chains can easily be identified. It incorporates all features of the kinematic chains and as such, violation of the isomorphism test is rather difficult. The method has been found to be successful in distinguishing all known 16 kinematic chain of 8-link.230 kinematic chain of 10-links having 1-F.The advantage is that they are very easy to compute using MATLAB software. It is not essential to determine both the structural invariants to compare two chains, only in case the [SACP] is same then it is needed to determine [MACP] for both kinematic chains. The [JJ] matrix can be written with very little effort, even by mere inspection of the chain. The proposed test is quite general in nature and can be used to detect isomorphism of not only planar kinematic chains of one degree of freedom, but also kinematic chains of multi degree of freedom.

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