CONCEPTUAL STAGE OF DESIGN IN MECHANICAL ENGINEERING

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Abstract - This paper gives a new thought for identifying the mechanism kinematic chains. The thought is based on Weighted Physical Connectivity Matrix [WPCM] of the considered mechanism kinematic chains. The two constants terms named [WPCM∑] (sum of absolute characteristic polynomial coefficients) and [WPCMax] (Maximum absolute value of characteristic polynomial coefficient) of are calculated from [WPCM] matrix. These two constant terms are used as the identity number of a mechanism kinematic chain. This study will help the designer to select the best possible mechanism to perform the specified task at the conceptual stage of design.

Key words - Kinematic Chain, Physical Connectivity Matrix, Mechanism

I. INTRODUCTION

A number of researchers have discussed structural synthesis in the earlier days. Chang, et.al. [1] proposed a method based on the eigen vectors and eigen values to identify isomorphism of mechanism kinematic chain. Yi-Qu [2] used extended adjacency matrix for molecules in chemical engineering. Agrawal and Rao [3] investigated a systematic method of analysis of the mobility properties of the kinematic chains by its loop freedom matrix and its permanent function which are used to identify it. Sethi and Agrawal [4] proposed a classification scheme on the basis of structural properties. Madan and Jain [5] considered the kinematic chains-isomorphism, inversions and degree of similarity using the concept of connectivity. Rao [6] threw the light on the enumeration of distinct planar kinematic chains. Misti [7] presented the position analysis in polynomial form of planar mechanisms with Assur groups of class 3 including revolute and prismatic joints. Uicker and Raicu [8] presented a method for the identification and recognition of equivalence of kinematic chains. Later on, this method failed. Mruthyunjaya and Balasubramanian [9] proved that the method proposed by Uicker and Raicu [8] is not reliable. Shende and Rao [10] work on the problem of detection of isomorphism. Chu Jin-Kui and Cao Wei-Qing [11] proposed a method for identification of isomorphism among kinematic chains and inversions using Link's adjacent-chain-table. Yadav, et.al. [12] Proposed a computer aided detection method of isomorphism among kinematic chains and mechanisms using the concept of modified distance. Yadav, et.al.[13] presented a paper mechanism of a kinematic chain and the degree of structural similarity based on the concept of link path code. Yadav, et.al.[14] presented a paper ‘computer aided detection of isomorphism among binary chains using the link-link multiplicity distance concept. Rao [15] used the application of fuzzy logic for the study of isomorphism, inversions, symmetry, parallelism and mobility in kinematic chains with some necessary and sufficient conditions. Kong, et.al. [16] Proposed a new method based on artificial neural network (ANN) to identify the isomorphism of the mechanism kinematic chain. Rao and Deshmukh [17] proposed method does not require any separate test for isomorphism in the generation of kinematic chains. He and Jhang [18] proposed a new method for detection of graph isomorphism based on the quadratic form. Tang and Liu [19] established a method ‘the degree code’ as a new mechanism identifier. Later on this method also failed. Zhao, et.al [20] put forward and more complete theory of degrees of freedom (DOF) for mechanisms. Hasan et al. [21] but the concept that these methods are based on seems to be unjustified as either link-link adjacency or joint-joint adjacency hardly differ in nature and are likely to fail at some stage or the other. Hasan [22-23]
proposed a new method in which kinematic chains are represented in the form of the Joint-Joint (JJ) matrix. Dargar et al. [24-25] proposed Link adjacency value method to identify the isomorphism by calculating the first and second link adjacency values. Rizvi et al. [26] presented a new method for distinct inversions and isomorphism based on a link identity matrix and link signature.

**Nomenclature:** C: Cylindric lower pair, F: Planer lower pair, G: Spheric lower pair, HP: Higher pairs (point contact), HL: Higher pairs (line contact), P: Prismatic lower pairs, R: Revolute lower pairs, SL: Screw lower pairs. All the kinematic pairs (KP) are distinguished by assigning different numeric values. Let R=1.1, P=1.2, C=1.3, SL=1.4, F=1.5, G=1.6, HP=2.1 and HL=2.2. These values are assumed to distinguish the kinematic pairs.

**II. SUMMARY OF THE METHODOLOGY**

**Step-1:** write the Physical Connectivity Matrix [PCM] of the given mechanism kinematic chain.

\[ [PCM] = \{ P_{ij} \}_{nxn}, \]

Where, \( P_{ij} \) = Type of kinematic pair between \( i^{th} \) link and \( j^{th} \) link that are directly connected.

\( = 0, \) when \( i^{th} \) and \( j^{th} \) link are not connected directly.

Of course; \( P_{ii} = 0 \)

**Step-2:** Write the Weighted Physical Connectivity Matrix [WPCM]

\[ [WPCM] = \{ g_{ij} \}_{nxn} \]

Where; \( g_{ij} = (P_{ij}) x (W_{ij}), W_{ij} = \frac{1}{2} [v_i/v_j+v_j/v_i] , V = [v_1 \ v_2 \ v_3 \ v_4 \ v_5 \ \ldots \ \ldots \ v_n] , \)

The degree vector (V) represents the type of individual link, like 2 for binary link, 3 for ternary link, 4 for quaternary link, etc.

**Step-3:** Using MATLAB Software, determine the identity numbers [WPCM∑] and [WPCMmax] of [WPCM] matrix

The characteristic polynomial of WPCM matrix is given by \( D(\lambda) \). The monic polynomial of degree \( n \) of WPCM matrix is given by:

\[ D(\lambda) = 1 \ WPCM - \lambda I \ 1 = \lambda^n + a_1 \lambda^{n-1} + a_2 \lambda^{n-2} + \ldots + + a_{n-1} \lambda + a_n . \]

1, \( a_1, a_2, \ldots, a_{n-1}, a_n \) are characteristic polynomial coefficients.

The two important properties of the characteristic polynomials are:

1. The [WPCM∑] is a constant , i.e. \( 1+|a_1|+|a_2|+\ldots+|a_{n-1}|+|a_n| = \text{constant} \)
2. The [WPCMmax] is also another constant for a WPCM matrix.

So, two identity numbers WPCM∑ and WPCMmax unique.

**III. ILLUSTRATIVE EXAMPLE**

Consider a KC with 10- links shown in Figure-1. We have to determine the equivalent links or equivalent mechanisms or total distinct mechanisms obtained from this kinematic chain.

![Figure-1: 10 Links kinematic chain](image-url)
Following the methodology, [WPCM] matrices of other inversions (by fixing the links in turn) are written. The numeric values of the constant for chain shown in Figure 1 are: \([WPCM_\Sigma] = 1.1243 \times 10^3\) and \([WPCM_{\text{max}}] = 393.6130\). These identification values for different mechanisms are given in Table 1.

Table 1: Numeric value of \([WPCM_\Sigma]\) and \([WPCM_{\text{max}}]\) for chain shown in Figure 1.

| Numeric value of \([WPCM_\Sigma]\) | Numeric value of \([WPCM_{\text{max}}]\) | Remarks |
|----------------------------------|----------------------------------|---------|
| \([WPCM_\Sigma]\) = 1.2580 \times 10^3 | \([WPCM_{\text{max}}]=-1=393.6130\) | Link 1 and link 2 are equivalent and will form only one mechanism. |
| \([WPCM_\Sigma]=2=393.6130\) | \([WPCM_{\text{max}}]=2=393.6130\) | Similarly links 3, 4, 5, 6, 7, 8, 9 and 10 equivalent links and will form another single mechanism. |
| \([WPCM_\Sigma]=3=393.6130\) | \([WPCM_{\text{max}}]=3=393.6130\) | Therefore, total distinct mechanisms obtained will be 2. |
| \([WPCM_\Sigma]=4=393.6130\) | \([WPCM_{\text{max}}]=4=393.6130\) | |
| \([WPCM_\Sigma]=5=393.6130\) | \([WPCM_{\text{max}}]=5=393.6130\) | |
| \([WPCM_\Sigma]=6=393.6130\) | \([WPCM_{\text{max}}]=6=393.6130\) | |
| \([WPCM_\Sigma]=7=393.6130\) | \([WPCM_{\text{max}}]=7=393.6130\) | |
| \([WPCM_\Sigma]=8=393.6130\) | \([WPCM_{\text{max}}]=8=393.6130\) | |
| \([WPCM_\Sigma]=9=393.6130\) | \([WPCM_{\text{max}}]=9=393.6130\) | |
| \([WPCM_\Sigma]=10=393.6130\) | \([WPCM_{\text{max}}]=10=393.6130\) | |

It is clear from Table 1 that 2 distinct mechanisms can be obtained from the given kinematic chain in Figure 1, because there are only two different values of the constants \([WPCM_\Sigma]\) i.e. 1.2580 \times 10^3, 1.5393 \times 10^3 for the mechanisms obtained by fixing the links 1 to 10 in turn. Note that the result obtained by using other methods available in the literature, the same result is obtained.

IV. CONCLUSION

The proposed [PCM] matrix is based on different kinematic pairs based on the contact among different links in a mechanism kinematic chain. The [WPCM] matrix is written with the help of
[PCM] matrix. This matrix takes care for the types of links used in the mechanism kinematic chains. The two constants known as identification number [WPCM∑] and [WPCMmax] are determined using MATLAB from the [WPCM] matrix. These identification numbers have been used for determining the distinct mechanisms from a given kinematic chain.

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