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INVERSION OF THE KINEMATIC CHAIN AND IDENTIFICATION OF ISOMORPHISM BY COMPUTATIONAL METHOD

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ABSTRACT

Isomorphism and inversion of a kinematic chain is an imperative topic in the field of kinematic chain. Due to the isomorphism many operations repeat itself. Therefore, many researchers are working for similar operations/mechanisms. There are lots of methods available like adjacency matrix, Weightage distinct mechanism, min code method, J-J matrix method etc. In this paper a computational method is proposed to determine the distinct mechanisms of a kinematic chain using Joint-Joint matrix. It takes less time than other method. This computational method is possible for ≥0 degree of freedom. It is a user friendly process by which we can easily identified.

Keywords: Degree of freedom, Distinct Mechanism, J-J matrix, Kinematic chains & Structural invariants.

I INTRODUCTION

The characteristic-polynomial methods were studied by Uicker and Raicu [1], Yan and Hall [2] etc. All these studies are based on adjacency matrix of kinematic chains or its different revisions. The main method is that they are logically efficient in computation. Some new approaches to these problems were also investigated such as Path generation using min codes [3], Genetic algorithm for topological characteristics[6] and artificial neural network [7] and so on. But most of these methods are complex and difficult to utilize. The min-code method [3] requires a complicated analysis of distance matrix as well as the connectivity matrix to start its procedure. The Hamming-number approach [10-11] introduced a new idea for isomorphism identification and topological structure analysis. Most of these methods are based on adjacency matrix or distance matrix [13-14]. The weighted distance matrix, JJ matrix are very lengthy procedure. It is effective but not efficient enough. Therefore, in this paper, the JJ matrix developed by computing and further identifies the isomorphism of given chains.

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II THEORY

Critical study of kinematic chain and mechanism structure has revealed that the performance of the joints is affected by the degree of the links (types of links). For this purpose, a new Joint-Joint [JJ] matrix has been defined. From the [JJ] matrix, the two structural invariants [SCPC] and [MCPC] are derived based on the characteristic polynomial coefficients of the [JJ] matrix. These structural invariants are the same for identical or structurally equivalent mechanisms and different for distinct mechanisms. Hence, in this way, it is possible to identify all distinct mechanisms derived from a given kinematic chain.

2.1 Structurally Equivalent Links

In an i-link kinematic chain, total 'i' number of inversions/mechanisms can be obtained by fixing the links in turn. Out of these 'i' mechanisms, some of them may be equivalent mechanisms. All equivalent mechanisms may be regarded as one distinct mechanism. The links forming equivalent mechanisms are called equivalent links.

Therefore, it is needed to identify structurally equivalent links to find out equivalent mechanisms in a given kinematic chain. These inversions can also determine by this program.

III DISTINCT MECHANISMS OF A KINEMATIC CHAIN

With the help of inversions, each chain leads to as many mechanisms as there are links in the chain. Some of the mechanisms /inversions are equivalent and therefore should be counted as one. Therefore, it is needed to develop an efficient algebraic method to identify the number of distinct mechanisms for a given family of kinematic chain so that designers have a choice to select the best-suited mechanism to fulfill their requirements.

3.1 Matrix Representation Of The Kinematic Chain

The (0, 1) adjacency matrix and the distance matrix are generally used to represent the kinematic graph of a kinematic chain. The adjacency matrix shows only the connectivity between adjacent vertices/links. The distance matrix has also the relation between the links that are not directly connected to each other in the form of shortest path distance. However, both adjacency and distance matrices are not able to furnish the information about the types of links those are directly connected with a joint or with the shortest path distances respectively. A generalized matrix representation is made in literature in which the elements of adjacency matrix a_{ij} represents the multiplicity (type) of the joint The value of a_{ij} is 1 if the joint between i^{th} and j^{th} link is a simple joint, 2 if it is double joint, 3 if it is ternary joint and so on. In the present paper the [JJ] matrix is used which is based upon the connectivity of the joints through a link.

3.2 Characteristic Polynomial Of [Jj] Matrix

D (λ) gives the characteristic polynomial of [JJ] matrix. The polynomial of degree n is given by equation (3.1).

$$| (JJ - \lambda I) | = \lambda n + a1\lambda n -1 + a2\lambda n - 2 + \text{---------} an - 1\lambda + an \qquad (3.1)$$

Where; n = number of simple joints in kinematic chain and 1, a1, a2,

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an-1, are the characteristic polynomial coefficients.

The two important properties of the characteristic polynomials are-

(a) The sum of the absolute value of the characteristic polynomial coefficients (SCPC) is an invariant for a [JJ] matrix. i.e.

| 1 | + | a1 | + | a2 | + ----- + | an-1 | + | an | = invariant

(b) The maximum absolute value of the characteristic polynomial coefficient (MCPC) is another invariant for a [JJ] matrix.

3.2.1 Structural Invariants [SCPC] And [MCPC]

The proposed [JJ] matrix provides distinct set of characteristic polynomial coefficients of the kinematic chain having co-spectral graph. Therefore, it is verified that the structural invariants 'SCPC' and 'MCPC' are capable of characterizing all kinematic chain and mechanisms uniquely. Hence, it is possible to detect isomorphism among all the given kinematic chain. These invariants are unique for [JJ] matrix.

IV IDENTIFICATION OF STRUCTURALLY EQUIVALENT LINKS AND DISTINCT MECHANISMS

A kinematic chain is represented by the [JJ] matrix. When any link of a kinematic chain is fixed, a mechanism obtained the corresponding joints of the fixed link work as pivots. If in the [JJ] matrix, the diagonal elements of the corresponding joints of the fixed link-'a' are changed from 0 to 1, it will be the representation of the first mechanism with fixed link 'a'. Then this new [JJ] matrix is represented by [JJ-a] matrix. The structural invariants of this [JJ-a] matrix are then calculated using software MAT LAB. These invariants 'SCPC-a' and 'MCPC-a' are the characteristic numbers of the first mechanism. This process is repeated for the second link 'b' and so on. In this way, a set of invariants equal to the number of the links are obtained. Some of them may be same and others are different. The same structural invariants represent the corresponding structurally equivalent links that constitute one distinct mechanism.

In n-link mechanisms;

Let, E = number of sets of equivalent links D = number of distinct links having distinct invariants

T = total number of distinct mechanisms

So, T = (E + D)

4.1 Illustrative Example-1

The first example concerns with 8–bars, 10-joints, single degree of freedom as shown in Fig.1.

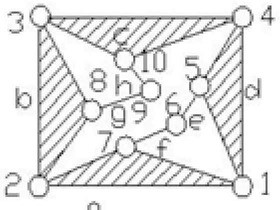

Fig.1: Eight –Link, Single DOF K C

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Degree of the links

The degree of links of kinematic chain shown in Fig.1 is:

d (la) =d (lb) =d (lc) =d (ld) =3 d (le) = d (lf) =d (lg) =d (lh) =2.

[JJ] Matrix

The [JJ] matrix representing the kinematic chain [Fig.1] using equation (1) is given as.

$$[JJ] = \begin{pmatrix} 0 & 3 & 0 & 3 & 3 & 0 & 3 & 0 & 0 & 0 \\ 3 & 0 & 3 & 0 & 0 & 0 & 3 & 3 & 0 & 0 \\ 0 & 3 & 0 & 3 & 0 & 0 & 0 & 3 & 0 & 3 \\ 3 & 0 & 3 & 0 & 3 & 0 & 0 & 0 & 0 & 3 \\ 3 & 0 & 0 & 3 & 0 & 2 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 2 & 0 & 2 & 0 & 0 & 0 \\ 3 & 3 & 0 & 0 & 0 & 2 & 0 & 0 & 0 & 0 \\ 0 & 3 & 3 & 0 & 0 & 0 & 0 & 0 & 2 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2 & 0 & 2 \\ 0 & 0 & 3 & 3 & 0 & 0 & 0 & 0 & 2 & 0 \end{pmatrix}$$

4.2 Structural Invariants of Kinematic Chain

The set of structural invariants derived from the [JJ] matrix using software MAT LAB for the kinematic chain shown in Fig.1 are:

SCPC = 3.0011e+005 MCPC=134784

4.3matrix Representation of The Mechanisms

Fixing link 'a', the first mechanism is developed. The link 'a' is a ternary link having joints 1, 2 and 7. Hence, changing the diagonal elements L_{11}, L_{22} and L_{77} from 0 to 1 (from zero to one) of [JJ] matrix. The [JJ-a] matrix is obtained and written as;

$$[JJ\text{-}a] = \begin{pmatrix} 1 & 3 & 0 & 3 & 3 & 0 & 3 & 0 & 0 & 0 \\ 3 & 1 & 3 & 0 & 0 & 0 & 3 & 3 & 0 & 0 \\ 0 & 3 & 0 & 3 & 0 & 0 & 0 & 3 & 0 & 3 \\ 3 & 0 & 3 & 0 & 3 & 0 & 0 & 0 & 0 & 3 \\ 3 & 0 & 0 & 3 & 0 & 2 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 2 & 0 & 2 & 0 & 0 & 0 \\ 3 & 3 & 0 & 0 & 0 & 2 & 1 & 0 & 0 & 0 \\ 0 & 3 & 3 & 0 & 0 & 0 & 0 & 0 & 2 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2 & 0 & 2 \\ 0 & 0 & 3 & 3 & 0 & 0 & 0 & 0 & 2 & 0 \end{pmatrix}$$

4.4 Structural Invariants of the First Mechanism

The structural invariants of the first mechanism are derived from the kinematic chain shown in Fig.1 and is given as;

SCPC -a = 3.4310e+005 MCPC -a = 1.6407e+005

Similarly, the links b, c, d, - - - etc are fixed in turn and the diagonal elements of all the corresponding joints in the [JJ] matrix of the fixed link are changed from 0 to one (from zero to one) of [JJ] matrix. The structural invariants of other mechanisms are obtained and given as:

SCPC -b = 3.4310e+005 MCPC -b = 164070

SCPC -c = 3.4310e+005 MCPC -c = 1.6407e+005

SCPC -d= 3.4310e+005 MCPC -d = 1.6407e+005

SCPC -e = 4.5503e+005 MCPC -e = 2.3069e+005

SCPC -f = 4.5503e+005 MCPC – f = 2.3069e+005

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SCPC -g = 4.5503e+005 MCPC – g = 2.3069e+005

SCPC -h = 4.5503e+005 MCPC -h = 2.3069e+005

4.5 Identification of The Distinct Mechanisms

Observing the structural invariants for the above eight mechanisms, it is found that the structural invariants of link – a, b, c and d are same. Hence, they are treated as equivalent links and form only one distinct mechanism. Similarly, the structural invariants of link- e, f, g and h are same, hence form second distinct mechanism. So we can write:

E=2 (number of set of equivalent links)

D=0(number of distinct links)

T= 2+0=2(total number of distinct mechanisms)

Therefore, 2 distinct mechanisms are obtained from kinematic chain shown in Fig.1

4.6 Computer Program

The above method is a very lengthy process. Therefore a computing program we will use to reduce the error and minimize the time.

```
clc
clear all
m=input('enter  the  number  of  links  =');
n=input('enter  the  number  of  joints  =');
x(n,n)=0;
i=1
for I=1:n
z= input('enter the no of joints connect with joints which position value is i = '); j=
input('enter the position no of joints which is connect with= ');
for a=1:z
J=j(1,a)
x(I,J)=input('enter the order of link= '); end
i=i+1 end
x
scpc=sum(abs(poly(x)))
mcpc=max(abs(poly(x)))
F=0; sm=[0
0]; for f=1:m
Xdm=x; F=
F+1
u=input('enter the no of joints at fixed links F=');
y=input('enter the position no of joints of fixed links F='); for
b=1:u
Y=y(1,b);
Xdm(Y,Y)=1;
end Xdm
scpc=sum(abs(poly(Xdm)));
mcpc=max(abs(poly(Xdm)));
sm=[sm; scpc mcpc];
end sm(1,:)=[]
```

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```
equvalance_links_are=[0 0]; for
k=1:m
for l=k+1:m
K=sm(k,:);
L=sm(l,:);
if abs(K-L)<[0.1 0.1];
equvalance_links_are=[equvalance_links_are; k l];
end end
end
R=equvalance_links_are;
equvalance_links_are(1,:)=[] if R
==[0 0];
fprintf('there is no one links are equvalance to other') end
```

V RESULTS

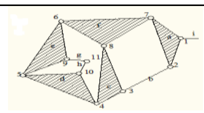
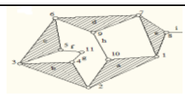
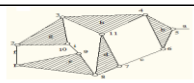
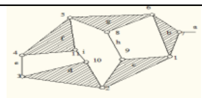
The proposed invariants SCPC and MCPC are able to detect isomorphism in kinematic chain and even in kinematic chain with co-spectral graphs. These result are Distinct Mechanism for 9 link, 2 DOF, open kinematic chains = 596. And for 9 links, 2 DOF, closed kinematic chains are 258. As shown in Table 1, 2 and 3.

VI CONCLUSION

In this paper, a new, user friendly computational method on MATLAB to identify the distinct mechanisms from a given simple jointed kinematic chain is proposed. The method based upon characteristic polynomial of matrix. The two structural invariants SCPC and MCPC are derived from the characteristic polynomial matrix. These invariants are able to detect the isomorphism among the kinematic chain having simple joints and even the kinematic chain with co-spectral graphs.

Table-1

The number of distinct mechanisms derived from 2-F, 9links open kinematic chain

K.C. Number	No. Of D.M.	Equivalent Mechanism	Figure
1	9	Nil	
2	6	2=3, 6=7, 1=4	
3	9	Nil	
4	6	4=6, 3=7, 5=9	

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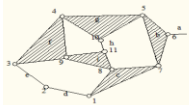
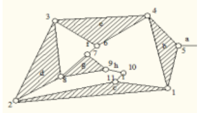
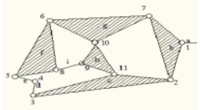
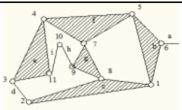
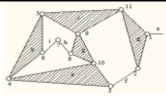
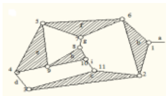
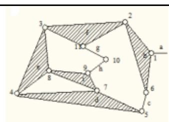
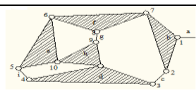
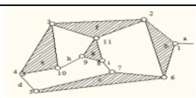
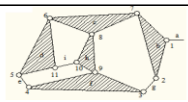
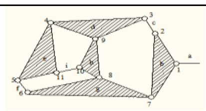
5	9	Nil	
6	9	Nil	
7	9	Nil	
8	9	Nil	
9	7	2=7, 8=9	
10	9	Nil	
11	9	Nil	
12	9	Nil	
13	9	Nil	
14	9	Nil	
15	9	Nil	

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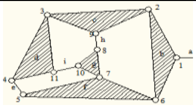
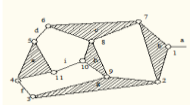
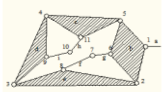
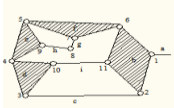
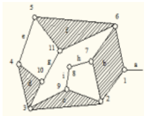
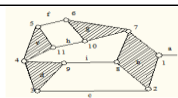
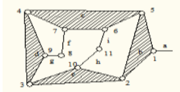
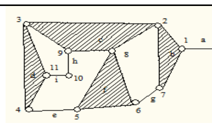
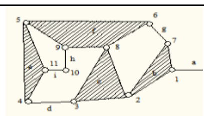
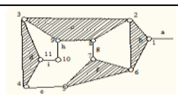
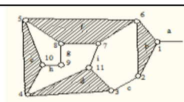
16	6	3=6, 4=7, 5=8	
17	7	3=7, 4=6	
18	9	Nil	
19	9	Nil	
20	8	5=7	
21	8	6=8	
22	9	Nil	
23	9	Nil	
24	9	Nil	
25	9	Nil	
26	9	Nil	

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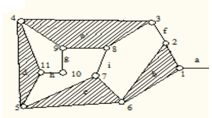
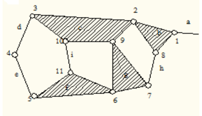
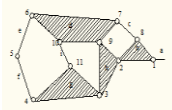
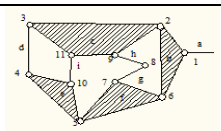
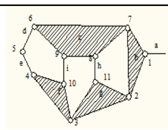
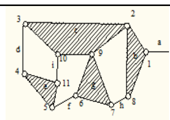
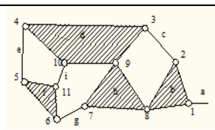
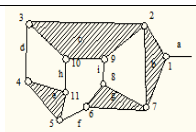
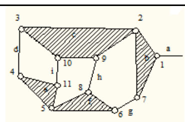
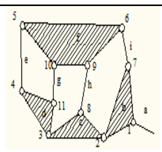
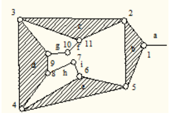
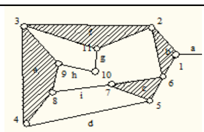
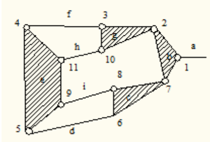
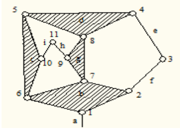
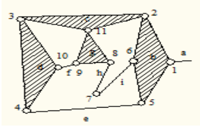
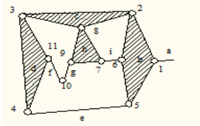
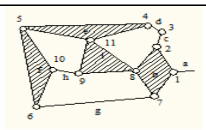
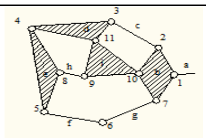
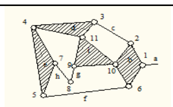
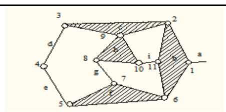
27	9	Nil	
28	9	Nil	
29	9	Nil	
30	9	Nil	
31	9	Nil	
32	9	Nil	
33	9	Nil	
34	9	Nil	
35	9	Nil	
36	9	Nil	

37	6	7=8, 6=9, 3=5	
38	9	Nil	
39	5	3=7, 4=6=8=9	
40	9	Nil	
41	9	Nil	
42	9	Nil	
43	9	Nil	
44	9	Nil	
45	9	Nil	
46	9	Nil	

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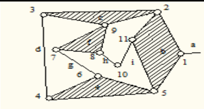
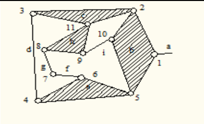
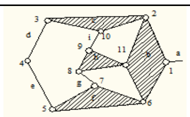
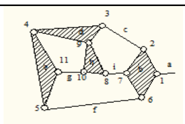
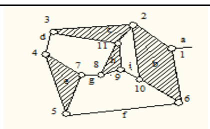
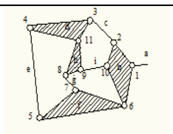
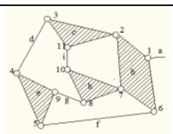
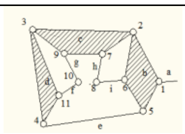
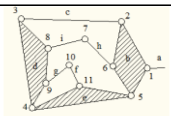
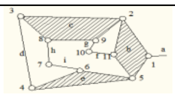
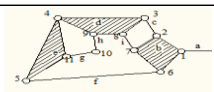
47	9	Nil	
48	9	Nil	
49	6	3=6, 7=9, 4=5	
50	9	Nil	
51	9	Nil	
52	9	Nil	
53	9	Nil	
54	9	Nil	
55	9	Nil	
56	9	Nil	
57	9	Nil	

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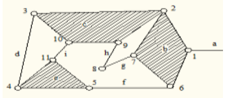
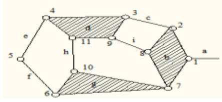
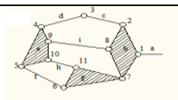
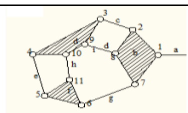
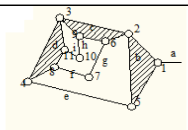
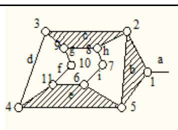
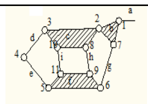
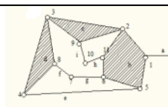
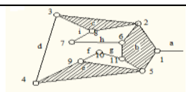
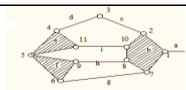
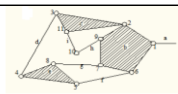
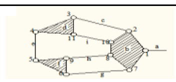
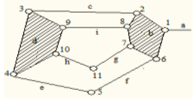
58	9	Nil	
59	9	Nil	
60	9	Nil	
61	9	Nil	
62	9	Nil	
63	6	6=7, 8=9, 3=5	
64	9	Nil	
65	9	Nil	
66	6	3=5, 7=8, 6=9	
67	9	Nil	
68	9	Nil	
69	6	8=9, 4=6, 3=7	

70	9	Nil	

Total Distinct Mechanism of 9-Link, 2-Dof, 70 open kinematic chains = 596.

Similarly, Total Distinct Mechanism of 9-Link, 2-Dof, 40 closed kinematic chains = 258.

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