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An Automated Procedure for Intelligent Mechanism Selection and Dimensional Synthesis

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This paper describes the fundamentals for the development of the intelligent selection system for the mechanism configuration and the development of an automated dimensional synthesis procedure. The selection system is a rule-based system. Using an interactive dialogue with a designer; the system converges to an appropriate mechanism configuration satisfying a prescribed synthesis requirements including type of synthesis problems, number of precision positions, and number of independent inputs. The user has an option to inquire the selection system to give reasons for the mechanism configuration selection. The automated synthesis procedure uses the data supplied by the selection system to generate the design equations. A powerful numerical algorithm solves the design equations giving all possible solutions without the need of supplying initial guesses. The complete system provides a valuable tool that performs a comprehensive design procedure with minimal user interaction and background knowledge in mechanism design.

1 Introduction

The process of designing a mechanical device to do a specific programmed task is often referred to as synthesis of mechanisms. This is a creative process. It blends knowledge, experience, and a certain amount of "intuitive feelings." When a specific mechanical design is finally realized and when it represents a certain amount of originality, it often becomes a candidate for a patent. Since inventing a new, original, patentable design forces one to search into many unknowns, it has been generally appreciated by everyone that this creative process is the most difficult one in designing a mechanism. However, the process of creating an alternate design is equally a creative task. As the mechanism synthesis science has developed over a period of 100 years, this process is becoming more rational and a knowledge-based system may be developed to arrive at alternate designs. Experience has shown that an industrial designer spends more than allowed time to arrive at the first design. Hence, he is neither in a position to search for alternate designs, nor in a position to provide an optimum design. A development of an expert system provides the opportunity to answer both of these needs of a designer.

Dimensional synthesis using analytical techniques has been found to be very useful in mechanism design. Two of the popular approaches in analytical techniques in linkage design are generally referred to as the complex number approach developed by Sandor [20] and the displacement matrix approach proposed by Suh [21] and extensively utilized by Soni [15]. Both of these approaches are quite suitable in developing an intelligent mechanism synthesis consultant system. Before Suh's development can be undertaken, it is however necessary to develop generalized algorithm to generate automatically the synthesis equations in algebraic form. Azeez and Soni [22], using the displacement matrix approach, first proposed such a development to synthesize linkage mechanism for point-path generation. This approach utilizes Edge-Edge, Vertex-Vertex, and Vertex-Edge matrices. The solution of such synthesis equations derived in algebraic form by a digital computer was not possible at the time of this development. With recent development by Morgan [23], Garcia and Zangwell [24], and Watson and Fenner [25], it is now possible to solve such equations to obtain all possible solutions. (Recent contribution on the inverse kinematics of a general six-axis robot by Tsai and Morgan [26] illustrates this accomplishment). Consequently, the authors investigated the general problem of automatic synthesis and incorporated it as part of the development of intelligent mechanism selection and synthesis of linkage mechanism.

The automatic synthesis generation procedure developed and presented in this paper is based on finding unique paths that connect a coupler link and the ground link to themselves or other coupler links. These paths provide the constraints that constitute the design equations. The nonlinear equations are solved using the newly developed numerical algorithm based on homotopic mapping, and requires no initial guesses.

2 A Systematic Approach for an Alternate Mechanism Design

A development of an expert system to arrive at an acceptable, optimum alternate mechanism design requires one to consider the following categories of synthesis problems:

(1) Configuration analysis.

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(2) Configuration synthesis. (An expert system development on this subject is under way by Thomas, Riley and Erdman [6]).

(3) Search for suitable configurations for specific design problems.

(4) Dimensional synthesis of selected mechanisms configurations.

(5) Acceptability of the synthesized mechanisms.

(6) Selecting an optimum and an alternate synthesized mechanism.

From the given original mechanism, one is able to determine the number and types of links, types of joints, and number of inputs to the mechanism that will produce constrained motion of the moving links with these data; one is able to perform configuration analysis and configuration synthesis of alternate design possibilities. From the original design, task specifications are known. Keeping these specifications in mind, a search is made to examine all possible unique configurations for their capabilities to accept the required design specifications. Once an appropriate selection is made for an acceptable configuration, acceptability of the final design is deferred until the mechanism configuration is synthesized and analyzed using other engineering criteria involving kinematics, dynamics, balancing, strength, space and other constraints.

One of the objectives of the present paper is to develop an intelligent mechanism selection consultant system. Such a system will permit its user to arrive in an intelligent selection of the mechanism configurations which should be considered for the dimensional synthesis for the specific motion program objectives. The selection system is identified as IMSC.1.

While on one hand, a designer is able to arrive at optimum alternate mechanism configuration, he also is able to build a database with the help of an expert system. Such database eventually becomes the knowledge base for the invention of new and hopefully patentable mechanisms.

The other objective is to dimensionally synthesize the selected mechanism. This part is identified as IMSC.2, which also includes IMSC.1 as a preprocessor.

3 Production Systems

How to use the expertise of the domain experts is the key of IMSC.1. It means how to represent, and how to manipulate the domain specific knowledge. AI researchers have developed several methods to represent knowledge. The most popular method is the rule-based system because of its advantages: modularity, uniformity, and naturalness.

Rule-based systems are evolved from a more general computational model known as a production system. Instead of viewing computations as a prespecified code, a production system views computations as the process of applying rules in a sequence determined by the data.

A production system has three major elements: (1) A global database as the central data structure, which contains facts or assertions about the problem being solved; (2) A rule base operating on the global database, which contains domain specific knowledge; (3) An interpreter which chooses the applicable rule for the problem-solving process, and ceases computation when a termination condition on the database is satisfied.

4 Architecture of IMSC.1

Researchers in mechanism synthesis have shown that the design of mechanisms for a variety of motion programs involving coordinating motions of input, output or coupler links can be achieved by either graphical or analytical techniques. In the automatical process, a designer starts with some function specifications related to those motion programs. How to choose an appropriate mechanism and certain links is usually time-consuming before dimensional synthesis for the mechanism can be achieved. However, an intelligent mechanism selection consultant, which has the expertise in motion program synthesis, and some heuristics, can provide an avenue for those less experienced designers.

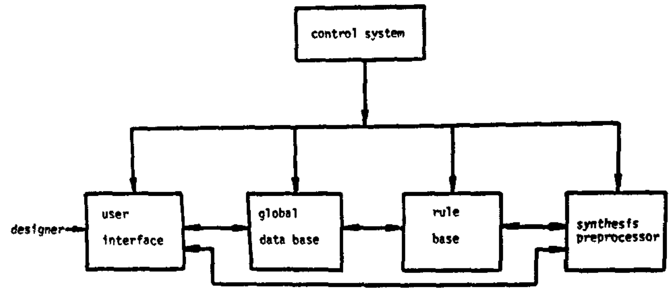

Fig. 1 Architecture of IMSC.1

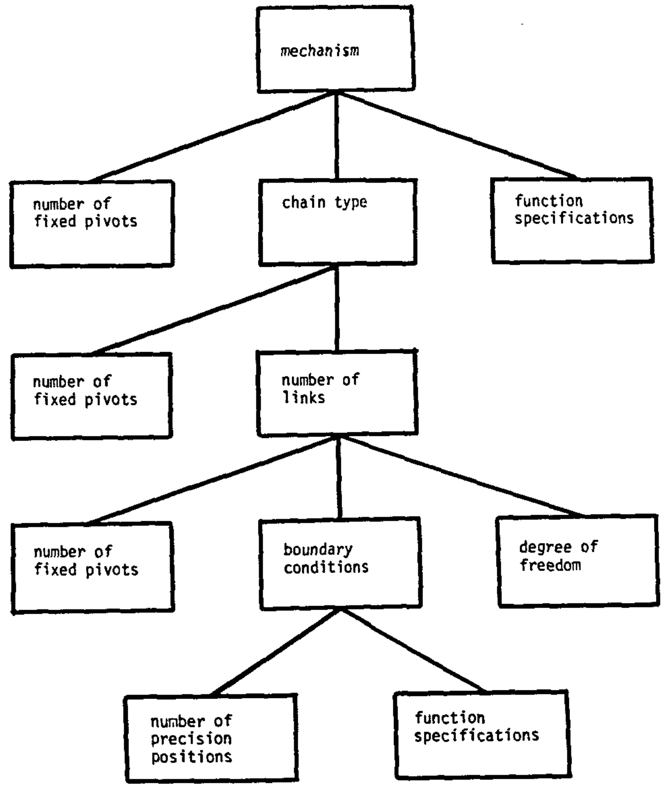

Fig. 2 Problem solving subtree

Based on the results from Soni, et al. [8–19], the IMSC.1 was implemented in Franz Lisp on a VAX/VMS computer system. The IMSC.1 has five components: user interface, global data base, control system, and synthesis preprocessor, as shown in Fig. 1.

The subtree, shown in Fig. 2, indicates the problem solving strategy executed by IMSC.1. At the beginning of a design, the system will ask the designer to input the function specification, number of precision positions, degree of freedom, and number of fixed pivots.

Currently, the system can handle mechanism with revolute pairs and one degree of freedom, and five different function problems: coordination of angular displacements of input and output links, coupler point-path generation, coupler point-path generation coordinated with the angular displacement of input link, rigid-body guidance, and rigid-body guidance coordinated with the angular displacement of input link.

4.1 Rule Base of IMSC.1. Knowledge is "power" for any intelligent system. IMSC.1 does not represent the

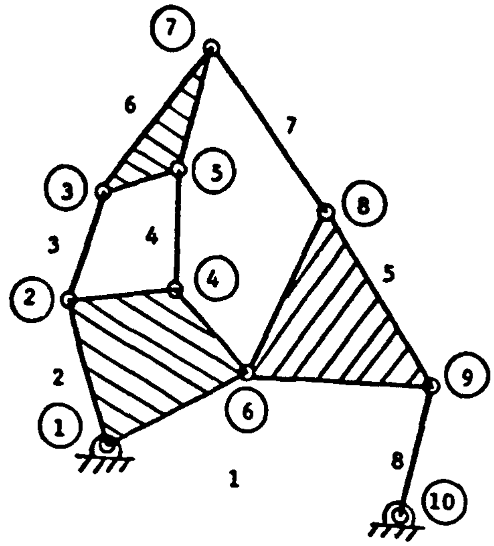

Fig. 3 Mechanism considered in the illustration example

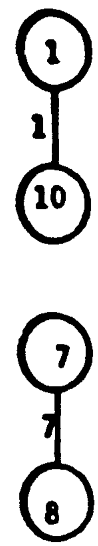

Fig. 4 Start of the path generation

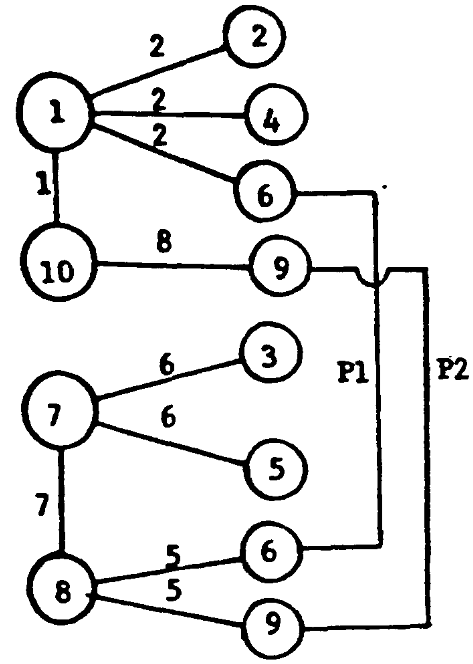

Fig. 5 Second stage of path generation procedure

knowledge of a single expert in mechanism design, rather we have used many sources of knowledge in building IMSC.1. The main sources include a variety of technical reports and expert advice.

The general form of production rule in IMSC is as follows:

Premise: (function specification and additional requirements)
Action: (conclusion)

For Example:
Premise: [(input-output)
(number of positions le 17 gr 11)
(or (2 fixed pivots)
(3 fixed pivots)]
Action: ⟨(8 bar)⟩

The English translation is as follows: if
(1) It is an input-output problem,
(2) The number of positions is less than or equal 17 and greater than 11,
(3) The number of fixed pivots is 2 or 3,
Then an eight-link mechanism is suggested as the selected configuration for this motion program requirements.

4.2 Development of a synthesis Preprocessor for Mechanism Selection. The synthesis preprocessor examines the geometry of a mechanism configuration. For a given set of motion program requirements, the preprocessor examines the moving links of interests and lays out different paths possible to connect the links of interests. Based on the algorithm developed, the preprocessor arrives at a path that yields minimum number of mechanism unknown which must be determined to synthesize a mechanism dimensionally.

4.2.1 Unique Paths Generation. In the following section, the synthesis algorithm is discussed in details and examples are provided.

Paths are generated among coupler link(s) and the ground link. The paths connectivity requirements provide the constraints equations. These paths must be unique in order to ensure independent design equations. The paths are generated in a systematic manner. The path generation procedure is accomplished by representing the mechanism as a directed graph. The mechanism links and joints are labeled in any convenient order. The following is a step-by-step explanation of how the paths are generated:

Step 1. Generate the initial links and joints by drawing the ground link and coupler link(s) if any exist.

Step 2. For the newly generated joints, check if a joint exists in two different locations. If it does, connect these locations to form a unique path.

Step 3. For all the remaining joints from Step 2 add their missing links with their corresponding joints (remember a joint connects two links). For each new joint, check if the same joint exists in another location; if it does, form a path. Do not add new links to joints generated in this step.

Step 4. Go back to Step 2 until all links are considered.

To illustrate this procedure, let us consider a mechanism shown in Fig. 3. Let link 7 be the coupler link. Start the link and joint generation as in Step 1. This is shown in Fig. 4. Check for repeated locations for any joint; at this stage none exist. Now add the missing links to each joint to get what is shown in Fig. 5. Check for repeated locations for any joint. There are repeated locations for joints 6 and 9. Therefore, form paths 1 and 2. Add the missing links to the remaining joint as in Step 2. This is shown in Fig. 6. There are two repeated locations for joints 3 and 5; they form paths 3 and 4, respectively. All links of the mechanism are considered now. There are 4 unique paths arranged in the following manner.

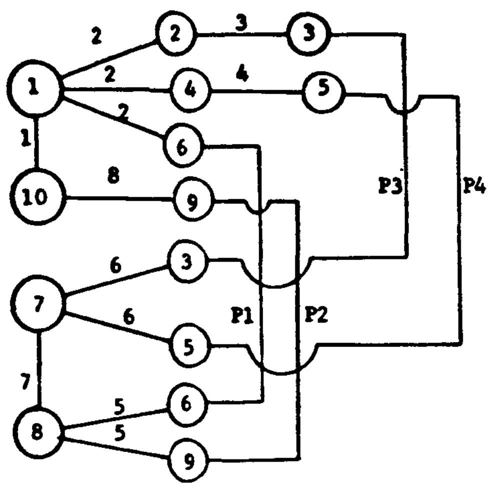

Fig. 6 Third stage in the path generation procedure

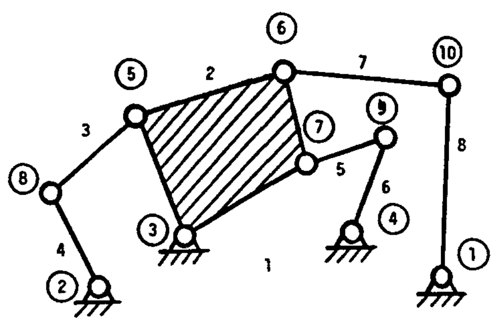

Fig. 7 Example for feedback

For the links, they are: $P_1=(1,2,5,7)$, $P_2=(1,8,5,7)$, $P_3=(1,2,3,6,7)$, and $P_4(1,2,4,6,7)$.

For the joints, they are: $P_1=(1,6,8)$, $P_2=(10,9,8)$, $P_3=(1,2,3,7)$, and $P_4=(1,4,5,7)$.

4.2.2 Path Testing and Modeling. The modeling procedure determines the design parameters of each path. These parameters consist of the following:

1 Number of equations that the path yields.

2 Number of unknown relative orientations incorporated in each path.

3 The type of constraints that the path impose.

4 Links used in writing the path constraints equations.

The testing procedure for each path depends on parameters 1 and 2. A path is limited in its freedom if the number of equations is greater than the number of links with unknown relative orientations. Consequently, the path is not limited if this condition does not hold. The modeling steps are given by the following:

1 Identify the ground link(s) of a path if they exist. (A path may contain the ground or any link more than once.)

2 Identify the links with specified relative orientations.

3 Search for a binary link in the path among the links unidentified by the aforementioned 1 and 2. The three following cases may exist:

(*A*) No binary link is found. The path has coordinate constraints.

(*B*) One binary link is found. Identify it for length constraints.

(*C*) More than one binary link is found. Pick one of them and identify it for length constraints.

4 For all the remaining links that are not identified in 1, 2, and 3, use unknown variables to define their unknown orientations. These are the links with unknown relative orientations.

5 After identifying all the links of a path, find the following:

(*A*) The number of links with unknown relative orientations (N_u). These are the links identified previously in 4.

(*B*) The number of constraints obtained from each path (N_c). It is 2 for coordinate constraints and 1 for length constraints.

6 Test the path for freedom limitation. If $N_c <= N_u$, the path is unlimited by itself. If $N_c > N_u$, the path is limited in the number of positions it can go through. The number of maximum positions for a limited path is given by

$$N_{\max} = M/(N_c - N_u) + 1$$

where M is the number of unknown coordinates along the path.

7 Find the maximum number of positions for the complete mechanism. To do this, find the number of links identified as links with unknown relative orientations throughout the mechanism (NT_u); then find the total number of constraints (NT_c) by adding the number of constraints of each path. The maximum number of design positions is given by

$$NT_{\max} = MT/(NT_c - NT_u) + 1$$

where MT is the total number of unknown coordinates in the mechanism. The actual maximum number of design positions is the smaller of $NT_{\max}$ and $N_{\max}$ for any limited path within the mechanism.

Lisp can process the foregoing algorithmic problems better than FORTRAN since it is a very powerful symbolic manipulation language. A preprocessor is built in IMSC.1 in arriving at an appropriate mechanism configuration and to supply the needed data for dimensional synthesis.

The preprocessor does two tasks: (1) generates the required data for synthesis, and (2) demonstrates the procedure leading to the selection of mechanism configuration.

4.3 Control System. The control strategy in IMSC.1 is depth-first forward chaining. Since the system operates in the interactive environment, it needs to turn the control to the user interface back and forth. Besides, it turns the control to the preprocessor when feedback is required. The following simplified procedure, called "consultant," is used in IMSC.1:

Procedure CONSULTANT
1 Global DB< –function specification and conditions
2 Until termination is satisfied, do:
3 Begin
4 Select some rule, R, in the set of rules that can
be applied to global DB
5 If more information is needed then
call user interface
global DB< –information
else
global DB< –results of applying R to global DB
6 End

Usually, the control strategy is simple for the problems which have small solution space, reliable data, and reliable knowledge. The implicit control and exhaustive search can be used. The computational costs of a production system include two categories: rule applicable costs and control costs [4].

The mechanism configuration selection problems involve a large solution space. Hence the simple control system results in high rule application costs. A hierarchy rule-base structure is implemented in IMSC.1 for reducing the whole computation cost. Currently, we separate the rule-base into two layers: link number selection, and mechanism selection. In mechanism selection, there are four knowledge chunks. One of them is used to select six-link mechanisms and the others are used to select eight-link mechanisms. The total computa-

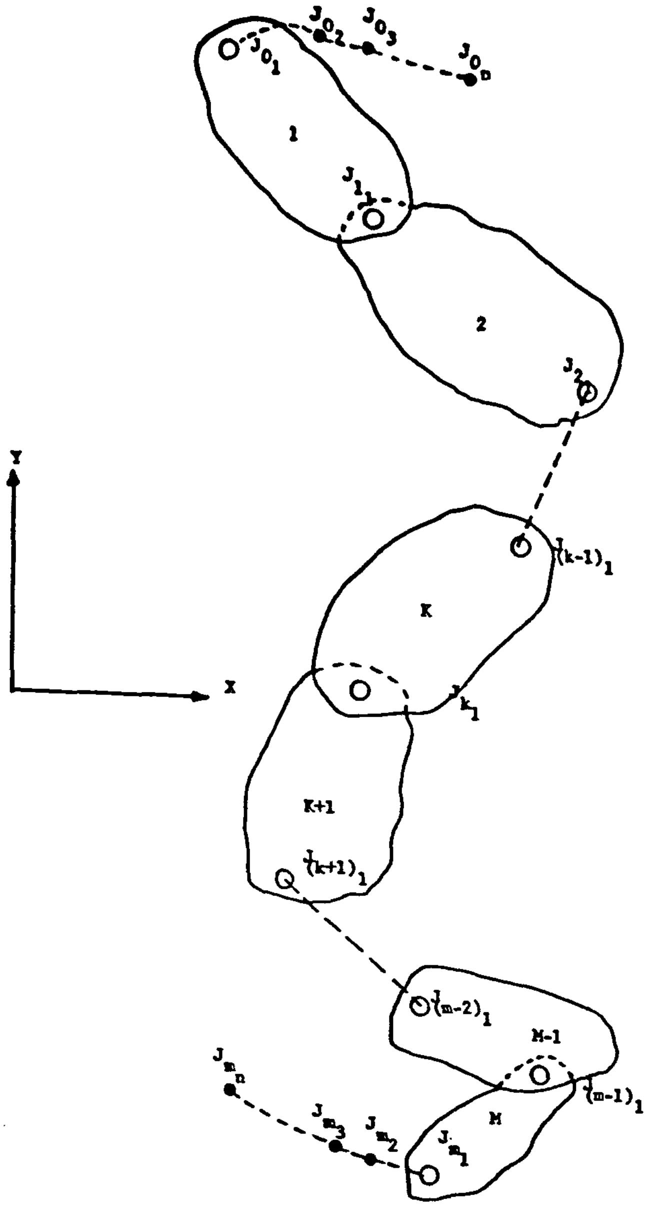

Fig. 8 General path with all the parameters shown

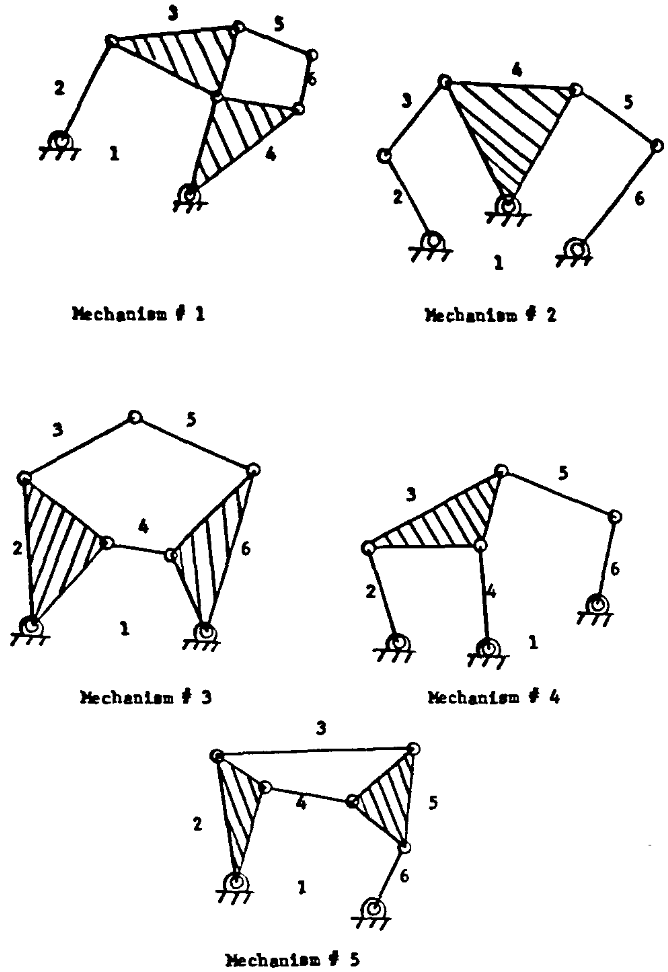

Fig. 9 Six-bar mechanisms used in the illustrative example

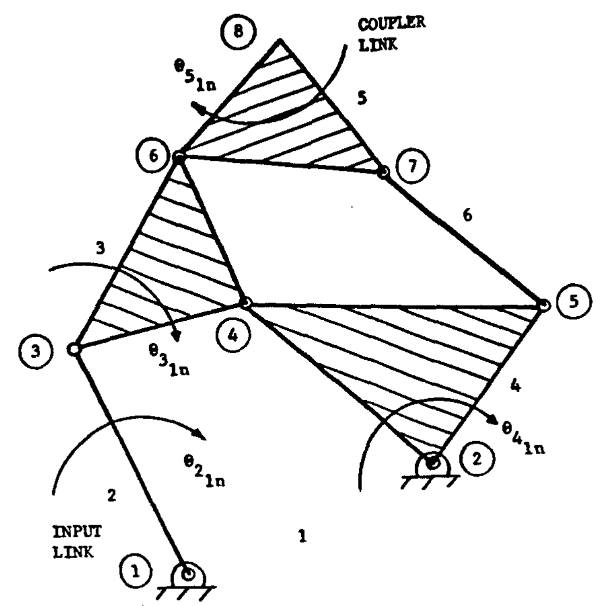

Fig. 10 Six-bar mechanism synthesized for input/rigid-body guidance

tion cost is reduced due to the result from the smaller rule application costs.

4.4 Global Database. In the simplest production system, the global database is simply a collection of symbols intended to reflect the state of the real world but the interpretation of those symbols depends on the nature of the application. For those sytems, which are intended to explore symbol-processing aspects of human cognition, there are two distinct memory mechanisms: long term memory, LTM, and short term memory, STM. The rule base is interpreted as modeling the LTM, while the global database is interpreted as modeling the STM. Hence the total length (typically around seven elements) and the organization of STM are two important issues. For systems, intended to be knowledge-based, the global database, consisting of facts and assertions, is of arbitrary size and has no *a priori* constraints on the complexity of the organization.

IMSC.1 system is knowledge-based and no such constraints are in the global database. The facts, assertions, and kinematic chains are stored in the global database in list structure.

4.5 User Interface. The user interface is an important component of the IMSC system. Although the work has not focused on a natural language interface, some simple techniques have been used to support the level of performance required. This approach has served to keep the interaction acceptably "natural" and "friendly."

5 Synthesis Equations Generation and Solution

The synthesis equations are generated by satisfying the constraints equations of each path for each of the design posi-

Table 1 Maximum number of design positions for six-bar mechanisms

Mech. no.	Input output	Point path	Rigid body	Input p. p.	Input r. b.
1	5 (1,4)	15 (5)	8 (5)	8 (2,5)	5 (2,5)
2	11 (2,6)	9 (3or5)	5 (3or5)	5 (2,3)	3 (2,3)
3	5 (2,6)	9 (3or5)	5 (3or4)	5 (2,3)	3 (2,3)
4	11 (2,6)	9 (5)	5 (5or3)	8 (2,5)	5 (2,5)
5	11 (2,6)	9 (3or4)	5 (3or4)	8 (6,3or4)	5 (6,3or4)

Table 2 Application of the *IMSC* program*

Design Objective: Five position of a rigid body to be coordinates with the five positions of the input crank. Design a suitable linkage mechanism.

Output of IMSC.1: Possible mechanisms for selection.

From Figure 9, 1)Mechanism # 1,
2)Mechanism # 4, and
3)Mechanism # 5.

New input: Design Watt six-bar with two pivots. The input-data is as follows (see Figure 10):

Positions		1	2	3	4	5
Path of Point 8 described by coordinates	$P_{8_{xn}}$	-1.0	0.0	0.5	0.0	0.5
	$P_{8_{yn}}$	3.5	3.0	2.0	1.0	0.5
Rigid-body rotations	$\theta_{5_{1n}}$	0.0	12.0	24.0	36.0	48.0
Input rotations	$\theta_{2_{1n}}$	0.0	6.0	16.0	25.0	40.0

x_6=1.5 and y_6=1.0

IMSC.2 1st output: The synthesis equations are:

The x and y coordinates of joint 3

1) $$[x_{31}F_{2x}-y_{31}F_{2y}]F_3F_5 - [(x_{36}F_{3x}-y_{36}F_{3y})F_5 + (x_{68}F_{5x}-y_{68}F_{5y})F_3]F_2 + x_{18n}F_3F_5F_2 = 0$$

2) $$[y_{31}F_{2x}+x_{31}F_{2y}]F_3F_5 - [(y_{36}F_{3x}-x_{36}F_{3y})F_5 + (y_{68}F_{5x}+x_{68}F_{5y})F_3]F_2 + y_{18n}F_3F_5F_2 = 0$$

The x and y coordinates of joint 4

3) $$[x_{42}F_{4x}-y_{42}F_{4y}]F_3F_5 - [(x_{46}F_{3x}-y_{46}F_{3y})F_5 + (x_{68}F_{5x}-y_{68}F_{5y})F_3]F_4 + x_{28n}F_3F_5F_4 = 0$$

4) $$[y_{42}F_{4x}+x_{42}F_{4y}]F_3F_5 - [(y_{46}F_{3x}+x_{46}F_{3y})F_5 + (y_{68}F_{5x}+x_{68}F_{5y})F_3]F_4 + y_{28n}F_3F_5F_4 = 0$$

Table 2(Continued)

The constant length of link 6

5) $$C_x = [x_{52}F_{4x}-y_{52}F_{4y}]F_5 - [x_{78}F_{5x}-y_{78}F_{5y}]F_4 + x_{28n}F_5F_4$$

$$C_y = [y_{52}F_{4x}+x_{52}F_{4y}]F_5 - [y_{78}F_{5x}+x_{78}F_{5y}]F_4 + y_{28n}F_5F_4$$

$$C_x^2 + C_y^2 - F_5^2F_4^2(x_{57}^2+y_{57}^2) = 0 \qquad n = 2, 3, 4, 5$$

where

$$F_{i_x} = 1-\phi_{i_{1n}}^2,\ F_{i_y} = 2\phi_{i_{1n}},\ F_i = 1+\phi_{i_{1n}}^2$$

$$X_{ij} = X_{i_1} - X_{j_1},\ Y_{ij} = Y_{i_1} - Y_{j_1},$$

$$X_{ijn} = X_{i_n} - X_{j_n},\ Y_{ijn} = Y_{i_n} - Y_{j_n},\ \text{and}$$

$$\phi_{i_{1n}} = \tan\frac{\theta_{i_{1n}}}{2}.$$

IMSC.2 2nd output: The design solutions

Coord.	Solution 1	Solution 2	Solution 3	Solution 4	Solution 5	Solution
x_1	3.7713	3.7713	3.7713	3.7713	5.6191	5.6191
y_1	5.3362	5.3362	5.3362	5.3362	1.8629	1.8629
x_2	3.7714	3.7714	2.7319	2.7319	2.7320	2.7320
y_2	5.3364	5.3364	2.8422	2.8422	2.8423	2.8423
x_3	1.8772	1.8772	1.8772	1.8772	1.5485	1.5485
y_3	1.8491	1.8491	1.8491	1.8491	3.7285	3.7285
x_4	1.8772	1.8772	1.2620	1.2620	2.9699	2.9699
y_4	1.8492	1.8492	1.6796	1.6796	2.1626	2.1626
x_5	1.8765	3.2417	1.2619	2.5711	2.9699	2.3779
y_5	1.8404	8.0050	1.6795	-0.0160	2.1626	1.9475
x_7	1.4991	3.7079	1.5000	6.7899	1.5000	5.4980
y_7	0.9993	7.1915	0.9986	-3.6321	0.9999	5.6756

* The output of the computer program is edited.

tions. Two types of constraints are present: (1) joint connectivity constraints and (2) constant length constraints. For each of these constraints, general equations are developed. Figure 8 shows a general labeled path. Consider this path for the generation of a general equation. The main idea is to express the coordinates of a joint along the path. In the case of joint connectivity constraints, a joint is approached from two directions starting from two different ends of the path. Then the two sets of coordinates obtained by the two approaches are equated. In the case of constant length constraints, the joints at the two ends of the binary link are approached from the two ends of the path, then the constant length requirement is imposed on the coordinates of those two joints. Therefore, the first step in writing the synthesis equations is to express the coordinates of a joint, say K, along a general path. Use the general displacement equations to express the nth (n=2, 3, . .) coordinates of joint K in terms of the initial path-joint coordinates. The X and Y-coordinates of J_k are

$$X_{k_n} = \sum_{i=0}^{k-1} [(X_{(k-i)_1} - X_{(k-i-1)_1})^*\cos\theta_{(k-i)_{1n}} - (Y_{(k-i)_1} - Y_{(k-i-1)_1})^*\mathrm{SIN}\theta_{(k-i)_{1n}}] + X_{0_n} \qquad (1)$$

$$Y_{k_n}=\sum_{i=0}^{k-1}[(X_{(k-i)_1}-X_{(k-i-1)_1})^*\mathrm{SIN}\theta_{(k-i)_{1n}}+(Y_{(k-i)_1}-Y_{(k-i-1)_1})^*\mathrm{COS}\theta_{(k-i)_{1n}}]+Y_{0_n} \quad (2)$$

Let joint L be the joint approached from the other end of the path. Similarly find its X and Y-coordinates for the nth position. In the case of joint connectivity constraints K and L represent the same joint. The constraints equations are

$$X_{k_n}=X_{l_n} \quad n=2,3,4,\ldots. \quad (3)$$

$$Y_{k_n}=Y_{l_n} \quad n=2,3,4,\ldots. \quad (4)$$

In the case of the constant length constraints, joints K and L represent the two joints of the binary link which has a constant length. The constraint equation for this case is

$$(X_{k_n}-X_{l_n})^2+(Y_{k_n}-Y_{l_n})^2=(X_{k_1}-X_{l_1})^2+(Y_{k_1}-Y_{l_1})^2 \quad n=2,3,4,\ldots. \quad (5)$$

Equations (3)-(5) represent the design equations. In these equations, the coordinates of the initial position of the joints may be unknown, and the relative orientations of the links also may be part of the unknown parameters as discussed in previous sections. It is clear from the development of the synthesis equations that a variety of motion programs can be considered. The designer can specify point path by defining coordinates of joints like J_0 and J_m (see Fig. 8). The designer can also specify the links with known relative orientations (input/output and rigid-body motion programs).

The design equations are highly nonlinear especially when unknown relative link orientations are considered. This is one of the reasons why researchers did not attempt to solve large-scale problems. However, a new numerical technique, known as homotopic mapping, has been developed that find solutions to a polynomial set of equations. Morgan [23] modified the technique by introducing the concept of homogeneous coordinates to the problem. With this modification the numerical technique converges for all the generic solutions even if the solution exist at "infinity." This numerical technique generates its own starting solutions. One advantage of using this technique lies in its ability to avoid magnetic roots. If a magnetic root is present in a set of nonlinear equations, most iterative solution techniques will always converge to that root or repel from it. Another very important advantage is that the technique does not require any initial guess to start the solution. Providing initial guesses in mechanism synthesis is very difficult. The numerical technique used here is the combination of Watson and Fenner's program with Morgan modifications.

7 Examples

Consider the 5 six-bar mechanisms shown in Fig. 9. The maximum number of design positions is determined for each mechanism considering 5 different motion programs. Table 1 shows the results and specifies the links used to perform the motion program (numbers in brackets).

8 Application of IMSC

Table 2 presents a demonstration of the application of the IMSC in designing a mechanism for five positions of a rigid-body guidance to be coordinated with five positions of input crank. The IMSC.1 program identifies a six bar as a possible choice. With the preprocessor, the Watt six bar, with two fixed pivots, and two Steven six-bar inversions were identified as possible candidates for the final solution. With IMSC.1 a choice was identified to design the Watt six bar with two pivots. Table 2 shows the synthesis equations derived by the IMSC.2 and the numerical solution.

9 Conclusion

We believe that the introduction of the rule-based system in automatic design of mechanisms will contribute to an increase in the use of computers for engineering design. The application of rule-based systems to mechanism design creates an interesting future prospect.

In the future, we will further our research in several directions. Particularly, we intend to – extend graphical display of mechanisms with real-time animation; – extend the rule base for solving more function specifications; – extend to mechanisms with other higher and lower kinematic pairs.

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APPENDIX

An Example of Consultation of Mechanism Selection

Is it an input output problem?
*No
Is it a point path generation problem?
*Yes
Please type in the degrees of freedom.
*1
Please type in the number of fixed pivots.
*2
Please type in the number of positions.
*9
You have two choices: 6 bar or 4 bar. 6 is better. Please type in the number of links: 6 or 4.
*6
You have two choices: chain6-1 (Watt) or chain6-2 (Stephenson). Please type in chain type: 1 or 2.
*1
Mechanism6 2 with coupler link 4 or 5 is the possible solution. Link 4 is better. Please type in chain type: 4 or 5.
*4
Solution:
Path: ((* 2 3 4) (1 2 3 4))
((* 1 5 4) (1 6 3 4))
((* 1 7 6) (1 6 5 4))
The number of coordinates is 14.
The number of unknown orientations is 3.
The number of equations is 4.
The maximum number of point path generation is 15.