Kinematic Synthesis of Industrial Robot Hand/Gripper –
A Creative Design Approach

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The purpose of this research is to synthesize industrial robot hand mechanisms. Investigations on DOF(F), complexity and the structure (Graph) will be presented. Therefore, a kinematic structure table of robot hand mechanisms can be generated. The advantages of using this reference table are as follows:

- Identification of the kinematic structure of robot hand mechanisms for robot hand standardization.
- The atlas of graph (structure) can be used to enumerate new robot hand mechanisms.
- Leads to creation or invention of new robot hand mechanisms according to the separation of structure and function.

This paper will present a creative design approach in designing industrial robot hand/gripper mechanisms. This research work was conducted while the author was at Columbia University.

Keywords: Kinematics, Grippers, Hand mechanisms.

1. Introduction

Robotic hand/gripper is the integral part in most of the robotic applications. Market study predicted that there will be over 60% robotic applications in assembly and material handling [1]. Design of the robotic gripping mechanism always becomes the key element for the entitled project. Often, very little time is spent in optimal kinematic structure (topology) design in the early stages of a design process. Time pressures sometimes force engineers to repeat topologies that have worked in similar applications in the past, rather than try to create better designs [2]. Chen [3] presented a complete survey of mechanisms used for grippers for industrial robots. Erdman et al. [2] suggested techniques of type synthesis based on graph theory and expert systems. Some extensive work in creating database for robotic hand (grippers) mechanism has been done by the author [8]. This paper will present a creative design ap-

North-Holland
proach in designing industrial robot hand/gripper mechanism. The development of the kinematic structure of robot hand/gripper mechanisms will also be presented.

2. Overview of Industrial Robot Hand (Gripper) Mechanism [3]

In general, grippers can be classified according to the following:
(1) Mechanical finger type: According to the number of fingers in a gripper, we have
   (i) 2 finger type
   (ii) 3 finger type
   (iii) multifinger type.
According to the number of hands mounted on the wrist of the robot arm we have
   (i) single gripper
   (ii) dual gripper
   (iii) multiple gripper (index type).
According to the part configuration, we have
   (i) linear motion gripper (parallel)
   (ii) angular motion gripper.
According to the kinematic structure, we have
   (i) linkage type
   (ii) gear and rack type
   (iii) cam type
   (iv) screw type
   (v) rope and pulley type (MIT/UTAH hand, Hitachi hand).

(2) Vacuum and magnetic type: this class includes three fitted with suction cup or electromagnets.
(3) Special hand and gripper: this class consists of inflatable finger, paper picking gripper.

In this paper, we will investigate mechanical finger type because most industrial robot hand/gripper mechanisms fall into this category.

2.1. Kinematic Synthesis of Robot Hand (Gripper) Mechanism

Mechanism creation based on the separation of structure from function was proposed by Freudenstein [4–7]. Kinematic structure can be enumerated in an essentially systematic, unbiased fashion as a function of the degree of freedom of the mechanism, the nature of the desired motion and a parameter representing an indication of the complexity of the mechanism. Each structure obtained in this way can then be sketched and evaluated with respect to the functional requirements of the mechanism. Potentially acceptable mechanisms can then be evaluated in depth until a final design is achieved.

Most mechanisms obey the following general-degree-of-freedom equation:

\[ F = \lambda (L - j - 1) + \sum f_i \]  

where

\[ F = \text{degree of freedom of mechanism} \]

<table>
<thead>
<tr>
<th>Degree of Freedom (f)</th>
<th>Kinematic Element</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><img src="H" alt="Helical Pair" /></td>
<td>Helical Pair (H)</td>
</tr>
<tr>
<td>2</td>
<td><img src="G" alt="Gear Pair" /></td>
<td>Gear Pair (G)</td>
</tr>
<tr>
<td>1</td>
<td><img src="R" alt="Turning Pair" /></td>
<td>Turning Pair (R)</td>
</tr>
<tr>
<td>1</td>
<td><img src="P" alt="Sliding Pair" /></td>
<td>Sliding Pair (P)</td>
</tr>
<tr>
<td>4</td>
<td>![Ball in Cylinder](MIT/UTAH hand, Hitachi hand)</td>
<td>Ball in Cylinder</td>
</tr>
</tbody>
</table>

Fig. 1. Common used kinematic elements in robot hand/gripper mechanism.
Table 1
Correspondence between graph and mechanism

<table>
<thead>
<tr>
<th>Mechanism</th>
<th>Graph</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Links ((L))</td>
<td>Vertices ((v))</td>
<td>•</td>
</tr>
<tr>
<td>Joints ((j))</td>
<td>Edges ((e))</td>
<td>—</td>
</tr>
<tr>
<td>Joined Links</td>
<td>Edge-connected vertices</td>
<td>•—•</td>
</tr>
<tr>
<td>Different Joints</td>
<td>Labeled Edges</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(R = ) Pin Joint</td>
<td>(R)</td>
</tr>
<tr>
<td></td>
<td>(P = ) Sliding Joint</td>
<td>(P)</td>
</tr>
<tr>
<td></td>
<td>(G = ) Gear Joint</td>
<td>(G)</td>
</tr>
<tr>
<td></td>
<td>(H = ) Helical Joint</td>
<td>(H)</td>
</tr>
<tr>
<td>Grounded Element</td>
<td>Fixed Link</td>
<td>•</td>
</tr>
<tr>
<td>Same Mechanisms</td>
<td>Isomorphic Graphs</td>
<td></td>
</tr>
<tr>
<td>Different Mechanisms</td>
<td>Nonisomorphic Graphs</td>
<td></td>
</tr>
<tr>
<td>Independent Loops</td>
<td>Independent Loops</td>
<td>(\text{LIND})</td>
</tr>
</tbody>
</table>

\(\lambda\) = mobility number (degree of freedom in which mechanism operates):
\(\lambda = 3\) for plane and spherical motions; \(\lambda = 6\) for general three-dimensional motions,

\(L =\) number of links,
\(j =\) number of joints, and
\(f_i =\) degree of freedom of relative motion at \(i\)th joint.

In terms of the graph of the mechanism, Equation (1) may be written as
\[
F = \lambda(v - e - 1) + \sum f_i
\]  \(\text{(2)}\)
where \(v =\) number of vertices of graph \((v = L)\)
and \(e =\) number of edges of graph \((e = j)\).

\(\text{LIND} = j - L + 1\)  \(\text{(3)}\)

\(\text{LIND} = \) Number of independent loops in the mechanism combining (1) and (3)

\[
\sum f_i = F + \text{LIND}
\]  \(\text{(4)}\)

For gear trains it can be shown \([7]\) that these equations specialize to the following:

\(L = F + 1 + \text{LIND}\)
\(j = F + 2 \text{ LIND}\)
\(j_G = \text{LIND}\)
\(j_R = F + \text{LIND}\)

where \(j_G, j_R\) denote the number of gear pairs and pin joints. Most robot hands (grippers) are open-loop mechanisms whose structures are generally simpler than those of close-loop mechanisms. The

Fig. 2. Typical robot hand mechanism and graph.
most common joints in robot hands (grippers) mechanisms are the turning pairs or pin joints (R), the sliding pair (P), gear pairs (G), helical pairs or screw-and-nut (H) (see Fig. 1).

Table 1 shows the correspondence between graphs and mechanisms. The graph representation of a typical robot hand mechanism is shown in Fig. 2.

The degree of freedom (F) and complexity (LIND) can be illustrated by use of example from Fig. 2.
Number of links (L) = 6
Number of joints (j) = 7
\[ \sum f_i = RRPRRRR = 7 \]
\[ \lambda = 3 \text{ (plane mechanism)} \]

Therefore
\[ F = 3(L - j + 1) + \sum f_i \]
\[ = 3(6 - 7 - 1) + 7 = 1 \]

The number of closed loops in this mechanism is (a)
\[ \text{LIND} = j - L + 1 \]
\[ = 7 - 6 + 1 = 2 \]

This should be equal to the result from the graph (b).

From Table 1 we know that the number of edges (e) in the graph is equal to the number of links in the mechanism. The number of vertices (v) in the graph is equal to the number of joints (j) in the mechanism.
Therefore LIND can be rewritten in the following form:

\[ \text{LIND} = 1 + e - v = 1 + 7 - 6 = 2 \]

2.2. Creating of Kinematic Structure (Graph) for Industrial Robot Hand/Gripper Mechanism

In order to lead to creation or invention of new robot hand/gripper mechanisms according to the separation of structures and functions, a kinematic structure reference table of industrial robot/gripper mechanism should be generated.

Over hundreds of different industrial robot hand/gripper mechanisms have been investigated by the author. Fig. 3 shows parts of these kinematic structures (design database) which are generated by the author. The advantages of using this reference table are as follows:

1. Identification of kinematic structure of robot hand/gripper mechanisms.
2. The atlas of graph (structure) can be used to enumerate new robot hand/gripper mechanisms.
3. Leads to creation or invention of new robot hand/gripper mechanisms according to the separation of structure and function.

2.3. Creative Design of Industrial Robot Hand/Gripper Mechanism

The following examples will show how to do creative design from the generated kinematic structure (design database).

Example 1. In Fig. 3, numbers 1, 2 and 3 have the same vertices \(v\), edges \(e\) and kinematic structure (graph). If we look at these graphs without looking at the robot hand mechanisms, we can find that the differences among these three graphs are kinematic element at link 2 - link 4, and link 2 - link 3. Number 1 is prismatic joint \(P\). Number 2 is gear joint \(G\) and number 3 is pin joint \(R\).

If we would like to design a new robot hand by use of another type of kinematic joint, we could use the Helical Joint \(H\). The \(H\) joint will replace...
the above mentioned $P$, $G$ and $R$ joints. Therefore, a new graph and hand/gripper mechanism can be presented and designed (Fig. 4). In Fig. 4 two fingers are driven by a motor through a pulley to drive a screw bar [11].

Example 2. Let us compare number 6 and 7 from Fig. 3. They have same number of vertices ($v$) and edges ($e$) and same graph. If we would like to modify these mechanisms by use of gears, what kind of modifications should be done?

Obviously, if we are going to use gears, the gears have to be fixed and rotate about the pin joint with the fixed link. Therefore, link 3 and link 5 have to be replaced by $G$. The modified graph and modified design of new robot hand/gripper mechanism can be shown in Fig. 5.

2.4. Expert System Approach to Robot Hand/Gripper Mechanisms

Expert systems consist of three major components [10]:

- a database;
- rules for transforming the database;
- a control strategy for selecting which rule to apply next.

The database is a representation of parameters important to the problem. The rules of an expert system encode knowledge about how to reason from one set of facts to another. The control strategy determines which rules to apply when several rules are applicable.

In general, expert systems are useful in the following sorts of task:

- debugging
- design
- diagnosis
- interpretation
- prediction
- monitoring
- planning
- instruction
- modification.

The most difficult phase of mechanical design is the conceptual phase. By use of the generated kinematic structure (Design Database), an expert system can be created. This knowledge base system contains general information about robot
hand/mechanisms, kinematic structures (graphs), functions, types of drive mechanisms and applications. The designer enters the design requirements, the master will select the appropriate mechanisms and graphs from design database according to the functions, drive mechanisms, and applications. The designer can then study these proposed kinematic structures. Potentially acceptable mechanisms can then be evaluated in depth until a final design is achieved. Fig. 6 shows the database retrieve and storage system in a knowledge base system for creative design of robot hand/gripper mechanism. Similar study has been conducted by Chase and Roberts [9]. Fig. 7 shows user-machine interface for creative design and robot hand/gripper mechanism.

3. Summary

By using kinematic structure (graph) theory, a creative design approach has been presented for designing robot hand/gripper mechanisms. A knowledge base design database system can also be created through the generated kinematic structure table of robot hand/gripper mechanisms.

References