CHAPTER 4

QUALITATIVE ATTRIBUTES BASED RATING OF ROBOT
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4.1 INTRODUCTION

The problem of robot selection is a complex task involving multi-criteria decision-making approach based on various attributes of robot. These attributes may be tangible or intangible, quantitative or qualitative, objective or subjective. The hamming number technique provides an easy, efficient, reliable and robust method to select the robot for an application. It can be effectively utilized for qualitative attributes for which there is no ready quantification available. Very little work has been reported so far as subjective attributes are concerned. The fast pace of technology is responsible for users' ignorance regarding latest developments leading to faster obsolescence. Subjective attributes include parameters such as vendor's service quality, programming flexibility, man-machine interface etc. To gain quantitative measure of performance of robot, different experts such as robotic expert, production expert, maintenance expert, finance expert, etc are asked for their opinion. The experts give their opinion for each subjective attribute, which is an integer value between maximum and minimum value and finally the judgment of each expert, related to each subjective criteria, are resolved into a single normalized value, obtained as a mean. Whatever robotic system is adopted, it should be capable of handling both the subjective and objective attributes. The subjective attributes are quantifiable by objective judgment of experts. To compare the performance of different industrial robots and to help in selection of best robot based on subjective attributes, hamming number technique is proposed.
Qualitative Attributes Based Rating Of Robot

methodology measures the performance of robots based on subjective attributes. Rao [90] introduced the concept of Hamming distances from information and communication theory to the study of kinematic structure and isomorphism in kinematic chains.

Earlier, Philip Y Huang and Parviz Gahodforough [44] developed an approach of subjective and objective factors measures for ranking the robot. In line of above we will consider only the subjective attributes. The following attributes are selected: Installation lead time, pre sale service, training provided by the vendor, quality of training, supervision and service engineer of the vendor, acceptability of robotic product by the workers, programming flexibility. Not all the attributes will have the same importance or weight age. The expert opinion for these attributes are given by 5 experts whose integer value are shown before them. The final weight is taken as an average of these opinion

<table>
<thead>
<tr>
<th>S No</th>
<th>Attributes</th>
<th>Expert opinion</th>
<th>Average</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Installation lead-time</td>
<td>[3,4,5,4,4]</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Pre sale service</td>
<td>[7,8,9,8,8]</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Training by vendor</td>
<td>[6,8,5,7,9]</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Vendor's supervision</td>
<td>[2,5,6,6,6]</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Acceptability by workers</td>
<td>[5,7,4,6,8]</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Vendor's Service personnel</td>
<td>[3,4,5,6,7]</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Programming flexibility</td>
<td>[8,9,7,5,6]</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Increased production</td>
<td>[10,10,10,10,10]</td>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>

Each of the subjective factors is assigned a score based on 10-point scale.

Table 4.1

EXPERT OPINION GIVEN TO THE ATTRIBUTES [44]
The higher the score more important is the factor.

The subjective vendor rating for candidate robots are given by the factors, which are shown below:

Excellent 4,
Good 3,
Average 2,
Poor 1,

If the factor is yes or no type then
yes =1, No =0

Table 4.2

ATTRIBUTES TO JUDGE THE VENDORS [44]

<table>
<thead>
<tr>
<th>Weightage</th>
<th>S.No</th>
<th>Subjective factors</th>
<th>Vendor 1</th>
<th>Vendor 2</th>
<th>Vendor 3</th>
<th>Vendor 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>1</td>
<td>Installation lead-time</td>
<td>Good (3)</td>
<td>Average (2)</td>
<td>Excellent (4)</td>
<td>Poor (1)</td>
</tr>
<tr>
<td>8</td>
<td>2</td>
<td>Pre sale service</td>
<td>Average (2)</td>
<td>Excellent (4)</td>
<td>Good (3)</td>
<td>Excellent (4)</td>
</tr>
<tr>
<td>7</td>
<td>3</td>
<td>Training by vendor</td>
<td>Yes (1)</td>
<td>Yes (1)</td>
<td>No training (0)</td>
<td>Yes (1)</td>
</tr>
<tr>
<td>6</td>
<td>4</td>
<td>Quality of training</td>
<td>Excellent (4)</td>
<td>Good (3)</td>
<td>No training (0)</td>
<td>Good (3)</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>Vendor's supervision</td>
<td>Yes (1)</td>
<td>Yes (1)</td>
<td>Yes (1)</td>
<td>Yes (1)</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>Vendor's Service personnel</td>
<td>Good (3)</td>
<td>Good (3)</td>
<td>Excellent (4)</td>
<td>Good (3)</td>
</tr>
<tr>
<td>5</td>
<td>7</td>
<td>Acceptability by workers</td>
<td>Good (3)</td>
<td>Average (2)</td>
<td>Average (2)</td>
<td>Good (3)</td>
</tr>
<tr>
<td>7</td>
<td>8</td>
<td>Programming flexibility</td>
<td>Excellent (4)</td>
<td>Good (3)</td>
<td>Good (3)</td>
<td>Excellent (4)</td>
</tr>
<tr>
<td>10</td>
<td>9</td>
<td>Increased production</td>
<td>Good (3)</td>
<td>Good (3)</td>
<td>Good (3)</td>
<td>Good (3)</td>
</tr>
</tbody>
</table>

Σ =58

Each of 9 attributes are assigned a normalized score based on relative importance to the user. Four different vendors are analyzed by combination of each subjective attribute.
4.2 THE METHOD

Hamming number technique and its application to detect isomorphism among kinematic chain has been already reported [89, 90]. This concept has great potential and can be used further to make the selection of robots. The hamming number is computed on the lines of hamming distance, a concept used in digital communication theory. The hamming number $h_{ij}$ related to the attributes $i$ and $j$ is defined as the number of digits at which the codes of attributes $i$ and $j$ differ. To write hamming matrix $(H)$, element $h_{ij}$ of which is given by the expression (as mentioned in the chapter-3)

$$h_{ij} = (a_k + a_{jk})$$  \hspace{1cm} (4.1)

Subject to the condition:

$$(a_k + a_{jk}) = 0 \text{ , if } a_k = a_{jk}$$

where $a_{ik}$ and $a_{jk}$ are the elements of the attributes matrix

The above data can be written in the form of a new matrix as shown

$$
\begin{pmatrix}
\begin{array}{cccc}
a_{11} & a_{12} & a_{13} & a_{14} & \cdots & a_{1m} \\
a_{21} & a_{22} & a_{23} & a_{24} & \cdots & a_{2m} \\
a_{31} & a_{32} & a_{33} & a_{34} & \cdots & a_{3m} \\
a_{41} & a_{42} & a_{43} & a_{44} & \cdots & a_{4m} \\
a_{51} & a_{52} & a_{53} & a_{54} & \cdots & a_{5m} \\
a_{n1} & \cdots & a_{nm} & \cdots & \cdots & a_{mn}
\end{array}
\end{pmatrix}
$$

4.1

Where $a_{ij}$ is the attribute(s)

A new matrix is formed with the help of the attributes mentioned in table -4.2

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The new matrix is shown below:

\[
\begin{array}{ccccccccc}
\text{Attributes} & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 \\
\hline
V1 & *0.02 & 0.021 & 0.04 & 0.041 & 0.021 & 0.023 & 0.025 & 0.034 & 0.043 \\
V2 & 0.013 & 0.042 & 0.04 & 0.031 & 0.021 & 0.023 & 0.017 & 0.025 & 0.043 \\
V3 & 0.027 & 0.031 & 0 & 0 & 0.021 & 0.031 & 0.017 & 0.025 & 0.043 \\
V4 & 0.006 & 0.042 & 0.04 & 0.031 & 0.021 & 0.023 & 0.025 & 0.034 & 0.043 \\
\end{array}
\]

\* \( a_{11} = 0.3 \times \frac{4}{58} \) and \( a_{12} = 0.153 \times \frac{8}{58} \)

The elements of the above matrix can be rewritten for generalization using the following expression (also used in chapter-3)
\( n \)

where \( C_i = \sum a_i \)

where \( C_i \) represent the elements in the column \( j \)

### Attributes Matrix

\[
\begin{array}{cccccccccc}
  & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 \\
 V1 & 0.02 & 0.021 & 0.04 & 0.041 & 0.021 & 0.023 & 0.025 & 0.034 & 0.043 & 0.268 \\
 V2 & 0.013 & 0.042 & 0.04 & 0.031 & 0.021 & 0.023 & 0.017 & 0.025 & 0.043 & 0.255 \\
 V3 & 0.027 & 0.031 & 0 & 0.021 & 0.031 & 0.017 & 0.025 & 0.043 & 0.195 \\
 V4 & 0.006 & 0.042 & 0.04 & 0.031 & 0.021 & 0.023 & 0.025 & 0.034 & 0.043 & 0.265 \\
\end{array}
\]

\[ \sum a_{1m} = 0.268 \]

### HAMMING NUMBER MATRIX

\[
H = \begin{pmatrix}
R_1 & R_2 & R_3 & R_4 \\
R_1 & 0 & 0.523 & 0.463 & 0.533 & 1.519 \\
R_2 & 0.523 & 0 & 0.45 & 0.52 & 1.493 \\
R_3 & 0.463 & 0.45 & 0 & 0.46 & 1.373 \\
R_4 & 0.533 & 0.52 & 0.46 & 0 & 1.513 \\
\end{pmatrix}
\]

From the above attribute matrix-using equation-4.1 the Hamming matrix is written directly below

\[ h_{12} = (a_{11} + a_{12} + a_{13} + a_{14} + a_{15} + a_{16} + a_{17} + a_{18} + a_{19} + a_{21} + a_{22} + a_{23} + a_{24} + a_{25} + a_{26} + a_{27} + a_{28} + a_{29}) = 0.523 \]

since \( a_{ik} \neq a_{jk} \)

and \( h_{ii} = h_{jj} = 0 \)

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The hamming value for any robot is the sum of all the elements in the $i^{th}$ row of hamming matrix. Thus the hamming value for robot $R_1$ is
\[(0+0.523+0.463+0.533) = 1.519\]

The greater the value, the better is the robot for example, the robot $R_1$ is having a hamming value of 1.519 and robot $R_2$ has the hamming value of 1.493 hence robot $R_1$ is better than $R_2$ and so on.

The evaluation and ranking of the candidate robots has been tabulated in the table 4.3

<table>
<thead>
<tr>
<th>S. No</th>
<th>Robot Vendor</th>
<th>Subjective factor Measure SFM1 (as per Philip Y Huang) [44]</th>
<th>Rank</th>
<th>Values based on Hamming Technique</th>
<th>Rank based on Hamming value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>0.272</td>
<td>1</td>
<td>1.519</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>0.259</td>
<td>3</td>
<td>1.493</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>0.199</td>
<td>4</td>
<td>1.373</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>0.269</td>
<td>2</td>
<td>1.513</td>
<td>2</td>
</tr>
</tbody>
</table>

From above table, we find that rank obtained of different robots vendor's by subjective factor measure [44] is exactly the same as computed by hamming number technique. Suitability can be further decided at the user's end.
4.3 CONCLUSIONS

The chapter presents a unique approach to robot selection process based on hamming number technique, which is reported in this area. It is based on identifying and analyzing a number of subjective attributes for the selection of the best robot among various candidate robots.

The utility of the work is as follows

1. The method is suitable to compare different robots vendor's based on subjective attributes.

2. The concept of hamming number provides us with a valuable tool to evaluate different characteristics of robots based on qualitative attributes, so that suitability can be ascertained.

3. Each of the attribute contributes to the overall performance of the robots.
A FUZZY VECTOR MODEL TO MEASURE THE ROBOT PERFORMANCE