Attribute Based Specification, Comparison And Selection Of A Robot

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ABSTRACT

The problem of robot selection has been of concern to manufacturers for many years, which has become more difficult in recent years due to increasing complexity. Here we are giving simple procedure for the robot user or purchaser to save time by providing a tool for selecting the robot system most suited for his operational needs. The elimination search based on the few critical selection attributes is used to shortlist the robots. Subsequently, the selection procedure proceeds to rank the short listed alternatives by employing different attributes based specification methods and graphical methods. The ranking of candidate robots is done with respect to the most suitable say benchmark robot for particular application. This ranking will provide a good guidance / guideline for the robot user / purchaser to select the robot.

INTRODUCTION

Robots with vastly different capabilities and specifications are available for a wide range of applications. The selection of the robot to suit a particular application and production environment, from the large number of robots available in the market today has become a difficult task. Various considerations such as availability, management policies, production systems compatibility, and economics need to be considered before a suitable robot can be selected.

There are a number of reported studies concerning the selection of robots for manufacturing applications using various comparison methods [1], while some literature discuss feasibility of usage of robots over human manpower [2]. Some researchers have considered work environment [3] as an aid for selection of robots. There are some papers available, which use MADM (Multiple Attribute Decision Making) [4] and TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) [5] methods for robot selection.

MANIPULATOR ATTRIBUTES AND THEIR QUANTIFICATION

Proper identification of manipulator attributes is critically important when comparing various alternative robots.

The robot manipulator will be expressed in detailed manner with the attributes identified e.g., payload capacity 35kg; repeatability 0.1 mm. But all attributes are not quantitative, e.g., built quality, after-sales service, etc. The robots can be rated on the scale of 1 to 5 or 1 to 10 for these attributes. There may be some attributes of which quantification is not readily available and has to be done by some mathematical model or experimentation and analysis such as reliability, life.

ALGORITHM OF THE SELECTION

The selection procedure algorithm can be summarized as follows.

Stage 1: Elimination search: Scan the database and obtain a list of robots, say candidate robots, which satisfy the minimum requirements of all the pertinent attributes.

Stage 2: Evaluation procedure

Step 1: Form the decision matrix $\mathbf{D}_{ij}$, where row (i) correspond to the candidate robot and columns (j) correspond to the attribute of it. This will be m × n matrix where m number of candidate robots and n number of attributes are under consideration.

Step 2: Form the relative importance matrix **A** of the relative importance of the attributes with respect to each other. This will be n × n matrix of which the symmetric terms will be reciprocals of each other.

Step 3: Obtain maximum eigen value λ and associated eigen vector as weight vector **W**, where w_i represents the weight of ith attribute.

Step 4: Construct the normalized decision matrix (**N**) using $n_{ij} = d_{ij} / \left(\sum_{i=1}^{m} d_{ij}^{2} \right)^{1/2}$ …(1)

where n_{ij} – an element of the normalized decision matrix

d_{ij} – numerical outcome of ith option with respect to the jth criterion

Step 5: Determine the weighted normalized decision matrix (**V**).

Step 6: Determination of the benchmark robot attributes.

Step 7: Application of graphical or non-graphical method for finding out the similarity with the benchmark robot.

Stage 3: Calculation of Coefficient of similarity (COS) and ranking of the candidate robots based on it.

GRAPHICAL REPRESENTATION

LINE GRAPH REPRESENTATION

We have various specifications matrices containing information of the candidate robots. These matrices can be represented graphically as line graph by plotting the magnitude of the attributes on the vertical axis and the attributes on the horizontal axis. These graphs will be distinct for all of the candidate robots and can be used as comparison basis. Here the area under the graph has been used as a consolidated index, which expresses the capabilities of the robot and can be used for comparison purposes. The area under the graph can be obtained as follows.

Let the horizontal distance between the two parameters on horizontal axis as unity and d_{ij}, n_{ij}, and v_{ij} are the elements of **D**, **N**, and **V** matrices for j = 1 to n.

Area under the line graph of specification of i^{th} robot can be found out as

$$AD^L_i = (d_{i,1}+2(d_{i,2}+\ldots+d_{i,n-1})+d_{i,n})/2 \quad \ldots(2)$$

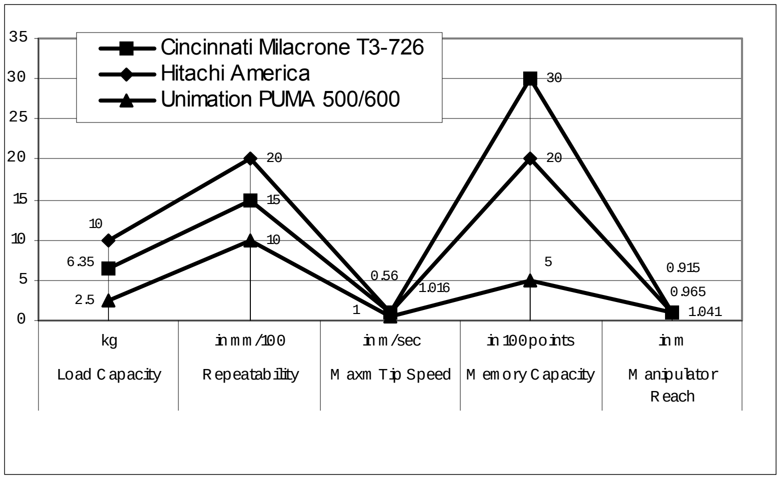

Fig. 1: Line graph plot for the specifications of few candidate robots

Similarly, area under the graph of normalized and weighted normalized specifications of the i^{th} robot, i.e., AN^L_i and AV^L_i using their respective elements for candidate and benchmark robots.

SPIDER DIAGRAM

In this method, the attributes have been considered to be forming the spider diagram, where the attributes are plotted on the concurrent axes and candidate robot will form a polygon. So the angle θ between the attribute axes can be calculated as $\theta = 2\pi/n$, where n number of attributes are under consideration. The attributes, normalized and weighted normalized specifications magnitudes are plotted to obtain the spider diagram, also known as polar or radar diagram, as shown in Fig. 2 for different candidate robots.

Here the area enclosed by the polygon formed on the spider diagram is the indication of the robot capabilities. All the specification magnitudes are boiled down to this single index. This area enclosed by the polygon of the i^{th} robot can be calculated as follows. In the spider diagram, $\theta = 2\pi/n$, where n is the number of attributes. Let d_{ij} represents the value of i^{th} attribute in the j^{th} robot along θ_i.

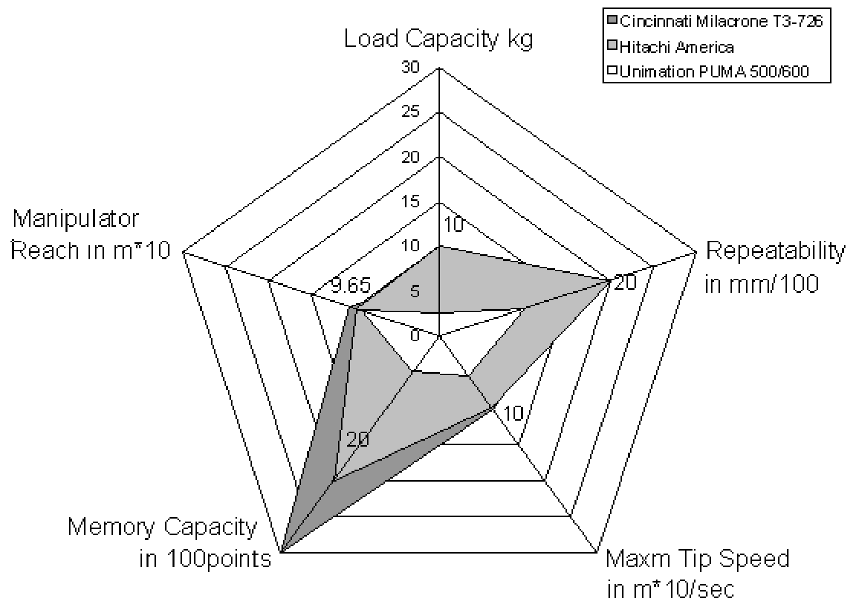

Fig. 2: Spider diagram polygon for the specifications and the area enclosed is shaded

$$AD^S_i = \frac{\sin\theta}{2}\left(\sum_{i=1}^{n} d_{ij} d_{i+1,j}\right); \text{ where } d_{n+1,j} = d_{1,j}. \qquad \ldots(3)$$

Similarly for normalized and weighted normalized specifications areas enclosed by polygons, i.e., AN^S_i and AV^S_i, respectively, are calculated for candidate and benchmark robots.

RMS VALUE METHOD

This is non-graphical method. Each robot has been expressed by the attributes. These attributes have different magnitudes and units so they cannot be processed and compared as they are. So these attribute magnitudes are unified by calculating their RMS value. The RMS value of the specifications, normalized specifications and weighted normalized specifications can be calculated as follows. For the RMS value of the specifications of the ith robot, AD^R_i can be calculated as $AD^R_i = \left(\sum_{j=1}^{n} d_{ij}^2\right)^{1/2}$ …(4)

Similarly for normalized and weighted normalized specifications RMS values, i.e., AN^R_i and AV^R_i, respectively, are calculated for candidate and benchmark robots.

IDENTIFICATION AND GRAPHICAL REPRESENTATION OF AN IDEAL ROBOT

We started with the basic minimum values assigned to the pertinent attributes for elimination search, but we know that the robots passing those criteria may not best suitable for the required application. So the group of experts will decide the attribute magnitudes for the robot, say benchmark robot, which will be perfect for the required application. All the candidate robots will be compared with the benchmark robot for the evaluation purpose. It will show the suitability of the robot for the particular task. Using these values of attributes and the benchmark robot can also be plotted on the line graph and spider diagram. Similarly, the areas under the line graph for benchmark robot, i.e., AD^L_B, AN^L_B, and AV^L_B are calculated. Similar procedure followed for spider diagram and RMS value methods.

COEFFICIENT OF SIMILARITY WITH IDEAL ROBOT

Now we have specifications matrices ready for all the candidate robots along with the benchmark robot. We need a measure to compare the candidates with benchmark robot. Let it be Coefficient of similarity (COS). It is the ratio of specification value of candidate to that of the benchmark robot. The value of COS can be any +ve number and will be a measure of the closeness of candidate robot with the benchmark robot. The candidates with COS magnitude closer to unity are preferable. There may be some candidate robots, which have better capabilities than the benchmark robot. So they will have value of COS higher than unity, while some robots will not be as good as benchmark robot and hence will have less than unity COS value. It is not only dependent on COS value since the robot with higher capabilities will have higher cost and the robot with lower than unity COS may be insufficient. Now the group of experts will take decision about selection and the robot with optimum COS value has to be selected.

Coefficient of Similarity (COS) based on specifications / attributes

$$COS^V_j = AV_j / AV_B \qquad \ldots(5)$$

AD_j for j^{th} robot and different methods, i.e., line graph, etc.

Coefficient of Similarity (COS) based on normalized and weighted normalized specifications, COS^N_j and COS^V_j, respectively, are calculated. Thus the COS calculations for all the n number of candidate robots and for 3 methods using the weighted normalized specifications should be done.

ILLUSTRATIVE EXAMPLE

Suppose we want to select a robot for some pick-n-place operation in workplace with obstacles. The minimum requirement for this application is as follows.

1) Load capacity -	minimum 2 kg	4) Memory capacity -	at least 250 points/steps
2) Repeatability -	0.5 mm	5) Manipulator reach -	500 mm
3) Maximum tip speed -	at least 255 mm/sec		

From the database, elimination search had provided manageable number of candidate robots and their pertinent attributes as shown in Table 1.

Step 1: Formation of the decision matrix, '**D**' by writing the attributes in matrix form.

Table 1: Attributes for the short-listed candidate robots

	Load capacity in kg	Repeatability in mm	Maximum tip speed in mm/sec	Memory capacity in points or steps	Manipulator reach in mm
ASEA-IRB 60/2	60	0.4	2540	500	990
Cincinnati Milacrone T^3-726	6.35	0.15	1016	3000	1041
Cybotech V15 Electric Robot	6.8	0.10	1727.2	1500	1676
Hitachi America Process Robot	10	0.2	1000	2000	965
Unimation PUMA 500/600	2.5	0.10	560	500	915
United States Robots Maker 110	4.5	0.08	1016	350	508
Yaskawa Electric Motoman L3C	3	0.1	1778	1000	920

Step 2. Construction of Relative importance matrix **A**

$$\mathbf{A} = \begin{bmatrix} 1 & 1 & 2 & 0.5 & 0.33 \\ 1 & 1 & 0.5 & 2 & 2 \\ 0.5 & 2 & 1 & 3 & 2 \\ 2 & 0.5 & 0.33 & 1 & 0.33 \\ 3 & 0.5 & 0.5 & 3 & 1 \end{bmatrix} \qquad \ldots(6)$$

Step 3: Finding out the maximum eigen value of the relative importance matrix **A**

$\lambda_{max} = 6$;

$$w_1 + w_2 + w_3 + w_4 + w_5 = 1 \qquad \ldots(7)$$

$\mathbf{W} = [0.1761; 0.2042; 0.2668; 0.243; 0.2286]^T$

Step 4. Calculating the normalized specification matrix

$$\mathbf{N} = \begin{bmatrix} 0.9702 & 0.7861 & 0.6355 & 0.1217 & 0.3559 \\ 0.1029 & 0.2948 & 0.2542 & 0.7304 & 0.3741 \\ 0.1102 & 0.1965 & 0.4321 & 0.3652 & 0.6023 \\ 0.1632 & 0.3931 & 0.2504 & 0.4869 & 0.3468 \\ 0.0404 & 0.1965 & 0.1398 & 0.1217 & 0.3285 \\ 0.0735 & 0.1572 & 0.2542 & 0.0852 & 0.1825 \\ 0.0485 & 0.1965 & 0.4449 & 0.2435 & 0.3303 \end{bmatrix} \qquad \ldots(8)$$

Step 5. Calculating the weighted normalized specification matrix

$$\mathbf{V} = \begin{bmatrix} 0.1709 & 0.1605 & 0.1696 & 0.0151 & 0.0814 \\ 0.0181 & 0.0602 & 0.0678 & 0.0908 & 0.0855 \\ 0.0194 & 0.0401 & 0.1153 & 0.0454 & 0.1355 \\ 0.0287 & 0.0803 & 0.0668 & 0.0605 & 0.0793 \\ 0.0071 & 0.0401 & 0.0373 & 0.0151 & 0.0751 \\ 0.0129 & 0.0321 & 0.0678 & 0.0106 & 0.0417 \\ 0.0085 & 0.0401 & 0.1187 & 0.0303 & 0.0755 \end{bmatrix} \quad \ldots(9)$$

The element values of weighted normalized specification matrix are used for the line graph or spider diagram plotting or RMS value calculations.

Step 6: The group of experts, which analyses the application has decided that the robot with following configuration will be best possible robot, i.e., benchmark robot for it. The specifications for benchmark robot are as follows.

1. Load capacity - 3.6 kg
2. Repeatability - 0.5 mm
3. Maximum tip speed - 500 mm/sec
4. Memory capacity - 500 points/steps
5. Manipulator reach - 500 mm

<u>Stage 3:</u> Suppose the area under the line graph for weighted normalized specifications of first candidate robot and for benchmark robot are $AV^L{}_1 = 0.4713$; $AV^L{}_B = 2.167$. The coefficient of similarity based on the weighted normalized specification of the second candidate robot is

$$COS^{VL}{}_1 = AV^L{}_1 / AV^L{}_B = 2.167 \quad \ldots(10)$$

Similarly the COS values using Line graph, Spider diagram and RMS value methods are calculated and tabulated in Table 2.

ROLE OF USER IN SELECTION

Here one can see, the COS values based on different methods differ from each other and so the ranking of the candidate robots. The user should find out which method is the best suited for him and his application. Thus the robots are ranked in order of preference based on the attributes selected. For the purchase of a new robot, the final decision rests with management, and is based on this set together with other considerations.

The ranking based on COS will work just as a guideline for the selection. Note here that though some robot are not acceptable due COS value to far from unity, but still they are acceptable for the application since they are above the basic cut-off. The final selection process will also depend on the various factors, which are not considered earlier such as Economic considerations, Political considerations, Environmental considerations, Managements policies and Corporate goals of the organization. But this procedure will reduce the overall time required for the selection.

Table 2: Weighted normalized specifications based COS values for candidate robots using various methods

	Line Graph COS^{VL}	Rank	Spider diagram COS^{VS}	Rank	RMS value COS^{VR}	Rank
ASEA-IRB 60/2	2.167	6	10.60	6	1.96	3
Cincinnati Milacrone T^3-726	1.24	3	2.62	4	1.009	1
Cybotech V15 Electric Robot	1.279	4	2.47	3	1.23	2
Hitachi America Process Robot	1.203	2	2.39	2	0.957	6
Unimation PUMA 500/600	0.614	7	0.511	7	0.615	7
United States Robots Maker 110	1.962	5	3.50	5	2.155	4
Yaskawa Electric Motoman L3C	1.063	1	1.48	1	2.77	5

CONCLUSIONS

The method identifies the various attributes needing to be considered for the optimum evaluation and selection of robots. It processes the information about relative importance of attributes for a given application without which inter-attribute comparison is not possible. It is used to rank the robots in order of their suitability for the given application. For the robot end user or purchaser it will help to select and buy the correct robot from the market. Novel graphical and RMS value method approach is used for quick and effective evaluation and ranking of the candidate robots. The method is simple and quick for selection process of the robot and do not involve rigorous mathematical treatment and hence its easy to understand and follow by even the newcomer.

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