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Selection, identification and comparison of industrial robots using digraph and matrix methods

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Abstract

In the present work, a methodology based on digraph and matrix methods is developed for evaluation of alternative industrial robots. A robot selection index is proposed that evaluates and ranks robots for a given industrial application. The index is obtained from a robot selection attributes function, obtained from the robot selection attributes digraph. The digraph is developed considering robot selection attributes and their relative importance for the application considered. A step by step procedure for evaluation of robot selection index is suggested. Coefficients of similarity and dissimilarity and the identification sets are also proposed. These are obtained from the robot selection attributes function and are useful for easy storage and retrieval of the data. Two examples are included to illustrate the approach.

Keywords: Industrial robot; Digraph and matrix methods; Robot selection index

1. Introduction

Recent developments in information technology and engineering sciences have been the main reason for the increased utilization of robots in a variety of advanced manufacturing facilities. Robots with vastly different capabilities and specifications are available for a wide range of applications. The selection of robots to suit a particular application and production environment from among the large number available in the market has become a difficult task. Various considerations such as product design, production system and economics need to be considered before a suitable robot can be selected. The selection problem is especially relevant bearing in mind the likely lack of experience of prospective users in employing a robot. Indeed, robots are still a new concept in industry at large, so it is not unusual for an industry to be a first-time robot purchaser. Many precision-based methods for robot selection have been developed [1–17]. Knott and Getto [1] suggested a model to evaluate different robotic systems under uncertainty and different alternatives were evaluated by computing the total net present values of cash flows of investment, labor components and overheads. Offodile et al. [2] developed a coding and classification system which was used to store robot characteristics in a database, and then selected a robot using economic modeling. While the attempt provides a valuable aid at the stage of the final selection, such an exercise will be prohibitive at the initial selection stage where the number of potential robots is large and many other considerations have to be taken into account. Imang and Schlesinger [3] presented decision models for robot selection and compared ordinary least squares and linear goal programming method. Agrawal et al. [4] employed TOPSIS method for robot selection. TOPSIS method can efficiently deal with robot selection factors of objective type but not with subjective type and the authors had not considered the subjective factors. Boubekri et al. [5] developed an expert system for industrial robot selection considering functional, organizational and economical factors in the selection process. Wang et al. [6] presented a decision support system which applies a fuzzy set method for robot selection. The objective factors were

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evaluated via marginal value functions while the subjective factors were evaluated via fuzzy set membership function. Data from both evaluations were finally processed such that a fuzzy set decision vector was obtained. However, the fuzzy method presented is a complicated one and requires more computation. Booth et al. [7] proposed a decision model for the robot selection problem using both Mahalanobis distance analysis, i.e. a multivariate distance measure, and principal-components analysis. Liang and Wang [8] proposed a robot selection algorithm by combing the concepts of fuzzy set theory and hierarchical structure analysis. The algorithm was used to aggregate decision-makers' fuzzy assessments about robot selection factors weightings and to obtain fuzzy suitability indices. The suitability ratings were then ranked to select the most suitable robot. Chu and Lin [9] pointed out the limitations of Liang and Wang [8] method and proposed a fuzzy TOPSIS method for robot selection. However, the authors had converted the available objective values of the robot selection factors into fuzzy values which violate the basic rule of fuzzy logic, i.e. the available objective values need not be fuzzified. Further, only a 5-point scale was adapted for rating of robots under subjective factors. Also, the fuzzy method is complicated and requires more computation. Khouja and Offodile [10] reviewed the literature on industrial robots selection problem and provided directions for future research. Khouja [11] presented a two-phase robot selection model that involved the application of data envelopment analysis (DEA) in the first phase and a multi-attribute decision making model in the second phase. However, DEA requires more computation and if the number of factors that the decision maker wishes to consider is very large and the number of alternative robots small, then DEA may be a poor discriminator of good and poor performers. Again, DEA may be at a disadvantage in terms of the method's rationale if the decision maker is unfamiliar with linear programming concepts.

Goh et al. [12] proposed a revised weighted sum decision model that took into account both objective and subjective attributes of the robots under consideration. The model incorporated values assigned by a group of experts on different attributes in selecting the robots. However, weighted sum model suffers from the additivity utility assumption and is not efficient as compared to other MADM methods. Goh [13] employed analytic hierarchy process (AHP) method for robot selection. The AHP method can efficiently deal with objective as well as subjective factors, especially where the subjective judgments of different individuals constitute an important part of the decision process. However, in some cases unmanageable number of pair-wise comparisons of factors with each other and that of the alternatives with respect to each of the factors may result. Parkan and Wu [14] presented decision making and performance measurement models with applications to robot selection. Particular emphasis was placed on a performance measurement procedure called operational competitiveness rating (OCRA) and a multiple attribute decision making method, TOPSIS. The final selection was made on the basis of rankings obtained by averaging the results of OCRA, TOPSIS, and a utility model. However, the models had not considered the subjective factors and no explanation was given on how to assign the weightings to different robot selection factors. Khouja and Kumar [15] used options theory and investment evaluation procedure for selection of robots. Braglia and Petroni [16] did investment evaluation using DEA for robot selection. Bhangale et al. [17] listed a large number of robot selection attributes and ranked the robots using TOPSIS and graphical methods and compared the rankings given by these methods. However, in general, TOPSIS method has been proved to be less efficient as compared to AHP and its revised version [18]. Hence, the application of TOPSIS method for robot selection may not provide reliable results.

Thus, there is a need for a simple, systematical and logical scientific method or mathematical tool to guide decision makers in taking a proper decision. The objective of a robot selection procedure is to identify the robot selection factors and obtain the most appropriate combination of the factors in conjunction with the real requirements of the industrial application. Efforts need to be extended to determine factors which influence robot selection for a given industrial application, using a logical approach, to eliminate unsuitable robots and selection of a proper robot to strengthen the existing robot selection procedure. This is considered in this paper using digraph and matrix methods.

Graph theory is a logical and systematical approach. The advanced theory of graphs and its applications are very well documented. Graph/digraph model representation have proved to be useful for modeling and analyzing various kinds of systems and problems in numerous fields of science and technology [19–28]. The matrix approach is useful in analyzing the graph/digraph models expeditiously to derive the system function and index to meet the objectives. In view of these advantages, digraph and matrix methods are proposed in this paper for robot selection.

2. Robot selection attributes digraph

Robot selection attribute is defined as a factor that influences the selection of a robot for a given industrial application. These attributes include: cost, configuration, load capacity, type of control, velocity of movements, type of programming, programming flexibility, reliability, repeatability, positioning accuracy, number of degrees of freedom, work volume, drive system, man-machine interface, vendor's service contract, training, delivery period, availability or assured supply, management constraints, etc.

Robot selection attributes digraph models the robot selection attributes and their interrelationship. This digraph consists of a set of nodes $N = \{n_i\}$, with $i = 1, 2, \ldots, M$ and a set of directed edges $E = \{e_{ij}\}$. A node n_i represents ith robot selection attribute and edges