Performance Evaluation of Robot Design based on AHP

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Abstract

In order to improve the efficiency and reliability of robot design, the performance evaluation becomes more and more important. A new comprehensive method was proposed based on the analytic hierarchy process which is a structured approach for solution of complex decision making problems. In this method, the decision tree was built with three or more layers. The factors which affect the target layer were proposed and optimized partly. The weights of different layer criterion were calculated through AHP, the value of different alternatives was evaluated and the performance of different robot design was obtained. The feasibility of this method was validated by an example. It's proved that the method can make a qualitative evaluation on the performance of robot design and can applies to both the theory study of robot and the application of robot design engineering.

Keywords: *robot, performance evaluation, analytic hierarchy process（AHP）*

1. Introduction

1.1 Introduction on the robot design

1.1.1. Robot introduction: Robot is the electronic mechanical device which can be provided personification. Robots are not in the simple sense to replace artificial of labor, but the comprehension of special features of people and machine. Robot has a rapid reaction and analysis judgment ability with the state of the environment. A long time to continue work, the high accuracy, the ability of adapted the bad environment, which provided by the machine, can be had by the robot. In a sense, it is the product of evolution process of the machine, the important production and service equipment in industry and the industrial, the indispensable automation equipment in advanced manufacturing domain [1]. So it's necessary for us to design the robot and evaluate robot design correctly in order to get the better conclusion and promote the development of the manufacturing industry in robot.

1.1.2. Robot design and evaluate: Studying of robot design is early, and have made great progress. Each research contents have a different focus. Focus on direction is different, and the effect each robot design obtained is different, too. The effect of the robot design mainly depends on the initial stage of design and the application effect of robot. Especially in the initial phase, according to the different design goals, a variety of design scheme can be formed, in the actual process, how to determine the best design is the key to success for subsequent work.

Comprehensive evaluation for multiple hierarchies and multiple targets is necessary for the evaluation on the effects of robots design. It needs experts and policy makers come from various fields to participate in order to ensure the credibility and accuracy of evaluation results. Many literatures do research and analysis on the effect of robots design, think that using the AHP method to evaluate the performance of robot is feasible, but because of the complexity of design scheme, it brings a lot of difficulties. Therefore, setting up performance evaluation index system of robot design has important significance.

The evaluation index system should include two main different parts. One is the indexes which belong to the initial design stage and the other is the indexes which belong to the application stage.

In initial design stage, the performance evaluation is related to all sorts of design index. Large cost and long term may be needed in this stage. In order to cut the cost and short the development cycle, robot designer should set up the clear product position and output target, formulate appropriate design scheme. The target should be integrated with current several mature technologies. It refers to use a certain scientific method under the certain economic conditions. The index obtained can be very beneficial in helping to reduce costs and increase productivity. A set of index system of comprehensive evaluation scheme of robot design can make design scheme optimization and ensure the smooth operation of the robot research and development.

In application stage, the technique and performance of the robot are the main evaluated index. All the application evaluated index can be used to measure, visualize, and analyze the static and dynamic performance of a robot and can be used to determine a robot’s accuracy, repeatability, exchangeability, speed, cornering, warm-up drift, *etc*.

1.2. Principles of AHP

AHP is developed in 1970’s by Thomas L. Saaty and it is a structured technique for organizing and analyzing complex decisions. Based on mathematics and psychology, the AHP helps decision makers find one that best suits their goal and their understanding of the problem. Published materials show that Analytic Hierarchy Process (AHP) has a very wide range of usage in almost all branches of real life. Because of its flexible structure and easily applicable mathematical formulation, this process is extensively used in the literature especially in last two decades.

Basic principle of AHP depends on ranking priorities of criteria affecting choice of an alternative amongst several alternatives. All criteria and sub-criteria are located in a hierarchy tree to obtain a structured solution. It provides a comprehensive and rational framework for structuring a decision problem, for representing and quantifying its elements, for relating those elements to overall goals, and for evaluating alternative solutions.

Firstly, the decision problem should be decomposed into a hierarchy of more easily comprehended sub-problems, each of which can be analyzed independently. The elements of the hierarchy can relate to any aspect of the decision problem. Once the hierarchy is built, the decision makers systematically evaluate its various elements by comparing them to one another at a time, with respect to their impact on an element above them in the hierarchy. In making the comparisons, the decision makers can use concrete data about the elements, but the judgments about the elements' relative meaning and importance can be used too. It is the essence of the AHP that human judgments can be used in performing the evaluations.

In the final step of the process, numerical priorities are calculated for each of the decision alternatives [2]. These numbers represent the alternatives' relative ability to achieve the decision goal, so they allow a straightforward consideration of the various courses of action.

1.3. Steps of AHP

1) Model the problem as a hierarchy: containing the decision goal, the alternatives for reaching it, and the criteria for evaluating the alternatives [3].

2) Construct a set of pair wise comparison matrices: Establish priorities among the elements of the hierarchy by making a series of judgments based on the comparisons of the elements. Each element in an upper level is used to compare the elements in the level immediately below with respect to it.

There are some different relative importance can be used for the element of the matrix. As shown in Table 1. And other numbers can be used too [4]. Such as 2, 4, 6. They can be used when two compared elements have the importance between the upper and lower criterions.

Table 1. Comparison of Value

Relative Importance	Value
Equal importance/quality	1
Somewhat more important/better	3
Definitely more important/better	5
Much more important/better	7
Extremely more important/better	9
Other numbers	2,4,6,8

3) Calculate order levels: Synthesize these judgments to yield a set of overall priorities for the hierarchy. Use the priorities obtained from the comparisons to weigh the priorities in the level immediately below. Do this for every element. Then for each element in the level below add its weighed values and obtain its overall or global priority. Continue this process of weighing and adding until the final priorities of the alternatives in the bottom most level are obtained.

4) Check the consistency of the judgments: The model provides a consistency ratio, which shows how consistent the evaluation of the criteria was during the comparison. The consistency of the judgment can be valued by CR. A low value (ideally below 0.10) is proof of good consistency [5].

$$CI = \frac{\lambda_{\max} - n}{n - 1}$$

$$CR = \frac{CI}{RI}$$

Table 2. Value of RI under Different n

n	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

When CR<0.10, the result can be acceptable, or else, the element of the matrix should be changed.

5) Come to a final decision: Come to a final decision based on the results of this process

2. Factors affecting performance evaluation of the robot design

2.1. Factors evaluating of the robot application performance

All the factors affect the application performance include performance indicators and technical indicators. Intelligent, function and physical can belong to the performance indicators. On the other hand, detection technology, workspace beast, features, dynamic and static characteristics, security stability, real-time interactivity and scalable features all belong to the technical indicators.

Intelligent: refers to the sensation and perception, including memory, operation, comparison, identification, judgment, decision, study and logical reasoning, *etc* [6].

The function: refers to the flexibility, general or space of possession.

Physical can: refers to the force, speed, continuous operation ability, reliability and life.

Detection technology: reflect processing technology of information detection, varieties range of the system and information fusion technology.

Workspace beast: the robot working space, including the global workspace features, characteristics, such as geometric features, surface, *etc*.

Features: the freedom degrees of robot structure and flexibility [7].

Dynamic and static characteristics: including state-owned frequency, speed, accuracy, *etc*.

Security stability: ability to adapt to outside interference that is job stability, security, *etc*.

Real-time interactivity: robot ontology information between communications and information and communication with the outside world.

Scalable features: function extension ability, including the hardware features, upgrade and update change, increase or decrease the software functional enhancements, upgrades and maintenance, and complete the replacement of means.

2.2. Factors evaluating of the design scheme

Support theory: the advanced nature, improved degree and the possibility of further improved of theoretical model used by the system design, including the theoretical model and control model.

Control technology: reflect system planning technology, computer control technology and reaction technology [8].

Connection technology: interconnection technology and extension technology which used during the part and mutual compose overall structure of the system.

Integrity and work: refer to the further research project, to a certain stage and have certain science and technology research workload (mainly refers to the inside and outside in the laboratory research work).

Independently: the project is most independently, the final match and design degree.

Creativity: very topology structure, which includes methods to solve the problems; the analysis of the data and the using of equipment and design [9].

Innovation design manufacturing cost: Design working hours, parts design, modification, assembly and motion simulation.

Table 3. Main factors evaluating of the robot scheme

Primary criteria	Subcriteria	Detail index			
Robot performance	intelligent	memory	operation	comparison	identification
		judgment	decision	Study reasoning	logical reasoning
	function	flexibility	General possession	Space possession	
	Physical	force	speed	reliability	operation ability
Design scheme	Integrity and work	independently	final match the design		
		For further research	To a certain stage	Science workload	Technology workload
	creativity	Topology structure	Methods to solve the problems	Analysis of the data	Use of equipment and design
	Manufacturing cost	Design hours	Part design	modification	Assembly simulation
		Material consumption	Processing cost	Engineering drawing	

3. Example

Just as 11 th Chinese teenagers robot soccer competition an example to prove the correct of the analysis.

Scheme 1 is for Guangdong team, scheme 2 is for Sichuan team and scheme 3 is for Zhejiang team.

In the robot performance evaluation system, Guangdong team has the strongest intelligent, Sichuan team's function is better than the other two teams and Zhejiang team has the most important physical characteristics.

In the other design scheme evaluation system, Zhejiang team has the best integrity and work, creativity and the lowest manufactory cost.

3.1. Set up the model of AHP

This phase involves formulating an appropriate hierarchy of the AHP model consisting of the goal, criteria, subcriteria and the alternatives.

More layers can be set up to build the model. Besides of the target layer A and alternative layer C, the criterion layer B can be separated to more layers. Evaluation of the scheme as the target layer A. Scheme1, scheme 2 and scheme 3 are the elements of third layer C. The model is shown as in Figure 1.

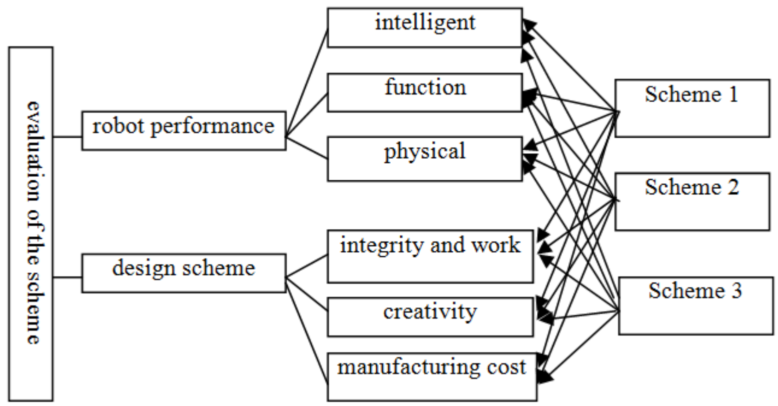

Figure 1. AHP Model of Robot Design Scheme

3.2. Structuring the Hierarchical Analysis Matrix

1) Setting up the matrix of the criteria and the target: judgment matrix consistency ratio is 0.0000; on the total weight of the target is 1.0000.

Table 4. Matrix of Criteria and Target and Weight of Different Criteria

Evaluating robot scheme	design scheme	performance	Wi
design scheme	1	5	0.8333
performance	0.2	1	0.1667

2) Setting up the matrix of the robot performance criteria and subcriteria: consistency ratio of judgment matrix is 0.0025; on the total weight of the target is 0.1667.

Table 5. Matrix of Subcriteria and Performance and Weight of Different Subcriteria

performance	intelligent	function	physical	Wi
intelligent	1	7	2	0.6153
function	0.1429	1	0.3333	0.0925
physical	0.5	3	1	0.2922

3) Setting up the matrix of the design scheme criteria and subcriteria: consistency ratio of judgment matrix is 0.0311; on the total weight of the target is 0.8333.

Table 6. Matrix of Subcriteria and Design Scheme and Weight of Different Subcriteria

design scheme	integrity and work	creativity	manufactory cost	Wi
integrity and work	1	3	0.25	0.2109
creativity	0.3333	1	0.1429	0.0841
manufactory cost	4	7	1	0.7049

4） Setting up the matrix of the intelligent subcriteria and alternatives: consistency ratio of judgment matrix is 0.0825; on the total weight of the target is 0.1025.

Table 7. Matrix of Alternatives and Intelligent and Weight of Different Subcriteria

intelligent	scheme 1	scheme 2	scheme 3	Wi
scheme 1	1	0.5	0.2	0.1088
scheme 2	2	1	0.1667	0.1626
scheme 3	5	6	1	0.7286

5）Setting up the matrix of the function subcriteria and alternatives: consistency ratio of judgment matrix is 0.0904; on the total weight of the target is 0.0154.

Table 8. Matrix of Alternatives and Function and Weight of Different Subcriteria

function	scheme 1	scheme 2	scheme 3	Wi
scheme 1	1	5	0.5	0.3643
scheme 2	0.2	1	0.25	0.0989
scheme 3	2	4	1	0.5368

6) Setting up the matrix of the physical subcriteria and alternatives: consistency ratio of judgment matrix is 0.0068; on the total weight of the target is 0.0780.

Table 9. Matrix of Alternatives and Physical and Weight of Different Subcriteria

physical	scheme 1	scheme 2	scheme 3	Wi
scheme 1	1	3	0.25	0.2176
scheme 2	0.3333	1	0.1667	0.0914
scheme 3	4	6	1	0.691

7) Setting up the matrix of the integrity and work subcriteria and alternatives: consistency ratio of judgment matrix is 0.0156; on the total weight of the target is 0.0487.

Table 10. Matrix of Alternatives and Integrity and Weight of Different Subcriteria

integrity and work	scheme 1	scheme 2	scheme 3	Wi
scheme 1	1	0.5	0.3333	0.1571
scheme 2	2	1	0.3333	0.2493
scheme 3	3	3	1	0.5936

8) Setting up the matrix of the creativity subcriteria and alternatives: consistency ratio of judgment matrix is 0.0370; on the total weight of the target is 0.0701.

Table 11. Matrix of Alternatives and Creativity and Weight of Different Subcriteria

creativity	scheme 2	scheme 1	scheme 3	Wi
scheme 2	1	3	0.3333	0.2583
scheme 1	0.3333	1	0.2	0.1047
scheme 3	3	5	1	0.637

9) Setting up the matrix of the manufacturing cost subcriteria and alternatives: consistency ratio of judgment matrix is 0.0176; on the total weight of the target is 0.5874.

Table 12. Matrix of Alternatives and Manufactory Cost and Weight of Different Subcriteria

manufactory cost	scheme 2	scheme 1	scheme 3	Wi
scheme 2	1	3	0.5	0.3196
scheme 1	0.3333	1	0.25	0.122
scheme 3	2	4	1	0.5584

4. Conclusion

In 11th Chinese teenagers robot soccer competition (primary sections), the order of the winner is Zhejiang team, Sichuan and Guangdong team. In this race, the different experts give the evaluation on the different team with all factors and the analysis result is consistent with the practical results. This method is useful to compare the performance between several robots and thus help to determine which robot is most appropriate for your particular application. You may also want to test currently used robots; testing robots annually during down times can be a proactive way to predict problems before they require major maintenance.

Table 13. Weights of Different Alternatives

Different alternatives	weight
scheme 1	0.1340
scheme 2	0.2723
scheme 3	0.5937

This paper presents a robot design solution of multi-objective and multi-level comprehensive evaluation index system using analytic hierarchy comprehensive evaluation. For the design of the robot case study proves that the index system and evaluation model in line with the actual situation, the evaluation system and evaluation model can be generalized to all kinds of robot design scheme evaluation and even can be extended to more in the evaluation of the system.

In the other hand, from this evaluation method, evaluator can make a right decision about how to evaluate the different robot design scheme according to the different weight of the alternatives. The use of the model indicates that it can be applied to improve the group decision making in evaluating the robot design scheme. It also can avoid the defects of other scheme and judge’s experts to the influence of the opinion effectively, so it can indicate the fair in robot race. This evaluation will help robot design scheme optimization and improvement and can promote the development of robot technology too.

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