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Decision-making analysis of scheme selection under different preferences

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Abstract

In the conceptual design stage of new product development, one of the major challenges is how to effectively determine the single best scheme from multiple alternatives. Based on the Axiomatic Design Theory, this paper proposes a new method to analyze and compare alternative schemes, and the Markov function is then used to calculate cost and determine the optimization direction of the chosen scheme. The cost of the optimal solution is estimated through calculations with utility functions. To add more details to the final design, it is necessary to consider both the working environment and user preferences, then to further analyze the schemes via fuzzy intuitions in order to determine the best prototyping and optimization strategy. This paper employs the design process of a library robot, which is designed in the context of university campus environment, as an illustrate example to showcase how to use the proposed method.

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1. Introduction

Alongside rapid advancements in technology, the demand for personalized products has increased substantially in recent years. To create a successful product scheme, the designer must consider both customer preferences and discrepancies in product usage. Traditionally, the design scheme is transformed into fuzzy set-theory for decision-making analysis [1]. Suggested by the Axiomatic Design Theory, there are a variety of different design decisions, which should be categorized into different domains. Furthermore, design decisions of the same kind should be organized into a hierarchy to accommodate their different abstraction levels. Despite many obvious advantages of such a two-dimensional design structure (i.e., domain and hierarchy), the design decision making process inevitably becomes more complicated, because design decisions are oftentimes fuzzy, in particular, during the early design phases. In the past, many researchers have attempted to address the fuzziness in axiomatic design [2]. For example, Hu et al. used a Markov model to predict the design direction of the discrete optimization design scheme [3]. By using a Markov model, Girard J. et al. proposed a set of optimized control logic, which controls the robot by mimic-learning [4]. Although these methods can only solve decision-making problems within a single domain, however. Due to the different preferences among decision-makers, several decision-making methods should be comprehensively applied and effectively integrated throughout the overall design process [5,6]. He et al. used the fuzzy intuition method to solve multi-program decision-making problem sunder a variety of circumstances [7]. Through this method, the designer transforms the index of several schemes into a compound matrix and then selects the best scheme by analyzing the matrix priority [8]. In the robot design field, Wallace et al. successfully improves the reliability of the robot design through an axiomatic design method [9].

Based on the existing axiomatic design theory, related works, and a combination of subjective and objective models, we quantitatively analyzed the decision-making process of a complex design scheme, and then comprehensively analyzed the possible problems of a partial or overall decision-making process during the design stage. We utilize the "I moving" robot, which works in the university campus environment, as an example to prove the effectiveness of this method.

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2. Theoretical framework

During the axiomatic design process, this paper established three designs on different research levels: conceptual design, product design, and technical design. The relationships among the three design stages are progressive but also iterative. It is obtained several conceptual design schemes, product design schemes, and function design schemes applicable throughout the process. The decision-making analysis was then applied to select the optimal scheme of the three different designs. The Markov model is used to predict the cost transition matrix of the product scheme in the conceptual design stage. In the product design stage, the utility function is used to discover the relationships between the risk, profit, and cost of a product. In the technical design process, the fuzzy intuition method is used to select the optimal scheme among several design schemes.

Axiomatic design serves as the theoretical foundation of the proposed framework. As shown in Fig. 1, cost estimation of the next stage can be obtained through the cost probability matrix. By doing so, we can preliminarily determine the cost of each function module of the next stage.

Next, three sets of prototype machines were proposed, and the one best suited to the operating environment. Due to the subjective influence of many factors, after obtaining several design schemes of the prototype machine, we analyzed the schemes through a subjective decision-making method, the fuzzy intuition method.

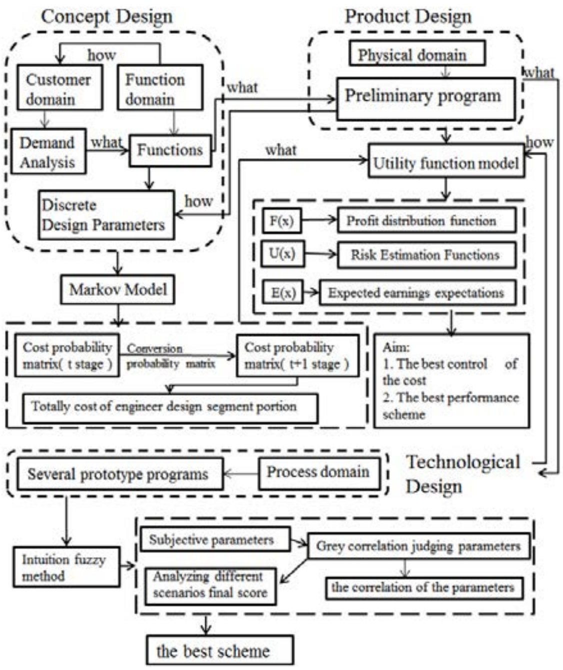

Fig.1. Framework of the proposed method

3. Preliminary scheme design

3.1. Markov function analysis

According to the independence axiom, the matrix of product design is determined by the mapping relationships between functional requirement (FR) and design parameters (DP) during the conceptual design stage [10]. A design matrix is used to represent the FR-DP relationships:

$$[FR]_{m\times 1} = [A]_{m\times n} \times [DP]_{n\times 1} \tag{1}$$

Where the parameter matrix of A is determined by

$$A_{ij} = \frac{\partial FR_i}{\partial DP_i} \tag{2}$$

If matrix A is a purely diagonal matrix, the scheme is uncoupled, meaning that all its functional requirements can be satisfied independent of each other.

This paper establishes a conversion probability function for the parameter matrix of the product via the Markov function. Under the conditions of discrete-time and finite-state, the first order Markov function forms a state sequence composed of random variables that are dependent only on the random variables of the previous stage. By using the transfer function, we can deduce the probability matrix of the next state from the probability matrix of the current state.

Let δ_i be the risk of cost fluctuation under the current state, and i=1,2,3,…,n.

The cost probability matrix for designing a certain function of the robot is:

$\mu=\{\mu_i,\mu_j,\mu_k\}$;

The converted cost probability matrix for adding a new function or changing the original function on the robot is

$$\mu' = \left\{ \frac{\mu_i}{\sum_{i=1}^{n}\mu_i}, \frac{\mu_j}{\sum_{j=1}^{n}\mu_j}, \frac{\mu_k}{\sum_{k=1}^{n}\mu_k} \right\} \tag{3}$$

$i,j,k \in C$.

Adding or changing a function on the robot will lead to an expected profit change (x), where:

$x=\{x_i,x_j,x_k\}$, $i, j, k \in C$.

The transition probability matrix is P. After analyzing the conceptual scheme, we can obtain the parameters of the basic functional system cost, the risk of cost fluctuation in the current state, and the estimated profit. The above parameters construct matrix P, which is the conversion probability matrix that converts the current cost probability into the cost probability matrix of the next stage. So,

$$P = \frac{\mu_{i,j,k}}{\mu'_{i,j,k} \cdot \sum_{i=1}^{n}\sum_{j=1}^{n}\sum_{k=1}^{n}\mu_{i,j,k}} \tag{4}$$

The state transition matrix of the next stage is

$$\mu_{i,j,k}^{t+1'} = \mu_{i,j,k}^{t'} \cdot P \text{ , } t \in C . \tag{5}$$

3.2. Dividing cost-utility stages

Because the Markov model can only predict the variation tendency of the design cost for the next stage, modular design should be adopted to realize the basic functions for moving, steering, and bearing during the design process. These functions are designed so that all functions meet the requirements of axiomatic design. While making an axiomatic decision, the