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The application of BP neural network in perceptual design of the overall shape of home service robots

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Abstract. The purpose of this paper is to establish the logical relationship between the users' perceptual intention and the overall shape design elements of home service robots. The samples of the overall shape of home service robots are obtained based on the constraints of technical supports to analyze quantitatively the design elements and perceptual intention with the methods of Principal component analysis, morphological analysis and BP neural network. The training BP neural network is used to predict and the results can provide the design reference. The next step should be to increase the numbers of nodes in the output layer of BP neural network to get the evaluation mean of the perceptual style, and consider the influence of the constraints of technical supports on the overall shape and design elements.

Key words. home service robots, Kansei Engineering, principal component analysis, morphological analysis, BP neural network.

1. Introduction

The service robots are the key method to deal with the trend of global aging [1]. Home service robots are the consumer products for users which have higher requirements in the appearance, human-computer interaction and other aspects. So the product design and evaluation would be carried out more scientifically only by using the mathematical analysis method to establish the logical relationship between the user's perceptual intention and the overall shape of the home service robots.

2. Related Works

Kansei Engineering is the method to explore the relationship between the sensibility of human and the design characteristics of thing by means of engineering technology [2]. In recent years, scholars have been committed to converting users'

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vague emotion into quantitative data by modern computer aided technology [3]. Our previous [4] study describes the overall shape of home service robots by the semantic differential method and express users' demand by analytic hierarchy process, which provides the judgment basis for the evaluation of design cases. Zhu Yan[5], etc. describe quantitatively the relationship between the head shape design elements of service robots and the intention perception of users' by Kansei Engineering and the BP neural network and construct the head form design system. The existing studies don't dig into the application of Kansei Engineering in the overall shape of home service robots, which couldn't verify and improve the accuracy of design evaluation model and couldn't form systematic design method of the overall shape of home service robots. The motivation behind this paper is to present a new idea which analyses quantitatively design elements of the overall shape of home service robots and users' perceptual intention by methods of Principal component analysis, morphological analysis and the BP neural network, moreover the validity of models is verified by testing.

3. Quantitative analysis of design elements of the overall shape of home service robots and users' perceptual intention

3.1. Constraints of the overall shape of home service robots

The overall shape of home service robots studied in this paper is constrained by the existing technical support, which should be designed based on the driving base and the internal support structure shown in figure 1. The diameter of top circle in the driving base is 485mm, and the height of the driving base is 430mm. The wheeled mobile robots are the most suitable form, and the shell of their body should be designed as cylindrical shape so that the large driving base could be contained inside the shell in the smallest volume.

3.2. Sample analysis of the overall shape of home service robots

According to the constraints of existing technology, totally 100 different overall shape schemes of robots are designed. The special or similar schemes are removed and 20 typical schemes are selected as the analytical samples after further comparison and selection, some of which are shown in figure 2.

A total of 105 groups of adjectives which describe the perceptual intention of the overall shape of home service robots are collected by questionnaires. After further evaluation and filter, the 12 most commonly used groups are remained as the perceptual evaluation scales, as follows, graceful-ugly, safe-dangerous, modern-traditional, concise-complex, elegant-vulgar, masculine-female, mature-childish, amiable-estranged, relaxed-serious, lively-stiff, fashion-outdated, strong-fragile.

Fig. 1. Driving base and internal support

Fig. 2. Part of samples

3.3. Principal component analysis and the determination of perceptual evaluation scale

The semantic differential method of seven point scale is used to design the questionnaire for the 12 groups of adjectives, and participants are required to score the 20 typical samples based on the 12 groups of them. For example, the interval value

of the scale is 7, for the scale of graceful-ugly, the samples which score 1 tend to be graceful, which score 4 tend to be neutral, and which score 7 tend to be ugly. A total of 70 participants are surveyed and 60 valid questionnaires are recovered, among whom 40 participants understand or have used home service robots. The data of 60 questionnaires are input into Excel software for statistics, the perceptual evaluation results of 20 samples for the 12 groups of scale are obtained. The data are analysed in the method of principal component analysis and the factor analysis results are obtained. The factor loading matrix is shown in table 1. The scale of amiable-estranged has the greatest impact on the overall shape of home service robots. Therefore this group is used as the evaluation scale for the further analysis.

Table 1.Factor loading matrix

Perceptual intention adjectives	Principal component		
	Principal component 1	Principal component 2	Principal component 3
graceful-ugly	0.892	0.141	0.286
safe-dangerous	0.881	0.156	0.005
modern-traditional	0.823	-0.321	0.191
concise -complex	-0.098	0.909	-0.165
elegant-vulgar	0.872	0.181	0.032
masculine-female	0.816	0.162	-0.067
mature-childish	0.567	0.211	0.738
amiable-estranged	0.921	0.121	-0.193
relaxed-serious	0.742	0.715	0.015
lively-stiff	-0.425	0.099	0.838
fashion-outdated	0.625	-0.113	-0.075
strong-fragile	0.311	0.655	0.026

3.4. Morphological analysis and the extraction of key design elements

As shown in table 2, by using the method of morphological analysis, the elements which determine the overall shape of the typical samples are split into the head, the display screen in face, the body and the base, each of which is divided into 2 or 4 types.

Table 2. Integral design elements of home service robots

Design elements	Types				
	1	2	3	4	5
Head X1	 spherical	 ellipsoidal	 cylindrical	 frustum of a cone	 organic
Display screen in face X2	 rectangular	 circular	 waist shaped	 trapezoidal	
Body X3	 cylindrical	 cylindrical section	 frustum of a cone		
Base X4	 cylindrical	 cylindrical section			

3.5. Construction of the matrix of perceptual evaluation

As shown in table 3, the matrix of perceptual evaluation about the scale of amiable-estranged for 20 typical samples is constructed based on the average value of perceptual evaluation and the overall shape design elements of home service robots from the previous analysis.

Table 3. Matrix of perceptual evaluation

Samples	Design elements				amiable-estranged
	X1	X2	X3	X4	Mean of perceptual evaluation
1	2	3	1	1	1.933
2	2	4	2	2	2.033
3	3	1	1	1	3.983
4	4	4	2	1	6.466
5	1	2	1	1	2.717
6	2	1	1	1	3.417
7	3	3	2	2	4.516
8	1	2	2	1	3.217
9	2	2	3	1	2.083
10	4	3	1	1	6.183
11	5	2	3	1	4.883
12	1	4	1	1	3.533
13	4	3	3	1	5.983
14	1	1	2	1	3.617
15	1	3	2	2	3.483
16	5	4	1	1	4.933
17	3	4	2	1	5.183
18	3	2	1	1	4.283
19	5	3	3	1	5.083
20	5	1	2	1	5.016

4. Application of the BP neural network

4.1. Construction of BP neural network

The BP neural network is used to study the data in table 2 based on the MatlabR2010 software platform. After several comparisons and analysis, the network is determined to be three layers, including the input layer, the hidden layer, and the output layer. The input layer is the number combination of four design elements, the number of nodes is 4, and the logsig function is chosen as the transfer function. The number of nodes in the hidden layer is 4, and the purelin function is chosen as the transfer function. The output layer is the average value of the perceptual evaluation of the measure of amiable-estranged, the number of nodes in which is 1.

4.2. Training of BP neural network

Data from the first 15 samples in table 2 are fed into the network for training. The learning times of BP neural network are set to 10000, and the error target value is 0.001, the result is measured by mean square error in the gradient descent method. The network achieves its training goal after 763 training times, thus the actual training error value is 0.00991.

4.3. Test of BP neural network

The reliability of the trained network is verified by the data of the remaining 5 samples. The combination of the design elements are imported into the input layer, and the values of the output layer are compared with users' evaluation data of the questionnaires, the results are shown in table 4. Thus it can be seen the relative error between the mean of actual perceptual evaluation of users' and the mean of perceptual evaluation of network prediction is not large, and the trained network accurately mapped the overall shape design elements of home service robots and the mean of perceptual evaluation.

Table 4. Test results

Samples	Actual mean of perceptual evaluation	Predictive mean of perceptual evaluation	Relative error%
16	4.933	5.069	2.76
17	5.183	4.976	3.99
18	4.283	4.408	2.92
19	5.083	4.932	2.97
20	5.016	4.947	1.38

4.4. Results and Conclusion

In this paper, four decisive design elements of home service robots have 120 combinations, which are imported into the input layer of BP neural network and calculated the corresponding mean of perceptual evaluation. 120 amiable-estranged design schemes about the overall shape of home service robots are obtained after the operation of BP neural network. Among them, the minimum value of perceptual evaluation is 1.853, and the maximum is 6.736, and the number of the corresponding design elements combination of which is respectively 1 3 1 1 and 5 4 2 1. It reveals that the overall shape with the previous design elements combination is the most amiable, on the contrary the latter is the most estranged. When home service robots with more amiable style are designed, designers should pay more attention to these aspects, such as the shape of the head tends to be spherical or the shape of the body and base tends to be cylinder. This method can provide a reference standard for the overall shape design.

5. Discussion

In this study, the perceptual evaluation scale which has the greatest influence on the overall shape of home service robots based on the constraints of technical supports is induced with the method of Principal component analysis, and the overall shape design elements are extracted by method of morphological analysis, then the relationship between the overall shape design elements and perceptual intention is analysed quantitatively by construction of BP neural network. As a result, the reference for design a certain perceptual style of home service robots is provided by the simulation of BP neural network prediction. This method can bring up the more rational model of the overall shape of home service robots for designers.

The overall shape design of home service robots involves many complicated factors. First of all, designers shouldn't rely on a single perceptual evaluation scale to design. The next step is to increase the numbers of nodes in output layer of BP neural network and obtain the evaluation mean of perceptual style, so that the diverse users' demands would be satisfied. Secondly, the changes of the overall shape style accompanied by the changing of the constraints of technical supports would lead to the changes of combination and quantity of design elements, all these factors would have more multiple influences on the construction of BP neural network. With further research and development, the design system of the overall shape of home service robots based on Kansei engineering would develop more comprehensively.

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