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Research on visual optimization design of machine–machine interface for mechanical industrial equipment based on nonlinear partial equations

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Abstract

With the continuous development and progress of machinery and industry equipment, human-machine interface has become an important operation in industry equipment and has been widely used in aviation, monitoring, traffic, special engineering vehicles, and a series of complex fields. Through the human-machine interface information system, information and data are provided for operators. As the human-machine interface information data of the mechanical equipment system are numerous, complex, and changeable, operators often make operation mistakes, misread and misjudge, and do not give timely feedback, resulting in task failure or, in serious cases, major mechanical faults and accidents. Therefore, the human-machine interface data information is screened, and the information useful for the operator is directly obtained according to the target set by the operator, so as to effectively solve the complex and changeable data information in the information system. Human-machine interface uses electronic communication technology, computer network technology, and database technology to expand and update machinery and industrial equipment. Among them, nonlinear partial differential equations comprise an important branch of equation in mathematics. In this paper, according to the nonlinear partial differential equations, we research and analyze the information system of the human-machine interface design field and solve the system of the cognitive load, which is too large, such as cognitive mismatch problem in the working mode of operating personnel, by satisfying the needs of different users. The human-machine interface of mechanical industrial equipment uses visual optimization design and innovation.

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1 Introduction

Whether in theory or in practical application, nonlinear partial differential equations are used to describe problems in the fields of mechanics and control processes. The use of nonlinear partial differential equations to describe the above problems fully takes into account the influence of space, time, and time delay, so it can reflect the reality more accurately. This paper mainly studies the differential equation theory of nonlinear partial differential equations and its application in human-machine interface optimization [1, 2]. Human-machine interface mainly plays a key role in information transmission, information exchange, and communication between humans and machine. It is composed of words, symbols, images, and colors. Human-machine interface has become an important step in the process of human-machine system interaction for the system to exchange human-machine information, experience human-machine effect, and reduce the production cost of enterprises. It provides operators with the basis for judging direction and controlling operations. At present, human-machine interface has been widely used in aerospace industry, nuclear power monitoring industry, intelligent vehicle industry, special engineering vehicle driving control and other mechanical equipment fields. With network information technology and communication, although computer hardware technology is gradually becoming perfect, the human-machine interface design of information technology still is insufficient in many places, causing many problems in the process of human-machine interface using information technology. The effect due to the information transmission between the user and the system is caused by the user's cognitive impairment and easy-to-produce misunderstanding and error, thereby limiting the system performance [3]. Therefore, by building a safe and efficient system information environment, the human-machine interface can be implemented smoothly. However, due to the diversity of information in the system itself, users need cognitive attributes, such as intelligence and understanding in the process of activities, so as to comprehensively solve the human-machine interface design problems faced by the system. How to design and develop reasonably efficient systems and use digital interface to solve enterprise and design problems form the key to the cross research of human-machine interface design and engineering. Therefore, in order to allow users to integrate into the system environment more naturally, it is necessary to make handling equipment easier and put forward requirements for human-machine interface design. In this paper, a mechanical equipment, which is the research object, shows a substantial from the traditional bridge operation mode through the digital, soft operation to the remote digital interaction mode, so that the space occupied by mechanical equipment is reduced, as are the operation and information interaction processes [4].

2 Methods

Nonlinear partial differential equations, also known as nonlinear mathematical physics equations or nonlinear evolution equations, are used in this paper. It is a mathematical model describing the nonlinear phenomenon of mechanical equipment, which is represented as follows:

$$F(x, x_1, x_2, \dots, x_n, u, x, u_{x1}, u_{x2}, \dots, u_{xn}, u_{x1x2}, u_{x1x3} \dots) = 0 \quad (1)$$

A generalized partial differential equation is shown as follows:

$$\begin{aligned} \frac{\partial^2 f}{\partial x^2} + \frac{\partial^2 f}{\partial y^2} &= 0 \\ \frac{\partial f}{\partial t} &= \alpha \frac{\partial^2 f}{\partial x^2} \\ \frac{\partial^2 f}{\partial t^2} &= c^2 \frac{\partial^2 f}{\partial x^2} \end{aligned} \quad (2)$$

The function is used to derive the equation, and the coefficient is dependent on either the dependent variable or the nonlinear equation whose derivative appears in the nonlinear form:

$$\begin{aligned} ff_x + bf_y &= 0 \\ af_x^2 + bf_y &= 0 \end{aligned} \quad (3)$$

2.1 Optimization design evaluation model based on interface color

Optimization design evaluation model is based on interface color, achieved mainly through optimization of mechanical equipment at the visual interface. The human-machine interface has characteristics such as hue, lightness, purity, and tonal factors (such as optimization), such that the observer perceives differences in color vision. Different solutions with direct impacts on manufacturing of equipment will fit in the human-machine system environment, enabling harmony of the human-machine system and functional consistency of manufactured equipment. Therefore, designers need to analyze the visual perception effect while manufacturing equipment. According to Munsell's color theory, the unified softness of color is related to the lightness and area of visual elements and is related to the saturation of color [5]. Its correlation is as follows:

$$\frac{Y_a \times G_a}{Y_b \times G_b} = \frac{S_a}{S_b} \quad (4)$$

Here, Y_a represents the brightness value of color block A; Y_b represents the brightness value of color block B; G_a represents the purity level of color block A; G_b represents the purity level of color block B; S_a represents the area of color block A; and S_b represents the area of color block B. By converting the color to gray with only a difference in brightness, we realize the simplified solution of the model, and its conversion formula is as follows

$$[YUV] = [RGB] \times \begin{pmatrix} 0.299 - 0.1480.615 \\ 0.587 - 0.289 - 0.515 \\ 0.1140.437 - 0.100 \end{pmatrix} \quad (5)$$

The human-machine optimization design evaluation model based on color of manufacturing of equipment is shown in the formula, where is the weight coefficient.

$$C = \alpha_c \times C_1 + \beta_c \times C_2 + \gamma_c \times C_3 \quad (6)$$

The r value of each part is obtained from the conversion relation and the brightness value of the color that occupies the largest part of the area after color block division. The formula for calculating the soft color uniformity C_1 of the manufactured equipment is as follows:

$$C_1 = \sum_{i=1}^n \left| (Y_{\max} - Y_i) \times \frac{S_i}{S} \right| \quad (7)$$

The function keys on industrial equipment are generally alarm, the pause/stop, and operation. The alarm key is red, the pause key is yellow, and the operation key is edge color, which is the most suitable setting for scientific research and practice [6]. In this paper, the luminance value of the alarm key, the luminance value of the pause key, and the luminance value of the operation key are used to represent the overall functional consistency index C_2 :

$$C_2 = \frac{|A_1 - y_1| + |P_1 - y_2| + |O_1 - y_3|}{3} \quad (8)$$

The solution formula of C_3 is as follows:

$$C_3 = \sum_{j=1}^m \left| (Y - Y_j) \times \frac{S_j}{S} \right| \quad (9)$$

2.2 Optimization design evaluation model based on modeling

According to the nonlinear equation of each component of the manufactured equipment's contour boundary, the type of the manufacturing equipment contour boundary is determined, and then the human-machine optimization design evaluation model of the manufactured equipment is determined.

$$F = \alpha_F \times F_1 + \beta_F \times F_2 + \gamma_F \times F_3 \quad (10)$$

Suppose that in a piece of equipment, the area of the circle is S_1 , the area of the rectangle is S_2 , and the area of the triangle in the equipment is S_3 . The area occupying the largest amount among the three is denoted as $S_{\max}$, and the result obtained by subtracting the maximum area of $S_{\max}$ is denoted as SH , as shown in the following formula:

$$\begin{aligned} S_{\max} &= \{S_1, S_2, S_3\} \\ SH &= \{(S_1 + S_2 + S_3) - S_{\max}\} \end{aligned} \quad (11)$$

The visual weight stability of the manufactured equipment is shown in Figure 1, and its stability calculation formula is shown in the following equation:

$$F_2 = |S_L * L_1 - S_R * L_2| \quad (12)$$

When F_2 is bigger, showing the color deviation, the greater is the human-machine design visual stability of the manufacture equipment; on the other hand, the better is the equipment. To simulate the nonlinear equation that can synthesize the manufacturing equipment outline border fitting a straight line, diagonal lines, and rounded corners, the corresponding function is the constant function, a function, and a dual function of the corresponding function, such as

$$\begin{aligned} z_1 &= b_1 \\ z_2 &= k_1 \times x + b_2 \\ z_3 &= k_2 \times x + b_3 \end{aligned} \quad (13)$$

The evaluation model of human-machine optimization design of manufacturing equipment is constructed in this manner. In this section, the index weight determination of the evaluation model is systematically elaborated based on the nonlinear partial equation (see Table 1). First, the scale method of judgment matrix is constructed.

Fig. 1 Area of center of gravity design analysis.

Table 1 Scaling methods for judging matrix elements.

Scale	Meaning
1	Indicates that two factors are of equal importance compared to each other
3	One factor is slightly more important than the other factor, in a comparison of the two factors
5	It means that one factor is obviously more important than the other
7	One factor is more important than the other
9	One factor is more important than the other
2, 4, 6, 8	The median of the two adjacent judgments above
Reciprocal	The judgment of the comparison between Factor I and J is the judgment of the comparison between Factor J and I . $a_{JI} = 1/a_{IJ}$

Comparative analysis:

$$CI = \frac{\lambda - n}{n - 1} \quad (14)$$

The decision matrix is established, and the elements in the matrix are obtained. If the importance evaluation matrix of the equipment's visual characteristics of k professional operators is obtained, and each matrix passes the consistency test, the decision matrix A^* is constructed as follows:

$$A^* = \begin{pmatrix} 1 & A_{12}^* & \dots & A_{1m}^* \\ A_{21}^* & 1 & \dots & A_{2m}^* \\ \dots & \dots & \dots & \dots \\ A_{m1}^* & A_{m2}^* & \dots & 1 \end{pmatrix} \quad (15)$$

$$A_{ij}^* = \{a_{ij}^1, a_{ij}^2, \dots, a_{ij}^k\}, i = 1, 2, \dots, m, j = 1, 2, \dots, m \quad (16)$$

The relative importance of the evaluation index at each level is calculated. The eigenvectors of D^+ and D^- are calculated to obtain the relative importance of the visual perception characteristic evaluation index of the whole machine corresponding to each matrix:

$$D^- = \begin{pmatrix} 1 & V_{12} & \dots & V_{1m} \\ V_{21} & 1 & \dots & V_{2m} \\ \dots & \dots & \dots & \dots \\ V_{m1} & V_{m2} & \dots & 1 \end{pmatrix} \quad D^+ = \begin{pmatrix} 1 & W_{12} & \dots & W_{1m} \\ W_{21} & 1 & \dots & W_{2m} \\ \dots & \dots & \dots & \dots \\ W_{m1} & W_{m2} & \dots & 1 \end{pmatrix} \quad (17)$$

$$H^- = (h_1^-, h_2^-, \dots, h_m^-)^T, \quad H^+ = (h_1^+, h_2^+, \dots, h_m^+)^T.$$

Similarly, the relative importance of other evaluation indexes at each level, namely, the weight value of each level, can be obtained. The basic importance of the visual characteristic evaluation index of the whole machine is synthesized. In other words, the basic important vector of all the evaluation indexes can be obtained, and the corresponding weight value can be used to optimize the human-machine interface design [7].

3 Experiment

First, 80 samples of digital human-machine interface were collected as research objects, and similar or unsuitable samples were deleted through evaluation. Meanwhile, five designers with >5 years of design experience were invited to design, so as to determine the representative samples. A questionnaire was composed of samples, scoring items, and rating scales, and Statistical Package for the Social Sciences (SPSS) software was used to obtain the variance rate and line graph. Table 2 directly reflects the relationship between the characteristic values and the number of components. As can be seen from the line diagram, the extraction process of common

factors is shown in Figure 2. Component 4 is a relatively obvious inflection point. The curve tends to be flat in the interval with a smaller eigenvalue, indicating that the first four factors have most of the information of the original data, and the four components are extracted as common factors. In this paper, the number of common

Table 2 Variance contribution rate.

Component	Total	Percentage variance of initial eigenvalues	Cumulative %	Total	Extract the load squared and variance percentage	Cumulative %
1	13.069	45.065	45.065	13.069	45.065	45.065
2	7.461	25.727	70.792	7.461	25.727	70.792
3	4.237	14.611	85.403	4.237	14.611	85.403
4	1.689	5.824	91.227	1.689	5.824	91.227
5	0.949	3.274	94.501			
...	...	...	...			
29		-2.357E-1	-8.129E	100.00

Fig. 2 Broken line diagram.

Fig. 3 Two-dimensional distribution matrix of scatter of perceptual information.

Table 3 Factor analysis.

Perceptual information	Factor			
	1	2	3	4
A8	0.976	0.075	−0.005	−0.027
A9	0.976	0.075	−0.005	−0.027
A19	0.974	0.050	−0.107	0.087
A13	0.974	0.050	−0.107	0.087
A27	0.951	−0.132	0.112	0.004
A15	0.951	−0.132	0.112	0.004
A29	0.948	0.057	−0.044	0.019
A11	0.940	0.087	−0.137	0.069
A21	0.899	−0.066	−0.368	−0.100
A6	0.859	0.162	0.372	−0.131
A17	0.859	0.162	0.372	−0.131
A25	0.780	−0.882	−0.331	0.142
A12	0.777	0.882	−0.589	0.109
A16	0.777	−0.844	−0.589	0.109
A3	0.644	−0.844	0.446	−0.227
A14	0.644	0.837	0.446	−0.227
A18	0.492	0.837	0.298	0.258
A23	0.088	0.685	0.291	0.131
A28	0.088	0.685	0.291	0.131
A22	−0.051	0.141	0.670	0.179
A10	−0.051	0.060	0.670	0.179
A24	0.007	0.060	0.536	0.293
A20	0.007	−0.426	0.487	0.293
A1	−0.166	−0.426	0.487	0.142
A7	−0.166	−0.240	0.410	0.640
A5	0.148	−0.067	0.410	0.447
A4	0.312	0.312	0.373	0.434
A26	0.108	0.312	0.373	0.418
A2	−0.085	0.061	−0.158	−0.328

factors was set as “4” in the SPSS software system, the evaluation score in the data information was analyzed by the factors, and the position of perceptual information vocabulary in the common factors was further determined. The square value of factor load in the matrix was polarized by orthogonal rotation with maximum variance. Finally, according to the rotated factor loading value, the perceptual information vocabulary of the above 29 pairs is summarized into four common factors, as shown in Table 3. Factor 1 expresses intuitive aesthetics and Factor 1 is named as “aesthetic factor”. Factor 2 includes functional use. Factor 2 is named as “functional factor”, Factor 3 is named as “experience factor” and Factor 4 as “emotional factor”. The above “aesthetic factors”, “functional factors”, “experience factors”, and “emotional factors” constitute the dimensional system of digital human-machine interface perception information. In order to further influence the relationship between information variables and evaluation factors, components are divided into two groups, and the specific distribution of the evaluation factors is analyzed and studied. From the data distribution in Figure 3, it can be seen that the variables affected by Components 1 and 4 are concentrated on the X-axis, indicating that the variables are similar, while other variables are somewhat different in Component 1. On the vertical axis, variables are distributed in different spaces, but most variables are concentrated in the region near the origin, and there is a certain correlation between different variables in space [8–11]. The spatial distribution of the combined principal components

is analyzed, and the data are obtained and analyzed in the same way. According to different perception information space models, the perception information of digital human-machine interface of engineering vehicles is evaluated, so as to study the basis of human-machine interface visual design of mechanical equipment.

4 Results

The main design of the digital human-machine interface of mechanical equipment is analyzed and the perceptual information is studied. The main machinery's digital human-machine interface development process is divided into three parts: areas of users, designers, and experts. According to the nonlinear partial differential equations, the main body of the perceptual information transmission model is established. Through the cognitive experiment of each design subject, cognitive differences were studied, using factor analysis to build the "aesthetic factors", "functional factors", "experience factor", and "emotion factor" through digital human-machine interface system. The fusion of perceptual information space distribution provides the possibility for the evaluation of digital human-machine interface design of mechanical equipment and lays a foundation for the visual optimization design of human-machine interface of mechanical industry equipment.

5 Conclusion

In this paper, the perceptual information in the visual optimization design is used to solve the difficulties in the design of the digital human-machine interface of mechanical equipment. Through complex digital design field, it can be found that the prevalence of cognitive load, such as cognitive mismatch problem, is too large. Through usability testing analysis and research of the human-machine interface design and its evaluation, this article mainly discusses the user interface. On the basis of cognitive information processing to meet the user's cognitive needs and develop mechanical equipment's digital human-machine interface design strategy, the nonlinear partial differential equations with human-machine interface cognitive model is applied to make human-machine interface more humane; the human-machine interface is made more explicit and concrete, perceptual and rational. This lets mechanical equipment be more beautiful and practical.

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