Interface Information Visualization of Intelligent Control System Based on Visual Cognitive Behavior

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Abstract. A typical intelligent control system, Trina Solar MES production line, is studied in this paper. To begin with, the system information characterization and encoding method are determined through the behavior experiment. Then, the layout of interface graphic elements and system information is found through eye movement experiment. The result indicated that, visual design model of intelligent control systems is set up based on cognitive behavior process and the best layout, which provides enterprises with realizable and optimized design strategy. That is applied to the MES production line of information control system in Trina Solar Technology Company. In conclusion, it provides theoretical support, physiological analysis methods and technical means for the research of information interface design from the perspective of behavior and physiological science so as to guarantee the enterprise's safe and efficient production.

Keywords: Intelligent control system · Information interface · Visualization

1 Introduction

With the rapid development of computer technology and information control theory, the control system becomes more complex and intelligent. The complex human-computer interactive process increases the operators' cognitive load when operators perform tasks such as production, scheduling and so on. When operators consume too much cognitive load, they are prone to operating errors and may even cause fatal accidents. In order to reduce the operators' cognitive friction and improve work efficiency, it is urgent to carry out reasonable characterization; coding and layout design of the huge and complex information in intelligent control system and find out the visual design model of intelligent control system. The rational visual design of intelligent control system plays an important role in maintaining the safety and stability of production and operation in large enterprises. Based on the relationship between intelligent control system and visualization, this paper takes the interface of intelligent control system as the research object and puts forward the method of reasonable visual design in intelligent control system (Fig. 1).

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Fig. 1. Monitoring interface of intelligent control system

2 Background

In recent years, many major accidents, such as nuclear explosions and aircraft crashes, have made us aware of the importance of interface design of control system. Some scholars mainly study the design of control interface from the perspective of human cognition, and some scholars study the design method of control interface. The following is a summary of the research status and dynamics at home and abroad, from the aspects of psychological cognition process, information visualization characterization, interface layout principles and other related fields.

2.1 Research on the Psychological Cognitive Process of Intelligent Control System Operators

In terms of psychological cognition process, Chen et al. [1] uses cognitive psychology to extract interface feature elements to achieve a fast understanding of the dynamic visualization of complex data. Wu [2–5] studies the visual limitation physiological experiment method of information interaction interface and analyzes the root causes of information omission and misperception in the process of visual search. Li et al. [6] found that visual perception stratification can be performed with the degree of attentional capture. And Zeng [7] believes that the core idea of information structure design of interactive interface is to make information adapted to the regularity of human visual perception with gestalt as the guiding principle and structuration as a method. And Li et al. [8] believe that too many human-machine interfaces will cause the cognitive load becomes heavier for the operators and the selection becomes difficult. According to a study by George A. Miller, psychologists, the information amount for humans to receive cognitive knowledge at one time should be 7 ± 2 bits. Through the study of the operator's cognitive process, information visualization and interface layout design can be effectively guided.

2.2 Research on Information Visualization and Interface Layout Design

In terms of information visualization, Annie [9] and Dong [10] conducted an experimental study on the visualization of automobile navigation; Reda et al. [11] studied how to visualize heterogeneous data sets; Basole et al. [12] discussed node-based view methods for visualization of big data; Christopher et al. [13] use graphical sorting algorithms and visual similarity matrix data for visual analysis. And Wang [14] believes that interface design should enable users to form a unified system in visual cognition. Besides, in the field of information visualization, many scholars have studied the methods and principles of visualization and their theories provide a good design reference for the later visualization of the interface of the intelligent control system.

In terms of interface layout principles, Kim [15] proposed the layout of the display interface according to the idea of queue, orientation and placement. Dowsland [16] pointed out that the layout problem refers to give layout space and a number of objects to be distributed and place the objects in the given layout space in a reasonable manner that can satisfy constraints in order to reach an optimal index. Guo [17] made a general consideration of the interface design of software users and proposed the design method of the icon. Chen [18] visually divided the interface into two parts: frame structure and visual elements and proposed optimization suggestions for the reading interface. Liu et al. [19] introduced the human-machine interface design method for the main control room of nuclear power plants based on human factors engineering to prevent and reduce human error. Yang et al. [20] studied the design of the digital interface of system of nuclear power plants from several aspects, such as human-machine interface design and display screen design, etc. By studying display and control interface of the aircraft cockpit, Liu [21] found that the information transmission designed by the principle of information importance and frequency of use is more reasonable. Wang et al. [22] studied the layout design of the display and control interface of the new generation of fighters and proposed a complex system interface layout method. Li et al. [23] proposed the design criteria of the display and control interface started from the perspective of uses. Hong [24] studied how to design a set of integrated information visualization scheduling, operating and controlling platform through reasonable design. Li et al. [25] proposed an interface layout scheme based on visual cognition and interaction habits.

Kamran [26] and Lee [27] proposed that a complete layout process can be extracted through the accumulation of experience. In addition, Amadieu et al. [28–31] studied the interface color and proposed that red, yellow and blue are colors that are the most attractive. At present, there are a lot of researches on information visualization and interface layout, but there is still a lack of research on the monitoring interface layout of intelligent control systems, so the research in this paper is of great significance.

3 Information Visualization of Intelligent Control System Monitoring Interface

3.1 Information Presentation

Taking the MES production line of Trina Solar co. LTD as a sample, this paper collects the workshop information and selects 8 procedures on the workshop assembly line as samples to analyze the functional characteristics of each processes, and also refers to Chengqi's [32] design guidelines of optimization of icons, which are "identification", "normative", "aesthetic", and "style unification" and adaptation to the trend of the times to visualize icon design. And the E-prime behavior experiment is performed on the icon, and the icon is further optimized by the correct rate and reaction time. As shown in Fig. 2, the optimized process icon is shown.

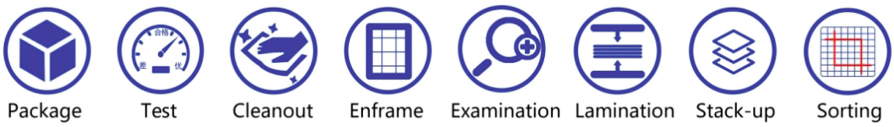


Fig. 2. Visualization of 8 process - icon design

3.2 Interface Layout

As shown in Fig. 3, the interface layout design of the monitoring interface of Trina Solar MES system takes Trina Solar MES as a sample and employs the icons showed above, which is also combined with the basic layout principles proposed by Chengqi [32]: classification principle, frequency principle, importance principle, control and display compatibility principle.

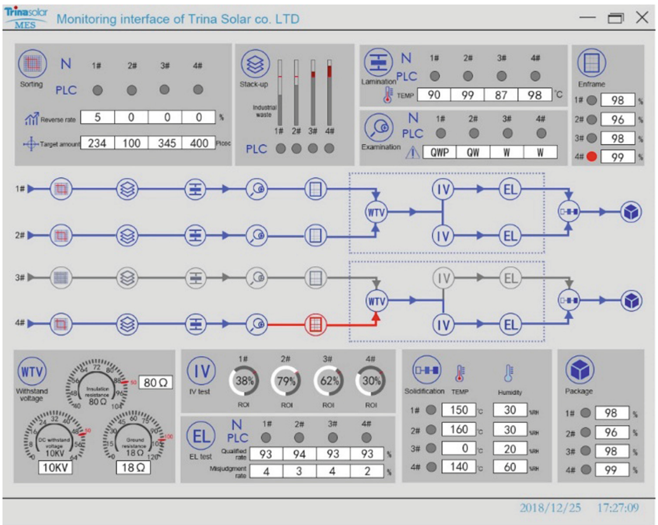


Fig. 3. Monitoring interface design of Trina solar co. LTD MES production line

4 Experiment

4.1 Experiment Objectives

The purpose of the experiment is to study the impact of changes in the layout of the monitoring interface of the production line's control system on human cognitive load.

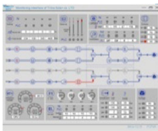
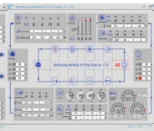
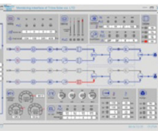
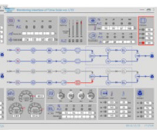
And the experiment is to find the optimal visualization mode of the monitoring interface by analyzing the influence of the changes of three factors (layout scheme, whether there is a warning box in the fault area or not, and how information blocks are presented) of the interface on the user's cognitive effect through Trina Solar's monitoring interface.

4.2 Experiment Design

The experiment takes the Trina Solar monitoring interface as the sample and employs three factors (layout scheme, whether there is a warning box in the fault area or not, and how information blocks are presented) as independent variables to do the data analysis through behavior indexes and visual physiological indexes.

As shown in Table 1, there are three tasks in the experiment and each task has two forms. Each form has three random experimental materials with a total of 2 × 3 × 3 stimulus materials randomly presented.

Table 1. Task type

Task types of experiments					
task one：interface layout		task two：without/with warning box		task three：Presentation of information Blocks	
shown in three lines	Around center	without warning box	with warning box	the warning lights displayed horizontally	The warning Lights displayd vertically
					
Three search tasks: lamination2#、enframe4#、IV test2#		Three search tasks: lamination2#、enframe4#、IV test2#		Three search tasks:2#target amount、3# temperature、4#reverse rate	

4.3 Experimental Equipment and Participants

The experiment introduces the stimulus material into the studio system of the eye tracking device TobiiX120 and sets the target and task materials. The experiment was carried out in the Human-Computer Interaction Laboratory of Hohai University, and 15 college students of engineering were selected as the participants. The eye tracking device recorded the search time of each task material of each participant and some related physiological index of reaction of eye movement.

5 Results

5.1 Behavioral Data

A total of 15 participants were selected for the experiment, and 12 people with data collection rate greater than 80% were selected. The data of 9 people was finally used in data analysis of the experiment.

(1) Correct Rate. With no time limits, the correct rate for both task one and task two is 100%. There are differences in the correct rates of the two presentations of the information block of task three. And after analyzing the variance of the correct rate, the conclusion is that the main effects ($F = 29.469$, $p = 0.006$, $p < 0.01$) of different information presentation were significant. The correct rate of the horizontal display of the warning light is 100%, and the correct rate of the vertical display of the warning light is 89%. It is considered that the searching effect of horizontal display of the warning information in the information block is better.

(2) Total Visit Duration. After analyzing the variance of the reaction time of three different independent variables, it was found that the main effects (layout scheme: $F = 12.704$, $P = 0.023$, $p < 0.05$; with or without a warning boxes: $F = 16.522$; $P = 0.015$, $p < 0.05$, the way information blocks are presented: $F = 12.976$, $P = 0.023$, $p < 0.05$) were significant.

As shown in Fig. 4, when the layout scheme is around center with warning boxes and warning lights for horizontal display, the search time is shorter, the search efficiency better, and the presentation of the interface better.

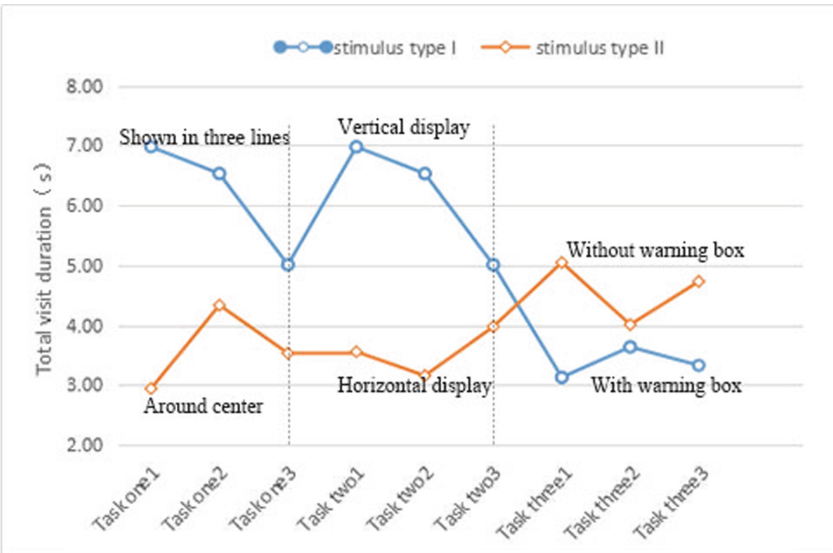


Fig. 4. Comparison of reaction time of experiment tasks

5.2 Visual Physiological Data

(1) Analysis of Index of AOI. The times of fixations refers to the total number of times of gazing, indicating the number of times the participant is looking for task information and performing cognitive processing. Fixation in AOI refers to the number of times the participants performing cognitive processing in the information area and the total fixation indicates the number of times the participants performing cognitive processing on the entire task interface. The higher the ratio of fixation in AOI, the higher the search efficiency. As shown in Table 2, through the variance analysis of fixations in AOI, it was found that the main effects (layout scheme: $F = 147$, $P = 0$, $p < 0.01$; with or without warning boxes: $F = 34.926$, $P = 0.004$, $p < 0.01$) were significant. The main effect ($F = 0.014$, $P = 0.912$, $p > 0.05$) of the warning light presentation is not significant.

Therefore, the layout scheme and the search efficiency of the warning box (with or without) can be analyzed by the ratio of fixations in AOI to the total number of times of fixations. From the ratio of fixations in AOI to the total times of fixations (shown in three lines: 36%, around center: 82%, without warning box: 36%, with warning box: 80%), it is found that the around center layout and the search box with warning boxes are more efficient.

Table 2. Analysis of variance of fixation in AOI

Variance analysis of ANOVA (dependent variable: points in AOI)						
Unit: piece		Sum of squares	df	Mean square	F	P
Layout scheme	Inter block	30.106	1	30.106	147.000	.000
	Interclass	.819	4	.205		
	Total	30.925	5			
With/without warning box	Inter block	42.667	1	42.667	34.926	.004
	Interclass	4.886	4	1.222		
	Total	47.553	5			
The way the information blocks are presented	Inter block	.054	1	.054	.014	.912
	Interclass	15.651	4	3.913		
	Total	15.705	5			

(2) Fixation. In the cognitive process, the fixation is closely related to the cognitive activities of the brain. When the brain thinks, eyes won't gaze, and the pause time will grow longer as the thinking time becomes longer. From the operator's gaze duration, the time spent on cognitive activities can be roughly observed. As shown in Table 3, through the variance analysis of gaze duration in AOI, it was found that the main effects (layout scheme: $F = 15.696$, $P = 0.017$, $p < 0.05$; with or without warning boxes: $F = 10.886$, $P = 0.030$, $p < 0.05$; the way information blocks are presented: $F = 46.486$, $P = 0.002$, $p < 0.05$) were significant.

Therefore, the search efficiency can be analyzed by the gaze time. As shown in Fig. 5, in the case that the correct target is found, the gaze duration is longer when the layout scheme is around center, with warning boxes and the warning lights are displayed horizontally, and the search efficiency and the interface presentation are better.

Table 3. The variance analysis of fixation duration

Variance analysis of ANOVA (dependent variable: fixation duration)						
Unit: MS		Sum of squares	df	Mean square	F	P
Layout scheme	Inter block	12125537.200	1	12125537.200	15.696	.017
	Interclass	3090038.802	4	772509.701		
	Total	15215576.003	5			
With/without warning box	Inter block	10881659.208	1	10881659.208	10.886	.030
	Interclass	3998260.633	4	999565.158		
	Total	14879919.841	5			
The way the information blocks are presented	Inter block	6955977.285	1	6955977.285	46.486	.002
	Interclass	598544.395	4	149636.099		
	Total	7554521.680	5			

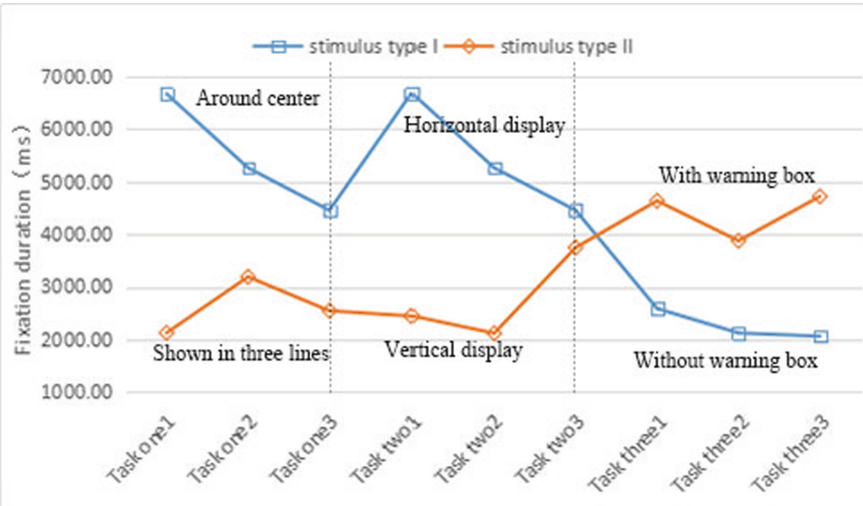


Fig. 5. Comparison of gaze duration of experimental tasks

(2) Saccade. Saccade is the process of visually finding a target. When an operator searches for a target, the movement of the eye appears as a saccade. And if the operator can quickly find the target, the number of times saccades will be less. As shown in Table 4, through the variance analysis of the number of times saccades, it was found that the main effects (layout scheme: $F = 8.699$, $P = 0.042$, $p < 0.05$; with or without warning boxes: $F = 8.017$, $P = 0.047$, $p < 0.05$; the way information blocks are presented: $F = 9.306$, $P = 0.038$, $p < 0.05$) were significant.

Table 4. Variance analysis of the times of saccades

Variance analysis of ANOVA (dependent variable: saccades times)						
Unit: time		Sum of squares	df	Mean square	F	P
Layout scheme	Inter block	76.755	1	76.755	8.699	.042
	Interclass	35.294	4	8.823		
	Total	112.049	5			
With/without warning box	Inter block	47.714	1	47.714	8.017	.047
	Interclass	23.805	4	5.951		
	Total	71.520	5			
The way the information blocks are presented	Inter block	39.784	1	39.784	9.306	.038
	Interclass	17.100	4	4.275		
	Total	56.883	5			

Therefore, the search efficiency of the interface layout form and the information block presentation mode can be compared by the times of saccades. As shown in Fig. 6, in the case that the correct target is found, saccades are lesser when the layout scheme is around center, with warning boxes and the warning lights are displayed horizontally, and the search efficiency and the interface presentation are better.

(4) Fixation/Saccade Ratio. The formula for visual search efficiency proposed by Goldberg and Kotval [33] is as follows:

$$\text{Ratio} = \frac{\textit{time for the cognation to process information}(f)}{\textit{Time to search for information}(s)}$$

In the formula, time for the cognation to process information refers to the gaze duration, which is f; time to search for information refers to saccade, as which is s therefore:

$$\text{R shown in three lines} = \frac{\text{f}}{\text{s}} = \frac{5463}{1594} = 3.4$$

$$\text{R around center} = \frac{\text{f}}{\text{s}} = \frac{2620}{547} = 4.8$$

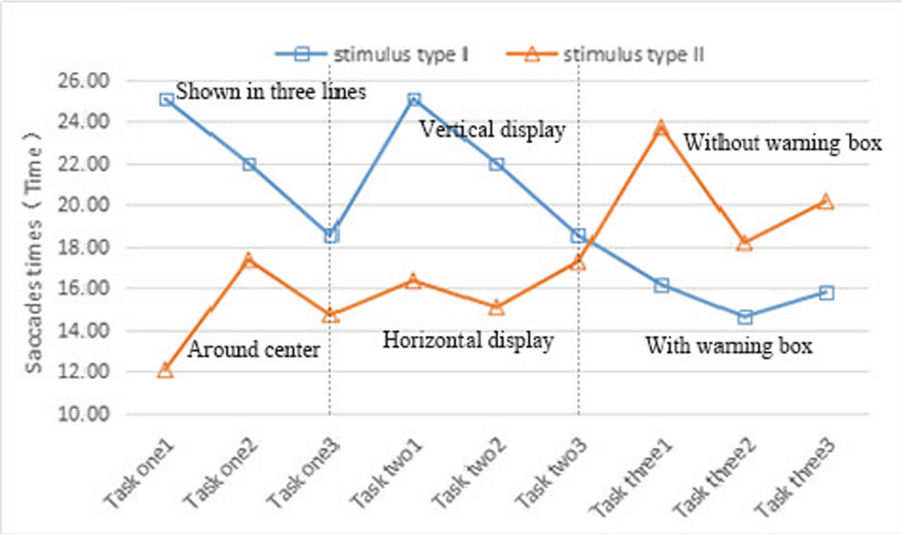


Fig. 6. Comparison of times of saccades

$$R\,\textit{without warning box} = \frac{f}{s} = \frac{5463}{1594} = 3.4$$

$$R\,\textit{with warning box} = \frac{f}{s} = \frac{2769}{738} = 3.8$$

$$R\,\text{horizontal display} = \frac{f}{s} = \frac{2257}{605} = 3.7$$

$$R\,\text{vertical display} = \frac{f}{s} = \frac{4410}{959} = 3.6$$

The search efficiency can explain the advantages and disadvantages of the information layout of the interface. The time for cognition to process should be much longer than the time for searching information, that is, the value of Ratio is greater than 1. And, the larger the number, the higher the search efficiency. It can be clearly seen from the number that when the layout scheme is around center, with warning boxes and the warning lights are displayed horizontally, the number is larger, the search efficiency is better, the search efficiency is greater than when the warning information is vertical displayed.

5.3 Optimized Design of the Interface

The experiment finds that when the interface layout is around center, warning boxes in the fault zone and warning information in the information block are arranged horizontally, the efficiency is higher. Thus, the layout of the monitoring interface is arranged in the way listed above, as shown in Fig. 7.

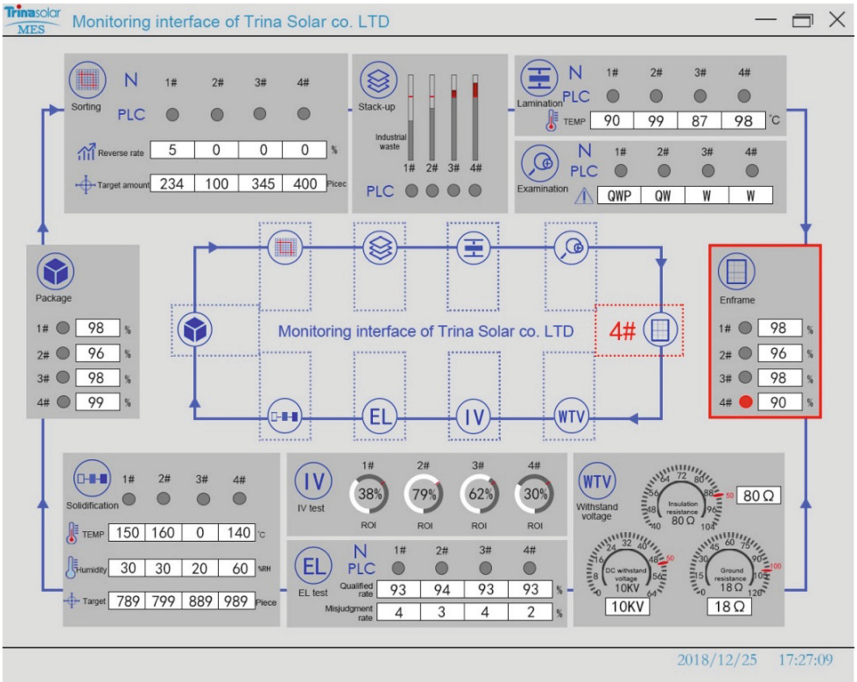


Fig. 7. Optimized design of the monitoring interface for Trina Solar co. LTD’s production line

6 Conclusion

When the information icon of the monitoring interface is presented in a blue circle without shading, the search efficiency is higher; the layout of the monitoring interface is better selected as around center, and the information block should be surrounded by the annular production line, so that the search path is relatively short and the efficiency is higher; the warning boxes in the fault area is more easily found by the operators; and when the warning information in the information block is arranged horizontally, the search time is short.

According to the operator’s psychological cognition process, information display and principle of interface layout, a monitoring interface in this paper is designed for Trina Solar’s MES production line and a design interface is proposed for the monitoring interface of intelligent control system for large enterprises. It is hoped to provide enterprises with feasible optimization strategies and to provide theoretical support, physiological analysis methods and techniques for design and research of information interface from the perspective of behavioral and physiological science, so as to ensure the safe and efficient production of enterprises.

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