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Optimization Method for an Information Interaction Interface from Error-Cognition to Information Feature Mapping

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Abstract: Background- With the rapid development of digital and intelligent information systems, display of visual information in interfaces has become an important challenge in the field of human-computer interaction. **Objective-** We propose a method for the optimization of information interaction interfaces from error-cognition through the mapping of information characteristics. **Method-** A mapping method of matrix description is adopted to analyze the association properties between error-cognition sets and design information sets. **Results-** Based on the mapping relationship between the domains of error-cognition and design information, a cross-correlational analysis is carried out between error-cognition and design information. **Conclusion-** We obtain the relationship matrix between the error-cognition of correlation between design information and the degree of importance among design information. **Application-** Taking the task interface of a warfare navigation display as an example, error factors and the features of design information are extracted. Based on the results, we also propose an optimization design scheme for the monitoring task interface.

Keywords: Information interaction interface, error-cognition, information feature mapping, visual information display, optimization

Description

We study the mapping between error, cognition and design. The transition from the mapping of error and cognitive domains to the mapping of design domain enables the process of optimizing interface information. The design solution process can be developed by importing error factors and combining them with visual cognition.

1. Introduction

1.1 Information Interaction Interface Literature Review

The human-computer interaction industry has long been exploring reasonable and feasible design methods to improve the information presentation problem faced by current digital, intelligent visual information interfaces. Especially in the field of complex information systems, researchers both at home and abroad have devoted time and effort to seek reasonable methods for information display through research on information coding and layouts. For instance, in the Human Measures and Performance Project (HMPP), NASA (1996) specifically studied the problems of color security and availability of the design of various complex graph display interfaces in the aviation field. Michelle and Wickens (2001) carried out experiments to investigate how to best exhibit relevant electronic information on battlefield maps. Montgomery and

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Sorkin (1996) performed an experimental study on the effect of luminance on an observer's degree of reliability in identifying information in a visual display. Tullis (1981) and Schum (1991) investigated the efficiency of identifying digital and graphical information coding. Patrick Monnier (2003) applied the experimental paradigm of visual delay in search tasks to study the relationship between colors and locations. Parsons et al. (2014) summarized ten attributes of interactive visual displays (including importance, relations and adjustability of interactions). Li Liangming, in 1984, at an early stage of the aviation industry in our country, analyzed and investigated the usage of circular scale instruments in different types of domestic airplane pilot seats to propose suggestions to improve their instrumental scales, pointers, digital display, benchmark of flight attitude, instrumental size and layout. Liu Baoshan and Ding Yaping (1992) studied the recognition effects of the relative locations of display interface in instrument panels of fighter planes and helicopters. Heather et al. (2012) performed research on the information representation of auto-battle recognition system. Lei Zhou, Jing Li, Yafeng Niu, Xiaoli Wu, Tao Jin, and Chengqi Xue et al. (2013~2015) performed physiological research on the information representation and interface design of human-machine interfaces of complex systems. All these works of research indicate the importance of information presentation in the process of monitoring task execution. They conclude that icons, symbols and colors are critical styles of expression for information presentation.

1.2 Error Factors Literature Review

With the rapid development of computer graphics and user interface technologies, the study of human errors has also been applied to the field of interface design to improve interface effectiveness. Nielsen (1994) and Shryane (1998) proposed methods for reducing the error rates to improve interface efficiency. Li Leshan (2004) proposed a system for the error classification of human-computer interfaces. He proposed that inattention and over-attention can both be regarded as key ideas which need to be taken into consideration in the research on human errors. Hassnert and Allwood (2002) concluded that it is not possible to have a uniform standard for error classification. They stated that the corresponding types of human errors should be identified through experimental methods. They conducted inductive classification towards user errors by means of user interface tests of the software. Krokos and Baker proposed error classification methods for interface cognition. Masion and Reeder (2005) investigated the use of the external subgoal support method to enhance the reliability of user interfaces by reducing errors. Javier (2013) used a driver behavior questionnaire to analyze the reasons caused by attention errors (driving errors, traffic violations and excessive behaviors) and found the key factors causing operational errors. Shappell (2007) analyzed aircraft accidents data in 2013 and also identified attention, comprehension and other related factors corresponding to skills and decision-making. Anokhin (2009) analyzed the ergonomics of control panel design of main control room in nuclear power station, concluding that the most typical design error is incompatibility between irregular layout and equipment; Shen Zupei (2009) established the theory and method of the human error cognition model; Wang Pei and Pei-luen Rau (2011) established an operator behavior model from the perspective of human factors engineering and decision-making behavior; Li Pengcheng (2011) established an evaluation model and a reliability evaluation method of nuclear power plant digital control system based on operator situation cognition; Wang Meng and Zhang Yijing (2014) analyzed the reason for operation mistakes in aerospace and provided a reference for improving astronaut operation performance.

This paper proposes a framework called the “Error-Cognition-Design”, based on our study of the association between error factors, visual cognition and design information. This framework offers a technique that can map the mechanism of error-cognition into the design factors of information interfaces, to perform optimization for the design of complex information interfaces.

2. The Optimized Method of Information Interaction Interface

In the research field of design methodology, the design process is regarded as a system that transforms a model from a concept-function to a structural mapping. This has been studied in depth since the end of the last century, and has been applied to the fields of machinery and product design. The direct mapping from a function to a structure was proposed by Pahl and Beitz in 1992 as a typical representation in the field. In 2000, Suh proposed an alternate reciprocating mapping in terms of function-structure mapping and structure-subfunction mapping. Based on Pahl's work, in 1996, Gero proposed a multi-level mixed mapping method which introduced a behavioral domain between the functional and structural domains. In the above-mentioned studies, the process of design solution is formed by mapping methods such as matrix description and genetic algorithms. This process opens up an effective method for the design of mechanical structures that can be widely applied to the innovative design of products. In the human-computer interaction field, for the optimization of design methods for complex information interfaces, we must discuss the feasibility of the designs from the perspective of error-cognition to design mapping. It needs to be seen whether this is able to open up a solution process for interface design while learning from error factors.

In this paper, we study the possible mapping between error, cognition and design. The transition from the mapping of error and cognitive domains to the mapping of a design domain enables the process of optimizing interface efficiency. The design solution process of a complex information interface can be developed by importing error factors and combining them with the visual cognition behavior of the information interface.

The optimization method of an information interaction interface from error-cognition to information feature mapping could provide a reliable analytical solution. This procedure is summarized as follows (Figure 1) :

1) given an error-cognition domain, we can determine the degree of relative importance of the error-cognition from the cross correlation between domain factors, and then the association properties of error-cognition can be solved;

2) we can establish a design information domain from analyzing design factors of information features. Using the same method of error-cognition, the association properties of the design information feature can be solved;

3) we can establish the design solution process from error-cognition to information feature mapping. We also need to determine the objective constraints of design information features;

4) in the case of task interface design of typical display systems, we can extract error factors based on the monitoring interface tasks and then obtain the solution process from error-cognition to information feature mapping from extracted error factors.

Figure 1. Procedure of the optimization method

3. Error-cognition factors and design information factors

3.1 Error factors of information interaction interface

In information interaction interfaces, for example an aviation information display, there are several possible tasks to be executed, such as monitoring status data, querying task information, monitoring threat and security state information, and so on. Display interfaces of complex information system display navigation, situation pictures, status data and other information. The monitoring task is likely to be performed: plan creating, state monitoring, burst scheduling, and so on. We can classify the monitoring interfacial task either by abrupt events and common tasks, or by the order in which tasks are performed. Thus, as shown in Table 1, we listed the monitoring interface tasks and corresponding error factors to extract the error characterization of a monitoring interface of a complex system.

Table 1 Characterization of error factor of monitoring interface task (Xiaoli Wu, 2016)

Tasks of monitoring interface A	Display format of information B	Cognitive behavior C	Error factor D	Representation of error E
A1 monitor/discover	B1 dynamic display	C1 search	D1 ignorance	E1 ambiguity states
A2 inquire state	B2 static display	C2 recognize	D2 omission	E2 visual limitation
A3 plan response	B3 navigation	C3 identify	D3 miss	E3 visual bluntness
A4 execute response	B4 status data	C4 judge&select	D4 misreading	E4 visual illusion
	B5 information icon	C5 decision-making	D5 misjudgment	E5 attentional load
	B6 alarm reminder		D6 misunderstanding	E6 visual disturbance
			D7 haven't seen	E7 overattention
			D8 confusion	E8 attention shift and distraction
			D9 cannot remember	E9 too nervous to do anything
			D10 input error	E10 cognitive bias
			D11 misregistration	E11 unreasonable match
			D12 cannot see clearly	E12 weak visibility
			D13 hard to distinguish	E13 thinking load
			D14 match incorrectly	E14 forget
			D15 cannot find	E15 inaccurate recall
			D16 delay	E16 lack of memory aids
			D17 inadequate	E17 intentionality decrease
			D18 irrelevant	E18 false memory
			D19 react too early	E19 unconsciousness
			D20 no reaction	E20 omission caused by inattention
			D21 select incorrectly	E21 time pressure
			D22 slip	

3.2 Information features of information interaction interface

As the analysis object of the design information characteristic, the monitoring task interface of some kind of navigation war is divided into four parts based on different tasks: (i) radar situation interface, (ii) weapon mounting interface, (iii) multi-sensor interface and (iv) flight data display interface, including the navigation, situation charts, state data, alarm reminder and other information display. There are four processes in monitoring tasks which may be performed such as monitoring/detection, state query, response planning and response execution. Table 2 shows the information content displayed in the different monitoring task interfaces, which will be regarded as the content of main information in searching, reading, recognition, judging selection and decision making. The radar situation interface mainly displays the information of the aircraft radar area including the

appearance of the target, the database calling, the different aircraft symbols in the range, the attacked target display, the driving route and other information. The weapon mounting interface mainly displays the selection of weapons, display, launch selection, the current state of selection and the weapon programming, etc; The multi-sensor display interface mainly displays radar setting and selection, satellite map information, radar proportional rendering and other information. The flight data display interface mainly displays the machmeter, forecast speed, attack angle, height, horizontal meter calibration, fuel and other indicators.

Table 2 monitoring task interface of typical navigation war display system

Monitoring interface	Interface information		Monitoring interface display
Radar situation interface	1 Range selection based on proportional rendering	9 Data contact target display
	2 Airspeed command window	10 Aircraft symbol	
	3 Height command window	11 Internal range circle	
	4 Radar target display	12 Command title symbol	
	5 Database links (D and L) selection	13 L & S target display	
	6 FLIR (FLR) selection	14 Attacked area reminder	
	7 Radar (RDR) selection	15 Current driving route information	
	8 Aircraft range		
Weapon mounting interface	1 Weapon program (PROG) selection	8 A / G gun selection
	2 launch Interval (INV)	9 Weapon Selection Station	
	3 Multiple Transmitter (MULT)	10 Major Armed Instructions	
	4 Number of launches (QTY)	11 Current armed display	
	5 Mounting place	12 Weapon station STEP	
	6 Bombing mode	13 Weapons programming storage	
	7 Weapon selection	14 Ignore HARM protection mode	
Multi-sensor interface	1 Azimuth Scanning selection (Radar Trigger)	6 Radar frozen (FRZ)
	2 Tactic range and radar range	7 Static(SIL)radar	
	3 Mode selection	8 Radar Declutter (DCLTR)	
	4 Expand 1/2/3 times mode	9 GPS map navigation	
	5 Range instruction based on proportional rendering		
Flight data display interface	1 Machmeter and air speed indicator	6 Horizontal indicator
	2 Target indicator	7 Bank angle indicator	
	3 Forecasting speed indicator	9 Altimeter calibration indicator	
	4 Attack angle loading indicator	10 Fuel consumption indicator	
	5 Altimeter indicator		

4. The Solution Process from Error-cognition to Information Feature Mapping

4.1. Analysis of the Association Properties of Error-Cognition

First, we need to analyze the association properties of the error-cognition domain. Let $R_{E0} = \{r_{e1}, r_{e2}, \dots, r_{em1}\}$ be the screened error-cognition set, where r_{ei} ($i = 1, 2, \dots, m_1$) denotes the error factor. Let us assume that $r_{ei}, r_{ej} \in R_{E0}$.

Since the corresponding processes of cognitive information are different, the same error factor will not have corresponding inclusion and crossing relations. For instance, take the case of misreading caused by visual restrictions or unreasonable matching of information. These two conditions do not have the properties of inclusiveness or intersection (Xiaoli *et al.*, 2014). They belong to error factors from different perspectives, and can be explained as errors resulting from different internal reasons. Hence, the relations r_{ei} and r_{ej} are both considered to be independent of each other. Hence, if the error factors included in r_{ei} are not related to the error factors included in r_{ej} , we can state that r_{ei} and r_{ej} are independent.

With respect to the existing correlation between error and cognition (Xiaoli *et al.*, 2014), when further screening the factors in the error-cognition domain, selections must be made among error-cognition factors with mutual exclusion. The choice for the appropriate factors must be made based on the sequence of the degrees of importance of the factors.

After screening, the error-cognition set can be denoted as $R'_E = \{r_{e1}, r_{e2}, \dots, r_{ep}\}$, where r_{ei} ($i=1, 2, \dots, p$) represents the error-cognition factor. For error-cognition factors with no correlation, mutual conflict or mutual collaboration, we refine them by sorting them based on their degrees of importance and deleting the unimportant ones.

In this paper, the method of Analytic Network Process (ANP) is employed to determine the degree of importance between error and cognition (Lee, 2000). This procedure of using ANP is summarized as follows:

Step 1: Without considering the correlation between error and cognition, the weights of error-cognition are determined. A numerical sequence of 1 to 9 is adopted for notation, and a normalization is conducted to

obtain the error-cognition weight vector w_r , $w_r = (w_1, w_2, \dots, w_p)^T$, where $\sum_{i=1}^p w_i = 1$.

Step 2: Determine the cross correlation between the error and cognition. The matrix E is used to describe such cross correlation. 1-3-9 is employed to express the weak, intermediate and strong cooperative relations between error and cognition; (-1)-(-3)-(-9) is adopted to denote the weak, intermediate and strong conflict relations between error and cognition. 0 denotes the irrelevance of error-cognition, where $e_{ij} = e_{ji}$, $e_{ii} = 9$.

$$\mathbf{E} = \begin{bmatrix} e_{11} & e_{12} & \cdots & e_{1p} \\ e_{21} & e_{22} & \cdots & e_{2p} \\ \vdots & \vdots & \ddots & \vdots \\ e_{p1} & e_{p2} & \cdots & e_{pp} \end{bmatrix} \quad (1)$$

The correlation information for each involved error-cognition factor can be calculated by analyzing the cross-correlation matrix E . Take the error-cognition factor r_{ei} as an example.

- 1) Positive correlation number R_{pi} denotes the number of error-cognition factors positively related to r_{ei} .
- 2) Negative correlation number R_{ni} denotes the number of error-cognition factors negatively related to r_{ei} .
- 3) Degree of positive correlation R_{spi} denotes the total sum of the correlation degrees of error-cognition

factors that are positively related to r_{ei} .

4) Degree of negative correlation R_{spi} denotes the total sum of the correlation degrees of error-cognition factors that are negatively related to r_{ei} .

5) Average degree of correlation R'_{avi} denotes the average value of the correlation degrees of error-cognition factors that are related to r_{ei} . R'_{avi} is represented by: $R'_{avi} = \frac{1}{p} \sum_{j=1}^p e_{ij}$.

The information above is fundamental to determining the degree of relative importance of the error-cognition. It is also used to select the values of error-cognition that have the same degree of importance. The method to identify values of error-cognition with identical degrees of importance is as follows:

1) First, find out the subset of error-cognition for $R_{ni} = 0$ ($i = 1, 2, \dots, p$). Then sort the values of the error-cognition R_{spi} in each set in a descending order and make selections;

2) If the result of the last step does not yield the desired values, increase the value of R_{ni} by 1. Find out the corresponding subset of error-cognition, and select the error-cognition factor which has a large value for R_{pi} and a large value for R'_{avi} . The value of error-cognition should also have a negative correlation with R'_{avi} , indicating a low degree of importance of error-cognition.

3) If the result of the last step does not satisfy the requirements, then return to 2) and repeat till the requirements are satisfied.

Step 3: Determine the relationship among the degrees of importance of the error-cognition. The matrix W_i is used to describe this relationship among the degrees of importance of the error-cognition. Take r_{ei} as an example. Based on the consideration that there is a correlation between r_{ei} and error-cognition, the degrees of relative importance of the other error-cognition factors with respect to r_{ei} are determined to obtain a matrix W_i .

Here $r_{ij} \in [0, 9]$; when $r_{ij} \neq 0$, $r_{ji} = 1 / r_{ij}$, $r_{ji} = 0$ when $r_{ij} = 0$. The AHP analytical method is employed to obtain the vector of the degrees of relative importance of the other error-cognition values specific to r_{ei} . This is represented as $w_i = (w_{1i}, w_{2i}, \dots, w_{ii}, \dots, w_{pi})^T$, where $\sum_{j=1}^p w_{ji} = 1$. Using this, we can solve the matrix for the degrees of importance of error-cognition W_r :

$$W_i = \begin{bmatrix} r_{11} & r_{12} & \dots & r_{1i} & \dots & r_{1p} \\ r_{21} & r_{22} & \dots & r_{2i} & \dots & r_{2p} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ r_{i1} & r_{i2} & \dots & r_{ii} & \dots & r_{ip} \\ \vdots & \vdots & \dots & \vdots & \ddots & \vdots \\ r_{p1} & r_{p2} & \dots & r_{pi} & \dots & r_{pp} \end{bmatrix} \quad (2)$$

$$W_r = \begin{bmatrix} w_{11} & w_{12} & \dots & w_{1i} & \dots & w_{1p} \\ w_{21} & w_{22} & \dots & w_{2i} & \dots & w_{2p} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ w_{i1} & w_{i2} & \dots & w_{ii} & \dots & w_{ip} \\ \vdots & \vdots & \dots & \vdots & \ddots & \vdots \\ w_{p1} & w_{p2} & \dots & w_{pi} & \dots & w_{pp} \end{bmatrix} \quad (3)$$

Step 4: Determine the degree of importance for the error-cognition. The vector w'_e is used to denote the degree of importance for the error-cognition as:

$$w'_e = W_r \times w_r = (w_{e1}, w_{e1}, \dots, w_{ep})^T.$$

Step 5: Determine the final error-cognition. According to the sequence of the degree of importance of

the error-cognition, unimportant factors of error-cognition are removed. When the difference in the degree of importance of the error-cognition is not significant, the decision method in (2) is employed to make decisions. Then calculate the final error-cognition represented by $R_E = \{r_{e1}, r_{e2}, \dots, r_{em}\}$; and the vector denoting the degree of importance of error factors as $w_E = (w_1, w_1, \dots, w_m)^T$, which corresponds to the normalized error-cognition set.

4.2 Analysis of the Association Properties of the Design Information Features

Operators can divide the monitoring tasks (Task i) into four processes. They are 1) surveillance/discovery, 2) status inquiry, 3) response planning and 4) response execution. Each process executes different tasks such as information search, information recognition and reading, information identification, information selection and judgment. Each of these tasks is associated with the relevant design information steps from 1 to n : Design (i_1), Design (i_2), $\dots$, Design (i_n). Let $C_{Q0} = \{c_{q1}, c_{q2}, \dots, c_{qn1}\}$ be the error-cognition set, where c_{qi} ($i = 1, 2, \dots, n_1$) represents the error factor, then for each c_{qi} , we have $c_{qi} \in C_{Q0}$.

An Interface for monitoring complex information systems displays numerous complicated information items. Such a display may sometimes not be systematic and may even contain a certain level of redundancy. Thus, it may become necessary to arrange, filter and analyze the designed information features. There are three kinds of relations which exist between c_{qi} and c_{qj} . They are inclusion, intersection and independence. The design information set after screening is denoted as $C'_Q = \{c_{q1}, c_{q2}, \dots, c_{qp}\}$, where each element c_{qi} ($i = 1, 2, \dots, p$) is an information feature. During the design process, after removing redundancies, these features may contain relations such as mutual exclusion, irrelevance, mutual conflict and mutual collaboration.

The ANP method is next adopted to determine the degree of importance of the features for information design. First, we determine the weight of the information features, as well as the mutual relations among them to obtain the mutual correlation matrix $\mathbf{Q}$:

$$\mathbf{Q} = \begin{bmatrix} q_{11} & q_{12} & \dots & q_{1p} \\ q_{21} & q_{22} & \dots & q_{2p} \\ \vdots & \vdots & \ddots & \vdots \\ q_{p1} & q_{p2} & \dots & q_{pp} \end{bmatrix} \quad (4)$$

The correlation information of each relevant feature can be obtained by analyzing the mutual correlation matrix $\mathbf{Q}$. Identical to the method used in the error-cognition set, taking the information feature c_{qi} as an example, the positive correlation number C_{pi} , the negative correlation number C_{ni} , the positive correlation degree C_{spi} , the negative correlation degree C_{sni} and the average correlation degree $C'_{avi} = \frac{1}{p} \sum_{j=1}^p q_{ij}$ can be obtained.

In this way, we can determine the importance of the degree of relationships of W_c from the information features. Take the information feature c_{qi} as an example. The ANP method is employed to obtain the vector of the relative degree of importance of the information features. This is represented by $w_i = (w_{1i}, w_{2i}, \dots, w_{ii}, \dots, w_{pi})^T$, in which $\sum_{j=1}^p w_{ji} = 1$. We can use this to solve the relation matrix $\mathbf{W}_c$ to determine the degree of importance of the information features:

$$\mathbf{W}_c = \begin{bmatrix} w_{11} & w_{12} & \dots & w_{1i} & \dots & w_{1p} \\ w_{21} & w_{22} & \dots & w_{2i} & \dots & w_{2p} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ w_{i1} & w_{i2} & \dots & w_{ii} & \dots & w_{ip} \\ \vdots & \vdots & \dots & \vdots & \ddots & \vdots \\ w_{p1} & w_{p2} & \dots & w_{pi} & \dots & w_{pp} \end{bmatrix} \quad (5)$$

Finally, from this the degree of importance of the design information $w'_q = W_c \times w_c = (w_{q1}, w_{q2}, \dots, w_{qp})^T$ can be determined. The eventual design information $C_Q = \{c_{q1}, c_{q2}, \dots, c_{qn}\}$ and the corresponding vector for the degree of importance of the design information (after normalization) can be written as $w_Q = (w_1, w_2, \dots, w_n)^T$.

4.3. Mapping from Error-Cognition to the Design Information

The relationship between the degrees of importance of the error-cognition and the design information is denoted by W_{qe} . When determining this relationship, we suppose that each design information is irrelevant, with respect to every item of the error factors. Then we compare the design information with each other, and the relationship matrix to obtain the relevant error factor. Then the Analytic Hierarchy Process (AHP) method is used to find solutions to the vector of the degree of importance for each design information for that error factor. This is represented as $w_{qe} = (w_{1i}, w_{2i}, \dots, w_{ii}, \dots, w_{pi})^T$. Regarding the vector of the degree of importance for each design information of each error factor, the relation matrix W_{qe} of the error-cognition and the design information is constructed as follow:

$$W_{qe} = \begin{bmatrix} w_{11} & w_{12} & \dots & w_{1i} & \dots & w_{1p} \\ w_{21} & w_{22} & \dots & w_{2i} & \dots & w_{2p} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ w_{i1} & w_{i2} & \dots & w_{ii} & \dots & w_{ip} \\ \vdots & \vdots & \dots & \ddots & \ddots & \vdots \\ w_{p1} & w_{p2} & \dots & w_{pi} & \dots & w_{pp} \end{bmatrix} \quad (6)$$

From the matrices W_{qe} and W_q , we obtain the relationship matrix between the error-cognition and the design information, while considering the correlation among the design information as follows:

$$W_{QE} = W_q \times (W_{qe})^T \quad (7)$$

Comprehensively, considering the influence of the degree of importance of error-cognition on the design information, the vector of the degree of importance of the design information is obtained as follow:

$$W_Q = W_{QE} \times w_E \quad (8)$$

4.4 Objective Constraints of Interface Layout

When optimizing the contents of information presentation, in addition to considering the degrees of importance of the features of design information it is also necessary to consider the rationality of information features in the interface layout. The interaction interface includes all kinds of information fragments, such as symbols, indicators, line symbols, characters, etc, which are assembled to become an information set from the information flow. Ibrahim (2013) states information structure is the form of information assembled. So in this paper, from the point of information instruction, combined with Parsons' (2014) 10 attributes of interacting visual display, we can define information blocks, functional divisions, task divisions and visual flows as design information features of interface layout. According to the objective programming approach, we establish a mathematical model for the optimization and decision-making for the design information features in the interface layout (Hu Yunquan *et al.*, 1998). We determine the objective constraints of design information features from several aspects as below:

1) **Information capacity inside the interface area.** The information units related graphics could be assembled as an information block. For example, different tactical models, such as Attacking, Defense, Expansive, etc. could be combined as one closely arranged information unit. In the monitoring task interface, this information block could be combined as unit A: $\{x_1, x_2, \dots, x_n\}$. There are Block A1, Block A2, Block A3, $\dots$ Block An, which could be formed into an Information (Info) Unit, that is Info: $\{A1, A2, \dots, An\}$. According to the characteristics of information interaction systems, it is known that as the complication and size of

information increases, so does the difficulty of the information layout. Hence, the quantity of information inside the interface, namely the *information capacity*, is a factor to be considered for design optimization. The amount of information can be quantified by a bit (Shannon and Weaver, 1949). With respect to the probability that the information occurs in the interface area, the capacity of different interface areas can be computed as follows:

$$H_{ave} = \sum_{i=1}^n p_i [\log_2(1/p_i)] \quad (9)$$

To serve as a constraint, we set the probability of events that can possibly happen during the corresponding execution of a task for all kinds of information features. Then we calculate the average information quantity of these information features.

2) **Visual flow of interface information:** The visual behavior of operators forms a certain visual flow in the interface. This is the second factor that is important for design optimization. According to visual behavior rules (Wickens, 2003) and eye tracking, the visual flow mainly includes sensitivity of stimulus, guidance of physical location, edge effect and the gaze-saccade process.

3) **The degree of relevance of information functions:** With respect to the difference between functions, an internal graph-element relation has been formed among the information. This will form information blocks that are relatively concentrated in the interface. This is the third factor for design optimization. Based on information blocks, we need to consider the functional correlation among information blocks. For examples, the speed controlling area is comprised of airspeed, height, heading, etc. The weapons mounting selective area is comprised of class, selection marking, etc. The function division area could be designated unit B: $\{y_1, y_2, \dots, y_n\}$. There are Area B1, Area B2, Area B3, $\dots$ Area An, which could be formed function Area (Func) Unit, that is Func: $\{B1, B2, \dots, Bn\}$.

4) **The tasks are partitioned according to their degrees of importance:** It is also necessary to consider the degrees of importance of the tasks in the interface layout. For different combinations of tasks, different task partitions are required. Hence task level is the most crucial factor in the interface layout. Based on the function division, we also need consider the operator's monitoring task. The monitoring task could be divided into different areas according to different processing of monitoring/detection, state query, response planning and response execution. There is a direct connection between the task division and the function division, such as fuel gage searching, indication radar setting and selection, weapon plan and bomb mode selection, etc. Therefore, the task division area could be as unit C: $\{P1, P2, \dots, Pn\}$.

4.5 Mathematical model and modeling procedures of objective programming

Combining the aforementioned analysis, we identify four constraints: 1) information capacity, 2) visual flow, 3) graph-element relations and 4) task level. They are categorized into quantitative constraints (information capacity) and qualitative constraints (visual flow, graph-element relations and task level). The weighted multi-objective programming method is adopted to obtain the optimal information feature set for design optimization. The general mathematical model of objective programming can be written as follow:

$$\min \omega_1(d_1^-) + \sum_{i=2}^k \omega_i \left(\frac{d_i^-}{R_i} + \frac{d_i^+}{R_i} \right) + \sum_{i=k+1}^m \omega_i(d_i^-) \quad (10)$$

$$\text{s.t.} \quad \sum_{j=1}^n w_{Dj} x_j + d_1^- - d_1^+ = 1, \quad \sum_{j=1}^n r_{ij} x_j + d_i^- - d_i^+ = R_i \quad i = 1, 2, \dots, s, \quad \text{and} \quad \sum_{j=1}^n w_{ij} x_j + d_i^- - d_i^+ = 1 \quad i = s + 1, \dots,$$

m .

where, ω_i stands for the weight of an objective ($i = 1, 2, \dots, m$), d_i^- represents the negative deviation to

the i -th objective, d_i^- represents the positive deviation to the i -th objective, x_j is the 0-1 variable, that stands for the j -th feature of the design information ($j = 1, 2, \dots, n$), w_{Dj} stands for the degree of importance for the j -th feature of the design information, r_{ij} represents the j -th feature of the design information that uses the i -th quantitative constraint, R_i stands for the i -th quantitative constraint, and w_{ij} represents the j -th feature of the design information with respect to the weight of the i -th qualitative constraint objective.

5. Case of Task Interface Design of Typical Avionics Display Systems

5.1. Error Factor and Extraction of Information Features of a Typical Avionics Display Interface

In order to verify the reasonability of our design method for mapping from error-cognition to design information, we will take the surveillance task interface of a complex information system as an example. This paper takes information features of the surveillance task interface of an avionics display system for analysis (as depicted in Figure 2), in which the error factors are extracted based on the monitoring interface tasks and corresponding error factors (Table 1) as follows:

- 1) Visual restriction – omission (r_{e1});
- 2) Visual mistake – misreading/misjudgment (r_{e2});
- 3) Visual interference – ignorance (r_{e3});
- 4) Attention shifting and distraction – miss (r_{e4});
- 5) Cognitive deviation – misunderstanding (r_{e5});
- 6) Unreasonable matching – confusion (r_{e6}).

With respect to six items of error factors, the designers target the monitoring tasks executed by the operators, and combine them with features from design information to determine seven items from the design information features:

- 1) Location of an information feature (c_{q1});
- 2) Visible range of an information feature (c_{q2});
- 3) Spacing of information features (c_{q3});
- 4) Intensity of visual attention of an information symbol (c_{q4});
- 5) Recognition of an information icon (c_{q5});
- 6) Degree of conciseness of an information icon (c_{q6});
- 7) Differences between information icons (c_{q7}).

Figure 2. Monitoring Tasks: Mode 1 (left) and Mode 2 (right)

Below, we will focus on six items of error factors from these typical error-cognition sets and seven items of design information features extracted by surveillance tasks executed by operators. The analysis will be conducted one by one with respect to the reaction chain. The optimizations of the intensity of visual attention are performed mainly with respect to the line symbol, the character symbol, and a combination of the line and character symbols. We also consider the significance, such as the allocation of colors and line frame symbols which affect the intensity of the visual attention. The relevant symbols of design information are illustrated in Figure 3.

Figure 3. Information blocks with relatively weaker visual attention

The optimization of the recognition and the distinction of information graphic symbols are mainly from the points of understanding, degree of cognition, similarity of graphic symbols. The relevant symbols of design information are shown in Figures 4-a, 4-b, 4-c.

Figure 4. Information symbols

With respect to the characterization methods of design factors for interface layout (Wu Xiaoli, 2015), the information structure of the interface can be extracted via abstract layouts. As a result, a layout analysis of the original interface results in the output of the layout abstracts of each sub-interface as depicted in Figure 4 (A, B, C and D).

A. Display of flight data

B. Display of horizontal location

C. Radar status

D. Weapons mounting

Figure 5. The information layout of a monitoring task interface

It can be seen from the information structure of the interface that this layout can be partitioned into four visual districts, and these districts are divided equally in such a way that they lack concern for visual searching behaviors. What needs to be considered for the factors of information layouts are the locations of information features (c_{q1}), the visible ranges of information features (c_{q2}) and the intervals of the information features (c_{q3}).

5.2. Mapping from error-cognition to design information

With respect to the mapping method from error-cognition to the features of design information, the procedure to obtain the optimized design information is set as below:

Step 1: Determine the relative weights of the error factors for the error-cognition. Suppose the error factors denoted by the numerical sequence of 1 to 9 are irrelevant. Then compare five items of error factors to get the solution such that $(r_{e1}, r_{e2}, r_{e3}, r_{e4}, r_{e5}, r_{e6}) = (3, 7, 5, 3, 9, 1)$. After normalization, we obtain the relative weighted vector of error factor w_r , where $w_r = [0.107, 0.250, 0.179, 0.107, 0.321, 0.036]^T$.

Step 2: Determine $\mathbf{W}r$, the relationship matrix of the degrees of importance of the error factors:

$$\mathbf{W}r = \begin{bmatrix} 0.652 & 0.000 & 0.148 & 0.183 & 0.016 & 0.000 \\ 0.000 & 0.619 & 0.000 & 0.016 & 0.127 & 0.239 \\ 0.148 & 0.000 & 0.503 & 0.309 & 0.023 & 0.019 \\ 0.184 & 0.015 & 0.309 & 0.492 & 0.000 & 0.000 \\ 0.016 & 0.127 & 0.023 & 0.000 & 0.577 & 0.255 \\ 0.000 & 0.239 & 0.017 & 0.000 & 0.257 & 0.487 \end{bmatrix}$$

Step 3: Determine the relationship matrix of the degrees of importance between the error factors and the features of design information:

$$\mathbf{W}_{qe} = \begin{bmatrix} 0.538 & 0.327 & 0.106 & 0.029 & 0.000 & 0.000 & 0.000 \\ 0.123 & 0.109 & 0.012 & 0.286 & 0.242 & 0.011 & 0.217 \\ 0.107 & 0.077 & 0.118 & 0.497 & 0.000 & 0.000 & 0.201 \\ 0.271 & 0.108 & 0.015 & 0.606 & 0.000 & 0.000 & 0.000 \\ 0.000 & 0.000 & 0.000 & 0.000 & 0.579 & 0.138 & 0.283 \\ 0.000 & 0.000 & 0.000 & 0.000 & 0.202 & 0.126 & 0.672 \end{bmatrix}$$

Step 4: Determine the relationship matrix of the degrees of importance of the features of design information:

$$\mathbf{W}_q = \begin{bmatrix} 0.723 & 0.234 & 0.029 & 0.000 & 0.014 & 0.000 & 0.000 \\ 0.234 & 0.527 & 0.135 & 0.104 & 0.000 & 0.000 & 0.000 \\ 0.029 & 0.135 & 0.660 & 0.049 & 0.116 & 0.011 & 0.000 \\ 0.000 & 0.104 & 0.049 & 0.548 & 0.012 & 0.129 & 0.158 \\ 0.014 & 0.000 & 0.116 & 0.012 & 0.546 & 0.197 & 0.115 \\ 0.000 & 0.000 & 0.011 & 0.129 & 0.197 & 0.506 & 0.157 \\ 0.000 & 0.000 & 0.000 & 0.158 & 0.115 & 0.157 & 0.570 \end{bmatrix}$$

Step 5: Calculate w_E , the weight of an error factor:

$$w'_e = \mathbf{W}_r \times w_r = [0.1181 \ 0.2058 \ 0.1470 \ 0.1314 \ 0.2320 \ 0.1628]^T,$$

$$R_E = \{3, 7, 5, 3, 9, 1\},$$

$$w_E = [0.107, 0.250, 0.179, 0.107, 0.321, 0.036]^T.$$

Step 6: Calculate w_Q , the vector of the degrees of importance for the features of design information:

$$\mathbf{W}_{QE} = \mathbf{W}_q \times (\mathbf{W}_{qe})^T = \begin{bmatrix} 0.4734 & 0.1193 & 0.0998 & 0.2241 & 0.0081 & 0.0028 \\ 0.3155 & 0.1176 & 0.1332 & 0.1854 & 0.0000 & 0.0000 \\ 0.1311 & 0.0684 & 0.1157 & 0.0620 & 0.0687 & 0.0248 \\ 0.0551 & 0.2073 & 0.3179 & 0.3441 & 0.0695 & 0.1249 \\ 0.0202 & 0.1658 & 0.0443 & 0.0128 & 0.3759 & 0.2124 \\ 0.0049 & 0.1243 & 0.0970 & 0.0783 & 0.2283 & 0.2091 \\ 0.0046 & 0.0868 & 0.0895 & 0.0951 & 0.1044 & 0.0813 \end{bmatrix}$$

$$\mathbf{W}_Q = \mathbf{W}_{QE} \times w_E = [0.1365 \ 0.0876 \ 0.0371 \ 0.2284 \ 0.2536 \ 0.0516 \ 0.2053]^T.$$

Step 7: Consider the quantitative objective constraints. For information features, information capacity is regarded as the quantitative constraint. Generally, in multi-dimensional comprehensive conditions, the transmission rate can be enhanced. However, they will always be below 10 bit/s. This is the limit of the human information transmission rate – information transmitted above this rate cannot be fully comprehended. In a complex information interface, the transmission rate of information is influenced by multiple factors such as the size of graphical symbols, color, position and connecting line symbols. These factors are called stimulus dimensions (Ding Yulan, 2000). Thus, the information transmission rate which is optimal for operators to comprehend is not a constant. It changes with the features and the dimensions of the different graphical information symbols and the complexity of the task to be executed.

Hence, for different tasks to be executed by operators, the visual cognition processes from monitoring /discovery, status inquiry, response planning to response execution can take between 30 to 180s. This may sometimes lead to situations where it is possible to miss the optimal time for task execution. As a result, we can say that the information capacity to simultaneously perform information processing in an information interface should be within 300 to 1800 bits. If this capacity is exceeded, it becomes hard for operators to

execute an information task. In this case, seven information features correspond to the task processes that need to be executed; they are c_{q1} , c_{q2} , c_{q3} , c_{q4} , c_{q5} , c_{q6} , and c_{q7} respectively (see Table 3).

Table 3. Probabilities of occurrence p_i of possible executed tasks corresponding to the information features

Information Features	A Monitoring/Discovery	B Status Inquiry	C Response Planning	D Response Execution
cq1	0.55	0.25	0.125	0.175
cq2	0.35	0.45	0.08	0.12
cq3	0.25	0.55	0.175	0.025
cq4	0.35	0.35	0.125	0.175
cq5	0.25	0.25	0.375	0.175
cq6	0.125	0.225	0.35	0.3
cq7	0.375	0.325	0.155	0.145

With respect to the computational formula for the average quantity of information

$$H_{ave} = \sum_{i=1}^n p_i [\log_2(1/p_i)], \text{ the computation can be performed as shown in Table 4.}$$

Table 4. Probabilities of occurrence of possible executed tasks corresponding to the information features

Information Features	A Monitoring/Discovery	B Status Inquiry	C Response planning	D Response Execution
p_i	0.55	0.25	0.125	0.175
$1/p_i$	1.82	4.00	8.00	5.71
$\log_2(1/p_i)$	0.86	2.00	3.00	2.51

The numerical value of c_{q1} is calculated as:

$$\sum p_i [\log_2(1/p_i)] = 0.473 + 0.5 + 0.375 + 0.439 = 1.787 \text{ bit.}$$

Similarly, the size of the relevant information of c_{q2} , c_{q3} , c_{q4} , c_{q5} , c_{q6} , c_{q7} can be calculated using the expression:

$$\sum p_i [\log_2(1/p_i)], \text{ as is shown:}$$

$$c_{q1}=1.787$$

$$c_{q2}=1.586$$

$$c_{q3}=1.545$$

$$c_{q4}=1.878$$

$$c_{q5}=1.972$$

$$c_{q6}=1.917$$

$$c_{q7}=1.883$$

The size of the information capacity as displayed in Table 3 does not take into consideration factors such as the quantity of information features of the same category. The quantity of different information features in the monitoring task interface is approximately between 1 and 100. For instance, the number of characters is between 20 and 80, and the number of graphical symbols is generally between 3 and 15. Therefore, the information from each of the seven categories of information features is below 200 bits and the total information capacity of all the categories is between 300 and 1800 bits.

Taking the correlation between the information features into consideration, the capacity of information features v can be expressed as follow:

$$w'_V = \mathbf{W}_q \times v = [1.7355 \ 1.6579 \ 1.6275 \ 1.8383 \ 0.9286 \ 1.9134 \ 1.8978]^T.$$

Step 8: Consider the qualitative objective constraints. We consider three objective constraints of information features. When carrying out interface layouts for design information these constraints are considered from the point of the visual flow, the graph-element relations and the task. For sufficient consideration of the optimization of design information with respect to the interface layouts, it is necessary to quantify the qualitative objectives. The method of “pairwise comparison” is used to compare seven items of information features. Next we obtain the weighted vector of each design information feature for the information capacity, visual flow, graph-element relations and task level considered in the interface layouts. They are denoted by w_F , w_R and w_T , respectively.

$$w_Q = [0.327, 0.195, 0.155, 0.254, 0.037, 0.011, 0.021]^T$$

$$w_R = [0.321, 0.114, 0.216, 0.103, 0.215, 0.013, 0.018]^T$$

$$w_T = [0.328, 0.187, 0.073, 0.373, 0.011, 0.011, 0.017]^T$$

$$w'_Q = \mathbf{W}_q \times w_Q = [0.2900 \ 0.2266 \ 0.1550 \ 0.1722 \ 0.0504 \ 0.0506 \ 0.0471]^T$$

$$w'_R = \mathbf{W}_q \times w_R = [0.2709 \ 0.1751 \ 0.1974 \ 0.0860 \ 0.1528 \ 0.0674 \ 0.0440]^T$$

$$w'_T = \mathbf{W}_q \times w_T = [0.2861 \ 0.2239 \ 0.1026 \ 0.2317 \ 0.0277 \ 0.0593 \ 0.0625]^T$$

Step 9: Determine the relative weights of the objective constraints. Results calculated by “Pairwise comparison” are shown in Table 5, where “RMC” represents the objective mapping from error-cognition to the design information.

Table 5. Relative weight of various objective constraints

	RMC	Information Capacity (v/%)	Visual flow (f/ %)	Graphic-Element Relations (r/%)	Task Level (t/%)	Relative Weight / w_r
RMC	1	3	2	$\frac{1}{2}$	$\frac{1}{3}$	0.170
Information Capacity	$\frac{1}{3}$	1	$\frac{1}{2}$	$\frac{1}{3}$	$\frac{1}{5}$	0.068
Visual Flow	$\frac{1}{2}$	2	1	$\frac{1}{2}$	$\frac{1}{3}$	0.118
Graphic-Element Relations	2	3	2	1	$\frac{1}{2}$	0.237
Task Level	3	5	3	2	1	0.407

Step 10: The weighted multi-objective programming model is established by using the results of the above-mentioned nine steps. The specific planning model is presented as below:

$$\min: \ 0.17(d_1^-) + \frac{0.068}{1800}(d_2^+) + 0.118(d_3^+) + 0.237(d_4^-) + 0.407(d_5^-)$$

With respect to the solution process of multi-objective planning by Lingo, the solutions to c_{q1} , c_{q2} , ..., c_{q7} can be obtained, as is shown:

$$c_{q1}=0.2140$$

$$c_{q2}=3.1820$$

$$c_{q3}=0$$

$$c_{q4}=0.6253$$

$$c_{q5}=2.1667$$

$$c_{q6}=0$$

$$c_{q7}=0$$

With respect to the results of multiple objective planning, four major information features, c_{q1} (the location of information feature), c_{q2} (the visible range of information feature), c_{q4} (the intensity of visual attention of information symbols feature), and c_{q5} (the recognition property of information graphic symbols feature) are regarded as the main objects of design optimization for this monitoring task interface.

5.3. Information display and interface design according to results of multi-objective planning

According to visual behavioral characteristics (Ding Yulan, 2000) and visual searching model (Wickens and Holiands, 2003), vision is directed from left to right, from up to down, and from the upper left, the upper right, the lower left to the lower right. The distribution of interface layouts is shown in Figures 6, including the main task execution area (optimal visual zone), task execution reserve (secondary visual zone) and task execution reserve (third visual zone). The layout should maximize the task execution area, and hide non-execution areas. It could adjust different information block displays in respect of position and visual range.

Navigation	Navigation	Navigation
Secondary Navigation	Secondary Navigation	Secondary Navigation
The Main Task Execution Area (Optimal visual zone)	Task Execution Reserve (Secondary visual zone)	Task Execution Reserve (The third visual zone)
Data Auxiliary View	Related Information of Auxiliary Task Reserve	Related Information of Auxiliary Task Reserve

Figure 6. The information optimized layout of the monitoring task interface

According to extraction of the error factors, analysis of visual behavior, the reaction chain of error factors and information features, and the results of multiple objectives planning, the avionics interface display can be optimized via the information symbols design and the information block layout. The 3 optimized modes interface display are shown in Figure 7 (Mode 1, Mode 2, and Mode 3) .

An optimized interfaces display (Mode 1)

An optimized interface display (Mode 2)

An optimized interface display (Mode 3)

Figure 7. 3 optimized Modes interface display

5. Conclusions

This paper innovatively establishes the correlations among error factors, visual cognition and design information. It proposes that the interface design of complex information systems can directly benefit from the information derived from the sources of task failures. It also opens up a new shortcut towards the study of the design method of complex information interfaces, and builds up this design method from error-cognition to the mapping of information features.

With respect to the design method of complex information interfaces, we explore a use-case for the design of a typical naval warfare display system. Error factors such as omission, misreading/misjudgment, ignorance etc., are extracted along with the description of the relevant information features of tasks for the operators. Through the solution process of mapping, we identify four significant areas of information display design that can be improved in the monitoring task interface. These results verify the validity of the design method for information interfaces based on the mechanism of error-cognition.

The features of design information, such as locations of information characteristics, visual range, separation distance and visual attention intensity of symbols, are determined in accordance with the reaction

chain of error factor-information characteristics. We find a solution to this problem by mapping from error-cognition to the information features. Based on the results, we also propose an optimization design scheme for the monitoring task interface.

Key points

Human computer interaction, Human Error, Visual Information Features, Error-cognition

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Figures

Figure 1

Procedure of the optimization method

Figure 2

Monitoring Tasks: Mode 1 (left) and Mode 2 (right)

Figure 3

Information blocks with relatively weaker visual attention

Figure 4

Information symbols

Figure 5

The information layout of a monitoring task interface

Navigation	Navigation	Navigation
Secondary Navigation	Secondary Navigation	Secondary Navigation
The Main Task Execution Area (Optimal visual zone)	Task Execution Reserve (Secondary visual zone)	Task Execution Reserve (The third visual zone)
Data Auxiliary View	Related Information of Auxiliary Task Reserve	Related Information of Auxiliary Task Reserve

Figure 6

The information optimized layout of the monitoring task interface

An optimized interfaces display (Mode 1)

An optimized interface display (Mode 2)

An optimized interface display (Mode 3)

Figure 7

3 optimized Modes interface display

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