An Interface Analysis Method of Complex Information System by Introducing Error Factors

Xiaoli Wu[1,2(✉)], Yan Chen[1], and Feng Zhou[1,2]

[1] College of Mechanical and Electrical Engineering, Hohai University, Jinling Road. 200, Changzhou 213022, China
wuxlhhu@163.com

[2] Institute of Industrial Design, Hohai University, Jinling Road. 200, Changzhou 213022, China

Abstract. With the rapid developments of computer technology and information technology, human-machine interfaces of aircrafts, ships, nuclear power plants, battlefield command system, and other complex information systems have evolved from the traditional control mode to digital control mode with visual information interface. This paper studies error factors of information interface in human-computer interaction based on visual cognition theory. A feasible error-cognition model is established to solve some design problems which result in serious failures in information recognition and analysis, and even in operation and execution processes. Based on Rasmussen, Norman, Reason and other error types as well as the HERA and CREAM failure identification models, we performed classification and cognitive characterization for error factors according to information search, information recognition, information identification, information selection and judgment as well as the decision-making process and obtained the comprehensive error-cognition model for complex information interface.

Keywords: Error factors · Design factors · Human-computer interface · Interaction · Visual cognition · Error-cognition model

1 Introduction

With the rapid developments of computer technology and information technology, human-machine interfaces of great intelligent manufacture equipment, nuclear power plants, even aircrafts, ships, battlefield command systems, and other complex information systems have evolved from the traditional control mode to digital control mode with information interaction interface. Compared with the conventional analog control which is generally monitoring and operating system, digital control shifts the role of operators from manual controlers to regulators and decision-makers, which increases the process of operator's visual cognition and needs a set of cognitive behaviors perform the task (as shown in Fig. 2). Because complex information interaction interfaces are characterized by the large quantity of information and complex information relationships, an operator may enter the complex cognition and lead to task

D. Harris (Ed.): EPCE 2016, LNAI 9736, pp. 116–124, 2016.
DOI: 10.1007/978-3-319-40030-3_13

Fig. 1. Analog control of an intelligent system (Left) and displays of digital control (Right)

failure, even serious system failures and major accidents due to operation errors, misreading, misjudgment, late feedback, and other cognitive difficulties (Fig. 1).

Complex information task interface is characterized by transforming systematic abstract information into user interfacial elements which are easy to identify and understand. Graphical user interface conveys several elements, including character, text, image, icon, colour, dimension, and so on. When the information displayed is complex, only the reasonable navigation design and structure design of information hierarchy can reach the rationality of information interaction. Thus, the design problem of information interaction interface has evolved into a hot spot and focus problem which was concerned mutually by researchers in human-factors engineering, automatic control, cognitive psychology, systematic science, design science and other disciplines. Then, whether the design factors of information interaction interface could begin with the source of task failures – error factors? The key point lies in how to understand correctly the interaction mechanism between 'error and cognitive', then, can we propose a reasonable design strategy for the optimization of visual information interface.

2 Objective

Many methods of classifying the human errors sprang up in the field of cognitive science and engineering application research. Based on the cognitive psychology, Norman (1981) divided operation errors into the three types: error, slip and mistake. To optimize the design of the system, Rasmussen (1986) proposed three types of cognitive control layers: skill layer, rule layer and knowledge layer and classified the errors systematically based on the three types. Reason (1987) thought the opinion proposed by Norman that operation errors include two types: negligence and error is not comprehensive, and he divided them into three types: mistake, slip and lapse. Later, Reason further consummate the error classification on the basis of the three types, and he believed that there were 8 basic error types: false sensation, attention failure, memory slip, inaccurate recall, mispercetion, error judgment, inferential error and unintended actions. Swain (1998) classified the errors into three modes: error of omission, error of commission, extraneous error. Li L.Sh (2004) proposed that inattention and overattention should be the main study objects of user error. Above classification methods have become major error types in the studies of human error, and combined with Human Reliability Analysis method are applied in engineering field.

Currently, few people in the field of visual information interface have started researches in the base of error factors, especially applied to aviation, military and other complex systems which are displayed by multilevel subsystems, whose error factors are concentrated in visual information display of executive monitoring, search and other tasks and its cognition mechanism of errors is an important hitting-point for improving interface design as well as the key for reducing cognition difficulties. Wu (2014, 2015) proposed a new interface design method by introducing error factors and established the error-cognition stratification model for complex information task interfaces. This paper studies error factors of information interface in human-computer interaction based on visual cognition theory. A feasible error-cognition model is established to solve some design problems which result in serious failures in information recognition and analysis, and even in operation and execution processes.

3 Methods

According to the CREAM and HEPA, we established operators' cognitive behavior model based on extended CREAM and the cognitive error recognition framework of operators' behavior based on HEPA, and obtained a possible human error mode for complex monitoring interfaces. We performed classification, extraction and cognitive characterization for cognitive behaviors of four monitoring tasks: monitoring/discovering, inquiring the state, planning the response and performing the response. Then, we established error-cognition set through the mapping relationship from error factors to cognition. According to the specific classification of every error types, we divided error factors into five types, including misperception set, perception confusion set, attention failures set, memory lapse set and inattention set.

The study analyzes different types of error factors from visual cognitive theories, further analyzes error factors at different levels through cognitive theories and sorts out relevant attention theories. Theeuwes et al. (1998, 2004) have held the opinion that, the occurrence of attention capture mainly depends on the significance level of the feature of one stimulus relative to that of other stimuli. The higher the feature significance level of a stimulus, the higher the possibility of its generating attention capture. Fleetwood and Byrne (2002, 2006) have found through experimental observation that, the first factor which influence the user's visual search is the quantity of icons, the second is the target boundary, and the last one is the quality and resolution of icons. In a conclusion, error-cognition model is established through the relevance between user error and cognition.

4 Model

4.1 Cognitive Behavior Model of Operators

According to error classification Norman (1981) and Reason (1987) proposed, misperception types are extracted from the visual cognitive perspective as the main object of study. In the visual information interface, they are mainly shown as: information misreading/misjudgment, omissions and other error factors caused by attention invalidation, attention transfer, visual interference and visual limitation in the visual search.

As shown in Fig. 2, based on the information central processing of monitoring task interface, forming the cognitive process from information input to information feedback. During the process, we need to analyze the operator's cognitive behaviors based on the execution of the task. Information search, information recognition, information identification, information selection and judgment as well as the decision-making process are just operator's cognitive behaviors of information observation, explanation, planning and execution during the process of executing the task. Thus, this paper will continue to explore the information process of complex monitoring task interface in depth.

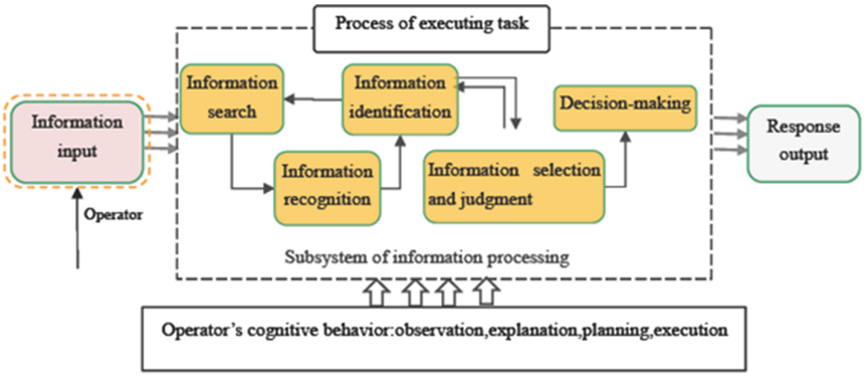

Fig. 2. Central processing of information of monitoring task interface

4.2 Analytical Model of Cognitive Error Recognition Based on HEPA

We can combine extended operator's cognitive behavior model with corresponding analytical model of error recognition, and further recognize the cognitive error of the interfacial task. The technology of HERA proposed by Kirwan (1997), which integrates several methods and enables the analysis results to be tested each other, is reliable relatively. Thus, this paper will apply error recognition framework to analyze the cognitive error recognition of information search, recognition, judgment and selection, as well as decision-making.

According to the process of operator's cognitive behavior, operator's task, task function as well as task steps and structure are unfolded, corresponding with the analytical opinion of human reliability, which includes task analysis, objection analysis, operation analysis, planning analysis, error analysis, psychological error mechanism analysis, performance shaping factor analysis as well as human error identification in systems tool analysis.

According to operator's cognitive behavior model based on extended CREAM (Hollnagel 1996, 1998), we extracted the main cognitive behavior in every period, and integrate into synthetic procedure of information search, recognition, judgment and selection as well as decision-making as its task function. Then, we analyzed the cognitive error recognition of different modules. Figure 3 shows the error recognition analysis of operator's cognitive behavior.

4.3 Cognitive Characterization of Error Factors

1. Classification of error factors

Through the extraction of error factors in the four cognitive behavior processes including monitoring/discovering, inquiring the state, response planning and response performing, we obtained error factor combination of cognitive behavior classification. To further study perception mechanism of error factors in visual cognitive interface, we need to perform classification and cognitive characterization for error factors. Thus, we need to exclude those error factors caused by non-visual cognition and remain those caused by information search, information recognition, information identification as well as information judgment and selection.

2. Cognitive representation of error factors

Error factors in cognitive behavior process are implicit, and manifest as explicit behavior errors, such as incorrect execution and selection, so what left to be resolved is cognitive analysis of implicit error factors. To further characterize the error factors of information interface, according to the interfacial task in complex system environment, operator need perform five following cognitive behaviors: search, recognition, identification, judgment and selection, decision-making. Keep the information display format of different task corresponding with cognitive behavior or possible error factors, then, we can characterize the errors.

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

4.4 Analytical Model of Error-Cognition

We classified n possible error factors in process of cognitive behavior into m nonvoid subsets(1 $\leq$ m $\leq$ n). There are s(n, m) methods of classification, and every method represents the process of cognitive behavior to information. For each integer n $\geq$ 1 and m $\geq$ 1, exists $S(n,k) = \frac{1}{k!}\sum_{i=0}^{k-1}(-1)^i C_k^i (k-i)^n$. Table 2 shows the error-cognition mapping.

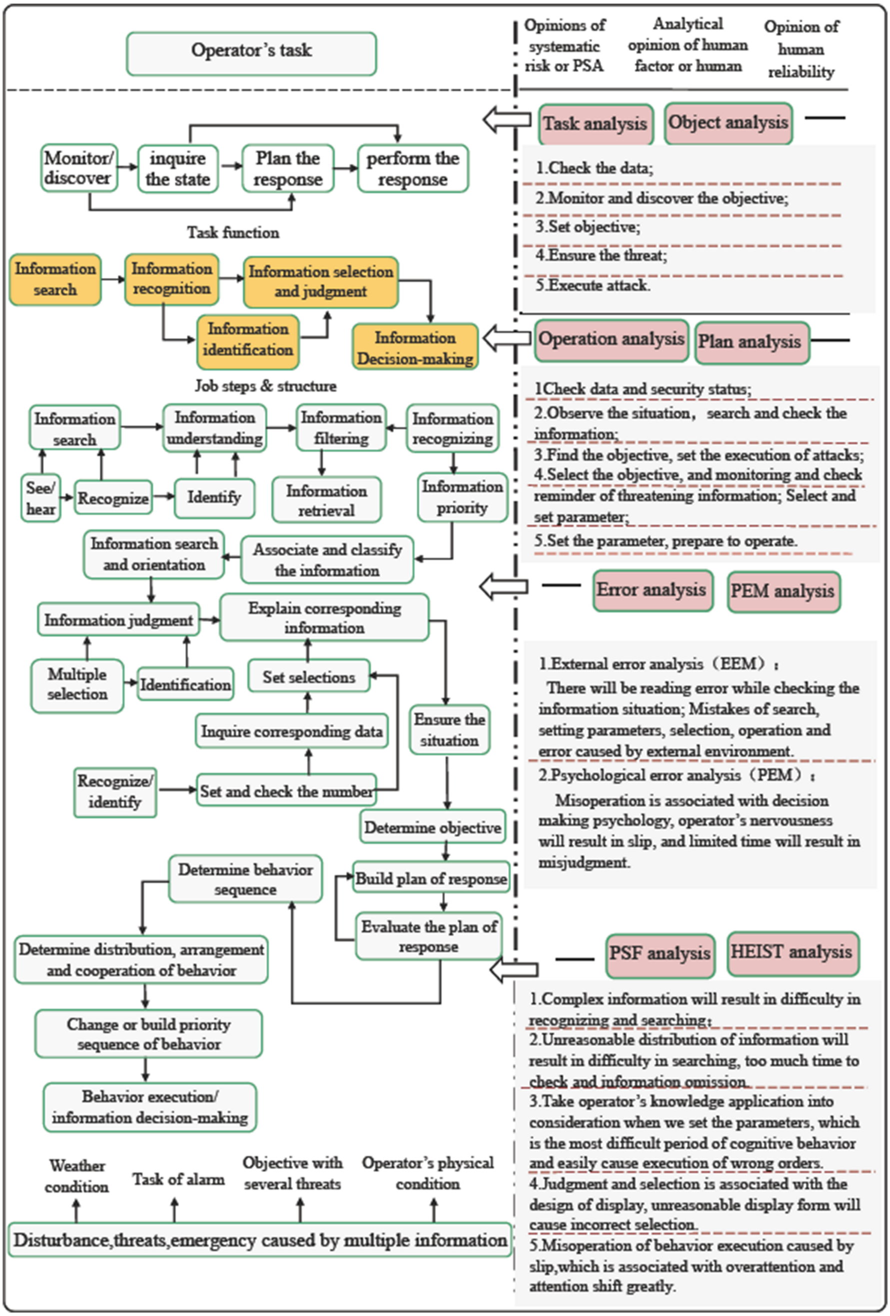

Fig. 3. Error recognition analytical model of operator's cognitive behavior based on HEPA

Table 1. Characterization of error factor of monitoring interface task

Tasks of monitoring interface A	Display format of information B	Cognitive behavior C	Error factor D	representation of error E
A1monitor/discover A2inquire state A3plan response A4execute response	B1 dynamic display B2 static display B3 navigation B4 status data B5 information icon B6 alarm reminder	C1search C2recognize C3identify C4judge&select C5decision-making	D1 ignorance D2 omission D3 miss D4 misreading D5 misjudgment D6 misunderstanding D7 haven't seen D8 confusion D9 cannot remember D10 input error D11 misregistration D12 cannot see clearly D13 hard to distinguish D14 match incorrectly D15 cannot find D16 delay D17 inadequate D18 irrelevant D19 react too early D20 no reaction D21 select incorrectly D22 slip	E1 ambiguity states E2 visual limitation E3 visual bluntness E4 visual illusion E5 attentional load E6 visual disturbance E7 overattention E8 attention shift and distraction E9 too nervous to do anything E10 cognitive bias E11 unreasonable match E12 weak visibility E13 thinking load E14 forget E15 inaccurate recall E16 lack of memory aids E17 intentionality decrease E18 false memory E19 unconsciousness E20 omission caused by inattention E21 time pressure

Table 2. Error factor to cognition mapping

Cognitive domain	1	2	3	⋯	n
C_1	E_{11}	E_{12}	E_{13}	⋯	E_{1n}
C_2	E_{21}	E_{22}	E_{23}	⋯	E_{2n}
⋮	⋮	⋮	⋮	⋯	⋮
C_i	E_{i1}	E_{i2}	E_{i3}	⋯	E_{in}
⋮	⋮	⋮	⋮	⋯	⋮
C_m	E_{m1}	E_{m2}	E_{m3}	⋯	E_{mn}

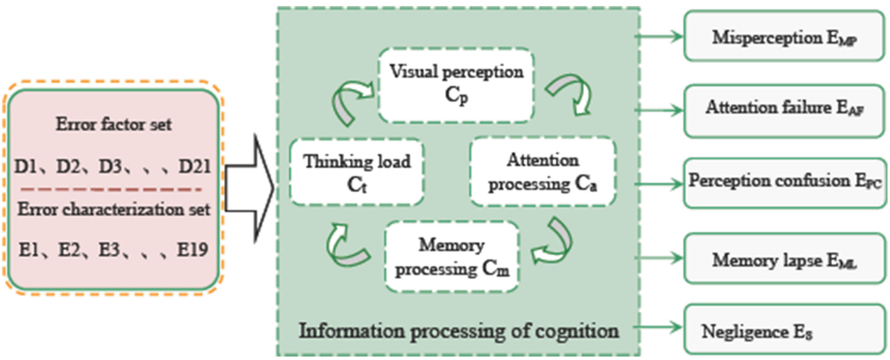

Fig. 4. Error-cognition model of visual information interface

Based on the error factor set, error characterization set as well as the process of cognition to information, we obtained five types of error-cognition: misperception, attention failure, perception confusion, memory lapse and negligence (as shown in Fig. 4).

5 Conclusion

1. The design problems, resulting in serious failures in information recognition and analysis, and even in operation and execution processes, could begin with error factors;
2. The relevance between error and cognition is existed, which could be established the error-cognition model to analysis design problems in information interface.

Acknowledgement. This work was supported by Fundamental Research Funds for the Central Universities (Grant No. 2015B22714), science and technology projects of Changzhou (CJ20140033), the Project of Philosophy and Social Science Research in Colleges and Universities in Jiangsu Province (2014SJD065).

References

Fleetwood, M.D., Byrne, M.D.: Modeling icon search in ACT-R/PM. Cogn. Syst. Res. **3**, 25–33 (2002)

Fleetwood, M.D., Byrne, M.D.: Modeling the visual search of displays: a revised ACT-R/PM model of icon search based on eye-tracking and experimental data. Hum.-Comput. Interact. **21**(2), 153–197 (2006)

Hollnagel, E.: Reliability analysis and operator modeling. Reliablity Eng. Syst. Safety **52**(3), 327–337 (1996)

Hollnagel, E.: Cognitive Reliability and Error Analysis Method. Elsevier science Ltd, Oxford (1998)

Kirwan, B.: Human error identification techniques for risk assessment of high risk systems-part 2: towards a frame work approach. Appl. Ergonomics **29**(5), 299–318 (1998)

Li, L.: Human Computer Interface Design. Science Press, Beijing (2004). (in Chinese)

Norman, D.A.: Categorisation of action slips. Psychol. Rev. **88**, 1–15 (1981)

Norman, D.A.: The psychology of everyday things. Basic books (1988)

Rasmussen, J.: Informaiton processing and human machine interaction: an approach to cognitive engineering. North-Holland, Amsterdam (1986)

Reason, J.: Human Error. Cambridge University Press, New York (1990)

Reason, J.: Human error: models and management. Br. Med. J. **320**, 768–770 (2000)

Swain, A.D., Guttmann, H.E.: Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications. NUREG/CR-1278, Nuclear regulatory commission, Washington, DC (1983)

Theeuwes, J., Burger, R.: Attentional control during visual search the effect of irrelevant singletons. J. Exp. Psychol. Hum. Percept. Perform. **24**, 1342–1353 (1998)

Theeuwes, J.: Top-down search strategies cannot override attentional capture. Psychon. Bull. Rev. **11**(1), 65–70 (2004)

Wu, X., Xue, C., Niu, Y., Tang, W.: Study on eye movements of information omission/misjudgment in radar situation-interface. In: Harris, D. (ed.) EPCE 2014. LNCS, vol. 8532, pp. 407–418. Springer, Heidelberg (2014a)

Wu, X., Xue, C., Feng, Z.: Misperception model-based analytic method of visual interface design factors. In: Harris, D. (ed.) EPCE 2014. LNCS, vol. 8532, pp. 284–292. Springer, Heidelberg (2014b)

Wu, X.: Study on error-cognition mechanism of task interface in complex in formation system. School of Mechanical Engineering, Southeast University, Nanjing (2015). (in Chinese)