A Study for Human-Machine Interface Design of Spacecraft Display & Control Device Based on Eye-Tracking Experiments

Qi Guo(✉), Chengqi Xue, Yun Lin, Yafeng Niu, and Mo Chen

School of Mechanical Engineering,
Southeast University, Nanjing 211189, China
ipd_xcq@seu.edu.cn

Abstract. The display & control device is the hub of human-machine interaction in the whole spacecraft's human-machine environment system. The rationality of its design affects the level of integration between human and machine directly. Therefore, the optimization design studies of manned spacecraft cabin's display & control device plays an important role on the development of spaceflight. The paper researches the design methods of manned spacecraft cabin's display & control device from the perspective of human-machine ergonomics. The specific steps of research are: Firstly, we will refine the design principles of human-machine interface by constructing the user behavior model; Secondly, we will work out the design and layout solutions of spacecraft cabin's display & control device based on the information from user behavior model; Finally, an eye-tracking experiment will be proposed to verify and optimize the solutions.

Keywords: Display & control device · Human-machine interface design · Behavior model · Eye-tracking experiment

1 Introduction

With the development of modern computer technology, the technology of human-machine interaction has become the key theory on the design of display & control device. The design concept of people-oriented is to change the behavior of the machine system into the act of communication between users and machine easily,thus it helps to improve the operation safety, reliability and efficiency. The display & control device is a main part of human-machine environment system, which bridge users and machine information exchange in the environment of human-machine system. British scholar [1] began to study the control panel layout in 1967, multiple computer control panel layout programs were developed (1973 and 1977 respectively), Dr. M.P. Dan [2] put forward computer aided design system (CADS) and expert system (ES), which are applied in the design of ergonomics in the cab of the vehicle. But the method can only be applied to the design of human-machine interface with few components and small layout area, Wei Ning Fang [3] established the constraints between control units and locomotive operation according to the task, function and ergonomics requirements, Wei Liu [4] studied the application of situated cognition in human-machine interaction

© Springer International Publishing AG 2017
D. Harris (Ed.): EPCE 2017, Part II, LNAI 10276, pp. 211–221, 2017.
DOI: 10.1007/978-3-319-58475-1_16

design, he pointed out that the study of situational awareness on transportation, intelligent home furnishing, robot intelligence and other related research fields have practical significance. In order to meet the requirements of ergonomics in the design of display & control device, it is necessary to carry out scientific research and experiment, such as the experimental method, the observation method, the subjective questionnaire, the virtual simulation method and the intelligent algorithm model, etc. Due to the limitation of space on the spacecraft, the display &control devices tend to be integrated and systematic. The visual perception and cognitive burden of astronauts are increased because of the excessive display parameters. Therefore, the research on the basic principles of human-machine interaction and physiological characteristics of human beings have become more and more important in the space exploration.

After analyzing the deficiencies of the existing methods of human-machine interface design, the following two steps are proposed to design the layout of display & control device based on physiological and psychological characteristics of astronaut:

1. The human cognition and performance as the two factors of human are the basic research on the information exchange between human and machine. In order to find out the rules of astronaut cognitive and operational behavior, GOMS (goal-operators-methods-selection) [5] is used to analysis the relationship between astronaut factors and interface design, so we can instruct the design of human-machine interface of display and control device.
2. Eye-tracking technology [6] is utilized to analyze and verify the design solution of the manned spacecraft cabin's display & control device. A normalized eye-tracking experiment is arranged to capture eye migration path, fixation point distribution, and the heat map of eye focus [7]. After that, we will find the hot spots of eye focus and the first effect. These parameters are chosen as the qualitative and quantitative evaluation indexes for the human-machine interface design, the experiment results are the important gist to improve and optimize the design solution.

2 Methodology

2.1 GOMS Model for Operating Tasks

GOMS model is applied to the design of human-machine interface for the first time, it plays an important role in the study of the display & control device on spacecraft, it can be used to find out the factors which influence the operation of the display & control device and study the relationship among these factors.

Based on the information processing theory of human problem solving, the GOMS model describes the solving process from four aspects: goal, operator, method and rule. Considering the confidentiality of project, this paper takes the operation process of the communication between the astronaut and the ground command center as an example, and makes the relevant task hypothesis to simulate the interaction between the astronaut and the speech control unit. The GOMS model is used to analyze the operation process of the astronauts and the effect of astronaut's cognitive behavior characteristics on the design of the display & control device, after that, the guidance of interface design will be extracted.

A. Task objectives and their decomposing steps

In this paper, the general objective of the communication task is decomposed into five sub-goals, namely startup, connection, conversation, records and safe operation. Sub-goals can be divided into more specific operational goals. The specific task decomposition is shown in Fig. 1

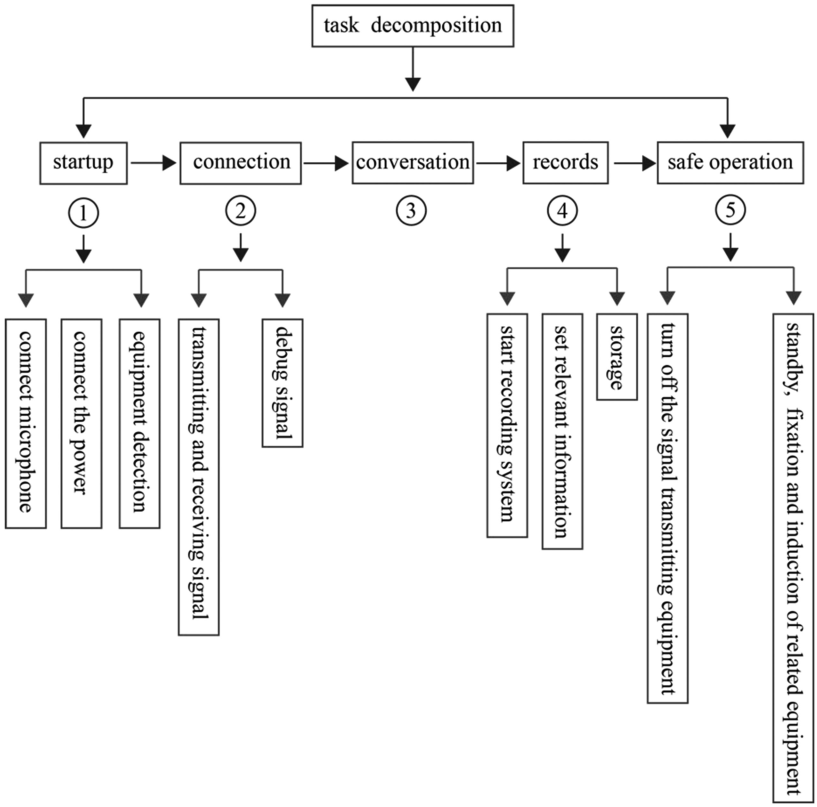

Fig. 1. Specific task decomposition

The following assumptions are made on the model for the astronaut's information processing:

The perception channel is mainly based on the vision and auditory sense, and the operation mode of the astronaut is the expert mode, namely, there is no error operation. The sub tasks of ①②③⑤ in Fig. 1 are sequential, with the ④ and the subtasks of ③ and ⑤ are simultaneous. Some key switch steps in "record" task: "space suit" - "call" - "volume control" - "recording" - "hang up". Then import the GOMS model.

The above behavior objectives are introduced into the GOMS model, and the analysis process of some subtasks is shown in Figs. 2, 3 and 4.

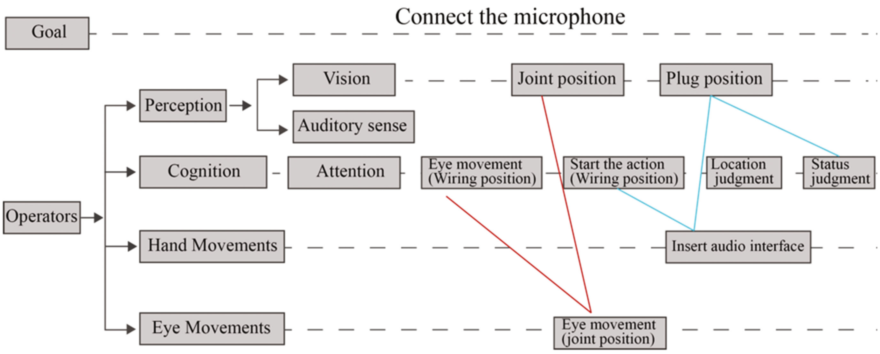

Fig. 2. Operational model of "connect the microphone"

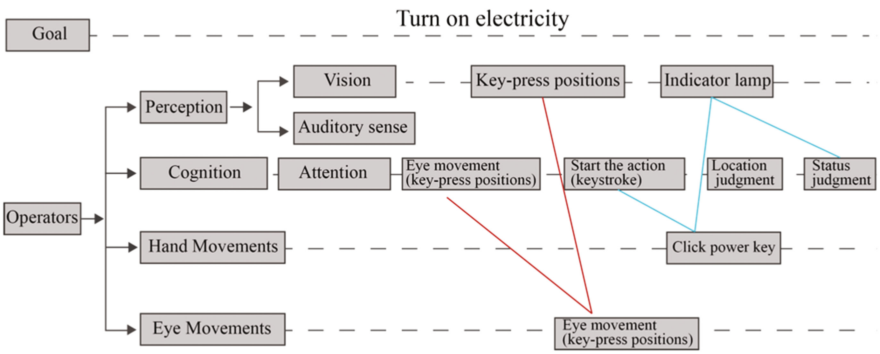

Fig. 3. Operational model of "turn on electricity"

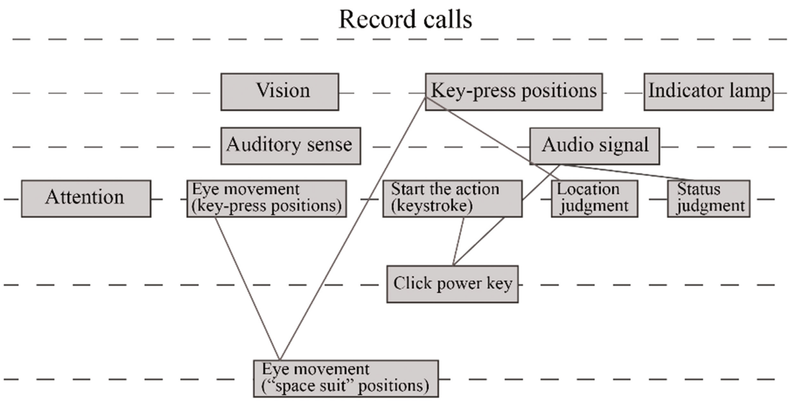

Fig. 4. Operational model of "record calls"

B. Design analysis and guidance

(1) Analysis of using process: there are many switching actions in the process, therefore, the matching of button position and operation process should be considered.
(2) Analysis of the environment: voice unit and other display & control device are arranged in the cabin on the operation panel, so the design should be coordinated with the environment of other equipment, including interface tone and overall styling.
(3) Analysis of the user error: astronauts' error prone to operational errors in the operation process. In order to prevent the situation, the designer will design the feedback result after each step of the operation to carry on the interactive design.

2.2 The Optimal Experiments on the Display & Control Device

2.2.1 Experimental Equipment and Experimental Procedures

Eye movement experiments were carried out with the EyeLink6, integrating and recording the results by the data processing software [8]. Twenty people were elected from the instrumentation engineering, mechanical manufacturing, automation, aerospace manufacturing engineering, aircraft design and other similar professional master of engineering as test subjects. Before the experiment, let the test personnel read experiment notes, and show some different types of display and controller for participants to make a general understanding of the content.

The subjects will observe the two pictures carefully, each picture is equipped with a guide, the first observation object is a blank rectangle with the length and width of 960 mm multiplied by 920 mm, the blank rectangle is divided into nine small areas and four intersections, the guide words are: "please look carefully at the image below the picture, may be round or rectangular, observation time is about 5 s". After the experiment, the fixation points of 20 test subjects will be exported.

2.2.2 The Analysis of Fixation Points

In a blank rectangle, there is no interference of eye gaze movement caused by other visual or cognitive factors. The number of fixation is proportional to the point of interest, the area with the largest amount of attention can be called the golden visual area. The fixation points of the 20 subjects were stacked into a superposition point of view as shown in Fig. 5. It is easy to find that the regions with the highest frequency are the areas marked in Fig. 6, which are the intersection areas, and the measured points were mainly distributed in area A, D, E and F, the area G, H and I below the rectangle is less than the rest.

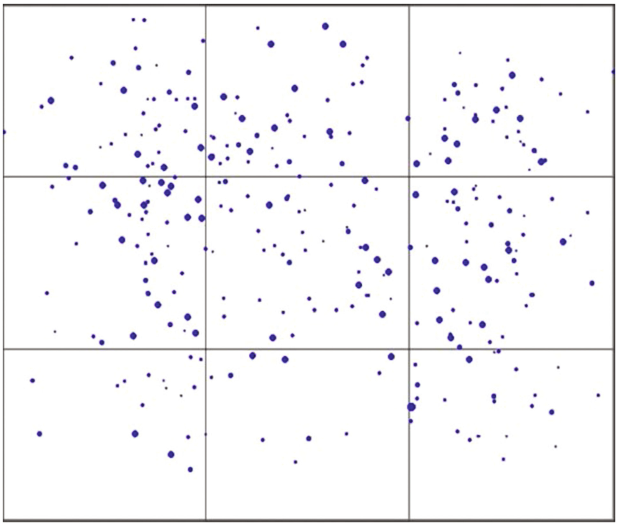

Fig. 5. Superposition diagram

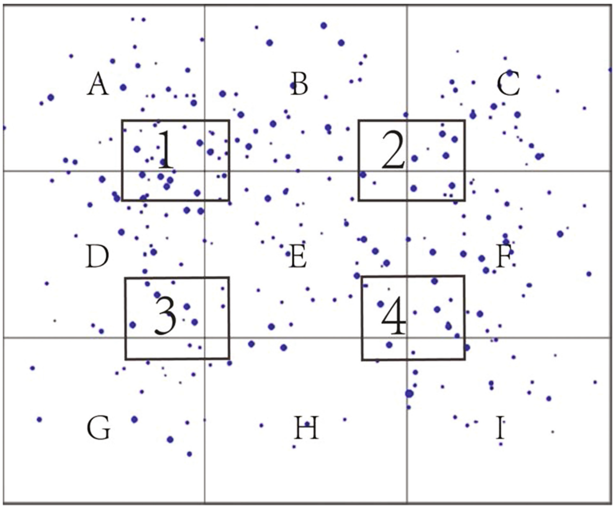

Fig. 6. Fixation distribution

2.3 The Verification Experiment on the Display & Control Device

2.3.1 Experimental Method and Experimental Procedures

The two groups were tested with each group of 20 people. The target scheme and the contrast scheme were selected as the test subject to verify the design of the interface morphology and semantics, the design of the color semantic and the rationality of the layout design. The number of fixation points and the average saccade amplitude were recorded by the EyeLink6. By calculating the mean and standard deviation of fixation time to evaluate whether the interface design is friendly, by calculating the mean and standard deviation of saccade amplitude, we can evaluate the rationality of the layout design.

In this paper, the design scheme of the experimental test is shown in Fig. 7, in which the A is the target scheme and the contrast schemes are B and C. The experiment was divided into two groups, each group consisted of 20 subjects, the first group of tests were A and B, the second group of tests was A and C.

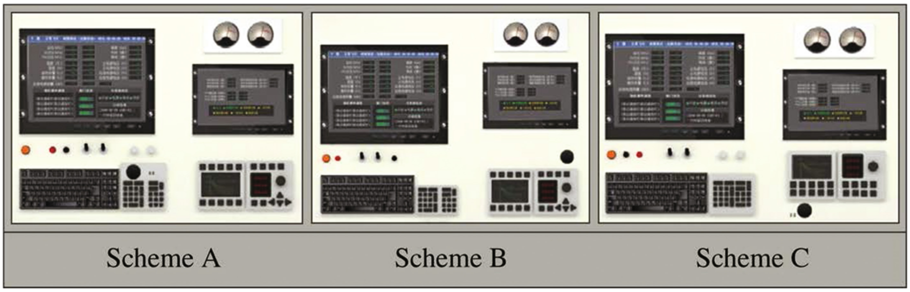

Fig. 7. Experimental scheme

The visual path of the scheme which is shown in Fig. 8.

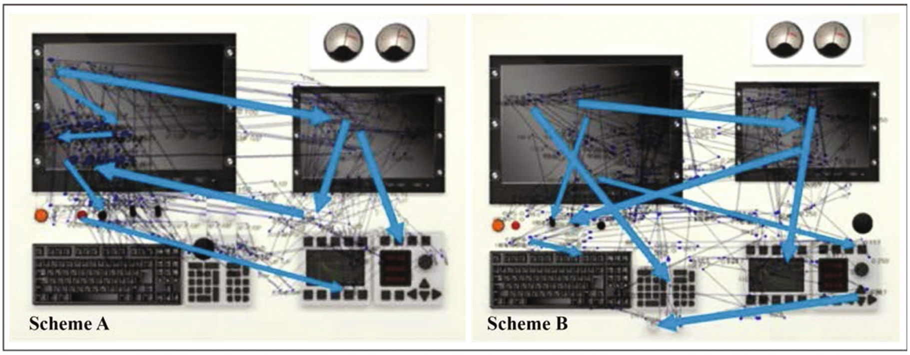

Fig. 8. The diagram of visual path

After analyzing the path characteristics of the eye movement in the task, we can obtain that the visual path of the scheme A is more clear, and the layout of scheme A is in line with the logic habits of human vision. Furthermore, the visual path of the scheme B is more chaotic, it is hard to find the target project except for a large visual jump. Because of the fewer changes of the longitudinal layout, the observational data is not obvious. Therefore, this paper only shows the average saccade amplitude of each tester's interface layout, as shown in Fig. 9.

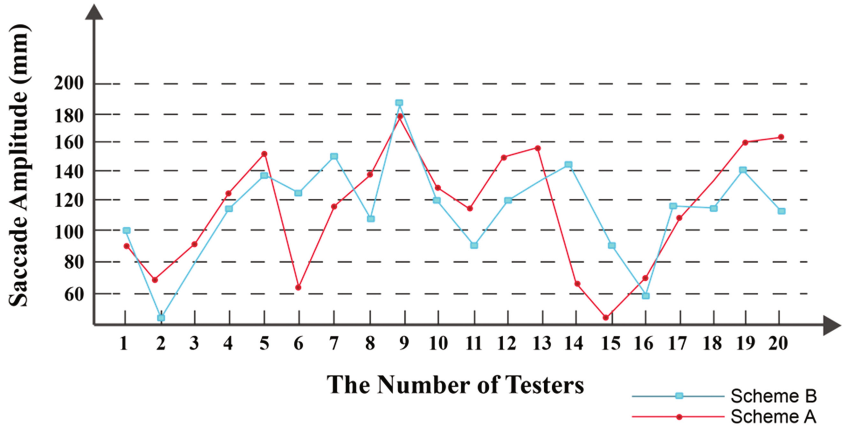

Fig. 9. Average saccade amplitude observed by the first group of testers

The data were analyzed by SPSS, the average saccade amplitude of scheme A is 130.8000 mm, the standard deviation is 34.2416, the average saccade amplitude of scheme B is 114.6794 mm, the standard deviation is 10.1108, it is obvious that the design of scheme A is better than the scheme B.

One-way ANOVA [9] was used to analyze the two sets of data, the original hypothesis is that there is no significant effect on the average saccade amplitude of scheme A and scheme B, let's suppose that the significant level is 0.05, and the results are shown in Table 1. It indicates that the total sum of squares of deviations of the observed variable average saccade amplitude is 37719.600, the mean square deviation of different interface layout is 1.600 and 991.103 respectively, dividing 1.600 by 991.103 to get F is 0.002, the corresponding significant level is 0.046, less than the significance level 0.05.

Table 1. The Analysis of one-way ANOVA based on saccade amplitude

	SSD	DOF	Average of SSD	F	Significant level
Inter-group	1.600	1	1.600	0.002	0.046
Intra-group	37718.0	38	991.103		
Sum	37719.6	39			

(SSD = sum of squares of deviations, ANOVA = analysis of variance)

Comparing with the number of fixation points observed by the second group of test subjects, as shown in Fig. 10. It can be concluded from the following diagram that the average number of fixation points of scheme A is 58, the standard deviation is 2.5948, the average number of fixation points of scheme C is 59, the standard deviation is 3.5254, as shown in Table 2. It can be seen that the design of scheme A is better than the design of scheme C.

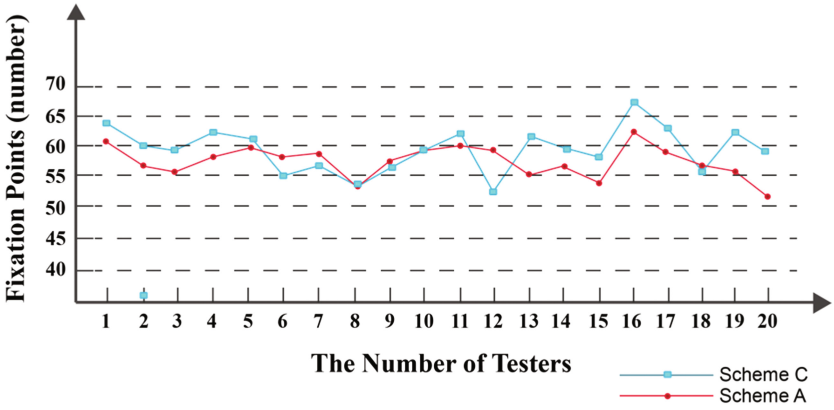

Fig. 10. Fixation points observed by the second group of testers

Table 2. Statistical tables of fixation points

	Scheme	Sample size	Mean	Standard deviation
Number of fixation points	A	20	57.55	2.5948
	C	20	59.4	3.5254

The original hypothesis is that it had no significant effect on the fixation points between scheme A and scheme C, let's suppose that the significant level was 0.05, and the results were shown in Table 3. Based on the above data, we can draw a conclusion that the variance of the sampling error is 0.021, and the mean squared deviations of them are 0.001 and 0.021, dividing 0.001 by 0.021 to get F is 0.048, and the corresponding probability P is 0.341, which is greater than the significance level 0.05, so the hypothesis has no significant effect on the fixation time.

Table 3. The Analysis of one-way ANOVA based on fixation points

	SSD	DOF	Average of SSD	F	Significant level
Inter-group	0.001	1	0.001	0.048	0. 341
Intra-group	0.021	38	0.021		
Sum	0.022	39			

2.3.2 Experimental Results and Discussion

From the analysis of saccade trajectory and average saccade amplitude, the interface design of scheme A is more reasonable than scheme B. From the analysis of the fixation points, the shape design of the scheme A is better than the scheme C, that is to say, the interface design of scheme A is more friendly and higher recognition.

However, it can be seen from the One-way ANOVA that the significant number of fixation points in the second group was significantly greater than the level of 0.05, that is we can accept the original hypothesis. There was no significant effect on the number of fixation points with different shape designs, therefore, it is difficult to evaluate the advantages and disadvantages of the two schemes on shape design. There are some reasons for the problem: sampling error of testing personnel, the arrangement of test sequence has some influence on the experimental results and the error caused by test instrument.

3 Conclusion

In this paper, a systematic and comprehensive study on human cognition and behavior characteristics is presented:

- By using GOMS model to analysis the astronaut's cognitive operation on the human computer interaction system, to extract the design guidance of the man-machine interface, so that the design of the man-machine interface can better play the role of the astronaut in the human-computer interaction system.
- By analyzing the data of the average saccade amplitude and fixation points in the eye movement experiment, we find out rationality and deficiency of scheme. This paper presents a set of analysis and optimization method based on eye-tracking.
- Combining theoretical analysis with experimental verification, a reasonable and systemic design method is proposed for display & control device. It will make a contribution to the design and optimization of other human-machine interaction system.

Acknowledgments. The paper is supported jointly by Science and Technology on Electro-optic Control Laboratory and National Aerospace Science Foundation of China (No. 20165169017), SAST Foundation of China (SAST No. 2016010) and National Natural Science Foundation of China (No. 71471037, 71271053).

References

1. Boney, M.C.: CAPABLE - a computer program to layout controls and panels. Ergonomics **20** (3), 297–316 (1977)
2. Dan, M.P.: Using man modeling CAD system and expert systems for ergonomic vehicle interior design. In: Proceedings of the 13th Triennial Congress of the International Ergonomics Association, Tempere, Finland, 29 June–4 July 1997, pp. 80–83 (1997)
3. Fang, W.: Influence of parameter adjustment on the visual effect of the liquid crystal display console. J. Railway Sci. **12**, 40–44 (2003)
4. Liu, W.: Situated Cognition in Human-Computer Interaction Theory and Application, pp. 15–68. China science and Technology Press, Beijing (2005)
5. Kieras, D.: GOMS models for task analysis. In: Diaper, D. (ed.) Handbook of Task Analysis for Human-Computer Interaction, pp. 83–116. Lawrence Erlbaum Associates, Mahwah (2003)
6. Carlos, H., Morimoto, M.R.M.M.: Eye gaze tracking techniques for interactive applications. Comput. Vis. Image Underst. **98**, 4–24 (2005)

7. Sun, R., Tian, C.: Eye movement analysis technique and application in aviation field. J. Civ. Aviat. Univ. China **27**(4), 1–4 (2009)
8. Zhuang, D.: Theory and Application of Pilot's Attention Allocation, pp. 31–38. Science Press, Beijing (2013)
9. Yang, X.: Analysis of variance analysis method: one-way ANVOA. Exp. Sci. Technol. **11**(1), 23–25 (2013)