

Development and Practical Applications of Color Combinations Evaluation Method for Human Error Reduction

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Abstract

In recent years, providing countermeasures to human error has become increasingly important among business operation systems. This trend is especially significant in the fields of aerospace and medical treatment, in which social solutions with high security and reliability are essential. We have developed a Color Combinations Evaluation Method to reduce human error and have applied it to an air traffic control system. This method quantifies three requirements for color combinations that are effective in reducing human error: "Harmony," "Visual attention of important information" and "Fatigue of eyes." It also quantifies "user's perceptual load" that users might receive from color combinations. Developers can determine the optimal color combinations based on calculated value. This paper introduces the Color Combinations Evaluation Method and its practical applications.

Keywords



human error, color combinations, harmony, visual attention, fatigue of eyes, perceptual load

1. Introduction

Recently countermeasures to human error are increasingly in demand in business operation systems because a decrease of operational accuracy due to human error sometimes leads to significant damages. Especially in the fields of aerospace, automobile and medical treatment, which provide solutions to our social infrastructure, a variety of efforts have been continuously made in order to achieve high secure and reliable social solutions. These include countermeasures provided in organization management such as the education and training of operators, pairs of operators working together, etc. and also countermeasures provided in system development such as automation, autonomy, error checking, redundancy, and so on. Even after providing these countermeasures, it is still difficult to reduce the risks due to human error.

We have researched requirements to reduce human error and are developing evaluation systems for HI (Human Interface) design in order to achieve more secure social solutions. This paper describes a Color Combinations Evaluation Method that is effective at reducing human errors such as missing or seeing wrong information. This paper also introduces the practical applications of this method.

2. Target of the Color Combinations Evaluation Method

2.1 Human Error that Occurs When Receiving Information

Human error can be seen on many occasions, but when observing them from the viewpoint of a human's process information (**Fig. 1**), human error can be classified into the following three types:

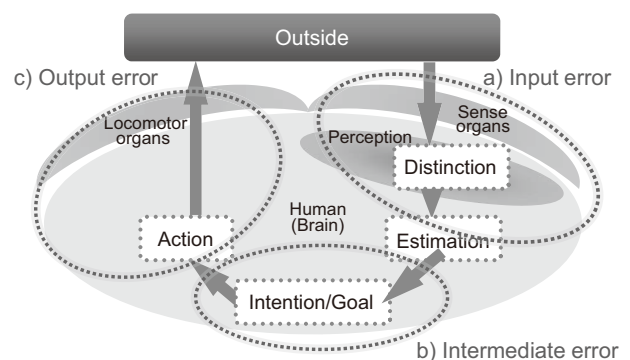


Fig. 1 Steps of human information processing.

a) Input error

When an operator receives information, he/she overlooks or sees wrong the information. This may cause misunderstanding and delays of judgment.

b) Intermediate error

When an operator determines a goal based on the received information, he/she makes a wrong judgment due to his/her insufficient expertise or wrong assumptions.

c) Output error

When an operator takes an action to achieve the goal, even if the goal is appropriate, he/she takes a wrong action due to his/her carelessness or insufficient skills.

Any error carries the risk of causing a serious accident. Therefore, it is essential to reduce the occurrence ratio of such error as much as possible. In business operations that error reduction is particularly important, possible countermeasures such as education and training of operators, installation of safety devices, etc., have already been provided. However, in business fields such as air traffic control and medical treatment, it is necessary to refer a large amount of information at once in accordance with business requirements.

A variety of complex information displayed on a screen too much for operators to handle. In such conditions, risks of oversights or mistaking the information are increased. Moreover, this type of error cannot be significantly reduced via training or education and, once one occurs, it can lead to further errors. In considering these facts, we found that it is necessary to provide countermeasures against being difficult to understand or causing eye strain. In accordance with these demands, we have developed a Color Combinations Evaluation Method in order to reduce human error when an operator receives information from outside the system.

2.2 Requirements for Human Error Reduction

Two main factors causing human error such as oversight and seeing wrong during operation of any systems can be listed as follows: (1) the difficulty in finding target information due to complexity of screen layout and bad color harmonization and (2) accumulation of fatigue caused by long hours of operation. If an operator cannot find target information quickly, he/she will not be able to grasp the current situation (i.e. find the appropriate information on the screen to judge the next action to be taken), which may cause wrong judgment and wrong action. Moreover, when an operator feels fatigue after long hours of operation, it is difficult for him/her to perceive information and make decisions appropriately. Therefore, in order to reduce oversight or seeing wrong, these countermeasures such as making important information easy to aware even on a complex screen and reducing fatigue even in extended operations must be considered.

In order to approach this issue, we have focused on color combinations, which is an important factor in designing screens. Color is used for various purposes, because of its high expressiveness. For designing screens, Developers have to consider visibility of information, adaptability of operators' culture and customs and so on. Therefore, it is difficult to determine optimal color combinations for screens with complex information. In appropriate color combinations might make it difficult to aware important information and increase operators' fatigue of eyes.

3. Development of the Color Combination Evaluation Method

The Color Combinations Evaluation Method that we have developed makes it possible to quantify three requirements in color combinations that are effective in human error reduction: harmony, visual attention of important information and fatigue of eyes. In addition to these requirements, this method also quantifies the perceptual load due to color combinations (**Fig. 2**).

So far these requirements were evaluated subjectively by developers or designers. Our evaluation method, however, makes it possible to quantify these requirements and optimize the color combination based on the calculated value. It is possible to optimize the color combination systematically and to satisfy multiple requirements. With our evaluation method, important information can be better emphasized while harmonizing the entire screen color combination, so that an operator is able to recognize the important information and understand its meaning quickly and clearly. Moreover, combinations of adjacent colors are chosen to not overly stimulate human eyesight, so that influence on operators' fatigue can be minimized. The developed evaluation method also quantifies the load level. The relationship between the load level and the error occurrence ratio has already been proven. By visualizing the load level in the process of reacting to stimuli and recognizing them, the effectiveness of error reduction, which was once difficult to verify, can be confirmed.

The relevant requirements and perceptual load are as follows.

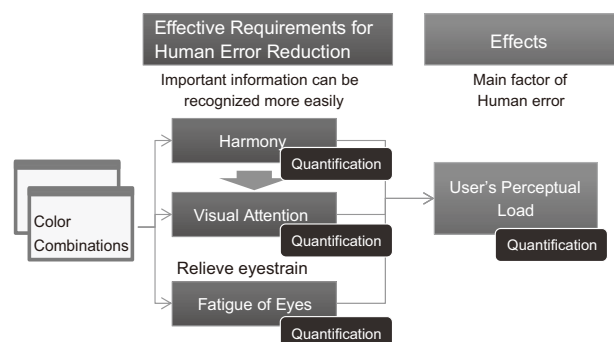


Fig. 2 Outline of the Color Combinations Evaluation Method.

3.1 Harmony

Our method calculates the predominant color of the screen from distribution of the background colors' hue or tone, and evaluates the harmony of the color combinations based on the color. We have developed an evaluation formula based on the knowledge and experience that we have accumulated through practice. For example, if the background colors hue or tone is dispersed outside the regulated range, most operators will feel that the colors do not harmonize. Harmonized color combinations provide a calm and beautiful impression to users and also it makes easier to emphasis important information.

3.2 Visual Attention of Important Information

The saliency of each item on the screen is quantified to evaluate how much important information stands out from other information. "Visual attention" expresses how much an item can draw visual saliency. It consists of features of the color itself (Feature-attention) and features when compare with others (Heterogeneity-attention). These degrees of saliency can be quantified and referred to as "visual attention." In order to apply to evaluate display screens, we have carried out verification experiments continuously based on existing research mainly in the field image processing. Then we developed the method to calculate the visual attention of each item on a screen. By considering the balance of saliency (visual attraction) of each item, operators are able to find important information more easily and to conduct their work more smoothly.

3.3 Fatigue of Eyes

Our system can quantify and evaluate how much various combinations of background colors next to each other make operators' eyes tired. When two colors whose hue, brightness or saturation are extremely different are placed next to each other, eye strain occurs more frequently. According to this Humans' Physiological phenomenon, we have developed an evaluation formula by optimally using our accumulated expertise. Color combinations that suppress eyestrain can minimize influence on operators' fatigue of eyes.

3.4 Operators' Perceptual Load

Our method also quantifies the perceptual load due to color combinations at each operational step. Humans generally feel burdens when they receive load from an external source; when these burdens accumulate beyond a certain level, they feel fatigue. Due to loads (burdens) and fatigue, operators lose their concentration, and the possibility of error occurrence increase. We have developed the evaluation method to calculate the perceptual load due to color combinations on a screen. This

method has been developed through continuous subject experiments using NASA-TLX, a scale of the subjective evaluation of mental workloads. This method makes it possible to quantify the perceptual load for each operational step and confirm whether each step is easy to cause an error, such as steps that the perceptual load is extremely high and steps that the load increases or decreases rapidly.

Verification experiments to construct a formula to quantify visual attention and perceptual load were conducted and developed in compliance with the ethical code of Human Interface Society.

4. Application to Air Traffic Control System Screens

We applied our Color Combinations Evaluation Method to air traffic control system screens and then proposed improvements. For the current air traffic control system screen, three colors (yellow, green and cyan) are used for aircraft images on top of the black background. In addition to these items, various other colors are used to indicate other information, such as alerts (red) that indicate a conflict between aircrafts, maps and air traffic routes (orange), etc.

Air traffic controllers carry out their operations while continuously watching the screen. They are expected to prevent close approach between aircrafts ("conflict") and to provide quick countermeasures when this occurs. Therefore, the alert indicating the conflict should stand out from other information. With the current screen, however, it is difficult to identify which information is important.

Fig. 3 shows the visual attention of each item on this current screen, which is calculated by our evaluation method. Items with higher degrees of importance are located toward the left of the graph. "Alert (red)," however, which is the most important item, has only visual attention to "Aircrafts (green and blue)."

Based on this result, an improvement proposal was made to adjust visual attention of each item according to its level of importance. **Fig. 4** shows the visual attention of each item

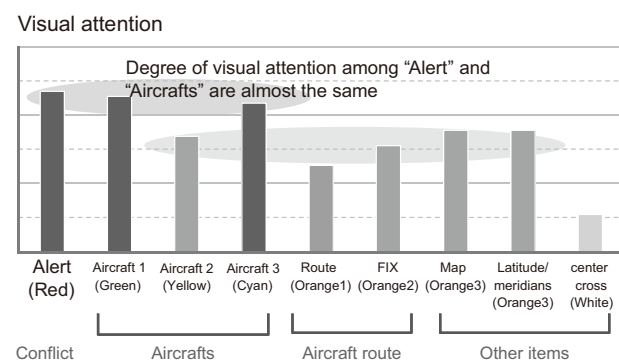


Fig. 3 Visual attention of each item (current screen).

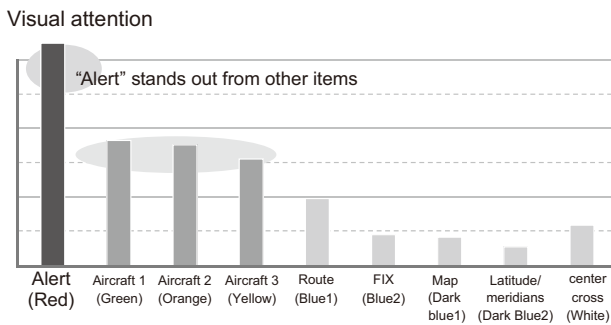


Fig. 4 Visual attention of each item (improved screen).

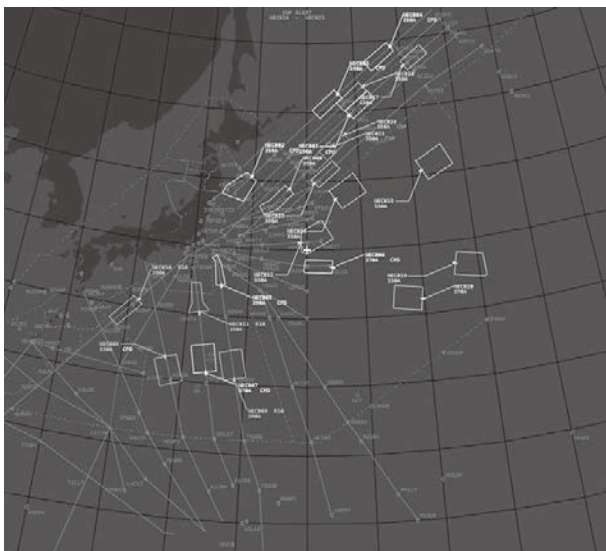


Fig. 5 Air traffic control system screen (improved design).

on improved screen and Fig. 5 shows the proposed air traffic control screen. The most important “Alert” stands out from any other items and all “Aircraft” are noticeable next to the “Alert.” At the same time, this proposed screen improves other requirements: making it easier to distinguish the color of each “Aircraft,” making a background color combination in consideration for harmony and fatigue of eyes and applying enough color contrast which increase text readability.

Next, Fig. 6 shows the comparison between the current screen and the improved screen, about how much load the operator will receive when he/she searches for each item. We have confirmed that improved color combination enables a significant reduction of the perceptual load for searching for items. Reduction of the perceptual load is confirmed with almost every item (21.6% average reduction and 41.7% maximum reduction).

As described so far, we will support the design of screen color combinations that are most suitable to each industry. We will introduce our method to practical screen design and cus-

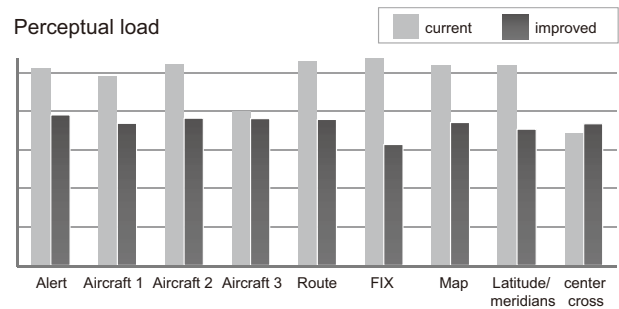


Fig. 6 Perceptual load comparison evaluation results (classified by item).

tomers proposals by showing the reasons for improvement (requirements) and effects on users (perceptual load reductions).

5. Conclusion

This paper describes the outline of a Color Combinations Evaluation Method for human error reduction and also introduces its practical applications. We will continue to improve this method to contribute to the development of systems with reduced human error by applying this method in the field in which slight error should be avoided such as medical treatment, air traffic control, etc. We will also continue to further enhance the accuracy of our method, verify its effectiveness in a wide range of fields, and develop more secure and reliable system.

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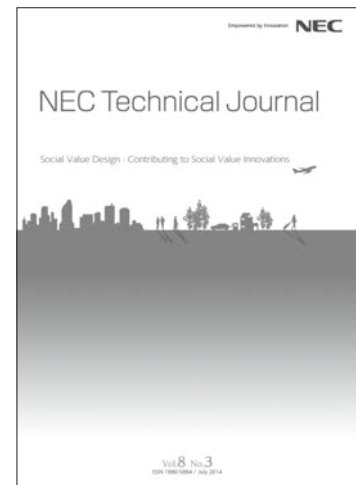
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