Research on Symbol Color of Automotive Augmented Reality Head-up Display

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Abstract. Complex environmental information and lighting conditions will affect the usability of automotive augmented reality display in the outdoor environment. In this way, users' recognition and semantic understanding of AR-HUD information may be affected. The driver's cognitive performance directly affects the driving safety and driving experience, so the color-coding of AR-HUD is very important for the driver to identify information easily, quickly, and accurately. Taken the automotive AR-HUD display as the object, this paper compared the visibility and significance of foreground object colors in different backgrounds in the way of combining both subjective and objective experiment methods. The experimental results show that the color of white, cyan, and green are recommended to be used in automotive AR-HUD display, which has a positive influence to improving the automobile AR-HUD color design.

1. Introduction
The application of AR-HUD in automobiles can be regarded as an widely-used and advanced technology [1]. The feature of AR-HUD is to use an optical combiner to combine the symbol color system with scene information. In Figure 1, it can be found that the challenge of using this technology relies on the complexity of external environment and light. The change of external conditions has great influence on the saturation and visibility of color information symbols [2]. When augmented reality technology is applied in the automotive field, manufacturers and developers must fully consider relative cognitive and identified problems that may be produced. At present, some influence factors that play an important role of enduring driving safety have been noticed in relevant research, such as information hierarchy, interface layout and other factors of AR-HUD [3]. The influence of the AR-HUD color factor is an important research direction, and related research has been carried out at home and abroad. However, the studies that aim to reduce the cognitive burden of users with user-centered color display and explore the influence of color on information transfer under different conditions are still not enough. This paper aims to explore the significance of AR-HUD symbol color under different environmental backgrounds and put forward suggestions on improving display color to guide the design of AR-HUD color coding.
2. Studies on Symbol Color of Automotive Augmented Reality Head-up Display

2.1. Research on lighting, background and color blending of AR-HUD
Gabbard et al. (2007) described the color mixing problem of AR images and typical outdoor scenarios of AR, and pointed out that the interaction between background and natural light will affect the usability of AR images. By studying AR colors and mixed colors on different real backgrounds, it is concluded that most of the perceived changes come from the great changes in chroma of each color, and when the background changes from completely dark to bright, the brightness changes refer to the perceived factor that has smaller impact, while color can be regarded as the main factor that influence the user perception [4]. Meanwhile, Gabbard et al. (2007) proposed that adaptive color AR-HUD user interface can be actively used, which can sample the real-time background information and lighting conditions behind the augment reality graphical interface. In this way, sample color of AR display can be changed in real time to ensure the consistency of color contrast ratio and visual agility [5].

2.2. Interface Color Study of Head-up Display
Moffitt et al. (2019) tested the visibility of symbols with different colors through experiments and finished the evaluation of quality and visibility of automotive HUD of different backgrounds and symbol colors under daylight conditions. It was concluded that the visibility of blue was the worst under daylight conditions, and the recognition and legibility of red were at a medium level. Moffitt et al. (2019) also proposed a test color of adding green to blue, which could improve the resistance to sunlight [6]. Peng Deyuan et al. (2018) analyzed the influence of environmental conditions on the automotive HUD. They calculated the influence degree of the foreground color under different brightness conditions in CIELUV*uv* chromaticity space by using the mixed calculation method, and concluded that green is less susceptible to background discoloration than red and blue, and the darker the environment, the less susceptible the displayed color of HUD is to background discoloration [7]. These research conclusions of HUD symbol color are consistent with our actual visual perception results.

3. Experiment Design and Discussion
The experiment simulates the visibility and quality of symbols under different illumination conditions in driving scenes to verify the performance of symbol colors in different backgrounds through experimental comparison. The experimental variables are set as the background environment and the character color.

3.1. Experimental Variables
Based on the CIE1976 chromaticity space, the experiment selected seven objected colors that widely used in AR-HUD. CIE1976, stimulated by International Commission on illumination, is a well-distributed chromaticity space that closer to the visual perception results of eyes, as shown in Figure 2 and Table 1.
Figure 2. 1976 CIE chromaticity diagram of the measured color space of a sample full-color LCD. The triangle connects the three primaries (red, green, and blue). The intermediate points between the primaries are yellow, cyan, and magenta. The point inside the triangle represents the white.

Table 1. Primary values for each of the colors.

|   | Blue | Green | Red | Yellow | Cyan | Magenta | White |
|---|------|-------|-----|--------|------|---------|-------|
| R | 0    | 0     | 255 | 255    | 0    | 255     | 255   |
| G | 0    | 255   | 0   | 255    | 255  | 0       | 255   |
| B | 255  | 0     | 0   | 0      | 255  | 255     | 255   |

The representative driving environment in urban streets is selected as background environment. The experiment stimulates the driving environment of daytime and night conditions with four images of different environmental illuminance in one day:

- a: In the morning, the ambient illumination is about 50000lx.
- b: At noon, the ambient illumination is about 100000lx.
- c: In the evening, the ambient illumination is about 10000lx.
- d: At night, the ambient illumination is about 5000lx.

In the experiment, there are 28 kinds of experimental samples, that is 4 kinds of scene pictures multiply 7 kinds of color symbol information, as shown in Figure 3.

Figure 3. Samples of test images (text and images) according to four conditions.
3.2. Experimental Environment and Materials
The experiment is written by the E-prime 2.0 program, which automatically executes the experimental pictures, demonstrates the pictures randomly and sequentially and records the experimental data. The program derives the original data and sums up the experimental data with an Excel table to analyze the data by using statistical theory.

The experiment was carried out on MacBookPro with a resolution of 2560*1660, so as to ensure that the color gamut of the LCD screen is suitable and color deviation of screen is under control. The brightness of the display screen is controlled at 130cd/m², and the ambient illumination is controlled at 5000lx.

The subjects in the experiment are 10 graduate students, 5 of them are female students, and 5 of them are male students in a university. All experimental subjects, aged between 22 and 27, have not conducted similar experiments, and their corrected vision is higher than 1.0, without color blindness and color weakness.

3.3. Experimental Process
The experiment carried out the visual performance task with subjective evaluation in line with the variable setting, and displayed the information text and image at a fixed position to the subjects. The subjects should judge whether the semantics of the text and symbols are consistent, and choose matching or different. For example, if the subjects judge the semantics of symbols and words are consistent, then they can press the keyboard "O", otherwise, press the keyboard "X". At the same time, the experiment will measure the response time of subjects, and then make the subjective evaluation. Through the short questioning survey (see Table 2), the subjects will grade the visibility and understandability of symbol colors from 1 to 7.

The images of the four scenes are displayed to the user in random order. During the experiment, it is not recommended to change the standing position of subjects. All subjects will see totally 28 images. And the experiments will record the response time of subjects’ judgement.

Table 2. Subjective survey assessing the perceptual quality of the augmented information for the four tested conditions.

| Category                  | Question                                                                 |
|---------------------------|--------------------------------------------------------------------------|
| Responses collected after each conditional treatment                |                                                                           |
| Q1: visibility            | I was able to distinguish between the foreground augmentation object from the background (1: not at all *7: very much so) |
| Q2: understandability     | I was able to quickly recognize and understand the foreground augmentation object (1: not at all *7: very much so) |

3.4. Experimental Results
Through sorting out and analyzing the experimental data, the experiment concluded the subjective evaluation and response time of different colors under four background (Figures 4 and 5). It can be seen that the grade of blue is far lower than other colors in the visibility and understandability evaluation. In this connection, blue is not recommended as the color code for displaying key information of AR-HUD. Compared with the other six colors, green and cyan have better distributed and more reliable performance quality, but cyan and green are easy to be confused. Moreover, white can be regarded as a color that is easy to recognize and understand, easy to see and read, which has best performance under all conditions. That means white can be used as the color of key information. Yellow, as a high-brightness color, will affect visibility in bright days. Red and magenta have low
grade in visibility and understandability evaluation, and are not recommended as the color of key information colors, but can be used as the color of auxiliary information.

![Visibility and Understandability Graphs](image)

**Figure 4.** Subjectively perceived quality (visibility and understandability) of subjects under four background conditions (a/b/c/d).

![Average Response Time Graph](image)

**Figure 5.** Average response time of different subject colors under four conditions.

This paper mainly studies the visibility quality of AR-HUD symbol colors under different background conditions, which has certain guiding significance for AR-HUD color design. The experiment is conducted in the laboratory, and it is difficult to accurately describe the type of background. The images of urban and natural environment in experiment has a moderate dynamic background, but it does not consider the real driving environment and the complexity of practical scenarios. The experiment has certain limitations. It is necessary to conduct further experiments to judge its reliability [8].

4. Conclusion
AR-HUD is a leading technology of the automobile display system, and it is expected to become popular shortly. When using AR-HUD, the influence of color and environmental changes on users should be considered [9]. Under different environmental conditions, it is necessary to use appropriate colors for information display. Experiment results show that white, yellow, green, and cyan have relatively stable quality performance of visibility and understandability evaluation. All these colors can be well identified and understood, and can be used as the color to display key information. Other colors can be used for auxiliary information display as needed. This paper provides a basis for the design and use of automobile AR-HUD symbol colors.

References
[1] Firth M 2019 AR in Your Car: How HUDs Are Changing Driving: virtual display technology promises to give drivers instant information, while improving driver safety Electronic Component News 63 20
[2] Sanders-Reed J, Arthur J, Harding T H, Rash C E, Lattimore M R, Statz J and Martin J S 2016 Perceptual issues for color helmet-mounted displays: luminance and color contrast requirements Degraded Visual Environments: Enhanced, Synthetic, and External Vision Solutions
[3] Gabbard J L, Fitch G M and Kim H 2014 Behind the Glass: Driver Challenges and Opportunities for AR Automotive Applications. Proceedings of the IEEE, 102(2) pp 124-136
[4] Gabbard J L, Swan J E II and Zarger A 2014 Color blending in outdoor AR: The effect of backgrounds and lighting on user interface pp 15-24
[5] Gabbard J L, Swan J E, Hix D, Kim S J, Fitch G 2007 Active text drawing styles for outdoor augmented reality: A user-based study and design implications Proc. IEEE Conf. Virtual Reality pp 35-42

[6] Moffitt K and Browne M P 2019 Visibility of color symbology in head-up and head-mounted displays in daylight environments. Optical Engineering, 58 05

[7] Peng D 2018 Analysis of Environmental Impact on Vehicle HUD Display Automobile parts pp 33-35

[8] Ahn E, Lee S and Kim G J 2017 Real-time adjustment of contrast saliency for improved information visibility in mobile augmented reality. Virtual Reality 22(3) pp 245-262.

[9] Ohtsuka S 2019 Head-up Display (HUD) Requirements Posed by Aspects of Human Visual System, IEEE International Conference on Consumer Electronics Las Vegas NV USA pp 1-4