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A Method Proposal for Evaluating Color Tolerance in Viewing Multiple White Points Focusing on the Vehicle Instrument Panels

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Abstract

Although chromatic adaptation eases us to adopt our vision to whites, viewing more than two substantially different white balances costs perceptual workload and appeals to poor quality control. This study proposed a method for evaluating the color tolerance of light modules using a uniformity analyzer focusing on the instrument panels in passenger cars, two premium line-up vehicles from Hyundai and Mercedes Benz. Using a luminance uniformity analyzer, we captured three main lighting regions in their instrument panels: clusters, steering wheel, and center console. Based on u' and v' values, we identified and compared the chromaticity coordinates of the white lighting components. The measurement-based judgment supports the manufacturer in achieving the quality objectively and consistently.

Introduction

When multiple white points are viewed within one's Field-Of-View (FOV), the differences may hinder user satisfaction. Recent researches tried to control the color of light sources in the vehicle objectively. For example, Brahme and Joshi introduced the standard of measuring and evaluating uniformity of cluster using CCD camera [1]. Faria et al. provides photometric validation guideline using images taken by digital camera with varying its aperture [2]. Both researchers pointed out that the harmony of interior lighting could increase user satisfaction. Especially the interior lighting should have uniform brightness and harmonious colors, usually white points.

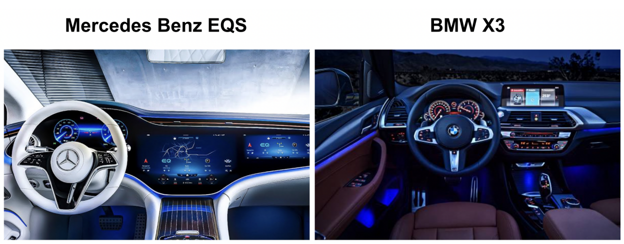

Figure 1. Interior of passenger cars launched recently which had multiple lighting modules (Left: Mercedes Benz EQS released in 2021, Right: BMW X3 released in 2021).

Recently, multiple light sources like displays, ambient lighting were adopted in the vehicle as shown in Figure 1. However, some essential buttons have remained in the vehicle interior with back-lit LEDs. Thus, drivers are exposed to multiple displays in their FOV while driving. As various vendors supplied the parts, quality control management is critical to improve user satisfaction.

Besides, previous studies focused on LED-lit components. The current evaluation mainly relies on subjective visual assessments to control the quality of multiple light sources. In this circumstance, this study proposes an objective method that quantifies the color difference of the lighting modules to support the decision-making of aesthetic judgment.

This study demonstrates the evidence-based approach to analyzing and discussing color tolerance among multiple white points, especially when viewed within one FOV. We focused on the instrumental panels in passenger cars in that various vendors supply the modules with light interfaces. Finally, we intend to describe how the measure and analysis may proceed to pursue proper tuning among various components.

Methods

Vehicle stimuli

Two premium-class cars launched on similar year were examined for the experiment, such as Hyundai Genesis EQ 900 launched in 2015 (Genesis hereinafter) and Mercedes Benz S Class launched in 2016 (Mercedes hereinafter) as shown in Figure 2.

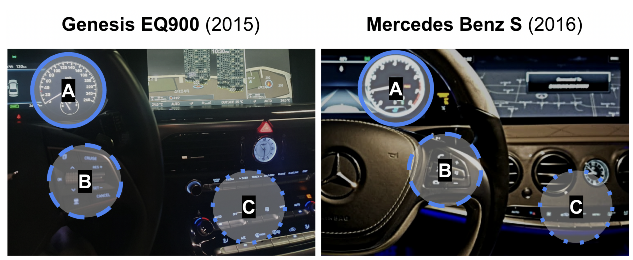

Figure 2. Luminance area in each car for examination (A: cluster, B: buttons on steering wheel, C: buttons on the center console).

We selected both vehicles as stimuli because those include multiple light sources: displays, panels, and buttons in the vehicle. The instrumental panels of both cars showed white as the base color. We selected both vehicles as stimuli because those include multiple light sources: displays, panels, and buttons in the vehicle. For Genesis, the color of panels and buttons is bluish-white, whether the color of display, panels, and buttons of Benz is white. Considering the driver's FOV, we focused on clusters (A in Figure 2), buttons on the steering wheel (B in Figure 2), and center console as the measurement targets (C in Figure 2).

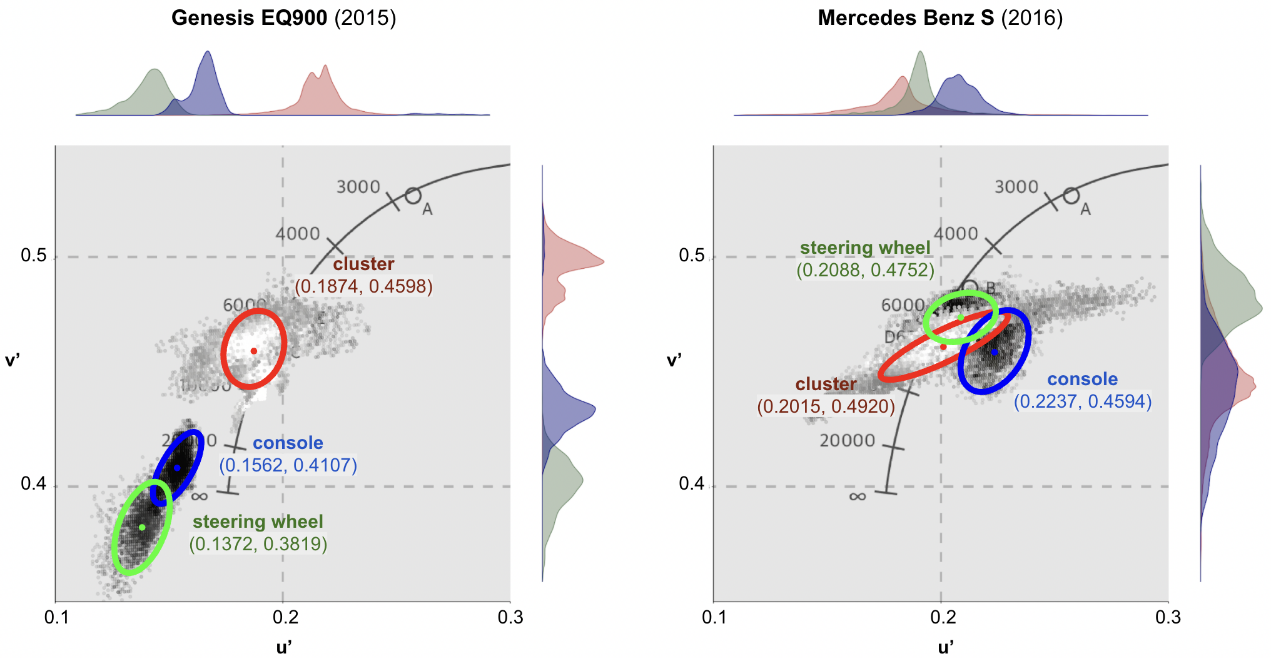

Figure 3. Clusters, buttons on the steering wheel, and buttons on the center console were plotted in CIE 1976 u'v' chromaticity diagram in mean and one-standard-deviation error ellipses (Red: cluster, Green: buttons on the center console, Blue: buttons on the steering wheel). The colorimetric value of A, B, C, D65 illuminants are also marked along with the Planckian locus.

Measurement protocol

The measurements were carried out in the dark place (under 1 lux). Using a luminance uniformity analyzer (Topcon UA-10SL, Japan), we measured the target surfaces horizontally from a 30cm distance. All data were collected through UA-10 SDK, and data were transferred into .csv format to filter and further analysis as shown in Figure 4.

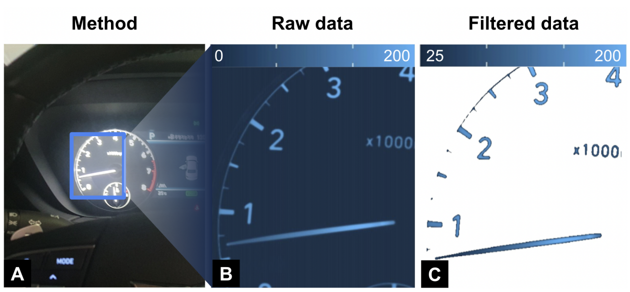

Figure 4. Overview of data filtering process for display white point calculation (A: Measuring method, B: Raw, C: Remove colored data and remove the data under max illuminance × .3)

Previous works and standards were analyzed through CIExyY color space. However, for considering users' color perception, we plan to analyze data through CIELUV 1976 color spaces. So, we converted the uniformity analyzer chromaticity data, which provided in CIExyY color space initially, to CIELUV 1976 values. To focus on the white points of the luminous targets, we took achromatic and bright (30% of max luminance or higher) regions into consideration. First, select white area as target white color, and remove colored area that u' v' color difference from target point is higher than .1. Then, remove the L data under max illuminance $\times$ 0.3 to prepare the data for analyze.

Results

Measured area were plotted in the CIE 1976 u 'v' chromaticity, as shown in the Figure 3. For comparing the white point of each stimuli, we calculated mean value of all color points and calculated delta u'v'. In the case of Genesis, the cluster (red ellipse) is found on the Planckian locus, while the steering wheel (green ellipse) and console (blue ellipse) are located apart. On the contrary, the three ellipses of Mercedes are located close to each other. The distance exceeds the just noticeable difference (JND), indicating that drivers are exposed to noticeably different white points within one FOV. To be specific, the Euclidean distance among the central white points of Genesis and Mercedes are 0.0345 and 0.0217, respectively.

Table 1: Color difference of measured area.

	Genesis	Benz
Cluster - Steering Wheel	0.093	0.015
Cluster - Console	0.058	0.022
Steering wheel - Console	0.034	0.022

For analyzing uniformity of illuminant area, we draw one-standard-deviation error ellipses for each measured area. Three area had different light sources (Cluster: display, Console: panel, Steering wheel: LED), all three measurement areas showed similar uniformity.

Discussion

This study presents a simple method to objectively report visual discomfort caused by the mismatched white points, especially when an alignment is anticipated. We focused on the instrumental panel in two passenger cars in their premium lineup and captured the luminous buttons and interfaces using a luminance & chroma analyzer. This study tried to collect objective data through which color management becomes evident.

We confirm that our method can be proposed in an improved way to provide quantitative evaluation guidelines for lighting in automobiles. First, we confirmed that the quantitative evaluation method for LED-lit displays suggested from previous studies can be applied to various light sources such as displays. Next, we suggested that color uniformity and difference calculation be based on the CIELUV color space. The existing color uniformity and color difference calculation were centered on CIExyY color space, which could miss users' color cognition. We expected the result of this research provides to evaluate more diverse light sources and draw user-centered objective evaluation guidelines.

In both vehicle light sources, color uniformity was confirmed to be well-produced without any inconvenience to users. However, it was confirmed that the white point of Genesis showed a higher color difference than Benz. As the price of Benz on the market is more than twice as high as the generation, so we confirm that the much more detailed part is well controlled. According to Korean industry regulations, car manufacturers are obliged to assemble the parts supplied by multiple vendors towards "fair trade." Consequently, quality control across the vendors is always a challenge. Based on the chromatic uniformity data, discussions and improvements are followed, and the challenges become explicit.

We also admire the limitations of this study. As shown in Figure 1, the ambient lights are also installed in the vehicle. Therefore, it is necessary to present the evaluation guide for controlling the quality of ambient light. As this study has expanded the evaluation application to the LED-lit environment to the display, it will be possible to provide the quality evaluation guide of ambient light if the method is expanded to the quantitative guide considering the characteristics of the ambient light. In addition, this study focuses on the white point of the vehicle interior lighting. However, recently, vehicle components such as ambient light have amplified the style by combining various colors. Therefore, it will be a better study to expand the multi-color combination guide by applying this study.

Conclusion

Although chromatic adaptation eases us to adopt our vision to whites, viewing more than two substantially different white balances costs perceptual workload and appeals to poor quality control. This study proposed a method for evaluating the color tolerance of light modules using a uniformity analyzer focusing on the instrument panels in passenger cars, two premium line-up vehicles from Hyundai and Mercedes Benz. Using a luminance uniformity analyzer, we captured three main lighting regions in their instrument panels: clusters, steering wheel, and center console. Based on u' and v' values, we identified and compared the chromaticity coordinates of the white lighting components. The measurement-based judgment supports the manufacturer in achieving the quality objectively and consistently.

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Author Biography

Taesu Kim received the B.S. degree from the Department of Industrial Design, KAIST, in 2018, where he currently pursuing his Ph.D. degree. He conducted design researches which assist the ambient lighting design process in the vehicle context. His research interests include affective engineering and lighting design.

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