A Color Scenario of Eco & Healthy Driving for the RGB LED *Based Interface Display of a Climate Control Device*

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***Abstract*-- The study demonstrates a process of synergizing both exploratory and confirmatory research approaches to design the color for a luminescent surface facilitated by RGB LEDs. Focusing on the relationship between color and in-door climate of automobiles, the study consists of three parts: In Part I, a workshop of ten designers was executed in which ideas were exploited to find in-car scenarios. The scenarios were evaluated based on the criteria of interesting, informative, and inspiring aspects to conclusively derive the scenario labeled "Eco & Healthy Driving"; In Part II, a user test was carried out to investigate the relationship between the attributes of luminescent color—hue, brightness, and purity- and an indoor climate condition. In the user test (n= 36), subjects were instructed to match a luminescent color to a given in-car climate condition. The user test results revealed that hue category of luminescent surface is related to temperature while brightness of luminescent color is correlated with blow level; Lastly, in Part III, by employing the results of user test, a guideline for implementing the new design scenario, "Eco & Healthy Driving" was projected for further development and application.**

I. INTRODUCTION

Researches on in-car interface take into account the ergonomic factors related to the drivers' recognition and reaction times. It is generally accepted that, unlike home appliances, the degree of complication of information displayed through the in-car interface exceeds the recognition load manageable by drivers and has a direct relationship with safety [1]. Lighting and color can be used to generate new methods of intuitively displaying information to drivers. [2] proposed that for cars that experience frequent emergency situations, using LED light on in-car interfaces can be an efficient method to induce coping. Moreover, [3] suggested that when LED is used in various different in-car interface displays, drivers should be provided with the potential to customize a range of functions from a standard list so as to best suit their environment. This provides supporting evidence for the possibility to efficiently provide users with intuitive information by implementing LED based indoor lightings and interface design. However, there is a need to further pursue research that determines how accurate the intuitive information provided through LED interface displays are communicated to the users. Therefore, by establishing a distinct relationship between certain color identities and methods of intuitive information expression, valuable knowledge for in-car interface design can be provided. This study focuses on designing the background color of interface display on in-car climate control devices (CCD here in and after) to ultimately increase user satisfaction and to increase the competitiveness of interface displays as a product of car design.

This study has been supported by the following programs: 1) "Convergent Design University Program" (H1101-12-1001); 2) "User-Centered LED Lighting System Development Enabling Daylight Spectrum for Educational/Residential Facilities" (IT R&D program of KEIT). Both funded by Ministry of Knowledge Economy.

II. LUMINESCENT COLOR SURFACE AS PRODUCT COLOR

The color of products does not only concern light reflected off of object surfaces, but also highlights direct light, especially when the direct light is observed by users. As such, the display color of interface design should be recognized as an element of product design. Accordingly, using symbolic and emotional features of color to design product interfaces is a general process followed by designers. By using the meaning of color derived from previous research, it is possible to interpret the meaning of colorful light created by RGB LEDs. [4] asserted that current status information about a product can be intuitively recognized by observing the color properties of the products' status lights. The study showed that contents of information that users intuitively associate with the color of RGB LED status lights are similar to those associated with actual object color. Based on the results, perceiving the color of luminescent surface can be seen as a phenomenon comparable to perceiving the color of object.

III. OBJECTIVE

The study is comprised of three parts and three goals were set respectively: First, Part I explores the intuitive information expressed in interface displays of CCDs to set a color design strategy; Part II conducts a user test to identify the scenario of color contents for surface lights that would provide reliability at a satisfactory level for the implementation of color design strategy. Lastly, by using the empirical results of the previous goals, Part III involves arranging a proposal on a complete surface light design that can be built into in-car CCD interface displays.

IV. PART I: FINDING THE SCENARIO OF COLOR OF INTERFACE DISPLAY

A. Objective

A color implemented in interface displays should serve not only functional needs but also emotional needs. Part I attempts to exploit and find a scenario of color presentation on the interface display by conducting a workshop aimed at pinpointing a color that can most intuitively be applied to a certain scenario.

B. Method

To generate color scenarios for the display of CCD, firstly, various instances detectable by CCD from inside and outside the car were collected: e.g. value of solar radiation, in-car temperature, discharge temperature, blow level, and outside temperature. The ergonomics standard data proposes the desirable temperature ranges for users depending on the type of building or space: For an indoor context with the occurrence of cognitive activities (e.g. office, auditorium, classroom, etc.) 24.5 °C ± 1.0°C is recommended for summer and 22.0°C ± 1.0°C for winter [5]. Based on the market research of domestic automobile industry in Korea, 23 °C is adopted by all Korean car manufacturers as the target in-car temperature for pleasant driving. In addition, the temperature range that a CCD can vary independently from the outside temperature is between 4 °C and 45 °C. Secondly, color attributes of interface display emitted by RGB LED were identified through the three characteristics, dominant wavelength (nm), luminance (cd/m2 or nit), and purity (%). Therefore, technically, the color scenarios can be seen as a combination between temperature-related measurements and color attributes.

During the workshop participants were instructed to investigate the potential of color presentation for the different scenarios as shown in Table 1 below. Five males and five females, for a total of 10 graduate students majoring in design were recruited to take part in the workshop. (M of age = 24.50, SD = 1.75).

C. Results

Participants were first asked to generate various matching combinations of input measurements and output colors, and then to extract five combinations that exhibited an intuitive correlation (Table 1). Each scenario was then evaluated from the user's perspective. The evaluation criteria were weighed from the users' initial thoughts on 1) "how interesting is it?" referring to whether the color emitted by the interface display helps derive an intuitive interest to its users; 2) "how informational is it?" referring to whether a scenario can actually deliver a sense of comfort in a real driving situation; 3) "how inspiring is it?" asking whether a scenario has the potential for prolonged satisfaction as oppose to temporary satisfaction that is acquired during the first encounter with the product. Scenario E was concluded by the 10 designer participants as the scenario that best satisfied all three criteria points.

Scenario E does not only take into account the excessive fuel used during winter, but also implicates health factors. Thus, Scenario E was distinguished from the other scenarios with the label "Eco & Healthy Driving" [2].

TABLE I

THE FIVE SCENARIOS GENERATED IN PART I

Scenario	The measurements that climate control device(CCD) reads	Color presentation
A	Value of solar radiation	Dynamically animated pure colors when starting a car in daytime/ Dynamically animated impure colors when starting a car at night
B	In-car temperature	Cool colors below 23 °C, Warm colors above 23 °C
C	Discharge temperature and Blow level	Change of dominant wavelength for discharge temperature, Increase of intensity[a] in proportion to blow level
D	Temperature difference between inside and outside of a car, Blow level	Increase of purity in proportion to increase of temperature difference, Increase of intensity in proportion to blow level
E	In-car temperature: above, below, or around 23 °C, Blow level	Cool colors below 23 °C, Warm colors above 23 °C, Another color around 23 °C, Increase of intensity in proportion to blow level

[a]Refers to the combination of lumination and purity, similar to the concept of how luminescent light from object color is expressed as a combination of value and chroma.

V. PART II: USER TEST TO MATCH DISPLAY COLOR AND IN-CAR CLIMATE CONDITION

A. Objective

A User Test was carried out to investigate the relationship between the attributes of color displayed in the interface of CCD and the perceived quality of the in-car climate condition. As participants were searching for the appropriate display color while directly experiencing the in-car climate, the effects that the display colors would have in actual circumstances and similar environment were also tested.

B. Method

Sixteen male and 20 female graduate students of different majors were recruited for a total of 36 participants. The average age of the subject population was 22.33 with a standard deviation of 2.95 years.

1) Collection of 45 color stimuli

In order to create a collection of display colors for the user test evaluation process, the aspects of hue category, luminance and purity were considered as follows. With reference to CIE 1976 Chromaticity Diagram, ten variations of hue categories — red, orange, yellow, yellowish green, green, greenish blue, blue, bluish purple, purple, and purplish red – were selected. The shaded region in Fig. 1 represents the color gamut emitted by the RGB LED of the CCD. Luminance is related to the intensity of a lighting surface and is measured by the unit of

[2] The concept of Scenario E is concerned with how the messages "it is hot" and "it is cold" can be transmitted to users, depending on whether the in-car temperature is higher or lower than the overall domain temperature of 23 °C, a temperature that Koreans find most pleasant. For instance, during the summer when the in-car temperature is higher than 23 °C, CCDs can make the interpretation that users will feel more comfortable with the air-conditioner turned on, whereas in the winter, it might communicate the information that turning the heater is unnecessary.

Candela per square meter (cd/m2), or "nit". However, since this study is more concerned with visual perception rather than physical properties, brightness was used to replace luminance. Brightness, as one of photometric term, refers to the perceptual quantity of the luminious strength of luminance [6]. This brightness of luminescent surfaces was divided into two levels; strong and weak. The strong level was the greatest level of luminescence that the RGB LED could generate, and the weak level was the half level of luminescence. Purity, which indicates the vividness of luminescent surface, was also taken into consideration. As a color is closer to the boarder line (i.e. purity 100%), it becomes more vivid. Oppositely, the closer it is to the white point (x= 0.330, y= 0.330; i.e. purity 0%), the less vivid a color becomes. In this way, each hue category had four variations: two levels of brightness and two levels of purity, to initially make up 40 chromatic color stimuli respectively. Because the Chromaticity Diagram does not show the Z-axis that corresponds to luminescence level, two dots seem to overlap at one point in Fig. 1.

Next, four whites with four brightness levels were added to the color stimuli, and finally, a dark olive was included to represent the power of the interface display when it was not connected to power. Therefore, a total of 45 color stimuli made up of 40 chromatic and five achromatic stimuli were collected for the user study.

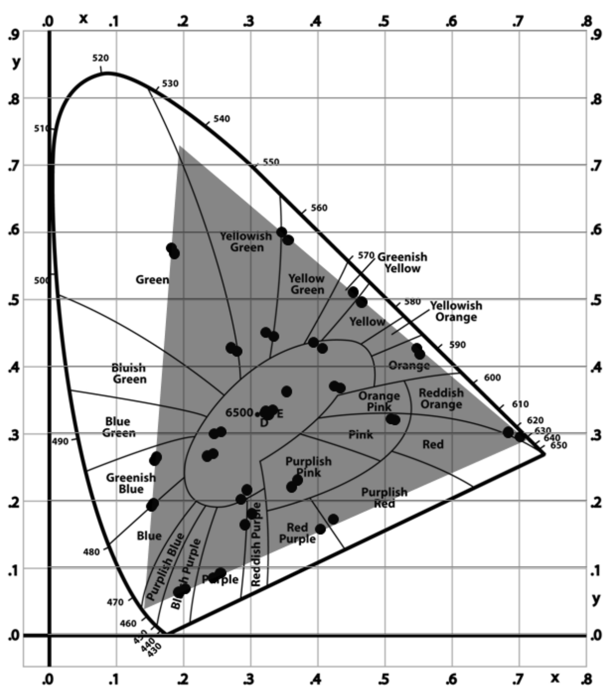

Fig. 1. The 45 color stimuli plotted in CIE Chromaticity Diagram: the shaded area is the color gamut of RGB LED of the climate control device.

In order to present the 45 color stimuli on the interface display, the appropriate R, G, and B input values had to be manually identified. While changing the values of each RGB channel from 0 to 255, a database was constructed to keep record of the x-y coordinates and luminance value of the background color. A Light Meter CS-100A of Minolta was facilitated to take the measurements. By this way, it was possible to determine the RGB input values that would render the desired 45 target color stimuli.

2) Twelve types of in-car climate

The CCD used in the user study had eight different stages of blow level with the temperature range of 5 °C to 40 °C. Four out of the eight different blow levels and three in-car temperature situations (the standard of 23 °C that Koreans find most pleasant, 30°C for the heating condition and 10 °C for the cooling condition) were implemented. Each temperature level allowed the participants to experience four blow levels, and hence, a total of 12 different in-car climate situations were prepared. Each participant was exposed to the twelve in-car climate types in random order, and were asked to find the interface display color that best expressed the given in-car climate type. Because the CCD used in the experiment was a product that was mounted on the H Motor "i30" model, the user test was also conducted in the i30 model car.

3) Matching the in-car climate with display color

In order to make it intuitive for the participants to find the interface display color based on the given in-car climate, a color palette that allows the participants to see all the 45 color stimuli at one glance was composed. Most similar colors to the 45 different types of color stimuli implemented on the CCD interface displays were formed on the laptop screen[3], and a color palette consisting of the 45 display colors was composed respectively.

The participants firstly selected one interface display color from the palette, which they felt most intuitively expressed the given experimental in-car climate condition that they experienced. Afterward, the experimenters took the colors that were most frequently selected, implemented those colors into a real CCD, and qualitatively recorded the opinions of the participants on these CCD interfaces.

C. Results and analysis of User Test

In the User Test, participants were instructed to only match one most appropriate interface display color to each of the twelve different in-car climate conditions. After having 36 participants match a color to each of the conditions, a total of 432 responses (36 selections for each of the twelve conditions) were collected. Some colors were selected several times while some were not selected at all. For example, Weak & Pale Purple was not selected by any of the 36 participants to represent any of the 12 in-car climate conditions. This indicates that Weak & Pale Purple is a color easily associated with typical in-car climate. In this way, based on the frequency of selection, the hue categories, yellow green, green, blue purple, purple, or purple red, should have lower priorities when designing the color scenario of interface display.

[3] The laptop computer used during the User Test was the Samsung Sense Mini-Notebook N310 model and had a 10.1 inch screen with a LED Back Light Unit..

TABLE II
THE FREQUENTLY SELECTED COLOR STIMULI (6 TIMES OR ABOVE) OF INTERFACE DISPLAY FOR EACH OF TWELVE TYPES OF IN-CAR CLIMATE

In-car temperature (°C)	Blow level			
	Low	Medium low	Medium high	High
Cold	Weak & Pale Greenish blue (11)[a], Strong & Pale Greenish blue (7)	Weak & Vivid Greenish blue (7)	None (None above 6)	Strong & Vivid Blue (10), Weak & Vivid Blue (7), Strong & Vivid Greenish blue (7)
Mild	Bright White (7)	Weak & Pale Yellow (7)	None (None above 6)	None (None above 6)
Warm	Strong & Pale Red (8), Weak & Pale Red (8)	Weak & Vivid Red (10)	Weak & Vivid Red (9)	Strong & Vivid Red (14), Weak & Vivid Red (8)

[a] Numbers in parentheses are the frequency

VI. PART III: IMPLEMENTATIN OF "ECO & HEALTHY DRIVING"

To implement the concept of Eco & Healthy Driving, the interface display colors from the results of Part II and the following aspects were taken into considerations: 1) First, similar to what was identified in Part II, the correlation between blue or greenish blue with cold in-car temperature and red with hot in-car temperature can be recalled intuitively. However, using greenish blue rather than blue was more desirable to represent cold temperature as greenish blue provided a greater contrast between the background color and the text and icons expressed on the interface display of a CCD, thereby improving legibility. Also, users dominantly preferred greenish blue especially for low blow level conditions; 2) Second, following what was derived from Part II, there was difficult to find a strong association between a mild 23 °C in-care temperature and hue category. Nevertheless, the association between weak & pale yellow and white and mild in-car temperature tended to exhibit a relatively more strong appeal. Among the two colors, as much as weak & pale yellow can be interpreted as yellowish white, white was selected as the main hue category to represent mild in-car temperature; 3) Third, the stronger the strength of the blow, the more vivid the chroma of the interface display color becomes, given the white hue category remains fixed.

Accordingly, to make it possible for the engineer to implement the design solution, a complete guideline with information regarding color and temperature was completed as shown in Fig. 2.

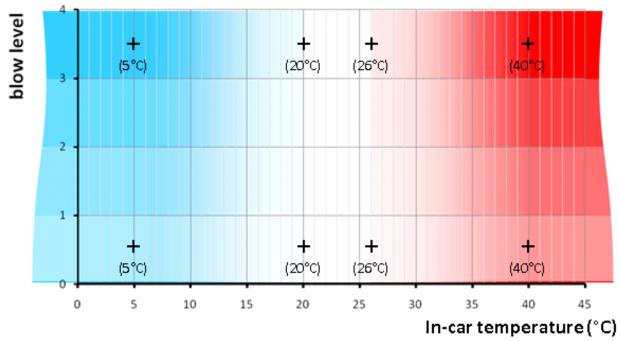

Fig. 2. The color scenario of "Eco & Healthy Driving".

VII. CONCLUSION

The challenge for designers is to find the parallel balance between diverging thinking for acquiring creative ideas and convergent thinking for finding scientific evidence. Part I of this experiment focuses on the divergent way of thinking for exploring the potential of in-car CCD to express relevant information to its users, whereas Part II focuses on the convergent way of thinking for implementing one of the potential ideas resulting from Part I and deriving reliable data. In Part II's case, it is possible to extract a clear research topic focused on color and climate perception that can be packaged as a research in the field of cognitive science. Yet there are limitations when trying to incorporate certain experiment designs and analysis methods for better experimental results into design practice. Therefore, results of Part II were directly used as resources for implementing ideas derived from Part I into Part III. It is only when the designers are able to foster their competence to persuasively implement creative ideas on their own that the creativity of the designers' ideas can be firmly recognized by others.

Furthermore, to support the new domain of design practice anchored to new technologies and LED as a new opportunity in design, designers must develop an intellectual curiosity for other academic fields. In all, the use of lighting surface as a new competitive factor in product design is greatly anticipated.

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