◈ Application Paper

Human Sensibility Ergonomics Investigation of Car Navigation System Digital Map Color Structure

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Abstract

Two experiments were conducted to examine the relationships between the color structure and the user preference of a CNS (Car Navigation System) digital map in terms of HSE (Human Sensibility Ergonomics). In the first experiment, the user's preference of color structures were investigated from the subjects' self-designed digital maps using a CNS digital map UIMS (User Interface Management System); in the second, statistical relation models between the user's color structure satisfaction level and the color components of *CIE (Commission Internationale de l'Eclairage)* of the real products were suggested. For each experiment, CIE L*u*v* and CIE LCH color space were adapted, respectively, because they have their own characteristics of perceptual uniformity which enables the color components to transform a linear function.

1. Introduction

Color structure of the CNS digital map is the most importantly regarded HMI (Human-Machine Interface) design object by the result of HSE evaluation among graphic dimension, landmarks, map scale, typography [2]. It means that the users want the human-centered digital map color structure that coincides with the individual preferences and the color perceptual abilities for more efficient and rapid perception of spatial and text information. Accordingly, main HMI objects of the various in-vehicle display (e.g., color structure, typography, information arrangement, icon, graphic dimension and so others) have been widely investigated to suggest the human-centered display design guidelines for the improvement of driver's safety by supplying the rapid and accurate information acquisition display format. Recently, the importance and the interests of this kind human factors study has been increased by the progress of ITS (Intelligent Transport Systems)-oriented in-vehicle information systems (e.g., head-up display, flat panel display of Advanced Highway System, CNS, including conventional instrumental panel).

Among various HMI objects, investigation of color structure is more difficult than others, because of its various degree of freedoms [13], difficulty of quantification and sensibility modeling of its components [2], and existing many considerable color systems. Various reports have been published about the map color selection guidelines and recommendations, which were generally based on RGB and Munsell color systems [5][12][17]. These kinds of color systems are very convenient to apply and evaluate the target system, however, they cannot represent and reproduce all existing human

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perceivable colors. Also, their results and suggested guidelines are not suitable for applying to the CNS color structure design, because they were developed for the paper map color structure of which HMI characteristics are different from LCD display. Therefore, the interests of CIE color spaces have been increased to investigate the human color perception in graphics areas, because they have been developed on the basis of human color perception appearance so that they have the characteristics of perceptual linearity and uniformity of human color perception that distinguishable from other color systems.

This study investigated the user's requirements of color structure and perceptual characteristics of the CNS digital map that focused on background and main road color using digital map UIMS and eight digitized real products. In this process, CIE L*u*v* and LCH color space were used as the color components measurement system for color quantification and human sensibility analysis. Also, this study reviewed the characteristics of existing color systems that have been developed for computer graphics applications.

2. Theoretical Frameworks

2.1 Reviews of Existing Color Systems and CIE L*u*v* Color Space

Many different color systems are existing in computer graphics area, and each model uses its own 3D coordinate system to identify the uniquely individual colors. Some models (e.g. CIE XYZ, CIE L*u*v*) are capable of representing all colors from the visible color domain, however, other models (e.g. RGB, HSV) are restricted to a subset of this domain. Also, certain models (e.g. CIE *L*u*v**, CIE Lab, Munsell) have been designed to try to provide other useful properties like isoluminance and control over perceived color difference [18]. Among them, Munsell and CIE systems were developed that based on the psychophysical measurements of human beings.

One of the most commonly used color systems is the RGB, that is the combination of R(Red), G (Green), and B(Blue). The color matching curves $r(\lambda)$, $g(\lambda)$, and $b(\lambda)$ define the amount of R, G, and B needed to match a color with a dominant wavelength of λ. An important point is that the red curve $r(\lambda)$ is negative from 438nm to 546nm. Color from this region of the visible frequency domain cannot be produced through a positive combination of R, G, and B. CIE addressed this problem of negative weights in the RGB color model in 1931. They defined three new primaries called X, Y, and Z to replace R, G, and B during color matching. Color matching curves $x(\lambda)$, $y(\lambda)$, and $z(\lambda)$ *define the amount of X, Y, and Z needed to match a color with a dominant* wavelength of λ. These curves were designed to be linear combinations of $r(\lambda)$, $g(\lambda)$, and $b(\lambda)$. None of $x(\lambda)$, $y(\lambda)$, and $z(\lambda)$ are negative in the range 380nm to 780nm, which means any visible color can be produced by a positive combination of X, Y, and Z. However, XYZ and RGB systems are far from exhibiting perceptual uniformity and are not exactly the unitary hues that are considered important in color appearance [6].

A system is perceptually uniform if a small perturbation to a component value is approximately equally perceptible across the range of that value. For example, the volume control on the radio is designed to be perceptually uniform; rotating the knob ten degrees produces approximately the same perceptual increment in volume anywhere across the range of the control. In 1976, CIE proposed the CIE color model to address this problem. CIE L*u*v* is a perceptually uniform of human eye perception and 3D color space incorporating both the UCS (Uniform Color Space) and lightness parameter. This system includes both saturation and chroma in the same color space and the u* and v* axes point at red, yellow, green and blue. Figure 1 shows CIE L*u*v* color space [7]. In this picture, L* is the nonlinear formula of lightness, which corresponds more closely to the perceived sensation. The medium 50% gray occurs at L*=50 [16]. And, u* and v* values correspond

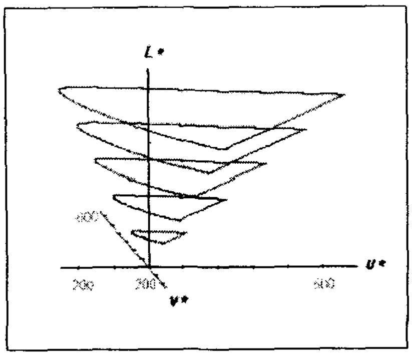

Figure 1. CIE L*u*v* color space

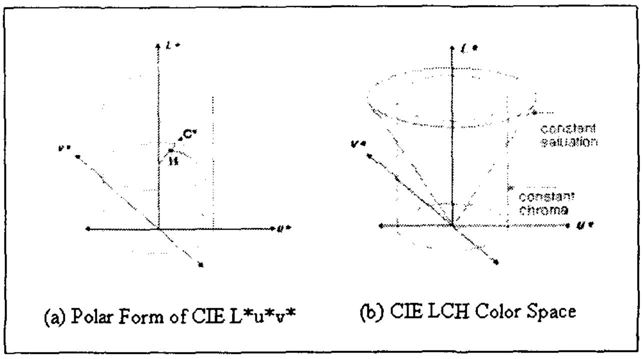

Figure 2. Polar Form of CIE L*u*v* and LCH Color Space

to translating the origin of the UCS diagram to the white point and scaling the relative chromaticity co-ordinates by the lightness so that the geometrical distance between two colors is reduced as they are made darker. This takes account of the fact that dark colors look more alike than light ones, even when the chromaticities are the same [14]. If a luminance is divided by some reference white, a relative luminance scale from 0 to 100% (black to white) is obtained. Measured luminance, however, does not correspond well to perceived lightness; the scale looks markedly nonuniform, with all the dark colors bunched up at one end. This system improves the 80:1 or so perceptual nonuniformity of XYZ to about 6:1 [16].

CIE LCH color space is the alternative polar form of CIE L*u*v* color space. As shown in Figure 2 (a), as the spectral colors form a loop around the origin, it is possible to define a hue angle h_{uv}, which specifies hue with a single numerical value. The positive u* axis is defined to be 0 and hue angles are measured anticlockwise. An advantage of this hue angle is that hue is readily understood concept. And then, the distance from the achromatic L* axis may then be used as a measure of chroma, or colorfulness. This is easier to use for mixing colors than CIE L*u*v*. The L* component has the rage of [-0, 100], the u* component has the range of [-134, 220], and the v* component has the range [-140, 122] [15]. Figure 2 (b) shows planes of constant chroma and constant saturation in CIE LCH space. Chroma is clearly seen as independent of lightness [14].

2.2 Transformation Process and Application of CIE Color Space

Color researchers have often made an implicit assumption that perceptual color space has a metric. This is one of the foundation blocks upon which all colormetry is based. The three formal conditions for a metric space can be reformulated as the following assumptions for the existence of a perceptual color metric space [1].

(1) If there is no noticeable difference between two stimuli, they occupy the same point in perceptual color space.
(2) The difference between color A and B is the same as the difference between color B and A.
(3) The difference between color A and color C is less than or equal to the difference between color A and B plus the difference between color B and C (triangle inequality).

These three assumptions seem reasonable enough, although the triangle inequality requires empirical evidence. Indow's experiment [9] shows that the subjects showed subadditivity in judging color differences, that is $\rho_Y(y_0, y_2) < \rho_Y(y_0, y_1) + \rho_Y(y_1, y_2)$ even when y_o , y_1 and y_2 are adjusted so as to try to approach collinearity. This evidence would tend to support the existence of the triangle inequality in the perceptual color space [6].

A stronger form of metric space is an Euclidean metric space. This has been efforts to create a representation of perceptual color space such that its conforms to a local Euclidean metric [19], a so-called UCS. However, fully Euclidean representation of perceptual color space has yet eluded researchers. Also, perceptual color space is implicitly assumed that the mapping the probability distributions of energy quanta of photons onto perceptual color space is continuous. This means that distance and difference can be interchanged as required. If colors A and B are twice as far apart as color C and D, then perceived difference between A and B is roughly twice the perceived difference between C and D. CIE L*u*v* provides a metric ΔE^*, that is perceptually equal like equation (1).

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta u^*)^2 + (\Delta v^*)^2} \quad (1)$$

To apply Euclidean metric for HSE approach for CNS digital map, color transformation process is required from initially obtained R, G, B values to L*, u*, v* and CIE LCH space components of h_{uv}, $C*_{uv}$, S* as following equations [14][16].

Step 1] Convert *RGB* (Rec.709 with D65) to *XYZ*

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.412453 & 0.357580 & 0.180423 \\ 0.212671 & 0.715160 & 0.072169 \\ 0.019334 & 0.119193 & 0.950227 \end{bmatrix} \cdot \begin{bmatrix} R \\ G \\ B \end{bmatrix} \quad (2)$$

Step 2] Convert *XYZ* to *xyz* (x+y+z=1)

$$x = \frac{X}{X+Y+Z}, \quad y = \frac{Y}{X+Y+Z}, \quad z = 1-(x+y) \quad (3)(4)(5)$$

Step 3] Convert *xyz* to $Y_{u'v'}$ or *XYZ* to $Y_{u'v'}$

$Y=Y$ ($Y=0.2125R + 0.7154G + 0.07215B$)

if $x+y+z=0$ then $u'=v'=0$ (6)

else, $u' = \frac{4x}{-2x+12y+3} = \frac{4X}{X+15Y+3Z}$, $v' = \frac{9y}{-2x+12y+3} = \frac{9Y}{X+15Y+3Z}$ (7)(8)

Step 4-1] Convert $Y_{u'v'}$ to *L*u*v**

$L^*=116(Y/Y_w)^{1/3}-16$ for most values of Y ($Y/Y_w>0.008856$) or (9)

$L^*=903.3(Y/Y_w)$ for very dark colors ($Y/Y_w \leq 0.008856$)

(Y_w, u_w, v_w = values of reference white point of D_{65})

$u^*=13L^*(u'-u_w)$, $v^*=13L^*(v'-v_w)$ (10)(11)

Step 4-2] Convert *L*u*v to *LCH***

$h_{uv}=\arctan(v^*/u^*)$, $C^*_{uv}=(u^{*2}+v^{*2})^{1/2}$, $S^*=C^*/L^*$ (12)(13)(14)

ITU R709 (Recommendation 709) of primary RGB values and D_{65} (x_n=0.312713, y_n=0.329016, z_n=0.358271) reference white point were adapted among various standards for above process, for example, NTSC (National Television Systems Committee), SMPTE (Society of Motion Picture and Television Engineers), EBU (European Broadcasting Union), each x, y values are described in Table 1. Because R709 is the internationally agreed HDTV (High Definition Television) standard, and its primaries are closely representative of contemporary monitors in studio video, computing and computer graphics [10].

3. Experimental Design and Evaluation Methods

The participants consisted of 20 graduate students (14 males whose average age was 27.3 and

Table 1. Various Primary RGB Standards

	NTSC		SMPTE		EBU		ITU-R709	
	x	y	x	y	x	y	x	y
R	0.670	0.330	0.630	0.340	0.640	0.330	0.640	0.330
G	0.210	0.710	0.310	0.595	0.290	0.060	0.300	0.600
B	0.140	0.080	0.155	0.070	0.150	0.060	0.150	0.060

Table 2. Classification of Color-Related Digital Map HMI Objects

Definition	Function
Background	This is an important area where the most digital map HMI objects are visualized. Then, verbal, graphical and spatial information is presented by visual contrast (hue, lightness, saturation) for more easy and rapid information acquisition.
Main road (road level 1)	This represents the street or highway for vehicles, as the part of large road network. This is the kernel object of route guidance function of CNS, and recommended route is generally presented on this road level.
Road level 2	This represents the road or street for vehicles lower level than main road. This is an important object, but its importance depends on the driving area and map scale.
Road level 3	This represents the road or street in a small road network, residential distinct, or spatial and administrative boundaries. This is an important object, but its importance depends on the driving area and map scale.
Recommended route	This is the optimal recommended route for driving that is represented mainly on the road level 1. Driver is generally driving depends on this line.
Verbal information	Names and descriptions of specific locations or buildings.
Landmark	Graphical symbols for specific locations or buildings. This generally represented with the verbal information.
Etc.	Mountain, river, lake, and so other natural environments

s.d. was 0.73, and 6 females whose age average was 22.76 and s.d. was 0.54) who had no eye diseases and color blindness for two experiments.

3.1 Experiment 1 : Investigation of Subject's Color Structure Preferences of a CNS Digital Map

UIMS is the most convenient and useful tool to collect the user's requirements of the CNS digital map HMI objects [2]. Because the UIMS mediates the interface between the end user of an application and the application code itself. This results in a separation of the responsibility between UIMS and application, with the application being responsible for carrying out the work while the UIMS handles all details of communication with the end user [11].

To collect the actual user's requirements of the digital map color structure, Navi-HEGS (Navigation system Human factors & Guideline System) was used [3]. This system consisted of a CNS simulator, a digital map UIMS, a human factors evaluation system and a design guideline database for the human factors research of CNS. Table 2 describes the color-related HMI objects of the digital map and their functions. Among them, background and main road color were considered for this study, because background and main road colors are the most important objects that affect on the driver's information visibility and they determine the color structure and configurations of other HMI objects. In the evaluation process, subjects were required to design the digital map HMI objects, as they wanted without time constraints in a daylight situation.

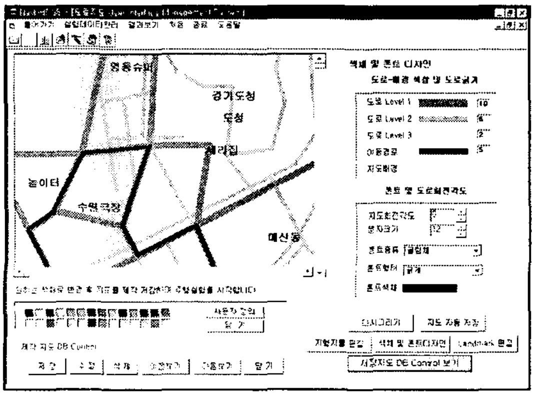

Figure 3. User Interface of Navi-HEGS UIMS

Navi-HEGS was implemented on the portable computer for more similar environment of a CNS LCD display under 800X600 resolution on 5-inch map display. Navi-HEGS supplies easy and simple user interfaces like Figure 3, and supports all Windows system supplied and user-defined colors.

Then, the subject's self-designed digital maps were collected as the basic data to investigate the perceptual characteristics of color structure between the background and the main road. Firstly, R, G, B values were acquired through Adobe^{TM} Photoshop, and then, these values were transformed to L*,u*,v* and h_{uv}, $C*_{uv}$, S* of CIE LCH components using transformation process described in section 2.2.

3.2 Experiment 2 : HSE Approach for Color Preference Modeling

11 adjectives that relevant to the sensibility of the CNS digital map color were finally selected through two phase of screening works from Cha *et al*'s previous study [2]. Initially, about an hundred of adjectives were collected from dictionary, catalogs, car and CNS magazines, and previous researches. Among collected adjectives, firstly, similar and opposite words were removed by the questionnaire from the human factors and CNS expert, then, 29 adjectives were selected. Secondly, fuzzy set theory based method was adapted that had been developed to improve the adjectives collection efficiency using 3 point scales and relationship chart. This method has following characteristics than other sensibility adjective screening methods [2][15].

(1) Enables to collect and analyze the detail sensibility using 3 bipolar point scale (certain, moderate, uncertain).
(2) Enables to detailed adjectives grouping using relationship chart that based on fuzzy set theory.
(3) Enables more efficient factor grouping instead of factor analysis.

Table 3 shows the finally selected 11 adjectives and their importance by Correspondence Analysis. Using these 11 adjectives, 8 real digitized CNS digital maps (4 Korean products and 4 Japanese products) were suggested to the subjects, because Japanese products are very similar with Korean ones and they are world-leading products. And then, sensibility evaluation was performed using Semantic Differential method.

4. Experiment Results and Analysis

4.1 Experiment 1

Result of this experiment showed the subjects' perceptual characteristic of the digital map color structure between the background and the main road. Table 4 describes the L*, u*, v* values of subjects designed map, their included areas in CIE chromaticity diagram, and the calculated perceptual distance from background and main road using Euclidean distance. And, Table 5 shows the categorized subjects requirements of CNS digital map color using CIE chromaticity diagram [4].

As shown in Table 5, most of the subjects designed the red and blue areas of main road colors in case of background was yellow area, and when the background was green area, most of them designed the source C and purplish blue area of main road. Except two subjects who trended away from others, the results of 18 subjects were divided into two background color groups in terms of perceptual distance. Then, t-test was performed to compare the differences of perceptual distance between above two background groups. Table 6 is the t-test result (α=0.05), whether there existed a difference of perceptual distance between two groups (null hypothesis is Ho : variance is equal).

Average perceptual distance was 168 (group its background color belongs yellow area) and 176

Table 3. Adjectives Grouping Results

Adjective	Complete	Bright	Roomy	Elaborate	Clean	Harmonic	Beautiful	Pretty	Original	Refine	Comfortable
Contribution	5.085	3.057	2.833	2.833	1.384	1.384	1.384	1.326	1.326	1.073	1.073

Table 4. Collected Subject's Color Structure Requirements using Navi-HEGS UIMS

Subject	Background			Color Area	Main Road			Color Area	Perceptual Distance
	L	u	v		L	u	v		
1	92.804	13.240	55.165	Source C	32.296	-9.4101	-130.330	Purplish blue	196.424
2	44.657	62.245	-80.443	Purple	0.000	0.000	0.000	Black	111.085
3	88.458	0.339	4.578	Source C	39.028	128.299	27.685	Reddish orange	139.108
4	87.735	-83.067	107.418	Yellowish green	100.000	0.012	0.029	Source C	136.326
5	97.140	7.717	106.808	Greenish yellow	32.296	-9.4101	-130.330	Purplish green	246.439
6	97.140	7.717	106.808	Greenish yellow	60.324	84.082	-108.664	Reddish purple	231.550
7	73.916	5.872	81.273	Greenish yellow	39.028	128.299	27.685	Red	138.121
8	66.442	-62.907	81.273	Yellowish green	32.296	-9.041	-130.330	Purplish blue	220.990
9	87.735	-83.067	107.418	Yellowish green	32.296	-9.041	-130.330	Source C	254.999
10	97.140	7.717	106.808	Yellow green	89.531	0.011	0.026	Source C	107.330
11	69.127	-53.463	-11.514	Bluish green	89.531	0.011	0.026	Source C	58.386
12	100.000	0.012	0.029	Source C	32.296	-9.4101	-130.330	Purplish blue	147.194
13	97.140	7.717	106.808	Greenish yellow	53.241	175.021	37.767	Red	186.238
14	89.531	0.011	0.026	Source C	97.140	7.717	106.808	Greenish yellow	107.330
15	97.140	7.717	106.808	Greenish yellow	53.241	175.021	37.767	Reddish orange	186.238
16	97.140	7.717	106.808	Greenish yellow	32.296	-9.041	-130.330	Purplish blue	246.439
17	87.735	-83.067	107.418	Yellowish green	32.296	-9.041	-130.330	Purplish blue	254.999
18	0.000	0.000	0.000	Black	76.189	0.009	0.022	Source C	76.189
19	87.735	-83.067	107.418	Yellowish green	32.296	-9.041	-130.330	Purplish blue	254.999
20	91.113	-70.467	-15.176	Bluish green	22.382	-6.515	-90.325	Purplish blue	120.254

Table 5. Categorized Color Structure by CIE chromaticity diagram

Color Area	Background	Main Road	Color Area	Background	Main Road
Yellow Area	Source C area	Purplish blue	Green Area	Yellowish green	Source C area
		Reddish orange		Green area	Yellowish green
		Greenish yellow		Yellow green	Source C area
	Greenish yellow	Purplish blue		Bluish green	Source C area
		Reddish purple			Purplish blue
		Red	etc. (disregarded group)	Black	Source C area
		Reddish orange		Purple	Black

Table 6. T-Test Result between Green and Yellow Background Colors

Group	N	Mean	Std. Dev.	Std. Err.	Min.	Max.	Variables	T	DF	Prob>|T|
Yellow Area	10	168.597	48.515	15.341	107.330	246.440	Unequal	-0.2328	11.1	0.8201
Green Area	8	176.036	79.262	28.023	58.386	255.000	Equal	-0.2457	16.0	0.8090

* For Ho : Variances are equal, F'=2.67, DF(7,9) Prob>F'=0.1718

(group its background color belongs green area) respectively, and there existed no significant differences between two groups (Prob. > |T| is 0.8090). It means that average perceptual distance between two groups did not show the significant differences, perceptually and statistically. This result shows the specific subject's preference pattern of CNS color structure that the average 168~176 perceptual distance of main road color from background is preferred whether it is yellow or green.

4.2 Experiment 2

Table 7 shows RGB, converted its L*u*v*, and LCH components values of 8 real digital maps directly obtained from the subjects to formulate the relationships between satisfaction level and color components. As the result, Table 8 explains the relationships between subject's color structure satisfaction level of 11 adjectives and 6 color components of CIE h_{uv}, $C*_{uv}$, S* values. Most of functions except 'complete' and 'original' have high R^2 values, and main road h_{uv} is the most effective factor to the subject's satisfaction level. This shows appropriate modeling result that is applicable for HSE color approach of CNS digital map color. Then, by controlling 6 LCH color components, it is possible to control the user's satisfaction level of digital map color structure.

Table 7. Suggested Digital Map Color Component and its Transformed Result

Color Value \ Digital Map		Korean Products				Japanese Products			
		Product1	Product2	Product3	Product4	Product5	Product6	Product7	Product8
RGB values of background color	R	255	180	255	255	222	187	189	223
	G	255	296	255	230	233	151	213	255
	B	204	228	0	200	220	149	165	219
RGB values of main road color	R	102	31	255	0	208	203	189	0
	G	204	20	0	0	73	208	213	174
	B	204	34	255	0	36	0	165	0
L^*, u^*, v^* values of background color	L*	99.439	90.060	97.140	96.588	94.858	82.999	91.761	95.118
	u*	1.307	-5.404	7.717	7.427	-0.177	11.961	-5.562	-0.363
	v*	17.989	-13.409	106.808	12.419	1.076	3.499	17.729	92.225
L^*, u^*, v^* values of main road color	L*	87.724	36.284	60.324	0	68.634	89.617	91.761	75.326
	u*	-30.346	8.703	84.082	0	65.653	5.428	-5.562	-71.318
	v*	-6.523	-15.331	-108.680	0	37.967	98.631	17.729	92.225
h_{uv}, C^*_{uv}, S^* values of background color	huv	1.498	1.188	1.499	1.032	-1.409	0.285	-1.267	-1.401
	C^*_{uv}	18.026	14.457	107.086	14.470	1.091	12.462	18.581	2.151
	S*	0.181	0.161	1.102	0.150	0.011	0.150	0.202	0.023
h_{uv}, C^*_{uv}, S^* values of main road color	h_{uv}	0.212	-1.055	-0.912	0.000	0.524	1.516	-1.267	-0.913
	C^*_{uv}	31.039	17.629	137.396	0.000	75.841	98.780	18.581	116.583
	S*	0.312	0.196	1.414	0.000	0.800	1.190	0.202	1.226

Table 8. Modeling between Subjects Satisfaction Level and Color Components

Adjectives (Subject Satisfaction)	Result of Multiple Regression Analysis (h_b : background huv c_b : background C*uv s_b : background S* h_r: main road huv c_r : main road C*uv s_r : main road S*)	R^2
Complete (Y1)	$Y1=1.233+0.332h_b-1.860c_b-178.458s_b+0.401h_r+0.417c_r-37.089s_r$	0.6615
Bright (Y2)	$Y2=0.683+0.466h_b-2.366c_b+226.793s_b+0.414h_r+0.448c_r-39.944s_r$	0.8082
Roomy (Y3)	$Y3=1.215+0.321h_b-1.699c_b+161.461s_b-0.093h_r+0.353c_r-31.027s_r$	0.7367
Elaborate (Y4)	$Y4=1.840+0.514h_b-2.331c_b+225.698s_b+1.401h_r+0.459c_r-42.408s_r$	0.7850
Clean (Y5)	$Y5=4.0999-0.263h_b+1.596c_b-152.656s_b-0.304h_r-0.376c_r+33.948s_r$	0.8648
Harmonic (Y6)	$Y6=0.453+0.633h_b-3.085c_b+295.810s_b+0.734h_r+0.642c_r-57.269s_r$	0.9300
Beautiful (Y7)	$Y7=1.001+0.654h_b-3.558c_b+341.911s_b+0.860h_r+0.696c_r-62.469s_r$	0.7672
Pretty (Y8)	$Y8=0.722+0.719h_b-3.435c_b+330.052s_b+0.856h_r+0.684c_r-61.332s_r$	0.8225
Original (Y9)	$Y9=1.368-0.574h_b-2.205c_b+212.628s_b+0.492h_r+0.503c_r-45.917s_r$	0.4929
Refine (Y10)	$Y10=0.857+0.665h_b-2.933c_b+281.815s_b+0.455h_r+0.573c_r-51.187s_r$	0.7753
Comfortable (Y11)	$Y11=1.141+0.468h_b-1.595c_b+152.025s_b-0.043h_r+0.312c_r-26.685s_r$	0.7393

5. Conclusions and Future Studies

This paper reviewed the characteristics of various color systems for HSE approach of the CNS digital map color structure. And, performed two experiments using CIE color spaces and HSE techniques to investigate the user's requirements and to verify the applicability of CIE color space. Results indicated that CIE L*u*v* and LCH color space are applicable color spaces for HSE approach, because of their perceptual uniformity and easy transformation process from initial R, G, B values. Result of first experiment indicated that in the range of 168 to 176 perceptually separated colors between background (green or yellow area) and main road was the preferable color structure for user's perception regardless the background color. And, the result of second experiment indicated that it is possible to modeling the user's sensibility by controlling the LCH components. However, several constraints are existing, because experiments only considered the background and main road color of the CNS digital map. Also, color sensibility depends on their size, environments, and array or contrast among various HMI objects. Therefore, more powerful algorithmic and mathematical techniques for integrated HSE approach of various digital map color and other HMI objects are strongly required to satisfy the user's various requirements and to suggest the effective color selection guidelines for the designers.

This research is deeply related to the driver's safety and the HMI standards of map-based CNS displays design and use in a vehicle. Also, very useful when designing the color structure not only for CNS digital map but also for other information color display designs of geographical information-based systems, vehicle instrument panel, head-up display, virtual reality, and so on. In addition, concept of perceptual distance of Euclidean color metric is somewhat ambiguous to understand and visualize the real perceptual differences. Hence, color selection and conversion system should be constructed that is capable of transforming and visualizing the color space and its component values for more user-centered digital map design and evaluation.

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