Position Recognition for an Autonomous Vehicle Based on Vehicle-to-Led Infrastructure

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Abstract. Self-driving cars are needed to ensure the location of the cars in order by recognizing obstacles around the vehicles, and creating and following travel routes. GPS based location determination system includes a very large error range, which limits the use of the GPS in tunnels, parking lots and large cities where radio signals are not able to travel through the air efficiently. High precision location determination technologies allow the cars to interact the navigation systems of self-driving cars with Intelligent Transportation System or ITS. The development of recent LED technology is applied to various industries. However, the technology is broadly used in the lighting system which is highly important for railroad traffic system. White color LED which is widely used for the lighting of lamps in tunnels, and it has various color temperature, which has different chromaticity coordinates. In this context, this paper aims at the location determination of self driving cars by analyzing the coordinates of chromaticity point, while grouping LED streetlamps which have different color temperature and shining optical focus on lanes. In addition, the paper evaluates the lane locations of the vehicles through the interrelation between their location and chromaticity coordinates under the laboratory environment. As a result, the paper identified the possibility of the location determination in the limited space of GPS signals.

Keywords: Autonomous vehicle · Vehicle-Infra (V2I) · Positioning · Light Emitting Diode · Color temperature · Chromaticity coordinates

1 Introduction

Recent studies have focused on accelerating the convergence of IT technology and automobile technology. As a result, automobile industry now shift forward self-driving cars which control themselves. So, vehicles are not just regarded as transportation. Various technologies are needed to materialize the self-driving. In particular, location determination technology is a core technology in the field of the self-driving cars [1–4].

Almost all of vehicle location determination system is based on Global Navigation Satellite or GNSS which provide absolute location information [5–11]. However, areas which are not able to receive satellite signals and dense urban areas limit the use of the system.

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High precision location determination technology for the self-driving is made possible for interconnecting the navigation system of the vehicles with Intelligent Transportation System or ITS based on V2X which means a connected network for traffic information exchange of vehicles to vehicles, vehicles to facilities and vehicles to people [12–14].

Recently, Light Emitting Diode or LED is remarkably advanced. Therefore, the usage of LED is now increasing in the field of infrastructure industries. In this sense, infra-based lightings such as streetlamps are replaced with LED. Among them, streetlamps for lighting can consist of various LED which has different color temperatures which picture different optical spectrum distributions. As a result, vehicle location determination is possible if the vehicles receive the light of LED streetlamps with chroma-meter and analyze the distributions and the streetlamps analyze road lanes which have different color temperatures [12, 15].

This paper analyzed the optical spectrum distributions of load lanes by examining the LED streetlamps in the tunnels which are GNSS-receiving area for the location determination of the load lanes and took account for the economic advantages of the study and the possibility of commercialization.

2 System Design

The location determination technology of the self-driving cars based on V2I can read the spectral sensitivity of the street lanes emitted by the LED street lighting and determine the location of the vehicles. There are many of technologies used by the road infrastructure. However, the paper takes account for the environment using the optical wavelength sensitivity of the road lanes on the tunnel lighting in tunnels which are the GNSS-receiving area or the area which are not able to receive the satellite signals as the following Fig. 1 [12].

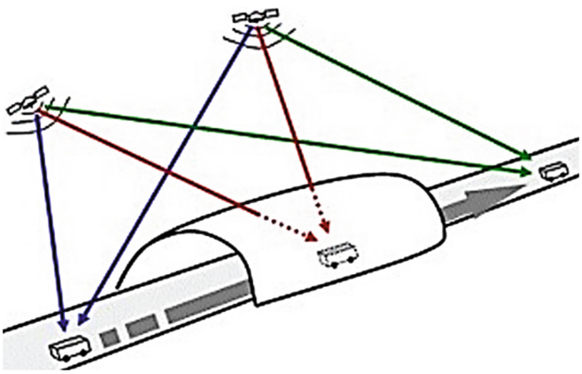

Fig. 1. GNSS receiving area

2.1 Color Specification

The color stimulus which makes color sense is normally shown as color equation consisting of the mixture of reference color stimuli, and the mixture of the representative reference color stimuli is in the following X, Y, Z. the value is as the formula [15].

$$\mathrm{X} = \mathrm{k}\int_{vis} \Psi(\lambda) \cdot \bar{x}(\lambda) d\lambda \tag{1}$$

$$\mathrm{Y} = \mathrm{k}\int_{vis} \Psi(\lambda) \cdot \bar{y}(\lambda) d\lambda \tag{2}$$

$$\mathrm{Z} = \mathrm{k}\int_{vis} \Psi(\lambda) \cdot \bar{z}(\lambda) d\lambda \tag{3}$$

In this formula, integral calculus $\int_{vis}$ is calculated in a visible ray area, and $\bar{x}, \bar{y}, \bar{z}$ is a color matching function. In addition, the color stimulus of an object color $\psi(\lambda)$ is $\psi(\lambda) = \mathrm{R}(\lambda) \cdot \mathrm{P}(\lambda)$ in the case of the reflection body, and it is $\psi(\lambda) = \mathrm{T}(\lambda) \cdot \mathrm{P}(\lambda)$ in the case of a transmission object. $\mathrm{P}(\lambda)$ is a spectral distribution, $\mathrm{R}(\lambda)$ is a luminous reflectance and, $\mathrm{P}(\lambda)$ is a luminous transmittance. The whole number k is calculated as the follows [15].

$$k = \frac{100}{\int_{vis} P(\lambda) \cdot \bar{y}(\lambda) d\lambda} \tag{4}$$

The mixture of the three color stimuli is indicated in a color space which is a three dimension color area. However, the color space is difficult to indicate it. So, XYZ color space defines X + Y + Z = 1 and the intersection of color vector (X, Y, Z) as the follows. It indicates two dimension $(\mathcal{X}, \mathcal{Y})$ [15].

$$\mathcal{X} = \frac{X}{X + Y + Z} \tag{5}$$

$$\mathcal{Y} = \frac{Y}{X + Y + Z} \tag{6}$$

This becomes the chromaticity coordinates of a random color, and the chromaticity coordinates is indicated in the following Fig. 2, chromaticity diagram. In this regard, the random color should be calculated for chromaticity coordinates to indicate chromaticity point in chromaticity diagram. Further, the chromaticity coordinates of monochromatic light is connected in wavelength order, and spectrum locus is indicated in the following Fig. 2 [15].

The color indication method that the paper explained is available for any color stimulus. However, color stimulus is in the case of blackbody radiation, and the method

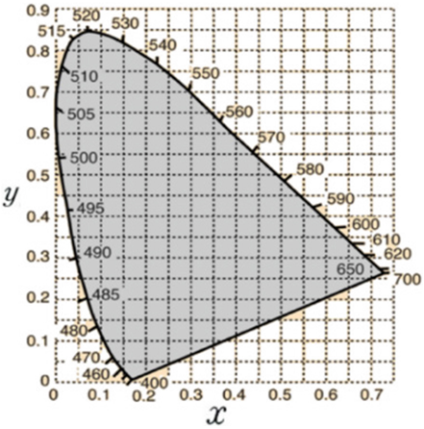

Fig. 2. *x*, *y* Chromaticity diagram in XYZ color system

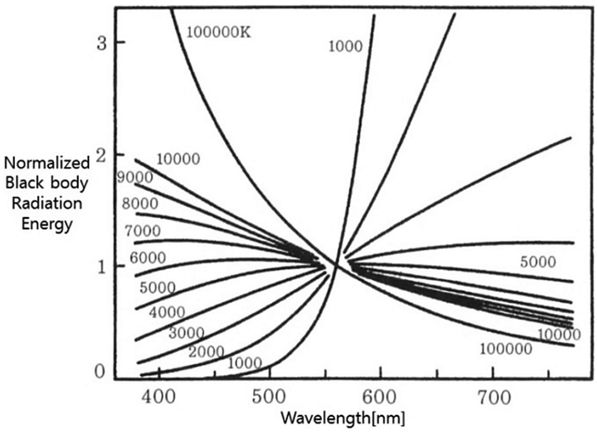

Fig. 3. The color temperature of blackbody to blackbody energy distribution (560 [nm] is normalized as 1)

can be more simplified. That is the absolute temperature of blackbody or the wavelength of blackbody radiation to color temperatures is shown as the following Fig. 3 [15].

In the case of the color temperature that light fixtures make, chromaticity point can be indicated in chromaticity diagram. For the color temperature, the chromaticity point of blackbody radiation can be defined as blackbody locus, which can be indicated in the following Fig. 4 [15]. The paper measures different colors according to x.y value of the chromaticity diagram and confirms that the value goes up when the color temperature shrinks as the following Fig. 4.

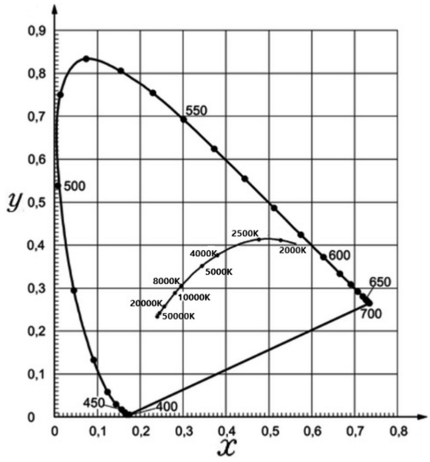

Fig. 4. Black body locus in chromaticity diagram

2.2 Color Measurement

The paper explained how to indicate color or light in the previous chapter. This chapter now focuses on explaining how to measure color or light that light fixtures make. There are color stimulus values and spectral sensitivity measurement to measure color specification values which is used for color indication. This paper uses photoelectric colorimeter which can immediately read illuminant from the output of photo electricity optical receiver which is satisfied with Luther condition. This colorimeter can immediately read the value of the color that the light fixtures can make [15] (Fig. 5).

Fig. 5. Chroma meter

2.3 LED Tunnel Lighting Design

This paper has the three LED groups which have three color temperatures in LED tunnels to distinguish three-lane loads, and every group should be controlled in order to equally shine the three roads.

Therefore, the angle of LED, the luminance of LED should be controlled. Further, the color temperature distribution of LED in the tunnels should be properly chosen to differentiate the spectrum distribution to every lane. The paper distributes the three types-LED light fixtures of 2 W which have every different color as in the following Fig. 6, and the proper luminance of the light fixtures is illuminated on three lanes.

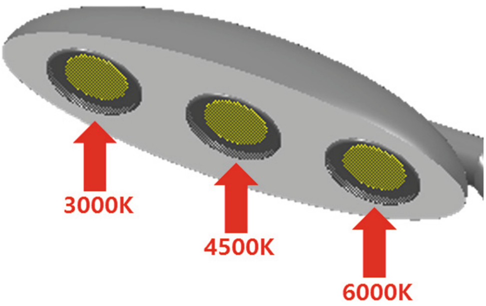

Fig. 6. LED tunnel lighting design

3 Experiment and Result Consideration

3.1 Chromaticity Coordinates Measurement to Every Lanes in LED Tunnels

This paper measures chromaticity points which have each 5 cm-distances from first lane to third lane as photo-electricity colorimeter. When the LED light fixtures are shined on the imagine road, which is an experimental condition. When three lights including 3000 k, 4500 k and 6000 k are shined on a street, the first line, the second line and the third line have every different color temperature. For example, when the light, 3000 k shines the first line, and the light 4500 k shines the second line, the lights are mixed in the two lines as the following Fig. 7. As a result, the paper measures the data of the mixed lights and records Table 1.

3.2 Chromaticity Coordinates and Functional Relation of Road Lane Position

The evidence of the Table 1 has the three real variable functions which can find the direction of the lanes. Therefore, there are 2 position functions: one is the position function which has a luminance variable and the other is the position function which has a color coordinate variable. In addition, the luminance variable has a large noise

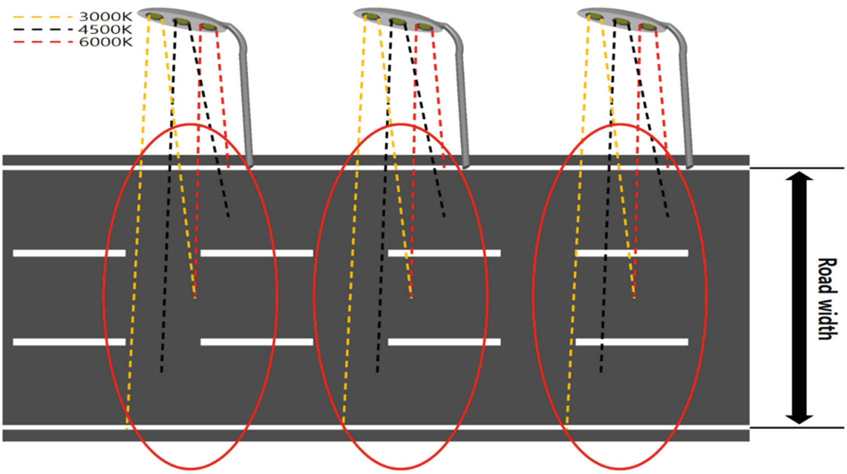

Fig. 7. Road condition shined by various LED streetlamp having different color temperature.

Table 1. Measured luminance and color coordinate to every point having the width of W

W (cm)	Ev(lx)	x	y
0	425	0.3446	0.367
5	502	0.3454	0.3675
10	583	0.3472	0.3687
15	659	0.35	0.3704
20	726	0.3538	0.3725
25	783	0.3585	0.375
30	833	0.3642	0.378
35	868	0.3702	0.3812
40	891	0.3765	0.3844
45	898	0.383	0.3878
50	893	0.3895	0.3911
55	873	0.3961	0.3944
60	839	0.4018	0.3974
65	785	0.4067	0.3999
70	713	0.4105	0.4019
75	625	0.4135	0.4033
80	533	0.4155	0.4043

factor around the light fixtures, and it position function determination on the variable includes a non-linear factor. Therefore, the other position function is chosen for self-driving car location determination because it is relatively indicated by liner function. Cubic position function formula from Table 1 data is as follows.

$$\text{Position} = 2226500y^3 - 2579600y^2 + 997490y - 128690 \quad (7)$$

With the above formula, location estimations and real-measured position value are arranged in Table 2. The result of this experiment is based on the analysis of the streetlamps to make sure the location determination of the road lanes, which it would be essential for expanding to the application of the location determination of self-driving cars.

Table 2. Road location and real-measured location determined by color coordinate function (RM: Ream measurement, DV: Determination value)

RM (cm)	DV (cm)	RM (cm)	DV (cm)	RM (cm)	DV (cm)	RM (cm)	DV (cm)
1	3.27267	21	21.0796	41	41.4072	61	61.073
2	3.27267	22	22.0339	42	42.1642	62	62.1789
3	3.64071	23	23.1883	43	43.0446	63	63.3256
4	4.36921	24	24.3017	44	43.9264	64	64.5147
5	4.72968	25	25.5859	45	44.8141	65	65.7479
6	5.79617	26	26.6149	46	45.7122	66	67.0269
7	6.84054	27	27.9957	47	46.4939	67	67.8169
8	7.86315	28	29.127	48	47.4237	68	68.8975
9	8.53598	29	30.2132	49	48.2393	69	70.01
10	8.86436	30	31.257	50	49.2165	70	71.1551
11	9.84454	31	32.4252	51	50.0796	71	72.3338
12	11.1193	32	33.3873	52	51.1201	72	72.936
13	12.0518	33	34.3162	53	52.2012	73	73.8557
14	13.2644	34	35.3619	54	53.1637	74	74.7954
15	14.1512	35	36.2288	55	54.3324	75	75.4331
16	15.304	36	37.2101	56	55.3767	76	76.4068
17	16.424	37	38.0286	57	56.4633	77	77.0675
18	17.5119	38	38.9613	58	57.5952	78	77.7377
19	18.5687	39	39.7449	59	58.7752	79	78.0763
20	19.847	40	40.5171	60	60.0061	80	78.7608

4 Conclusion

Automobiles are not just regarded as transportation but they are shifting forward the step of self-driving cars. Further, the location determination technology is a key to realize the self-driving cars.

The location determination system is usually based on GPS. However, the areas which are not able to receive the satellite signals and the high density areas have the large disadvantages of the use of it. In this context, recent studies focus on the location determination technology based on the connection of ITS using V2X and vehicle navigation system.

This paper aims at the use of LED streetlamps while using the technology of the location determination. In this regard, this paper arranges various LED streetlamps which have different color temperatures and shines them on each road lanes. The experiment recognized that the experimental cars facilitated the location of them and the functional relations of different color coordinates of the LED streetlamps and analyzed where they are with the color coordinates of the LED.

Advanced studies are expected that the technology can analyze the real time color coordinates to make sure the location determination of self-driving cars and it can develop more advanced self-driving cars in the following years.

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