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Research on Image Color Test Method for Automotive Camera Monitor System

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Abstract

Image color performance, as a fundamental component of human visual perception, possesses significant research value in the evaluation of Camera Monitor System (CMS). This study constructs a white balance test method applicable to CMS based on the test methodology framework of QC/T 1128 standard. The study involves the testing and analysis of the white balance characteristics of Class I and Class III CMS at 2800K, 4000K, and 6500K color temperatures. The findings indicate a substantial correlation between the white balance parameter indexes and the visual perception of the human eye. This method has been demonstrated to be a highly effective means of evaluating the color performance of CMS at various color temperatures. In addition, it provides a methodological supplement to the color rendering evaluation system as outlined in the ISO 16505 international standard.

Keywords

Camera Monitor System; Image Color Test; Color Performance; White Balance.

1. Introduction

The advent of intelligent automotive technology has precipitated a transition of automotive products towards electronic formats. The limitations of traditional mirror system, such as their restricted field of view, susceptibility to weather conditions, and suboptimal night vision, have led to an increased focus on electronic mirrors[1] .An electronic rearview mirror constitutes a product of camera and monitor integration, also referred to as Camera Monitor System (CMS), as shown in Fig. 1. The camera captures images of the surrounding environment and transmits them to the monitor for subsequent image processing, enabling drivers to access various information regarding the road, the environment, and the surrounding area, thereby ensuring driving safety[2].

Fig. 1 The CMS equipped on a certain model of automobile.

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In comparison to conventional rearview mirrors, CMS provide a number of advantages, including an expanded field of view and a reduction in blind spots[3,4]. The enhanced visibility provided by the camera's wide field of view assists the driver in perceiving their surroundings more effectively. The reduction in wind resistance and fuel consumption is a consequence of the smaller and more streamlined design of CMS. This results in a significant decrease in wind resistance during vehicle operation[5]. Additionally, CMS are equipped with automated brightness adjustment mechanisms, which can adapt to the ambient light conditions, ensuring the driver's visual comfort and preventing visual discomfort from oncoming traffic glare during nighttime operation[6]. Furthermore, the CMS has strong environmental adaptability. With optimized image processing algorithms and the function of automatically adjusting image brightness, contrast and other parameters, it can provide drivers with a clear and effective view under adverse weather conditions such as rain, fog or nighttime.

CMS, as a product with a strong emphasis on safety that provides drivers with a rear view, should prioritize the quality of the real-time display screen, i.e., the image performance, which is closely associated with the rear view.Color is an extremely intuitive visual perception in CMS monitors, and images that deviate from the desired color spectrum will significantly diminish the driver's visual comfort. This paper aims to address this critical issue by conducting a comprehensive study on the color performance of CMS images and formulating a systematic test plan for image color testing. This study is expected to serve as a valuable reference for the objective evaluation of the image color quality of CMS.

2. Standardization and Vehicle Regulation

In fact, Japan and Europe have long allowed conventional sight glass systems to be replaced by CMS. In 2015, the international standard for CMS, ISO 16505-2015[7], was officially published, specifying requirements and test procedures for ergonomic and performance aspects of CMS, and in 2016, the European Standard UNECE Regulation No. 46 was updated to officially allow the the use of CMS instead of traditional mirror system[8], marking the fact that vehicles equipped with CMS can legally be on the road in Europe. Japan adopted the UNECE R46 in 2017. The Class III CMS fields of vision required by UNECE R46 is shown in Fig. 2.

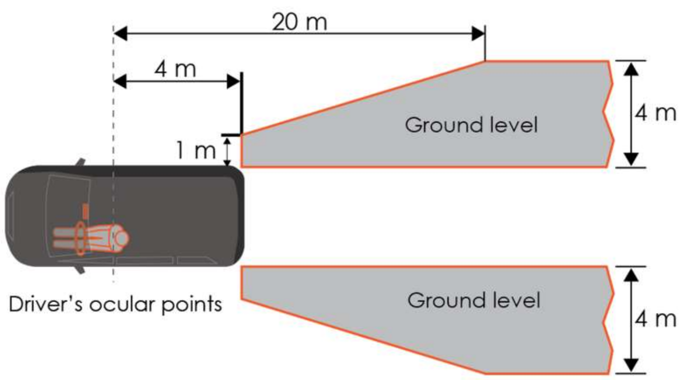

Fig. 2 Required fields of vision for Class III CMS in UNECE R46.

China's national standard on CMS, GB 15084 'Motor vehicles-Devices for indirect vision-Requirements of performance and installation' has been officially released in December 2022 and will be officially implemented on July 1, 2023[9]. The standard stipulates that not only can electronic exterior mirrors be installed, but also replace traditional mirrors. With the maturity of the technology and the relaxation of the regulations, it is foreseeable that more and more models will carry original CMS legally on the road in the future.

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3. Color Performance of CMS

ISO 16505 standard defines stipulate the color rendering performance of CMS as follows, as shown in the Fig. 3 below, the hue angle of the chart patches reproduced on the monitor shall meet the following requirements:

a) The red color coordinates shall not exceed the range of [0º, 44.8º] or [332.2º, 360º];

b) The green color coordinates shall not exceed the range of [96.6º, 179.9º];

c) The blue color coordinates shall not exceed the range of [209.9º, 302.2º];

d) The yellow color coordinates shall not exceed the range of [44.8º, 96.6º];

e) The chromatic distance from each patch (red, green, blue, yellow) to the white patch should be not less than 0.02.

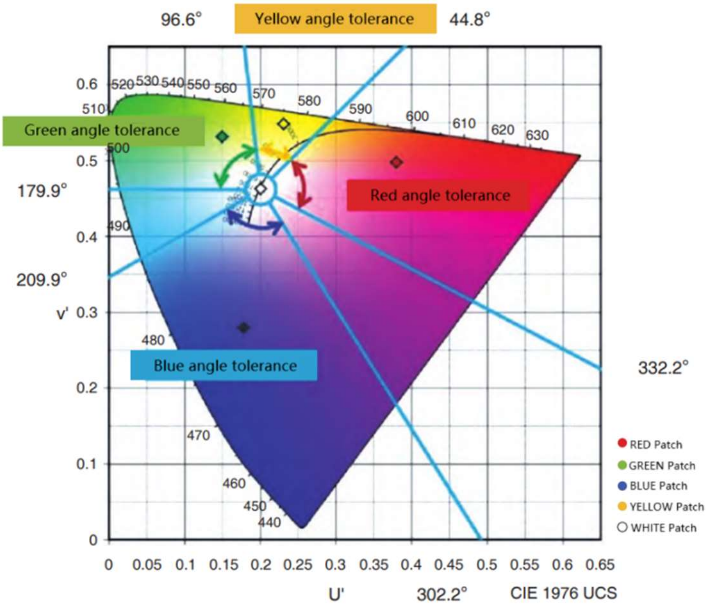

Fig. 3 Illustrative tolerance range described on CIE 1976 uniform colour space.

The standard specifies the color reproduction test process in the ambient light conditions, that is, illuminance (>500lux) and color temperature (6500K±1500K), of which the color temperature is a constant value. Although the standard for the test has been mentioned to be in the CMS camera white balance under the state of stable testing, but did not take into account the impact of different color temperatures on the color. Indeed, color temperature exerts a considerable influence on the color of an imaging system. The color temperature undergoes constant fluctuations throughout the day. For instance, at sunrise and sunset, the color temperature typically ranges from 2000K to 3000K. However, in the middle of a sunny day, it can reach 6000K to 7000K. The human visual system has color constancy, i.e., when the environmental light source changes, the color perception of the objects in the scene remains unchanged, ensuring that the perceived color is still the color of the object itself. The CMS camera operates on a different principle than the human visual system. The color constancy of the camera is achieved through the image sensor's ability to maintain a balanced white balance. This technology involves the analysis of color information from the three components of the image (R, G, B) and the adjustment of the electronic amplification ratio of the three light-sensitive circuits based on the ambient color temperature. The objective is to calibrate the image to a state that is visually comfortable for the human eye. The result is a color reproduction that does not exhibit significant off-color phenomenon.

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4. Test Method

Through the above analysis, combined with the problem of color deviation of CMS under different color temperatures, the test focuses on the white balance ability of CMS under three color temperatures. The test program is as follows:

a)Subjective test

The subjects were selected as 15 automobile operators with similar driving experience, 8 males and 7 females, all of whom were physically and mentally healthy, with normal or corrected vision and without color blindness or color weakness, to avoid the influence of human factors on the test results. The CMS camera was installed to obtain a realistic picture of the object, as shown in Fig. 4, the test scene supports three color temperature adjustments of 2800K, 4000K and 6500K. And the subjects were allowed to observe both the actual scene and the scene displayed on the CMS monitor, and then scored the realism of the image color and the comfort of viewing the image color, with the worst being 0 and the best being 10, and the average of the scores of the 15 subjects was taken as the subjective test score.

Fig. 4 Schematic diagram of subjective test scenario.

b) Objective test

The idea of objective testing of CMS image performance is to capture a specific target object by a camera in a controlled ambient light scenario, capture a real-time image on the monitor screen, and finally execute a mathematical analysis based on optical and image principles. The test scene layout is shown in Fig. 5.

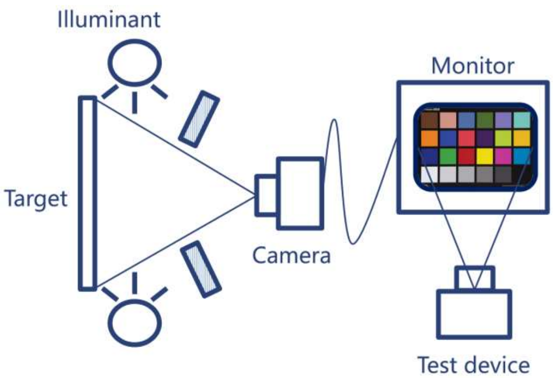

Fig. 5 Schematic diagram of CMS objective test layout.

To ensure the controlled ambient light scenario is met, the test darkroom's wall reflectivity is maintained at (18 ± 2)%, the floor is coated with matte black paint, and the reflectivity is limited to

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5% or less. All light sources within the test darkroom are deactivated, and the visible light illuminance is kept below 1 lx to prevent the influence of stray light on the image test. The temperature of the test environment is 17~27℃ and the relative humidity is 25~75%RH. The test chart card utilizes a standard 24-color ColorChecker chart card and a neutral gray background with 18% reflectivity, with a surface illumination of 800 lux and less than 10% uneven illumination. The test chart card is designed to occupy as much of the monitor display area as possible. The color temperature was set to 2800K, 4000K, and 6500K for the testing procedure. The monitor image was subjected to analysis using an imaging luminance meter. According to the provisions outlined in QC/T 1128[10], the subjective evaluation of the white balance effect is predicated on the premise that there should be no discernible color discrepancy in the lower row of colors on the chart card, and the image should not induce color deviation. The objective quantitative index is the color saturation of the 21st and 22nd grayscale cards of the standard 24-color ColorChecker chart card in the HSV color space. The formula for its calculation is as follows:

$$S = \frac{MAX_{(R,\ G,\ B)} - MIN_{(R,\ G,\ B)}}{MAX_{(R,\ G,\ B)}} \tag{1}$$

In the formula:

S--color saturation;

$MAX_{(R,\ G,\ B)}$--Maximum of R, G, B;

$MIN_{(R,\ G,\ B)}$--Minimum of R, G, B.

Converting the R, G and B values of the monitor image color patches to the CIEL*a*b* color space, the corresponding luminance and chromaticity values of the respective color patches can be found out, as seen in formulas (2~4), respectively, and substituting into formulas (5), the color difference ΔE* between each of the 24 color patches and the standard map card can be calculated.

$$\Delta L^* = L_1^* - L_2^* \tag{2}$$

$$\Delta a^* = a_1^* - a_2^* \tag{3}$$

$$\Delta b^* = b_1^* - b_2^* \tag{4}$$

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \tag{5}$$

In the formula:

a_1^*, b_1^*--Chart Card Colorimetric Standard Values;

L_2^*--Monitor Image Luminance Standard Value;

a_2^*, b_2^*--Monitor Image Chromaticity Standard Value;

ΔL^*--luminance difference;

Δa^*, Δb^*--chromaticity difference.

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5. Analysis of Test Results

This section presents an analysis of the test results. The samples for this test were selected from the most commonly used Class I CMS and Class III CMS for passenger cars. These samples have passed the ISO 16505 color reproduction test. The white balance test is now conducted according to the method described in the previous section. Their monitor imaging are shown in Fig. 6 and Fig. 7, respectively.

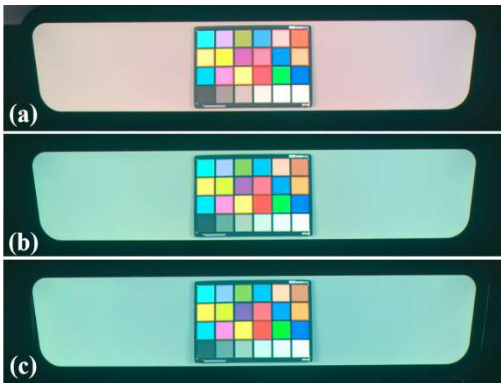

Fig. 6 Imaging of a Class I CMS under ambient light conditions with different color temperatures (a) 2800K, (b) 4000K, (c) 6500K.

Fig. 7 Imaging of a Class III CMS under ambient light conditions with different color temperatures (a) 2800K, (b) 4000K, (c) 6500K.

The following results are analyzed according to the categories of electronic rearview mirrors. Table 1 and Table 2 show the white balance and color analysis of Class I and Class III CMS, respectively. It can be seen from Table 1 that the color saturation of the Class I CMS product is larger under the condition of 2800K color temperature, with 20% for the 21# color patch and 29.7% for the 22# color patch, which indicates a relative lack of white balance adjustment of the samples under the condition. When combined with the monitor imaging in Fig 6a, the monitor screen appears to have an overall warm tone, and the color patches corresponding to the red domain are more pronounced. This is illustrated by the high total chromatic difference of 24 color patches.

Next, the white balance color performance of Class III CMS is analyzed. A meticulous examination of Table 2 and Fig. 7 reveals that the sample's color performance under varying color temperature conditions exhibits remarkable stability. The 18% neutral gray background plate maintains its color consistency, unaffected by changes in color temperature. Correspondingly, the 21# and 22# color blocks of the R, G, B color channel gain level remain constant, with minimal fluctuations in average color saturation, as indicated by the 13% nearby. These observations suggest that the white balance effect of the sample is commendable, thereby enhancing its imaging quality in color. Under 2800K conditions, the monitor screen shows a slightly lighter overall color, with the sum of the color differences of the 24 color blocks being 838.8. As the color temperature is raised to 6500K, its color performance gradually approaches the standard graphic card colors, with the color difference of the 24 color blocks becoming 732.8.

Table 1. Image color test results of a Class I CMS under ambient light conditions with different color temperatures

Test Indicators		2800K	4000K	6500K
21# color patch	R	203.9	211.0	254.2
	G	254.9	254.5	247.9
	B	247.4	237.9	237.0
	S	20.0%	17.1%	6.8%
22# color patch	R	154.2	175.2	230.5
	G	219.2	219.1	199.8
	B	204.0	199.2	194.7
	S	29.7%	20.0%	15.5%
Total chromatic difference of 24 color patches		772.0	705.8	670.6
Average score of subjective test		5.3	7.8	8.0

Table 2. Image color test results of a Class III CMS under ambient light conditions with different color temperatures

Test Indicators		2800K	4000K	6500K
21# color patch	R	219.4	220.1	220.5
	G	252.8	252.9	252.6
	B	227.1	227.1	227.3
	S	13.2%	13.0%	12.7%
22# color patch	R	189.8	189.3	190.4
	G	219.3	217.5	218.0
	B	193.8	194.0	195.5
	S	13.5%	13.0%	12.7%
Total chromatic difference of 24 color patches		838.8	765.7	732.8
Average score of subjective test		6.9	8.2	8.3

The combination of the test results for the two aforementioned types of CMS samples indicates a positive correlation between the color saturation of the 21# and 22# color patches and the white balance of the samples. Furthermore, a decrease in overall color deviation is associated with a more natural color reproduction and an increased level of comfort for the human eye when observing the monitor.

6. Conclusion

The image color performance of CMS is the result of the joint action of camera, monitor, and related hardware and software. The camera is the strong relevant influencing factor. The enhancement of natural color performance has been demonstrated to alleviate driver discomfort when observing the rear field of view, thereby facilitating concentration on driving and consequently leading to a reduction in traffic accidents and an enhancement in the user experience. This paper extends the white balance test method for camera single product in QC/T 1128 standard to the CMS, and analyzes the color performance of a certain Class I CMS and a Class III CMS under different color temperatures. The test results suggest that the color saturation of 21# and 22# color patches, i.e., the white balance test indicator, has a certain correlation with the color performance of electronic rearview mirrors observed by the human eye, and it can be complemented as a color rendering item in ISO 16505, which can provide a reference for the reasonable assessment of the monitor image color of CMS.

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In the context of CMS product development, ensuring the accurate and natural display of image colors is paramount. To this end, color correction and adjustment for multi-color temperature or multi-scene are essential to ensure the stability of the display effect. With the development of intelligent connected vehicle technology, CMS will take on more environment sensing and interaction functions, and its functions will be extended to the field of multi-sensor fusion and artificial intelligence decision-making. The image color evaluation of CMS will also develop from color accuracy to environment adaptability and target recognition reliability. The systematic evaluation method can provide a scientific basis for the design, optimization and standardization of CMS, and provide a solid foundation for the technological breakthrough and industrial upgrading in the field of automotive electronics.

References

[1] Zhang Yonggang, Yang Yuanlei, Zhang Fang, et al. Development and Application of Camera Monitor System[J]. Automotive Digest, 2023 (3): 39-43.

[2] Huang Na, Shang Chao, and Li Bo. Analysis on Camera-monitor System of Automobile[J].Automobile Applied Technology, 2020, 45(20): 173-175.

[3] Johansson P, Jonason S. Designing Camera Monitoring Systems in Cars for Enhanced User Performance[D]. Gothen burg: Chalmers University of Technology, 2021.

[4] Schmidt E A, Hoffmann H, Krautscheid R, et al. Camera-monitor systems as a replacement for exterior mirrors in cars and trucks[J]. Handbook of Camera Monitor Systems: The Automotive Mirror-Replacement Technology based on ISO 16505, 2016: 369-435.

[5] Moore A, Yuan J, Ou S, et al. Key considerations in assessing the safety and performance of camera-based mirror systems[J]. Safety, 2023, 9(4): 73.

[6] Huang Zhen, Fang Ruihua, Ge Ruhai. Principle of Electronic Anti-Dazzling Rear-View Mirror[J]. Journal of ChongQing Jiaotong University (Natural Science), 2012, 31(02): 318-320+334.

[7] International Organization for Standardization. Road vehicles-ergonomic and performance aspects of camera monitor systems-requirements and test procedures: ISO 16505-2015[S].International Organization for Standardization, 2019.

[8] The United Nations Economic Commission for Europe. Uniform Provisions Concerning the Approval of Devices for Indirect Vision and of Motor Vehicles with Regard to the installation of These Devices:ECE R46: 2016[S]. The United Nations Economic Commission for Europe, 2016.

[9] State Administration for Market Regulation. Motor vehicles-Devices for indirect vision-Requirements of performance and installation: GB 15084-2022[S]. Beijing: Standard Press of China, 2022.

[10] Ministry of Industry and Information Technology. Automotive camera: QC/T 1128-2019[S]. Beijing: Beijing Science and Technology Press, 2019.