Study on National Technical Specification of the Standard Retroreflectivity Measurement Device

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Abstract. The study aims to explore the technical specifications of the standard retroreflectivity measurement devices. Based on the measurement principle of retroreflection coefficient, the metrological characteristics of standard retroreflectivity measurement devices were proposed and the three main metrological indices of light source (color temperature, illuminance and positioning error of incident angle) were experimentally explored. The allowable error range of the retroreflection coefficient measurements was determined to calculate the corresponding ranges of metrological indices. With the entropy weight method, the weight of the influence of each index on retroreflection coefficient measurements was analyzed. The analysis results showed that the illuminance had the most significant influence on the retroreflection coefficient and accounted for 41.30%, followed by color temperature (34.43%) and angle change (24.26%). The study provides the important technical support for the development of technical specifications of standard retroreflectivity measurement devices.

1. Introduction
A standard retroreflectivity measurement device is a device used to test the highest retroreflectivity standard in transportation sectors and the traceable benchmark for the photometric performance of retroreflective materials. The reflection of the reflected light from the direction, which is basically opposite to the incident light, is called retroreflection. If the reflected light can still maintain this property even when the incident direction of the incident light is changed in a large range, the reflection material is called a retroreflective material, which is widely used in traffic, municipal construction, public security and other fields. For example, retroreflective materials are mainly used in safety facilities such as traffic signs, road markings, raised road signs, outline signs, and place-name signs. Through the illumination of the headlights of motor vehicles, the retroreflector with retroreflection characteristics transmit the information carried by traffic facilities to visual organs of drivers and passengers, thereby improving the visibility of facilities at night and ensuring driving safety [1-6]. The accuracy of standard retroreflectivity measurement devices is directly related to the accuracy of the retroreflectivity measurement system in the transportation industry. A standard retroreflectivity measurement device is important in the transportation industry since it is the traceability source of retroreflection devices.

In the transportation industry, two kinds of devices are generally used to evaluate the photometric performance of retroreflectors: handheld retroreflectometers and the devices based on the absolute measurement method of retroreflectivity. The two types of devices have different scopes of application and features. Handheld retroreflectometers are convenient, flexible and suitable for most on-site testing environments, but the accuracy is lower. The devices based on the absolute measurement
method of retroreflectivity have the higher accuracy, but because the devices are large and only suitable for laboratory environments.

At present, many problems in the traceability of standard retroreflectivity measurement devices in China remain to be solved. Handheld retroreflectometers including the verification devices have been developed by the National Road and Bridge Engineering Testing Equipment Metrology Station and the verification of handheld retroreflectometers has been implemented. However, the verification procedure or calibration specification of the devices based on the absolute measurement method of retroreflectivity has not been established at home and abroad. Currently, various metrological indices of the devices are calibrated according to different regulations in China. For example, according to JTG 245-2005 Verification Regulation of Illuminance Meter, the illuminance of the light source is calibrated. According to JTG 213-2003 Verification Regulation of Standard Lamps for Distribution (Color) Temperature, color temperature and uniformity are calibrated. In the above calibration process, the metrological indices and requirements are inconsistent, thus resulting in inconsistent measurement standards. In order to ensure the accuracy of the traceability of standard retroreflectivity measurement devices, it is urgent to determine the traceability items of the devices for the purpose of compiling the national technical specification of the standard retroreflectivity measurement device.

2. Principle of retroreflection coefficient measurement

Commercially available retroreflection coefficient measurement devices are basically based on the ratio method and the principle of standard coplanar geometric conditions. In JT/T 690 Test Method for Photometric Characteristics of Retroreflectors compiled by Su Wenying et al., the composition of a standard retroreflectivity measurement device and the measurement method of the retroreflection coefficient of a retroreflector are introduced. The standard retroreflectivity measurement device should be composed of five parts: standard light source, micro illuminance meter, incident angle adjuster, observation angle adjuster, and control system. In JT/T 689-2007 Test Method for Coefficient of Retroreflection of Utilizing the Coplanar Geometry compiled by Su Wenying et al., the composition and requirements of a standard retroreflectivity measurement device are introduced and the method for measuring the retroreflection coefficient is also proposed. The schematic diagram of the device is shown in Figure. 1.

![Figure. 1. Schematic diagram of a retroreflection coefficient measurement device.](image)

3. Metrological indices

According to the principle of retroreflection, a retroreflective material reflects the light back to the origin position of the light source. When it is applied to various scenarios in the transportation industry, the angle system, light path direction, and standard light source (A) and other geometric conditions are different, so the measured retroreflection coefficients are also different. Therefore, in the measurement
of the retroreflection coefficient of retroreflective materials, it is necessary to reproduce the conditions of retroreflective materials in their application scenarios so that the test geometric conditions (including angle system, light path direction and light source) are consistent with their working conditions [7].

The retroreflectivity measurement instrument is generally used to measure the reflective performance of retroreflective traffic safety facilities such as traffic sign boards, reflective films, road markings, and raised road markers. The study only focused on traffic sign boards. According to the measuring geometric conditions in the specifications of retroreflectometers (JT/T612-2004 and JJG059-2004), the photometric performance test system of retro-reflectors and retroreflective materials (RT100A, Hangzhou Yuanfang Instrument Co., Ltd.) was adopted in the study. The experimental conditions were set as follows: standard light source (A), incident angles of -4°, 15°, 30°, and 40°, observation angles of 0.2°, 0.33°, and 1°, and standard measurement distance of 15m ± 0.2 m in a dark room.

3.1. Influences of the color temperature of standard light source (A) on calibration results

According to the regulations of International Commission on Illumination (CIE), a gas-filled spiral tungsten lamp with a color temperature of 2856 K was selected as the standard light source (A). Color temperature is the most important indicator that affects the color reproduction ability of a light source. Therefore, the influence of color temperature on measurement results of retroreflection coefficient was explored in the experiment.

The tested objects were standard plates of retroreflective sign that met the requirements of retroreflective sign coefficient required in GB/T 18833. Five plates with different colors were adopted: white, yellow, red, green, and blue and the size of plates was 100 mm×100 mm. The experimental conditions were set as follows: standard light source (A) with a color temperature of about 2856 K, observation angles of 0.2°, 0.5°, and 1°, and incident angles of -4°, 15°, and 30°. The color temperature range of 2600 K to 2950 K was obtained through adjusting the current. Three measurements of retroreflection coefficient under a color temperature of 2856 K were averaged as the standard retroreflection coefficient. The variation of retroreflection coefficient with color temperature was determined (Figure. 2).
Figure 2 Variations of measured retroreflection coefficients of tertiary boards in different colors with color temperature: (a) white, (b) yellow, (c) red, (d) green, and (e) blue.

In the above experiments, under the same incident angle and observation angle, the measurement errors of retroreflection coefficient measured at different color temperatures were different. With the increase in the difference between testing color temperature and standard color temperature, the measurement error of retroreflection coefficient increased. The influences of color temperature on tertiary boards of different colors were slightly different. Therefore, the intersection of the test data of the five tertiary boards with different colors were determined. When the measurement color temperature was within the range of 2856 K ± 50 K, under the testing geometric conditions, the influence of color temperature on the measured retroreflection coefficient was small and the measurement indication error of retroreflection coefficient was within 5%.

Therefore, the color temperature range of the standard retroreflectivity measurement device shall be controlled within 2856 K±50 K and the color temperature measurement device with a measurement range of 2856 K±50 K can be used for the calibration. In addition, the expanded uncertainty of the standard retroreflectivity measurement device is required to be no more than 20 K.

3.2. Influences of illuminance on calibration results

Under the same light source, the illuminance of light source varied with color temperature. By adjusting the current value, the color temperature range of 2600 K~2950 K was determined based on the measurement results of illuminance meter. Then, the illuminance of the light source were measured (Figure 3).

Figure 3. Relationship between color temperature and illuminance of standard boards of retroreflective signs.

In the above tests, the color temperature of the standard plates of retroreflective signs of different colors varied from 2600 K to 2950 K and color temperature was positively correlated with illuminance (Fig. 3). Illuminance increased with color temperature. As discussed above, the color temperature range of the standard retroreflectivity measurement device shall be controlled within 2856 K±50 K.
this range, minimum illuminance was 11.256 lx. Therefore, the illuminance of the standard measurement device shall be 10 lx. The device can be calibrated with a standard illuminance meter with a measurement range of 2 lx to 6000 lx. The relative extended uncertainty of the device is required to be no more than 1.0%.

3.3. Influences of the positioning error of incident angle on calibration results

The tested objects were Type-1, Type-3, and Type-5 standard plates of retroreflective sign that met the requirements of retroreflection coefficient required in GB/T 18833. Five plates with different colors were adopted: white, yellow, red, green, and blue and the size of plates was 100 mm×100 mm. The experimental conditions were set as follows: standard light source (A) with a color temperature of 2856 K, observation angles of 0.2°, 0.5°, and 1°, and incident angles of -4°, 15°, and 30°. Under a fixed observation angle, the incident angle was changed by ±0.1°, ±0.5°, and ±1°. The measurements of retroreflection coefficient as well as corresponding errors were obtained (Figure. 4).

![Figure 4](image)

Figure 4: (a) Variations of measured retroreflection coefficients of tertiary boards in different colors with incident angle: (a) white, (b) yellow, (c) red, (d) green, and (e) blue.

The measurement error data of retroreflection coefficients of the above-mentioned tertiary boards under different positioning errors of incident angle indicated that the positioning errors of incident angle affected the retroreflection coefficient measurements. When the positioning error of incident angle was within ±1°, the measurement error of retroreflection coefficient was within 5%. Therefore, the positioning error of incident angle in the standard retroreflectivity measurement device shall be
controlled within ±1°. An electronic inclinometer with a measurement range of -60° to 60° and a maximum allowable error of no more than 40° can be used to calibrate the standard device.

4. Analysis of influencing factors of retroreflection coefficient

In Section 3, when the measurement error of retroreflection coefficient was controlled within 5%, color temperature, illuminance, and the positioning error of incident angle of the standard device were preliminarily determined. With the entropy weight method, the influences of the three indices on measurements of retroreflection coefficient were further explored. According to the entropy weight method, an objective weighting method, the weight of each index can be determined based on observation values of each indicator.

Under the same light source, through changing illuminance and color temperature of the light source simultaneously, the variations of retroreflection coefficient measurements were obtained and analyzed.

The weights calculated from the above data were firstly averaged and then the weighting coefficients of color temperature, illuminance, and retroreflection coefficient were determined to be 0.354098, 0.424738, and 0.221164, respectively.

The weight coefficients of angle change and retroreflection coefficient were firstly calculated based on the change of the positioning error of incident angle and then the weighting coefficients of angle change relative to retroreflection coefficient were determined to be 0.054591 and 0.048387, respectively.

Through normalization of the above relative weighting coefficients, the weighting coefficients of color temperature, illuminance, and angle change relative to retroreflection coefficient were determined to be 0.344334, 0.413026, and 0.242640 (Figure 5).

Figure 5 Weighting coefficients of the influences of illuminance, color temperature, and angle changes on retroreflection coefficient.

According to the above calculation results, the influences of illuminance on retroreflection coefficient measurements was the most significant and accounted for 41.30%, followed by color temperature (34.43%) and angle change (24.26%).

5. Conclusion

In this study, based on the measurement principle of retroreflection coefficient, the metrological characteristics of standard retroreflectivity measurement devices were explored and the main measurement indices of the device were proposed. Several measurement indices of retroreflection coefficient such as color temperature, illuminance, and positioning error of incident angle were analyzed experimentally. When the measurement error of retroreflection coefficient was controlled within 5%, color temperature, illuminance, and the positioning error of incident angle of the standard
device were preliminarily determined. Finally, the weight coefficient of each measurement indicator was further determined with the entropy method.

In the future, our group will investigate the measurement errors of retroreflection coefficient of commercially available devices and determine corresponding technical indices with the weighting coefficients in order to provide the technical basis for developing the technical specifications of the standard retroreflectivity measurement device for transportation sectors. The study also provides the important technical support for the supervision of retroreflective products in the transportation industry.

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