A design of calibration single star simulator with adjustable magnitude and optical spectrum output system

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Abstract: In order to achieve multi-color temperature and multi-magnitude output, magnitude and temperature can real-time adjust, a new type of calibration single star simulator was designed with adjustable magnitude and optical spectrum output in this article. Xenon lamp and halogen tungsten lamp were used as light source. The control of spectrum band and temperature of star was realized with different multi-beam narrow band spectrum with light of varying intensity. When light source with different spectral characteristics and color temperature go into the magnitude regulator, the light energy attenuation were under control by adjusting the light luminosity. This method can completely satisfy the requirements of calibration single star simulator with adjustable magnitude and optical spectrum output in order to achieve the adjustable purpose of magnitude and spectrum.

According to the function classification, the star simulator can be divided into two types[2]. One is calibration type and the other is function detection type. The calibration type usually simulates the optical parameters such as the magnitude and color temperature of a single star point image. Calibration type is mainly used for the detection of satellite sensors, optical signal resolution and processing capacity calibration. Therefore, this method pays special attention to the accuracy requirements. The functional detection is to simulate the actual position and distribution of multiple stars and to study the technical requirements of the star sensor for the conversion of the optical signal, the conversion of the coordinates, the accuracy of the star point simulation position. The location of the image requires a lot of attention[3].

This article discusses the calibration of a single star simulator. The function to be achieved by this method is to provide a simulated star in the laboratory that is in agreement with a single real star in terms of photometric properties, spectral characteristics and geometric features.
1. System composition

The design principle of this project is that the light emitted by the electric light source is transmitted through the optical fiber bundle into the multi-band light intensity controller\(^4\). After the band-pass filter of each controller, the light source has a certain wavelength bandwidth of light. According to the given fitting coefficient to adjust the aperture of each light intensity controller, you can get a lot of different spectra, different intensity of light. The light is then projected through the fiber bundle into the hexagonal prism integral bar for uniform mixing, in order to achieve the star color temperature simulation. When the light of different color temperature is fitted into the star control system, the controllable aperture can be controlled by the controllable diaphragm and the mirror, and then the controllable aperture can be attenuated by the required magnification. We can simulate the brightness of the star, in order to achieve the star brightness characteristics of the simulation.

The overall structure consists of power supply, light source, band light intensity controller, Six prism, star controller, industrial control box, PC.

![Diagram of single star simulator system components](image)

1. Industrial computer  
2. The electrical box  
3. Light source module  
4. Band light intensity controller  
5. Hexagonal prism  
6. Frosted glass  
7. Star controller  
8. Power supply

**Figure 1.** Single star simulator system components

The system needs to have a range of 0~+6.5MI between the peak spectrum of 350nm and 950nm, and the equivalent blackbody temperature is: 2600 K, 3600 K, 4300 K, 5000 K, 5500K, 6000 K, 6800 K, 7600 K, 9800 K.

![Spectral range graphs](image)

(a) Spectral range of high pressure xenon lamp  
(b) Spectral range of halogen lamp

**Figure 2.**

At present, the commonly used optical light source has laser light source, light-emitting diode, xenon lamp, halogen lamp, halogen lamp, tungsten lamp, incandescent lamp and so on. Due to system design reasons for the relatively high light requirements, it needs to cover 350nm ~ 950nm, and in this
spectrum of the luminous frequency is relatively large and uniform. After a number of theoretical
analysis and specific experimental system error analysis, a single light source, the previous system
used xenon lamp light LED lamp compensation and other programs were ruled out. In the end, a
dual-light source was chosen using a xenon lamp and a halogen lamp, which improved the final output
of the improved system in terms of accuracy and stability.

In the vicinity of 350nm to 600nm xenon lamp smooth and strong light intensity, so 350nm to
600nm near the use of xenon lamp was used as a light source. Between 600nm and 950nm, the
spectrum of the tungsten halogen lamp gradually rose, and was smooth, the light intensity was large.
So between 600nm and 950nm, the halogen light was used as the system light source. The smooth
band was taken in the spectral characteristics of the xenon lamp and the halogen lamp so that they
worked in the corresponding band of the system, so that they could well avoid the jittering part of their
spectral properties[5].

2. Color temperature simulation

In this design task, the spectral curves were selected at each color temperature based on black body
radiation law. Then we controlled the intensity of the different bands, evenly mixed synthesis, so as to
achieve the purpose of high-precision simulation of color temperature.

2.1 Transmission of light

In the system, the required wavelength span was 350nm ~ 950nm. Every 50nm was divided into a
control unit, a total of 13 branches. So that 13 fibers were required for spectroscopy. 11 glass fibers
were selected to complete the light in the 450nm~950nm band of light transmission and 2 quartz fibers
in the 350nm~400nm (ultraviolet light band). In the process of light transmission, the temperature of
the fiber bundle would increase with time going on. Therefore, liquid core fibers were used. This kind
of fiber was filled with transparent liquid in the polymer coating with a lower refractive index. It has
the advantages of large core diameter, large numerical aperture, high transmission efficiency and wide
spectral transmission range. So the liquid core fiber was used in the system.

![Figure 3. Schematic diagram of the structure of liquid core fiber](image)

2.2 Band light intensity control

The simulation curve of the spectral color temperature was simulated by mathematical modeling so
as to get the corresponding fitting coefficient. The transmittance of the iris could be determined by its
fitting factor. In the system design, the code was used to control stepper motor according to the
corresponding fitting coefficient to control the transmittance of the iris diaphragm. The light source
passed through the collimator lens into the variable iris and was propagated to the 10% beam splitter.
After 10% of the beam splitter, part of the light went into the photovoltaic cells. It could be used to
detect the light intensity of the current light source. The stepper was controlled motor to the iris based
on the current light intensity and adjusted the control panel in real time to achieved control of the light intensity. So that It was needed to be calibrated when the code could be used to control the system calibration, but also could use light intensity feedback control of the system real-time light intensity to control feedback adjustment.

2.3 Uniform light synthesis

After controlling the temperature of the star by the band light intensity controller, the light from the light source brought together the 13 light intensities. This process required a light system to mix the 13 light evenly[6].

The integral sphere was considered in the preliminary design of the system, but the integrating sphere is actually an optical attenuator. The light source is attenuated by the integrating sphere and can not satisfy the requirements of the subsequent system[7].

Ultimately, the hexagonal prism integral bar was chosen. In the exit face of the hexagonal prism, the energy of the light of different wavelengths was relatively concentrated at the exit point, so that a clear bright spot was formed on the exit face of the hexagonal prism. The ideal of uniform light was not achieved. The ground glass which is similar to the diffuse reflection principle of the integrating sphere was installed. The rougher the surface of the ground glass was, the lower the light transmittance would be. The light through the light of the glass would be weaker. Therefore, it could only as far as possible to meet the light source in the case of light to select the highest roughness of the ground glass. A piece of ground glass was placed after the prism, so that each sub-light source could be in the transmission to the glass when the occasional refraction. When the light source becomes even, the purpose of the even light can be achieved. After passing the ground glass and the converging lens, the light source converges into a point light source into the next optical system.
3. Star magnitude simulation

After the study, it was found that the use of neutral density filter could achieve the required adjustment purposes. In the case where the light energy transmittance was substantially constant, the neutral density filter could equally attenuate the light intensity at all wavelengths of the light source. In the system, in order to adjust and control convenience, the circular gradient of the neutral density filter was chosen to use.

Two neutral density filters were used in the system. The light source passed through the band light intensity controller after passing through the prismatic light system. Two rounded neutral density filters were installed after the frosted glass, and the decay times of the two neutral density filters were 10 and 1000 times, respectively. When the light source arrived, the first neutral density filter was adjusted, to whatever the light source was attenuated to the same energy level, and then fine-tuned the second neutral density filter. Two neutral density filters were controlled by two stepper motors.

The use of neutral density filter as the stars and other adjustments was the biggest advantage of the system is the adjustment of the stars and the band was completely separated from the regulation, that was, the system's spectral adjustment and light intensity adjustment completely separated. So the system of stars and other adjustments would no longer be affected by the previous light source system, thus enhancing the system's anti-jamming capability.

4. Experimental verification

A test platform was built for labs and spectrally adjustable single-star simulator systems. The main optical instrument used was a spectrometer, and the software used was OSM-Analyst. The color temperature was tested in 2600K, 3600K, 4300K, 5000K, 5500K, 6000K, 6800K, 7600K, 9800K under the circumstances of the various spectra. Figure 5 and Figure 6, respectively, 9800K color temperature simulation and the overall star simulation test results. Verification could be a high-precision simulation of single stars, and in the reliability and cost control had a good performance.

Figure 6. Spectral fitting curve at 9800K
Table 1. Standard stars and other color temperature in the case of the actual test table

| star standard value | 9800 K | 7600 K | 6800 K | 6000 K | 5500 K | 5000 K | 4300 K | 3600 K | 2600 K |
|---------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| 0                   | 2.1    | 2.17   | 2.1    | 2.09   | 2.18   | 2.12   | 2.15   | 2.13   | 2.11   | 2.05   |
| 0.5                 | 1.33   | 1.32   | 1.32   | 1.31   | 1.35   | 1.34   | 1.34   | 1.33   | 1.33   | 1.3    |
| 1                   | 0.836  | 0.83   | 0.84   | 0.81   | 0.86   | 0.84   | 0.85   | 0.82   | 0.81   | 0.82   |
| 1.5                 | 0.527  | 0.53   | 0.52   | 0.51   | 0.55   | 0.53   | 0.54   | 0.53   | 0.52   | 0.52   |
| 2                   | 0.333  | 0.35   | 0.34   | 0.32   | 0.37   | 0.34   | 0.35   | 0.34   | 0.31   | 0.32   |
| 2.5                 | 0.21   | 0.22   | 0.21   | 0.24   | 0.23   | 0.2    | 0.2    | 0.2    | 0.2    | 0.2    |
| 3                   | 0.132  | 0.13   | 0.14   | 0.13   | 0.12   | 0.13   | 0.14   | 0.13   | 0.13   | 0.12   |
| 3.5                 | 0.084  | 0.085  | 0.08   | 0.086  | 0.079  | 0.086  | 0.088  | 0.085  | 0.081  | 0.084  |
| 4                   | 0.053  | 0.05   | 0.052  | 0.054  | 0.049  | 0.055  | 0.051  | 0.055  | 0.052  | 0.055  |
| 4.5                 | 0.033  | 0.03   | 0.031  | 0.035  | 0.034  | 0.034  | 0.029  | 0.036  | 0.034  | 0.035  |
| 5                   | 0.021  | 0.021  | 0.022  | 0.02   | 0.019  | 0.022  | 0.023  | 0.024  | 0.019  | 0.02   |
| 5.5                 | 0.013  | 0.013  | 0.014  | 0.015  | 0.012  | 0.014  | 0.011  | 0.012  | 0.013  | 0.012  |
| 6                   | 0.008  | 0.008  | 0.007  | 0.006  | 0.009  | 0.008  | 0.009  | 0.008  | 0.007  | 0.008  |
| 6.5                 | 0.005  | 0.005  | 0.004  | 0.005  | 0.005  | 0.005  | 0.006  | 0.005  | 0.005  | 0.005  |

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