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Adjustable contrast optical target device for test of acquisition of photoelectric theodolite

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A new device used to detect the low contrast target acquisition of photoelectric theodolite is designed and its reliability is experimentally demonstrated. The adjustable contrast optical target device, which can simulate the sky background luminance and a low contrast target, is established. It utilizes a big integrating sphere and a small one to simulate the luminance of the background and target respectively. Importantly, by controlling the luminous flux of the two integrating spheres, the targets and background radiance can be continuously adjustable under the condition of constant color temperature. Thus, the contrast can be controlled continuously in the range of 0%–90% and its stability is better than 1%. The biggest background luminance exceeds 60 W m^{-2} str^{-1} in the spectral range of 400–800 nm.

photoelectric theodolite, adjustable contrast, integration sphere, collimating lens

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1 Introduction

The ability to capture and recognize low contrast target of tracking and measuring equipment television system is an important index. It directly affects the device tracking performance and effect of distance [1−3]. In order to examine the tracking and measuring equipment visible light TV system for weak signal detection and acquisition ability, it is necessary to study and test its target contrast index. Many factors implicate the index such as optical lens imaging quality, transmittance, stray light coefficient, signal-to-noise ratio, image processing algorithms etc. [4−6]; however, there is no special device which can be used to test it.

Up until the present moment, the validation method is using a known signal-to-noise ratio of the analog electrical signal to test whether the image processor can capture it or not. It does not contain the effects that the optical system, television sensor and circuit noise signal roll in the target contrast. Therefore, this method cannot reflect the overall performance of the TV system [7−11].

The best method is to establish a target device whose contrast can be adjusted continuously. This device can simulate different luminance of the target and background. In addition, the luminance of the target and background can be real-time measured and get known contrast target. The target geometry can be made into various styles according to the needs. The reliability and authenticity of the device's performance can be ensured when the photoelectric tracking and measuring equipment for low contrast target capture capability are studied and validated through the target whose contrast is known.

Many types of photoelectric tracking and measuring

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equipments such as theodolite and aerospace photoelectric detection device have clear inspection requirements to target contrast [12]. The currently used test methods are not sufficient to verify the requirements, so it is very necessary to develop a device, which can test the low track and capture contrast target ability.

ACOTD (adjustable contrast optical target device) is designed for photoelectric equipment to test low contrast target acquisition capability. It can simulate the sky background radiation brightness and the context of an adjustable contrast target which ranges from 0 to 90%. The contrast can be obtained by spectral radiance meter for measurement and calibration. Photoelectric equipment television system receives this known contrast target, so that the acquisition ability on the contrast target can be tested.

2 Design scheme

The device is mainly composed of two integrating spheres. The big one simulates background light and the small one simulates the target. The two integrating spheres have their own lighting source. They adjust the diaphragm to control the brightness of the two integrating spheres to form the contrast of target and background respectively. The collimating lens and a target plate are installed on the big integrating sphere, and the target plate is placed on the collimating lens focal surface to form an infinite target that is lighted by the small integrating sphere. Two integrating spheres are respectively installed on a spectral radiance meter in order to measure the integrating spheres' spectral radiation brightness real time and calculate the contrast of target and background. The principle diagram is shown in Figure 1.

The device can be used to simulate the sky uniform background and the context of a target. Background luminance changes meet the dawn to dusk day variation range, and the maximum brightness should reach sky brightness on the summer solstice when the solar elevation angle reaches 70°. Target contrast range is mainly to meet the needs of low contrast test. 0–20% of the target contrast is the most commonly used range. Target brightness range and the maximum value are close to background brightness. In addition, the aim should be infinite target. It should satisfy the testing within 250 mm aperture. The system design includes collimating lens optical and structural design, the integrating ball design, lighting design and so on. The design should meet the general requirements of photoelectric equipment contrast testing.

2.1 Collimating lens optical design

As an infinite target benchmark testing equipment, the caliber of the collimating lens should be wider than the detected optical system aperture. The ratio of the collimating lens focal length to the measured system focal length is bigger, the detection precision is higher, and the detection accuracy is higher. However, the cost is 3–5 times of the inspected optical system focus.

Collimating lens is mounted in the bigger sphere, and it makes the simulated target become an infinite one [13, 14]. The simulated target is in integrating sphere, and it should be in the collimating lens focus at the same time. So collimating lens rear intercept should be larger than the integrating sphere diameter, and the error cannot exceed the collimating objective overall adjustment distance.

According to this requirement, collimating lens offer the following technical requirements: 1) aperture D=250 mm; 2) rear intercept L=2000 mm; 3) designed wavelength w= 0.5–0.70 μm; 4) collimating lens system aberration is better

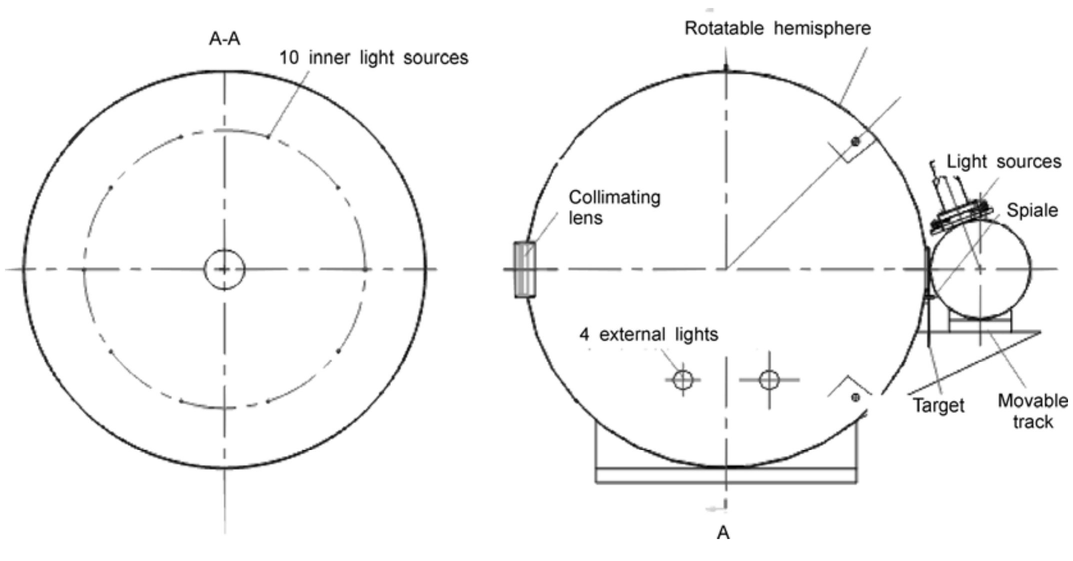

Figure 1 Structure diagram of the big and small integrating spheres.

thanλ/10 (rms).

At present, the basic forms to detect collimating lens are the following ones: reflection, transmission, catadioptrics, etc. [15, 16]. According to the requirements of the implementation of the program, the collimating lens uses double separation optical system. Image aberration of the dual lens system functions very well. However, in order to ensure the rear intercept, it needs precise alignment and two lens groups must be in the tolerance range.

2.2 Integrating sphere structure design

There are two basic types in the integration sphere structure. One is that the two hemispheres are fixed through the flange connection, which makes the integrating sphere have good integral rigidity and not easy to be deformed. The second is that one hemisphere is fixed and the other connected with it through a rotating shaft. This connection mode makes the two hemispheres rotate relatively, so that it will be easy to be installed and maintained routinely. Considering the usage, the small sphere is manufactured with the first structure and the large one with the second structure.

The large integrating sphere is installed on collimating lens, lighting source, detector, target board and other parts. The small one is mounted on lighting source and detector. It should take full account of all the parts of the installation, adjustment and rationality of the layout when designing the integrating sphere structure [17, 18].

According to the principle of integrating sphere, the following relationship is established [19]:

$$L_s = \frac{\Phi_i}{\pi A_s}\frac{\rho}{1-\rho(1-f)}, \quad (1)$$

where L_s is the surface radiance of the integrating sphere; Φ_i, radiation flux of the light source; A_s, total surface area of the integrating sphere (including the opening part); ρ, diffuse reflectance of the integrating sphere surface; f, orifice coefficient, and $f = \frac{A_0}{A_s}$; A_0, orifice area of the integrating sphere surface.

Let $M = \frac{\rho}{1-\rho(1-f)}$, M is the amplification factor. It is of value, which is related to the integrating sphere parameters, and it directly affects the output spectral radiation brightness of the integrating sphere. When the input radiation flux is constant, it is proportional to the output of the integrating sphere. Figure 2 shows the relation between the integrating sphere parameters and M. As can be seen from the figure, the small opening coefficient and high diffuse reflectivity can greatly improve the value of M. Proper selection of F and ρ can reduce incident radiant flux at the premise of ensuring the integrating sphere spectral radiance, thereby reducing the amount or intensity of illumination light source.

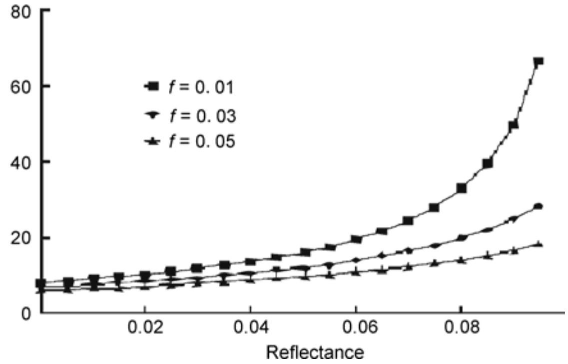

Figure 2 Relation curve of integrating sphere parameters and the amplification coefficient M.

According to the inspection of optical lens technical requirements, the integrating sphere structure size should meet the following conditions [20, 21]: the large integrating sphere diameter is 2 m; collimating lens is installed at the opening, whose effective aperture is 250 mm; installation hole diameter is not more than 280 mm and maximum object size is 50 mm; the small integrating sphere light outlet diameter is not less than 55 mm, whose diameter is 500 mm; at last, two 30 mm-diameter installation holes are set apart for installing spectral radiance meter probes in the two integrating spheres.

According to the selection principle, the parameter f of the integrating sphere should not be greater than 0.05. In order to achieve better effect, f is determined not more than 0.02 to design the lighting opening size and number in the integrating sphere.

Integrating sphere opening is used to install collimating lens, external illumination source, detector and target board. In the large integrating sphere, there are 10 halogen lamps as the built-in illumination light sources and the opening diameter is 20 mm. And other settings are: external light sources adopting 4 halogen lamps, the opening diameter 100 mm, detector openings 5, diameter 10 mm, target maximum opening diameter 50 mm, collimating lens opening diameter 280 mm, the calculation of f=0.01. In small integrating sphere, there are 2 halogen lamps as external illumination light sources and the optical aperture is 70 mm, detector opening 1, diameter 10 mm, target maximum opening diameter 50 mm, the calculation of f=0.02.

In the large integrating sphere, the distributed position principle of 10 built-in light sources and 5 detectors distributed position principle is: light sources are installed in the mobile hemisphere and with the horizontal plane 45°. In order to study whether the radiance of different fields of imaging view is uniform or not, the detector is located outside the field of imaging view and close to its edge arranged horizontally. There is shading plate before the light source, and its size should be suitable so that the light is not directly irradiated to the opening of the collimating lens, the target and the detector.

Four external illumination sources of the large integrating sphere distribution method should make parallel beam projection position the farthest from the center of sphere surface, so that it can effectively control the beam which reflects once through the integrating sphere upon the arrival of collimating lens opening and a target hole. Similarly, two external illumination sources of the small integrating sphere distribution method should make parallel beam projection position farthest from the center of sphere surface, it can effectively control the beam to reach the goal of opening when being reflected through the integral ball, at the same time detector installation location can have direct light.

The small integrating sphere connects with the active hemisphere of the large one. In order to facilitate the replacement of target board, the pitch between the two spheres should be able to adjust. So the small sphere is installed on a linear mobile platform and it can realize the adjustment of the two spheres' space.

Target hole is designed as a series of different diameter holes. In order to reduce the replacement numbers of the target holes, a plurality of target hole is arranged on the circumference of a large circular plate. The mounting hole is in the center of the circular plate that is eccentrically mounted on the large integrating sphere opening. The eccentric distance makes the target hole just locate in the center of the view of the collimating lens. The circular plate can rotate around the center rotation, which can freely used by the target board. Figure 3 is the schematic diagram of the target plate.

2.3 Illumination source design

There are two options of lighting, namely the illumination source is in the integrating sphere or out of it. There is diffuse light inside the integral sphere. And the spectral radiance of the light is uniform [22]. When the spectral radiance of the target and background is measured, there should be no illumination source lighting a receiver directly. Like using integrating sphere lighting way, the advantage is that it can use the light flux fully and reduce the quantity of illumination light source. However, it needs many baffles to shade the direct rays of light source, so that the illuminating beam cannot be directly incident on the field of imaging view of target and background and cannot be directly injected from the collimating lens either. In this way, it is difficult to control the luminous flux through adjusting the aperture. It can be completed only by adjusting the current way to change the brightness of the light source, but the light temperature will be changed at the same time and this makes the light source spectral distribution change which affects the spectral radiance measurement. Thus, the light way should not be selected at all.

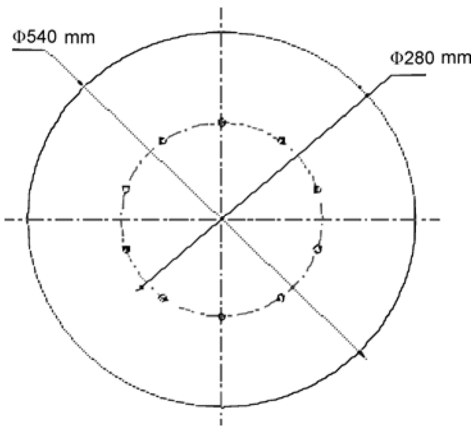

Figure 3 Schematic diagram of target plate.

The outdoor lighting way of integrating sphere should consider how to use the luminous flux of the light source and arrange the light source in the parabolic mirror focus, so that the divergent beam can be made into parallel beam and irradiate the inner wall of the integrating sphere. It controls the luminous flux irradiating into the integrating sphere by adjusting the diaphragm aperture. As a result, the light flux can be fully utilized, while the light source heat dissipation and integrating sphere radiation brightness adjustment can be realized easily. However, it is costly to manufacture this kind of external light sources compared with inner ones. The lighting source and control power supply will have to be increased for the integrating sphere to reach the same light spectral radiance. Based on the advantages of these two kinds of lighting way, the large integrating sphere uses a combined method. 10 inner and 4 external light sources are installed in the sphere, these light sources maintain stability current and voltage during using. The aperture is adjusted continuously to control the external luminous flux, which should be close to an inner light source while the luminous flux adjustment quantity is equivalent to it. In order to make the radiance continuously change the diaphragm aperture should be readjusted. Thus, we can get arbitrary contrast target. An external light source mechanical structure is shown as in Figure 4.

Parabolic mirror 5 via the radiating cylinder 6 connects with the integral ball 7 and is fixed on the connecting board. In addition, the filament can be adjusted to the parabolic mirror focus. The adjustable stop mechanism is mounted on the integrating sphere connecting plate and it drives the diaphragm-moving blade by the way of the screw nut rotating screw rod. Above the ϕ100 mm aperture there are two half round blades which move relatively to change the actual aperture size, so as to achieve the purpose of control flux. Adjustable diaphragm mechanism diagram is shown in Figure 5.

The external lighting CAD effect diagram is shown in Figure 6.

2.4 Contrast calibration

Target contrast calibration measurement is the important

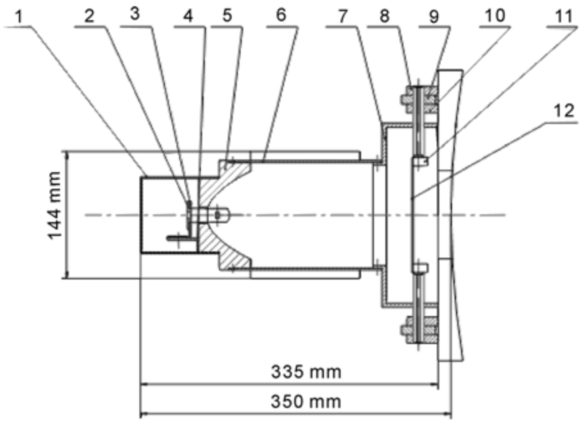

Figure 4 External illumination light source structure. 1, Mask body of wires; 2, connection columns; 3, lamp holder; 4, connector between 1 and 5; 5, parabolic mirror; 6, radiating tube; 7, fixing plate of 6; 8/10, fixed columns of 9; 9, adjustable diaphragm nut; 11, wire rod; 12, the through hole.

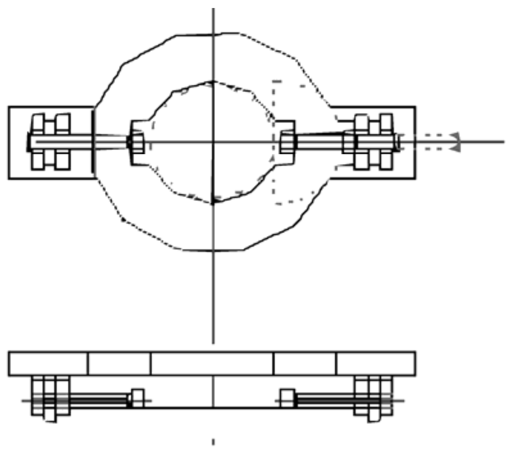

Figure 5 Adjustable diaphragm structure diagram.

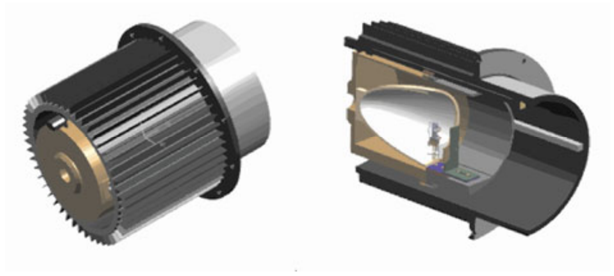

Figure 6 External lighting CAD effect diagram.

part in the development of ACOTD. The development objective sets measurable targets with low contrast device. Contrast is measured and calibrated according to the brightness of the target and background in the actual use. The contrast C is calculated according to eq. (2) [23]:

$$C = \frac{N_B - N_M}{N_B}. \tag{2}$$

In which, N_B and N_M are the brightness of background and target respect.

The measuring instrument used to calibrate target contrast is PR735 spectral radiometer produced by the United States PHOTO RESEARCH (Figure 7).

The PR735 spectral radiometer is placed on the imaging side of the collimating lens, and the image of the measured target or background is formed within the effective view of it through the collimating lens. The target or background brightness is measured respectively and the target contrast is obtained by calculation. This measurement includes the effects of the collimating lens and background environment on target contrast, and it is consistent with the actual test situation. So the calibration measurement is accurate.

3 Test results of the technical indices

When ACOTD is developed completely, each technology index is inspected and the test results meet the requirements of various technical specifications.

3.1 Contrast range

Index requirement: 0–90%.

Inspection method: The target and background spectral radiance should be measured on the imaging side of the collimating lens by using PR735. At last, the target and background contrast are calculated. Because independent control light sources are used to control the spectral radiance of the target and background, the background and target contrast C can achieve the contrast range. When the target and background radiation brightness is uniform, calculation contrast is 0. When the target illumination sources are close, the background radiance and the largest object luminance are measured. Through calculation, the contrast is 91.4%.

Test result: 0–91.4%.

3.2 Effective aperture

Index requirement: ⩾ϕ250 mm.

Figure 7 PR735 spectral radiometer.

Effective aperture refers to the effective aperture of the collimating lens, and it decides the applicable scope of ACOTD. When the collimating lens is designed, this index has been ensured to meet the requirements from the optical and structural size.

Inspection method: It should use tape to measure the collimator diameter to confirm its conformance.

Test result: ϕ250 mm.

3.3 Spectral range

Index requirement: 350–1050 nm.

The purchased product fiber optic spectrometer QE65000 works in the wavelength range of 350–1100nm. The spectral radiometer PR735 works in the wavelength range of 380–1080 nm. Both can satisfy the measurement requirements.

3.4 Color temperature of the light source

Index requirement: 3000 K±5 0K (or according to the actually purchased light source).

In the integrating sphere, it chooses halogen light as light source and uses PR735 to measure the color temperature. The measurement temperature is 2849 K. It is worth mentioning that, as the whole equipment is in normal operation and on the premise of steady operation, all the halogen lamps are opened to the brightest state. The inside brightness of each integrating sphere is changed by adjusting the diaphragm in front of every halogen lamp. The color temperature of each integrating sphere is determined by the degree of opening and closing the apertures, so it is constant in different brightness.

3.5 Contrast steady precision

Index requirement: $|\Delta C| \leqslant 1\%$.

Inspection method: Contrast steady precision mainly refers to the steady precision under low contrast. Under the 3% contrast, it chooses any background luminance to measure repeatedly and calculate its repeatability.

Test result: 0.3%.

3.6 Maximum background radiance

Index requirement: 38 W m^{-2} str^{-1} (380–780 nm).

Inspection method: PR735 is used to measure the spectral radiance of the background, which is formed by integrating sphere and near target (to ensure the measuring position in the imaging field of view). The measurement condition is that all the light sources in the integrating sphere are opened and spectral radiometer measurement ranges are from 380 nm to 780 nm band.

Test result: 43.3 W m^{-2} str^{-1}.

4 Conclusions

ACOTD is used to test the low contrast target acquisition capability of a photoelectric theodolite. The test contains 4 test points: 1) bright target from capture to the lost state; 2) dim target from the lost state to capture state; 3) dim target from capture state to the lost state; 4) bright target from the lost state to capture state.

Table 1 gives the test results of the photoelectric theodolite for capability of low contrast target acquisition.

The 4 states are the working ones of the theodolite in the practical use. There has never been a quantitative test result of the 4 states of the contrast. Through testing the photoelectric theodolite for capability of low contrast target acquisition using ACOTD, the test, for the first time in China, achieved quantitative evaluation and obtained resulting data of the target acquisition capability. This development fills the domestic gaps in the field of photoelectric measuring equipment and it is important for future work in the field of measurement. At the same time, it provides an effective means for quality inspection of military equipment.

The project has achieved the anticipated target:

1) A measurable low contrast device has been set up for the first time.

2) The photoelectric theodolite for low contrast target

Table 1 Test results

Background luminance: highlight (35 W m^{-2} str^{-1})			
Target brighter than the background		Target darker than the background	
Work state	contrast	Work state	contrast
From the target search state to the target capture state	6%–13%	From the target search state to the target capture state	12%
From the target capture state to the target lost state	5%	From the target capture state to the target lost state	9%
Background luminance: dark (6 W m^{-2} str^{-1})			
Target brighter than the background		Target darker than the background	
Work state	contrast	Work state	contrast
From the target search state to the target capture state	12%	From the target search state to the target capture state	10%
From the target capture state to the target lost state	8%	From the target capture state to the target lost state	6%

acquisition capability test has been realized for the first time

3) Low contrast target acquisition capability testing methods and procedures are proposed filling the gaps in the field of photoelectric equipment inspection in China.

In future work, in order to make the target and background state reach the best level and further enhance the contrast measurement accuracy, we will further improve the device performance and explore better manufacturing materials and manufacturing processes especially the target plate making process.

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1 Li H Y, Hu Y A. Correction method for photoelectric theodolite measure error based on BP neural network. In: Proceedings of ICICIS, Heidelberg: Springer, 2011. 225–230
2 Zhao W G, Wang L Y, Wang Y K, et al. The study of film theodolite precision measurement in outside by measuring star based on GPS time system (in Chinese). J Changchun Univ (Nat Sci), 2006, 29(4): 27–29
3 Gao C, Qiao Y F. Real-time error-correction method for photoelectrical theodolite (in Chinese). Opt Precis Eng, 2007, 15(6): 846–851
4 Du W C, Wang G H, Gao X Q. New method to extract radial acceleration of target from short-duration signal at low SNR. Sci China Tech Sci, 2008, 51(5): 556–575
5 Huang K W, Tao R, Wu K, et al. Study on interference suppression based on joint fractional Fourier domain and time domain. Sci China Tech Sci, 2011, 54(10): 2674–2686
6 Li M, Gao H B. Tracking error modeling of the theodolite based on GRNN method. Appl Mech Mater, 2012, 121(10): 4870–4874
7 Long H W, Shen X H, Ma J. Miss distance error due to rotation of CCD sensor imaging surface and its testing method (in Chinese). Opt Precis Eng, 2003, 11(6): 607–611
8 Yin L M, Zhang Y. Image processing method for small target in low contrast image. In: Proceedings of IEEE Conference on Intelligent Information Systems and Applications (the International Symposium, Qingdao, China), 2009
9 Zhang Y, Yong Y, Zhang Q H. Detection of dim point target with low contrast. High Power Laser Particle Beams, 2010, 22(11): 2566–2570
10 Li L Y, Wang Y F, San X G. Stray light analysis of solar photoelectric detection system on space target. Science, 2012, 466-467: 196–200
11 Ye L, Gu L S, Shen X H. Design of adjustable contrast optical target (in Chinese). J Appl Opt, 2010, 31(5): 681–684
12 Mi Y. Focusing control system of photoelectric theodolite based on CAN bus. In: Proceedings of IEEE Conference on Computer Engineering and Technology (ICCET) (2010 2nd international Conference, Chengdu, China), 2010
13 Kothiyal M P, Sirohi R S, Rosentoruch K J. Improved techniques of collimation testing. Opt Laser Technol, 1988, 20(3): 139–144
14 Liao Z P. Transmitting boundary and radiation conditions at infinity. Sci China Tech Sci, 2001, 44(2): 177–186
15 Suzuki H, Sugie T. Optimal input design for system identification in the presence of undermodeling. 46^{th} IEEE CDC, New Orleans, 2007. 5522–5527
16 Aguero J C, Goodwin G C. Choosing between open-and closed-loop experiments in linear system identification. IEEE T Autom Control, 2007, 52(8): 303–307
17 Alfred D C, Arnold D, Eric G, et al. Design of an Integrating Sphere as a Uniform Illumination Source. IEEE T Educ, 1997, 40(2): 131–134
18 Leo N H. Integrating-sphere system and method for absolute measurement of transmittance, reflectance, and absorptance of specular samples (in Chinese). Appl Opt, 2001, 40(19): 3196–3204
19 Li W Y, Zhang W L, Yuan C, et al. Discussion on the position of light emitting diodes (LEDs) in the total flux measurement with integrating sphere. J Fudan Univ (Natl Sci), 2007, 46(3): 356–359
20 Li W J, Zhang Y, Chen Y H, et al. Portable target generator with adjustable contrast. Opto-electr Eng, 2005, 32(10): 56–61
21 Tim B, Alan I, Paul B, et al. Advanced test systems for production testing of cameras with day/night and visible/NIR capabilities. Proc SPIE, 2005, 57(84): 272–279
22 Yamamoto Y J. Development of a spectral response calibration system using a wavelength-tunable laser and an integrating sphere. SICE, 2002, 5(7): 2082–2087
23 Wang G, Yu B X. Approach to estimate infrared point_target detection range against sky background based on contrast (in Chinese). Opt Precis Eng, 2002, 10(3): 276–280