Applied research on the homogenization technology of laser illumination

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Abstract: In order to achieve laser uniform illumination, a new laser homogenization system was designed based on the analysis of regular homogenization technology, and the homogenization technology and the uniformity of laser illumination were researched. The new homogenization system used brushless motor to drive a light shaping scatterer to rotate at a frequency faster than the electronic shutter of cameras, making multiple light superimposed in integration time to form a uniform illumination effect. The new homogenization system can eliminate laser speckles and interference fringes, and realize the purpose of homogenization. Experimental results show that the new homogenization system makes the illumination uniformity reach up to 95% and the energy efficiency reach up to 90% in the effective area. The new homogenization system improves the uniformity of illumination and utilization rate of laser, thus improves the image quality of the illuminated target.

Key words: laser illumination; homogenization technology; light shaping scatterer; uniformity; utilization rate of laser

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激光照明匀光技术的应用研究

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摘 要:为了实现激光均匀照明,在分析常规匀光技术的基础上设计了新型的激光匀光系统,并对该系统的匀光技术及光斑均匀性进行研究。新型的匀光系统是利用无刷电机带动光束整形散射器以高于摄像机电子快门的频率旋转,使多支光束在积分时间内叠加,形成一个均匀照明效果。新型的匀光系统能够消除激光散斑与干涉条纹,实现匀光的目的。实验结果表明:新型匀光系统使激光光斑有效区域内均匀性到达 95%以上,光能利用率为 90%。新型匀光系统提高了照明均匀性及光能利用率,从而提高了被照明目标的成像质量。

关键词:激光照明; 匀光技术; 光束整形散射器; 均匀性; 光能利用率

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0 Introduction

Now the microlight night-vision technology and the Complementary Metal Oxide Semiconductor(CMOS) and Charge Coupled Device(CCD) imaging technology with low illumination have made great progress, however, light is so weak that they can only get high noise and low resolution images in low illumination circumstances. The near-infrared night vision technology can improve the illumination effect at night especially over long distance. The technology can provide illumination at night to meet the illumination requirements of the target scene when imaging or shooting at night with a character of concealment. The near-infrared night vision illumination technology adopted mainly two types of light sources, one is Light-Emitting Diode (LED) source and the other is laser source. Single LED source could not satisfy the requirements of application owing to the limitation of illumination distance and intensity. In order to realize night vision illumination with high brightness and long distance scenes, the number and power of LED lamp beads are increased at the expense of heat dissipation ability and service life. The above problems seriously restrain the application of LED in security field.

Semiconductor laser is applied more and more extensively in the field of security because of its high luminous efficiency, small divergence angle and high brightness. Well-packed laser diode can′t directly used for night vision illumination like LED light source. The distribution of laser source is not uniform in the vertical section, light intensity approximately obeys a Gaussian distribution[1], and become weak gradually from the middle to the edges of illumination district. The monochromaticity of laser will cause multiple beam interference and produce laser interference fringes and speckles[2-3]. The above two shortcomings seriously affect the image quality of illumination target. The nonuniformity of semiconductor laser[4] largely hinder its application in the field of illumination. So near infrared laser needs to be homogenized making the laser project to the illumination target surface uniformly so as to improve the image quality of target.

1 Analysis of present homogenization technologies

Now security precaution night vision illumination commonly uses two types of laser homogenization, one is frosted glass homogenization and the other is optical fiber transmission homogenization[1]. The frosted glass is made of common flat glass by mechanical sandblasting, manual grinding or hydrofluoric acid dissolution and so on. The surface of frosted glass spreads many small particles which are equivalent to micro lens[5-6]. It can shape laser beam[7-11]. Laser beam is refracted by micro lens and then randomly superimposes on the target surface[12]. It is the superimposition that makes each laser interference fringe distributes discretely. Although the frosted glass can smooth the laser interference fringe, but the surface with micro structure can make the laser beam project to the target surface and present large speckles[13]. Besides the glass has larger divergence angle (more than 10°) and low light transmittance(50%-60%), so it is hard to gather and utilize the light. In a word, the frosted glass homogenization can improve the uniformity of illumination intensity, but the uniformity is not very good. Furthermore, the frosted glass reduced the energy utilization of laser, so the effect of the frosted glass homogenization isn′t so perfect.

Optical fiber transmission homogenization means that laser beam is coupled into the fiber from the entrance of the optical fiber, then lights generate multiple total reflection and spread forward in the optical fiber. Finally the laser beam redistributes in the export of optical fiber. Although the exit energy from optical fiber is relatively uniform, the small laser speckles can still be detected. Because the length of optical fiber should not be too long in actual application, so its homogenization effect is not so good. Furthermore, the optical coupling efficiency of fiber is relatively low resulting in lower energy utilization and higher manufacture cost [1]. These deficiencies are not conducive to its application and promotion in the market[14].

2 Design of novel laser homogenization systems

The previously mentioned common homogenization methods are not ideal, they all have some deficiencies in some degree. This paper designs a new laser homogenization illumination system which uses brushless motor to drive the homogenization device to rotate at a high speed.

2.1 Beam shaping diffuser

Traditional homogenization methods have low light transmittance and poor uniformity. To make up for the deficiencies of the present laser homogenization method, this paper chooses a scattering screen which produced by holographic exposure technology as the new laser homogenization device, we named this device as Light Shaping Scatter (here in after abbreviated as LSS). The sub-micron microstructure is arranged aperiodically on the surface of LSS (as shown in Fig.1). Every micro structure is

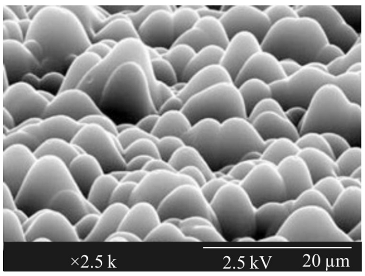

Fig.1 Aperiodic microstructure of LSS surface

equivalent to a micro lens, the light will be refracted, reflected and scattered by micro lens in multiple angles and multiple directions, relying on the split beam and the superimposition of the split sub-beam to make the laser beam uniformly distribute. The size, shape and arrangement of the small particles jointly determine the shape, divergence angle, light transmittance and the other energy distribution information of the laser beam[15-16].

The wavelength and divergence angle of the beam determines the transmittance of LSS with the same material and the same thickness. To the light of 400 nm to 1 500 nm wide spectral, the transmittance of 2 mm thickness LSS is in the range of 85%-92%, specific value of the transmittance depends on the divergence angle and wavelength of the beam. The light transmittance of LSS with the divergence angle of 1° and 10° are shown in Tab.1.

Tab.1 Relationship between divergence and transmittance

Angle	532 nm	632 nm	808 nm	1 064 nm	1 550 nm
1°	92%	91%	90%	89%	89%
10°	90%	90%	89%	89%	88%

In order to collect and utilize the laser beam, LSS with 1° divergence angle is selected, and its light transmittance to the 808 nm laser is 90%. LSS make the beam split and superpose to achieve energy uniform distribution. Although LSS has improved the light transmittance and the uniformity compared with the conventional homogenization methods, owing to the microstructure of LSS, there are a lot of speckles on the target surface, which will affect the illumination effect. So just use LSS alone cannot achieve perfect homogenization effect.

2.2 LSS rotating homogenization system

Homogenization system not only should eliminate the interference fringes of laser beam, but also should homogenize the granular speckle produced by LSS. In this paper, brushless motor is used to drive LSS to rotate at a high speed, and then enables multiple coherent beam to superimpose within the visual integration time. It has the characteristics of statistical distribution. The average visual effects eliminated the laser interference fringes and the granular speckles, and then achieve the goal of laser uniform illumination.

In order to avoid illumination speckles vibrating, LSS periodically rotation needs to meet the two conditions: first, the rotation axis of the motor should parallel to the optical axis direction (LSS plane should perpendicular to the optical axis); second, the rotation frequency of the motor driven LSS is greater than the frequency of the camera electronic shutter. If the two conditions are satisfied, equal area region receives the same amount of energy on the target surface, it means that the energy density equal on the target surface. Rotating LSS will effectively eliminate the laser interference fringes and speckles, then make light uniformly project on the target surface. LSS rotating homogenization system is shown in Fig.2. Laser illumination system is composed of 808 nm laser source with 2 W power, zoom optical system and LSS rotating homogenization system.

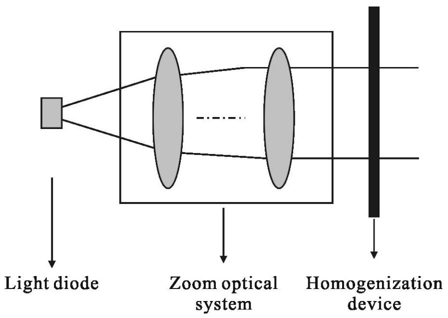

Fig.2 Laser illumination homogenization system

3 Experimental measurements and results analysis

3.1 Experimental measurements

Building experiment platform, in the pure dark night vision environment, laser illuminator without homogenization, and laser illuminator with frosted glass homogenization, optical fiber homogenization, LSS static homogenization and LSS rotating homogenization are respectively chosen as night vision source. In addition, DS-2CD864F-E IP camera (IPC) and TV0515D - MPIR zoom lens are combined as a surveillance camera. The measured parameters of the samples are as follows: the power of the public laser diode is 2 W; the thickness of frosted glass is 2 mm; the length of optical fiber is 1.5 m, NA=0.22; the divergence angle of LLS is 1°, the thickness is 2 mm.

Night vision test is conducted respectively in the above five groups of light sources, each group of experimental test has two tasks, the specific tasks and steps are as follows:

(1) The transmittance test of the homogenization devices

Using the PM100D & S310C type optical powermeter (THORLABS, a company of America) measured exit optical power and incident optical power of each homogenization system, the ratio of above two power is the light transmittance of the optical device. The calculation formula of light transmittance is shown in Eq. (1), the experimental measured data is shown in Tab.2.

$$T=\frac{P_o}{P_i} \quad (1)$$

where P_o is the exit optical power; P_i is the incident optical power; T is the light transmittance.

Tab.2 Transmittance of homogenization systems

Item	Qriginal	Frosted glass	Fiber	LSS static	LSS rotation
Exit power	2.00 W	1.20 W	1.52 W	1.80 W	1.80 W
Incident power	2.00 W	2.00 W	2.00 W	2.00 W	2.00 W
Transmission rate	100%	60%	76%	90%	90%

(2) Using DS-2CD864F-E IP Camera and TV0515D-MPIR zoom lens as surveillance cameras, and then respectively combined with five kinds of laser illumination systems to take images, as shown in Fig.3-7.

As shown in Fig.3, when there is no homogenization device, the semiconductor laser source generates some interference fringes. Fig.4 is the image of the laser illumination system with frosted glass,

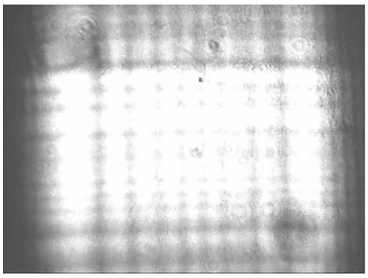

Fig.3 Laser interference fringes without homogenization

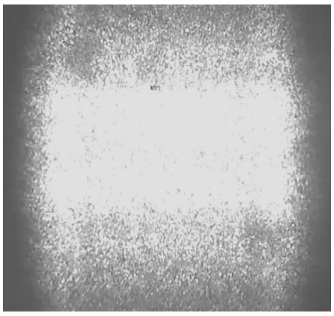

Fig.4 Illuminance image for frosted glass

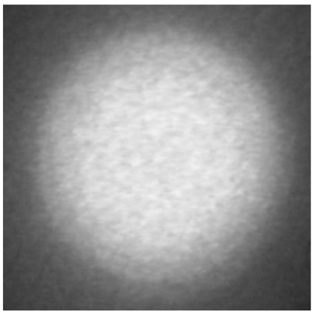

Fig.5 Illuminance image for fiber homogenization

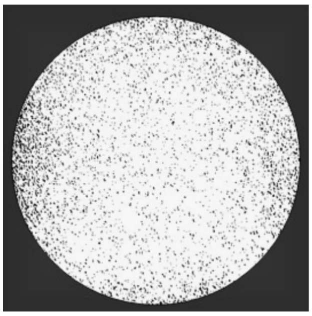

Fig.6 Illuminance image for LSS stationary

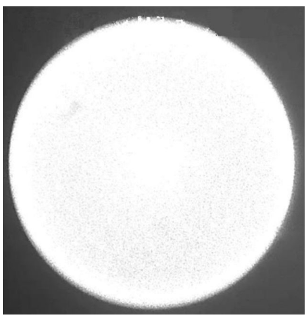

Fig.7 Illuminance image for LSS rotation

although the laser interference fringe has been eliminated, the micro particles on the surface of frosted glass generate the laser speckles. Fig.5 is the image produced by optical fiber, its homogenization effect is slightly better than the frosted glass. Fig.6 is the static LSS homogenization image, its effect is better than that of frosted glass and optical fiber, but the laser speckles are still clearly visible. Fig.7 is the image produced by LSS rotation homogenization, its uniformity is the best of previous several methods.

3.2 Results analysis

Matlab language is used for editing image processing program, and then respectively uses the program to process and analyze experimental images. We can respectively get three-dimensional illumination distribution figures, as shown in Fig.8–12.

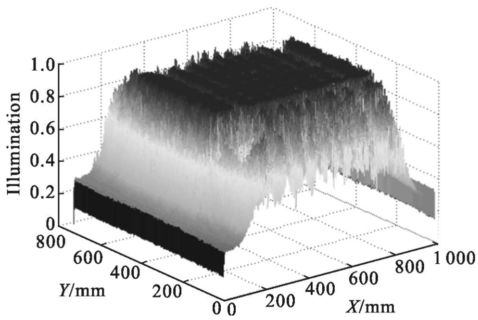

Fig.8 Illuminance distribution without homogenization

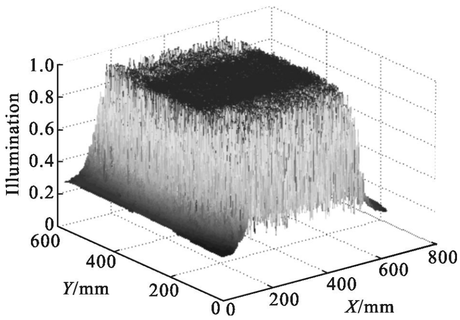

Fig.9 Illuminance distribution for frosted glass

From the three dimensional figures of illuminance distribution, we can more intuitively observe the nonuniformity which generated by the laser interference fringes and speckles . Fig.11 shows the illumination intensity distribution of speckles generated by LSS stationary, its uniformity is better than the traditional ones. But as shown in Fig.12, the homogenization effect of LSS rotation method is the best of the above five methods.

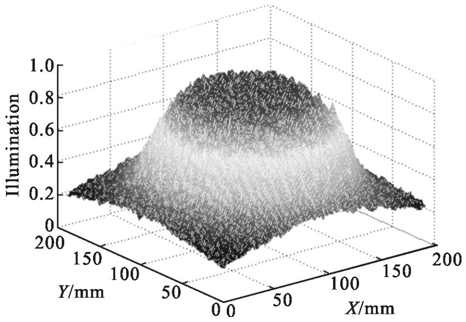

Fig.10 Illuminance distribution for fiber

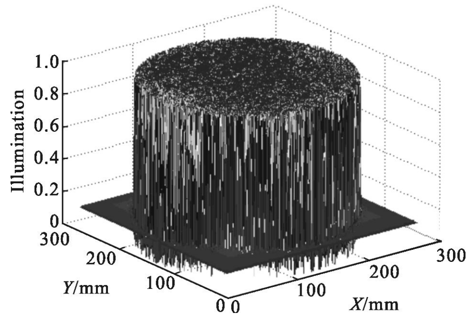

Fig.11 Illuminance distribution for LSS stationary

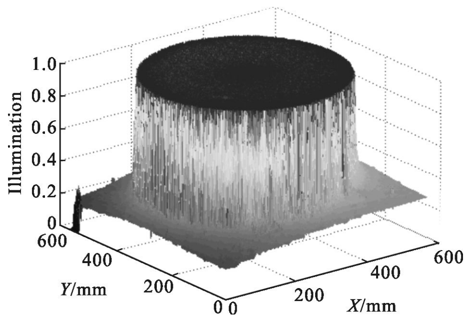

Fig.12 Illuminance distribution for LSS rotation

The properties of each homogenization method are compared from the transmittance, divergence angle, uniformity, image characteristics and the cost, as shown in Tab.3. The formula of the uniformity is

$$U=\frac{U_{ave}}{U_{max}} \tag{2}$$

where U_{ave} is the average intensity of illumination in the effective area of the target surface and U_{max} is the maximum intensity of illumination in the effective area of the target surface.

Tab.3 Characteristics of different homogenization methods

Method	Transmission rate	Uniformity	Divergence angle	Characteristic	Cost
Original	100%	49%	Original	Interference fringes	Low
Frosted glass	60%	67%	≥10°	Discrete spot	Low
Fiber	76%	71%	Change	Discrete spot	High
LSS stationary	90%	85%	1°	Discrete spot	Low
LSS rotation	90%	95%	1°	Uniform	Low

The divergence angle is defined as the divergent angle of the parallel light through the homogenization device. As shown in Tab.3, the divergence angle of the LSS rotation homogenization system is 1°, and the small divergence angle is easy to collect and utilized. In addition, the transmittance and the uniformity of LSS rotation homogenization system are 90% and 95% respectively. The comprehensive analysis of above all shows that the LSS rotation homogenization has the advantages of high light transmittance, better uniformity of illumination intensity, small divergence angle and low application cost, so it can solve the problem of nonuniformity of illumination which influences the image quality.

4 Conclusions

The laser beams interfere with each other and produce interference fringes with white and black patterns, so it seriously affected the image quality of the illumination target. The modern security industry requires the laser illumination high uniformity and high transmittance. So this paper proposes the LSS rotation homogenization method, design and analyzes the LSS rotation homogenization system. Through the comparison with traditional homogenization methods, we find that the light transmittance of LSS rotation homogenization system reaches up to 90% , the uniformity of the energy distribution runs up to 95% and the cost is lower. The LSS rotation homogenization system can perfectly solve the problem of the energy distribution nonuniformity which can influence the image quality, so it has broad prospects in the field of laser illumination.

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