Technique of pulse infrared laser assistant night vision*

BAI Lian-fa, ZHANG Yi, QIAN Wei-xian, ZHANG Chuang, CHEN Qian

(School of Electronic Engineering and Optoelectronic Technology,Nanjing University of Science and Technology, Nanjing 210094, China)

Abstract: On the basis of analysis on the stadia equation of the low light level (LLL) night vision system, the possibility is demonstrated that using pulse infrared laser array can improve the stadia of the LLL night vision system. The pseudo random laser enhancement technique is put forward to handle the limitation that the laser assistant system is easy to be detected. The pseudo random coding theory is studied, the control circuits of pseudo random laser modulating and image capturing synchronously are designed. The pulse infrared laser assistant system is established, many experiments and some observation evaluation on the experiments have been carried out. Some good results are obtained.

Key words: Low light level imaging; Laser assistant vision; Pseudo random coding; Image fusion; Synchronously control; Hue space mapping

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脉冲红外激光助视夜视技术研究*

柏连发,张 毅,钱惟贤,张 闯,陈 钱

(南京理工大学 电子工程与光电技术学院,江苏 南京 210094)

摘要:在分析微光夜视系统视距理论的基础上,论证了用脉冲红外激光阵列助视提高微光夜视系统视距的可行性。针对激光助视易于暴露的缺陷,提出了微光夜视伪随机瞬态激光增强技术。系统研究了伪随机编码理论,并硬件实现了瞬态激光伪随机编码调制及同步图像捕捉控制电路。建立了脉冲红外激光助视微光夜视系统,进行了多次室内、野外试验及试验结果观测评估,取得了较好效果。

关键词:微光成像; 激光助视; 伪随机编码; 图像融合; 同步控制; 色空间映射

0 Introduction

Night vision technology plays an important role in modern wars. The digital and color night vision is the development tendency and the improvement of the stadia of the night vision system is a permanent theme in the night vision technology[1].

In this paper, on the basis of the research of both

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作者简介:柏连发(1965-),男,山东临沂人,教授,主要从事光电探测成像及其信息处理方面的研究工作。

passive working mode and active mode night vision technology, improvement was made on research of the pseudo random coding, digital video control and process, and color display technology, thus a new active mode night version system which had hiding property was formed. This new system can greatly improve the quality of night vision image and increase the efficient distance of the system.

1 Stadia of pulse laser assistant night vision system

The vital factor limiting the stadia of the night vision system is that the system's photoelectric characteristics make the system not work effectively under all weather and outside radial illuminations conditions. The western countries have been making studies to handle the limitation of full passive work mode since the 1970s.

The core of the active mode is using an auxiliary light source to improve the illumination of the objects so that high effective definition solution can be gained and the stadia can be improved when the system works in bad environments. The auxiliary light source is mainly infrared laser or illumination bomb. In this paper, the improvement of the stadia of the laser illumination passive work mode is calculated by using infrared pulse laser array assistant illumination technique. There are too many factors involved [2~5]. In order to highlight the stadia improvement of laser illumination active mode system compared to the traditional passive one and to be more convenient while discussing, the equal factors to both systems are ignored. In other words, the real LLL imaging system as an ideal imaging system is considered simply.

The stadia equation and the threshold detect theory of the LLL vision system have been researched for many years and a quantity of experiments and theory analysis have been done. The classic threshold detect theory of the LLL image system considers that the objects can be observed when the vision signal-to-noise ratio provided by the imaging system is higher than the threshold signal-to-noise ratio of the human eye. Because of the quantum character of the photon and the electron, the process of the image transmitting and the enhancement of the LLL image system is fluctuated, the definition solution between two neighbor units is decided by the fluctuation of the photon in these units. The photon emission is a random process so the frequency distribution of the quantum is Poisson distribution.

Suppose the detail area of the objects is $a\,(\mathrm{m}^2)$, system accumulate time is $t\,(\mathrm{s})$, the sum of the photons from the object per unit area per unit time is n_1, the sum of the photons from the background per unit area per unit time is n_2, the threshold signal-to-noise ratio is $\Phi_{\min}$. The gained signal-to-noise ratio is

$$\Phi^2 = 2\bar{n}C^2 ta \tag{1}$$

According to the Devries-Rose criterion, the object can be distinguished when the signal-to-noise ratio Φ is higher than threshold signal-to-noise ratio $\Phi_{\min}$. The limitation is

$$2\bar{n}C^2 ta = \Phi^2_{\min} \tag{2}$$

Suppose the noise power factor of the image intensifier is F_ϕ; S is the integrating sensitivity of the photoelectric cathode(μA/lm); E_i is the illumination of the input window (lx); E is the electron charge (μC); ε is the length to width ratio of the object, the object's detail area is

$$a = \frac{10^{-6}\varepsilon}{4A_k^2} \quad (\mathrm{lp/mm})$$

$\bar{\rho}$ is the object's average reflectivity, f_0' (mm) is the objective focal distance, τ_0 is the objective transmittance. Given the night sky illumination E_0 (lx), the definition solution of the system A_k can be expressed as the equation

$$A_k=8.06\times10^{2}\frac{CD}{f_0'}\left(\frac{S\rho tE_0\tau_0\varepsilon}{f_\phi}\right)^{\frac{1}{2}} \quad (3)$$

The detecting distance of the LLL image system R_L can be expressed as the equation

$$R_L=\frac{f_0'A_kH_t}{N_e} \quad (4)$$

where H_t is the object's size; N_e is the space frequency needed to discover or tell apart the object.

From equation (3) and (4), its drawn that to the same object, if all the parameters of this LLL night vision imaging system remain unchanged, it is feasible to improve the stadia of the system by means of increasing the illumination of the environment (E_0). Pulse near infrared laser array can increase the illumination of the environment E_0, thus improve the spatial resolution of the system A_k, and the detecting distance of the system. Since the natural illumination is about 10^{-3} lx under starlight condition at night, and the illumination on photosensitive surface will be lower by two orders of magnitude because of optical reflection, the real working illumination of optoelectronic devices is about 10^{-5} lx. So the system resolution will be restricted by the photonic noise. According to characteristic curve of resolution, if the illumination on photosensitive surface is increased by one order of magnitude, the system resolution compared with the old one can be double. Since using the pulse near infrared laser array of 10^{-1} lx, the stadia of the system theoretically can be greatly improved. Considering the effect of all kinds of factors and losses in the real working conditions, the stadia of the system get considerable improvement anyway.

2 Pseudo random coding

In order to reduce the discovered probability of pulse infrared laser assistance night vision system, the emission of the laser should possess randomness as its basic requirement. Using pure random signal to control the laser emission is the best in theory, but it is very difficult to produce and copy and control the pure random signal [6]. While the pseudo random sequence has some statistic properties similar to random signal and it is easy to be produced and reproduced [7]. So pseudo random sequence (*m* sequence) is chosed to modulate the laser pulse. In this paper, the control part of pseudo random coding is programmed to be realized in FPGA apparatus by using VHDL language. 8 grades shift registers cascade connection is used and the fourth register's output feed back to the input port in reverse. A video signal from LLL CCD vidicon is synchronously separated, and then its vertical signal (V_{syn}) is used as these shift registers' clock signal. Fig.1 presents the pulse signal's actual test waveform of negative lever trigger.

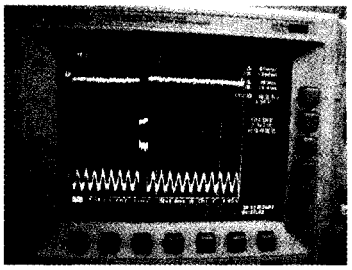


Fig.1 Pulse signal's actual test waveform of negative lever trigger

3 Pulse laser assistant night vision system

Pulse laser assistant night vision technique is a LLL CCD imaging technique that improves the passive imaging system's contrast and statia by using laser assistant. In image processing, the real-time capturing and display of LLL image and laser image is a basic and critical technique. Image capturing system accomplishes LLL image and laser assistant video signal pretreatment, digitization, synchronization separation, synchronization phase locked control, storage and real-time display.

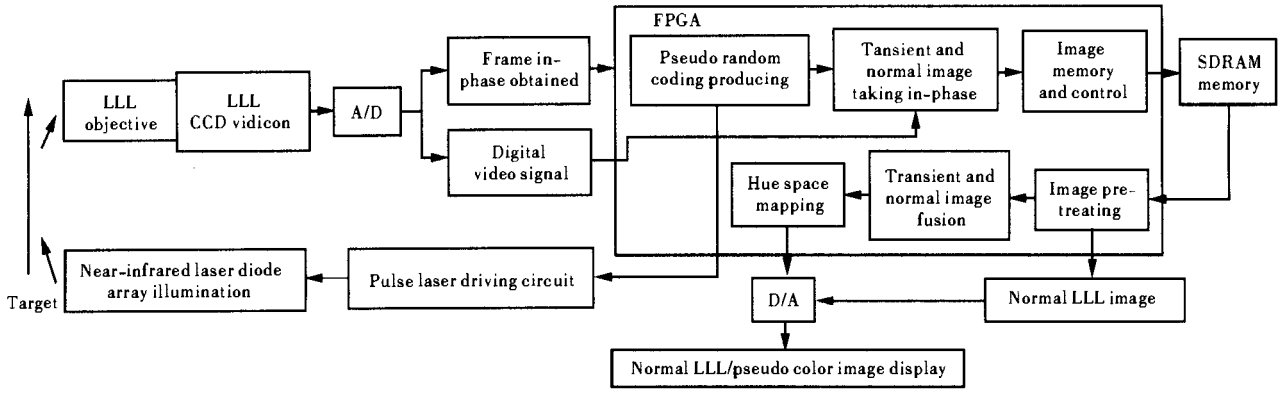


Fig.2 Structure diagram of pulse laser assistant night vision system

The pulse laser assistant night vision system is constituted of enhanced LLL CCD TV vidicon with real -time image processing function and long focus LLL object lens, near-infrared laser diode array illuminator and its driver, pseudo random coding, transient and normal image capturing control and video monitor. The system's block diagram is presented in Fig.2.

Fig.3 is the actual photo of pulse infrared laser assistant night vision system.

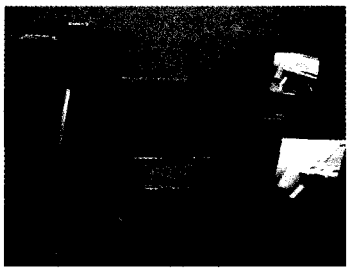


Fig.3 Photo of pulse infrared laser assistant night vision system

4 Laboratory and field experiments

By using pulse infrared laser assistant night vision system, many laboratory experiments are carried out, normal LLL images and transient laser assistant images have been captured, and their histogram analysis are obtained(shown in Fig.4).

From the histogram analysis, compared with the normal LLL image, the near -infrared laser assistant image has apparent higher luminance, larger gray dynamic range and contrast, then the necessary information for the fusion of transient laser assistant image and normal LLL image is provided.

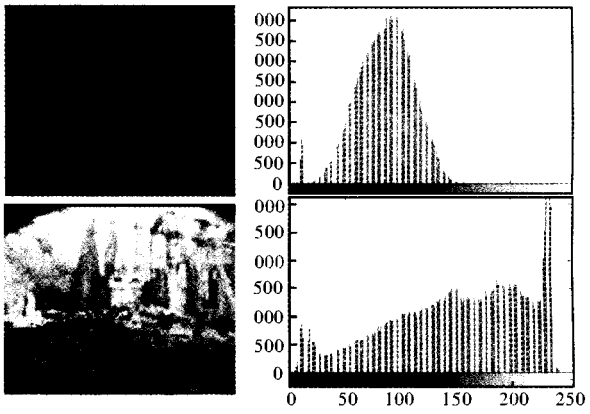
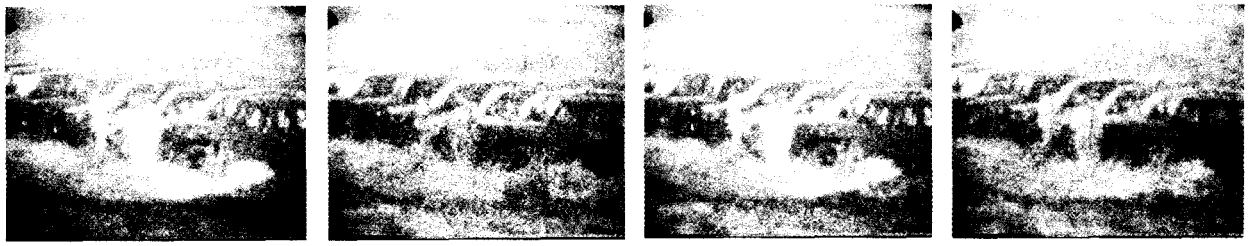


Fig.4 LLL images and laser assistant images and their histograms

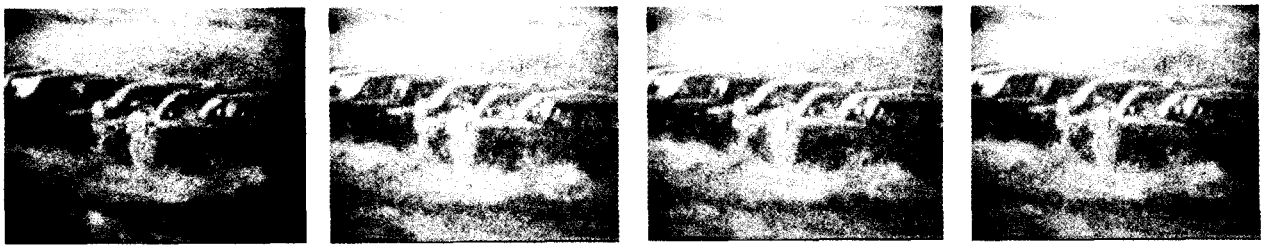
Many field experiments have been carried out and quantities of prime LLL images and laser assistant images are captured. Grouping image pretreatment is done. Improved algorithm and new algorithm of LLL image and laser assistant image are used to the result including simulating test of LLL image and infrared image gray modulation[8],frequency field fusion and exceptional element fusion (superimposition and modulation). Fig.5 is a group of results of fusion and hue space mapping.

5 Fusion result evaluation

In order to evaluate the fusion result in quantity, a series of systemic investigation questionnaires are designed to every group of 4 images. Picking out



(a) LLL image (b) Assistant image (c) Gray modulation fusion image (d) Spectrum fusion image



(e) Exceptional element fusion image (f) Gray modulation color image (g) Spectrum fusion color image (h) Exceptional element fusion color image

Fig.5 Fusion results of LLL image and laser assistant image

randomly two classes for investigation and presenting an image to observers ever ten seconds in sequence. Everyone's discovery situation to different objects and background is recorded in details. Two tables are given as follows.

Tab.1 Testing result of 68 students on Nov.21, 2003

Normal LLL image/laser assistant LLL image	Sum of students who can see the object	Sum of students who can see the background tree	Sum of students who can see the background grass
1.Normal LLL image	1(1.47%)	56(82.35%)	0(0%)
2.Laser assistant LLL image	8(11.76%)	60(88.24%)	0(0%)
3.Fusion image	15(22.06%)	63(92.65%)	1(1.47%)
4.Color display	22(32.35%)	63(92.65%)	1(1.47%)

The above statistic result indicates that object and background's discovery and identification probability of laser assistant image has a significant improvement comparing to the normal LLL image and the discovery and identification probability of the fusion and color space mapping image is even higher than the laser assistant image.

Tab.2 Testing result of 68 students on Dec.12, 2003

Normal LLL image/laser assistant LLL image	Sum of students who can see the object	Sum of students who can see the background tree	Sum of students who can see the background grass
1.Normal LLL image	0(0%)	69(86.3%)	10(12.5%)
2.Laseras sistant LLL image	15(18.8%)	70(87.5%)	8(10%)
3.Fusion image	29(36.3%)	73(91.3%)	13(16.3%)
4.Color display	54(67.5%)	77(96.3%)	17(21.3%)

6 Conclusion

As to the night vision system stadia, the possibility is demonstrated that using pulse infrared laser array can improve the stadia of the LLL night vision system on the base of analysis on the stadia equation of the LLL night vision system. The pseudo random laser enhancement technique is put forward and new night vision image fusion and hue space mapping algorithm is applied. The pulse infrared laser assistant system is established, many laboratory and field experiments and some observ ation evaluation on the experiments have been made. These research works (下转第 695 页)

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show that far stadia and concealment are the two most important properties of pseudo random pulse laser assistant LLL imaging system.

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