Study on infrared CCD detector imaging technology under high energy laser background

Peng Liu [1,2], Xiaoman Wang[1], Ying Chu [1], Bo Sun [3]

[1]College of Electronic Information and Engineering, Changchun University of Science and Technology, Changchun 130022, China;

[2]Key Laboratory of Technology of Photo-Electronic Measure-Control and Laser Transfers, Ministry of Education, Changchun Jilin 130022, China

[3]ChangChun New Industries Optoelectronics Tech. Co., Ltd, Changchun 130000, China

Abstract. In the non-equal intervals emitting laser synchronous capture technology research, the measured laser emitting a pulsed laser emitting a non-equal intervals, and the pulse width of ns level, the integral control infrared CCD detector sync pulse and the laser pulse synchronization between crucial. A method for infrared CCD detector imaging was proposed in the paper, which based on adaptive way to achieve light trigger and electric synchronization, and ensured synchronization control CCD detector integration time and contented the image clarity and solved problems of synchronization capture the high-energy laser pulse for infrared CCD detector, reduced the influence of background noise and improved the ratio of signal to noise effectively for CCD infrared detector simultaneously and effectively improved the accuracy capture spot.

Keywords: High-energy laser pulse; infrared CCD detector; light trigger; electric synchronization.

1. Introduction

Laser is widely used in the military field, and becomes one of the most important technologies in modern military reconnaissance and distance detection due to its features of good direction, long range, strong anti-interference ability and good for hiding. Especially, the high-energy pulsed laser technology plays a crucial role in improving air defense, naval warfare, the remote and land-based weapons attack.

The high-energy pulsed laser has an extremely important characteristic of spatial distribution of the laser light intensity. It has a direct relationship with study of laser beam quality, spatial structure of the beam, the divergence angle of the beam and other various characteristics. Most current CCD detectors are equipped for continuous laser, however, there is a big difference between pulsed laser measurement and continuous laser measurement, the key issues are whether it can accurately capture the pulse, eliminate the influence of stray light as much as possible and accurately reflect the energy distribution of the light spot [1].

In this paper, we proposed a precise light trigger and electricity synchronization method on the basis of in-depth analysis the principle of pulse laser for the issue of difficult to capture pulsed images and at the same time reduced the integration time, reduced the influence of background noise and effectively improved the signal to noise ratio.

2. Technical principles design

For the CCD detector, in the absence of synchronization, the laser pulse arrival time of the CCD detector is random.

In this paper, the principle of the method is as shown below in Figure 1.

1) Place the laser scattering counting controller at the exit of the high-energy pulsed laser for sensing atmospheric scattering nanosecond level narrow pulsed laser signal;

2) High energy laser sends out laser pulses to the diffuse reflection plate;

3) Infrared CCD detector captures diffuse reflection high-energy pulsed laser plate spot images using the light trigger and electricity synchronization method.

This method effectively ensures precise synchronization between Infrared CCD detector integration pulse signal and high-energy laser pulse signal, thus effectively improves the spot capture accuracy and signal to noise ratio of infrared CCD camera.

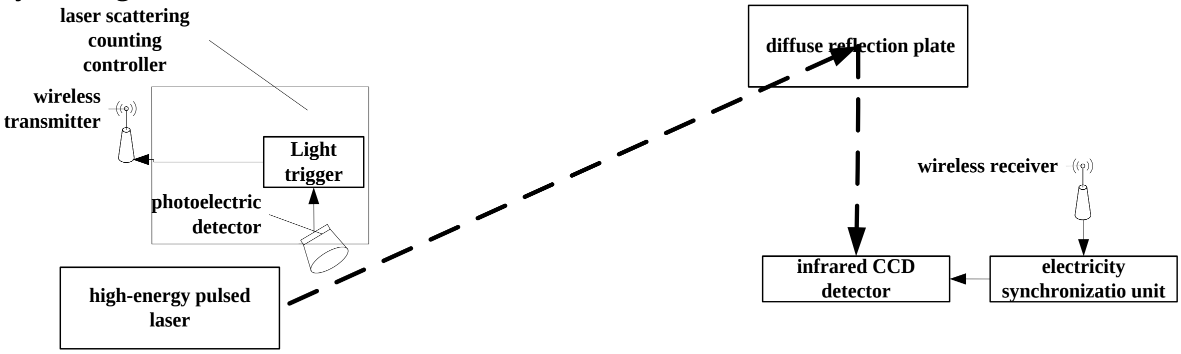


Fig. 1 Block diagram of the system

3. Laser scattering counting controller design

The laser scattering counting controller is an measure equipment. It gets the pulsed laser from the beam scattered by the pulsed laser which fired at target, and then triggers infrared CCD detectors after process [2] [3] [4].

The laser scattering counting controller consists of photoelectric detection unit, data acquisition unit, GPS (global position system) timing system unit and adaptive counting unit. Block diagram is shown in Figure 2.

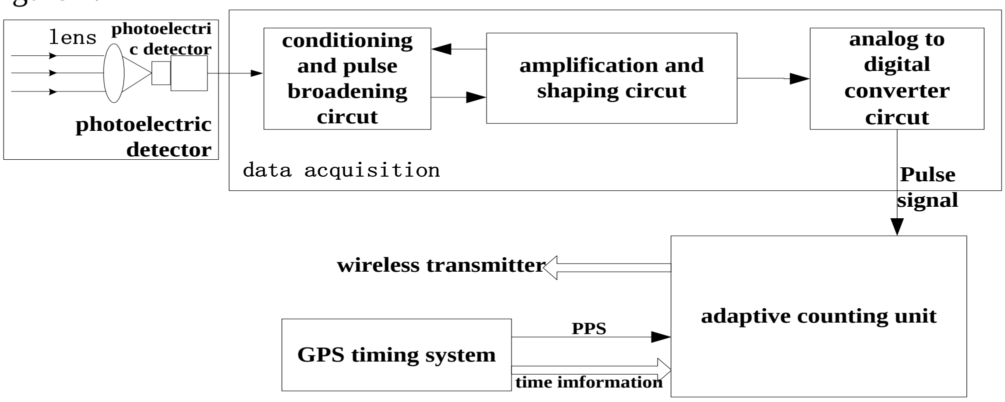


Fig. 2 Block diagram of laser scatter counting controller

(1) Photoelectric detection unit

As the laser pulse width is narrow, as a few nanoseconds, photoelectric detection unit requires the use of avalanche photodiode detector that has high sensitivity, wide bandwidth and excellent frequency response.

(2) Data acquisition unit

There is great difference between the light intensity near atmospheric scattered and light intensity distant target reflected in amplitude. Large amplitude dynamic range exists in the laser pulse signal in a very short time, and the laser pulse width is narrow, thus when design with the unit, we process the detected laser pulse signal with conditioning, pulse broadening, amplification and shaping. Additionally, with combination of high speed Analogy to Digital converter, then gets a complete laser pulse signal.

The amplifier system is divided into two stages. Primary stage is current-voltage conversion, and the key issue is to ensure the amplification of useful weak signals under high-bandwidth condition. Gain noise mainly from three aspects, voltage amplifier noise density, current noise density and temperature resistance noise. The first two standards are used to choose amplifier. Resistance noise is proportional to the square root of the resistance, and the signal is proportional to the resistance, great feedback resistor is generally required to obtain weak signal. Another standard to choose amplifier is high gain bandwidth. Primary gain is fixed at 106 to 107. Laser is affected by atmospheric turbulence movement when it is transmitted in the atmosphere, detector receives a signal which ranges from a few Hertz to several hundred Hertz, and amplifier bandwidth needs to be higher than the turbulent velocity. OPA657 is an amplifier whose gain-bandwidth product reaches 1.6Ghz and bias current is 2 picoampere .It meets the demand, and can convert nava level optical signal into millivolt level voltage signal(The converted voltage signal is greater than the offset voltage of the amplifier should be more than 10 times). The Secondary gain is variable, which completes the millivolt signal to a volt level voltage signal conversion, for subsequent processing.

(3) GPS timing system unit

The GPS timing system unit provides time reference and time information for the adaptive counting unit, PPS (pulse per second) signal triggers the microprocessor external interrupt to receive accurate timing information. PPS signal is synchronized with the crystal, frequency and counting after entering into FPGA, achieves a refinement of the second signal, then get nanosecond level time information [5].

(4) Adaptive counting unit

Adaptive counting unit is mainly to complete the synchronization capture time forecasts, and forecast model is the key. Forecast synchronous timing is shown in Figure 3.

Forecast model used in this paper is probabilistic data association, which has a plurality of measurements for a single target, it does not use a certain standard measurement as a newer measurement. Instead, it weights all the candidate echo that fall in the tracking trigger gate and then get a fusion value to update the state, the weights are derived from the probability of each candidate echo of the target posterior, namely probabilistic data association algorithm [6].

One trigger at most produces one measurement result. Assuming the effective measurement set that falls into the tracking trigger gate is $\{z(k+1)^j\}_{j=1}^m$, $\beta_{k+1}^{(j)}$ said the j-th measurement posterior probability derived from the target, $\beta_{k+1}^{(0)}$ represents the target which did not produces a measurement posteriori probability .

$$\beta_{k+1}^{(j)} = \frac{\exp[-0.5\gamma^T(k+1)^j S^{-1}(K+1)\gamma(K+1)^j]}{b_{k+1}+\sum_{j=1}^{m}\exp[-0.5\gamma^T(k+1)^j S^{-1}(K+1)\gamma(K+1)^j]} \tag{1.1}$$

$$\beta_{k+1}^{(j)} = \frac{b_{k+1}}{b_{k+1}+\sum_{j=1}^{m}\exp[-0.5\gamma^T(k+1)^j S^{-1}(K+1)\gamma(K+1)^j]} \tag{1.2}$$

$$b_{k+1} = (2\pi)^{m/2} C\,|\,S(k+1)\,|^{1/2}\,(1-P_D P_G)/P_D \tag{1.3}$$

Where, C is the clutter density, PD is the prior probability of the target detected, PG indicates the priori probability when target is detected and real measurement falls inside the tracking trigger gate. All valid measurement weighted, we can get the following PDA algorithm fusion measurement.

$$z(k+1)_{PDA} = \sum_{j=1}^{m}\beta_{k+1}^{(j)} z(K+1)^j] \tag{1.4}$$

Use formula (1.4) to update the target.

Forecast synchronous timing with this method is shown in Figure 3.

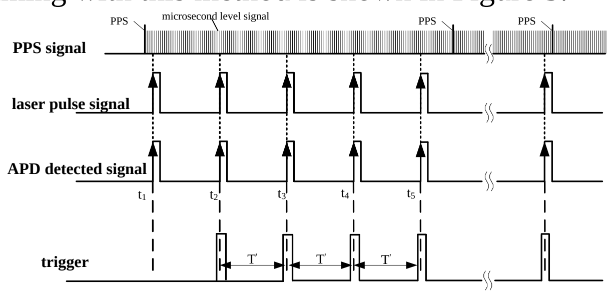


Fig. 3 Synchronization timing sequence diagram

4. The infrared CCD imaging design

In the absence of synchronization, the laser pulse arrival time of the CCD detector is random, which leads to laser pulse part may fall into the CCD integral time zone and the other part to the charge transfer time zone, laser pulse signal may also simply not fall within the CCD area detector integration time .Thus, we must force the infrared CCD detection reset before the laser pulse arriving, that is to let the stored charge in the photosensitive area quickly transfer to the shift register and keep CCD detector in integral state then waiting for the arrival of the laser pulse [7] [8] [9] [10].

The camera trigger timing is shown in Figure 4.

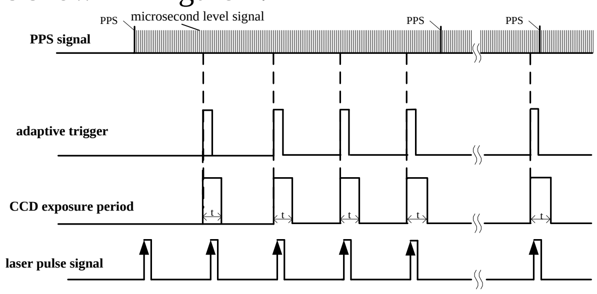


Fig.4 Diagram of camera synchronization timing sequence

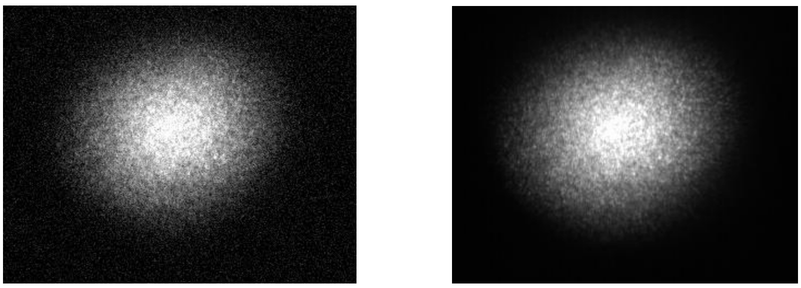
5. Results

This paper carried out a set of experiments in order to verify the feasibility and efficiency of this method. Laser pulses is emitted by the laser, two sets of images are obtained through turning on and off the timing synchronization function. Carries on the analysis of figure 5, we get the following conclusions.

1) Figure 5 (a) is the infrared spot image captured with normal method, from this picture the CCD integration time is extended due to the randomness of the infrared laser pulse arrival time of the CCD detector, which leads a lot of noise and poor spot quality. After using the synchronization capture function, noise has been eliminated obviously as shown in 5 (b), and get a better spot.

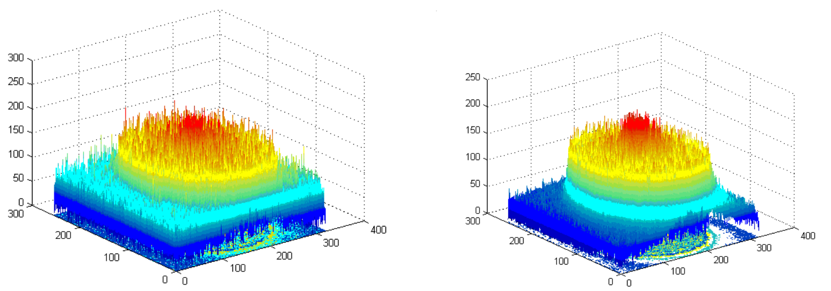
2) As is shown in figure 6, light energy distribution using synchronization is better than that without synchronization.

3) Figure 7 shows that the spot jitter amplitude of the light intensity after synchronization is much smaller than unsynchronized situation.



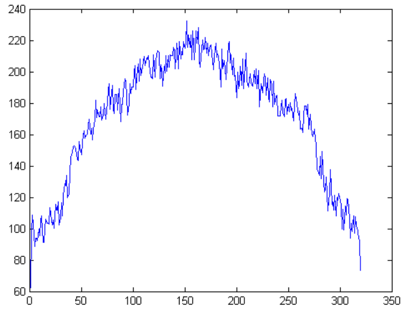
(a) Picture without synchronization (b) Picture with synchronization

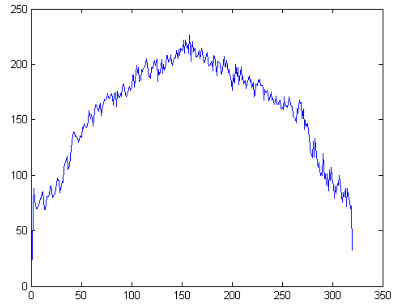
Fig.5 Picture of infrared spot



(a) Picture without synchronization Picture with synchronization

Fig.6 Scattergram of three-dimensional intensity of light





(a) Picture without synchronization (b) Picture with synchronization

Fig.7 Scattergram of two-dimensional intensity of light

6. Conclusions

In the non-equal intervals emitting laser synchronous capture technology research, laser pulse is emitted from the laser under test for non-equal intervals, and the pulse width is nanosecond level, therefore, the synchronization between CCD camera integral control pulse and the laser pulse is very important. This paper presents an adaptive way to achieve light trigger and electric synchronous infrared CCD detection method using CCD camera integration time to ensure image clarity, signal to noise ratio (SNR) and dynamic range requirements, meanwhile, satisfies the synchronization relationship between integrated pulse signal and the laser pulse signal, thus effectively improves the accuracy of the spot to capture, and appropriate for the modern laser weapons' firing hit rate test system requirements.

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