Optics Communications 432 (2019) 79–83

Contents lists available at ScienceDirect

Optics Communications

journal homepage: www.elsevier.com/locate/optcom

Research on streak tube imaging lidar based on photocathode range gating method

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ARTICLE INFO

Keywords:
STIL
3D imaging
Range gating
Photocathode

ABSTRACT

In this paper, a streak tube laser lidar(STIL) based on cathode gating (CG) method is introduced,range gating of laser echo is realized by triggering the photocathode voltage of the streak tube. A Nd:YAG pulse laser is used as the light source, with a wavelength of 532 nm and a maximum repetition rate of 10 Hz,the raw image was collected by CCD with a resolution of 640×480. Imaging experiments of a target with a stand-off distance of 2 km are carried out by using the developed STIL system, the intensifier gating (IG) method and the CG method were used respectively. The experimental results show that, compared with IG mode, the CG mode with the same parameters has the advantages of strong detection ability and high signal-to-noise ratio(SNR). It is proved that CG mode is more suitable for the range gating of the STIL, and the SNR of the raw image is raised from 4.2 dB in non-gating mode to 16.8 dB in CG mode which effectively improves the image definition.

1. Introduction

STIL has become an efficient method for 3D data acquisition because of its advantages of high resolution [1,2], large field of view, high frame frequency [3,4]. In recent years, it has attracted more and more attention. It has important applications in many fields, such as topographic mapping, underwater obstacle detection, power line survey and the short scale sea-wave imaging [5–7].

However, scattering and absorption caused by transmission medium affect the detection ability of the lidar system [8,9], how to suppress backscattering and background interference effectively is the key problem of laser active imaging [10,11]. Range gating is one of the most effective methods to improve the SNR of the lidar system [12,13]. IG is a widely used method in the lidar system [14,15] and this method realizes the range gating of laser signal by triggering the image intensifier to improve the SNR of the lidar system. But when the method is applied to a STIL system, there are two shortcomings: firstly, because the range gate width is smaller than the afterglow time of the fluorescent screen of the streak tube, the intensifier cannot receive all the light intensity of the target signal, which leads to the attenuation of the detection signal intensity; secondly, in the process of range gating, the detection signal is superimposed by the interference afterglow outside the range area and the target echo inside the range area, which results in a decrease in the SNR of the raw image. In CG mode, the laser signal is range gated by triggering the photocathode. Only photoelectrons excited by the echo signal in the range area are allowed to enter the STIL system, and all screen image information comes from the range area, by which the interference signals outside the range area are filtered effectively. At the same time, the intensifier works in continuous mode, and the intensity of the raw image on the CCD can be effectively improved by making full use of the afterglow intensity of the fluorescent screen of the streak tube.

In this paper, a dual-gated mode STIL system is developed based on the existing research foundation [16]. The imaging experiments of a target 2 km away was carried out by using the system in different gating modes. The experiments use the same lidar system, in which the streak tube, the receiving lens, the optical system and the scanning system are all exactly the same. The experimental results show that CG mode is more suitable for STIL range gating system. At the same time, compared with the non-gating mode, the raw image obtained by CG mode has higher SNR, which further improves the imaging ability of STIL system in strong backscattering environment. And the superiority of this method is proved.

2. System structure

The developed STIL system is mainly composed of 4 parts, emission subsystem, receiving subsystem, control subsystem and data processing subsystem. The schematic of the system is shown in Fig. 1. The emission subsystem uses a Nd:YAG pulse laser with a wavelength of 532 nm, a pulse width of 8 ns, a pulse energy of 100 mJ and a maximum repetition rate of 10 Hz. The divergence angle adjustment is carried out by using the beam expanding mirror, and the laser beam is transformed into a

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https://doi.org/10.1016/j.optcom.2018.09.041
Received 23 May 2018; Received in revised form 24 August 2018; Accepted 17 September 2018
Available online xxxx

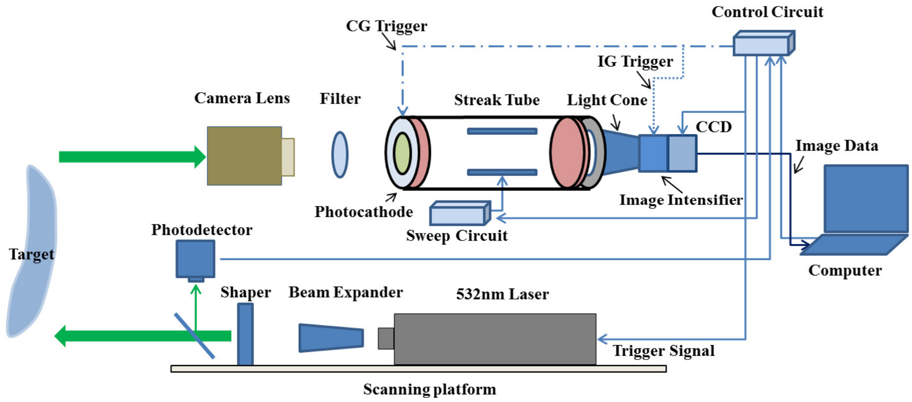

Fig. 1. Schematic of the STIL system based on a 532 nm wavelength illumination.

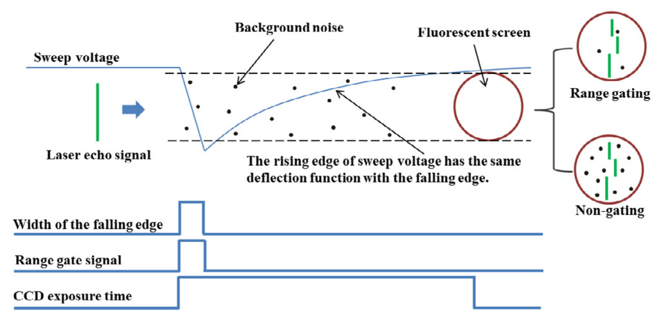

Fig. 2. Operating process of streak tube sweep voltage and the trigger timing of main equipment.

linear beam by a cylindrical lens. The receiving subsystem is mainly composed of receiving lens, streak tube, light cone, image intensifier and CCD. Cassegrain lens is used as a receiving lens in the receiving subsystem with a focal length of 800 mm and a view angle of 3°. The received light passes through a narrow bandpass filter with a center wavelength of 532 nm and a bandwidth of 3 nm then focused on the photocathode of the streak tube.

The laser echo signal is converted into photoelectrons by the photocathode of streak tube. The electrons are accelerated by the electric field between the photocathode and the grid, and then go into the deflection electric field. The raw image of the target will be obtained after the electron bombardment on the screen. The streak tube uses a P43 fluorescent screen, the afterglow time is 1.2 ms, the raw image is coupled to the image intensifier by a light cone, and the enhanced image is collected by CCD. The system does not adopt slit at the photocathode, therefore the system can quickly obtain the 2D image of the target without changing the hardware. By determining the relative position of laser beam and the target, the time spent on searching and matching can be reduced. The image data processing subsystem is based on the LabVIEW platform on computer, which can realize the processing of the raw image in real-time. And the intensity image, range image and 3D image can be displayed in real time synchronized.

The control subsystem is mainly composed of computer, signal generator card, precision delay device and power supply. The pulse frequency of the laser and the exposure time of the CCD are adjusted by the signal generating card which controlled by computer. A photodetector is used to monitor the time of laser emission and its output signal is also used as the time reference of the control circuit. After a precision delay with a minimum step length of 6 ns, the signal is sent to the gating device as the trigger signal. The power supply of the streak tube has two working states, static and sweep, at the same time, there are also two working modes of cathode voltage, continuous and triggered. In IG mode, image intensifier is the gating device and the photocathode works in continuous state. In CG mode, the signal is transmitted to the streak tube power supply, and the photocathode voltage is triggered.

3. Gating principle

The operating process of streak tube sweep voltage and the trigger timing of main equipment are shown in Fig. 2.

During the working process, the sweep voltage between the deflecting plates will experience two processes: rising edge and falling edge. The display area of the screen depends on the voltage between the deflection plates which composed of offset voltage and sweep voltage. Since the linearity of the falling edge is significantly higher than that of the rising edge, we use the falling edge as the deflection voltage and the range resolution of the streak tube mainly depends on the slope of the falling edges. The rising edge of the sweep voltage lasts much longer, and has the same deflection ability of the falling edge. During the rising time, light signal unwanted can also be detected and displayed on the fluorescent screen. At the same time, since the minimum exposure time of CCD is longer than the duration of the falling edge and the rising edge, the interference signal during the rising edge will also be collected by CCD, resulting in the reduction of the SNR of the system. In order to improve SNR of the system, a range gating system is designed to reduce the interference in the rising edge of the sweep voltage.

We have designed two modes in the range gating system, one is IG mode and the other is CG mode. The timing control of the STIL system is accomplished by the signal generator card controlled by computer. The gating process is shown in Fig. 3.

The laser signal entering the system mainly includes background interference, jamming target echo and target signal. In Fig. 3, three kinds of signals are labeled by 1, 2 and 3, in which 1 and 2 are interference signal, 3 is an effective signal.

In sweep condition, static images can be deflected from the screen area by adjusting the offset voltage between deflecting plates, which mainly includes 1 and 2 types signal.

Gating process in IG mode is shown in Fig. 3(a), the photocathode voltage of the streak tube is constant, the photo-excited electron can enter the streak tube at any time. In order to reduce the noise interference, the image intensifier is controlled by trigger signal. The image inside the range gate is enhanced, and then collected by CCD. The enhanced image contains not only the target echo information, but also the afterglow of the interference signals, which reduce the SNR of the system. At the same time, due to the gate width limit, the target signal is only partially collected, which reduces the intensity of the raw image and affects the detection ability of the system. Compared with IG mode, streak tube photocathode is controlled by trigger signal in CG mode, as shown in Fig. 3(b), and the image intensifier works in continuous mode. In CG mode, only the signal in the range gating area can enter the streak tube, the background interference and the noise caused by the rising edge are removed effectively while making full use of the afterglow intensity of the signal. Therefore, the raw image obtained by the system will get a higher SNR.