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Study on real time 3D imaging of streak tube lidar based on LabVIEW

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ABSTRACT

This paper introduces a streak tube imaging lidar (STIL) used for real-time 3D range imaging. Based on the LabVIEW platform, this system realized system control, image acquisition, data processing and image display through PC. Long distance target imaging experiments have been carried out with our self-designed system. The frame rate of raw image processing is up to 100 Hz, and the real-time display of the intensity image and range image is realized. For a specific target with a distance of 2000 m away, the experimental results show that our system has realized spatial resolution up to 0.1 m and the range resolution up to 0.18 m, which can be further improved. Compared with the traditional STIL system using FPGA, DSP and other hardware control and processing methods, our system has the advantages of short design cycle, low cost and high flexibility.

1. Introduction

The streak tube imaging lidar (STIL) system is an efficient means for 3D data acquisition, which has the advantages of high range resolution, wide field of view and high frame rate [1–3]. The STIL has attracted a lot of attentions in recent years and has been widely used in terrain mapping, power transmission line monitoring, engineering building modeling, underwater target detection [4,5] and other fields.

Using linear scanning voltage, the difference in the time-of-flight in a beam line is transformed into different spatial locations on the screen. By processing the raw image, the 3D information of the target can be obtained [6,7]. Currently, high-speed real-time image processing usually uses FPGA, DSP etc., hardware processing methods [8,9], which have advantages of high-speed processing. However, they have shortcomings of complex structure, long design cycle and poor flexibility. With the rapid development of computer technology and data processing software in recent years, the use of PC to perform the STIL system control and high-speed image acquisition and processing has gradually become possible [10,11].

This paper adopts LabVIEW for system control and image data processing, and develops a high frame rate STIL system, which can cover remote imaging distance up to 10 km. This system has been put into experiment for high resolution 3D scanning and high-speed image processing of a particular target up to 2000 m away. The experimental results show that the LabVIEW program used for system control can also achieve high frame rate of real-time processing together with display of raw STIL image concurrently. This has proved the feasibility of the method. Compared with the traditional way of the hardware approach, the system development needs less effort, and it is flexible to do algorithm integration and system parameter changes.

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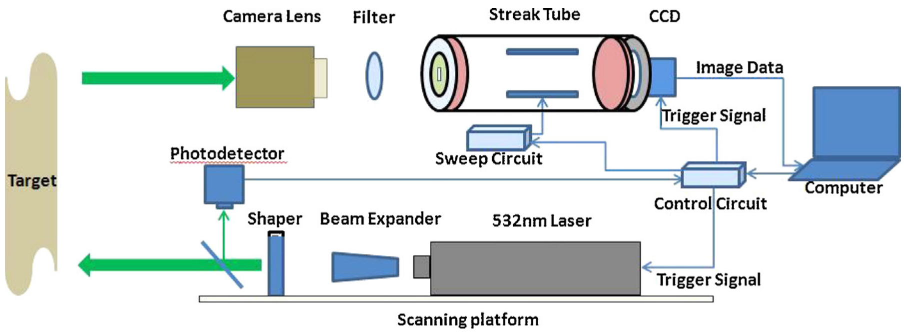

Fig. 1. General schematic diagram of the experimental setup of STIL system.

2. System structure

The STIL system is mainly composed of 4 parts, emission sub system, receiving sub system, optical sub system and control and data processing sub system. The working principle of the system is shown in Fig. 1, in which the emission sub system uses Nd:YAG pulse laser, with wavelength of 532 nm, pulse width of 8ns and the highest frequency of 150 Hz. The optical sub system is further divided into emission optical sub system and receiving optical sub system. The emission optical sub system uses beam expander to adjust the divergent angle, and the outgoing laser is transformed into a linear beam by a cylindrical lens and a Cassegrain lens is used for the receiving optical sub system. In order to reduce the interference of background light, an optical filter is installed with a center wavelength of 532 nm. For receiving and acquisition of the laser signal, the receiving sub system is mainly composed of streak tube, light cone, image intensifier and CCD. For the purpose of realizing the overall control of the system, the control and data processing sub system is mainly composed of a PC, a signal generating card and a precise delay device.

The STIL uses LabVIEW software on the PC to control signal generating card to send frequency, delay time, scanning speed and other system control commands. A laser beam splitter will be used to divide the light into two light beams of different intensities. The stronger beam is shaped into line beam, by using a collimation telescope and a cylindrical mirror, and then the line beam is used to scan the target. The weaker one is received by a light detector, and the signal then is used as the time reference of a delay generator. The set delay time is output to the streak tube deflection circuit, so as to ensure that the reflection signal with a predetermined detection distance lies inside the range gate of the streak tube.

After the laser beam has irradiated a target, an echo signal is received by the receiving sub system, and then the signal is converged to the streak tube photocathode. A light cone will be used to couple the streak tube image to the image intensifier, and then, the enhanced image is captured by the CCD and its data will be processed by the computer.

The LabVIEW software is used to acquire the CCD images, and at the same time, image data processing is being carried out. A reconstruction algorithm is used to achieve real-time display of the target intensity image and range image.

3. System control and data processing

Image processing and system control of the STIL is realized by the LabVIEW, which is a kind of graphical virtual instrument development platform, with a variety of control and computing nodes and rich visual function modules [12,13], and therefore, the LabVIEW platform has been widely used in industrial manufacturing and other fields.

3.1. Graphical software control interface

The operation interface of STIL is shown in Fig. 2, which is mainly composed of control part and display part. The control part mainly carries out the adjustment of system parameters, including CCD settings, imaging frequency control, and scanning speed regulation, etc. The CCD settings can be used to achieve the parameter settings of exposure time, gain, and contrast, etc. The “Frequency” slide bar is for adjusting the laser trigger signal and CCD signal acquisition control. The “Motor speed” text area for controlling the speed of the scanning motor, when combined with the “Frequency” slide bar, can achieve different resolutions of the target imaging.

The image display part is mainly for the real-time display of the raw images, the intensity images, the range images and the 3D images. The raw image, displayed on the upper left panel, is a streak image acquired by a laser beam, while the other images, displayed on the remaining three panels respectively, are real-time synthetic images. The intensity image shows the reflection characteristics of the target by a single color and the range image uses pseudo color to display the distance information of the target. The 3-D target information, residing on the lower left panel, is real-time displayed.

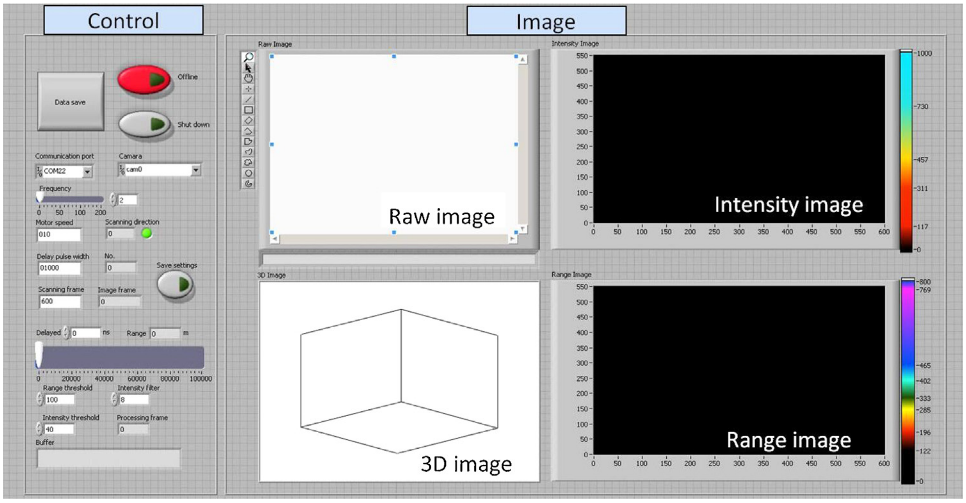

Fig. 2. image processing and system control program interface based on LabVIEW.

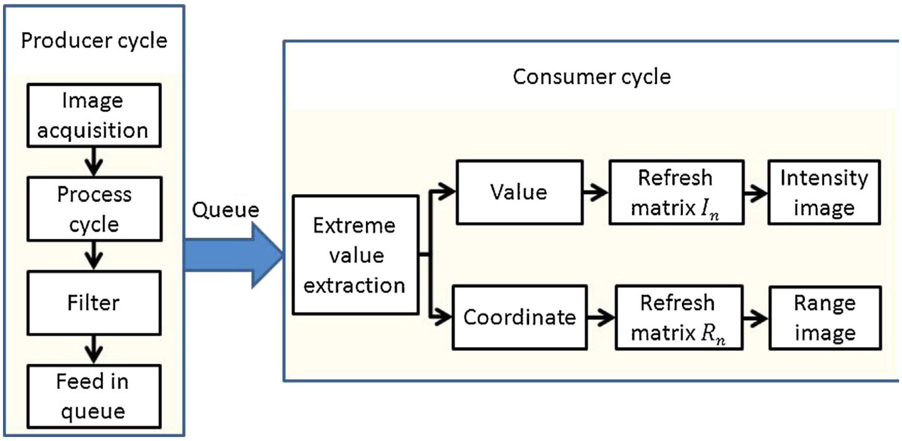

Fig. 3. Schematic diagram of image processing procedure.

3.2. *Image processing method*

The 3D image acquired by the STIL needs to be reconstructed by using multi frames of raw images. To accomplish the real-time display of 3D images, the image acquisition and data processing must be performed concurrently. To effectively improve the processing speed of the raw image, the producer-consumer model in the LabVIEW uses a queue to transmit data to achieve multi loop parallel execution, and the image acquisition and data processing can be done concurrently.

The image processing procedure is shown in Fig. 3, in which the image data is sent to the producer cycle, filtered and then fed into the queue. The consumer cycle reads queue data cyclically. The pixel with the maximum intensity value in each time resolution channel of the raw image will be selected and its value and coordinates will be processed by two parallel processing procedures as shown in Fig. 3. In order to achieve high-speed processing of the raw image, pixel values are used to refresh intensity image matrix I_n, and at the same time, coordinate values are used to modify the range image matrix R_n.

In the consumer cycle, the high-speed processing of the raw image provides the basis for the real-time intensity threshold filtering, in which 3D image filtering is accomplished, with the data processing flow shown in Fig. 4. After the system is initialized, the raw image is converted into gray image, and the maximum intensity pixel in each time resolution channel is extracted. For reducing the background noises, if the pixel intensity value is greater than the set threshold value, the value and the coordinates of the pixel are reserved, otherwise, when the pixel value is less than the set threshold value, the value and the coordinate values of the point will all be set to zero.

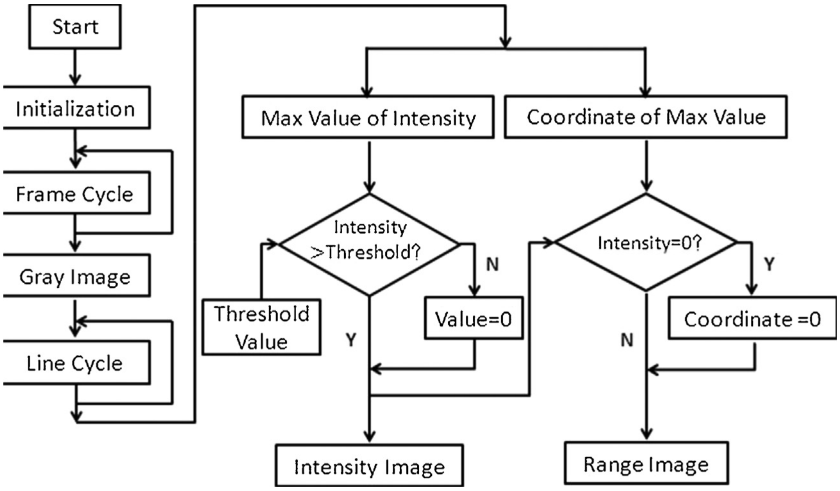

Fig. 4. Flow chart of threshold filtering for 3D images.

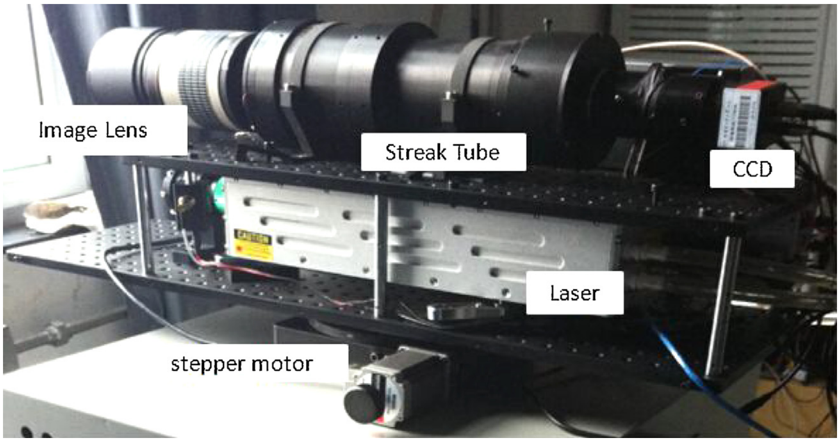

Fig. 5. Physical diagram of experimental equipment based on the 532 nm wavelength illumination and a streak tube camera detector.

Fig. 6. Close-up photograph of the target in which the three surface with different distances are outlined for Imaging effect evaluation.

4. Experimental results and analysis

The STIL system used in the experiment is shown in Fig. 5. The system is divided into three layers. The bottom layer is the scanning stepper motor, the middle layer is the laser and the emitting optical system, etc., and the upper layer includes the receiving optical system, the streak tube and the CCD.

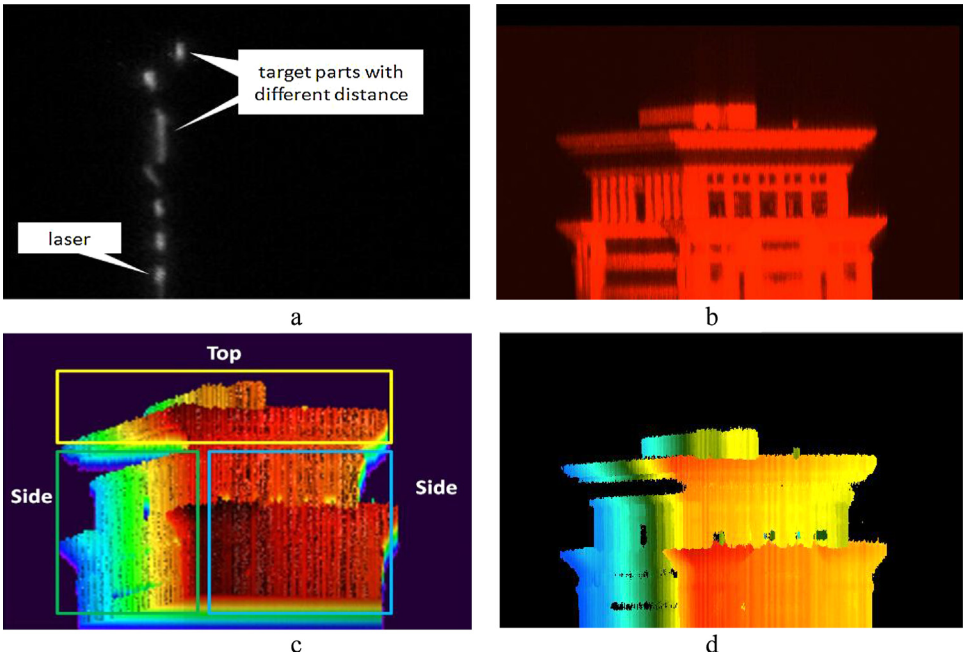

Fig. 7. 3D imaging experiment results of the target shown in Fig. 6. (a) raw image (b) intensity image (c) 3D image (d) range image.

In this experiment, we tested the outdoor target with the shape of the building shown in Fig. 6. The building is about 60 m long, 28 m wide, and the distance is about 2 km. The system has been used to acquire data of the raw image of the mentioned building from Fig. 6 and then generates intensity, range and 3D images, shown in Fig. 7. The number of pixels of each 3D image is 640*600.

Fig. 7(a) shows the raw image of the target with different positions in the horizontal direction to represent the range information of the target. The vertical direction illustrates the building's space positions, with the signal intensity representing the reflection characteristics of the building to the laser. Fig. 7(b) illustrates the synthetic intensity image displayed with monochrome. The values of pixels in the image are used to represent the reflection intensity of the laser. Fig. 7(c) is used for showing the real-time display 3D image of the target by the LabVIEW program. In order to improve the signal to noise ratio, a threshold and median filtering algorithm are used in the reconstruction process. Fig. 7(d) is a synthetic pseudo color range image, in which different colors represent different relative distances.

The STIL resolution is mainly affected by the streak tube deflection voltage slope, CCD resolution, laser pulse width and other factors, and among them, the streak tube deflection voltage slope is one of the most important factors influencing the range resolution. The range resolution increases with the increase of slope, but the imaging depth decreases along with the increasing slope. Therefore, to get a complete imaging of the target, a specific voltage slope is needed. The maximum depth of field imaging is expressed as D_m defined as below:

$$D_m = \frac{(\varphi \cdot t \cdot \mathrm{C})}{2d \cdot \mathrm{V}} \tag{3-1}$$

where φ is the diameter of the streak tube fluorescent screen, t is the voltage change time, C is the speed of light, d is the deflection sensitivity of streak tube and V is the deflection voltage. In this study, according to the size of the target building, the width of the deflection slope is set to 500 ns, deflection voltage is 700 V, and the maximum depth of field is about 66 m.

For the 3D image of the target obtained from using the LabVIEW platform during the scanning process, the distance between the lidar and the points on the target is expressed as $\mathrm{R}=R_{xiM} + (C \cdot T_0)/2$, where R_{xiM} represents the relative distance of the target in the 3D image, T_0 is the system's delay length, and the calculated target distance is 2034 m. Imaging resolution D can be expressed as:

$$\mathrm{D}_R = \mathrm{L} \cdot \sin\alpha / \Delta\mathrm{Y} \tag{3-2}$$

$$\mathrm{D}_x = \mathrm{L} \cdot \cos\alpha / \Delta\mathrm{X} \tag{3-3}$$

where L is the distance between the two feature points of the target, α is the angle between the target and the laser beam, ΔY is the difference between the coordinate values of the two points and ΔX is the difference between the number of frames of the two points. D_R and D_x are the range resolution and the lateral spatial resolution of the target respectively. By calculation, the range resolution of the system D_R is 0.18 m, and the horizontal spatial resolution D_x is 0.1 m.

5. Conclusion

This paper introduces a STIL system, which uses LabVIEW platform for system control, image acquisition and data processing, and the outdoor imaging experiment is carried out and analyzed. The experimental results show that the STIL system realizes 100 Hz raw image data processing and the real-time display of the synthesized image. The most remote imaging distance of the system is more than 10 km. For the target of a building with a distance of 2034 m, the spatial resolution is 0.1 m, and the range resolution is 0.18 m.

The software system controls the system, and concurrently, carries on the high-speed acquisition and processing of the raw images. Compared with the methods used in hardware way to do system control and data processing, the flexibility of the system is improved and the difficulty in system development is reduced.

However, the image denoising and image recognition processing program still occupies a lot of system resources. To further improve the effect of frame rate, more efficient image processing mechanism will become the focus of our future research.

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