Control and image processing for streak tube imaging lidar based on VB and MATLAB

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In this letter, we develope a control and image processing system for Streak Tube Imaging Lidar (STIL). In the system, the data acquisition card control and the software interface are programmed in Visual Basic (VB) while the image processing is finished by MATLAB. A STIL imaging experiment is carried out in the laboratory. We obtained the intensity and range images of targets with pseudo color by image processing and reconstruction for a set of raw streak images of targets at different distances acquired by STIL. The range resolution is better than 2 centimeters.

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Laser radar has been widely applied in the fields of measurements of cirrus clouds[1], wind speed measurement[2−3], pollution detection, gas sensing, sea detection and so on due to the rapid developments of laser technology and photodetector[4−7]. In recent years, Streak Tube Imaging Lidar (STIL) has been widely studied for its advantages, such as sub-nanosecond range measurement accuracy, wide field-of-view (FOV) and high transverse resolution[8−11].

STIL is composed of a streak tube, Charge Coupled Device(CCD), high power laser and a control and image processing system. Image processing systems based on embedded image processing platform and smart camera are usually adopted in STIL[12]. Both of these two systems can process images at high frame rate, but they have the disadvantages of programming complexity and high cost. In this letter, Personal Computer (PC) is used to accomplish control and image processing for STIL by software programming. The data acquisition card control and software interface are programmed in VB while the image processing is finished by MATLAB. After the streak images are acquired, the intensity and range images of the target are rebuilt by reconstructing algorithm in the software. In the experiment, the intensity and range images for 4 targets at different distances were obtained by the STIL we designed. The three-dimensional (3D) imaging capability of this system was demonstrated.

The principle of STIL is illustrated in Fig. 1. The pulsed laser which was collimated is spread out into a cross-track fan beam by the cylindrical lens, and then illuminates a thin strip of the target surface[13]. Assuming that the target is ladder shaped, the light signals backscattered from the target reach the streak tube at different times. The light signals collected by received optical system hit the photocathode and converted to electrons. The electron beam is then accelerated to the anode via a high voltage between the cathode and the anode. Then a pair of sweep plates, which have a linear voltage-ramp applied to the electron beam. After electron beam bombardment, a raw image is displayed on the phosphor screen, thereby converting photon arrival time to position on the phosphor screen in the sweep direction. A CCD is used to record the phosphor image. The image from CCD is processed and displayed by PC. The horizontal direction in raw streak image represents the spatial information of target and the vertical direction represents the time-resolved channel[14]. The light signal is separated along the vertical direction due to different arrived times in the duration of a laser pulse. Additionally, owing to the target being ladder shaped, the returned light signals are shown on different positions along the vertical direction. The different vertical locations on the screen represent the targets' relative distances[15]. In this case, the range information of different parts on the thin strip are derived by combining the vertical and horizontal locations of the corresponding parts of laser pulse peak on the image. If the cross-track fan beam scans the target in along-track push-broom style, the intensity and range image of the whole target will be received after image processing[14].

The control and image processing system for STIL is mainly responsible for (1) controlling the system timing and (2) rebuilding the range and intensity image of the target by processing the real-time raw streak images[12]. The system software is written in VB and MATLAB.

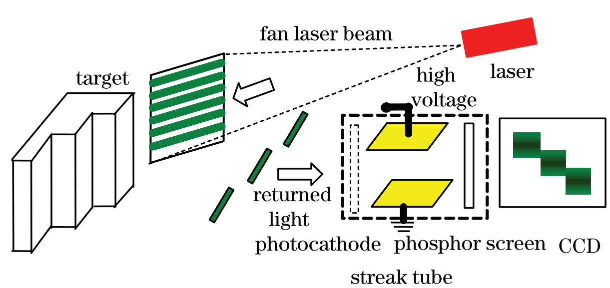

Fig. 1. Illustrative diagram of streak tube camera imaging

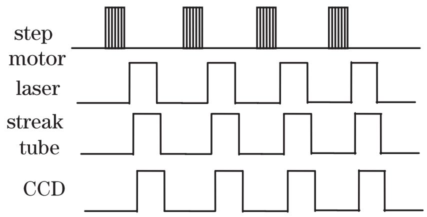

Fig. 2. Timing diagram of system.

We use VB to design the user-friendly interface which controls the data acquisition card to drive the step motor to scan and trigger the laser and CCD. MATLAB is used for image processing and image display in a VB environment. Several key aspects of the system design are discussed in detail in the following section.

A high resolution 3D image of the scene is produced from multiple sequential frames formed by repetitively pulsing the laser in synchrony with the CCD frame rate as the laser fan beam scans over the scene[8]. Therefore, the control system needs to properly sequence the laser and receiver operations[15]. In the system, VB program controls the step motor, the laser, CCD and the streak tube via data acquisition card. As shown in Fig. 2 this procedure includes: 1) VB program generates a trigger pulse by data acquisition card to drive the step motor. A trailing edge of a pulse signal is interpreted by the step motor driver as an effective pulse which can drive the motor to move one step. 2) After signaling the step motor, VB program triggers the laser by data acquisition card. Avalanche photo diode (APD) detector senses the laser light and then converts the light signal to electrical signal. The electrical signal is feed through a delay generator before reaching the trigger input of the streak tube[16]. As a result of passing through the delay generator, the sweep voltage of streak tube can be precisely synchronized with the laser pulse. 3) Finally, VB program signals CCD through the application programming interface to capture the streak tube phosphor image and upload it to PC which saves the image as a raw streak image.

The target image can be obtained by extracting the position, intensity and range information of the target from the raw streak images. Scanning the target vertically by horizontal fan laser beam, the intensity and range image of the target can be reconstructed. Assuming that the size of the phosphor image captured by CCD is $M \times N$ pixels, $f_{\mathrm{q}}(i,j)$ represents the gray value of every pixel of the image. The pixel values of the reconstructed intensity and range image are $I(i,q)$ and $R(i,q)$, respectively. The image processing includes: 1) Enhancement of Streak Image. Due to the disturbance of image signal, impulse noise always exists in raw streak image. We use median filtering function in MATLAB to reduce the impulse noise so that the image quality can be improved. 2) Reconstruction of Intensity Image. After the enhancement of raw streak image, we use the average gray values of each column of the enhanced raw image as the intensity of the streak image. Therefore we obtain the pixel value of the intensity image, $I(i,q)$. 3) Reconstruction of Range Image. Then we use the max function in MATLAB to locate the maximum gray value of each column of enhanced raw image. The location of the maximum value in column denotes the range information of the target[17]. In this case, we can reconstruct the range image of the target from the location information of maximum value. In addition, we can calculate the distance between the sensor and the range gate, R_0, according to the delay between the trigger signal of streak tube and the light signal returning from the target. Hence, the distance between each spot of the target and the sensor is: $R(i,q) = R_0 + Rm(i,q)$.

The control and image processing system of STIL calls MATLAB in a VB environment to perform image processing task. 1) Design the Component Object Model (COM) component. COMTOOL function in MATLAB is used to call the MATLAB Builder for COM. and produces a DLL component. 2) Call dynamic link library (DLL) in VB; After the software project is opened in VB, introduces the DLL component produced by MATLAB to VB. In this case, user can call M functions in VB program. These functions are used as methods of COM objects.

3D imaging experiments of STIL were carried out in the laboratory as shown in Fig. 3. From near to far, the targets are: a person, then Board 1, then Board 2, then Board 3, then left wall, then right wall. The person is 0.5 meter far from Board 1. Board 1 is one meter far from Board 2. Board 2 is one meter far from Board 3.The target scene consisted of three boards and one person situated 15 meters far from the sensor. In the experiment, STIL scanned the target horizontally by vertical fan beam. In scanning, the laser pulses are fired to the target at a certain repetition and each laser pulse yields a two-dimensional (2D) azimuth-range image. Figure 4 is one of the streak images. The system software processed 200 successive raw streak images by median filtering and reconstruction algorithm. After the scanning process, the range and intensity image can be generated immediately. The reconstructed intensity image is shown in Fig. 5. This figure is a pseudo color image in which range information is encoded in different color. Specifically,

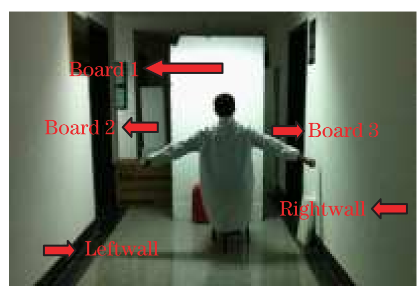

Fig. 3. Photograph of targets.

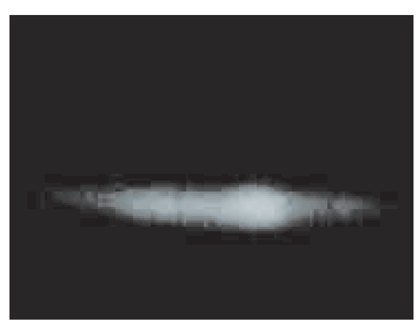

Fig. 4. Raw streak image.

blue denotes long distance while red denotes short.

The intensity image shows that the shapes of the person and the boards are well defined and the person casts a shadow on the board. As shown in Fig. 6 the range image illustrates clear contours of the person and the boards. The three boards and the person are in different colors corresponding to different ranges. The wall, person, Board 1, Board 2 and Board 3 are yellow, green, cyan, light blue and dark blue respectively. These images demonstrate the range and intensity imaging capability of the system, and also demonstrate the high-precision range information that the system can generate. Moreover, the range image has desirable performance on demonstrating details of the target and can be further enhanced with the intensity information.

On the raw streak image, there are 100 lines of pixels between the return signals of the person and the Board 1. The spatial distance between these two targets is 50 centimeters. Therefore, theoretically, the range resolution is 0.5 centimeters. According to our experimental results, the range resolution of this STIL is better than 2 centimeters. The sweep plates have an important influence on the range resolution, a more rapid change linear voltage-ramp, means a higher range resolution. At the same time, pulse width and CCD pixels are also influencing factors. Narrow pulse width and higher resolution CCD can get a higher resolution.

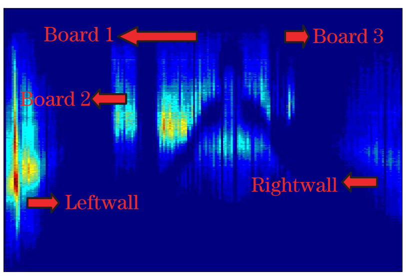

Fig. 5. Intensity image.

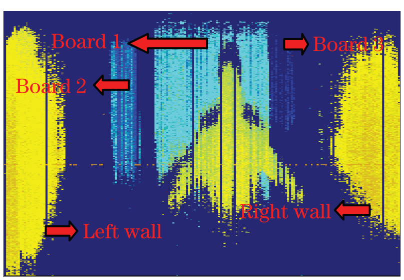

Fig. 6. Range image.

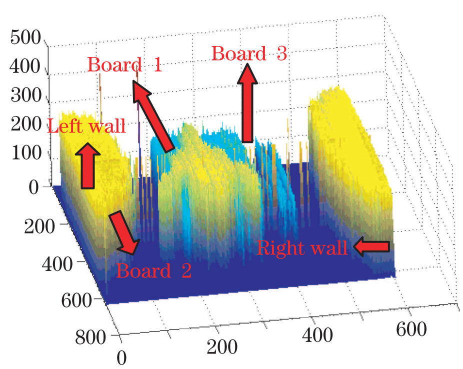

Fig. 7. 3D range image.

Figure 7 is the 3D image corresponding to Fig. 6. This image provides geometric information of the targets not readily visible with the intensity image, giving an improved identification capability.

The system we discussed provides a comprehensive solution to the task of control and image processing for STIL. By utilizing VB's graphics feature and MATLAB's computing capabilities, this system can operate efficiently based on low cost and compact components while perform the required data analysis and processing satisfyingly.

In the experiment, STIL imaged a set of targets at different distances and presented the precise dimensional resolution in all three dimensions rendered in 2D intensity and range image. The range image provides unambiguous geometric shape information which can be of much greater value than conventional intensity image.

STIL is well suited for a variety of applications, including object detection, classification, identification and high resolution digital elevation mapping. And due to different photocathode materials, streak tube can earn response from the near infrared to X ray. Compared with Multiple-Slit Streak Tube Imaging Lidar(MS-STIL), it has a better ability in range gating, and has less disturbances, but because of the scan structure, the system is bulky. With future development of the imaging processing algorithm, STIL automatic target recognition for both civil and military applications can be realized.

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