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Experiments on the range resolution measurement of a slit Streak Tube Imaging Lidar

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ABSTRACT

This paper describes the range resolution of a linear focal plane arrays imaging lidar. Through the measurement experiments of a flash lidar imaging technique that uses a streak tube (K008) camera as a receiver, range resolution under different conditions has been discussed. Its range accuracy can be about 2 cm under laboratory conditions, less than 0.65 m during long distance (4 km) target detection, and 1.5 cm in the experiment of underwater targets measurement, which are in accordance with the theoretical calculating values.

1. Introduction

Flash imaging lidar is a promising imaging system that has higher frame and spatial resolution than the conventional scanning system. It is able to image large areas very quickly [1,2]. In additional, the flash imaging lidar using a streak tube camera as a receiver can directly supply the range and intensity information with high resolution.

This system of linear focal plane arrays is also able to acquire the time of different photons reflected from the target's surface through deflecting voltage below a highly sensitive photocathode. According to the time and the numbers of photons, it can directly supply range and intensity information. The range information can supply 3D imaging of targets. Through the intensity information, we are able to recognize the target surface material from the data supplied [3,4].

The range resolution of the streak tube affects the imaging quality of an imaging laser radar system directly when the streak tube is used as the detector and the target recognition. After several decades of development, this streak tube camera's time resolution is in the region of a Pico second and its range accuracy is about centimeter level [5,10]. But few people do the measurement and discuss the range resolution under the different conditions.

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This paper firstly discusses the differences between the focal plane arrays imaging lidar and the traditional radar and proposes three experiments to measure range resolutions under the different conditions with a slit Streak Tube Imaging Lidar (STIL) as an example. In addition we can demonstrate that the measured range resolutions are almost consistent with the theoretical calculating values, which prove the previous discussion and that STIL has the ability of imaging with high quality and signal-to-noise ratio (SNR).

2. Imaging theory

2.1. Streak tube imaging lidar (STIL)

STIL is a promising imaging system because of its high frame, spatial and range resolution. The receiver is a streak tube camera which is a type of device that is used for instantaneous optics [6,7]. It can identify photons with different time characteristics with high sensitivity and record the time and photon numbers. It is used as a receiver such that the reflected light from the target's surface is imaged onto a slit in front of the streak tube photocathode by a conventional lens, and the time (range) is resolved by electrostatic sweep within the streak tube, this process generating the 2-D (azimuth) range and intensity images on each laser pulse, as is shown in Fig. 1. By orienting the fan beam perpendicular to the vehicle track, the along-track dimension is sampled by adjusting the pulse repetition frequency (PRF) of the laser to the forward speed of the vehicle, thus sweeping out the three-dimensional ocean volume. Fig. 2 shows the operational principle of STIL. Through

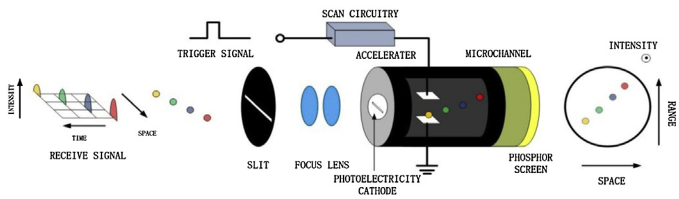

Figure 1. The imaging principle of the streak tube detector.

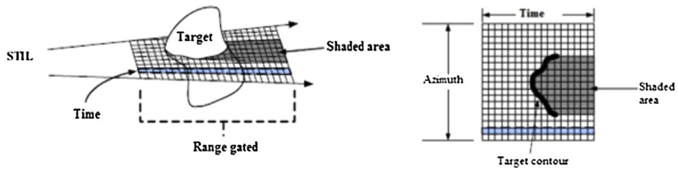

Figure 2. The operational principle of STIL.

rebuilding every frame of imaging, we can get 3D imaging and 2D intensity imaging of the target [8].

2.2. Range resolution of the focal plane arrays imaging lidar

The range resolution affects the imaging quality and target recognition of an imaging laser radar system directly. Traditionally, the range resolution is defined as the maximum fuzzy distance in the same azimuth angle. Due to the focal plane arrays imaging lidar, this description is not suitable. As is shown in Fig. 3, there are three targets in the lidar field of view. It also shows the position relation among the three targets in the receiver. Figure 4 shows the echo

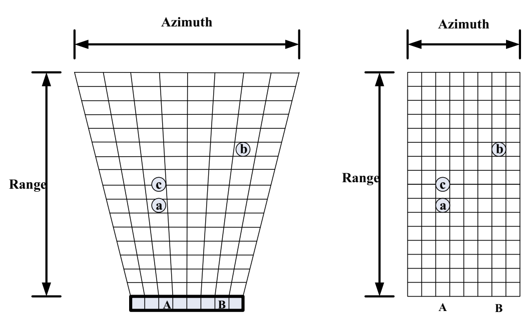

Figure 3. The diagram of the targets imaging using a focal plane arrays lidar.

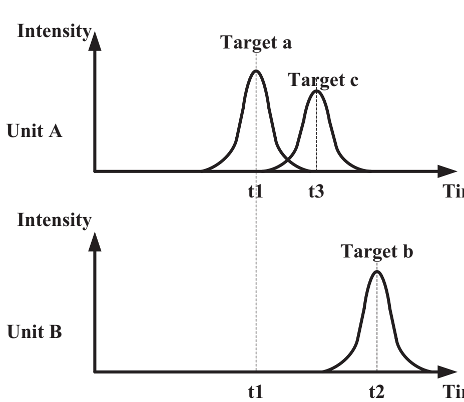

Figure 4. The echo signals of the units A and B in the receiver.

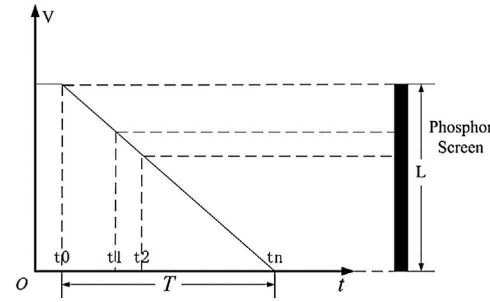

Figure 5. The principle of electrostatic sweep.

signal of the target of different detection unit. In the detection unit A, the distance between targets a and c can be described as

$$\Delta R = \frac{C(t_3 - t_1)}{2} \tag{1}$$

where C is the speed of light. The similar as the traditional radar, the range resolution can be described as

$$Range_{\min} = \frac{C\tau}{2} \tag{2}$$

where τ is the pulse width. And the range resolution is also affected by the repetition frequency. If the repetition frequency is less than $1/\tau$, the resolution also can be written as

$$Range_{\min} = \frac{C}{2f} \tag{3}$$

where f is the repetition frequency.

The traditional radar received all the echo signals in the space through only one antenna. When the distance is less than the fuzzy distance, the two echo signals fused and can not be distinguished. But to the focal plane arrays imaging lidar, the echo from different spatial azimuth can be received by different detection unit. Similar as the condition of targets a and b, the distance between them can be described as

$$\Delta R = \frac{C(t_2 - t_1)}{2} \tag{4}$$

So the range resolution is no longer limited by the fuzzy distance. It is only affected by the sampling time.

2.3. Range resolution of STIL

According to Section 2.1, the reflected photons from the target's surface are imaged onto a slit in front of the streak tube photocathode by a conventional lens, and the time (range) is resolved by electrostatic sweep within the streak tube [9]. Through the positions on the phosphor screen, it can mark the time of photons received by STIL, as is shown in Fig. 5.

The range between the target and STIL can be written as

$$Range = \frac{C \cdot t}{2} \tag{5}$$

where t is the time of echo.

The time of electrostatic sweep can be written as

$$T = \frac{L}{V_{screen}} \tag{6}$$

where V_{screen} is the scanning velocity of electrostatic sweep; L is the vertical length of phosphor screen.

Then the range accuracy can be written as

$$Range_{\min} = \frac{C \cdot V_{screen} L}{2M} \tag{7}$$

where M is the number of a column of pixels. In our STIL, M is 480; L is 2 cm; V_{screen} can be chosen as 10 µs/cm, 1 µs/cm, 0.1 µs/cm,