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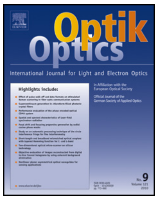

Original research article

Noise filtering strategy in photon-counting laser radar using the multi-gates detection method

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ABSTRACT

Single-photon detector possesses the ultra-high sensitivity, so that a photon, whatever signal or noise, can trigger the avalanche output. Due to the existing unavoidable noise, false alarms triggered by noise become the biggest barrier in the application of photon-counting laser radar based on the single-photon detector. In this paper, the multi-gates detection method is proposed to reduce the false alarm probability. With the proper threshold in the multi-gates detection, signal and noise can be distinguished efficiently. Comparing with non-multi-gates detection, the experimental results show that the multi-gates detection method can filter noise and reduce false alarms efficiently.

1. Introduction

In order to detect the extremely weak echo signal, such as signal from remote targets and highly scattered and/or absorbing media, Photon-Counting Laser Radar (PCLR) with the single-photon detector has been developed greatly in the last decade [1–3]. Geiger mode Avalanche Photodiode Detector (Gm-APD) and Superconducting Nanowire Single-Photon Detector (SNSPD) are typical single-photon detectors, and they are the most ideal device for low-light-level detection due to the ultra-high sensitivity and the ultra-fast photoelectric response. Besides, there are other advantages, including direct digital output, no need for a post-amplifier, small size, low power, and high stability [4,5]. Due to the ultra-high sensitivity, Gm-APD is also easily triggered by noise (including the background noise and the dark counting noise), resulting in false timing pulses [6]. This impacts the detection performance of PCLR system greatly.

In 2003, Daniel G. Fouche researched the false-alarm probability of the laser radar using Gm-APD. The multiple-pulses method was used to reduce the false-alarm probability efficiently. In his paper, the writer took the conditions of three pulses and five pulses as examples, and showed that identifying in data from as few as three pulses can reduce the false-alarm probability by orders of magnitude [7].

In 2011, Hong Jin Kong proposed a new method of obtaining a clear 3D image by reducing false alarms caused by noise in the stage of acquisition of raw time of flight (TOF) data. They divided a laser-return pulse into two Gm-APD arrays and used an AND gate to compare the arrival time of the electrical signals from two Gm-APD arrays. The false alarm probability

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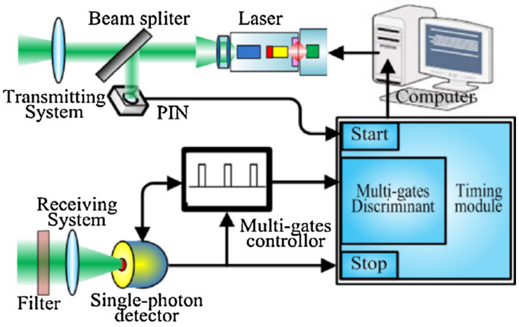

Fig. 1. PCLR system diagram with the multi-gates detection method.

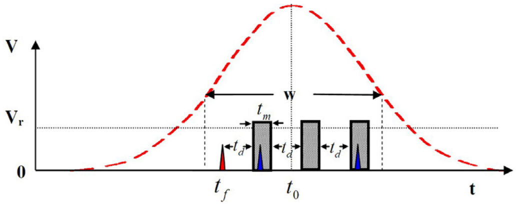

Fig. 2. Schematic diagram of multi-gates detection.

is drastically decreased, because the noise distributed randomly in the time domain is filtered out. Finally, the experimental measurement was in agreement with the theoretical analysis [8].

In this paper, a novel noise filtering strategy is demonstrated, which adopts the multi-gates detection after the timing pulse. With the proper threshold in the multi-gates detection, the timing pulse triggered by signal or noise can be distinguished. Then noise is filtered out and signal is preserved. As a result, a clear 3D image is obtained from the experimental system of the multi-gates detection method despite the background noise of the sunny day.

2. The multi-gates detection system

PCLR system diagram with the multi-gates detection method is shown in Fig. 1. The laser pulse signal comes from a semiconductor pulse laser and then is sent out through the transmitting system. A tiny part of the signal energy is reflected to PIN detector to start the timing module. After a round trip time, the echo signal which is reflected from the target arrives at the receiver. A narrow band filter is used to reduce background noise. The echo signal is focused on the photo-sensitive area of the single-photon detector. Once the single-photon detector is triggered to produce an avalanche timing pulse, the timing module will be stopped, and meanwhile the multi-gates controller will be driven to perform the multi-gates detection.

The schematic diagram of multi-gates detection is shown in Fig. 2. The red dashed line is the echo pulse signal, whose Full Width at Half-Maximum (FWHM) is w and peak position is t_0. The single photon detector is triggered at t_f, and produces an avalanche pulse (the red pulse at t_f in Fig. 2). This avalanche pulse is used to stop the timing module, therefore also called the timing pulse. No matter signal or noise triggers the single photon detector, timing pulses are the same and can't be distinguished. In order to distinguish signal and noise, the multi-gates detection is added after the timing pulse. In Fig. 2, the shadow boxes are multiple detection gates, whose widths are t_m. The interval between two neighboring gates is set as t_d, which is more than the dead time of the single photon detector in order to eliminate dead time effects. To ensure all detection gates are in the echo signal, the number of multi-gates n should satisfy $n \le w/(t_d + t_m)$. If the timing pulse is triggered by noise, the probability of existing avalanche events in the following n-gates is very small due to the noise distributed randomly; if the avalanche timing pulse is triggered by signal, the probability of existing avalanche events in the following n-gates is very high due to the following n-gates being in the echo signal.

3. The theoretical analysis

For the single-photon detector, the avalanche events triggered by the echo signal, the background noise, and the dark count noise can be approximated to Poisson distribution [9]:

$$P(k;t_1,t_2) = e^{-\left(\int_{t_1}^{t_2} mdt\right)} \frac{\left(\int_{t_1}^{t_2} mdt\right)^k}{k!} \tag{1}$$