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Research of detecting the laser's secondary reflected echo from target by using Geiger-mode avalanche photodiode

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ABSTRACT

When the Geiger-mode avalanche photodiode (Gm-APD) laser detection and ranging (LADAR) carries out the air-to-ground detection, it can detect the echo that is successively reflected by targets and the ground, which causes the false target in the image obtained by the LADAR. In this paper, the echo which is successively reflected by two surfaces is called the secondary reflected echo, and the echo which is just reflected once is called the single reflected echo. Considering the Gm-APD's superior ability to detect photon, we investigate and analyze the triggering characteristics of the Gm-APD for detecting the secondary reflected laser echo from the targets, also, we carry out the experiments on detecting the secondary reflected echo in near field and far field by using array Gm-APD to verify that the array Gm-APD can effectively detect the secondary reflected echo, and this paper lays the foundation for the research of the secondary reflection's influence on the images obtained by Gm-APD. In this paper, firstly, we use the echo triggering model, which contains LADAR ranging equation and Poisson probability model, and the Monte Carlo simulating method to completely verify the possibility of detecting the secondary reflected echo by using Gm-APD, in theory. The theoretical results show that Gm-APD can detect the secondary reflected echo, and the wider the field of view(*FOV*) is, the longer the detecting range is, besides, the higher the LADAR is located at, the lower the target's secondary reflected echo's intensity is and the higher the ground's single reflected echo's intensity is; then, using the Gm-APD with an array of 64×64 and 32×32 to detect the indoor scene and the moving van in far field, respectively, the results show that the indoor experiment obtains the complete first and second reflected image and the single pixel can detect the secondary reflected echo from multiple targets, also, for the far-field experiment, the single reflected echo and second reflected echo can be obtained in a single frame image, and under this experimental conditions, two pixels which are studied, realize the range extension of 25.6 m and 41.9 m respectively, which shows that the Gm-APD can likely detect the false target in the far field; finally, the methods that finding the secondary reflected surface by using the multiple-frame statistics for static targets and the image of triggering position in chronological order for moving targets, respectively, are proposed to eliminate the secondary reflected image. This article can provide some theoretical references for eliminating the secondary reflection before target recognition.

1. Introduction

In recent years, the laser active imaging technology is paid more attention by researchers, and its potential is being excavated. Now, the LADAR has been widely used in military and civil fields, such as, terrain mapping, obstacle avoidance, target recognition, weapon guidance, etc. [1]. The detection sensitivity of the detector has great influence on laser active imaging technology, and it mainly impacts the LADAR's minimum acceptable energy. Gm-APD, as a kind of single photon detector which can capture echo at a very low level of photons, has a higher detection sensitivity compared with the linear-mode APD and streak tube detector, so the LADARs based on Gm-APD have become an important branch in the community of LADAR [2–9].

In this paper, the echo which is successively reflected by two surfaces is called the secondary reflected echo, and the echo which is just reflected once is called the single reflected echo. At present, the LADAR which is used for far-field target detection mainly adopts the line-of-sight imaging [10], which means that the target is within the *FOV* (field of view), and the detector mainly receive the single reflected echo directly from target. The reason for detecting the single reflected echo is that the receiving echo power has a relationship of inverse square of the target's distance with reflecting echo power and it leads to the low

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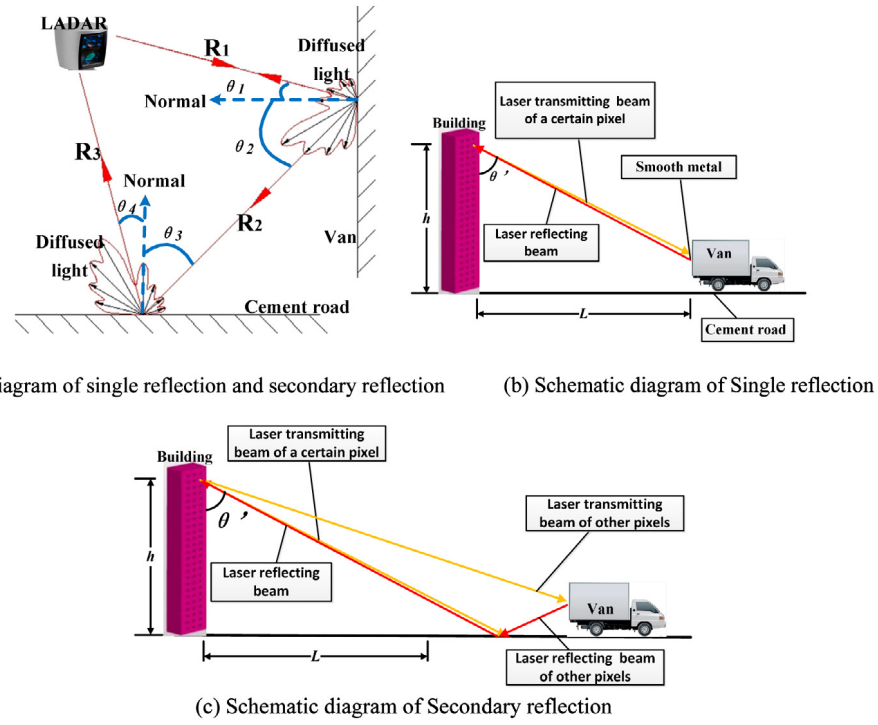

(a) Schematic diagram of single reflection and secondary reflection

(b) Schematic diagram of Single reflection

(c) Schematic diagram of Secondary reflection

Fig. 1. Schematic diagram of detecting the moving vehicle by using LADAR . (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

receiving echo power, if the single reflected light is reflected twice or more again by other median surface, the received echo will be so lower that cannot be detected because of the diffuse scattering of the median surface. So, for the linear-mode APD and streak tube detector, it is no need to consider the influence of the multiple reflected echo. However, due to Gm-APD's excellent photon detection ability, it has the ability to detect multiple reflected echo signal originating from targets, and one of the important applications is non-line-of-sight imaging, which means that the LADAR can detect the targets outside of the *FOV*. In the process of non-line-of-sight imaging, the light is reflected at least three times before it is received by detectors, and it mainly applied to detect the target behind the street corners or walls. Gariepy [11,12] uses non-line-in-sight imaging based on 32 × 32 Gm-APD to effectively detect the moving target which hides behind the wall indoor and the target is at a distance of 1m from the camera, they expect to detect at a distance of 10 m; Buttafava [13] successfully uses non-line-of-sight imaging based on single Gm-APD to detect letter 'T' made of white paper and the target is at a distance of 1.5 m from the detector; Jin [14] uses non-line-of-sight imaging to obtain the targets' 3D range image through a small hole with diameter of 2 cm, and the targets' distance are shorter than 2 m; Chan [15] uses non-line-of-sight imaging to detect the moving targets which is behind the corridor's corner, and the targets' distance is 50 m. For the non-line-of-sight imaging, the median surface's reflectivity must be relatively high, and to our best knowledge, the farthest distance of the detection is about 50 m, which is just called near-field imaging, and multiple reflections still limit the detecting distance of Gm-APD. However, the non-line-of-sight imaging fully highlights the Gm-APD's advantage of detecting lower flux and it incurs the consideration of the line-of-sight imaging that the echo which triggers the Gm-APD may not be the single reflected light of the target, it might be the multiple reflected light from other targets, and treats the current target as the final reflected surface. The multiple reflected light will make a great influence on the array imaging, because the position of the multiple reflected echo in the image is the spatial position of the last reflected surface, which can make the camera detect the target which does not exist at the current position, so the false target appears, and this problem is not currently considered in the Gm-APD imaging.

In this paper, we will do research on the secondary reflection by use of Gm-APD, there are two main reasons, the first, the secondary reflection is the basis of the multiple reflection, and the multiple-reflected model can be regarded as the secondary-reflected chain; the second, we focus on the imaging in the far field, the long range has made the single reflected echo relatively low, if the echo is reflected multiple times again, the echo will be much lower, which makes no difference on the total echo intensity, however, there are some strongly reflected targets in the natural scene, if the echo of which is reflected again, the secondary reflected might affect the Gm-APD's triggering. To our best knowledge, in the research papers we have investigated, there is no discussion on the phenomenon of the secondary reflection based on Gm-APD, not to mention the array Gm-APD.

In this paper, firstly, we build a theoretical model on detecting the moving van's echo based on Gm-APD, and the model regards the van as the strongly reflected target, and the ground as the secondary reflected surface. By using the theoretical model, we investigate the triggering characteristics of the secondary reflected echo, and it is verified that even if the target is beyond the receiving *FOV* of a certain pixel of the array detector, within a certain distance, the pixel can still detect the target's echo; then, using the array Gm-APD to detect the indoor scene and the moving van outdoor, respectively, and it is verified that Gm-APD can effectively detect the secondary reflected echo in the image, which makes the image contain the false target; finally, it is a simple discussion about how to eliminate the secondary reflected image.

2. Theoretical model

2.1. Model of detecting the moving target

The schematic diagram of detecting the moving vehicles is shown in Fig. 1. The LADAR is placed into the building, and it detects the vehicle which moves from near to far on the ground. The material of the vehicle's rear is regarded as smooth metal and the material of the road is regarded as cement. As is shown in Fig. 1(a), it is the schematic diagram of the single reflection and the secondary reflection. The light's