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Comparison of Digital Filtering Techniques Used in Time-of-Flight Laser Range-finder

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ABSTRACT

Laser range-finders are attracting attention as they are used in many areas like autonomous driving, metrology and military. It combines many advanced technologies from hardware to software to accomplish longer range and higher resolution sensitivity. For this silicon photomultipliers are one of its important components which increasingly getting attention in many areas where low signal detection is needed. Although SiPM offers very high gain, it suffers from intrinsic noises such as dark count pulses which are always present unless it has not been cooled down sufficiently. Therefore, besides hardware improvement, measurements require careful signal processing techniques in order to have acceptable signal to noise ratio. Here, we present the different signal processing techniques applied to raw data and compare their performance with real data.

1. Introduction

Laser range-finders (LRF) find wide applications in many civilian and military applications. It is a critical device especially when it is used for military purposes since it defines position, movement or maybe dimension of object just by means of measuring distances [1,2]. The application is not limited only for military purposes, but also surveillance, autonomous driving for vehicles, sport activities are just a few application areas [3,4,5]. There are mainly two different techniques in laser ranging methods which are time-of-flight and phase shifting. In this work, we use time-of-flight technique which measures the time interval of laser pulses during its travel between laser and target. LRF consists of transmitter which sends out series of pulses, receiver which detects the reflected pulses, electronic units which control both units and process data. All its parts are equally important and require a special design process to get the measurement done. Below (Figure 1) shows a basic component of LRF. The pulsed LRF works based on the time of flight of an optical pulse that is emitted by the Transmitter, reflected from the object or target, and then received by the Receiver. The sensing distance (d) can be expressed using the following equation

$$d = c\Delta t/2$$

Δt is the time delay and, c is the speed of light.

As the distance is more than a few kilometers, lasers with high peak power (kW levels) must inevitably be used which are often expensive and bulky. In this work, for low-cost purposes, we use low power diode laser and therefore, both photon detection and signal processing become crucial. For the photon detection unit, we prefer to use silicon photomultiplier (SiPM) instead of an avalanche type photon detector. Along with functional mechanical and optical design, our aim is here to show the detection algorithms play critical role as well. For this purpose, we make a real measurement to compare well-known several algorithm techniques like Convolution, Wavelet and Wiener-Hopf.

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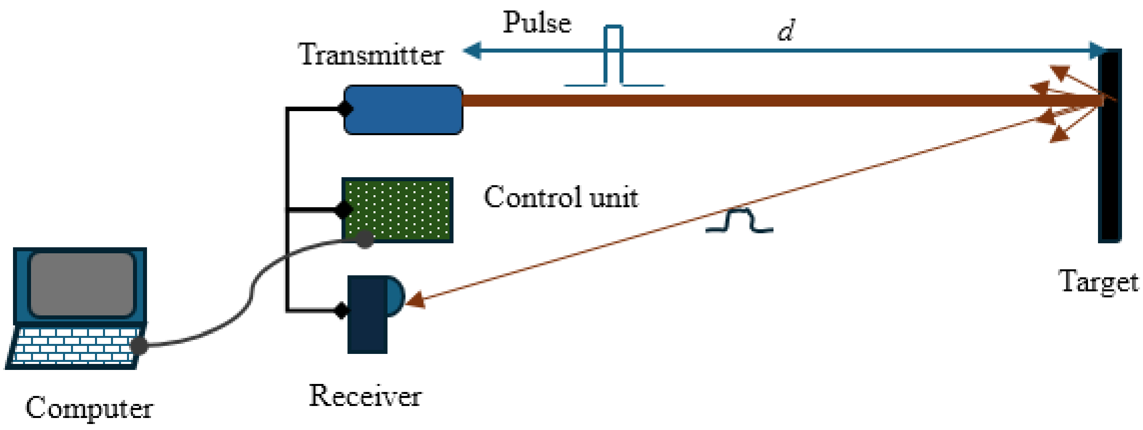

Figure 1. Schematic of laser rangefinder used in the experiment.

2. Experiment

Photon detection under very low light level in noisy environments is very challenging for many applications including LiDAR and laser rangefinder (LRF). Silicon photomultipliers with growing interest are semiconductor detectors due to their superior characteristics of high gain, high detection efficiency, low operating voltage, low cost and compactness. SiPM consists of a dense array of small microcells which is also called single-photon avalanche diode (SPAD) functioning in Geiger-mode, each one with its integrated passive quenching resistors. These cells are arrayed in a matrix form and connected in parallel making common anode and cathode. SPAD arrays are also known as SiPM which consists of microcell densities from a few hundreds to a few thousands per mm^2, depending on the size of the microcell which are independent photon micro counters working in the Geiger mode with a gain of 10^6. SiPM has its own unique performance and well-characterized and described in detail in Ref. [6, 7,8,9].

The designed LRF below uses only a peak power of 90 W semiconductor laser and detector made by SensL (SensL is now ON Semiconductor) as SiPM references with a pin adapter board MICRORB-SMTPA−10020. The experimental setup is shown in the Figure 2 below. The laser was fired at a repetition rate of 1 kHz with a 100 ns pulse width. As a demonstration, 2 by 2 meter sized black wooden target is located at a distance of 1929 meter which was measured with 1064 nm, 8 mj commercial LRF. The received signal was recorded by the NI-7932R FlexRIO FPGA module that operates synchronously to drive laser and NI-7932R. Measured data is recorded and fed into the signal extraction algorithm to analyze further.

Figure 2. Experimental LRF setup on the breadboard.

3. Data Processing and Results:

Three different techniques are used to analyze the measured data. These digital filtering techniques are Convolution, Wavelet and Weiner-Hopf. In the experiment, the number of frames we record to analyze the data is 4000 and each with 2500 data point. The signal processing method starts with pulse accumulation and goes with coherent averaging. After applying Convolution, Wavelet and Wiener-Hopy techniques, signal to noise ratio (SNR) is calculated using the equation below where A is the highest obtained amplitude and σ is standard deviation in the measured data.

$$SNR = A/\sigma \quad (1)$$

Figure 3 shows the results of processing real data. Probability of false alarm rate is found to be Pfa = 0.0024 when the target is not present using Rayleigh cumulative distribution function. Using this, threshold value is computed separately for each filtering technique. The red line shown in Figure 3 is the computed thresholds which are slightly different from each other. Signal to noise ratios for each filtering techniques are found to be 6.8 for Averaging, 8.8 for Convolution, 9.1 for

Wavelet and 10.1. The programming code for those analyses is written in Matlab [10] environment. In the averaging process, coherent method of pulse integration is used. The number of frames that are used in the averaging is 4000. Note that all other techniques use this averaged data. In the convolution process, the acquired signal is convolved with the array of ones representing the pulse. In the wavelet denoising process, universal threshold with wavelet families of sixth level Daubechies (db6) is used. In the Wiener-Hopf method, using Wiener equations, we obtain suitable filter coefficients. The filter with consists of those coefficients works as a low pass filter which carries the characteristics of desired and noisy signals. Therefore, those coefficients need to be recalculated at each measurement.

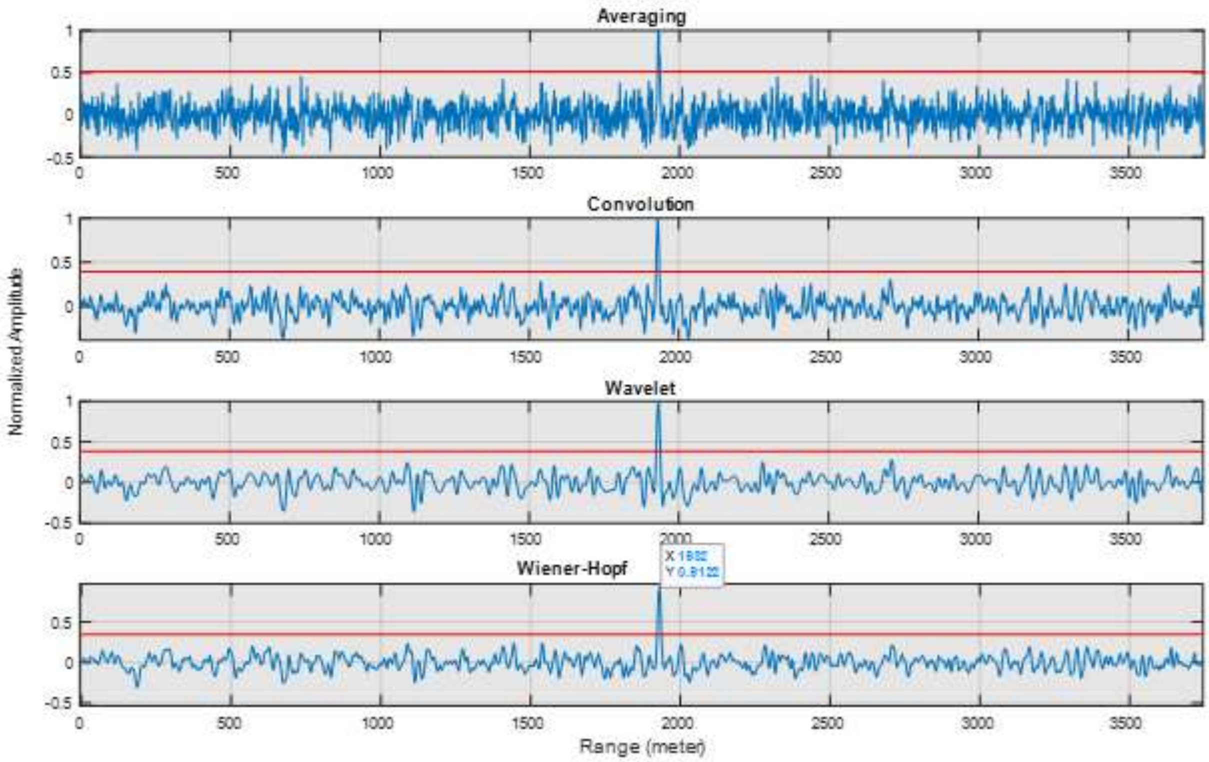

Figure 3. Acquired raw signal reflected from the target and its processed signal. From top to down: Averaging, Convolution, Wavelet and Wiener-Hopf.

4. Conclusion

In this work, we have made use of SiPM for the range detection and the detection range has been improved not only by the use of SiPM but also by the applied signal processing techniques. There different digital filtering techniques are applied to the obtainedecho signal of LRF. Naturally, the echo signals are buried in noise because it subjects to absorption and scattering along its travel path. Moreoveri, besides its large gain advantages, SiPM has some intrinsic noise which might be worse than that of avalanche photodetector It is customary to apply averaging processes which may help reduce the noise level to some extent, it is not enough to vercome the intrinsic noises that arises from the SiPM. So, we have applied additional filtering to improve the SNR. Although the results of three filtering techniques resemble each other, the best result is obtained by the Wiener-Hopf filtering technique which has the highest SBR value. Therefore, this technique shows the best promises among others.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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