Increased Efficiency Within Time of Flight LiDAR Systems Through the Inclusion of Mid-IR Components

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Abstract: NIR ToF LiDAR systems suffer from atmospheric attenuation and noise caused by background solar irradiance. By incorporating Mid-IR components, we propose a direct ToF LiDAR system with increased efficiency when compared to conventional NIR systems.

1. Introduction

The recent increase in availability of Mid-infrared (Mid-IR) components has served as a major motivation within research groups to create systems and devices that employ these components for specific tasks and applications [1,2]. One field of applications that has seen an increased interest with the employing of these mid-infrared devices, specifically in the 4.6 μm region, is within the field of light detection and ranging (LiDAR) [1,2]. The motivation behind this interest is due to the current inefficiencies that are present within conventional LiDAR systems. These inefficiencies, which are mainly caused by the presence of an overabundance of background noise generated by solar irradiance as well as the presence of signal absorbance-based attenuation generated by atmospheric molecules (nominally from solid and vaporized water molecules that have a near-infrared-based absorption dependency), severely limits the potential maximum distance that conventional LiDAR systems are able to operate under [1,2,3]. By removing and replacing near-infrared components with Mid-IR components, we propose a time of flight (ToF) LiDAR system that is capable of overcoming the previously discussed limitation. In this paper, brief discussions on the processes used to perform ToF LiDAR as well as the specific ToF LiDAR process that will be employed, the near-infrared (NIR) LiDAR system that will be used as a basis when constructing the proposed Mid-IR LiDAR system, the Mid-IR components that will be used as replacements for the respective NIR components, and expected comparative results between the two systems will be provided.

2. ToF LiDAR

ToF LiDAR is a set of techniques, which are used to determine the round-trip time for a transmitted signal to propagate through a medium, reflect off of a target, and detect the returned signal [4]. ToF LiDAR is typically used to measure the distance between targets, measure the speed of a moving target, or to map an area by recording multiple distance measurements across a specific field of view [4]. Two popular techniques that are used to determine the round-trip time involves either the direct measurement of elapsed time between signal transmission and signal detection or the measurement of the shift in phase, which can then be used to calculate the elapsed time, between the transmitted and detected signals [4,5]. Because of the nature in how these techniques operate, they have been respectively designated as direct-ToF and indirect-ToF [4,5].

Direct-ToF LiDAR operates by using a pulsed light source to emit a narrow pulse towards a targeted area, using a photodetector to capture the reflected pulsed light and convert into an electrical signal, and using either time-to-digital converters (TDCs) or analog-to-digital converters (ADCs) to record the moment of emission and the moment of detection [4,5]. By using the following expression, $x = \frac{c*\Delta t}{2}$, where Δt is the elapsed time, c is the speed of light within the medium, and x is the measured distance, one may determine the distance between the LiDAR system and a target of interest [5]:

Indirect-ToF LiDAR operates by using a continuous light source to emit either an amplitude or frequency modulated signal towards a targeted area, using a photodetector to capture and convert the reflected signal into an analog electrical signal, and using analog-to-digital converters to digitize the transmitted and reflected signals [4,5]. Post-processing techniques, which typically includes Fourier transformation, are then used to determine the shift in phase between the captured signals [4,5]. By using the following expression, $\Delta t = \frac{\Delta\phi}{2\pi*f}$, where $\Delta\phi$ is the difference in phase and f is the frequency of the modulated signal, one may determine the elapsed ToF, which can then be used to determine the distance between the LiDAR system and a target of interest [5].

Due to the operational simplicity and readily available components, it was decided that the method that will be employed by the proposed system will be the direct-ToF method. In the following section, the NIR LiDAR system that was selected to serve as a foundational basis for the Mid-IR system is presented.

3. NIR LiDAR System

The NIR direct-ToF LiDAR system that has been selected to serve as a foundational basis for the proposed Mid-IR system is based on the Osram Opto Semiconductor Inc. designed SPL PL90_3 Range Finder [6]. Rather than using a commercially available and self-contained system, this system was selected due to the highly modular nature of the design, which was assumed to be helpful when replacing the NIR components with their Mid-IR counterparts.

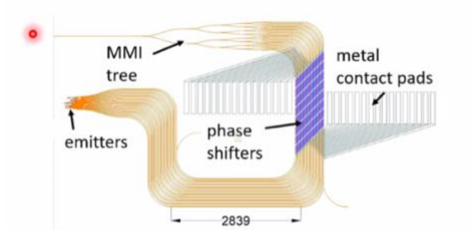
This system employs the use of the SPL PL90_3 laser diode, which is a 904nm emitting laser diode capable of providing high-powered pulses that have pulse widths along the range of 10-100ns, and the MTAPD-06-016, which is a silicon-based avalanche photodiode with a highly sensitive operational wavelength range that includes 904nm [6]. A TI TDC7200 evaluation module, along with a TI MSP430EXP5529 launch pad and TI developed functional GUI, are used to visualize and measure the ToF of the transmitted and reflected signals [7]. In the following section, the Mid-IR components that will be used to replace the NIR components will be presented.

4. Mid-IR LiDAR System

The first component that will be removed is the SPL PL90_3 laser diode and accompanying driver board, and the laser diode will be replaced by a QCL-IR laser system, which is capable of providing high powered pulses with pulse widths along the scale of 100s of nanoseconds. Furthermore, the specifically identified system allows for individual quantum cascade lasers (QCLs) to be tuned to various wavelengths that fall within the range of 3-13μm, which includes the proposed system operating wavelength of 4.6μm. The other component that will be removed is the MTAPD-06-016 detector, and the detector will be replaced by a custom 4x4 separate absorption charge and multiplication (SACM) linear mode APD, which is capable of detecting the proposed system operating wavelength of 4.6μm. The custom device fabrication and design was outsourced to SK-Infrared, which has been acting as a supporting team for the overall project. In the following section, the experimental setup and expected results are discussed.

5. Experimental Setup and Results

The experimental setup that will be used to serve as a proof of concept for the direct-ToF 4.6μm-based LiDAR system, as well as serving as a platform to conduct a rough comparative system analysis between the NIR and Mid-IR systems, will involve the indoor placement of the system at various known distances from a highly reflective target and measuring the respective ToF between emitted and reflected pulses. The operational procedure for the experiment will include the emission of a pulsed signal, the propagation of the signal through a beam splitter, which has the reflected output be directed to a reference APD and the transmitted output be directed towards the target, the detection of the reflected signal by secondary APD, and the measurement of the elapsed time between detection. This procedure will be conducted with both the NIR and Mid-IR systems, and a rough comparison in system performance will be performed to validate the expected increase in system efficiency within the Mid-IR system. Furthermore, our group proposes the incorporation of a Mid-IR-based optical phased array (OPA) built on an InP platform, which was featured in previous research endeavors [1,2]. The complete functional block diagram that illustrates the operational procedure can be seen in the images below. Ultimately, we expect the complete system to have the maximum distance ranging potential to increase by a factor of 160%, when compared to the NIR system. This increase in distance ranging potential was calculated by analyzing the ratio of absorption-based attenuation between ~0.9μm (0.75) and ~4.5μm (0.6) [3].



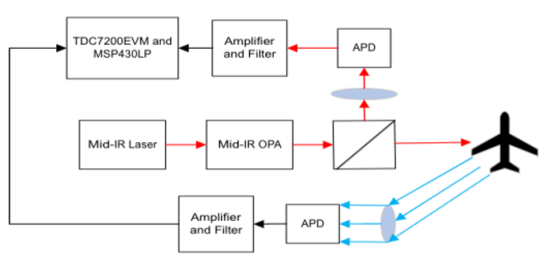


Figure 1a and 1b: (a) InP OPA and (b) Proposed Experimental Setup of Mid-IR 2D-Scanning LiDAR System

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