Multi Tone Continuous Wave LIDAR

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Abstract: Multi tone continuous wave LIDAR system is being discussed for range and velocimetry measurements. Potential implementation of AI algorithms will be presented.

1. Introduction

The adaptation of artificial intelligence (AI) in numerous fields such as autonomous vehicles and robotics manifested the demand for an optical backbone to create an environmental awareness for such remote systems. Fast camera modules with image processing and LIDAR systems with pulsed time of flight (PToF) technique were previously employed to map the surroundings with various range and accuracy limitations [1]. The state of the art PToF LIDAR systems for autonomous vehicles can provide data acquisition up to 200m range with >30cm scanning and >3cm depth accuracy [2]. In addition, the velocity of a moving frame is constructed via data processing based on the timing information in PToF LIDARs, which is a time and power consuming process. Even though it yields a reasonable accuracy, the latest autonomous car incidents create the demand for greater precision to reduce the potential fatalities for the pedestrians and drivers. For more accurate environmental mapping and instantaneous velocity readings of the moving media, we utilized amplitude modulated continuous wave (AMCW) LIDAR approach with multiple radio frequency (RF) tones that enables data acquisition with <1cm depth and <10cm 2D planar-scanning accuracy up to 300m range with a standard power budget by carefully selecting the bandwidth (<10 GHz), and the beam size of the laser [3]. The AMCW systems employ high-speed RF electronics to modulate the light intensity, while keeping the frequency constant. The range information is further obtained by convolving an optical local oscillator with the time-delayed return signal similar to phase shift LIDARs, while the velocity information can be gathered by facilitating photonic Doppler velocimetry (PDV) technique. Previously, enhancement of range and depth resolution measurements by using single-tone and/or multi-tone continuous wave (MTCW) LIDAR was demonstrated for quasi-CW lasers [4]. In addition, single-tone AMCW PDV was formerly demonstrated for an oscillating target with acceleration [5]. The multi-tone modulation can enhance the AMCW technique by increasing the velocity and range resolution of the system for longer ranges. Here, we also present the high accuracy velocity measurement capability of a moving target with constant velocity by using MTCW methodology. This technique can be used as an optical backbone by further enhancing the areal coverage via implementing a scanning MEMS mirror and integrating to an image constructing an algorithm to form the environmental map of a remote AI system.

2. Methodology

The measurement setup for 4-tone MTCW LIDAR system is presented in Fig. 1. A 1550nm CW narrow-line-width laser diode is employed and pigtailed to a single mode fiber. The polarization of the laser is monitored via a polarization controller (PC) in order to achieve optimal throughput after modulation, which is provided by a Mach-Zehnder modulator (MZM). 4 different RF tones are generated and combined, then fed to the MZM to modulate the amplitude of the CW optical signal. Amplification of the modulated light is conducted by an Erbium-doped-fiber-amplifier (EDFA), which is connected to an optical fiber collimator (CL). Heterodyning is performed by implementing a reference mirror on the other side of the receiver branch after a beam splitter (BS) that enables Doppler shift detection through interference. The target mirror is placed on a motorized translational stage, which moves the target with a constant velocity (v) parallel to the laser beam. The receiver branch consists of a collection lens (L1) and a PIN InGaAs photodetector that is further connected to a digital storage oscilloscope for data acquisition (DSO).

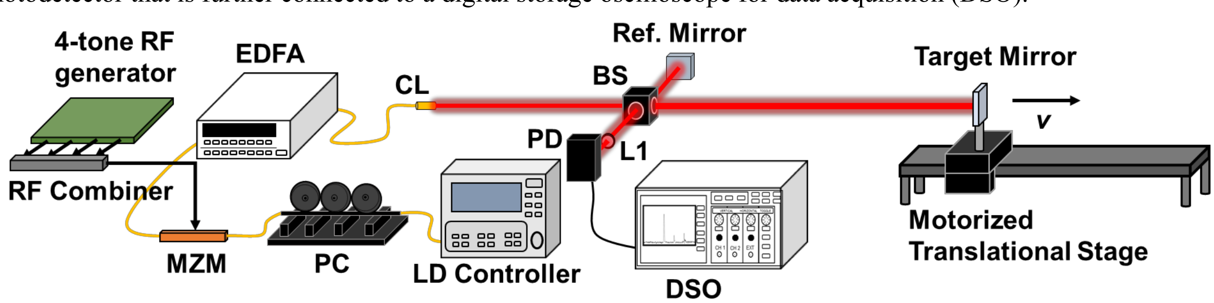

Fig. 1. MTCW LIDAR measurement setup with 4-tone RF modulation for velocity measurements.

After data acquisition, fast Fourier transform (FFT) is performed on the collected time-domain data to measure the Doppler shifts to extract the speed information. With $\Delta f = 2 f_o \times (\Delta v/c)$, it is possible to relate the resultant frequency

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shifts to the velocity, where Δf is the measured frequency shift, f_o is the optical carrier frequency and is 193.4THz, c is the speed of light, and Δv is the speed of interest. Since the translational platform provides a constant speed over the mid-section of the platform, the frequency shifts nearby the multiple tones will yield the velocity of the system.

3. Experimental Results and Analysis

The 4-tones we used during the experiment are 25MHz, 70MHz, 130MHz and 200MHz. We set the time window of the oscilloscope to 2ms and the resolution to 250ps, which enables a broad frequency domain. The modulation tones and the intermediary peaks due to their beating are indicated on the broad spectrum in Fig. 2(a). When zoomed into base-band, it is possible to observe a Δf of 130kHz as in Fig. 2(b). To further investigate the shifts near the modulation frequencies, we selected the lowest and highest modulation frequencies of 25MHz and 200MHz, which are presented in Figs. 2(c) and (d). The same Doppler shifts are observed near each modulation frequency. There are low amplitude oscillations around the Doppler peaks. These fluctuations are due to small acceleration and/or declaration of the motorized stage during its motion. It is possible to map these oscillations into a speed profile by applying short-time-Fourier-transform (STFT) [5]. To calculate the constant velocity of the target, we used the peak of the Doppler shift region, since the majority of the target's motion is under constant speed. The calculated speed of the target is 10.07 cm/s. The accuracy of the system can be improved by increasing the frequency resolution of the system. These additional tones can play a significant role during the data acquisition in longer ranges since it can improve the range and velocity resolutions.

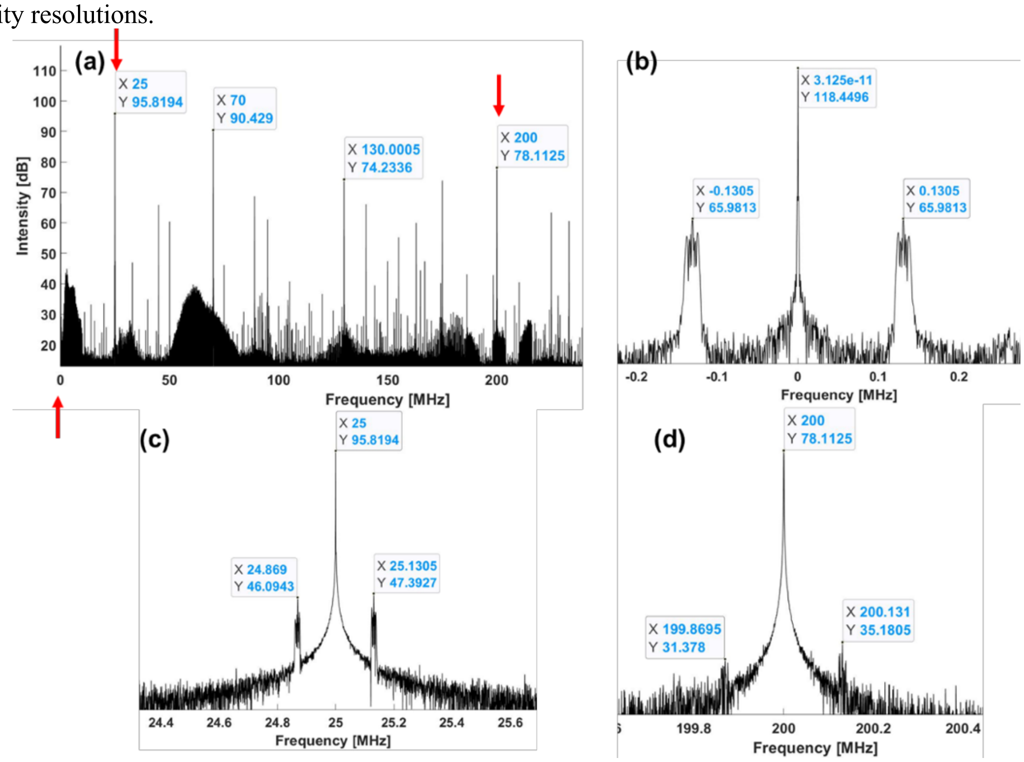

Fig. 2 (a) The broad spectrum indicating the modulation frequencies. (b-d) Base-band, 25MHz and 200MHz tones and their Doppler shifts.

A combination of this method with scanning optics and information extraction algorithms will result in an enhanced environmental mapping system for remote AI systems such as autonomous vehicles, robots and UAVs. The acquired data cloud can be further used in training the computers of remote AI devices through neural networks by utilizing machine learning methods to map the surroundings as a virtual reality with higher accuracy for longer ranges.

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4. References

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