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Distance Measurement of Low Reflectance Objects Using Indirect Time of Flight LiDAR

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ABSTRACT

Remote sensing is a system that enables data collection without physical contact with the object or its environment. Light detection and Ranging (LiDAR) technology is increasingly important in various industries, particularly developing autonomous vehicles. In autonomous vehicle applications, LiDAR is expected to detect multiple objects from high and low reflectance to make it easy to recognize its surrounding area. We have designed a biaxial LiDAR range finder system based on indirect time of flight technology, which has been tested to measure the distance of an object with high reflectance. In this work, we employ the system to measure the distance of an object with low reflectance from High Impact PolySterene (HIPS). The results show that the systems can measure objects from HIPS up to 33 m, which is lower than when the system measures an object with high reflectance.

Keywords: i-ToF, LiDAR, Low Reflectance Object

ABSTRAK

Penginderaan jarak jauh merupakan sistem yang memungkinkan pengumpalan data tanpa sentuhan fisik dengan objek atau lingkungannya. Teknologi Light Detection and Ranging (LiDAR) telah digunakan secara luas dalam berbagai sektor, terutama kendaraan otonom. Pada aplikasi kendaraan otonom, LiDAR diharapkan dapat mendeteksi objek dengan reflektansi tinggi. Pekerjaan ini, kami memanfaatkan sistem tersebut untuk mengukur jarak objek dengan bahan reflektansi rendah dari bahan High Impact PolySterene (HIPS). Hasil pengukuran menunjukkan bahwa sistem LiDAR mampu mengukur objek dengan bahan HIPS tersebut sampai dengan jarak 33 m. Dimana lebih pendek disbanding dengan ketika sistem mengukur objek dengan reflektansi tinggi.

Kata Kunci: i-ToF, LiDAR, Objek dengan Reflektansi Rendah

1. Introduction

Remote sensing systems allow data collection without physical contact with objects and their environment [1]. Optical and microwave remote sensing systems depend on the imaging method and wavelength [2]. Remote sensing has utilized various sensors and platforms, such as LiDAR [3]. Light detection and ranging (LiDAR) is a component of an earth system that requires active sensors that compare the characteristics of the signals sent and received [4]. The ability of remote sensing imagery to capture vast amounts of data in real-time, without needing to be physically present, makes it a powerful and adaptable resource that plays a vital role in many sectors [5]. LiDAR is a remote sensing technology that uses a continuous light laser emitted by a transmitter and received by a receiver [6]. LiDAR has become a powerful resource for applications in various fields, allowing for precise measurement of target range, velocity, and vibration [7]. LiDAR technology has been widely used in various industries, including autonomous vehicles [8]. Autonomous driving technology seems to be the transportation solution in some regions [9]. Autonomous vehicles are defined as vehicles driven by mechanical or electronic devices without a human driver [10]. The main principle of LiDAR work is that the sensor emits a laser to the object's surface and then reflects back to the detector [11]. The principle of LiDAR of a particular type is relatively simple. However, it requires sampling radio frequencies directly for digital processing since any modulator that will be used to measure RF signals will later acquire target information [5]. Due to its affordability and user-friendliness, Time of Flight (ToF), LiDAR stands out among other LiDAR technologies. It comes in two main types: Direct (d-ToF) and Indirect (i-ToF) [8].

The Time-of-Flight (ToF) method is used to find peaks in a signal. This method relies on the idea that a peak corresponds to a point where the signal strength reaches either a high point (maximum) or a low point (minimum). These extreme points are relatively easy to identify in the data [12]. Newer ToF sensors are being designed with higher resolution and accuracy to meet the demands of today's applications. Additionally, i-ToF sensors use a lower pixel bias voltage than d-ToF [13]. Commercial devices often rely on i-ToF for distance measurement. This technique utilizes a continuous wave or modulated light source to calculate the transmitted and reflected light [14]. While shrivels in i-ToF sensors are more superficial, it create a new challenge. As the sensor packs more pixels, the high current surge during operation becomes a significant issue [13]. Many industries rely on high-powered lasers, including data storage, communication, signal processing, and scientific instruments [15]. The emitter and receiver design configuration for LiDAR can be categorized into coaxial or biaxial, which have disadvantages and advantages. The coaxial configuration has the disadvantages of internal optical cross-talk, but the biaxial configuration offers a practical solution to overcome the coaxial configuration [16].

The LiDAR system employed i-ToF and biaxial transceiver in ref [9], and it has good performance in detecting an object with high reflectance up to a distance of 55 m. This work aims to determine the object with low reflectance due to real applications, such as autonomous vehicles; the LiDAR is expected to be capable of an object with various reflectances to recognize its surroundings when driving on the road. This work also observes the phase difference.

2. Methods

LiDAR system is designed based on the i-ToF method and a biaxial optical system configuration. This system uses a laser diode with wavelength (λ) = 915 nm outperencut power (P) =~40 mW(Thorlabs LP915-SF40). A signal generator regulates the laser's intensity. The generator periodically alternates the modulation frequency between a low value (f_1) of 2 MHz and a high value (f_2) of 10 MHz, with a switching period of 1 second. The laser sends a coded light signal to the target, which reflects it, where a sensor captures the signal (*photodetector*). The photodetector converts the received light into electrical signals. These signals and the original signal from the signal generator are captured by the data acquisition system, the PicoScope 4424. The signal from the receiver arrives later than the original signal because the light's modulation is affected by the distance it travels (round trip) and the frequency used for encoding. The data acquisition module reads the reflectance and measured signals, which will be implemented using the proposed algorithm in the LabView software program.

3. Result and Discussion

With the proposed design and algorithm, the system is tested to measure an object with low reflectance from High Impact PolySeterene (HIPS) with an interval distance of 1 m from 1 m up to the system that no longer obtained the signal. Measurement emphasis on the boundary area, use of DC (I) drive to laser diode = 100 mA, and amplitude voltage (V) = 1260 mV for modulation frequency. Measurements are repeated 3 times in the same area, and the average value will be used in the analysis. The LiDAR design uses the i-ToF method in the biaxial optical system; the receiver arrangement is next to the transmitter [9]. It can be seen in Figure 1, that there is a dramatic decrease in the strength of a received signal from a distance 1 m to 5 m, then rises again at a distance of 6 m, then peak to peak tends to weaken until a distance of 33 m at about 0,003 mV. Compared to meaning objects with high reflectance in ref [9], the maximum distance the system can reliably detect objects has decreased.

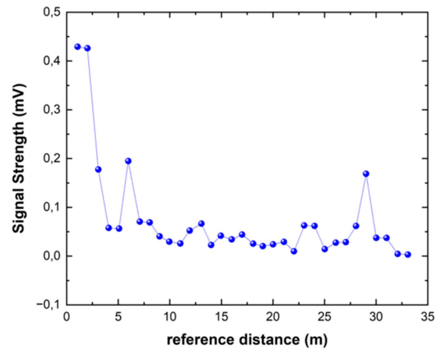

Figure 1. Signal Strength as a function of reference distance from 1 m to 33 m.

Figure 2 shows the phase difference due to the object's distance from 1 to 33 m, linear from 12.83° to 781.90°. The difference in the wave patterns (phase difference) reveals the established laser distance meter (LDM).

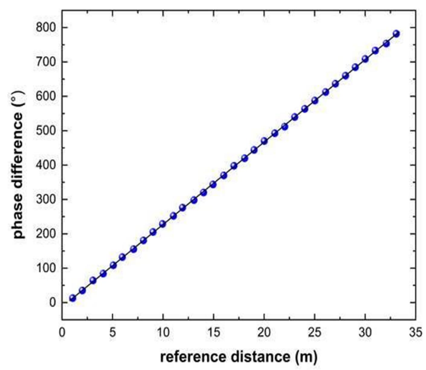

Figure 2. The phase difference of the system as a function of reference distance from 1 m to 33 m.

To obtain the measured distance, the phase difference (φ) is converted into the measured distance (d) using Equation (1).

$$d = \frac{c}{2f_M}\frac{\varphi}{360°} \tag{1}$$

where, in the context, c represents the constant speed of light while f_M stands for frequency modulation, which is 10 MHz. Then, the comparison between measured and reference distance can be seen in Figure 3. It is shown that it is very liner.

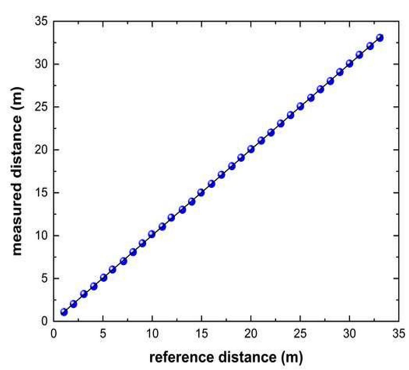

Figure 3. Measured distance as a function of reference distance from 1 m to 33 m.

Figure 4 illustrates the proximity of the measured distances to the actual distances. The measurements exhibited the highest accuracy, with a deviation of only 0.004 meters, at distances of 4 and 27 meters. The discrepancy between the actual and measured distances is referred to as the error. To achieve more accurate measurements, minimizing the error between the transmitter and receiver is essential.

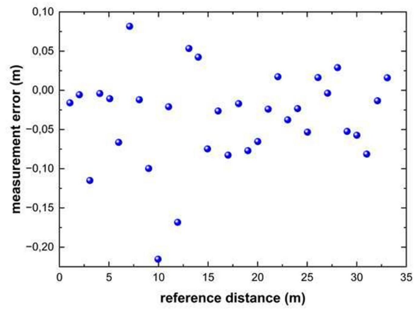

Figure 4. Measurement error as a function of reference distance from 1 m to 33 m.

4. Conclusion

The design of distance measurement with i-ToF LiDAR in this biaxial optical system uses a laser diode using the proposed frequency and algorithm. The proposed system has been experimentally demonstrated in measuring a distance of low-reflectance objects up to 33 m, which is different from high-reflectance. It is recommended that the system be added with an auxiliary component, such as a controller or amplifier, to be applied in real applications where the object has various reflectances.

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