Underwater Signal Measurement and Transmission Experiment Equipment Design for LiDAR

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Abstract. When carrying out related test experiments of shipborne LiDAR, it is necessary to launch lasers to areas with different water depths and confirm the working conditions of LiDAR according to the received waveform conditions, to debug the LiDAR. There is no special introduction to the indoor platform for this kind of testing. This article proposes an indoor LiDAR experiment platform, which will focus on the basic settings of the laser, sink, and reflector in the experiment, the design ideas and rationality of the sink and reflector modules, the experimental steps, and how to effectively obtain the waveform. This platform has good applications in parameter correction, waveform acquisition, water depth measurement, and other aspects of LiDAR design.

1. Introduction

The application of LiDAR in ranging, ocean exploration, atmospheric surveying, and mapping engineering is becoming more and more mature. Due to its wide range of uses, the differences in the design of each module of LiDAR are also very obvious. Water depth measurement is the basic work of underwater topography measurement [1]. At present, LiDAR are increasingly used in ranging and water depth measurements. JO Klepsvik et al. proposed to calculate the sea depth by recording the flight time of the pulsed laser signal in the water and obtain the distance information of the seabed topography [2]. The 532nm laser has a strong ability to penetrate water. Arshad et al. used a sinusoidal modulation 532nm laser to generate a detection signal and measured the distance of an underwater target by measuring the phase difference between the transmitted and received signals [3].

The LiDAR detection system is a full-echo system, and the recorded information is the time-related laser echo signal, which can more completely record each backscattered pulse [4]. The acquisition of the echo signal is vital to the early stage of the LiDAR design. The parameter correction of each module and the verification of the feasibility of rang are very significant. The LiDAR emits a laser beam, the underwater reflection signal is detected by the APD or PMT array, and then the signal is amplified and collected by subsequent processing [5]. Aiming at the problem that the bottom echo signal data cannot be collected more concisely during the design of the LiDAR, so that the parameters cannot be corrected more efficiently. An experimental platform is mainly designed in the article to find out how to receive the echo signal in a laboratory environment and the process of experiments and other issues are introduced.
2. Platform Design

2.1. Structure and functions
The construction of the experimental platform is mainly composed of two parts: LiDAR and sink. In the experiment, the optical emission system of LiDAR emits 532nm band laser at a certain frequency. The laser irradiates the target through water and generates a weak echo signal and LiDAR uses its optical receiving system to identify and receive the signal. And then amplify it through the amplifying module of the LiDAR to get the original echo signal data. The sink is used as a device for holding experimental liquids. The device can hold water bodies of different water qualities to simulate the experimental environment in the field to explore the influence of water bodies and other factors on the experimental results.

2.2. Design of sink
When the sink is designed, the outer tray uses 10mm thick acrylic board, the length * width * height is 2300mm*600mm*300mm, the internal sink uses 15mm thick acrylic sheet, the length * width * height is 2100mm*400mm*400mm, as shown in Figure 1. It is calculated that the tank can hold up to 336L of liquid, and the outer tray can hold up to 432L of liquid. Therefore, even if the internal tank is damaged, the liquid contained in it will not overflow. After calculation, the pressure it bears is completely within the range of the acrylic material. It can be used normally after being filled with water. The three-dimensional structure diagram is shown in Figure 1.

![Figure 1. Three-dimensional diagram of the sink](image)

After querying, the relevant parameters of the design platform that can affect the experimental results are shown in Table 1.

| Category                              | Parameter     |
|---------------------------------------|---------------|
| Laser attenuation coefficient in tap water | 1.20/m        |
| Refractive index of water             | 1.33          |
| Absorption rate of target plate to laser | 0.01-0.02    |
| Reflectivity of mirror               | 0.85-0.90     |

The lower load-bearing platform is made of stainless steel. After calculation of its bearing pressure, it can bear the weight of the tank and tray filled with water. Because the LiDAR requires a certain height, the height is designed to be 400mm, and the length and width are the same as the size of the external tray. This total height can just meet the needs of the experiment. Generally speaking, the space in the laboratory environment is limited. Under the guidance of optical theory, a reflector is added to the sink to maximize the use of the sink space, and the position of the reflector can also be adjusted according to experimental needs. So that we can change the transmission distance of the laser in the air. The specific flow chart of the experiment is shown in Figure 2.
3. Experiment

3.1. LiDAR
LiDAR is mainly composed of laser, optical receiving system, APD and PMT module for receiving surface and underwater echo and amplifying circuit module. Its general structure is shown in Figure 3. The laser adopts the Shanghai Hann Star green band 532nm continuous single-frequency fibre laser. Different specifications of filters should be added for PMT reception and APD reception. The pump power, repetition frequency, pulse width, and other parameters of the laser source can be set through the host computer software. The APD module uses the KY-ARPM series of Beijing Keyang Company. Its responsivity at 532nm wavelength is about 0.35A/W, which will not easily reach saturation. Interference; PMT uses the H11526 series of Hamamatsu, Japan, whose repetition frequency is 10kHz, and its responsivity at 532nm wavelength is about 0.04A/W.

3.2. Experiment process
The water used in the experiment is tap water that is easily available in the laboratory environment. Certain substances can be added to change the diffuse attenuation coefficient of the water according to the needs of the experiment. At the beginning of the experiment, adjust the position of the LiDAR bearing bracket so that it will not move and affect it when working, and then fix the reflector bracket on the tank and make it flush with the tank. Adjust the reflector on the upper side of the reflector bracket so that the angle between the reflector and the sink is 45°, and the lower reflector and the bottom of the sink are also maintained at 45°, and the target obstacle is fixed in a suitable position. Inject a certain
amount of water or other experimental liquid into the sink so that it can completely submerge the target obstacle and be lower than the warning water level. Start the LiDAR, and the laser beam is reflected by the upper mirror of the laser reversing bracket, and then enters the water from the horizontal direction to the plumb direction, and then irradiates the lower mirror, the laser beam changes from the plumb direction to the horizontal direction Target obstacles.

Then use an infrared rangefinder to measure the distance between the LiDAR and the reflecting point of the reflector and the distance between the obstacle and the reflector and record it. Then observe the received echo signal through an oscilloscope and record it. After that, you can simulate different water depths by moving the target obstacles, and record the actual distance and the received echo signal waveform. You can also change the angle of the upper reflector to change the incident angle, and adjust the angle of the lower reflector accordingly to ensure that the laser is irradiated on the target, and the corresponding angle and waveform are recorded.

![Figure 4. Schematic diagram of the experimental platform](image)

### 4. Discussion

Repeat the experiment according to the above experiment process, and take several experiments for an explanation. The curve in figure (a) is the signal received by the small field of view PMT detector in the laser radar receiving optical system when the distance is 32cm from the water surface. The first larger signal is the water surface echo signal, and the second smaller signal is the echo signal of underwater obstacles, and the rest is noise or interference signals received by partial backscattering, not the target signal. The lower curve in figure (b) (c) (d) is the signal received by the large field of view PMT detector in the LiDAR receiving system. The distance between the obstacle and the water surface is 84cm, 210cm, and 210cm, respectively. The waveforms obtained are as follows.
According to the laser ranging principle formula:

\[ R = \frac{1}{2} ct \]  

(1)

Where \( C \) is the speed of light, which is about \( 3.0 \times 10^8 \text{m/s} \) in air, and \( 2.25 \times 10^8 \text{m/s} \) in water, which is three quarters of the vacuum, and it is the transmission time in air. The formula can be calculated as follows:

| Name | Transmission time(ns) | Calculation of distance(cm) | Error(cm) |
|------|-----------------------|----------------------------|-----------|
| a    | 3.3                   | 37.1                       | 5.1       |
| b    | 7.1                   | 79.9                       | 4.1       |
| c    | 18.4                  | 207.0                      | 3.0       |
| d    | 18.1                  | 203.6                      | 6.4       |

According to the data analysis, the longer the measurement distance, the greater the error. After repeated experiments, the error of each measurement basically fluctuates around 5cm. Taking into account the limitations brought by the reflector and measurement tools, the size of the error is within an acceptable range, it can be shown that the system error of this platform meets the experimental requirements and will not cause major interference to the experimental results.
5. Conclusion
This paper proposes a LiDAR test experimental platform for a laboratory environment and gives a more detailed introduction to its application and experimental methods. Through theoretical study and analysis of experimental results, the following conclusions can be obtained: Based on this platform, the receiving and ranging process of LiDAR echo signals in the laboratory can be realized, and its accuracy is high, which can meet the experimental requirements in the initial testing process of LiDAR design. Various interference factors work together in the field, which is not conducive to debugging and correcting the parameters of each module of the LiDAR. The platform built in this article can effectively solve the problem of the inability to conduct simulation experiments in the laboratory environment during the design of LiDAR, and greatly simplify the complicated procedures during experimental testing. However, the real working environment is complex and changeable, and cannot be fully simulated, and further testing of larger distances is needed.

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References
[1] Zhang M.T., Zhang J.Z., Zhang J.G., et al. Chaotic modulation LiDAR for underwater ranging[J]. Progress in Laser and Optoelectronics, 2016(5):232-239.
[2] Klepsvik J O, Bjarnar M, Brosstad P O, et al. A novel laser radar system for subsea inspection and mapping[C]// Oceans. IEEE, 1994.
[3] Arshad M R, Lucas J. Underwater optical ranging system for ROVs[M]. 1998.
[4] Liu Y.M., Deng R.R., Qin Y., Liang Y.H.. Data processing and application of airborne LiDAR sounding data[J]. Journal of Remote Sensing, 2017, 21(06): 982-995.
[5] Zhou G. Q., Zhou X.. Imaging principle, technology and application of planar array LiDAR [M]. WUHAN: WUHAN University press,2018.
[6] Zhou G. Q., Zhou X.., Hu H.C., Xu J.S.. Design of a LiDAR optical-mechanical system for water depth measurement[J]. Infrared and Laser Engineering, 2020, 49(02): 63-70.
[7] Shi J.L., Guo P.F., Huang Y., Qian J.C., Wang H.P., Liu J., He X.D.. The influence of temperature, humidity and pressure on the attenuation characteristics of laser in water[J]. Acta Physica Sinica, 2015, 64(02): 220 -225.
[8] Chen J., Zhang Q.L., Yao J.H., Fu J.B.. Research on laser absorptivity of metal materials[J]. Applied Optics, 2008(05):793-798.