Low-cost optical techniques for detecting and imaging different objects underwater

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Abstract. The camera has been commonly used in underwater image acquisition experiments, but the image noise is high, and the distance is limited because of the underwater scattering effect. In this paper, the optical detection device of underwater objects, 520 nm continuous laser modulation by PWM pulse modulation (10 Hz, 60% space ratio), was used to scan and detect two completely different objects (such as advanced resin and green leaves). The photodetectors were used to replace cameras, collect and process the received laser echo signals, and image and display the data. The detected objects images can be visually displayed in the form of grayscale images (resolution of 143 * 62), and the corresponding effects have been discussed. In the experiment, we used a 70 cm long ultra-white glass cylinder and detected a distance of 45 cm, and the results were very consistent with the actual situation.

Keywords: Obstacle detection, grayscale image, diffuse reflection, data acquisition

1. Introduction
Water in nature exists in three physical states: solid ice, liquid water, or gaseous stream, which can be transformed between different states under certain conditions [1, 2]. Approximately 71% of the earth's surface is cover by water, of which ocean water accounts for 96.5% of the total global water. Currently, only 5% of the oceans have been explored, and 95% of the remaining areas have not yet been developed, which means there is an unsolved mystery of the ocean surface [3]. Through the development of science and technology, people have used a variety of technological means to detect underwater objects[4, 5]. Acoustic waves are observed and measured in the water, which has unique conditions for underwater detection of objects, so sonar technology has been widely used to detect unknown underwater targets [6-8]. Recently, Sonar technology has been used widely to observe and measure underwater objects. This technology has a unique condition, which makes it suitable to take images of objects under the water bodies. In the Proceedings of OCEANS 2018 MTS/IEEE, Risholm et al. [9] posited that Sonar technology application is limited at certain resolution and accuracy in a given situation. Further, it is often not enough to meet the needs of real-time underwater exploration. For example, submarines and other underwater stealth targets have great strategic deterrence and
strong battlefield information reconnaissance capabilities, making the traditional sonar detection methods meet new challenges.

Optical technology is currently studying to detect and image underwater objects [10-12], as the advantages provided by lasers include high directivity, high response, high precision, and increased range accuracy. In 1963, when Duntley SQ and Gilbert GD and others were studying the propagation characteristics of light waves in the ocean. They found that the attenuation of blue-green light in the 470–580nm band of seawater was much smaller than that of other light bands, which proved that it is in the ocean. There is also a transparent window similar to the existence of the atmosphere [13]. The blue-green laser is easily penetrable in seawater, causing the absorption of turbid water to be reduced, and can be used as an additional way of detecting submarine water. It can further improve the detection efficiency of underwater stealth targets, so the laser emits blue-green light. It shows great application potential in underwater target detection, control, communication, and other fields. Most underwater laser systems are based on the radiation in the blue-green area of the laser’s visible spectrum [14, 15].

Optical detection and imaging in an underwater environment, as water and particles absorb and scatter light. The result is reduced resolution and accuracy of range measurement and reduced image contrast. The main obstacle that limits the performance of laser-based systems in turbid water is the scattering process [9, 16], which often causes background noise to the system receiver and reduces image contrast and resolution. In different sea conditions, the distribution of laser scattering energy at different angles is quite different, which has a great influence on the detection efficiency. It is of great significance to study the imaging characteristics of diffuse reflected light of different objects in the water [17, 18].

In order to collect and store the target reflection signal, the author in [19] uses a high-resolution CCD camera and blue-green laser for the underwater laser imaging system to collect the image and is used in the image processing phase to minimize scattered noise and to detect the structure of the object underwater. The image of the object was extracted from the scattering noise by the background and edge detection method. A recent report by Wu [20] proposed an underwater optical imaging device designed with a high-sensitivity sCMOS camera that effectively increased picture quality with low visibility due to underwater scattering and signal attenuation under artificial illumination. The author uses a contrast ratio and a contrast signal-to-noise ratio (CSNR) to evaluate picture obtained using an LED light source and an LFS under varying water turbidity. In [21], underwater image acquisition and target recognition methods were developed using a camera to facilitate the accurate extraction and recognition of an underwater object. The model coefficients were calibrated with images collected underwater and, in the air, verifying the transmission error model. The studies in [22] proposed a method based on correlation analysis, K-L transform, morphology, and underwater laser imaging, which was practicable and valid. The underwater laser images have low contrast, small target dimension, and complex background characteristics. This method can detect a small underwater target in the various complex backgrounds and not be affected by laser image contrast and ambiguous target gray. In recent years, the imaging distance and quality have been greatly improved. The use of lasers has addressed the problem of imaging distance. These improvements are all due to the use of non-traditional imaging and laser technology [23].

In this paper, a low-cost underwater laser detection system is built to detect the underwater object. A continuous narrow beam laser pulse modulation was proposed for detecting underwater objects, which can visualize the form and size of a different object through scanning imaging. Different underwater objects such as green leaves and advanced resin were scanned and detected automatically under the simulated seawater environment. In analyzing and processing the synchronously collected data, the grayscale image is imaged pixel by pixel. For the use of lasers, the design of the underwater detection system is of importance for further underwater object detection, which provides a way of thinking and method for the optical detection of near-shore underwater objects, and lays a firm foundation for the identification of obstacles in the future.
The rest of this paper is organized as follows. In section 2, we introduced the underwater laser detection system's detection principle in this paper, using the Lamber illumination model for analysis. Section 3 details the composition of the experimental device and the design of the detection experiment. In section 4, we detected two different underwater objects, performed an imaging display, simulated the image, and outlined the size of the measured underwater target on the screen. Finally, we summarize this research paper in section 5.

2. Principle of Lamber model
In a complex water environment, diffuse reflection occurs when light sources hit the surface of objects. In order to simulate the lighting phenomenon on the surface of rough underwater objects, we used the Lamber lighting model to analyze the light reflection of underwater objects in this experiment. This model is empirical, and it is also the simplest diffuse reflection model [24, 25], can be used as a lighting model for calculating the direction of the light source.

Assuming that the surface of the object is an ideal diffuse reflector, i.e., only diffuse reflection occurs on the object surface. At the same time, because the water in the glass tank of this experiment is very clear, and the laser modulation frequency is low (10Hz, the duty cycle 60%), the lower the laser frequency, the lower the degree of scattering occurring in the water. So, the condition of particle scattering in the water body is not considered for the time being. To simplify the analysis, we consider only two light effects. One light is ambient light (diffuse intensity calculation, as can be seen in Eq. 1). The other light is directional light (diffuse intensity calculation, as illustrated in Eq. 2). Then we calculated the diffuse reflection phenomenon caused by the two kinds of light irradiating on the rough surface. Finally, we added the results of the two types of lights to get the total light intensity value after the diffuse reflection and the total intensity of the diffuse reflection generated by the two lights. The total diffuse intensity calculation of the two kinds of light generated (as indicated in Eq. 3) is usually the main component of the detector's receiving energy intensity. Therefore, this experiment is based on diffuse reflection theory, and the photodetector receives the diffuse reflection light echo signal.

\[ I_{ai} = K_d I_1 \]  

(1)

\[ I_{ai} \] is the light intensity reflected for the interaction between the ideal diffuse reflector and ambient light \( I_1 \), is the ambient light intensity \( K_d \) is the diffuse reflection coefficient of the object material to the light and satisfied \( 0 < K_d < 1 \).

\[ I_{dr} = K_d I_2 \cos \varphi \]  

(2)

\[ I_{dr} \] is the light intensity of the ideal diffuse reflection sports direction \( I_2 \), is the point light intensity, \( \varphi \) is the angle between the incident laser and the vertex normal, it’s called the angle of incidence and satisfied \( 0^\circ \leq \varphi \leq 90^\circ \).

\[ I(R) = I_{ai} + I_{dr} \]  

(3)

\[ I(R) \], to integrate ambient light and directional light, the point at which irradiated \( R \) of lambert’s total intensity of the diffuse reflection of the lighting model is irradiated.

The same surface reflects light in different ways, and the lambert lighting model assumes that light reflects at the same intensity in all directions of space, i.e., that the brightness of the surface of the object is independent of the angle of view. The diffuse reflected light intensity reflected from the surface of an ideal diffuse object is proportional to the angle of the cosine between the incident light and the natural surface of the object. Incident angle \( \varphi \) the cosine value is equivalent to the light vector \( L \), and surface normal \( N \). The point product of the two vectors (as shown in Eq. 4). The light vector refers to \( R \) point to the unit vector of the laser-emitting source. The surface law defines the
point to be illuminated $R$ unit method vector (as shown in Figure 1). Calculating the light intensity generated by the ambient light, the complete image light intensity expression can be obtained (as in Equation 3).

$$\cos \varphi = N \cdot L$$  \hspace{1cm} (4)

![Image of Lambert model]

**Figure 1.** Lambert model.

### 3. Experimental devices

The system's overall architecture shown in Fig 2, the experimental device is shown in Fig 3, the experiment uses two microcontrollers, the controller 1 is the STM32F429 control board, complete the task of collecting A/D signals and displaying LCD data. The controller 2 is the smallest system board of ST89C51, which mainly completes the control of DM542 driver and the control operation of 5 keys (KEY1~KEY4 realize the operation of different motor states). Whiles controller 2 controls the DM542 driver by controlling the duration of the pin's high and low voltage, and then the stepper motor is driven by the DM542 for normal operation. The photodetector receives the optical signal after the computational amplification unit, A/D (the ADC2 PB0, PB1, PC0, PC1 four channels selected in the STM32F429 controller in this experiment) is collected and stored in controller 1 for the data analysis and processing of subsequent experiments.

![Diagram of experimental device]

**Figure 2.** The overall structure of the system.
The laser uses a laser with an output wavelength of 520 nm (as shown in Fig 4) with a power of 100 mw. It can be modulated with TTL (Transistor-Transistor Logic) modulation with automatically recognized positive and negative reverse protection. The system experiment achieves TTL modulation of the laser by controlling the PWM square wave signal's output. The pulse frequency and the demand ratio were freely adjusted according to the experimental objectives. The square wave signal pulse frequency of the TTL port of the laser input laser was 10Hz, and the parting ratio was 60%. During the whole experiment, professional laser protective glasses was worn to avoid damage to the glasses.

The photodetector unit uses four separate silicon photodiodes to convert the laser's echo signal into an electrical signal, which is collected and stored by the 12-bit A/D unit in controller 1 after processing. The real-time acquisition of the voltage signal can be achieved by interval 0 to 3.3V. The four photodetectors’ position distribution was 3.5cm from the center of the circle (Figure 5.).
4. Study on observation and imaging measurement Experiments
The laser with an output wavelength of 520nm is fixed to the two stepper motors' fronts together with the photodetector. The controller 2 controls the stepper motor by controlling four separate keys. The scanning trajectory of the two-stepper motors is shown in Fig 6, moving vertically along the Y-axis and then horizontally along the X-axis, so on, until the scanning task for the entire area is finally completed. The controller 2 describes the key control ports and keys' functions, as shown in Fig 7.

![Figure 5](image)

**Figure 5.** Location distribution of the four photodetectors.

![Figure 6](image)

**Figure 6.** The trajectory of the stepper motor.

![Figure 7](image)

**Figure 7.** The function and interface of the independent keys.
The scanning area set by this experiment is a 140mm x 120mm rectangular area. Two different underwater objects, such as fake mountains and underwater leaf were placed in the center of the rectangular area. The rotation of X-axis motor and Y-axis motor, the laser continuous, and complete scanning of the rectangular area and the A/D collected data. It can not only be displayed on the LCD screen in real-time (take the average of 20 consecutive data of each photodetector) but also real-time data storage and analysis. In order to ensure the validity of the collected data, the speed of the stepper motor was reasonably controlled. Here, the A/D acquisition speed cannot be too slow to ensure that the collected data is more real to achieve full coverage of the scanned area. The y-axis longitudinal data was considered as the final storage data since the total length of each run of the Y-axis direction screw is 120mm (i.e., the step motor in the Y-axis direction rotates 30 times and the screw runs 4mm per turn), and the X-axis direction. The total length of each rotation of the screw is 2mm (i.e., half a turn of the stepper motor in the X-axis direction rotates, half a turn and the screw run 2mm per half turn), and we set the speed of the X-axis stepper motor to run twice the speed of the Y-axis stepper motor. The X-axis data was not considered due to the very short running length (2mm). This processing method is similar to the rectangular area by each small rectangle composition, and at this time, the width of each small rectangle is infinitely small, resulting in the rectangle approximates a line. We do not consider the impact of width, only consider the impact of small rectangular length, which is also the mathematical limit processing. For the above-described reasons, data was collected in the Y-axis direction but in the not X-axis direction.

![Figure 8](image_url)  
**Figure 8.** Underwater detection of two different objects (a) High-grade resin, (b) Underwater green leaves.

We carried out experimental detection on two different underwater objects (as shown in Fig 8), the detection distance was set at 45cm. The four photodetectors received and collected the optical signals after processing by the operational amplification unit. The A/D collects and saves the data, and finally processed the image, as shown in Figure 9 and Figure 10 above. From the figure, it can be seen that the imaging of each sensor is slightly different. There are many reasons, such as different areas of the surface of the object roughness, the return of the echo light signal will be different. Simultaneously, the sensor's location will also lead to different intensity of the receiving light signal. From the image, it can be intuitively seen that the size and shape of the outline of the object and other features.
Figure 9. Detection of underwater advanced resin imaging, (a) 1 Detector image (b) 2 Detector image (c) 3 Detector image (d) 4 Detector image.
Figure 10. Detecting underwater green leaves, (a) 1 Detector image (b) 2 Detector image (c) 3 Detector image (d) 4 Detector image.

5. Conclusion
In this paper, two different objects, such as advanced resin and green leaves underwater, were scanned and detected by pulsed 520nm (power 100mW) laser with pulsed modulation (10Hz, 60% space-to-air ratio). After the photodetector receives the echo signal, it is amplified and processed by the A/D for acquisition and storage, and finally, the data is imaged and displayed. The current project provides a solution for short-range underwater object detection and its related experiments. More so, it accumulates a valuable experience for subsequent experiments. It can be concluded that the use of optical technology for the detection of different objects underwater was more efficient, the traditional detection method. We propose that further research work must be done to explore and detect varied objects underwater environment by controlling significant factors such as adjusting the laser power, water turbidity, and detecting distance down to the water floor.
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