Research upon the Smart Diving Suit Based on Visible Light Communication

Yang Zhou, Jinpeng Wang(✉), Xin Guan, Ailing Zou, and Nianyu Zou

Dalian Polytechnic University, Dalian 116034, China
wangjp@dlpu.edu.cn

Abstract. Due to the poor anti-noise performance and high delay of the traditional underwater communication technology in the signal transmission process, the safety of divers is potentially threatened in the complex underwater environment. To solve this problem, this paper designed a real-time monitoring of physiological data smart diving suit. Based on the addition of sensor functions to diving suits, this paper researched the overall architecture of visible light communication model. Taking advantage of the high transmission rate and strong stability of visible light communication, blue LED light source is used for signal transmission, and simulation experiments and tests are carried out. The results show that the basic requirements of underwater data transmission are satisfied within a certain communication distance. This provides a reference for further research on underwater communication technology.

Keywords: Visible light communication · The sensor · The smart clothing

1 Introduction

At present, with the increasing research and exploration of various waters, the demand for underwater activities has become increasingly diversified. However, the traditional methods of underwater activities still have some limitations. On the one hand, due to the complex water environment, the irregular operation of divers and the poor diving equipment, the health and safety of divers cannot be guaranteed [1]. On the other hand, traditional wireless communication is difficult to effectively use underwater. The current mainstream underwater wireless communication methods are underwater acoustic communication technology, underwater radio frequency communication technology and underwater quantum communication technology [2, 3]. Underwater acoustic communication has the problems of being greatly affected by complex underwater channels, serious multipath effects, and low communication rates; Although the traditional underwater electromagnetic wave communication is stable, the attenuation of electromagnetic waves in water is very serious. Experiments conducted by Lloret J. in 2016 showed that RF signals can be transmitted at a rate of up to 100 Mbps, but the transmission distance is extremely short, the effective communication distance is only about 15 cm [4]. Visible light communication has developed rapidly in recent years, which provides a new way

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for underwater communication. For the development of visible light communication, Japan has started its related technology research earlier and matured. Japan's Uema H team has developed a portable underwater communication system to address the drawbacks of traditional underwater word board communication, it meets the communication needs of underwater entertainment [5, 6]. The basic principle of blue-green visible light communication is that the part of the blue-green light in the range of 450–550 nm is in the transmission window [7, 8], it has strong anti-fading ability in water and can achieve the purpose of underwater communication.

This paper proposes a research on an intelligent diving suit based on underwater blue light LED communication. The sensors is implanted in the diving suit to achieve the purpose of dynamically monitoring the physiological data and underwater environmental data of the diver. The blue-green optical communication method has the characteristics of low loss and high transmission rate, which can be used to improve the effectiveness and reliability of the whole communication system [9, 10].

2 System Design Principle and Scheme

The system is mainly composed of a sensor data collection module and a blue visible light communication module. Its system block diagram is shown in Fig. 1. The function of the sensor data collection module is to embed the temperature sensor MLX90614, the heart rate sensor MAX30102, the pressure sensor MS5803 and the MCU into the diving suit through embedded technology. The function of the sensor data collection module is to embed the temperature sensor MLX90614, the heart rate sensor MAX30102, and the MCU into the diving suit through embedded technology, collect the physiological data information of the diver, and then use the blue visible light communication module to modulate the physiological data information after modulation processing. Send to the host computer to complete the physiological data collection and monitoring of the diver.

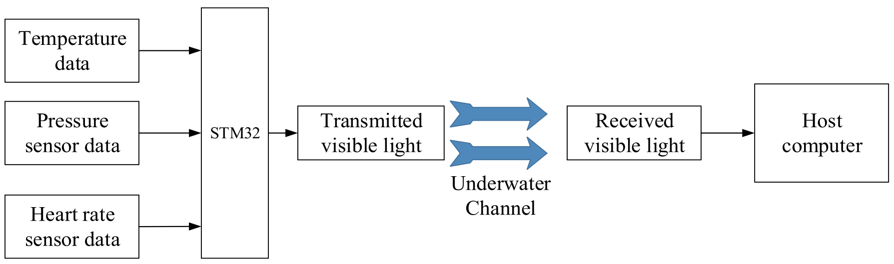

Fig. 1. System block diagram (Color figure online)

In order to meet the needs of practical application, the design of this system should meet the requirements of low power consumption, lightweight, low cost and fast transmission rate.

3 Sensor Data Acquisition Module

3.1 Sensor Module of MLX90614

The MLX90614 sensor can be powered by 3 V or 5 V, and the measurement range reaches −70 °C + 380 °C. In order to meet the requirements of medical applications, the MLX90614 can also meet the high accuracy requirements (±0.1 °C) in the human body temperature range. In addition, its non-contact temperature measurement method, which uses the internal infrared induction thermopile chip to convert the target's thermal radiation signal into an electrical signal [11], it has the advantages of short response time and easy to realize dynamic measurement. The bottom view of the MLX90614 chip structure and function is shown in Fig. 2. Among them, the function of pin 1-SCL/Vz is to realize serial clock input, and the function of pin 2-SDA/PWM is to perform digital input and output, and can be read Measure the temperature of the object.

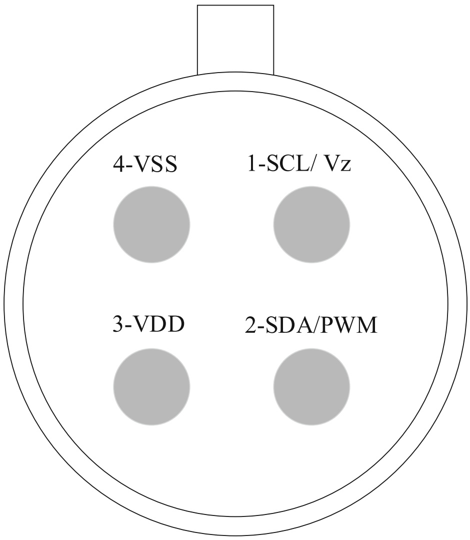

Fig. 2. Bottom view of MLX90614 chip

3.2 Sensor Module of MAX30102

The working voltage of the MAX30102 sensor can also be 3.3 V or 5 V. Its communication interface can use the standard I2C interface for data transmission. Its data output speed is fast, the sampling rate is high, and the operating temperature range is −40 °C to +85 °C. At the same time, the sensor can be controlled by software to close or open, the standby current is close to zero, and the power supply is always maintained [12, 13]. The light source working inside the chip is red light at 660 nm and infrared light at 880 nm. The optical signal is received by a high-sensitivity phototransistor. The received signal is amplified to support both analog filtering and digital filtering. Finally, the processed data is stored in the internal memory for external MCU to read. The pin diagram of MAX30102 is shown in Fig. 3.

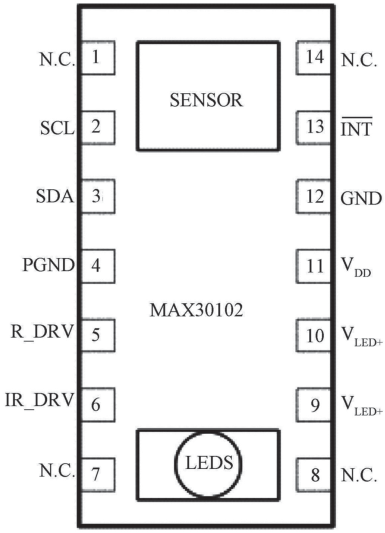

Fig. 3. MAX30102 pin diagram

3.3 Sensor Module of MS5803

MS5803-01BA is a high resolution professional measuring pressure sensor, its outer package is made of ceramic material. It includes an ultra-low-power 24-bit ADC and high linearity sensing module. The communication protocol is simple and does not require programming in the device's internal registers. What's more, it provides a variety of different operating modes, allowing the user to select the conversion speed and sampling frequency.

3.4 Application Principles of Sensor Embedding

The application of sensors in diving suit must fully consider the characteristics of safety, stability, comfort and miniaturization [14]. The details are as follows.

(1) Security. While ensuring the normal operation of the components, it is also necessary to consider whether the electronic components will adversely affect the human body. To ensure safety, for example, a flexible circuit board can be used for packaging.
(2) Stability. The overall package of the system should be firm and electronic components should not be placed in the body's joints and other active parts.
(3) Comfort. The way of wearing must not hinder the normal underwater activities of divers, and it embodies the "people-oriented" principle.

(4) Micromation technology. Components should meet the requirements of small size and light weight, to avoid the appearance of foreign body feeling when wearing, and do not affect the structure of the diving suit [15].

3.5 The Safety Range of Related Physiological Indicators

Heart rate and body temperature are important physiological parameters for monitoring underwater activities of personnel. It is of great significance to maintain the optimal heart rate and normal body temperature to ensure the safety of personnel [16]. In exercise physiology, Table 1 shows the relationship between heart rate and human tolerance. In Physiology, Table 2 shows the relationship between body surface temperature and human subjective feelings. As can be seen from the table, the exercise heart rate of divers is guaranteed to be below 160 BPM, and the body temperature is maintained at 31.5 °C to 34.5 °C, which is relatively appropriate.

Table 1. The relationship of heart rate and body limits

Heart rate (BPM)	Exercise intensity
120–140	Low amount of exercise
140	Normal load
141–160	Medium amount of exercise
161–180	Sub-limit load
More than 180	Ultimate load

Table 2. The relationship of surface temperature and subjective feeling

Surface temperature (°C)	Subjective feeling
Less than 27	Extremely cold
28–29	Shiver
30–31	Cool
31.5–34.5	The most suitable

3.6 The Combination of Wearable Devices

Figure 4 is a schematic diagram of the arrangement of electronic components in a smart diving suit. Place the LED light on the chest to transmit the signal, fix the heart rate sensor on the inside of the cuff with Velcro, and place the temperature sensor on the back. Pressure sensor placed on the neck of the suit. Each sensor is packaged in a soft, comfortable fabric in the form of a pouch, which is secured with Velcro. These devices can be applied to human skin for a long time and reduce friction, so as to reduce the foreign body sensation caused by wearing skin. In addition, the wires are arranged to ensure that the overall circuit is smooth, and fixed with adhesive tapes to prevent short circuits. Finally, after analyzing the underwater activities of the divers, we know that the frequency and amplitude of the activity on the back of the human body is relatively small, so the controller is placed in a patch pocket on the back to ensure the stability of the system work.

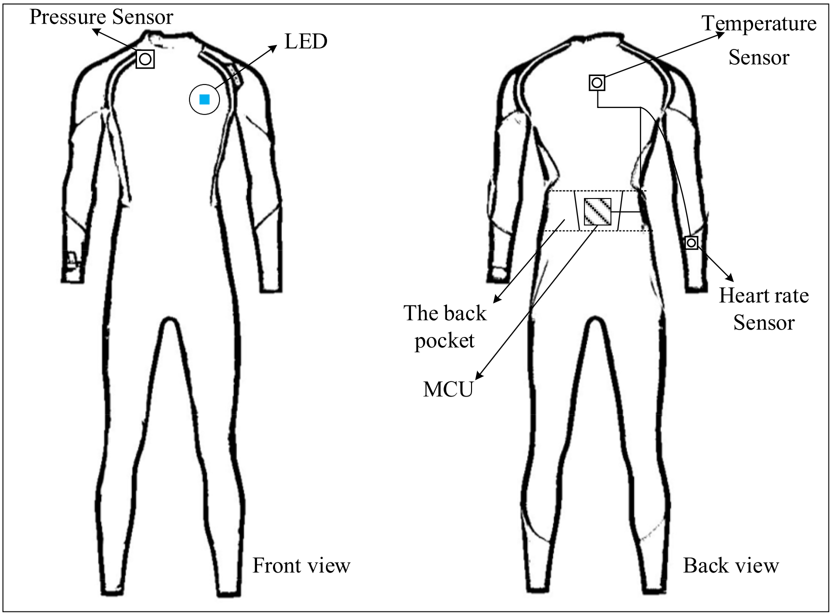

Fig. 4. Schematic diagram of arrangement of sensors and other components

4 Blue Visible Light Communication Module

4.1 Overview of Visible Light Communication System

The schematic diagram of the communication system is shown in Fig. 5. The transmitting end is mainly composed of blue LED and signal modulation drive circuit. Its main function is to modulate the data of the sensor, drive and light the blue LED lamp, and modulate the obtained electrical signal into the driving current of the LED lamp to realize the transmission of blue visible light. In order to effectively increase the bandwidth of the system, Osram LB25 series high-power LED lamps with a shorter carrier lifetime were selected [17], and its wavelength range is 455 nm–470 nm. At the signal receiving end, the photoelectric detector is used to convert the optical signal received from the transmitting end into an electrical signal, and then the operational signal is amplified by the operational amplifier circuit. The amplified electrical signal is restored to the original after demodulation and A/D conversion data. The photodetector chooses PIN photodiode, which has a high response frequency and a much cheaper price than APD avalanche photodiode. Moreover, the use of PIN photodiode to transmit signals has the characteristics of high signal-to-noise ratio, stable performance and small noise.

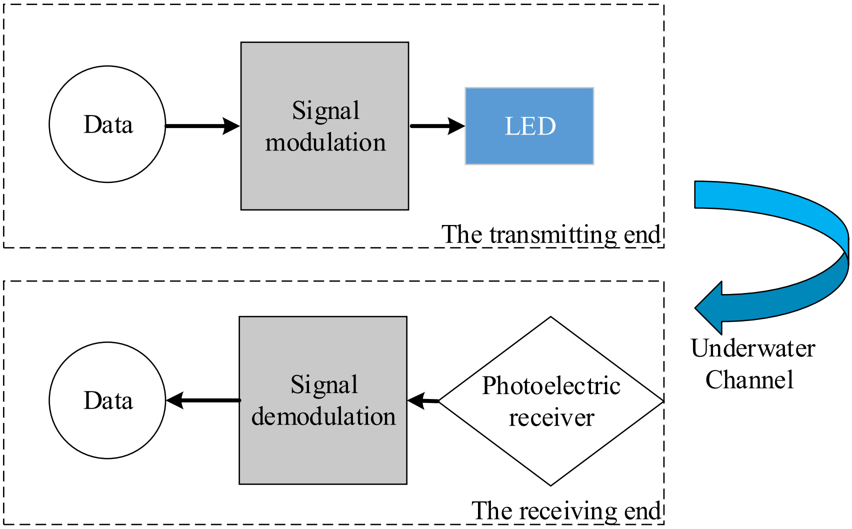

Fig. 5. Schematic diagram of VLC (Color figure online)

4.2 Modulation of Blue LED Signals

This article uses CAP (Carrier-Free Amplitude/Phase Modulation) modulation technology to modulate the optical signal. CAP modulation technology is developed based on QAM modulation technology, they are all single carrier modulation [18]. Compared with OOK modulation, CAP modulation is less disturbed by the pulse noise with abundant low frequency energy and the near-end crosstalk of high frequency. There is no low frequency delay distortion, and the inter-code interference caused by group delay distortion is also smaller.

The synthesis and modulation of CAP signal can be realized in the digital domain, and because of its characteristics of modulation without carrier, even if it is used in the visible light communication system which is more sensitive to the system nonlinearity, the peak-to-mean power ratio of the system will not be too high, so this is a major advantage of the modulation technology applied in the visible light communication [19]. The block diagram of CAP modulation principle is shown in Fig. 6.

4.3 Blue LED Driving Circuit

After the sensor signal is modulated, the working system needs to drive the LED light source to convert it into a light signal and pass it to the receiving end. However, the driving

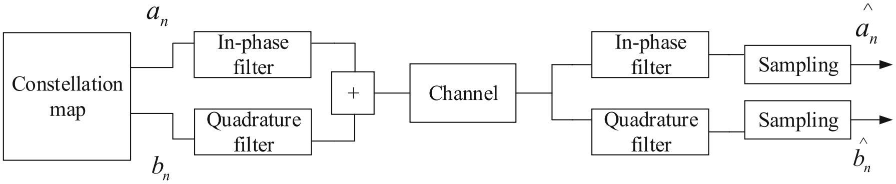

Fig. 6. CAP modulation principle block diagram

capability of the single chip microcomputer is insufficient, so an additional transistor is used to improve the driving efficiency. The function of the capacitor C1 is to increase the switching speed of the LED driving circuit and improve the frequency performance of the entire circuit. Among them, R1 is an adjustable resistor, and R2 is used to balance the impedance of the input terminal and balance the voltage. R3 and R4 play the role of protection circuit to prevent short to ground. R5 is a DC bias resistor. By adjusting the size of resistor R5, the current through the blue LED light source can be adjusted to meet different requirements for actual communication. The schematic diagram of LED drive circuit is shown in Fig. 7.

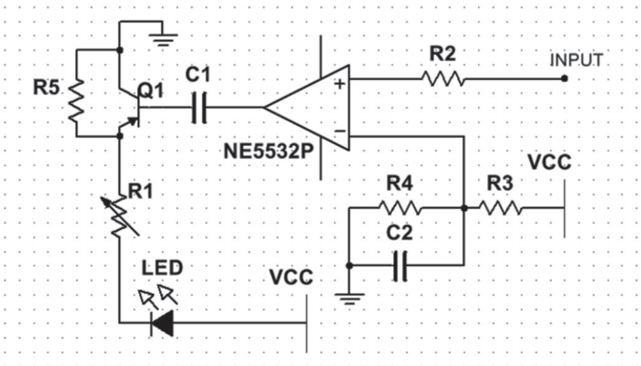

Fig. 7. LED drive circuit block diagram

4.4 Visible Light Receiving Circuit

The signal receiving end is mainly composed of a photodetector, a preamplifier circuit, a controller, and a power supply. The function of the capacitor C1 is to filter out the AC component, so that the DC stabilized power supply VCC outputs a stable DC. Capacitor C2 can filter out the noise superimposed on the signal to achieve the effect of noise reduction. The photodiode D1 converts the light signal emitted by the receiving end into an electric signal, but at this time the signal is relatively small, it needs to be amplified by a preamplifier circuit, and then the controller demodulates it to obtain sensor data. Finally, the diver's body data information is sent to a host computer, and the monitoring party analyzes the dive's physiological indicators to ensure the safety of the diver's underwater activities. The schematic diagram of the photoelectric receiving circuit is shown in Fig. 8.

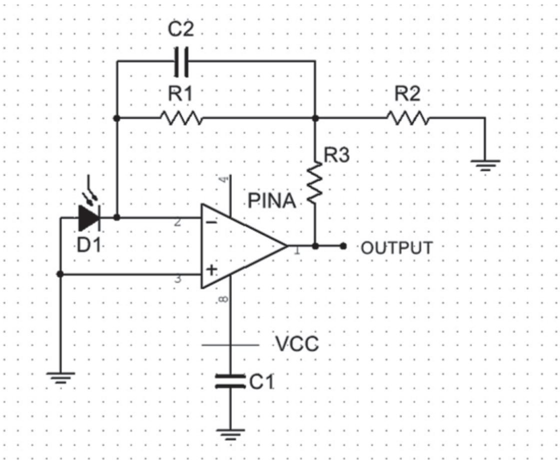

Fig. 8. Visible light receiving circuit block diagram

5 System Test

5.1 Indoor Environment Test

The test location is Lab 103, Teaching Building B, Dalian Polytechnic University. The underwater test chamber with a size of 70 cm * 30 cm * 40 cm is used to simulate the underwater channel. As shown in Fig. 9.

The test in this paper first sets the effect of sending and receiving sensor data under ideal conditions through programming and software simulation, as shown in Fig. 10. The upper square wave is the ideal waveform output by the blue LED driving circuit, and the lower square wave is the ideal waveform of the visible light receiving circuit.

The second step is to use an oscilloscope to detect the waveform sent by the LED in the actual communication process and the waveform received by the circuit at the receiving end, and to compare it to verify the communication effect of the system. After the data information of the sensor is modulated, it is transmitted through the drive circuit of blue light LED. The photodiode of the receiver module receives the optical signal, the signal is amplified by the amplifier circuit, and finally sent to the upper computer through the demodulation of MCU. Figure 11 is the waveform generated by the LED driver, and Fig. 12 is the waveform generated by the photoelectric receiver. The test results show that the waveform of the output signal of the photoelectric receiving end of the communication system is basically the same as the signal of the transmitting end, which indicates that the communication scheme of the system is feasible.

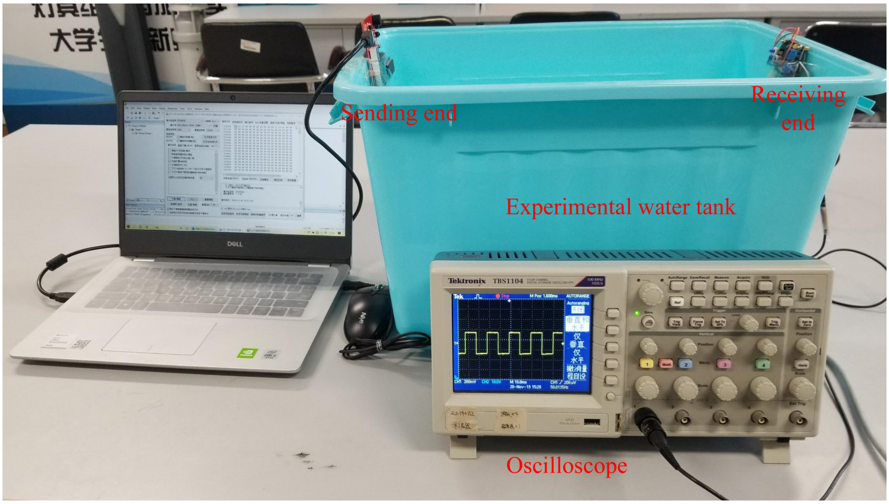

Fig. 9. System experimental environment

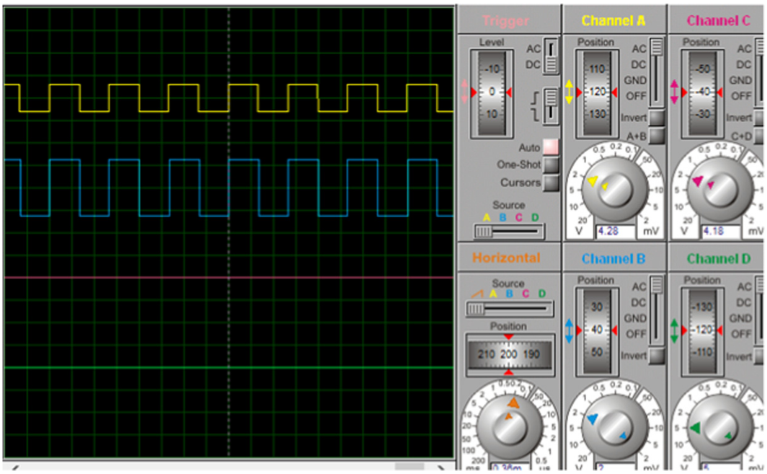

Fig. 10. Software simulation waveform

5.2 Outdoor Environmental Test

The outdoor experiment was conducted in a large artificial lake on campus. Compared with the indoor experimental communication system, the outdoor experimental communication system adds a condenser lens at the emitting end of the LED to reduce the emission Angle of visible light, so as to increase the intensity and distance of visible light and greatly improve the transmission quality of visible light signals. As shown in Fig. 13, when the illumination direction of the blue light LED is aligned with the direction of the photoelectric sensor at the receiving end with the power supply of 5 V, the length of the beam directly observed is about 5.4 m.

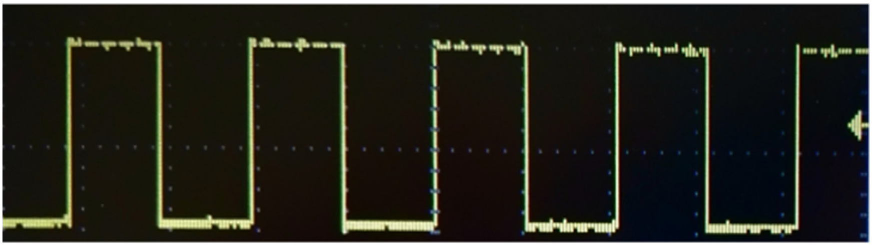

Fig. 11. Waveform output from the driver

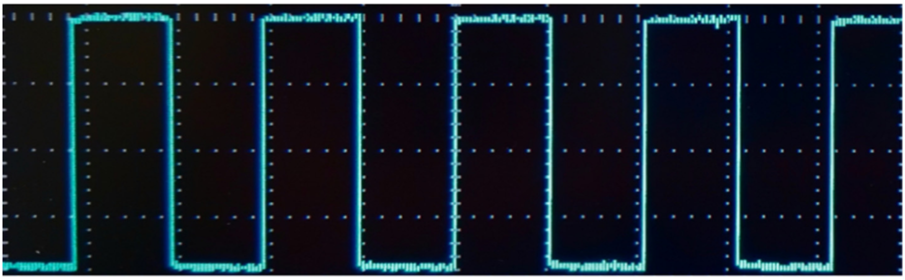

Fig. 12. Waveform received by the receiver

Fig. 13. Blue visible beam for outdoor experiments. (Color figure online)

The experimental data obtained after calculation and arrangement of the experimental data are shown in Table 3. The experimental results show that the system can meet the daily data transmission requirements in outdoor natural underwater channels. In addition, error-free data transmission is achieved when the communication distance between the transmitting end and the receiving end is 5 m and 8 m.

Table 3. The experimental results

Communication distance (m)	Number of error bits	Bit error rate (%)
5	0	0.000
8	0	0.000
15	2	0.277
20	5	0.694

6 Conclusion

Aiming at the disadvantages of traditional underwater equipment and communication methods for divers, this paper designs a smart diving suit that can measure human physiological data based on the underwater visible light communication system. This paper introduces the design idea of the sensor information acquisition module and the overall structure of the visible light communication system. The blue LED light source was used to transmit signals in the underwater channel, and the sensor data was successfully received, thus achieving the purpose of monitoring and warning human physiological indicators. This study also provides reference for future underwater communication activities. Based on the above design, the scheme of the system can still be further optimized, for example, by adjusting the power of the LED light source to meet the communication needs in different environment, there by improving the effectiveness and reliability of data transmission.

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