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Image Transmission System Designing of Triphibious Robot*

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***Abstract* - With the rapid development of underwater robots and multi-phibious robots, signal and image transmission underwater become particularly important. This paper explores a low-cost real-time image transmission scheme for underwater application which is based on OV7725 camera module and HC-12 wireless transmission module. Images acquired by OV7725 are compressed by STM32F407 control board and then transmitted to the software on computer by HC-12 wireless transmission module to decompress and display.**

Index Terms - Robot, underwater, image transmission, real-time

I. Introduction

A. Traditional Robot and Triphibious Robot

A robot is a machine that can perform its work automatically. It can either take orders from humans, or run pre-programmed programs, even operate according to principles laid down by artificial intelligence. It is designed to assist or replace humans to work, mainly in manufacturing, or some dangerous places, such as robotic arms on automated production lines, intelligent transport vehicles in warehouses, intelligent restaurant delivery robots and many rescue robots as shown in Fig. 1.

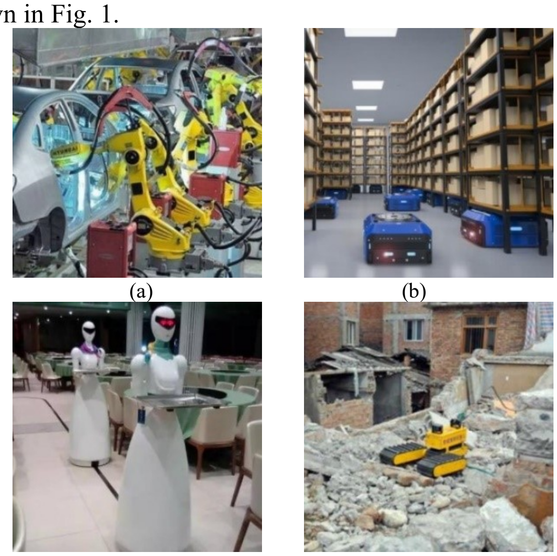

Fig. 1 Traditional robots: (a) robotic arms (b) intelligent transport vehicles (c) intelligent restaurant delivery robots (d) rescue robots

With the development of technology, there are more kinds of robots with more powerful functions. However, most of them have a single movement mode and poor adaptability to complex environments. Therefore, many researchers have focused their eyes on robots with stronger environmental adaptability, such as amphibious robot or triphibious robot which can work in different environment. Our team is also actively engaged in the research of triphibious robot and have successfully developed a triphibious robot based on multi-rotor unmanned aerial vehicle (UAV). This robot is composed of rotor institution, cylinder protection mechanism, and waterproof sealing mechanism. This triphibious robot can not only fly in the air and dive in the water, but also roll on the land and the three motion modes share a set of power system, which can be called a real triphibious robot as shown in Fig. 2.

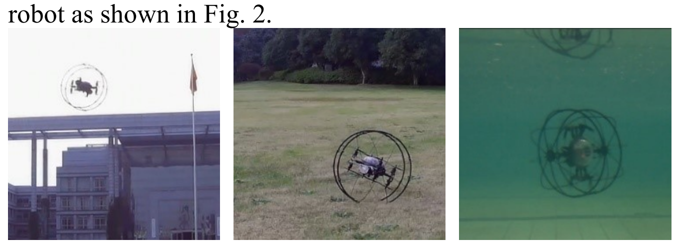

Fig. 2 Our triphibious robot

B. Importance of Underwater Robot Research

As we all know, the area of sea accounts for 71% of the area of earth. And sea is the second largest space that human beings rely on to survive and develop after land, and has the greatest development potential. After entering the 21st century, the shortage of land resources, which is the most realistic problem, is becoming more and more serious. The ocean will become an important base of sustainable development for humans and is a hope for the future. Since its birth in the second half of the 20th century, underwater robot has been developing along with the process of understanding, developing and protecting of the ocean. In the 21st century, as the most important means to explore the ocean, the underwater robot will certainly get unprecedented attention and development.

Underwater robot is also known as unmanned underwater vehicle (UUV). At present, most underwater robots are type of frame and slender body like submarine. With the development of bionic technology, underwater robots that imitate the shape or even the motion mode of fish will continue to develop.

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Underwater robots can be divided into the following two types according to the control mode:

1) Underwater Robot with Cable or Remotely Operated Vehicle (ROV): ROV acquires power from a mother ship by cable, and it is not completely independent because of controlled by humans through the cable. Cable for ROV is just like the umbilical cord for fetus. The long cable become one of the most vulnerable part of the ROV and greatly limits the moving range and efficiency of the ROV.

2) Underwater Robot without Cable or Autonomous Underwater Vehicle (AUV): AUV is a new generation of underwater robot. It has its own power and intelligent control system, which can make decisions by itself to complete the mission given by humans. Due to its promising economic and military applications, many countries have put the development of intelligent underwater robot on the agenda.

The ocean which contains abundant resources, is the field that each country rushes to explore. UUV has high potential value for both military and civilian applications. While underwater communication technology is a necessary condition for the operation of unmanned underwater vehicle. Due to the restriction of transmission medium, underwater communication technology has always been the hot spot of research. The rapid development of optical communication technology, acousto-optic composite communication technology and mobile network communication technology, as well as the emergence of new materials, have opened a new road for underwater communication [1]. Therefore, the triphibious robot which has the ability to move in three environments has more value of application.

II. Difficulty and Feasibility Analysis of Underwater Wireless Communication

Communication on the surface of the earth is very convenient and smooth because of broadcast, satellite signals, GPS and so on. But none of these are available underwater. Refraction and transmission attenuation loss underwater of the most convenient means of communication - electromagnetic wave, is very large. The severe aquatic channel conditions (e.g., absorption, scattering, turbulence, etc.) pose great challenges for underwater wireless communications (UWCs) and significantly reduce the attainable communication ranges [2]. Even if the long transmission distance is obtained through improvement, it will cause high transmission delay, low speed and other problems.

A. Classification of Underwater Wireless Communications and Advantages and Disadvantages of Each Communication

1) Underwater Acoustic Wireless Communications (UAWCs): UWCs are implemented using communication systems based on acoustic waves, radio frequency (RF) waves, and optical waves. So far, UAWCs have become the longest and most effective carrier for UWCs, but acoustic waves still have many drawbacks including scattering, high delay due to the low propagation speeds, high attenuation, and low bandwidth. The acoustic noise constrains the range of typical frequencies used in acoustic systems between the 8 and 155 KHz, which makes very difficult to achieve high data rates [3]. Moreover, acoustic signals generated by communication systems and high-power sound navigation and ranging (SONAR) devices have adverse impact on the underwater mammals and fishes [4-5], so UAWCs is difficult to meet the requirements of great depth, large amount of data, real-time and environment-friendly.

*2) Underwater Optical Wireless Communications (*UOWCs*):* In 1963, Duntley found that attenuation within the range of 450–550 nm wavelengths (blue and green lights) is much smaller compared to the other wavelengths[6], the maximum penetration degree of up to 600 m, which is mainly because of the photosynthesis activity of algae especially during the warm seasons and in the coastal water. Hence, underwater optical communications and sensor systems for coastal applications are designed to work in the green spectral range.

Compared with underwater acoustic communication, the blue and green lights communication has advantages of smaller volume of equipment, large depth, long distance and high bandwidth of communication. The power of lights directly decides the penetration degree, the greater of the power, the deeper of the penetration, so it needs to study high-power lights.

3) Underwater Radio Frequency (RF) Wireless Communications: Although UAWC systems are suitable to provide command and control applications due to their long transmission range, their data rate is insufficient for underwater multi-media applications. Therefore, research is carried out in the past to use low-frequency RF waves, which can transmit data over tens of kilometers over the surface of the ocean water.

However, RF based UWCs require huge antennas and are limited to the shallow. Even though operating at ultra-low frequencies yields reduced attenuation levels, this is achieved by high hardware costs and low data rates. Acoustic transmissions may be used in the future for underwater links covering distances that exceed 200 m, while RF communication may be used for distances less than 200 m [7]. optimum propagation distance under water can be achieved by proper selection of the signal frequency. For Extremely Low Frequency (ELF) system there is hardly any fading in signal level for underwater propagation and the system was operated at 76 Hz for the US system and 82 Hz for the Russian system.

For a specified medium, value of skin depth fully depends on the operating frequency of the RF signal. For 1 MHz operating frequency skin depth into sea water is 25 cm and for fresh water skin depth is 7.1 meter. When an electromagnetic wave passes through one medium to another medium some part of EM wave is reflected back from the interface. This loss is known as interface loss. Interface loss decreases with the increase of frequency but the variation of loss is minimum for the different values of conductivity. Attenuation loss increases with the increase of conductivity of the medium as well as frequency of the transmitting signal. With the increase of frequency, interface loss is decreased and attenuation loss is increased but the frequency after which value of the attenuation loss is higher than the interface loss for 10 m propagation distance is 33.489 kHz and at this value of frequency attenuation loss= interface loss=63.32 dB [8].

B. The Reason Why We Choose Underwater RF Wireless Communications

Comparison of underwater wireless communications [9] is shown in table I.

TABLE I
COMPARISON OF UNDERWATER WIRELESS COMMUNICATIONS

Parameters	RF	Acoustic	Optical
Range	<100m	<20Km	100-200m
Attenuation Factors	Frequency & Conductivity	Conductivity	Distance and inherent optical properties
Speed	2.25×10^8 m/s	1500 m/s	2.25×10^8 m/s
Power	≈100W	≈10W	≈1W
Data rate	<0.1Gbps	<10KBps	<10Gbps
Antenna size	0.5m	0.1m	0.1m
Latency	Moderate	High	Low

1) Due to the wider application of RF wireless transmission in daily life, such as broadcasting and satellite communication, the development is more rapid and mature.

2) Both UAWCs and UOWCs require large transmitting and receiving equipment, so they are not suitable for triphibious robot which requires light weight and small size.

3) The speed and distance of acoustic wireless communication in the air will be greatly reduced. After leaving the water body, the optical wireless communication will be greatly affected by ambient light and will be unable to be used, while the RF wireless communication is mainly due to the communication in the air. Therefore, RF wireless communication is the preferred communication mode for triphibious robot. In addition, Futaba FM 72MHz remote controller is used for manual operation of the robot to realize the remote control of the robot, especially the control underwater, which has successfully verified the feasibility of using RF wireless communication underwater. Therefore, the application research of triphibious robot will continue to use RF communication.

III. HARDWARE SELECTION AND SOFTWARE DEVELOPMENT

A. Hardware Selection

The process of image acquisition and display is shown in Fig. 3.

Fig. 3 Process of image acquisition and display

Due to the high requirements of quality and volume of the triphibious robot, these two aspects should be considered in the hardware selection of image acquisition module and wireless transmission module.

1) Image Acquisition Module: There are two main camera modules used now. One is CCD, the other is CMOS. For CCD camera, its output is analog signal, which needs to be decoded to get digital signal. For CMOS camera, it outputs digital signal directly and can be connected to the control board directly. These two kinds of image cameras are not superior to each other in image quality. Under the same conditions, CMOS camera uses fewer components, which leads to lower power consumption and higher data processing speed than CCD camera. Therefore, CMOS camera is used here.

ATK-OV5640, ATK-OV2640 and ATK-OV7725 are mature image acquisition module, as shown in Fig. 4, which are widely used in image acquisition systems due to their low cost and power consumption and ability to complete the acquisition of multiple image formats. Too many pixels can make it difficult to transmit, since underwater wireless transmission is much slower than in the air. In addition, ATK-OV5640 and ATK-OV2640 have high requirements on the main control board, while ATK-OV7725 comes with FIFO chip, which can reduce the pressure of MCU. Therefore, OV7725 is selected as the image acquisition module here.

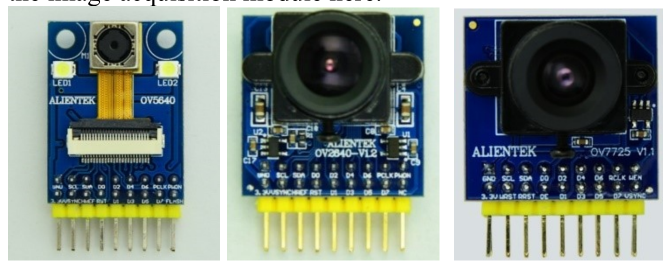

Fig. 4 OV series image acquisition modules

2) Wireless Transmission Module: The basic composition of the communication system is shown in Fig. 5. Wireless communication sending and receiving devices are shown in Fig. 6 and Fig. 7.

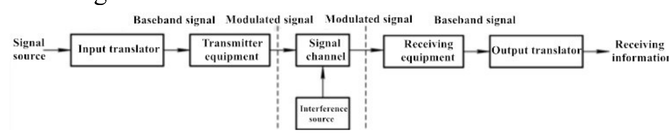

Fig. 5 Basic block diagram of communication system

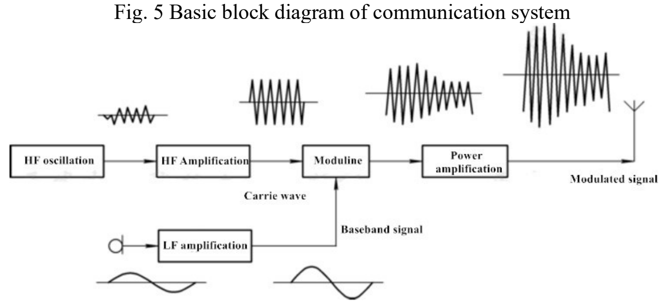

Fig. 6 Wireless communication sending device

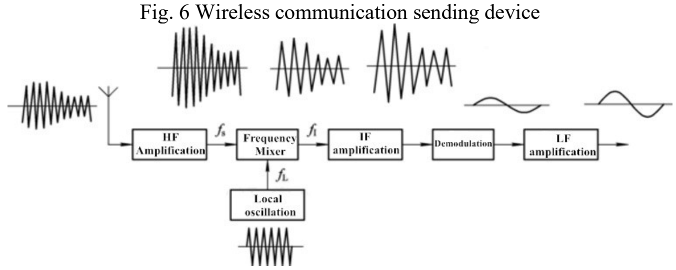

Fig. 7 Wireless communication receiving equipment

The role of antenna in wireless communications is very important. It will translate modulated signal into electromagnetic waves. According to antenna theory, to effectively transmit a radio signal, the length of the antenna must be the same order of wavelength of radio signal. For example, the frequency of a radio signal is generally lower than 20 kHz and the corresponding wavelength is longer than 15 km. So, length of the antenna is about 4 km, but it is impossible to use such a huge antenna.

Length of the antenna is inversely proportional to the frequency and directly proportional to the wavelength. The higher the frequency, the shorter the wavelength and the shorter the antenna can be made. When length of the antenna is 1/4 of the wavelength, the transmitting and receiving efficiency of the antenna is the highest. Therefore, the length of the antenna will be determined by the frequency, or the wavelength of the transmitted and received signals.

The relationship among the wavelength, frequency and propagation speed of radio waves is:

$$\lambda = \frac{c}{f} \tag{1}$$

The wavelength and frequency of radio wave and size of antenna are shown in table Ⅱ.

TABLE Ⅱ

THE WAVELENGTH AND FREQUENCY OF RADIO WAVE AND SIZE OF ANTENNA

No	Frequency （Hz）	Wavelength (m)	Band	size of antenna
1	80	3.75×10^{6}	ELF	937.5km
2	200	1.5×10^{5}	VF	37.5km
3	20K	15000	VLF	3750m
4	200K	1500	LF	375m
5	1M	300	MF	75m
6	20M	15	HF	3.75m
7	72M	4.17	VHF	1.0425m
8	433M	0.69	UHF	17.25cm
9	2.4G	0.125	UHF	3.125cm

In actual communication applications, each wave has a different use: Extremely low frequency (ELF) is usually used to low-frequency telemetry. Voice frequency (VF) contains frequencies associated with the humans' voice, so is usually used in standard telephone channel. Very low frequency (VLF) including the high-end of humans hearing, is used in some special government or military system, such as submarine communication. Low frequency (LF) is mainly used in ships and aircraft navigation. Medium frequency (MF) is mainly used in commercial AM radio (535 ~ 1605 kHz). High frequency (HF) is often used as two-way radio communications, amateur and civilian radio signals is also in the HF band. Very high frequency (VHF) is often used in mobile communications, shipping and aviation communication, commercial FM radio (88 ~ 108 MHz) and some commercial television broadcasting (54 ~ 216 MHz). Ultra-high frequency (UHF) is often used by the commercial TV broadcast, land mobile communication business, cellular phone, some radar and navigation systems, microwave and satellite radio systems. Generally, frequencies above 1 GHz are considered microwave frequencies, which include the high end of the UHF range. Superhigh high frequency (SHF) is mainly used in microwave and satellite radio communication system.

HC-12 wireless transmission module is a new generation embedded wireless data transmission module of multi-channel. The frequency range of working is 433.4- 473.0MHz, and multiple channels can be set, with steps of 400KHz. The maximum transmitting power of the module is 100mW (20dBm). The receiving sensitivity is -116 dBm at air baud rate of 5000 bps, and the distance of transmission is 1000 m in the open ground. The size of the module is 27.4mm×13.2mm×4mm (including antenna cap, excluding spring antenna). There is an MCU inside the module, so users don't need to program the module. The principle and process of working are shown in Fig. 8.

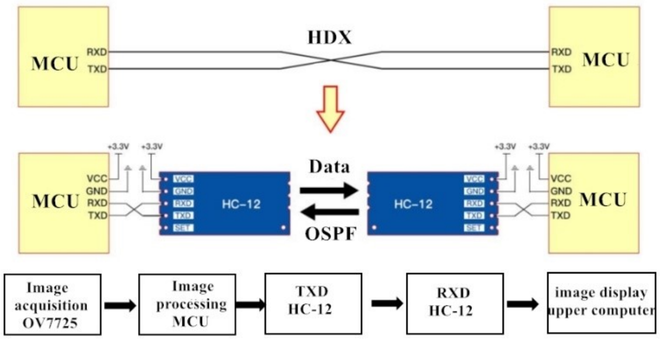

Fig. 8 Working principle and process of HC-12

B. Development of Control Program and Upper-computer Software

OV7725 mainly provides pins of eight digital pixel output signals D0~D7, frame synchronization signal VSYNC, line synchronization signal HREF, pixel synchronization signal PCLK, bus (SDA and SCL) register configuration signal SCCB and working clock signal XCLK. There is a 24M SITIME on pin of XCLK to work as clock signal of OV7725. SCCB bus is similar to the I2C bus and data output format of different image, resolution adjustment, automatic exposure control, automatic gain control, automatic white balance, saturation, brightness, contrast and other parameters of the camera are configured by simulating SCCB bus protocol using universal IO of STM32F407. OV7725 supports output of different image data formats of RGB or YUV, and supports image resolutions such as VGA (640×480) and QVGA (320×240).

In order to ensure the complete of frame data, frame synchronization and row synchronization must be achieved. The sequence diagram of control signal of OV7725 is shown in Fig. 9.

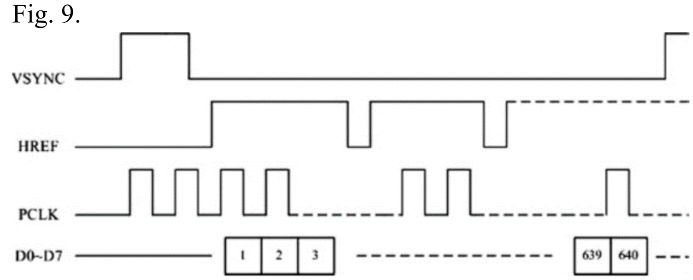

Fig. 9 Sequence diagram of control signal of OV7725

The system connects VSYNC to the external interrupt of STM32F407 and ensures the synchronization of frames by starting the acquisition of one frame from the descending edge of interrupt. A universal IO of STM32F407 is designed a signal to start writing AL422B together with the line synchronization signal HREF. After writing a frame signal, the next rising edge of VSYNC closes the writing signal or starts the acquisition of the next frame to ensure that AL422B stores a complete frame signal.

The interface schematic diagram of STM32F407 and OV7725 camera module, the schematic diagram of FIFO chip

AL422B and the schematic diagram of OV7725 are shown in Fig. 10.

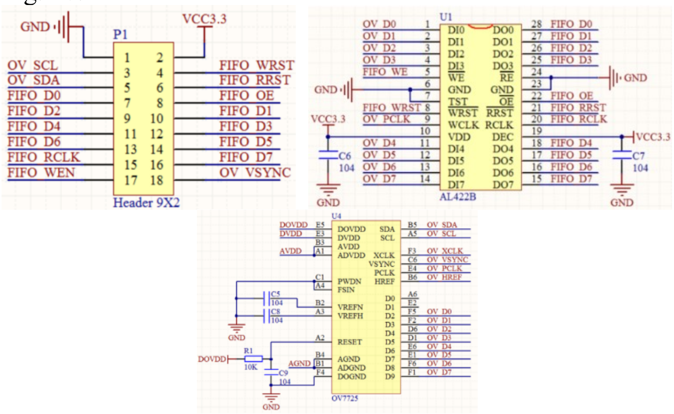

Fig. 10 Connection schematic diagram and schematic diagram

When images that OV7725 outputting are grayscale, one byte is required for each pixel. After collection and compression by DMA, the size of one frame image at 240x240 is 57.6 KB. If OV7725 outputs binary pixels directly, so that one byte can represent 8 pixels, thus 57600 pixels can be compressed into 7.2 KB.

In order to avoid the conflict between the sequence of OV7725 and the sequence of HC-12, transmission is adopted after the acquisition of an image. The data of a frame image is 7200 bytes, and 0x03 is added to be the frame head and 0xAA is added to be the end of the frame to facilitate the processing of the upper computer. Therefore, the total size of a frame image is 7202 bytes.

Upper computer program is compiled by MATLAB. MATLAB has serial port to read the data and has a series of image display control, what's more there are a lot of mature algorithm can be used to process the gray image. The data reading from the serial port is in the form of a stream, so a data buffer larger than one frame image needs to be set. Since the maximum baud rate of HC-12 is 115200, the serial port baud rate is also set as 115200.

The image data can be decompressed and displayed after a valid frame is judged. A byte of data can be decompressed into a binary two-dimensional Boolean array and the image can be displayed through the drawing control. When the data is continuously transferred to the upper computer, the image control will constantly refresh the data and form a video stream.

However, the experiments show that the result that image directly compressed from gray image of 256 levels to binary image is unsatisfactory. The binary image is shown in Fig. 11(a). We continue to explore that one byte stores two pixel points, which means that each pixel has 16 levels. In this way, the display effect of image has been greatly improved, and the obtained gray image is shown in Fig. 11(b). However, it will increase the size of image to 28.8KB, which is still difficult to transfer smoothly. So, we also try to take pixels at intervals to form data of image and interpolation compensation for the image on the upper computer. In this way, the size of the image was reduced by three-quarters to 7.2KB, which was equivalent to the size of binary image, but the practical effect was greatly improved. The obtained image is shown in Fig. 11(c).

(a) (b) (c)

Fig. 11 Images of three experiments

IV. PROCESS AND RESULTS OF EXPERIMENTS

A. Problems Encountered in Experiments and Solutions of Them

ATK OV7725 module can collect and transmit image smoothly. In the early experiment, serial port communication was conducted with data lines. When the baud rate was set as 1.5 MHz, gray image transmission could be carried out smoothly, which verified the connectivity among the image acquisition module, the main control board and the upper computer software. Then We replaced the data line with wireless serial port transmission module HC-12. It can convert the data that needs to be transmitted by data line into wireless transmission mode and has the characteristics of long transmission distance and stable data transmission. The working frequency of this module is generally between 433.4 MHz and 473.0 MHz, and the depth of underwater transmission can reach to 1.5 m. When two HC-12 modules work, they are equivalent to two devices in half duplex mode. RXD port receives data, and after received the data, it is transmitted into the air in the form of radio waves. TXD port restates the original data after received the radio waves, and transmits the data to the upper computer. However, due to the maximum baud rate of HC-12 is 115200, the image transmission is not very smooth. The process of experiments is shown in Fig. 12.

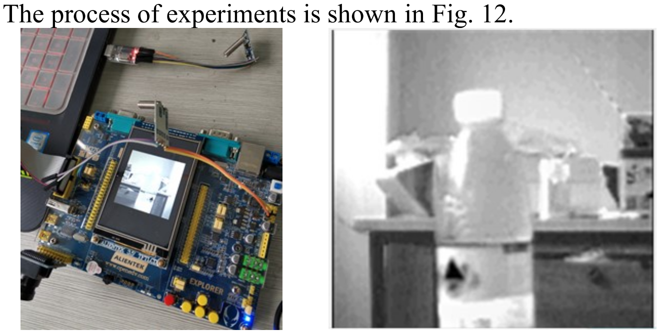

Fig. 12 process of experiments

The relation between baud rate and transmission speed is:

$$n = \frac{b}{8} \qquad (2)$$

Where n is number of bytes, b is baud rate. For example, when baud rate is 115200 BPS, number of bytes is 14400 bytes per second, so the transmission speed is 14.4 KB /s. In theory, it will take seconds to transmit an image, which will seriously affect the application of this design.

As described in chapter 3, there are two methods to improve the speed of image display. One is reducing the quality of image, by using binary image. Originally, a pixel of grayscale needs 8 bits to store data, but only one bit is needed in binary image, the size of data is reduced to 1/8, that means a binary image of 240×240 only needs 7.2 KB. In this way, the real-time image can be displayed continuously and the value of application is also greater [10-11].

Another method is using gray image of 16 levels and reducing the number of pixels to reduce the data amount. For example, when the image is displayed on the upper computer, the data amount can be reduced to 1/4 of previous level by taking points with one pixel of four spaced horizontally and vertically. Experiments show that this method can greatly improve the speed of image transmission, and the quality of image is not so bad. Therefore, we choose method two after comparative.

B. Results

When displaying an image of 24-bit bmp, a pixel occupies 3 bytes. When a gray image of 256 levels is displayed, a pixel occupies 1 byte. When displaying a gray image of 16 levels, a byte can store 2 pixels.

Due to the limitation of the baud rate of wireless transmission module, the maximum transmission speed is 14.4KB/s, which will cause problems such as inability to display the 24-bit bmp and large delay of displaying gray images of 256 levels. After compression by method 2, the main part of the object can be shown smoothly. As shown in Fig. 13, the wireless transmission module of 433MHz suffers less attenuation under water and can still transmit images and provide a basis for the feasibility of underwater wireless image transmission.

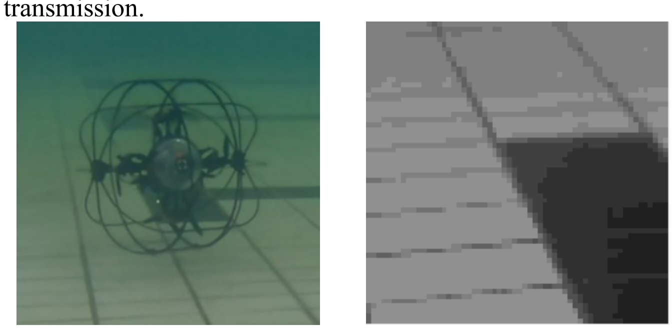

Fig. 13 process of experiments

V. CONCLUSION

The locomotion ability of triphibious robot in three kind of environments has been well realized, and it will be improved and perfected continually in the future. However, the traditional UWCs cannot be used normally underwater, which seriously hinders the development of underwater robot.

We study the breakthrough method of underwater real-time image transmission from image acquisition and transmission. We found that HC-12, a wireless transmission module of lower frequency, can transmit image collected by the CMOS camera OV7725 underwater. The image is preprocessed by STM32, the image information with smaller amount of data is obtained, and then the transmission can be carried out smoothly.

The processed image will lose some of its information. Therefore, we will add SD storage function to store the uncompressed image information later to facilitate operators to observe the situation underwater, conduct target tracking and accurate underwater control of robot. The video can be replayed to find valuable information after the robot is recovered.

In this way, the underwater application of triphibious robot has been developed preliminarily and has preliminary practical value of application.

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