Underwater Acoustic Communication using QPSK Modulation Method

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Abstract

Acoustic communication has a lot of influence of noises, and difficulties in sending and receiving data correctly because of the noise from robot's thrusters and other acoustic devices. To improve the acoustic communication performance, this research developed acoustic communication system against the thruster's noise. Communication message includes not only data (payloads) but also sync signal and error correction bytes, and the message is converted to acoustic wave by QPSK modulation which four phase data represent two bits.

Keywords: Acoustic communication, QPSK modulation, Error correction, Noise canceling.

1. Introduction

Acoustic transmission which its baud rate is only 1/1000 of conventional Wi-Fi communication has less attenuation than those of radio or light and is communication between underwater robots. However, acoustic communication has a lot of influence of noises, and difficulties in sending and receiving data correctly because of the noise from robots and surroundings. The noise includes ambient noise from the wave and marine organisms and self-noise from the robot's acoustic devices and thrusters. Ambient noise level is relatively low because underwater robots are operated only in calm sea conditions of WMO sea state code 3 or less, and not many marine organisms make sounds that interfere with communication. High frequencies sound of several hundred kHz is used for acoustic devices such as observation devices and sensors due to require high resolution measurement at a short distance. The noise from the acoustic devices gives little influence on acoustic transmission using sound of several tens of kHz that because the frequency band of the oscillator for acoustic transmission is narrow. On the other hand, the noise from the thruster is high value in a wide frequency

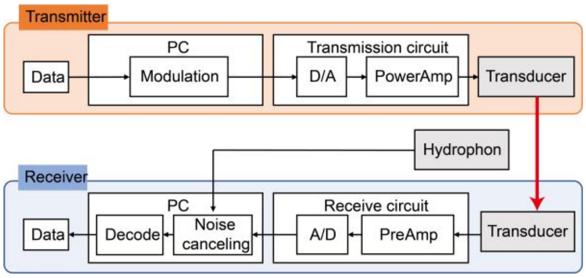


Fig.1 System architecture for acoustic communication

band on the order of several kHz to several tens of kHz and acoustic communication may fail due to the noise from thruster [1].

Acoustic communication with error correction has been developed for improving communication success rate [2-3], but robots is difficult to receive acoustic command when its cruises by full thrust. For reliable and high-speed acoustic communication in noisy situations, this research developed acoustic communication using QPSK modulation method and noise canceling method. This paper explains our acoustic communication and shows experimental results using our system.

2. Acoustic communication system

2.1. *Hardware configuration*

Our acoustic communication system consists of transmitter and receiver units, and the units have a transducer which can transmits and receives acoustic wave. The transducer consists of a PC for modulating data, a circuit for converting digital data to amplified analog data, and a transducer for transmission. The receiver has a PC for recording data, a circuit for amplifying and converting analog data to digital data, a transducer, and a hydrophone for receiving thruster noise. Transceiver and receiver units can have the same structure by using the transducer, but the unit is separated into two structures to make its smaller. Thus, our acoustic communication system can transmit in only one direction.

Sonar head of FURUNO fish finder is used as transduce for transmitter and receiver units. The frequency characteristic is measured because nobody knows it specification. Figure 2 shows frequency characteristics of sonar head for transducer. The transducer has the lowest impedance at 50kHz and 200kHz, and the phase at that frequency was a practical value. Acoustic communication of higher frequency has high baud rate,

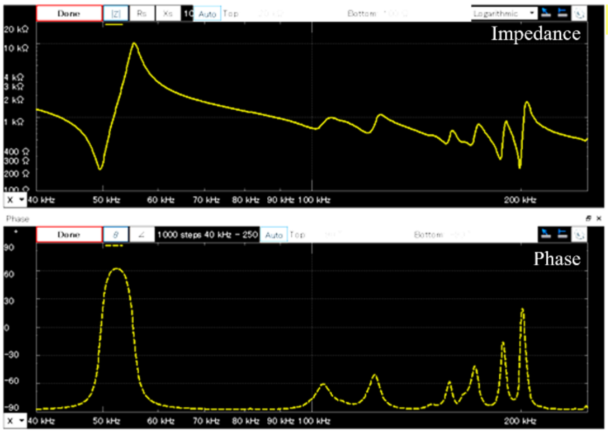
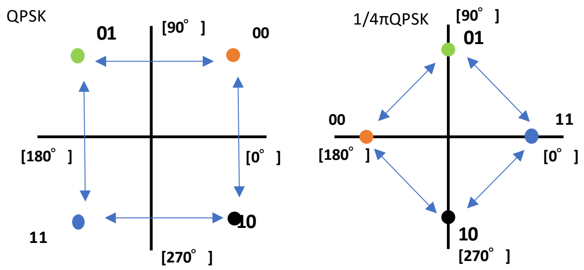


Fig. 2 Frequency characteristics of sonar head for transducer



(a) QPSK (b) π/4 shift QPSK

Fig.3 Phases for QPSK

but its acoustic wave doesn't reach far. To develop a practical acoustic communication that can transmit up to several hundred meters, this research used frequency of 50kHz.

2.2. *Communication format using QPSK*

Communication message in our format is separated into header, payload, error correction code. In this research, synchronization of acoustic wave is very important due to that baud rate of acoustic communication is improved by modulation. The header in the message is represented chirp signal for synchronization. Accuracy of synchronization by time correlation is decreased by the noise when normal sine wave is used as synchronization signal. Even if a part of acoustic wave is transformed by the noise, accuracy of time correlation doesn't decrease so much because frequency of chirp signal changes over time. Payload in the message is used for data transmission, and it is modulated by QPSK (**Q**uadrature **P**hase **S**hift **K**eying) modulation which two bits are

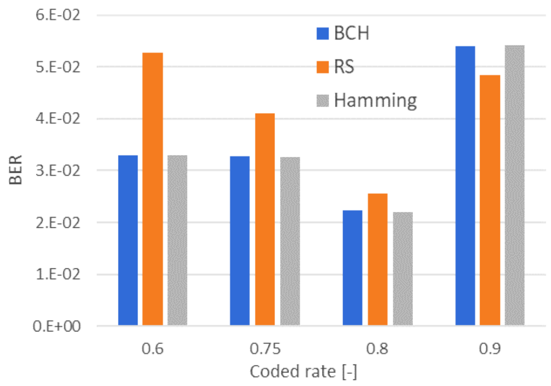


Fig.4 Bit-error rate of each correction method

represented in four quadrants, as shown in Fig.3. QPSK modulation is more robust to the noise than ASK (**A**mplitude **S**hift **K**eying) and can code by single frequency unlike FSK (**F**requency **S**hift **K**eying). This research used π/4 shift QPSK which uses phases of 0, 90, 180, 270 deg. Even if acoustic wave is perfectly synchronized, decoded payload may include error bit by the noise. Error correction code is added to the end of the message to improve acoustic communication quality. When code rate which is ratio of correction code bit to data bit is high, error correction code corrects many data bit, but communication baud rate is low. The correction performance depends on the correction method. This research evaluates correction performance of BCH code, RS (Reed-Solomon) code and Hamming code by the simulation using additive white gaussian noise. Figure 4 shows BTR (**B**it-Error **R**ate) after error correction by each correction methods. The smaller code rate other than 0.9, the smaller BTR of each method. Correction performance at code rate of 0.9 was low because correction code bit includes most error bits, and there was almost no difference in performance each method at code rate of 0.8 and 0.9. This research used RS code which is high performance against burst error, and RS code was used for communication between underwater robot [4-5].

2.3. *Noise canceling method*

To improve decoding accuracy at receiver unit, the noise from robot's thruster is removed from received acoustic wave by LMS (Least Mean Squares Filter) adaptive filter, as shown Fig.5. The filter adapts the transfer function according to optimization algorithm. In this research, the sound data from the hydrophone for listening thruster noise enters to adaptive optimization block, and thruster noise is removed using filter factor from adaptive algorithm. Figure 6 shows received acoustic wave with thruster noise and acoustic wave after filtering by LMS adaptive filter. The received acoustic wave has a waveform close to a sine wave by applying the filter.

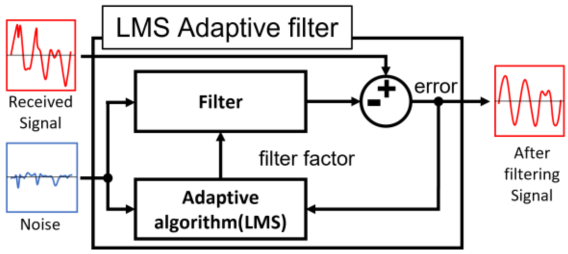


Fig.5 LMS adaptive filter

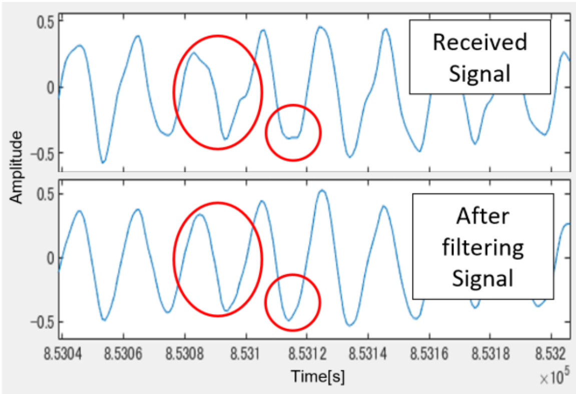


Fig.6 Received acoustic wave before and after filtering

3. Wet test

3.1. *Thruster noise measurement*

To verify the effect of thruster noise on the acoustic communication, the noise during thruster drive was measured. RoboPlus Hibikino thruster which was located on small experimental tank was used for the measurement, and the noise was measured when three levels of thrust to the maximum output were generated. Figure 7 shows power spectrum obtained by FFT analysis of measured noise. Sound pressure of the noise depends on the thrust from the thruster, and the noise is in the frequencies from 5kHz to 35kHz. The thruster made the noise of 110dB at the frequency of 14kHz when it produced the thrust of 24N. The frequency of maximum noise from the thruster is different from the frequency of

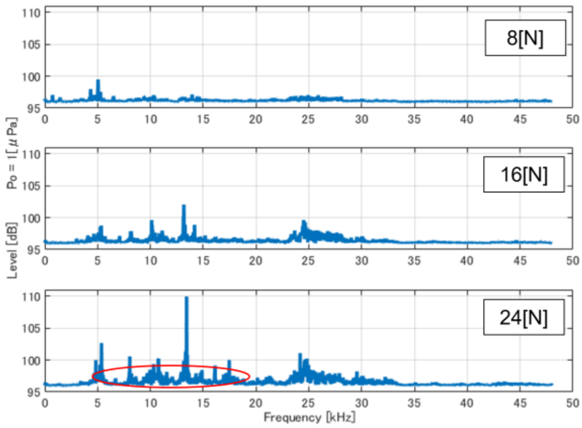


Fig.7 Power spectrum of thruster noise

the acoustic communication (50kHz), but the waveform of acoustic communication may be deformed by the peak noise and the wideband noise. If the waveform is deformed, decoding results of QPSK modulated acoustic wave includes several error bits.

3.2. *Communication performance evaluation*

To evaluate the performance of developed the acoustic communication system, BER of the communication in the presence of the noise when the thruster produced the thrust of 24N was measured. At this time, the sound pressure of acoustic wave produced by the transceiver was set that SNRs (**S**ignal **N**oise **R**atio) to the thruster noise were 2dB, 5dB, 10dB, 15dB and 20dB. The message that its payload were the data of 5,001bits and the code rate of RS is 0.9 is used for the evaluation. Figure 9 shows the BERs of each communication vs. SNR. Our communication method that used QPSK with error correction and noise cancel had a BER of 1/3 compared to the normal QPSK modulated communication, at the SNR of 2dB. At SNR above 10dB, there was almost no BER in the communications with normal and the error correction, and the communication of our method included some BER. This means that the noise canceling method using LMS adaptive filter reduces communication performance a little in an environment with almost no noise. However, the increase in BER by our method is very small, and there can be no environment with almost no noise when the underwater robot is used. Thus, the communication using QPSK with

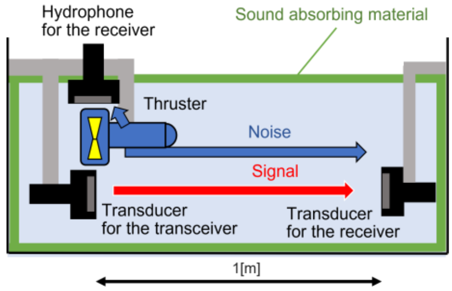


Fig.8 Setup for communication performance evaluation

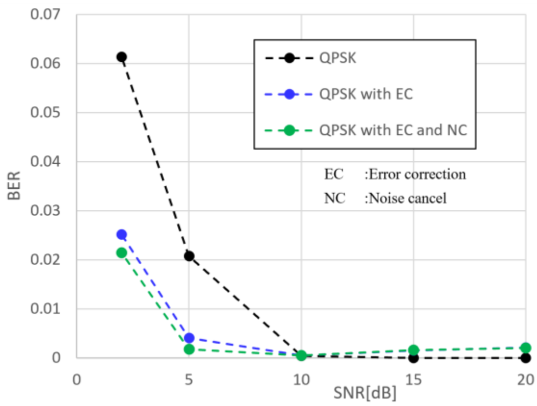


Fig.9 the BER of each communication vs. SNR

error correction and noise cancelling method is the effective communication for the underwater robots.

3.3. *Image transmission test*

To verify whether a large size data can be transmission, the photo image was transmitted by using our acoustic communication system. Transducers for receiver and transceiver was installed on the tank which its diameter is 6m and height is 1.5m, the distance between the transducers was 2m and 5m. Artificial turf was installed behind the thrusters to reduce the effect of multipath of the acoustic wave. This test didn't use noise cancelling method by using LMS adaptive filter because there was no noise resource in the tank. Figure 10 shows the original image and images transmitted 2m and 5m ahead. The communication in the distance of 2m had no BER and decoded image was the same as the original image. Decoded image from the communication data in the distance of 5m had the BER of 0.20 and included different colors on some pixels. The reason why the BER increased in the communication at the distance of 5m is considered to be low sound pressure of transmitted acoustic wave. Signal level of the acoustic

Fig.10 Images before and after image transmission

communication closed the noise level from acoustic wave multipath, due to attenuation of the acoustic wave. Then, the decoder made some error bits due to a decrease in the SNR.

4. Conclusions

This paper proposed the acoustic communication using QPSK modulation to improve the communication performance in noise situation. The message in our communication consists of chirp signal for synchronization of acoustic wave, payload for user and error correction code based on Read Solomon code. The payload was modulated by QPSK modulation which two bits are represented in four quadrants before transmission. For decreasing error bit during decoding, the noise from the thruster is removed by LMS adaptive filter from received acoustic wave before. Our communication had a BER of 1/3 compared to the normal QPSK modulated communication at the SNR of 2dB, and can transmit photo image to 2m away without data loss.

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