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Development of an Acoustic-Based Underwater Image Transmission System

Young-Cheol Choi*, Yong-Kon Lim*, Jong-Won Park*, Sea-Monn Kim*, Seung-Geun Kim*, Sang-Tae Kim**

*Ocean Development System Laboratory, KORDI, Daejon, Korea

** Electrical Engineering Department, Arizona State University, USA

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ABSTRACT : Wireless communication systems are inevitable for efficient underwater activities. Because of the poor propagation characteristics of light and electromagnetic waves, acoustic waves are generally used for the underwater wireless communication. Although there are many kinds of information type, visual images take an essential role especially for search and identification activities. For this reason, we developed an acoustic-based underwater image transmission system under a dual use technology project supported by MOCIE (Ministry of Commerce, Industry and Energy). For the application to complicated and time-varying underwater environments all-digital transmitter and receiver systems are investigated. Array acoustic transducers are used at the receiver, which have the center frequency of 32kHz and the bandwidth of 4kHz. To improve transmission speed and quality, various algorithms and systems are used. The system design techniques will be discussed in detail including image compression/decompression system, adaptive beam- forming, fast RLS adaptive equalizer, ∂/4 QPSK (Quadrilateral Phase Shift Keying) modulator/demodulator, and convolution coding/Viterbi. Decoding.

1. Introduction

In order to perform effective underwater activities, not only handling data being used (for example, measurement data, image, status, navigation data, control command, etc.) but also transmitting them to another place, such as a mother ship or a remote underwater vehicle, is very important. Generally, the underwater transmission techniques can be classified into two methods depending on the existence of a physical line between a transmitter and a receiver. One is the method to use a line like a tether cable of an ROV (Remotely Operated Vehicle), and the other is wireless communication, which is widely used for the navigation and control of an AUV (Autonomous Underwater Vehicle).

There are several types of wireless communication method. Electromagnetic waves, light, and acoustic waves are the examples. Among them, electromagnetic waves and light cannot propagate long distance, because of their high loss of energy during the propagation in water. Therefore, acoustic waves should be used for long-distance underwater communication.

제1저자 최영철 연락처: 대전광역시 유성구 장동 171
042-868-7537 ycchoi@kriso.re.kr

However, because of their high reflection coefficients at the free surface, bottom, and large objects, transmission channels form a multi-paths system, especially in shallow water or basins without anechoic lining at the walls. Because these multi-paths reduce the communication quality [1], a special algorithm, such as an adaptive equalizer is needed for minimizing the multi-path effect. In addition, a beam-forming algorithm for array signal processing and JPEG/Wavelet image compression, and a QPSK (Quadrature Phase Shift Keying) modulation/demodulation method are also needed for increasing transmission speed and quality.

For this reason, Korea Research Institute of Ships and Ocean Engineering (KRISO), the engineering branch of Korea Research and Development Institute (KORDI), developed an underwater transmission system under a dual use technology project supported by MOCIE (Ministry of Commerce, Industry and Energy). The aim of the project is the development of an underwater image transmission system. In this paper research results and the current status of the project are described in detail.

2. System Configuration

The system shown in Fig.1 is the block diagram of

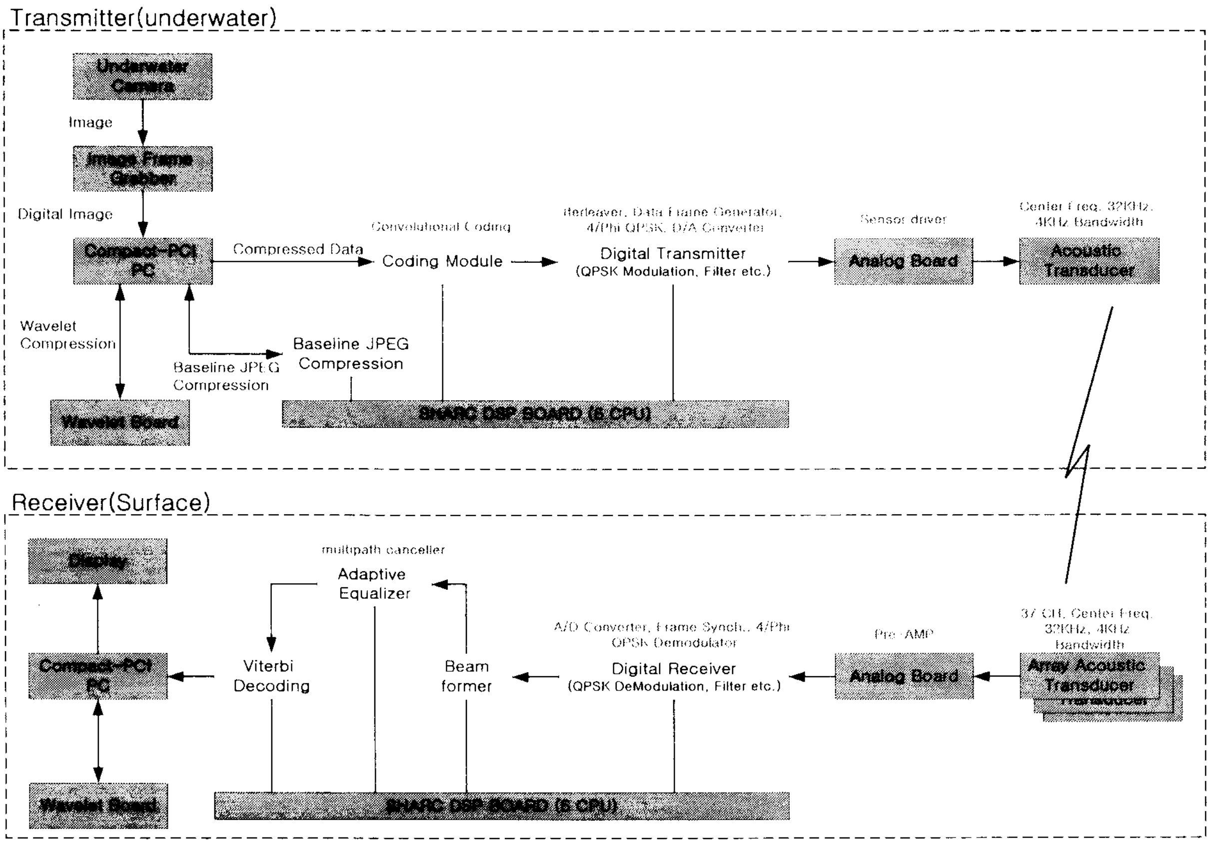

Fig. 1 Underwater image transmission system configuration : the final target system to be developed

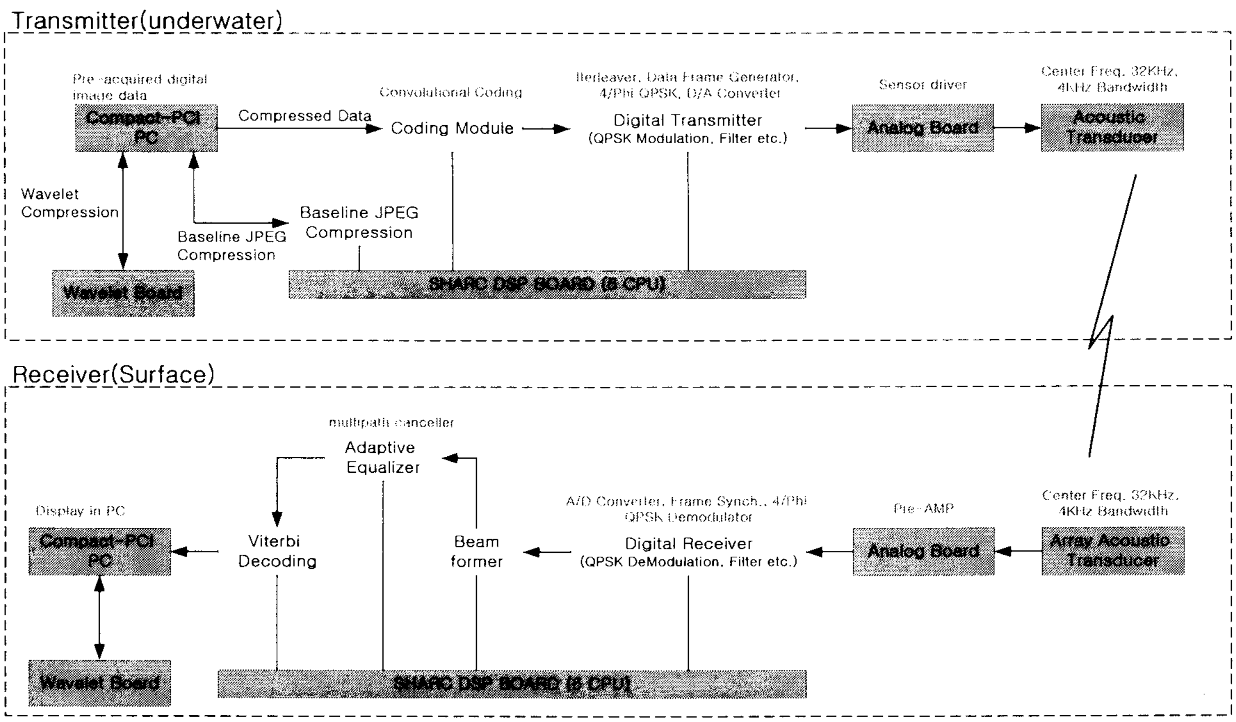

Fig. 2 Underwater image transmission system configuration: current system

the final target system to be developed. The system is divided into two parts: a transmitter and a receiver. Acoustic transducers are used for transmitting and receiving image data. The transmitter is composed of a compact-PCI PC, an underwater camera, an image frame grabber, a wavelet image compression board, a SHARC DSP board with 6 CPUs, an analog board, and an acoustic transducer. The receiver is composed of array acoustic transducers, an analog board, a SHARC DSP board, a wavelet decompression board, a compact-PCI PC, and a display monitor.

The image frame grabber module, which is image acquisition system, converts analog camera images to digital images and send them to the compact-PCI computer to save them in the computer memory. The SHARC DSP board processes the digital data stored in the memory. For fast image data transmission, image compression techniques are needed, especially when a bandwidth limitation of transducers exists. In our system, we use both baseline JPEG and wavelet compression techniques.

The baseline JPEG image compression technique, convolution coding, and p/4 QPSK modulation are implemented in the SHARC DSP system of the transmitter part. A Beam-forming method for array acoustic transducers, an adaptive equalization method, p/4 QPSK demodulation, DPLL, Viterbi decoding, and baseline JPEG decompression are implemented in the DSP board of the receiver part.

All sub-systems except the transducer driving analog boards and the pre-amplifier for the acoustic transducers can be implemented inside DSP boards. Those systems are called as all-digital transmitter and receiver. We deal with detailed description of all digital transmitter and receiver at another paper (A Phase Coherent All-Digital Transmitter and Receiver for Underwater Acoustic Communication Systems, UDT2002 by Young-Cheol Choi at al.).

We used several digital signal processing techniques for robust underwater image communication. They are convolution coding, Viterbi decoding, QPSK modulation/demodulation which has very efficient characteristics in limited bandwidth condition of acoustic transducers, adaptive equalization technique that removes the reflection effect of acoustic signal, and a beam-forming algorithm for array signal processing.

Figure 2 shows the system configuration of the current version. The image frame grabber, camera, array acoustic transducers, and display monitor in Fig. 1 will be implemented next year.

Table 1 shows the specifications of the underwater image transmission system.

Table 1 Specification of the underwater image transmission system

Detail Description	Value
Physical Transmission Media	Acousic
Transmission Distance	1,000 m
Max. Transmission Throughput	9,600 bps
Image Information	320*320, 8bit Gray/Color
Center Frequency	32 KHz
Bandwidth	4 KHz
Modulation/Demodulation	$\pi/4$ QPSK
Main Processor	SHARC DSP
Image Compression	JPEG, Wavelet
Coding/Decoding	Convolution, Viterbi
Adaptive Equalizer	RLS
Beam Former	RLS

3. Image Compression/Decompression

Digital image data captured by a camera should be compressed for efficient image transmission. In the image compression algorithm, we use baseline JPEG and wavelet compression/decompression methods. Typically, the wavelet method has about 350:1 ratio, whereas the baseline JPEG method has 64:1 compression ratio. Moreover, the wavelet method has no blocking artifact effect that is generated in the baseline JPEG method with high compression ratio. Thus, it could be a very good solution for image compression if channel characteristics is not too bad. When channel condition is bad like in shallow water, transmitted data have so many errors that compressed image by the wavelet method cannot be retrieved to original data due to the destruction of a total frame. However, the image compressed by the baseline JPEG can be recovered with little image distortion. The system being developed uses both baseline JPEG and wavelet image compression methods, but it will select either method according to underwater environmental conditions.

Because floating particles reduce image compression performance as described in Table 2, an pre-processing algorithm for removing them from images should be used. The algorithm uses the characteristics of moving particles that their positions are changing as time goes on. Average of several image frames captured from the same view angle can remove them. However, this method has a critical drawback that an important object like fish can be removed and images can be blurred due to the movement of the camera. Now we are trying to improve the compression algorithms.

Fig. 3 shows original black image with floating particles, and Fig. 4 shows processed image. Figure 5 shows the pre-processing structure of the removing algorithm.

Table 2 The effect of removing floating particles in an image

Contents	Image Size [bytes]	Compression Ratio
Image with floating particles	9117	33.69
Image without floating particles	7218	42.56

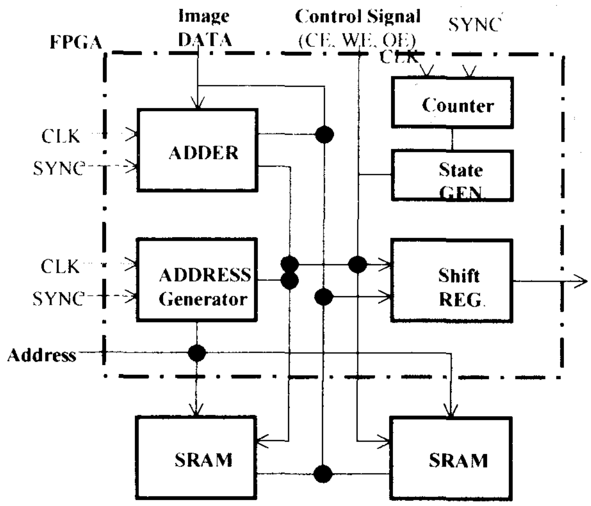

Fig. 5 The Pre-processing structure of the removal module of floating particles

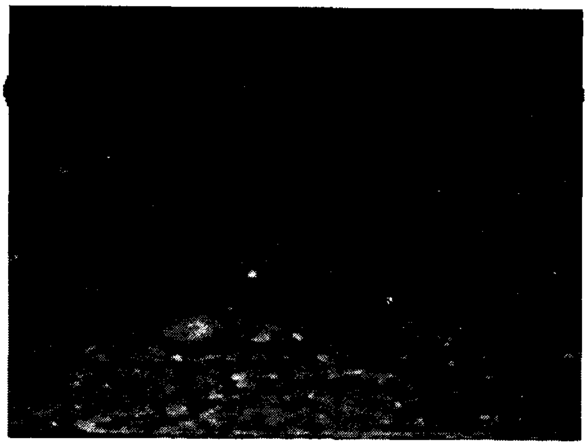

Fig. 3 Image with floating particles

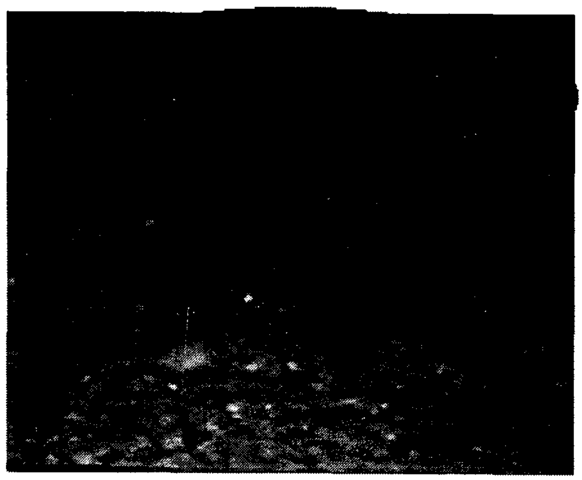

Fig. 4 Image without floating particles after applying the removing algorithm

4. Digital Transmitter/Receiver

The all-digital transmitter and receiver systems were made by changing analog modules to software types. While analog systems have difficulty in system modification, digital systems have many profits of easy modification of system parameters due to software-based development procedure. Figures 6 and 7 show the block diagrams of the digital transmitter and receiver of the image transmission system, respectively. The all-digital transmitter and receiver systems include many functions, such as data frame generator, QPSK modulation & demodulation, convolution coding, Viterbi decoding, beam-forming technique, adaptive equalization, and DPLL etc.. The all-digital transmitter and receiver systems are implemented by SHARC DSP systems with 6 CPUs.

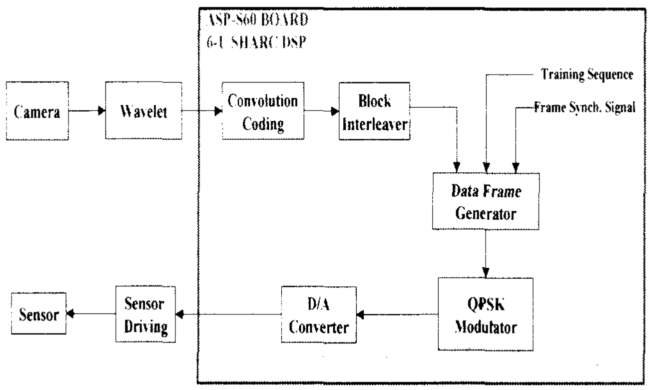

Fig. 6 Block diagram of the all-digital transmitter

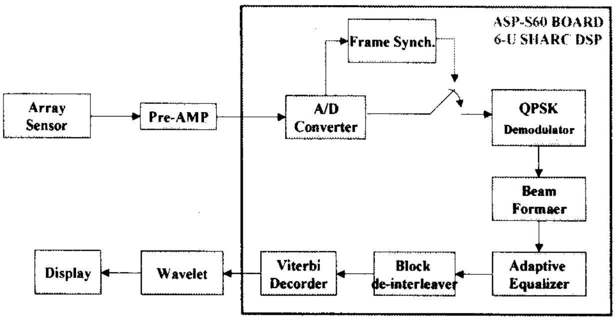

Fig. 7 Block diagram of the all-digital receiver

At first, KRISO tried to develop an analog system, which has the function of QPSK modulator & demodulator, low pass filter etc.. Figure 8 shows the block diagram of the analog system. Figure 9 shows its prototype made in 2001. However, whenever modification of system parameters, addition/elimination of functions, and calibration of acoustic sensors were required for increasing transmission performance, we spent a lot of time and effort. For this reason, we adopted SDR (Software Defined Radio) concepts for the development of the transmission system.

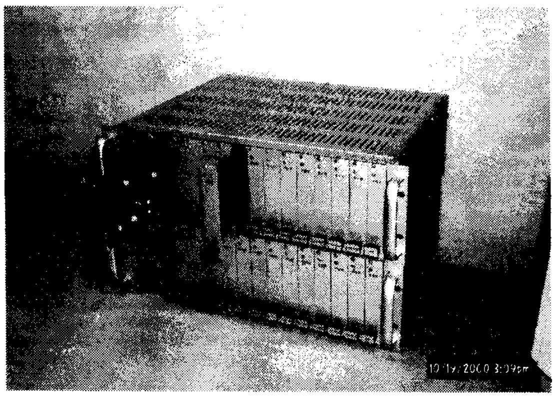

Fig. 9 Photograph of analog modulator & demodulator

At present, each functional module is implemented via DSP boards. More details are described in the paper on the all-digital transmitter and receiver (A Phase Coherent All-Digital Transmitter and Receiver for Underwater Acoustic Communication Systems, UDT2002 by Young-Chol Choi et al.).

5. Diver Phone

We also developed a set of underwater scuba diver phones as a result of the research. A Diver phone is defined as a system by which divers can communicate one another through their voices. The diver phones use acoustic sensors and the analog FM (Frequency modulation) method. Because diver phones are operated by batteries with limited power, they should consume little energy and have small size, but clean communication quality without any cross talk.

Table 3 shows the specifications of the diver phone prototypes. Figure 10 shows the block diagram of the diver phone, and Fig. 11 shows its photograph. The diver phones were tested at underwater anechoic basin at KRISO. In the experiment the distance between the diver phones is 2m and the depth is 1.5m. The results verify their clean communication quality. We have a plan to test them in the ocean next year.

Table 3 Specification of the diver phone

Specifications	Criteria
Transmission Distance	Max. 100m
Transmission Media	Voice
Operating Depth	Max. 30m
Transmission method	Half Duplex
Operating Time	2-3 hours
Center Frequency	68.5 Khz
System Composition	Headsets, Sensor, Board, and Batteries

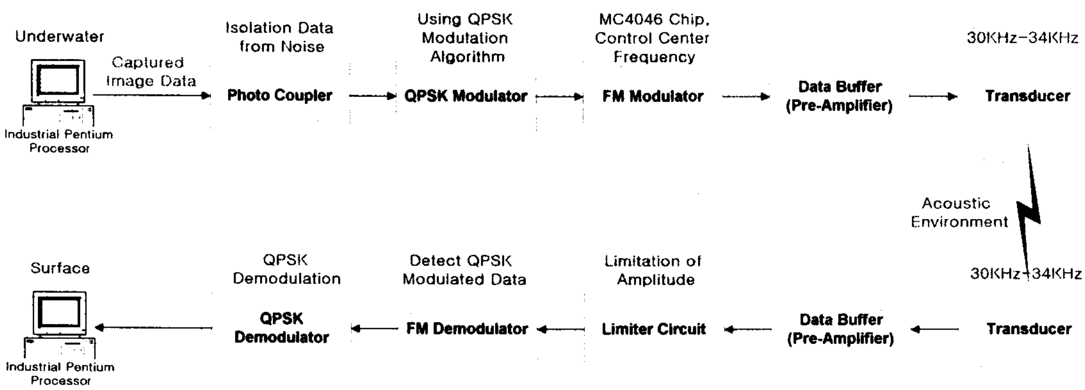

Fig. 8 Block diagram of analog modulator/demodulator

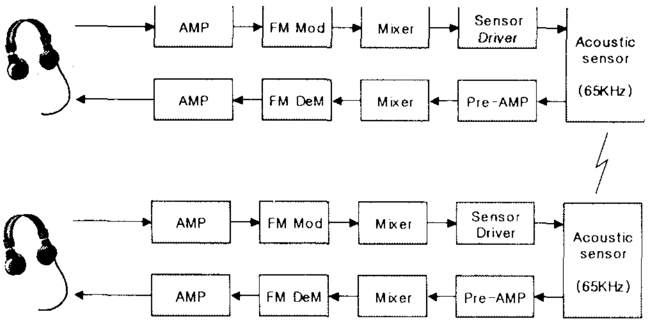

Fig. 10 Block diagrams of the diver phone

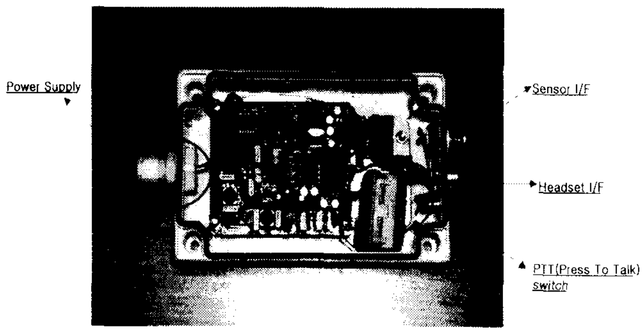

Fig. 11 Photograph of the diver phone

5. Conclusions

This paper introduces the underwater communication systems developed by KRISO under the dual use technology project Development of Acoustic-based Underwater Image Communication System supported by MOCIE. KRISO is developing more efficient transmission system by using all-digital transmitter and receiver systems with DSP boards. The developed analog transmission system shows good quality at the transmission rate of 9600bps. The experiment was performed in the underwater anechoic basin at KRISO. In the experiment the depth and distance were 1.5m and 2m respectively. We believe that the performance of the all-digital transmission system can be verified by October, when we are scheduled to finish the development of the digital transmitter and receiver system.

Aknowledgements

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