Video streaming using ultrasound as a communication channel: towards a standalone device

Zhengchang Kou
Beckman Institute for Advanced Science and Technology
University of Illinois Urbana-Champaign
Urbana, Illinois
zkou2@illinois.edu

Michael L. Oelze
Beckman Institute for Advanced Science and Technology
University of Illinois Urbana-Champaign
Urbana, Illinois
oelze@illinois.edu

***Abstract*— A future clinical goal of capsule endoscopy is to transmit high definition (HD) video in real time from inside the human body to an external device. Current electromagnetic wave approaches do not provide enough data rates to achieve video streaming let alone at HD. In a previous study, we verified high-speed communication through tissue using ultrasound with data rates up to 30 Mbps [1]. The system used single-element focused transducers operating at 5 MHz using a Tabor WW1281 arbitrary waveform generator and power amplifier. To move towards a capsule endoscopy system, a smaller hardware footprint is required. We designed an OFDM modulation scheme, which was compatible with an in-tissue ultrasound communication channel and verified the scheme with 2-mm sonomicrocrystal as the transmit transducer and IP103 linear array as receive transducer. A 3 Mbps data rate was achieved with this setup. Furthermore, we implemented the transmitter with an FPGA to achieve real-time video streaming through tissue.**

Keywords—Ultrasound, Communication, OFDM, Array

I. INTRODUCTION

Traditional EM-based wireless communication approaches [2][3][4] face several limitations for in-body communication, especially in the hospital environment. First, the high attenuation of EM waves inside the human body can result in low signal-to-noise ratio (SNR) and limited penetration depth. Second, the power supply of the capsule is limited because the batteries must be small to fit in the capsule, which limits the transmit power. Third, the temperature rise caused by the absorption of EM energy by tissue also limits the transmitting power [5]. Because of these limitations, capsule endoscopy using EM wave communication in the human body has not achieved data rates capable of real-time video streaming.

As an alternative to EM communications, ultrasound has been studied as an effective way for communication through human tissue. In a previous study [1] from our group we demonstrated up to 30 Mbps data rate with a large diameter, focused transducer (1.92cm diameter) through 5-cm thick pork loin and beef liver. However, the transducer size was too large to fit into human body and required accurate alignment because of directionality.

In another study by Bos et al. [6], small sonomicrocrystal (2cm diameter) was used as transducer for in tissue communication. Both single carrier QAM modulation [6] and multicarrier OFDM modulation [7] were tested, and over 300 kbps data rate was achieved. These studies demonstrated the potential of using a small sonomicrocrystal and OFDM as a communication scheme for high-speed in-body communication. However, the demonstrated data rate was still insufficient for real-time video transmission.

To move towards a capsule endoscopy system, both a smaller hardware footprint and higher data rate are required. The objective of this study was to demonstrate video streaming using a small sonomicrocrystal operating at 2.4 MHz with transmission hardware utilizing a FPGA having a small footprint and receiving the signals and processing with an ultrasonic scanner. In this paper, Section II describes the methodology employed for transmitter and receiver, the test setup and FPGA implementation of transmitter. Section III provides the results of the study for phantom-based test. The last section (Section IV) provides discussion and conclusions regarding the study.

II. METHODOLOGY

A. Modulation Scheme

We used OFDM modulation with a narrow subcarrier bandwidth to simplify the equalization process. A block type pilot pattern with interval size of 12 was chosen to provide better channel estimation accuracy in frequency domain. We selected a 4096 points FFT OFDM modulation with 512 points cyclic prefix to alleviate inter symbol interference (ICI). A total of 3072 out of 4096 subcarriers were chosen as active subcarriers, which resulted in 512 subcarriers in each side as guard subcarriers. The baseband sampling frequency was set to 1.25 MSPS, which resulted in a total bandwidth of 937.5 kHz. Modulation on each subcarrier was set to 16 QAM. The overall data rate achievable with this set up was 3Mbps. Another high data rate with baseband sampling frequency at 5 MSPS resulted in 3.75MHz bandwidth. By using 256 QAM we could achieve a data rate to 24 Mbps.

B. Transmitter

The Redpitaya STEM 125-14 Soc development board was used to build an OFDM transmitter, which included 4K FFT and digital up conversion. The camera interface that was used to connect to the OV7670 and a program to code the registers

This work was supported by NIH(R21EB025327)

978-1-7281-5448-0/20/$31.00 ©2020 IEEE

inside the camera was also included in the FPGA. The image size was 160*50 pixels with RGB565 color coding. In this resolution, 24 image frames per second could be transmitted by the transmitter. The transmitted ultrasound signal's center frequency was 2.4 MHz with 937.25 KHz bandwidth. A small 2-mm sonomicrocrystal was used as the transmit transducer. Sonomicrocrystal had low directionality at 2.4 MHz and was used to transmit the video signal.

C. *Receiver*

A Sonic Concepts IP103 phased array, which has 64 elements, was connected to a Verasonics Vantage 128 system and used as the receiver. The IP103 array was located 6.5 cm from the sonomicrocrystal, which was embedded in a gelatin phantom (Fig.1). We implemented passive receive focusing with the IP103 array (Fig.2). Signal quality was improved, and frequency selective fading was mitigated by subcarrier wise maxim ratio combining with multiple receive channels.

Fig.1 Phantom and IP103 probe

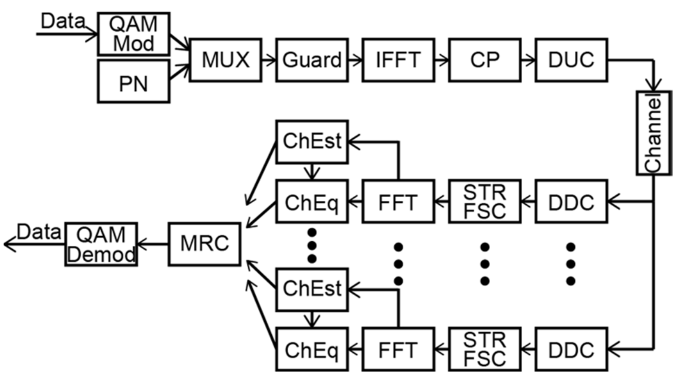

Fig.2 Processing flow diagram

III. Result

A. *Video Frame Transmission and Receive*

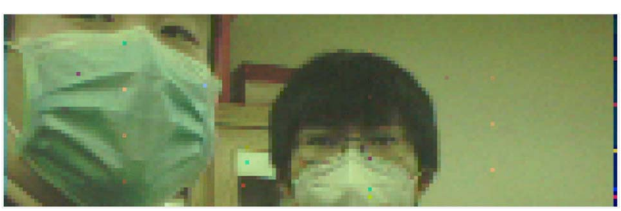

Fig.3 Received video frame

Live video was transmitted with the FPGA development board and sonomicrocrystal. Ultrasound signals were received and demodulated by Verasonics Vantage 128 ultrasound machine. Visually low noise images were recorded, as shown in Fig. 3.

B. *BER Performance*

By replacing video signal with pseudo noise sequence, we tested the BER performance of this setup with different transmit voltage and number of active receiving channels. The result is shown in Fig.4

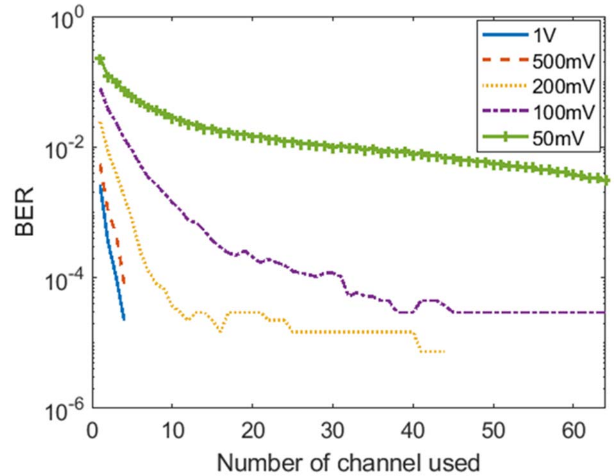

Fig.4 BER performance comparison

The comparison of single channel received constellation and 64 channel combined received constellation is shown in Fig. 5.

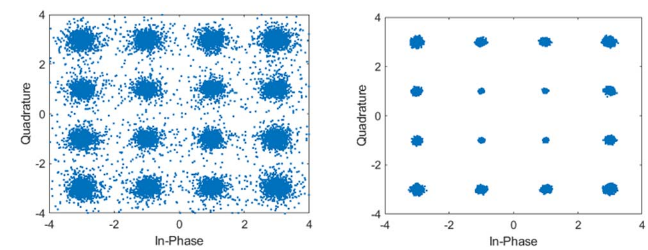

Fig.5 Received constellation comparison. Left side is single channel received constellation. Right side is 64 channel combined received constellation.

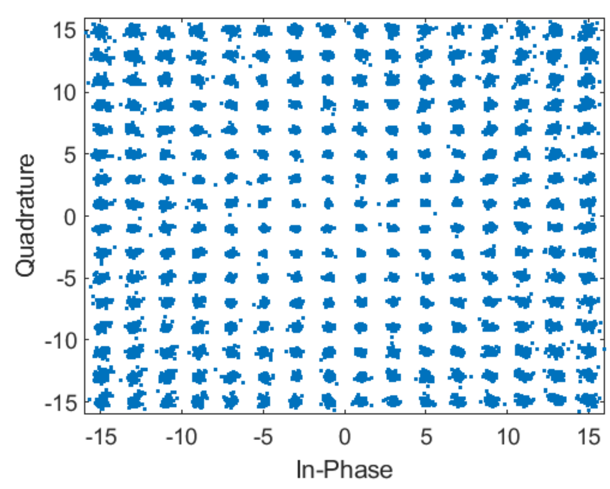

Fig.6 128 channel combined received constellation for high data rate mode.

The high data rate with 24 Mbps data rate was tested with a L14-5 linear array at 5 MHz center frequency in underwater environment. At 4 cm distance, we achieved 1e-4 BER performance. The received constellation is shown in Fig. 6.

IV. CONCLUTSION

In this study, the transmission signals were constructed on an FPGA board to enable real-time video transmission on a small platform. The performance of the communication scheme indicated that the communication protocol was suitable for video capable ultrasound capsule endoscopy. The use of an array at the receiving end allowed for improved transmission rates over single transducer receivers. The real-time video transmission based on the current platform is still limited by the processing ability of the software-based receiver as the digital down converter needs for each active received channel, which composed of multiple stage of FIR filter, slow down the overall performance of the receiver. In the future work we will design and implement a hardware-based receiver to enable continuous receiving with real-time processing abilities. In this way, compressed high definition video transmission can be achieved.

REFERENCES

[1] Singer, Andrew, Michael Oelze, and Anthony Podkowa. "Mbps experimental acoustic through-tissue communications: MEAT-COMMS." 2016 IEEE 17th International Workshop on Signal Processing Advances in Wireless Communications (SPAWC). IEEE, 2016.

[2] Iddan, Gavriel, et al. "Wireless capsule endoscopy." Nature 405.6785 (2000): 417-417。

[3] Nakamura, Tetsuya, and Akira Terano. "Capsule endoscopy: past, present, and future." Journal of gastroenterology 43.2 (2008): 93-99.

[4] Iddan, Gavriel J. "A Short History of the Gastrointestinal Capsule." Video Capsule Endoscopy. Springer, Berlin, Heidelberg, 2014. 1-3.

[5] J. Faerber et al., "In Vivo Characterization of a Wireless Telemetry Module for a Capsule Endoscopy System Utilizing a Conformal Antenna," in IEEE Transactions on Biomedical Circuits and Systems, vol. 12, no. 1, pp. 95-105, Feb. 2018.

[6] T. Bos, W. Jiang, J. D'hooge, M. Verhelst and W. Dehaene, "Enabling Ultrasound In-Body Communication: FIR Channel Models and QAM Experiments," in IEEE Transactions on Biomedical Circuits and Systems, vol. 13, no. 1, pp. 135-144, Feb. 2019.

[7] T. Bos, W. Dehaene and M. Verhelst, "Ultrasound In-Body Communication with OFDM through Multipath Realistic Channels," 2019 IEEE Biomedical Circuits and Systems Conference (BioCAS), Nara, Japan, 2019, pp. 1-4.