First Step Towards Low-Cost, Open-Source Optical Modem for Underwater Communication with Experimental Results

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ABSTRACT

Acoustic modems enable long-range underwater communication, but are relatively expensive with limited data rates. Low-cost modems have been developed to address the high cost of commercial products, but data rates are still limited. For underwater robotics applications with the need for short-range (<50 m), high-speed communication, there exists a different communication solution; optical. However, there currently is no available low-cost, open-source optical modem to address the needs of the community. In this paper, we discuss our progress towards development of such a modem and experimentally verify our hardware on land. We demonstrate a transmission distance up to 50 m (on land) with a worst-case signal-to-noise ratio of 18.8 db (direct line-of-sight).

CCS CONCEPTS

• Hardware → Wireless devices; *Emerging optical and photonic technologies*; Analog, mixed-signal and radio frequency test; • Networks → *Wireless access points, base stations and infrastructure*.

KEYWORDS

optical, modem, open-source, low-cost, underwater, aquatic

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1 INTRODUCTION

Aquatic research generally requires specialized equipment – underwater robots, underwater communication hardware, sensor packages, etc. – which can be prohibitively expensive for small research groups. To lower the barrier to entry for aquatic research, researchers have addressed the expense of underwater communication by developing open-source, low-cost acoustic modems such as the BlueBuzz [1, 2] and the CoralCon [4].

While acoustic modems have great range, communication speeds are quite limited, and robotics research generally relies on highspeed communication. The need for higher-speed (>10 kb/s) communication for robotics is supported by research such as: the Robotarium using WiFi to control a deployed robot swarm [7], the Georgia Tech miniature autonomous blimps (GT-MABs) using radio to communicate with ground stations for manual/autonomous control [6], the Kilobot swarm utilizing 30 kb/s infrared communication for peer-to-peer communication [3], and many more. For underwater robotics applications with the need for short-range (<50 m), high-speed communication, there exists a different communication solution; optical. The aquatic research community has explored optical communication and building optical modems [5, 8], but none of the modems we are aware of have been released opensource or with active ambient light rejection. To address this missing component needed by the underwater robotics community, we are developing an open-source optical modem with active ambient light rejection.

In this paper, we discuss our transmission/receive hardware and experimentally verify our hardware on land. We demonstrate a transmission distance up to 50 m (on land) with a worst-case signalto-noise ratio (SNR) of 18.8 db (direct line-of-sight).

2 HARDWARE DESIGN

The hardware of the optical modem consists of two sections – the emitter board and the processing board (see Figure 1 for data flowchart).

2.1 Emitter Board

The emitter board contains the LEDs for transmitting and the first stage of the receiving circuitry.

The transmitting circuit uses a modulated signal generated by the processing board to drive an array of LEDs at a frequency up to 1 Mhz with power up to 9 W.

The receiving circuit amplifies the received signal, filters out ambient light, and filters out any other unwanted noise using a transimpedance amplifier and a reverse biasing amplifier. The transimpedance amplifier converts the signal current generated by the photodiode to a voltage with a million V/V gain and the reverse biasing amplifier cancels out the ambient light received by the photodiode which prevents saturation in brighter environments.

2.2 Processing Board

The processing board receives data from the digital interface and modulates it into a high-frequency signal, and vice versa. The current modulation method used is binary frequency shift keying (BFSK). For receiving, the processing board contains a high-pass

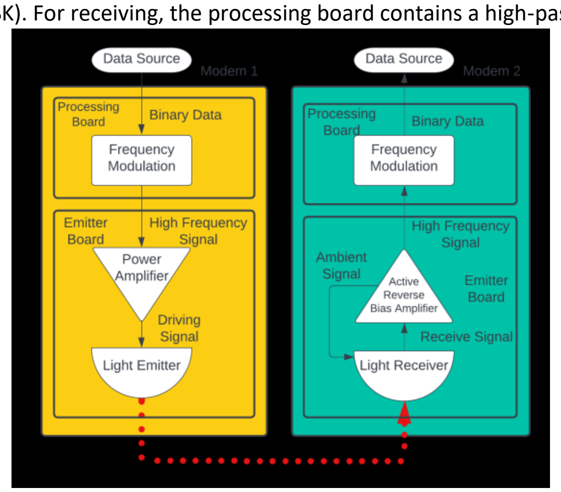


Figure 1: Data flow of the optical modem. To transmit, the MCU encodes, modulates, and transmits a message using LEDs. The receiver amplifies the modulated light while rejecting the ambient light, and the signal is then demodulated.

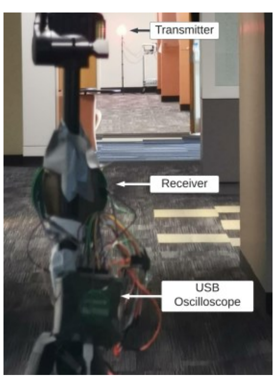


Figure 2: Field test of optical modem.

filter and gain step that amplifies the modulated analog signal from the photodiode.

3 EXPERIMENTAL TESTS AND ANALYSIS

The tests were performed in a hallway at varying distances (5 m, 17 m, 28 m, 38 m, and 49 m) with two different frequencies – 45 kHz and 65 kHz. One modem transmitted, the other received. For each distance/frequency combination, the receiving modem was also rotated 0 degrees (direct line-of-sight), 45 degrees, and 90 degrees offset from the transmitter. A desktop signal generator was used for signal generation and a USB oscilloscope (Analog Discovery 2) was used to record the raw data from the receiver (see Figure 2 for image of testing setup).

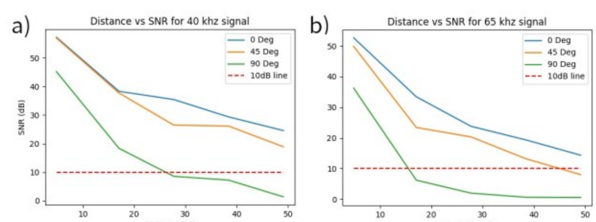
Using 10 db as an arbitrary threshold for "quality" communication, the optical modem stays above this threshold with direct line-ofsight between the transmitter and receiver for all tests (see Figure 3). Even with the receiver at a 45 degree angle to the transmitter, the SNR only slightly dipped below 10 db for the 65 kHz test at 49 m.

Figure 3: Distance vs SNR at a) 40kHz b) 65kHz

4 CONCLUSION AND NEXT STEPS

The first steps towards an open-source optical modem have been made. The land-based experimental results show that the system has a high SNR up to a range of 50 m.

The next steps include: measuring underwater communication capabilities, improving real-time modulation for communication,



tuning amplification and gain of the receive hardware, integrating into an AUV for real-time control, and swapping the red light LEDs and paired photodiodes with blue light versions.

The optical modem still requires further development, but may offer a bright future for underwater communication research.

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