Poster: Affordable Acoustic Modem for Small-Sized Autonomous Underwater Vehicles

Christian Renner, Alexander J. Golkowski, and Erik Maehle
Institute of Computer Engineering
University of Lübeck, Lübeck, Germany
{renner,maehle}@iti.uni-luebeck.de

Abstract

The development of small, cheap AUVs offers a plethora of applications for underwater inshore monitoring. For online reporting and controlling as well as swarm interaction, communication is required. We present a prototype of an acoustic modem that is (i) small enough to be carried by small-sized AUVs in the sub 10 L class, (ii) consumes little enough energy to not diminish operation times of its host, (iii) comes at a much lesser unit cost than commercial solutions. Our evaluation indicates that communication is reliable at distances up to 43 m and beyond.

Keywords

acoustic, underwater, communication, AUV, swarm

1 Motivation

Advances in electronics and robotics have lead to stationary underwater sensor networks, mobile underwater robots, and hybrid solutions. These techniques enable automated, unsupervised environmental underwater inshore monitoring. Practical applications are water quality monitoring, structural monitoring, and the study of marine life [5].

In this domain, swarms of autonomous underwater vehicles (AUVs) offer a monitoring solution that is flexible, reusable, and self-organizing. For inshore applications, relatively small and inexpensive AUVs have been developed—e.g., the MONSUN robot in [6] has a length of only 60 cm, a corpus diameter of 10 cm, and an approximate unit cost of €2 000. Its typical mission time is 5 h with an energy budget of 70 W h. Autonomous robot swarms are hence within reach, if swarm members can communicate underwater over several meters. For this, acoustic communication appears to be most suitable, since radio and optical communication suffer from low communication ranges due to heavy absorption of the medium. Existing acoustic modems (e.g., [4, 3]) usually aim at multi-kilometer communication and therefore suffer from large dimensions, a unit cost of several thousand Euros, and a power consumption of a few Watts, hence rendering their application in inexpensive swarms of small-sized AUVs infeasible. The approach for sensor networks in [2] requires a self-made piezo transducer and has a low data rate plus a relatively high transmit power of some Watts.

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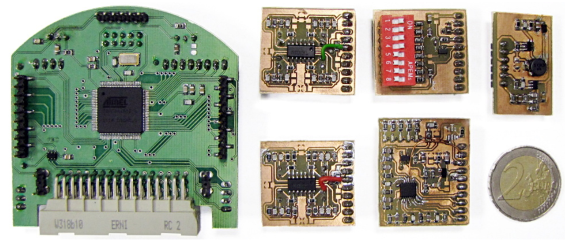

Figure 1. Acoustic modem prototype (left to right, top to bottom): mainboard, filters (high- and lowpass), amplifier and pre-amplifier, send power amplifier.

We present our ongoing work on an acoustic underwater modem for robot swarms of tens of low-cost, low-power AUVs like MONSUN. It features a small form factor, low price, modularity, flexibility, and low power consumption.

2 System Design

To achieve flexibility and modularity, we opted for a hardware/software solution. The fully custom hardware is restricted to filtering and amplifying the analog acoustic signal, while the software running on an AVR32 μC controls de-/modulation. The four-stage receive filter chain and the send power amplifier are realized as individual add-on boards. The former consists of an electronically adjustable max. 65 dB preamplifier, 8th order high and low passes, and a manually adjustable amplifier. We use two Aquarian Audio miniature AS-1 hydrophones [1] with a bandwidth of 100 kHz and a length of 40 mm at a 12 mm diameter. Our prototype (without hydrophones) is depicted in Fig. 1.

We use incoherent binary frequency shift keying (BFSK), since it is well suited for communication between moving devices and keeps the hardware layout simple and cheap. To account for the Doppler effect at speeds of only a few m s^{-1}, frequency spacing is 400 Hz. With a symbol duration of 2.5 ms, we guarantee orthogonality. Synchronization is achieved through a preamble of alternating frequencies to improve preamble detection (the reader is referred to [7] for

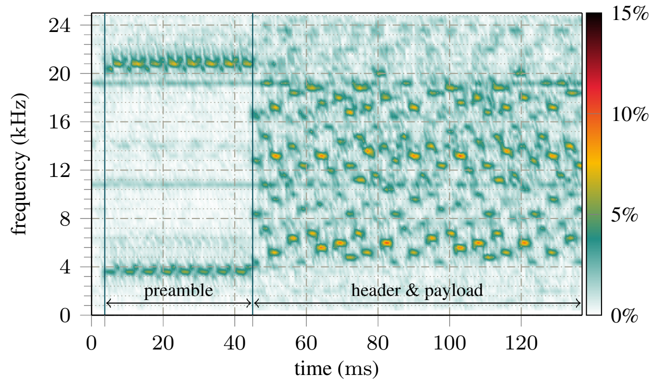

Figure 2. Spectrogram of a received packet showing the relative amplitudes of the available ADC range. The frequency resolution is 400 Hz **with a time window of** 2.5 ms **(one symbol length) and time resolution of** 0.5 ms**.**

a discussion of typical problems of the underwater acoustic channel). To elevate the data rate, we employ parallel transmission using up to four carriers. We apply spread spectrum techniques to counter inter-symbol interference caused by multi-path propagation. Extended Hamming codes, interleaving, and CRC address interference and absorption.

This setup gives a net 260-780 bit s^{-1} data rate and requires a baseband bandwidth of 19.2 kHz. Noise from ships, animals, and the AUVs' thrusters resides in sub or low kHz regions. The low-pass characteristic of the medium water puts a limit at roughly 100 kHz, and the maximum achievable sampling frequency for de-/modulation on the AVR32 restricts the signal frequency to 75 kHz. We hence chose the band from 50-75 kHz for communication.

3 Preliminary Evaluation

Our prototype has a size of 7 cm × 7 cm × 4 cm. Hardware cost is € 1 000, where € 800 are due to the hydrophones. Consumption is 150 mW for the μC, 100 mW for the filter chain, and 150 mW for the send amplifier.

We ran several experiments to evaluate the communication performance; due to the page limit, we only present the results for the number of successful synchronizations (syncs) and the packet reception rate (PRR). We placed two modems on different boardwalks of a small marina in the Ratzeburger Lake at distances of 9 m, 24 m, and 43 m. Their hydrophones were let into the water at half the water depth of 1.5 m without particular orientation. At each of these distances, we sent 50 packets each of payload sizes from 4 B to 36 B. Packets were sent in intervals of 2 s. To evaluate the fundamental function of the modem, we increased the receive gain by 6 dB when advancing the distance.

To illustrate the challenges of acoustic underwater communication, Fig. 2 shows the spectrogram of a successfully received short packet and its preamble at a distance of 24 m. The spectrogram is based on the ADC samples recorded by the receiver and shows the heavy deviation in perceived amplitudes of the signal components, e.g., frequencies around 9 kHz are notably low. Two of the four preamble frequencies can hardly be distinguished from noise.

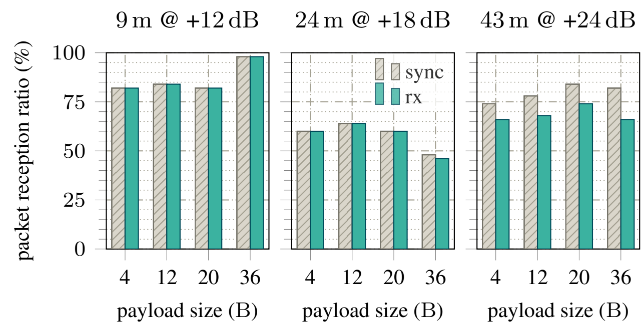

Figure 3. Synchronization percentile and Packet Reception Rate (PRR) vs. distance and payload size.

The detailed results of the experiment are depicted in Fig. 3. The PRR is high considering that we have not fine-tuned any parameters such as preamble and spread code length. The results indicate that the majority of missed packets was caused by a failure to detect the preamble (no sync). It is hence fundamental to improve on the number of successful syncs. There is a notable gap between PRR and syncs at 43 m that requires further analysis; it is likely due to more spread in absorption at higher distances and the fact that there was another boardwalk in between sender and receiver (the one at 24 m distance). It is also obvious that PRRs are not constant, since the relation between distance and amplification is not maintained. There is no general decay of PRR (vs. syncs) in relation to payload length. This is due to our countermeasures against absorption and distortion. We are confident that higher communication ranges at similar PRRs are achievable, as we used relatively low gain values.

4 Future Work

We are planning a measurement campaign with moving MONSUN AUVs to evaluate PRR and ranging for underwater self-localization. To cut costs, we are working on a circuit that strips off the second hydrophone. We are also exploring FPGA and DSP solutions for de-/modulation to increase speed and decrease consumption. To increase the communication range, we intend to investigate methods for automatic gain control.

5 References

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