Poster: Simulation and Experimental Evaluation of Wireless Remote Controlled Underwater Vehicles

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ABSTRACT

Wireless remote control of a single or a group of underwater vehicles by a single human operator offers the opportunity to collect more real-time data than a single ship or vehicle. Commercial underwater modems are often too large to fit small-size submersibles, prohibitively expensive for large-scale deployments, and typically closed source which limits their compatibility with other sensors and therefore their application in research. In this work, we focus on establishing wireless communication between a remotely operated vehicle (ROV) and a surface station using an in-house built low-size, weight, power, and cost underwater acoustic modem and an affordable underwater ROV. To assess wireless communication performance we built a high-fidelity simulation framework in an underwater robotics simulator. Additionally, we verify the simulation with physical tests of the ROV and modems. Finally, to evaluate the feasibility of deploying a fleet of ROVs we designed and built a small, lightweight, low-cost ROV. This ROV will serve as the platform to test connected underwater robotics technology in future work.

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CCS CONCEPTS

• **Hardware → Wireless devices**; • **Networks → Physical links**; • **Software and its engineering → Software implementation planning**.

KEYWORDS

Underwater Communication, Wireless ROVs, Ocean IoT

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1 INTRODUCTION

Wireless remote control of a single or a group of unmanned underwater vehicles is challenging due to the limited bandwidth and communication range of existing underwater wireless technologies based on acoustics, optics and radio [2]. Underwater remotely operated vehicles (ROVs) are used in a variety of industries search-and-rescue, military, recreation and discovery, aquaculture, marine biology, oil and gas, offshore energy, shipping, submerged Infrastructure, and more. They allow operators to capture photo and video footage to inspect and monitor ports, harbours and vessels, bring innovation to pipe inspections, locate underwater targets and explore the depths of our oceans, lakes and rivers.

ROVs are typically operated in real-time via an optical fiber cable, the so-called umbilical cable, which inherently limits mobility of the ROV due to cable strain and entanglement risks. Also operation of a group of ROVs is not possible by a single human operator since ROV-to-ROV communication cannot be established. Over the past decade, both academics and the industry have been studying the feasibility of developing fully wireless underwater ROVs [9, 1, 3]. Recently, the marine industry demonstrated untethered operation of an ROV at sea using acoustics [4] and light [8] to communicate data from the ROV to a human operator at the sea-surface. In this paper, we focus on the development of software tools and hardware to test wireless underwater ROVs in an end-to-end fashion. More specifically, we developed a simulation platform that combines underwater acoustic communication and channel models, open-source ROV control and mission planning software and a realistic underwater robotics simulator to test wireless ROVs in a digital twin of the real-world environment. We developed bi-directional communication protocols and a medium-access-control scheme to integrate and test a compact software-defined underwater acoustic modem [5] for remote control of a commercially available off-the-shelf ROV. Finally, we designed, built and tested a new mini/compact wireless ROV that can be used to test the deployment of groups of wirelessly connected underwater vehicles.

2 SIMULATION

Due to the difficulty and expense of underwater field trials, a high-fidelity underwater simulator is required for testing and developing wireless remote controlled underwater vehicles. We used simulations to replicate each part of the underwater data transmission/reception and ROV control. There are four main parts to the simulation: (i) ROV control message generation; (ii) message modulation to an acoustic signal, (iii) signal propagation through an underwater channel; (iv) signal demodulation and message decoding. Parameters of the underwater environment that affect signal propagation and wireless link quality such as bottom loss, channel depth, velocity and relative location of the ROV and the topside station were dynamically updated from HoloOcean [7]: an open-source underwater robotics simulator built upon Unreal Engine 4, providing it with high-fidelity imagery and accurate underwater dynamics built upon the PhysX physics engine. Simulation of modulation/demodulation was done in MATLAB, where data bits that are generated from either the ROV or the top-side station (based on QGroundControl) in the form of MAVLink messages are modulated into acoustic signals based on a binary frequency shift keying modulation scheme. Examples of common MAVLink messages exchanged between the ROV and the top-side station are shown in Table 1.

Table 1: Common MAVLink messages.

Message	Size (bytes)	Frequency
HEARTBEAT	17	1 Hz
SYS_STATUS	39	10 kHz
MANUAL_CONTROL	22	2 Hz
SET_MODE	47	On demand
ARM/DISARM	37	On demand
BATTERY_STATUS	56	1 Hz
ATTITUDE	28	2 Hz
SCALED_PRESSURE	18	100 Hz

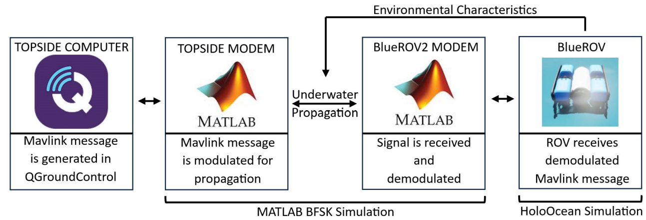

Figure 1: Framework for simulating communication between ROV and the topside station.

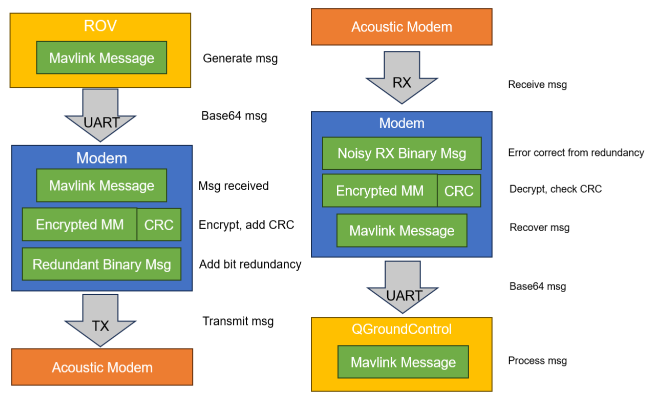

Figure 2: MAVLink message exchange over the underwater acoustic channel.

3 EXPERIMENTAL EVALUATION

We use a custom-built low size, weight, area and power (SWaP) underwater acoustic modem developed by researchers at the Center for Connected Autonomy and AI at FAU CA-AI [5] and a commercial off-the-shelf available ROV built by Blue Robotics namely, BlueROV2 to experimentally evaluate wireless command and control of an ROV.

Figure 2 summarizes the steps required for exchanging a MAVLink message between the ROV and the topside station at the sea-surface. MAVLink messages are generated by the host, i.e., either the ROV or the topside computer. MAVLink messages start out as a dictionary in Python and are converted to binary in a zero-padded (if required) 64 byte array. The message is then converted to base64 format and sent to the modem over a UART connection. The base64 MAVLink message is converted back to binary form on the modem. A 32-bit CRC (Cyclic Redundancy Check) is generated and added to the tail of the message. Data whitening and repetition coding is implemented to deal with potential errors that may be created by the underwater acoustic channel.

On the receiver side, the process is reversed. Binary data is received after signal demodulation, possibly with some bits flipped due to channel propagation errors. Repetition coding provides error protection for sets of bits that have errors. We then de-whiten the message and the CRC is checked. If the received message is corrupted, it is discarded. If the message is received with no errors, the recovered binary MAVLink message is converted back to base64 format and is printed by the modem to the serial connection. Finally, the MAVLink message is sent back to the host.

During our tests in a water tank in the lab, 82% of our MAVLink messages are received without any errors when 5x repetition coding is adopted. This rate is sufficient to maintain a stable connection and remotely control the ROV. Modem parameters include: symbol guard periods of 5ms, 16 Orthogonal Frequency Division Multiplexing (OFDM) symbols per frame/message, 1024 subcarriers, bandwidth of 50 kHz, a cyclic prefix of 256 samples, binary phase shift keying (BPSK) modulation, 50% zero-padded carrier density, Tx gain of 23 dB, Rx gain of 45 dB, and a center carrier frequency of 125 kHz. More information about the modem and the implementation of the OFDM transceiver can be found in [5, 6].

4 MINI ROV

To reduce the size, cost and power required by each ROV and accelerate deployment of groups of wirelessly controlled ROVs, we started building our own ROV using off-the-shelf parts and our in-house built underwater wireless modems [5]. In comparison to COTS ROV models like the BlueROV2, the mini ROV design depicted in Fig. 3 and Fig. 4 uses fewer components while maintaining robust performance for increased durability and offers significant advantages in terms of rapid deployment in large numbers. This streamlined shape of the ROV minimized hydrodynamic resistances and allows it to be launched from a watercraft, or even an aircraft, at higher speeds.

The mini ROV does not have as much fine-tuned control as the BlueROV2, however, it still has a full range of motion. By utilizing a thruster for forward and backward control and a servo-powered rudder for left and right control, the ROV ensures full maneuverability in the horizontal plane. Additionally, the incorporation of a ballast tank, operated by a DC motor connected to a piston, allows for controlled changes in buoyancy, enabling the ROV to navigate different water depths effectively. This combination allows for a cheaper, yet versatile ROV that can explore underwater spaces with a full range of motion and control.

3D prints were incorporated for the mount that holds all of the electronics, a mount for the ballast tank, the thruster mount, the rudder, and the ballast tank plunger.

ROV components were connected using GPIO cables, establishing links between the Raspberry Pi and different parts for data exchange and power distribution. The Electronic Speed Controller (ESC) is connected to the thruster, and the servo and rudder are connected to the PWM GPIO ports for precise control. The DC motor, connected to the L298N H-Bridge to control forward and backward motor movement, is paired with the ballast tank to regulate buoyancy and depth. In terms of program flow, the Raspberry Pi acted as the central controller, running software that employed pygame for joystick input and pigpio for GPIO control. The program's structure began with GPIO and joystick initialization. Joystick inputs were mapped for motor and servo control, utilizing sensor data for stability. Fail-safes were integrated, enabling motor arming/disarming via joystick buttons and incorporating limit switches to prevent piston over-extension in the ballast tank. This approach ensured user-friendly control, responsiveness, and safety. We tested the combination of connected modular components and the software we developed and demonstrated effective movement and depth control for the mini ROV in a small water tank in the lab.

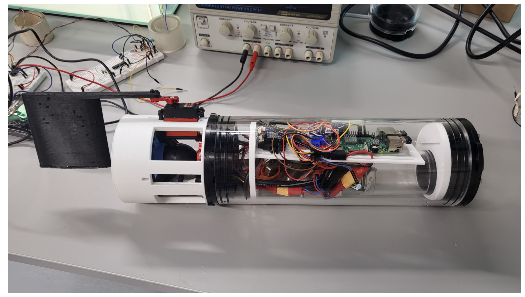

Figure 3: Mini ROV.

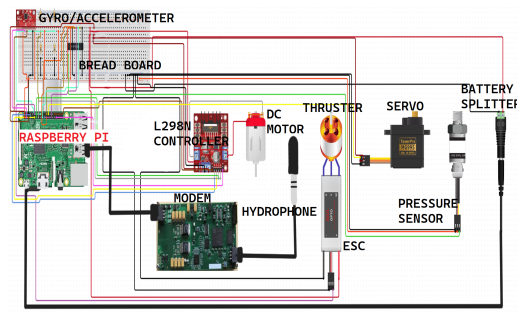

Figure 4: Mini ROV wiring diagram.

REFERENCES

[1] Filippo Campagnaro, Federico Favaro, Paolo Casari, and Michele Zorzi. 2014. On the feasibility of fully wireless remote control for underwater vehicles. In *2014 48th Asilomar Conference on Signals, Systems and Computers*, 33–38. DOI: 10.1109/ACSSC.2014.7094391.

[2] Filippo Campagnaro, Alberto Signori, and Michele Zorzi. 2020. Wireless remote control for underwater vehicles. *Journal of Marine Science and Engineering*, 8, 10. DOI: 10.3390/jmse8100736.

[3] Eric Gallimore, Dennis Giaya, Brennan Miller-Klugman, Caileigh Fitzgerald, Kayleah Griffen, Laura Lindzey, and Lee Freitag. 2022. Ros message transport over underwater acoustic links with ros$_{a}comms$. In *2022 IEEE/OES Autonomous Underwater Vehicles Symposium (AUV)*, 1–6. DOI: 10.1109/AUV53081.2022.9965848.

[4] Inc. Greensea Systems. 2023. Opensea edge delivers untethered autonomous operation to commercially available rovs. (Mar. 2023). Retrieved March 22, 2023 from https://greensea.com/opensea-edge-delivers-untethered-autonomous-operation-to-commercially-available-rovs/.

[5] Jared Hermans, George Sklivanitis, and Dimitris A. Pados. 2022. A first-of-its-kind low size, weight and power run-time reconfigurable underwater modem. In *2022 Sixth Underwater Communications and Networking Conference (UComms)*, 1–5. DOI: 10.1109/UComms56954.2022.9905700.

[6] Jared Hermans, George Sklivanitis, and Dimitris A. Pados. 2023. Soc-based implementation of a multipath-resilient broadband underwater ofdm system. In *10th Convention of the European Acoustics Association (Forum Acusticum)*.

[7] Easton Potokar, Spencer Ashford, Michael Kaess, and Joshua G. Mangelson. 2022. Holoocean: an underwater robotics simulator. In *2022 International Conference on Robotics and Automation (ICRA)*, 3040–3046. DOI: 10.1109/ICRA46639.2022.9812353.

[8] Hydromea Wireless Underwater Robotics. 2022. Exray: the world's first wireless rov. (Feb. 2022). Retrieved Feb 1, 2022 from https://www.hydromea.com/exray-wireless-underwater-drone.

[9] Deniz Unal, Sara Falleni, Emrecan Demirors, Kerem Enhos, Stefano Basagni, and Tommaso Melodia. 2022. A software-defined underwater acoustic networking platform for underwater vehicles. In *ICC 2022 - IEEE International Conference on Communications*, 2531–2536. DOI: 10.1109/ICC45855.2022.9839033.