INTERNET OF THINGS OF THE SEA

Project Overview

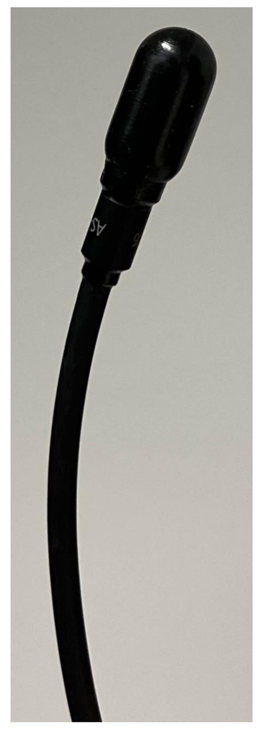
- Researchers at Pacific Northwest National Laboratory (PNNL) and other marine scientists deploy many underwater sensors to collect real-time marine data.
- Data retrieval currently involves recovering the devices to retrieve the data, which is costly in time and money.
- The objective is to design and implement a wireless underwater communication system to eliminate the need for frequent retrieval of the sensors.
- We developed an open-source, low-power communication system that can be integrated with an ROV (Remotely Operated Vehicle) and the sensor network.

Key System Requirements

- Our system must transfer 1MB file/hour with 1 meter difference in nodes.
- Must have two nodes that communicate with each other bi-directionally, in a half-duplex manner.
- Able to transmit data in a 30 m underwater environment under pressure.
- All hardware must fit into an enclosure the shape of a 1 L bottle.
- Must be driven by one 12V power supply.
- Our system must be low power, drawing around 5W.

Communication Medium: Acoustic Hydrophones

- Acoustic hydrophones are omnidirectional, which is optimal for unpredictable marine conditions.
- Hydrophones are capable of both transmitting and receiving.
- Factors such as power consumption, novelty, or signal attenuation favored acoustic over other mediums.

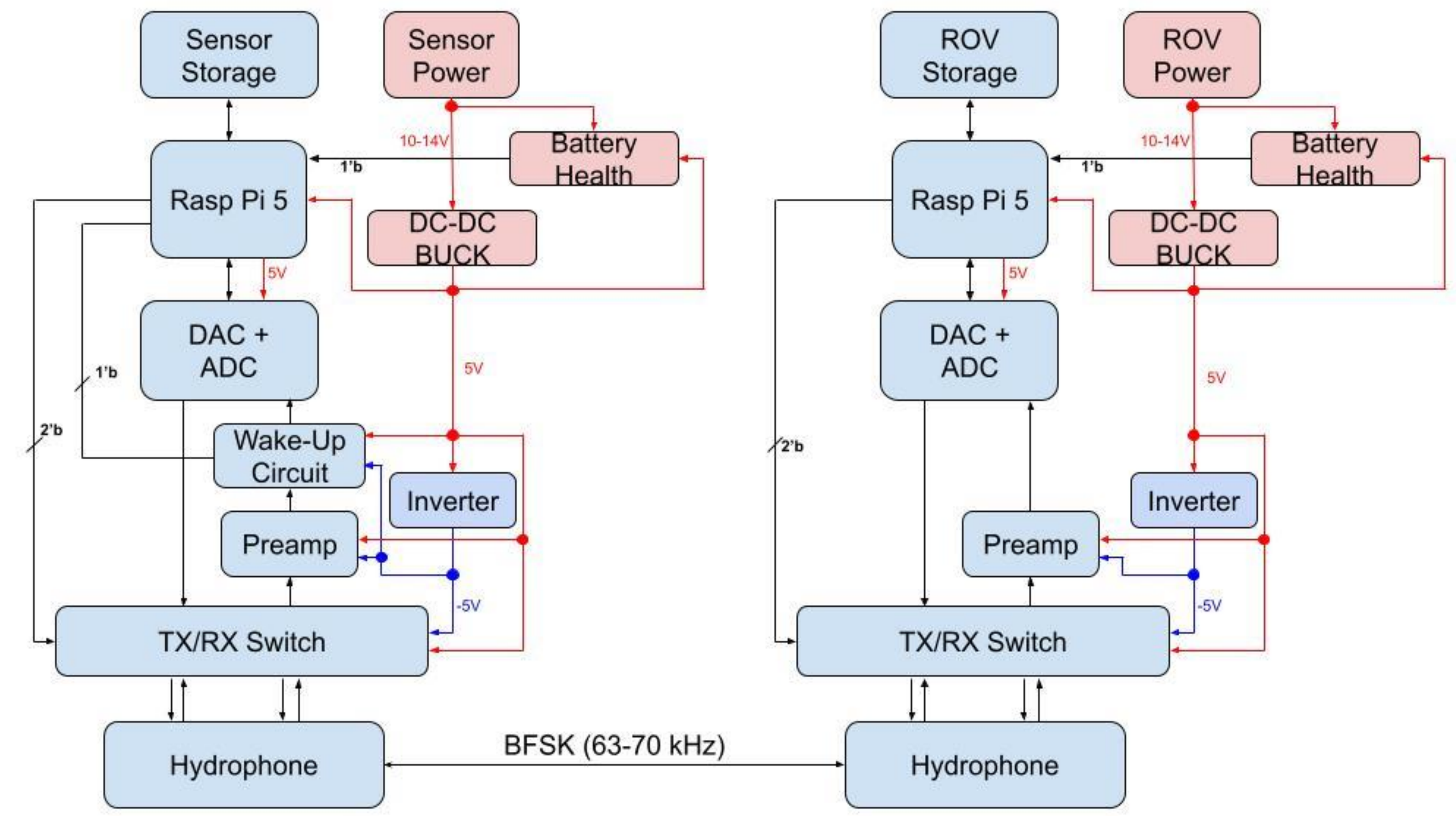


AS-1 Hydrophone

Underwater Hydrophone Testing Setup

Hardware

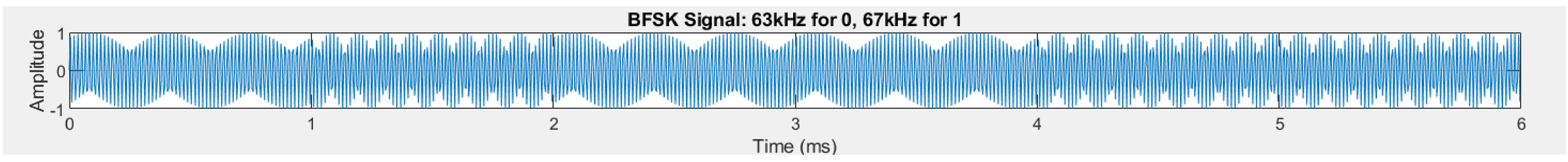
- Raspberry Pi 5s handle data processing, protocol logic, and TX/RX switch control.
- A custom preamplifier boosts the received signal.
- TX/RX Switch is used to select the receive or transmit signal path to mitigate collision.



Underwater Sensor Node ROV Node

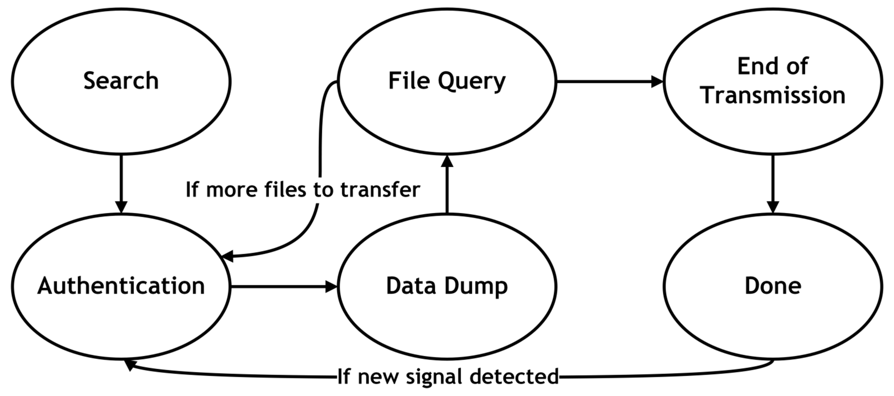
Communication

- Utilizes 63/67 kHz binary frequency-shift keying (BFSK) with Goertzel-based demodulation for noise-resistant, low-power underwater data transfer.
- FFT-accelerated cross-correlation enables real-time preamble detection and precise symbol alignment.
- Implements CRC-8 to detect transmission errors and ensure data integrity in every frame.
- Communication is facilitated through a state-based protocol which requires handshaking and response signals to improve reliability.



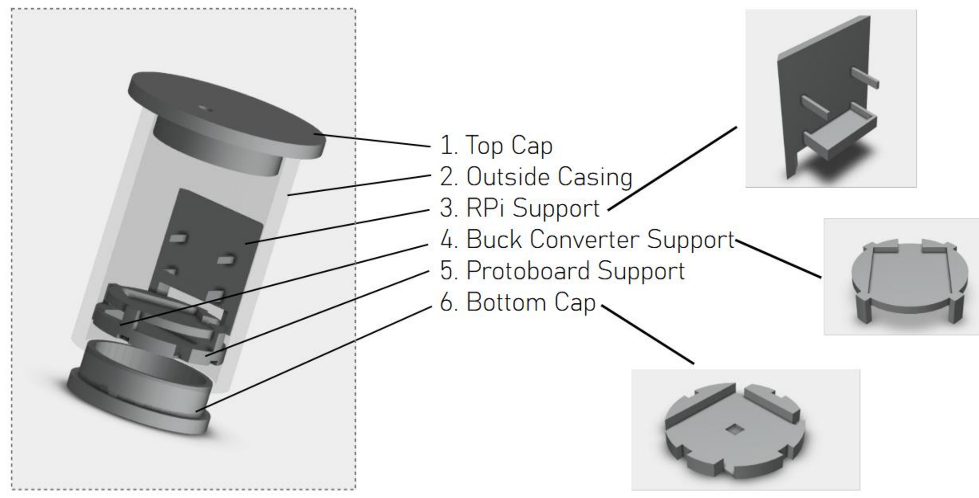
Above: Protocol Packet Format and Signal Waveform

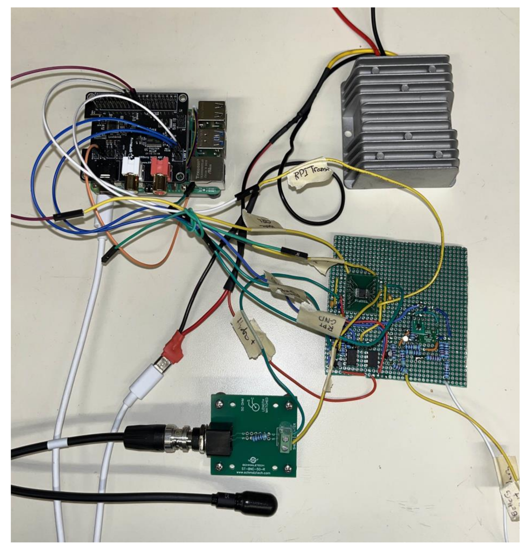
Right: Protocol Sequence Abridged State Diagram



Results

- Achieved reliable bidirectional data transmission using hydrophones in 1-meter-deep underwater environment.
- Designed and implemented a robust protocol featuring handshake, authentication, error checking, and retransmission.
- Reached 1 kbps data rate with bit error rate <10% and packet loss <15% under real water conditions.
- Kept system power efficient when provided 12V we pull a total of:
  - 0.24W when OFF
  - 3.24W when ON (idle)
  - 4.80W when ON (transmit)
  - 5.64W when ON (receive)
- Target system cost: $2,500
- Actual system cost: $1,007.21
- Implemented wake-up hardware that wakes up system when ROV node is near to save power when not actively transmitting.
- Implemented battery-monitoring circuitry to shut-off system and let battery regenerate to healthy voltage.

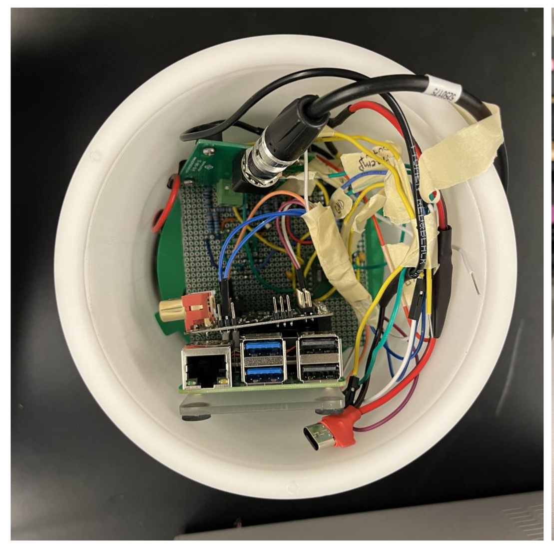




Top Left: Housing Mechanical Design

Top Right: Hardware System

Bottom: Housing Internal and External Views



Future Work

- Decrease power consumption and cost by moving to a smaller processor like an ESP32 or STM32 microcontroller.
- Improve data rate by utilizing a more bandwidth-efficient protocol like orthogonal frequency-division multiplexing (OFDM) or decreasing symbol time.
- Implement encryption for secure data transfer.
- Design and manufacture custom PCBs to hold the hardware circuitry.

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