Prototype Development & Testing of a Smart Buoy System for Coastal & Marine Ecosystems Using IBIS

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Abstract

Effective environmental monitoring traditionally required physical presence at research sites. IoT technologies now enable remote data collection, revolutionizing this field. This work presents a prototype of smart buoys designed for coastal and marine ecosystems. Located in the IBIS testbed, these buoys are equipped with various sensors and Single Board Computers (SBCs). They provide real-time data to assess marine ecosystem health and support conservation efforts. Initial tests demonstrate their capability to monitor environmental parameters accurately, enhancing weather forecasting, storm tracking, and maritime safety. The results highlight the potential of IoT-based smart buoys to advance remote monitoring and research.

CCS Concepts: • **Hardware** → **Sensor applications and deployments**; **Very large scale integration design**.

Keywords: IoT (Internet of Things), Smart Buoy, Environmental Monitoring

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1 Introduction

Remote data collection is crucial for managing coastal and marine ecosystems [5]. Traditional methods are resource-intensive and restrictive [9], requiring significant logistical coordination and limiting data collection frequency [8]. Arduino-based systems, though useful, face limitations in processing power. The Raspberry Pi, with its superior capabilities, is a better choice for advanced systems [4]. Our project uses the IBIS platform [1] to create smart buoys equipped with sensors for comprehensive data collection [7]. This prototype provides a scalable, cost-effective monitoring solution by integrating multiple sensor technologies. Our system significantly enhances environmental monitoring in marine environments [3]. Source code and documentation are available on GitHub [2, 6].

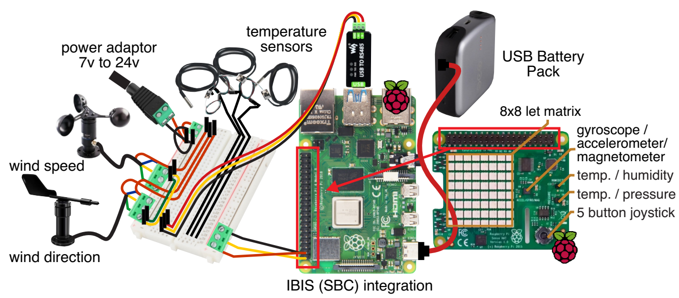

Figure 1. Schematic of Internal Wiring & Peripheral Connection

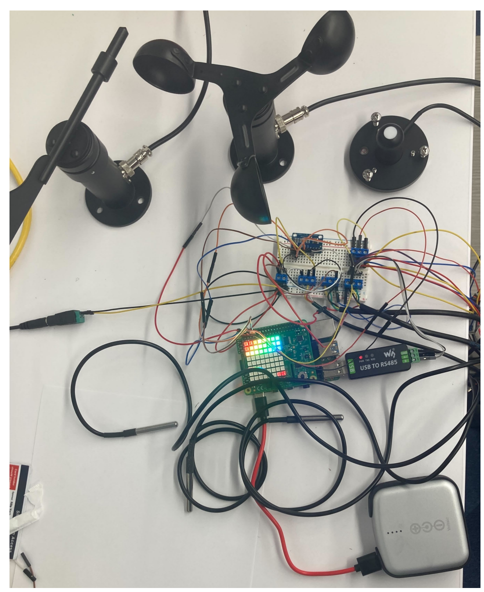

Figure 2. Actual Smart Buoy device connections.

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2 Approach

Our prototype architecture, detailed in **Figure 1** with parts from **Table 1**, builds on Babić et al.'s work demonstrating that advanced IoT sensors can enhance marine environmental monitoring. We use the IBIS testbed as the core computing unit, aiming to facilitate environmental measurements and data relay for remote research.

Our smart buoy system is designed for diverse marine environments, featuring sensors for water temperature, salinity, and turbidity, and operates on solar power for sustainable field use. The IBIS testbed enables complex data processing and real-time analysis. Our modular prototype leverages the SBC power of IBIS for advanced monitoring and enhanced data accuracy."

Component	Description and Quantity/Details
Raspberry Pi 4	Central computing unit (1)
SD Card	Storage for data (1)
Breadboard	Prototyping (1)
Jumper Wires	30 Female, 20 Male
Temperature Sensors	3 per station (DS18B20 or SMA PT-1000)
Inertial Measurement Unit (IMU)	Sense Hat for vertical acceleration (1)
Wind Speed Sensor	Open-source or commercial options
Power Supply	Voltaic with battery
Pulse-to-Digital Converter	ADS1115 Byte 4 Channel I2C
Solar Radiation Sensor	Surface light intensity (1)
Power Measurement Sensor	(1)
Networking Peripherals	Cellular or satellite (optional)

Table 1. Hardware Components Used in the Smart Buoy System

3 Development Challenges and Solutions

During the development of our prototype, we encountered several challenges related to resource availability and integration. Below, we outline the issues and the solutions we applied.

System Compatibility: Ensuring compatibility between different sensors and systems was a significant challenge. To address this, we developed custom adapters and interfaces, enabling seamless communication between sensors and the Single Board Computer (SBC). Initial scripts and examples were designed for platforms like Arduino, which have different hardware interfaces compared to the Raspberry Pi 4. We adapted these scripts by rewriting code and implementing Raspberry Pi-specific libraries and drivers. Additionally, we created custom bridging code to integrate various hardware components with the Raspberry Pi 4.

Integration of Multi-Platform Resources: Integrating resources from different hardware platforms required a deep understanding of both the source systems and the Raspberry Pi's architecture. To overcome this, we conducted extensive testing and validation of each component and script to ensure compatibility and proper functionality.

During the development of our prototype, we faced several challenges related to resource availability and integration. Below we provide issues and the respective solutions we applied to successfully address them.

Integration of Multi-Platform Resources: integrating resources designed for different hardware platforms required a comprehensive understanding of both the source systems and the Raspberry Pi's architecture. To address this challenge, we conducted thorough testing and validation of each component and script to ensure compatibility and functionality.

4 Prototype integration and testing

In this stage of the project, we are focusing on integrating and testing environmental sensors within our IBIS testbed. Our goal is to ensure proper operation, functionality and reliable data collection. Below, we will describe the development of a master script, assessment of wind direction readings and the evaluation of inertial measurements.

4.1 Master Script Operation:

The master script is a key part of the smart buoy system, managing data collection, storage, and transmission. Operating on the Raspberry Pi, it coordinates interactions between sensors and data management modules.

Data Collection: The script initializes and reads data from sensors at set intervals. It executes commands for measurements like temperature, wind speed, and inertia, formatting data into structured records with timestamps and sensor IDs for accurate analysis.

Data Storage: Collected data is stored in local memory on the Raspberry Pi, organized into CSV files or a local database. This allows buffering during network outages and prevents data loss during reboots.

Data Transmission: The script periodically sends stored data to a remote server using protocols like MQTT, ensuring timely updates.

This approach allows the smart buoy system to monitor environmental parameters effectively, with reliable data storage and transmission for analysis and decision-making.

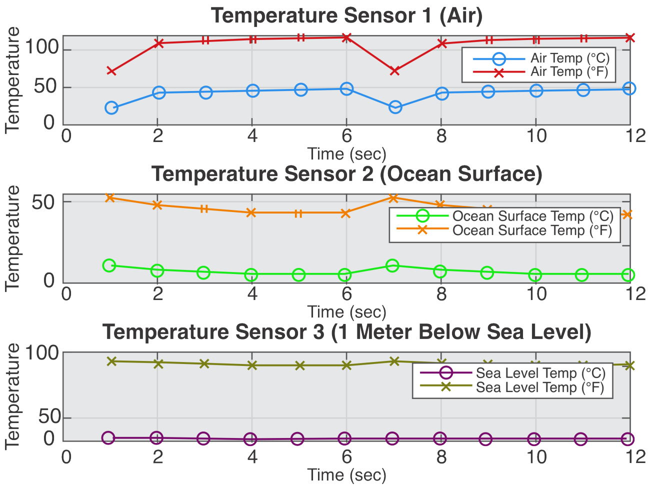

Figure 3. Readings from the (3x) Temperature Sensors

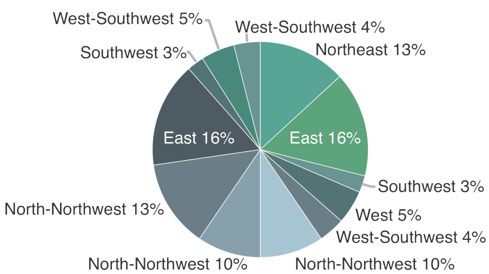

Figure 4. Wind Direction Readings

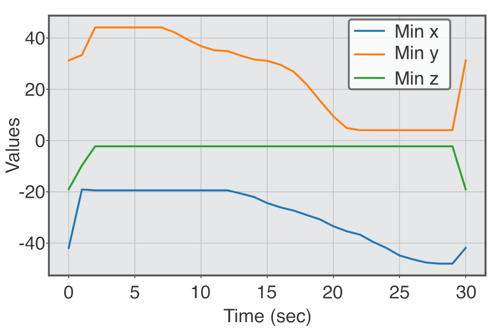

Figure 5. Inertia Measurements from the IMU

5 Cost Efficiency and Conclusion

Our smart buoy system, costing under $500, offers a highly affordable alternative to commercial systems, which can exceed several thousand dollars [9]. This affordability is achieved through budget-friendly components like the IBIS testbed, Raspberry Pi, and modular sensors. The modular design ensures robust environmental monitoring and easy upgrades, providing flexibility often missing in high-cost systems. Leveraging inexpensive hardware and open-source development, our system delivers accurate, real-time data collection.

The prototype demonstrates the capability to integrate various sensors, such as for temperature, solar radiation, and wind conditions, ensuring effective data acquisition in marine environments. Initial tests confirm the system's accuracy and cost-effectiveness, proving that high-performance monitoring does not require high costs. Future work will focus on refining the prototype and validating its performance in real-world settings.

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