Inexpensive Tide and Wave Gauge

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Introduction

Our goal was to further develop the tide gauge and fix existing software and hardware issues with the previous generation. This year, we implemented a single-PCB design for improved reliability and replaced the ultrasonic sensor with a centimeter-accurate XM125 radar module. We updated the software to fix issues with inaccurate self-surveying and added Bluetooth file transfer to allow for wireless data collection.

Application

Vertical land motion (VLM) is quite pervasive in California due to the presence of plate tectonics. If not monitored, the unpredictability of sea-level rise can create coastal flood risks, potentially causing preventable damage to infrastructure. A precise reference point and accurate distance measurements are important to track and mitigate possible disasters

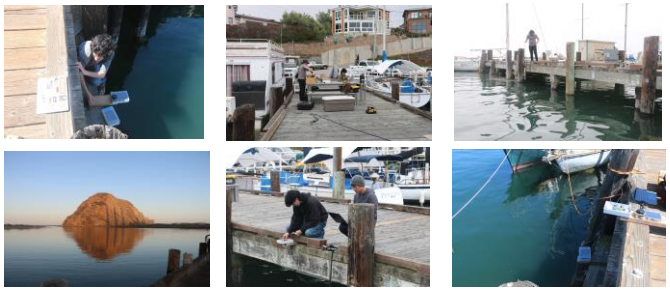
Software

The codebase is a modular C++ system built on FreeRTOS and compiled to an ESP32-WROOM via PlatformIO, designed for tide monitoring and surveying. It integrates an XM125 radar for centimeter-level water measurements, a U-Blox GNSS module for positioning and timekeeping, and synchronizes monthly with an external RTC. Core functionality is distributed across dual-core tasks managed by priorities, flags, and a watchdog for reliability. Data is logged to an exFAT SD card with mutex protection, while BLE communication with a Nordic interface enables secure, automated file transfers with rotation and checksum validation. Operating modes include continuous monitoring, monthly surveys, and standalone tide gauging. The modular structure supports easy integration of new hardware or tasks for future expansion.

Codebase	Utilities
Language	C++, FreeRTOS
Compilation	Espressif ESP32-WROOM SoC via PlatformIO

RTOS Tasks	Component
Task SD	Writes to SD card, rotates files
Task Clock GNSS	Sets RTC and surveys land using PPP
Task Sleep	Sets sleep cycles and wakes tasks up
Task Voltage	Sets deep sleep dependent on battery %
Task Watchdog	Monitors tasks, resets system if any are stuck
Task Bluetooth	NORDIC BLE communicator with checksum validation
Task Radar	Measures distances and publishes result to SD

Field Work



Collecting data from these gauges often involves accessing hard to reach places. This is one of the reasons sending commands and gathering data over BLE was implemented.

Ultrasonic vs. Radar

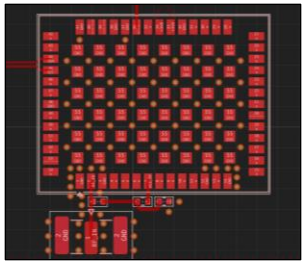
The previous ultrasonic sensor required temperature and humidity corrections, line-of-sight access, and housing holes that increased water intrusion risk. It was replaced with the XM125 radar, which uses radio waves unaffected by air conditions, sees through the plastic housing, mounts directly to the circuit board for easier assembly, and includes onboard hardware for future firmware updates—eliminating extra sensors, post-processing, and sealing concerns.

	Ultrasonic	Radar
Maximum Range	6.45m	20m
Accuracy	Limited by 12.7mm resolution	2.67 - 5.05mm
Precision	Limited by 12.7mm resolution	Sub-5mm
External Factors	Temperature, humidity, wind	None

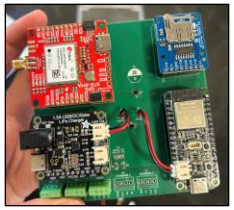
ZED-F9P GNSS Module

The ZED-F9P multi-band GNSS receiver is very sensitive to internal and external noise. Extra care was taken during the design process to ensure an accurate GNSS signal can be acquired.

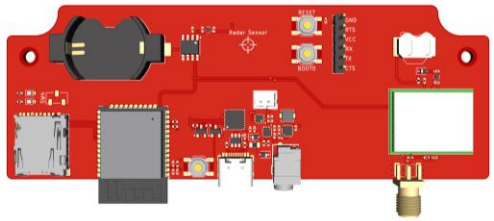
Feature	Implementation	Benefit
Chip Placement	Far from radar sensor and microcontroller	Minimizes internal noise coupling
Power Delivery	Dedicated LDO with low-ESR filter caps	Stable, clean voltage supply
Via Stitching	Multiple ground vias under/around module	Low-impedance return path; confines EM fields
PCB Stackup	4-layer w/ dedicated ground/power planes	Allows for 50Ω ±5% antenna microstrip impedance matching



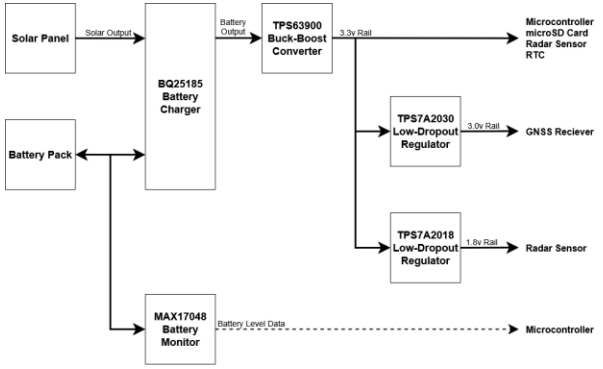
Circuit Board Development



Our initial prototype used separate circuit board modules purchased from Adafruit and SparkFun for each component in the design. Using these off-the-shelf components saves on development time and lowers single-unit production cost. The final design integrates all components on one printed circuit board, which saves space, improves reliability, and is cheaper at higher production volume.



The power delivery system is capable of 1A of battery charge current, solar power input, and precision battery monitoring, while also having very low quiescent current.



Future Work

- Ongoing long-term monitoring and stress testing in real-world environments.
- Compare accuracy and precision of radar sensor measurements using different lens shapes and configurations.
- Further enhance BLE file transfer with a user-friendly web interface.
- Optimize data analysis and post-processing workflow to integrate PPP functionality.