# Wave Profile and Tide Monitoring System for Scalable Implementation

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*Abstract*— **A versatile, miniaturized, cost-effective, low-power wave profile and tide monitoring system, capable of long-term and scalable deployment, was developed to integrate pressure and temperature sensors in an RS485 network, for standalone operation with organized memory or real-time shared data monitoring. The pressure and temperature sensors are controlled by low-power microcontrollers, that communicate the data periodically to a datalogger, that depending on the application, store it in a removable SD card or send it to a server via Wi-Fi. The data is then analyzed to compensate for the loss in amplitude sensitivity according to the sensor's depth. The wave profile can be sampled at a maximum rate of 100 Hz, with a 1 cm resolution. The system was tested successfully in real-life conditions, in rivers Douro and Cávado, and off the coast of Viana do Castelo.**

***Keywords— Wave and tide monitoring system; Underwater pressure sensor; Ocean and river monitoring; Datalogger; Low-power.***

## I. INTRODUCTION (*Heading 1*)

With rising sea levels, worsening weather conditions, and growing human activity, it is increasingly important to understand and monitor how costal and shore erosion affect human structures and ecosystems. Although sea monitoring is an already widespread concept, it may also be of interest to study river waves. The constant boat and ship traffic generate wakes that collide with the riverbank, which may lead to accelerated deterioration of natural or man-made structures and disturb protected areas [1], [2]. There is an increasing demand for real-time systems with localized or spread-out monitored areas. Most sensors capable of monitoring the wave profiles are too power-hungry and costly, have significant dimensions, and are designed for specific applications. The most used technologies are accelerometers or gyroscopes [3], level RADAR [4] and LIDAR sensors [5].

Pressure sensors are used in many applications and are a well-known technology. These sensors are easy to install, have reduced dimensions, and can be deployed close or away from the shore, but when measuring the wave profile, need to account for the loss in sensitivity the deeper they are installed. We propose a versatile, cost-effective, low-power pressure reading technology-based wave profile and tide monitoring system developed to integrate multiple interconnected nodes. The low-power specs are compatible with energy harvesting or renewable systems, increasing its long-term deployment time limit without user intervention. The simplicity of the sensors is one of its key characteristics, allowing for a compact design, low-current consumption, and easy implementation capabilities, allowing for deployment in areas where the least possible impact is preferable.

## II. PRESSURE SENSOR

### A. *Component selection*

A commercial TP (Temperature and Pressure) sensor was selected for its accuracy, small size, low-power specs, and integrability with microcontrollers. MS5837-30BA was the preferable candidate, as it can measure pressure in the range of 0 bar to 30 bar with a maximum of 0.2 mbar precision while making temperature corrections from -20° C to 85° C. The temperature may also be a variable of interest, so the sensor can store temperature data as well. To determine the timing of measurement and manage the data, the stm32L082KZT6 was chosen from the low-power branch of STM32 processors, once again for its low current consumption, its processing capabilities, and versatility [6], [7].

### B. *System design*

The microcontroller interacts with the TP sensor via I2C protocol and, according to the application, stores the data in a removable SD card or sends it through RS-485 communication to a datalogger. Storing the data in the SD card is most adequate for stand-alone deployment while sending data via RS-485 is preferable for sensor networks with several nodes, interconnected and controlled by a datalogger with capabilities to store the data locally or send it via wireless communication. Renewable energy generators above water or even energy underwater harvesting technology allow extended time without battery recharging or replacement [8]. Wi-fi communication was already tested with success above sea level, sending the data to a website where it was possible to watch the evolution of the tide in real-time. Fig. 1 represents a possible monitoring system, interconnected by RS-485 communications, with two or more wave and tide sensors, a datalogger that stores the data in an SD card, and energy harvesting generators, increasing the lifetime of the system's batteries.

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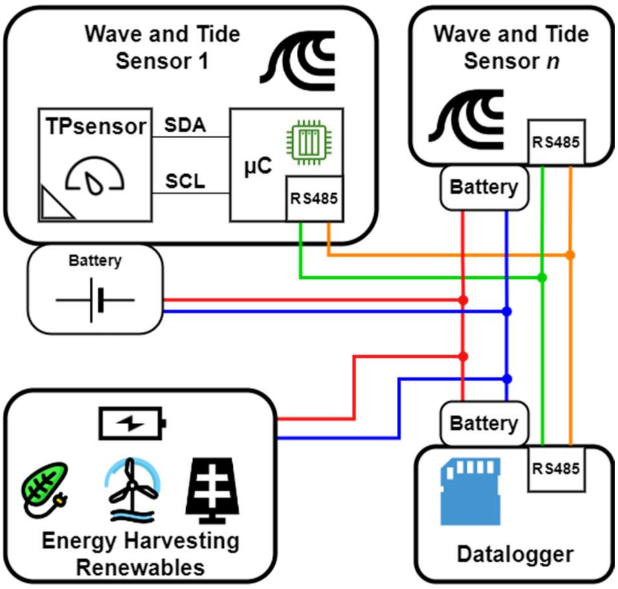


Fig. 1. Diagram of a wave and tide monitoring network. Wave and Tide Sensor 1 is a more detailed representation of a sensor. The sensors aquire and sent data periodically to the datalogger. Each node has a battery recharged by energy harvesting generators.

## III. Wave and Tide Monitoring Results

The monitoring system was tested in several scenarios, initially in controlled conditions in the laboratory, moving on to monitoring the tide cycles for long periods. It was then installed in more adverse conditions, first in the river to test the capability to monitor waves generated by passing boats, moving on to acquire the wave profile off the coast of Viana do Castelo, this time deployed at almost 30 m deep. Finally, the wave amplitude compensation according to the depth was contemplated and tested.

### *A. Laboratory Testing*

The sensor was previously tested in a laboratory, to prove its response to periodic waves in a tank. Installed 26 cm deep in the tank, was successful in measuring generated waves with an amplitude of 12 cm and a period of 1 s, but due to the pressure wave attenuation, the aquired amplitude was just 6 cm. Therefore, a correction calibration was needed to acquire the real amplitude value [9].

### *B. Cávado Estuary Tide Monitoring*

The first test outside the lab was made in the Cávado river, to monitor the tide shift, both in terms of depth and temperature. The sensor was deployed at an average depth of 2 m, and connected to an already installed network, using RS-485 communication, converting the acquired values into a string with an identifier, and sending it to the datalogger [10]. More than three months of data were then collected, compared, and verified with the available information on an online weather forecast website. The acquired measurements are represented in the graph of Fig. 2, showing the variation of the tide from 19th January to 30th April. Both depth and temperature variation coincided with the tide daily cycle, the difference between ebb tide and spring tide, the increased temperature as the weather gets warmer, and the effect of heavy rainfall in the depth of the estuary, especially in the low tide.

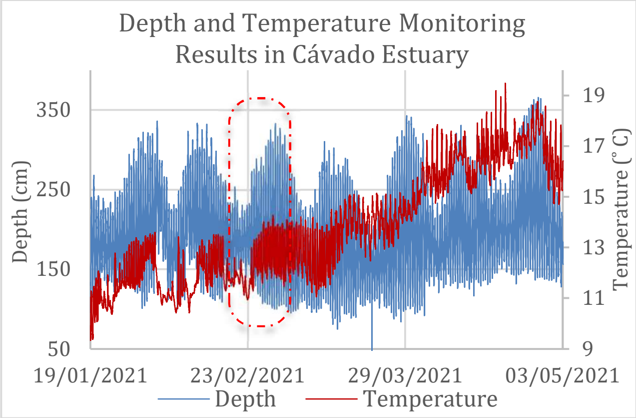


Fig. 2. Graph with pressure (blue) and temperature (red) data from 19-Jan-2021 to 30-Apr-2021.

In Fig. 3, a detail of the acquired data is presented, showing the tide cycle and the difference between ebb tide (around 21-feb) and spring tide (around 28-feb). During the spring tide and according to the winter season, the difference in the temperature is clear, as the colder water from the river was around 12˚ C and the seawater was reached 13.5 ˚ C.

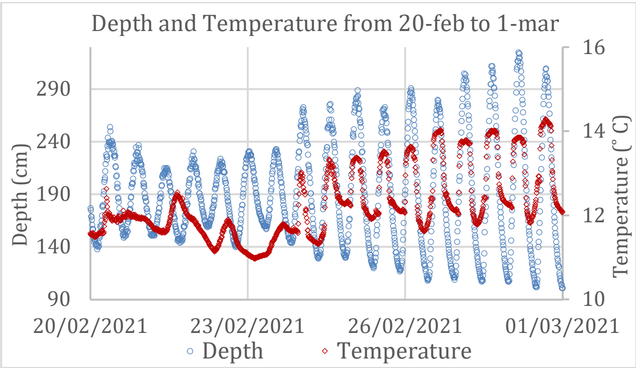


Fig. 3. Graph of depth (blue) and temperature (red) data from 20/feb/2021 to 1/mar/2021. The tide cycle is visible both in the depth and the temperature data.

### *C. Measuring waves generated by boats*

For the first real environment test of the sensor as a wave profile monitoring system, it was deployed at a depth of 3 meters in the Douro River, measuring the waves generated by boats passing nearby [11]. As expected, there was an attenuation of the wave pressure signal measured by the sensor. Approximately 20 cm waves were observed, while the sensor measured peaks of 8 cm, as in Fig. 4.

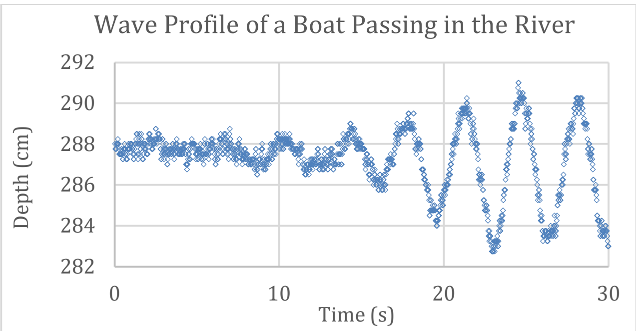


Fig. 4. Graph of the acquired wave profile of a boat passing in the Douro river, Melres.

## D. *Sea wave test in Viana do Castelo*

In Viana do Castelo, the sensor was dropped at a depth of 25 meters to measure the wave profile for 16 minutes, and then in another adjacent location, at a depth of 26 meters for 6 minutes. It is possible to see the measured pressure as the sensor is deployed in Fig. 5. Once again, the waves measured by the sensor were attenuated. The sensor measured waves that reached an amplitude of 90 cm, while at the surface, some waves surpassed 2 meters.

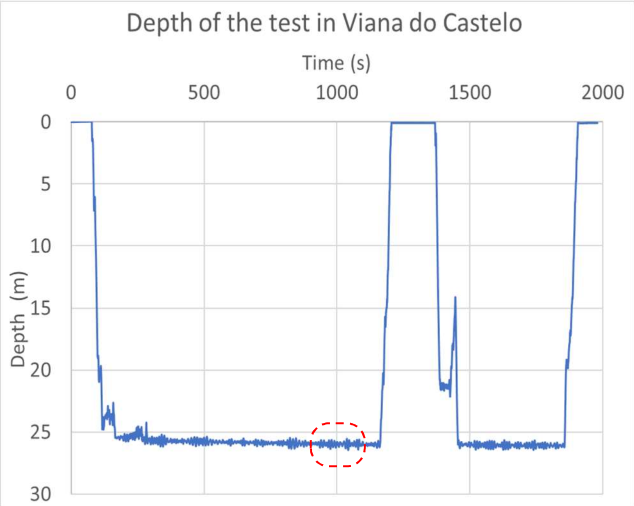


Fig. 5. Graph of the measured depth in the test off the coast of Viana do Castelo.

Fig. 6 depicts a detail section of the measured depth with wave pressure variation along a mean value. Although further sacaling based on the total depth is still required, this test demonstrates the system's capability to monitor wave profiles at greater depths.

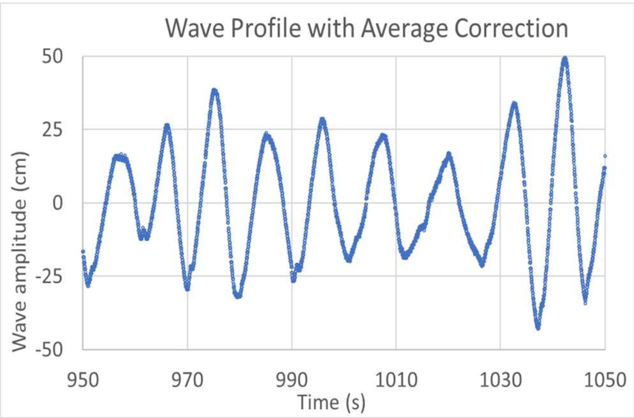


Fig. 6. Graph of the measured wave profile, during the test off the coast of Viana do Castelo. The collected pressure values were processed to be centered at an average value, to display more plainly the wave's amplitude, period, and overall profile.

## E. *Depth Correction*

To accurately estimate the height of a wave from the pressure measured underwater, one must consider the attenuation that the pressure suffers as it travels the water column. According to the Linear Wave Theory [12], the pressure at a given depth can be estimated empirically through the equations:

$$p = -\rho g z + \rho g \frac{H}{2} \cos\,(kx - \omega t) K_p(z) \qquad (1)$$

$$K_p(z) = \frac{\cosh\{k(h+z)\}}{\cosh\,(kh)} \qquad (2)$$

In (1) and (2), p is pressure (Pa), ρ fluid density (kg/m³), g gravity's acceleration (m/s²), H wave height (m), z depth relative to the reference level (m), h seafloor depth (m), k is the wave number, related to the wavelength of the wave (rad/m), x is the horizontal position of the sensor in relation to the wave (m) and ω angular frequency of the wave (rad/s). Equation (1) may be divided into three parcels: static pressure, dynamic pressure, and attenuation factor. $-\rho g z$ represents the static pressure, which depends on the weight of the water column; $\rho g (H/2) \cos\,(kx - \omega t)$ represents the dynamic pressure, which depends on the wave profile; finally, $K_p(z)$is the attenuation factor, which mainly depends on the depth of the sensor and the frequency of the wave.

Using this equation, with special attention to the attenuation factor, it is possible to estimate the wave height and characterize the wave profile by measuring the pressure at the seafloor. However, it should be noted that this is an empirical theory, and the pressure propagation is influenced by various factors, including the morphology of the seabed. Therefore, for accurate measuring, it is essential to perform on-site sensor calibration to ensure the accuracy and reliability of the estimations.

# IV. CONCLUSION

Using pressure sensors for wave measurement exhibits significant potential for large-scale implementation. With a cost-effective production rate of 30 EUR per sensor and top power consumption up to 6 mW, establishing an interconnected network of sensors in aquatic environments can prove instrumental in monitoring vast expanses, such as open seas, estuaries, and rivers. Calibration procedures for pressure attenuation along the water column are imperative, requiring thorough tests involving a minimum of three sensors positioned at various depths to derive an accurate calibration curve. Additionally, it is crucial to ascertain the maximum achievable depth for reliable wave measurement, potentially confining the deployment of these sensors to shallower coastal areas. Incorporating underwater wireless communication methods such as acoustic technology can significantly augment sensor versatility and simplify deployment processes [13].

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