Monitoring Water Quality with a Spectrophotometer: a Proof of Concept of a Smart Buoy

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***Abstract*—Marine fisheries and aquaculture are fundamental resources in the livelihood and development of many countries. Real-time monitoring of the environmental conditions of marine aquaculture allows targeted interventions to maintain the health of fish species and the marine environment.**

This work describes the design and first low-cost prototyping of a proof-of-concept of a smart buoy to monitor the quality of water in IoT deployments. The buoy is connected to the Internet by a LoRaWAN link that transmits data acquired by a spectrophotometer that in principle allows us with a single sensor to obtain multiple parameters on water quality. Our solution is aimed at those countries that, despite basing their economies on aquaculture, do not have sophisticated and expensive technologies.

***Index Terms*—Blue Growth, Internet of Things, low-cost prototyping, multi-parametric sensor.**

I. Introduction

The ocean makes an essential contribution to the worldwide economy, offering jobs to hundreds of thousands of people. Nevertheless, we are witnessing persistent overexploitation of marine resources generating in many cases unsustainable pollution [1].

Aquaculture is one of the sectors with the most significant growth perspectives. In 2018, international aquaculture produced more than 110 million tonnes worth about USD 243 billion [2]. At least 64% of aquaculture is inland and the remaining marine is concentrated in coastal regions and represents a resource for the coastal population especially in developing countries.

Global demands for food from aquatic environments are expected to increase in future decades to meet the needs and demands of a growing human population. Aquaculture production is rising while wild-capture production is almost stable due to the need of preserving wildlife.

However, marine and aquatic ecosystems are under stress: climate change, overfishing and unsustainable fishing and aquaculture practices in some areas, as well as pollution from various other human activities, lead to ocean acidification and declining biodiversity.

Global fisheries and aquaculture could be both more productive and sustainable if they were optimally managed.

Some of the most important quantities to monitor water quality include [3], [4]:

- the existence and percentage of phytoplankton and zooplankton (food);
- the percentage of oxygen;
- the presence of nitrogen dioxide, of nitrogen catabolites, of ammonia;
- the droppings (dejections produced by fishes);
- the percentage of Ph and of salinity and the bioaccumulation of heavy metals, dioxins, polychlorinated biphenyls.

Trends and distribution of toxins are affected by sea temperature and many other environmental parameters. Contaminants and chemical substances including pesticides, heavy metals and chronic natural pollution, can increase in fish and shellfish and may pose a public fitness issue.

Fish can soak up chemical substances in 3 main ways: a) via meals or feed for wild and cultured fishes; b) via drugs to preserve fish health in aquaculture and reduce the risks of infection; c) via uptake from the water column.

These chemicals can be eventually transferred to humans eating the fishes and they can represent a serious hazard for their health.

Nowadays, in most aquaculture sites, the quality of water is still performed periodically with onsite measurements.

Together with the quantities listed in the previous section, temperature, turbidity and hardness (i.e. mineral content) of water are likewise vital. These water parameters are traditionally measured by technicians employing handheld instruments and consequently, the sampling frequency is relatively small. In some cases, the sampling interval can be of hours during which serious hazards are not detected with possible serious consequences on the health and quality of the production. Furthermore, and even more importantly, without a sufficient amount of data, technicians could not understand the causes behind the problems thus reducing the possibility of avoiding the occurrence of the same issues in the future.

An autonomous monitoring system [5], capable of providing good measurements at a sampling interval of seconds or minutes, would allow more accurate planning of the farming activities, the triggering of alarms in case of hazardous water situations, the immediate application of corrective actions in case of a dangerous situation and additionally the creation of a rich database to help technicians and scientists to improve the performance of aquaculture.

The main purpose of this paper is to build a low-cost DIY Proof-Of-Concept (POC) of a smart buoy capable of autonomously monitoring by a spectrophotometer some of the relevant parameters to evaluate the quality of water at sea and to deliver the observed data to the cloud over a long-range wireless link connected to a gateway.

II. The prototype for Laboratory experiments

The smart buoy will be equipped with a spectrophotometer because it allows us to observe multiple parameters related to the water quality with a single device. This approach has been already explored in [6] where a low-cost, easy-to-use, do-it-yourself (DIY) spectrometer for measurement of a variety of relevant solute concentrations is proved to be accurate-enough to offer a viable alternative to commercial solutions. In [7] the authors show how to use a spectrophotometer to detect heavy metals in water using colorimetric reagents paired with ultraviolet–visible light (UV–vis) spectrophotometry while [8] presents the design, use, and performance of an accurate, precise, and extremely affordable LED spectrophotometer for drinking water and other testing with limited resources. The employment of similar techniques underwater has been investigated in [9]

The choice of a spectrophotometer is motivated by the fact that at least in principle we can monitor multiple parameters by a single sensor. The basic working principle of a spectrophotometer consists in the detection of the spectrum of a sample light (with a wide range of wavelengths) reflected by the analysed surface and can be used to get a fingerprint of the composition of a liquid mixture.

In the classical approach, the spectrophotometer is used to infer the absorbance or reflectance of material, and thus infer its concentration applying the Beer–Lambert law. Each type of molecule and atom reflect, absorb, or emit electromagnetic radiation in its own characteristic way. Spectroscopy uses these characteristics to deduce and analyze the composition of a sample.

Our experimental set-up is shown in figure 1 where a SparkFun Triad Spectroscopy Sensor (material 19) is interfaced with an Arduino via an I2C protocol. This spectrophotometer, combines three AS7265x spectral sensors together with visible, UV, and IR LEDs to illuminate a surface and detect the reflected/absorbed wavelengths and their intensity from 410nm (UV) to 940nm (IR) .

The main purpose of the in-lab performed experiments is to acquire experience on the operation of the spectrophotometer and having a first validation in a controlled environment the reliability of the selected device.

A. Measures of water quality by a spectrophotometer

By graphically reporting the recorded values of wavelength and intensity of absorbed radiation, the absorption spectrum of the examined substance is obtained. In nature, each substance has its own absorption spectrum, so careful examination of the spectrum allows us to identify the substance. This is done by comparing the spectrum obtained by the spectrophotometer

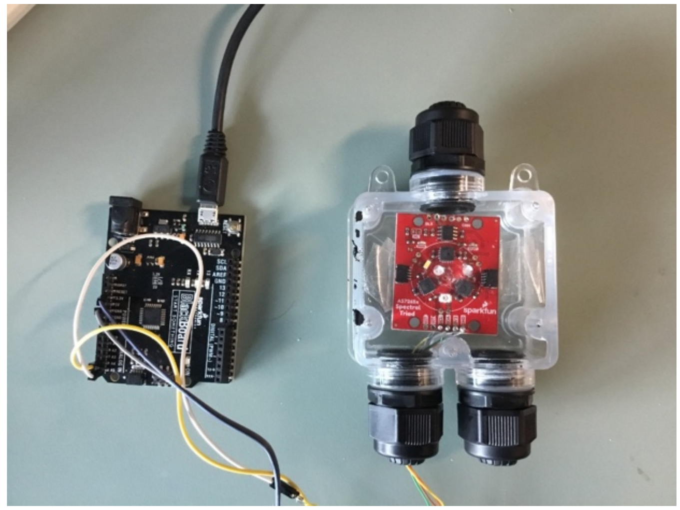

Fig. 1. The integration of the Arduino with the spectrophotometer

with reference samples also available in a spectral databases (such as AIST: Spectral Database for Organic Compounds, SDBS https://sdbs.db.aist.go.jp/sdbs/cgi-bin/cre$_index.cgi$).

The correct classification of composite organic and inorganic materials in seawater is a complex task. As foreseen in [6], [7] the actual employment of a spectrophotometer for monitoring water quality would require the employment of inexpensive commercially-available reagents which upon reacting with the solute produce a large absorbance signal in the visible spectrum range. However, for the sake of simplicity, in our in lab experiments, we simulate those reactions with an increasing concentration of dye color.

To approach this problem, we first built a reference set of samples of different concentrations of a given colour in the same water tank.

More specifically, in each trial of the experiment, the tank was filled with two litres of water. The intensity measured by the spectrophotometer is dependent on the position of the sensor in the container and this can slightly vary between experiments. This is why the first step in each experiment is the normalization of measures with respect to pure water or blanc. The blanc measurement should always be the first trial when a new experiment starts. Then all the subsequent measurements should be normalized to this first one. The experiment consist of an increasing number of teaspoons of a given colour added and mixed in the water sample. The tank was closed during the measurements to avoid the presence of external light.

Figure 2 shows the result of the experiment performed adding up to 5 teaspoons of red dye into the tank.

The wavelength of orange-red is between 600nm and 700nm. Observing the results of this experiment we can notice that the wavelengths around 620nm show a linear correlation between the measured intensity and the percentage of red in the solution. In particular, increasing the concentration of red dye the observed spectral response around 620nm decreases coherently

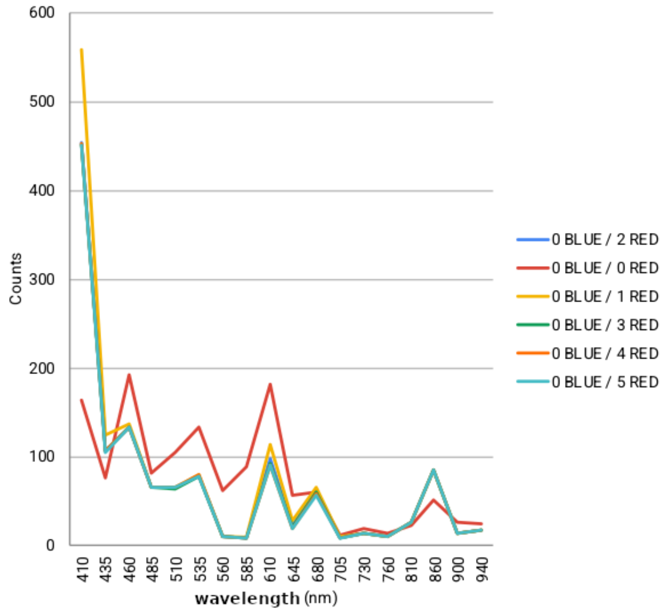

Fig. 2. An experiment to define the reference set of entries for different concentrations of red.

with the hypothesis that the absorption of light at that frequency increases and with the Beer–Lambert law. Furthermore, the consequences of the increased concentration of red dye are less evident on the other frequencies. These particular points are therefore good candidates to detect the concentration of red and further experiments confirmed the availability of these points for all the colours.

B. Experimental Estimation of Energy Consumption

A key aspect of any IoT deployment is Energy Consumption. In this section, we focus our analysis on the energy consumption of the spectrophotometer. The INA226 (material 17) is a current shunt and power monitor, connected via I2C to an M5Stack (material 18) to show in real-time the power consumed by the AS7265x connected to the INA226 as suggested in the datasheet. The whole experimental setup is shown in Figure 3.

The M5Stack run a program to show the measures of the INA226. We can select sampling rates ranging from 2-50 ms and threshold values on the current to trigger the collection of data. We selected 4ms for the period and 3mA as a threshold.

Figure 4 shows the energy consumption of the spectrophotometer when LEDs are switched on every second. During the active period, the consumption is about 60mW for 200ms. For the remaining 800ms, the consumption is constant at about 30mW. Consequently, the average consumption is 24mW per second. Assuming 12 measures each day and sleeping mode in the remaining time, the consumption per day is about 432 mW.

III. Smart Buoy POC in field experiments

In this section, we illustrate the proof of concept of a smart buoy equipped with a spectrophotometer to evaluate water

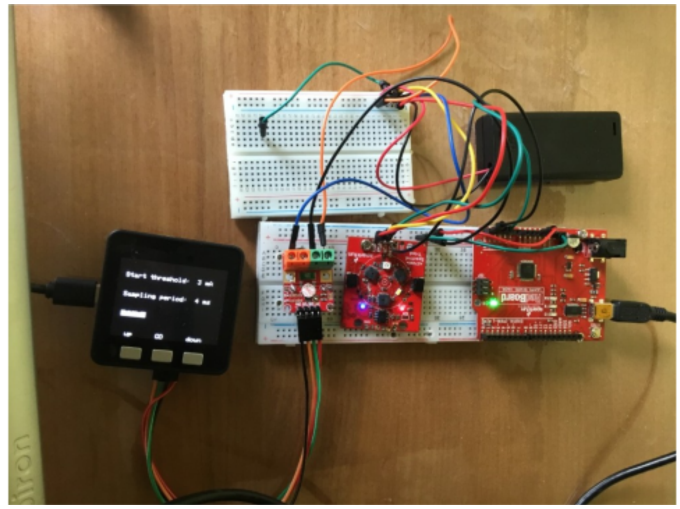

Fig. 3. The experimental set-up to measure energy consumption

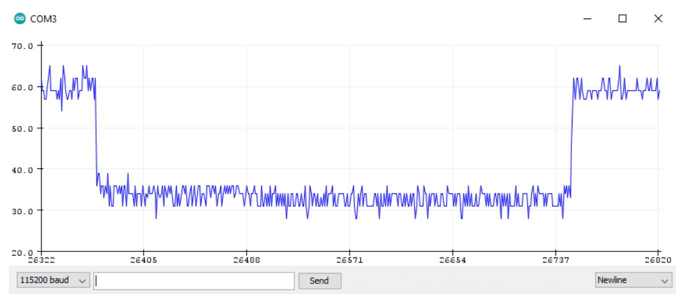

Fig. 4. Energy Consumption of the Spectrophotometer

quality parameters in real-time and capable to transmit the observed parameters to a control unit.

Smart buoy prototypes have been presented in many works. The Korea Institute of Ocean Science and Technology (KIOST) developed the Intelligent Buoy System (INBUS) [10] for long-term observations of the vertical structures of the water properties in macrotidal environments. Contrary to our buoy, INBUS is a complex and big (both in terms of weight and size) system exploiting advanced and expensive hardware. [11] presents the design, development, and testing of a Smart Buoy for real-time remote access to underwater devices. The life buoy, presented in [12] shares some of the design constraints in terms of dimensions and hardware of our prototype, but focuses on a life preserver, a crucial safety tool on board of any marine ships. A nice design of a smart buoy equipped with simple sensors, that share our goal to develop a low-cost DIY solution, is available at https://www.instructables.com/Smart-Buoy/

The buoy will be typically deployed in marine environments, in the proximity of fish farms and in general in locations potentially not in close proximity to coastal areas and thus it should be capable of transmitting wireless data to a gateway onshore consuming minimal amounts of power to maximize the operation time. Our POC relies on LoRaWAN technology to meet the low-power long-range requirements of the system.

A. Manufacture and construction of the LoRA Smart Buoy prototype

The spherical body of the buoy is made up of two polystyrene hemispheres with a diameter of 40 cm (material 1) suitably treated with adhesive (material 2) and epoxy resin (material 3).

At the end of the assembly of the internal components, the two hemispheres were sealed with silicone (material 4) to prevent infiltration and damage to the internal circuits.

The outer circumference of the polystyrene sphere was encircled with a bicycle air chamber in order to increase its stability in case of strong waves (material 5).

The spectrophotometer was therefore mounted inside an IP68 waterproof box (material 6) and attached to a 50 cm long stainless steel capillary tube (material 7). Inside the capillary steel tube run both the electrical wires for connecting and powering the spectrophotometer and the braided nylon rope used to tie the anchor (material 8).

The anchorage of the buoy prevents it from drifting when subject to waves and currents, without damaging the structure of the buoy itself.

In fact, the anchor rope is attached to the wooden platform (material 5) that splits the hemispheres of the polystyrene buoy. This wooden platform is of fundamental importance as it plays a number of roles:

1) It strengthens the internal structure of the polystyrene buoy
2) It separates the lower watertight chamber of the buoy (in contact with the water) from the upper one (which contains the circuits of the Internet of Things)
3) It constitutes the base to which the capillary tube is fixed so that it does not oscillate or move
4) It allows the circuits to be securely fixed and housed on a breadboard
5) It allows the nylon rope to which the anchor is connected to be fixed in order to prevent tears or stresses from taking the anchor away.

The upper part of the buoy is equipped with two mini solar panels (material 10) and a LoraWAN 868Mhz Antenna (material 11) an Arduino compatible SparkFun BlackBoard C (material 12), the B-L072Z-LRWAN1 board (material 13), the TP4056 Lithium Battery Charger Module (material 14) and a Lithium Rechargeable Battery (material 15)

The Arduino compatible board governs the monitoring activities performed by the spectrophotometer and forward the acquired data to an STMicro B-L072Z-LRWAN1 in charge of delivering the data to a gateway.

B. System Architecture

The data on water quality collected by the smart buoy are finally delivered by the LoRaWAN network to a Gateway connected to The Things Network via a WiFi connection.

The gateway can be placed on the coast or in the proximity of the smart buoy, in order to enable LoRaWAN communications. It has been implemented on a Raspberry PI equipped with an iC880A concentrator module (material 16). This module provides a complete RF front end thus enabling robust communication between the LoRa gateway and a number of LoRa end-nodes (i.e. smart buoys) spread over a wide range of distances.

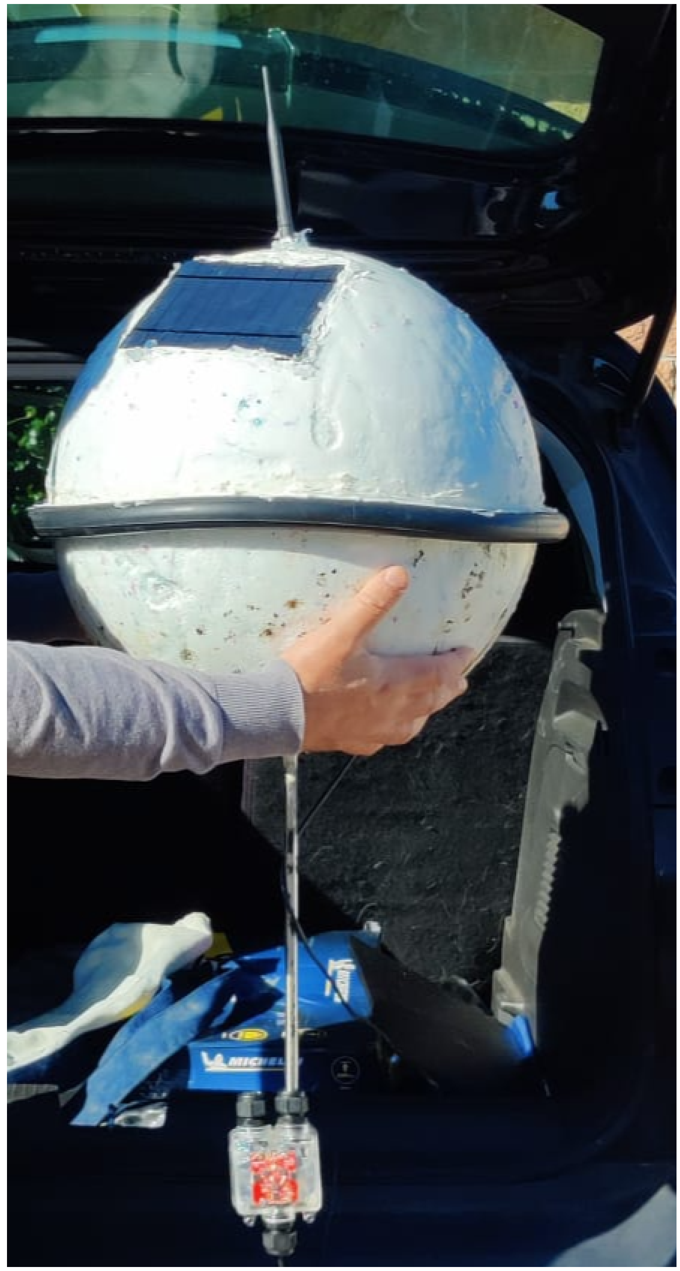

Fig. 5. The final prototype before the deployment at sea

C. Energy Power Consumption

The Buoy is mainly powered by a rechargeable battery (see material 15), but also a small solar panel is installed on the top of the buoy to provide some support in terms of solar energy harvesting. Energy consumption is the main concern since once deployed at sea, the Smart Buoy is hermetically

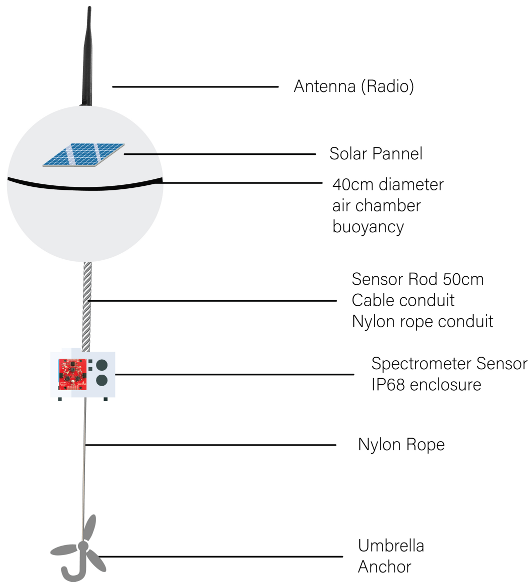

Fig. 6. A sketch of the main components of the smart buoy

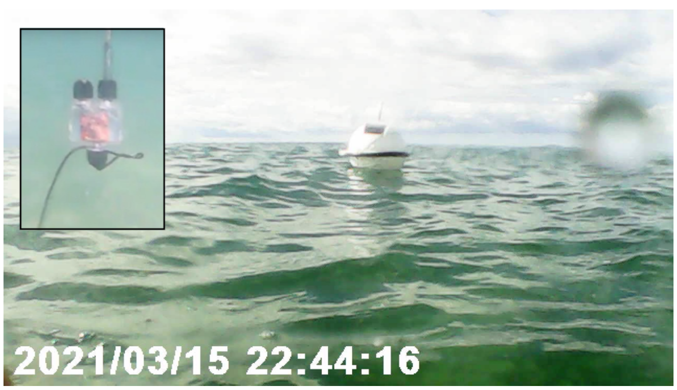

Fig. 7. Deployment at sea of the smart buoy

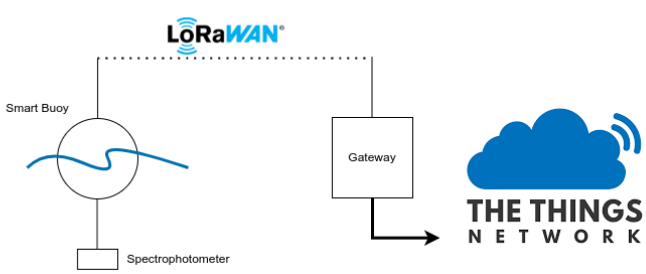

Fig. 8. Data acquired by the smart buoy are delivered by a LoRaWAN link to a Gateway that makes them available via The Thing Network

sealed and left unattended for long periods of time without the possibility of intervention.

The main sources of consumption are the spectrophotometer As7265x, the BlackBoard Arduino Uno and the B-L072Z-LORAWAN1. The energy consumption of the spectrophotometer has been already analysed in section II-B here we provide a first estimation of the consumption of the other sources. Experimental in-field measurements are foreseen as future work.

The B-L072Z-LRWAN1 board consumes 38mA in Tx and 11mA in Rx. Assuming as in section II-B a single transmission per hour, the daily consumption for the transmission is about 456mA. To these peaks, we have also to add the consumption in stand-by that can be reduced to few μA. The power consumption of the BlackBoard Arduino Uno is in the order of 12mA. A more accurate estimation can be performed adopting the approach proposed in [13], however the above figures justify a future effort to develop a solution where all components can be optimised in a single energy efficient device that will be finally tested in a real deployment at sea.

IV. Conclusion

This work demonstrates the feasibility of a low-cost proof-of-concept of a smart buoy to monitor the quality of water in IoT deployments. The total cost of material comprising smart buoy manufacture and electronics is 415 euros. The buoy has been actually deployed at sea (see figure 7) proving that the design is robust enough to run in the hostile sea environment. This is the preliminary necessary step to future measurement campaigns aiming at collecting real-time in-field data. Those data will be used to train suitable machine learning algorithms to detect the presence and the concentration of pollutants in the water thus classifying hazardous situations and promptly triggering corrective actions in marine aquaculture farms. While our initial deployment can be considered a success, we still need some work to finalize an effective and efficient solution. The design has to be further refined and some work is still needed to make the buoy more resistant to the see environment. As an example, during the deployment we experienced some issues related to the quality of electronics wiring, however, we do believe that most of such issues can be easily resolved in our final design. The spectrophotometer has the potential to detect a number of pollutants by a single sensor, but its effective in-field employment has still to be proved. Our preliminary in-lab experiments on colour are a first attempt to prove the viability of this approach in a controlled environment. Finally, the energy consumption evaluation has to be extended in the real deployment to all the components of the smart buoy, thus proving the viability of the proposed approach for long-term measurements campaigns.

V. List of Materials

1) Polystyrene sphere https://www.amazon.it/RAYHER-3306300-SFERA-POLISTIROLO-SEMISFERE/dp/B004P1933K

2) Gripping for Plastic https://www.amazon.it/Arexons-3441-Smalto-Spray-Aggrappante/dp/B00GTVGJN6
3) Epoxy Resin https://www.amazon.it/Resina-Epossidica-Trasparente-Bicomponente-Rivestimento/dp/B087Q6XXS4
4) Silicone https://www.amazon.it/Pattex-1504208-Bagno-Silicone-Facile/dp/B00A37RUO4
5) Bicycle air chamber https://www.amazon.it/Schwalbe-10412310-Camera-pollici-colore/dp/B000NN3B00
6) IP68 waterproof box https://www.amazon.it/ATPWONZ-Trasparente-Impermeabile-Connessioni-Connettore/dp/B072PZ9744
7) Stainless steel capillary tube https://www.amazon.it/REFURBISHHOUSE-Capillare-Inossidabile-Diametro-Lunghezza/dp/B07R9Z3H6P
8) Anchor https://www.amazon.it/OSCULATI-Ancora-Ombrello-0-7-kg/dp/B00Y9X2Q2Y
9) Wooden platform https://www.amazon.it/Primolegno-Cerchi-Sagome-Decorazioni-Spessore/dp/B08KLNW1CF
10) Mini solar panels https://www.amazon.it/ALLPOWERS-500mAh-Caricabatteria-Solare-Pannello/dp/B073XKPWY7
11) LoraWAN 868Mhz Antenna https://www.amazon.it/Paradar-connettore-radioamatori-aviazione-Software/dp/B09522Y6H9
12) SparkFun BlackBoard C https://www.sparkfun.com/products/15050
13) B-L072Z-LRWAN1 https://www.digikey.it/product-detail/it/stmicroelectronics/B-L072Z-LRWAN1/497-17068-ND/6616000
14) TP4056 Lithium Battery Charger Module https://www.amazon.it/ZHITING-Ricarica-Ricaricabile-Caricabatterie-Protezione/dp/B0859WJBPQ
15) Lithium Rechargeable Battery https://it.rs-online.com/web/p/batterie-a-dimensioni-speciali-ricaricabili/8183005
16) IMST iC880a board http://www.wireless-solutions.de/products/radiomodules/ic880a
17) INA226 i2c output current/voltage/power monitorhttps://www.ti.com/product/INA226
18) M5stack. Modular Open Source IoT Development Platform https://m5stack.com/
19) SparkFun Triad Spectroscopy Sensor - AS7265x https://www.sparkfun.com/products/15050

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