A LoRaWAN Network for the Real-Time Monitoring of the Venice Lagoon: Preliminary Tests

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***Abstract*—Coastal and littoral biodiversity hotspot areas, such as the European Natura 2000 protected areas and the Venice lagoon, are understudied sites due to their diversity caused by the very heterogeneous conformation, including the intersection of many channels and rivers carrying different types of sediments. The current sampling systems are based on periodic sampling campaigns performed by human operators, that only allow the collection of a very limited number of measurements in time and space. In this paper we present the first prototype of a low-cost wireless sensing floating device able to provide measurements to an in-land server in real time: the device, named SENSWICH, is composed of a LoRaWAN node and a complete set of water quality sensors, selected with the help of the researchers operating in the Chioggia Marine Hydrobiological Station of the University of Padova, where the first sensor will be deployed.**

***Index Terms*—Wireless sensor networks; LoRaWAN, climate change; Venice Lagoon.**

I. Introduction

Climate change has a tremendous impact on coastal and littoral areas, strongly affected by seaquakes and floods. Moreover, global warming may cause dramatic changes in the biodiversity of rivers, seas, lakes, including biodiversity hotspots such as the the Natura 2000 protected areas [1], and a similar impact is caused by pollutants. This calls for a large-scale long-term action, e.g., the European Biodiversity Strategy for 2030, that aims to protect nature and reverse the degradation of ecosystems, or the United Nations Decade of Ocean Science for Sustainable Development (2021-2030) to globally strengthen the international cooperation needed to develop the scientific research and innovative technologies that can connect ocean science with the needs of society. Both actions are supporting the use of innovative solutions such as smart sensors deployed to monitor aquatic environmental parameters in order to predict, manage and mitigate these effects. Given that coastal systems are highly heterogeneous in space and variable over short (daily), medium (seasonal), and long (interannual) timescales, setting up reliable but affordable monitoring is indeed a challenging task.

In this paper we focus on the specific case of a quite peculiar and challenging ecosystem, namely, the Venice lagoon in Italy. The water of the lagoon is brackish and mostly shallow, with numerous salt marshes, and an intense tidal cycle. The characteristics of this unique area make it hard for researchers to perform quantitative analysis of the water parameters compared to a more stable environment, such as the open sea, where changes are more easily predictable. Currently, the measurements are performed through periodic sampling campaigns, that involve the use of boats and personnel dedicated to retrieve water samples in hotspot areas. This process has two main drawbacks: the high cost in terms of resources (equipment, fuel, boat maintenance) and human power, and the small granularity in time and space of the measurements that are in fact very sparse, as the data can be logged only a few times per day in very few locations. The deployment of a low-cost dense wireless sensor network will provide the researchers with data that have a much finer granularity, both spatially and temporally, allowing a better characterization of the observed environment.

The sensors of interest for biologists and marine scientists have been analyzed with the help of the staff of the Chioggia Marine Hydrobiological Station of the University of Padova, Italy, in synergy with the Italian National Center for Biodiversity [2]. Due to the fact that some of these sensors need to measure the characteristics of the water close to the surface, while some other sensors take measurements of the sea sediments, three different types of nodes are envisioned in the final deployment: (i) underwater nodes, equipped with an acoustic modem, that sample the water sediments; (ii) surface nodes, equipped with radio devices, that measure the water quality; and (iii) gateway buoys, equipped with both acoustic and radio frequency modems, that forward the data collected from submerged nodes to shore.

In this paper we first present the architecture and the preliminary tests on the surface node, which integrates a complete set of sensors, and exploits the Long Range (LoRa) modulation and the associated LoRa Wide Area Network (LoRaWAN) protocol stack for data transmission. The rest of the paper is structured as follows. In Section II, some related works are presented. Section III presents the architecture of the sensor node as well as their deployment, while the experimental setup is presented in Section IV. The preliminary tests are described in Section V, while the conclusive remarks are presented in Section VI.

II. Related Works

The study of the marine ecosystem with smart sensor buoys is something that started many decades ago, initially to study meteorology [3], then currents [4] and, more recently, other water parameters, with the actual deployment of large scale oceans observatory systems in hotspot areas [5]. These observatories are composed of mooring systems deployed offshore and equipped with cutting edge technology and a sensor chain that measures water parameters up to a depth of hundreds or, in some cases, thousands of meters. Each buoy composing the observatory can cost up to a few million US dollars, as it includes a chain of expensive sensors, including Conductivity, Temperature and Depth (CTD) probes, Acoustic Doppler Current Profilers (ADCPs), fluorometers, meteorological sensors, solar panels, large batteries (that can exceed 30 MJ energy capacity) industrial-rated PCs on board, and high-power, long-range radio and/or satellite communication systems [5].

Coastal, river, as well as lagoon monitoring, instead, requires the deployment of several sensors in extremely shallow water areas whose depth hardly exceeds 5 m. Given the large diversity of the area due to the intersection of several channels, the presence of several river mouths and salt marshes, the use of a single large observatory buoy in that area is not the most appropriate solution, and the use of several buoy observatories is not feasible due to the high deployment and maintenance costs. In this case, instead, the use of a low-cost easy-to-maintain system is a more suitable solution. In recent years, some efforts have been performed in this direction. In [6], the authors developed an experimental testbed of an Internet of Underwater Things that includes an underwater node and a surface node. The two nodes, both equipped with sensing devices, communicate with each other using acoustics: the data collected from the underwater unit is sent to the surface unit, which then forwards it to a shore server through LoRaWAN. The prototype, based on an industrial grade acoustic modem for offshore applications, was developed to prove the feasibility of the system rather than for medium- or long-term installations. In the subCULTron project [7], several low-cost underwater and surface sensors and vehicles [8] have been developed, all equipped with a very low-cost acoustic modem and a WiFi module: some of these sensory systems, including a low-cost surface vehicle, recently became commercial products of H20Robotics, a startup company of the University of Zagreb. In [9], a feasibility study of a sensor for smart port based on an Arduino MKR WiFi microprocessor and a miniaturized solar panel was proposed, while from an analysis performed in [10] the authors indicated LoRaWAN as the above water radio transmission technology that suits best a coastal sensor network deployment. Starting from the concept and the network architecture presented in [10], where a simulation study proved the feasibility of a heterogeneous network deployment including low-cost underwater and above water sensors, we developed the first prototype of the system, comprehensive of all sensors of interest for carrying out climate change and biodiversity studies in the Venice Lagoon. In contrast to the aforementioned traditional observatories based on expensive mooring systems [5] that can cost millions of US Dollars, our first prototype has a total cost of approximately 800 US Dollars, price that can be further reduced in production phase and by using low-cost microcontrollers instead of Arduino boards.

III. System Architecture

A. Sensor Node Architecture

The LoRaWAN node was customized to acquire a set of water parameters and to periodically transmit them to a remote LoRaWAN gateway. To this aim, the system architecture includes a set of off-the-shelf sensors, a Micro-Processing Unit (MPU), a LoRaWAN module, and a powering sub-system.

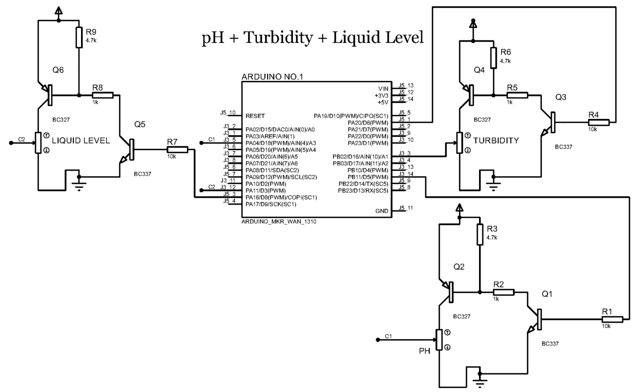
Concerning the set of sensors, these have been selected with the assistance of the staff from the Chioggia Marine Hydrobiological Station of the University of Padova [11]. Thus, the following sensors have been integrated in the sensor node [12]:

- Analog Industrial pH Sensor/Meter Pro Kit V2 (SEN0169-V2);
- Analog Electrical Conductivity Sensor/Meter K = 10 (DFR0300-H);
- Analog Turbidity Sensor (SEN0189);
- GPS Module with Enclosure (TEL0094);
- Waterproof DS18B20 Temperature Sensor Kit (KIT0021);
- Analog Dissolved Oxygen Sensor / Meter Kit (SEN0237-A);
- Photoelectric High Accuracy Liquid Level Sensor (SEN0205).

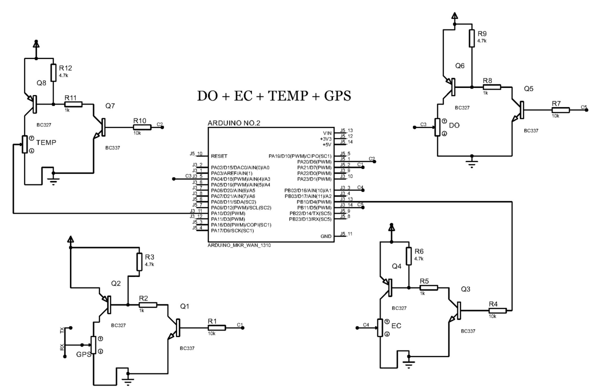
For data acquisition and transmission, for the first prototype we chose to use an Arduino MKR WAN 1310 board: this device integrates on the same platform a SAMD21 Cortex-M0+ 32bit low-power ARM MCU and a Murata CMWX1ZZABZ LoRa chip operating at the frequencies of 433, 868 and 915 MHz. The MCU features 7 Analog input pins and 8 Digital I/O pins: thanks to this configuration, all the sensors may be connected to a single board. However, we encountered certain challenges when employing the pH sensor alongside the electrical conductivity and dissolved oxygen sensors as will be explained in Section V. Furthermore, it became apparent that a single Arduino unit was insufficient to power all the sensors simultaneously. As a result, we made the decision to utilize two separate Arduino units, each serving a specific purpose. Moreover, for each Arduino a sleep and wake-up routine was set up in order to turn off the devices between subsequent data acquisitions. This configuration was mandatory in order to increase the overall lifetime of the node: however, in the final configuration the Arduinos are expected to be replaced with lower-power MCUs (e.g., ATTinys), enabling a significant reduction of the overall energy consumption. Moreover, in the final configuration the two MCUs are expected to be synchronized, in order to make sequential their operation without the risk for overlapping: this will allow a quasi simultaneous data collection without any risk of interference.

The first Arduino unit (Figure 1a) measures pH value, turbidity, and liquid level. The second Arduino unit (Figure 1b) measures dissolved oxygen, GPS coordinates, electrical conductivity, and temperature. Each Arduino unit is powered by eight 3300 mAh Lithium-ion (Li-Ion) 18650 batteries with 3.7 V nominal voltage and 4.2 V maximum voltage when fully charged. These batteries are connected as follows: four batteries are connected in parallel to create a battery set, and two of these sets are connected in series, obtaining an 8.4 V 13200 mAh battery pack when fully charged. To ensure the proper functioning of the Arduino units, we implemented a transformer circuit to adjust the voltage level. Specifically, we employed a DC/DC circuit that transformed the voltage from 8.4 V to around 5.7 V. This modification was implemented to ensure the Arduino units function optimally.

Finally, in order to reduce the overall energy consumption of the sensor node, a couple of BJT transistors (one npn and one pnp) arranged as high-side switches were employed to turn on the sensors only for the actual time of the measurement, while turning them off for the rest of the time. Indeed, sensors account for a significant part of the overall energy consumption of the sensor node.



(a) Arduino 1 Schematic



(b) Arduino 2 Schematic

Fig. 1: Structures of the Two Arduino Units: Arduino 1 Schematic (a) and Arduino 2 Schematic (b).

B. Deployment Setup

In the final deployment setup in the Venice Lagoon, the distance between nodes is expected to be, on average, 500 m: such distance provides a good trade-off between a fine enough data granularity and the economic costs. In the real scenario, this distance should be tuned with respect to local changes: on the one hand, if we expect water parameters to change frequently and unexpectedly in a small area (e.g., where multiple canals intersect with the water flow), we may have to decrease the distance between the sensors; on the other hand, the distance could be increased in areas where parameters vary slowly and more predictably.

Different sensors have different requirements in terms of spatial and time granularity. Indeed, the GPS position can be acquired once a day, just to check that the sensor is still anchored in its desired position: this frequency may even be reduced or an asynchronous reading following a downlink trigger message may be envisaged. Salinity and temperature, instead, vary slowly during the day, hence they can be acquired once per hour. Finally, all the other parameters are subject to a faster variability, and their measurements should be collected at least once every 15 minutes. This information can also be used to lower the energy consumption, as the sensors can be powered off between two consecutive acquisition times. Moreover, keeping the GPS on for only 5 minutes (i.e., the maximum time it may take to acquire one stable GPS position) per day will drastically reduce the energy consumption, as the GPS is the most power-demanding device installed in the sensor nodes.

Due to the water stratification, it is of interest for biologists and ecologists to analyze water measurements along the water column and, most importantly, close to the sea bottom to also characterize the sediments: for this reason, we also envision to install in the future some submersed sensor nodes at different water depths and close to the seafloor.

IV. Experimental Setup

The existing absence of an economically viable intelligent buoy suitable for deploying internal water sensors has necessitated the development of a prototype known as SENSWICH, an acronym derived from ”sensing sandwich,” owing to its sandwich-like configuration. Illustrated in Figure 3a, this buoyant structure comprises a conventional lifebelt characterized by an inner diameter of 40 cm and an outer diameter of 60 cm, along with two wooden panels with an inner diameter of 9 cm, measuring 80 cm x 60 cm, and an IP67 enclosure with dimensions of 25 cm x 20 cm x 7.5 cm. SENSWICH bears a height of 15 cm and features a central aperture within the panels, facilitating its mooring to the poles situated within the Venice lagoon, thereby permitting it to remain stationary while afloat.

The sensors are affixed to the lower panel, as delineated in Figure 3b, and are interlinked with the control box through the utilization of IP67 cable glands. The IP67 box, securely housed within the upper panel of the floating system, as depicted in Figure 3c, accommodates batteries, microprocessors, and control circuits. The constructed prototype serves as a testament to the feasibility of the envisaged system's functionality in the intended environment. In forthcoming iterations, our vision encompasses the integration of small-scale solar panels for recharging the batteries and microcontroller units (MCUs), in lieu of Arduino boards, as a means to reduce energy consumption. Additionally, we plan to explore the implementation of water-jets for periodic sensor cleansing and the mitigation of bio-fouling.

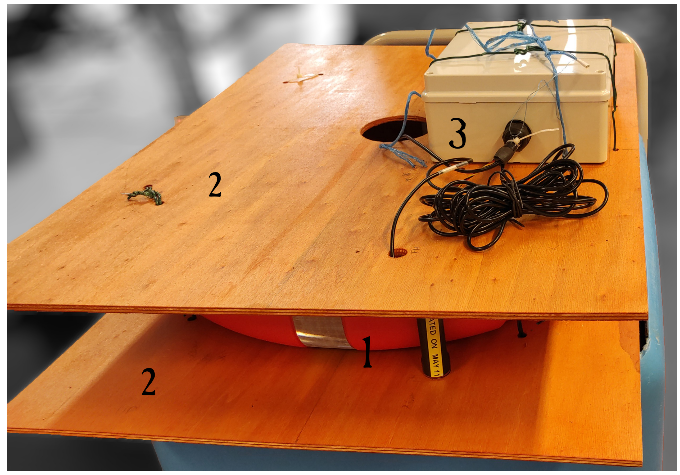
Fig. 2: SENSWICH Components: Wood Panels (Left), Life-Saving Tube (Center), and Plastic Box (Right).

V. Preliminary Tests

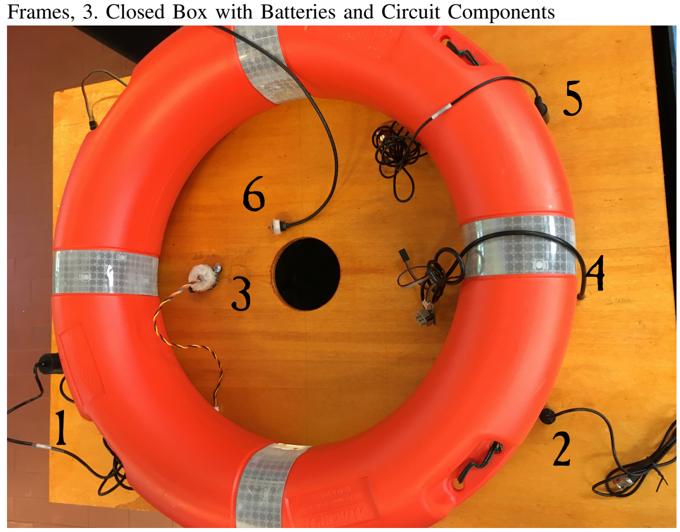
A. Laboratory Tests

Different sets of preliminary tests were carried out in our laboratory to analyze the correct operation of the single sensors as well as of the overall sensing structure. A first set of tests was carried out to identify the behavior of the sensors when used for the acquisition of parameters for prolonged periods: the correct operation of the sensors was tested in fresh water, as well as in salt water, created adding a quantity of salt consistent with the average salinity of the Adriatic Sea, which is around 35 mg/L. Following these tests, the stability of the values acquired by the sensors was validated for two weeks.

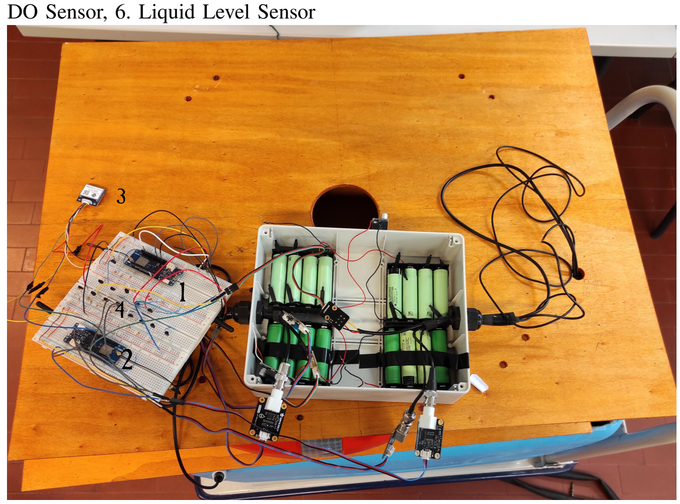
The second set of tests was devoted to the integration of the sensors within a single platform. Initially, a single Arduino board was used to acquire the data from all the sensors, that were put in a single bucket filled with fresh water. However, a significant outcome of this test was the incompatibility of the pH sensor with the other sensors, in particular with the temperature, the DO and the conductivity sensors: such incompatibility led to wrong readings of the pH value when



(a) Profile View of SENSWICH with: 1. Red Sealing Tube, 2. Two Wooden Frames, 3. Closed Box with Batteries and Circuit Components



(b) Bottom Panel of SENSWICH (removed top wooden panel) with Sensors: 1. pH Sensor, 2. EC Sensor, 3. Turbidity Sensor, 4. Temperature Sensor, 5. DO Sensor, 6. Liquid Level Sensor



(c) Circuit Box with Components and Two Packs of 8-Batteries: 1. Arduino 1, 2. Arduino 2, 3. GPS Module, 4. Circuit Components

Fig. 3: SENSWICH Node: (a) Profile View, (b) Bottom Panel, (c) Circuit Box and Batteries.

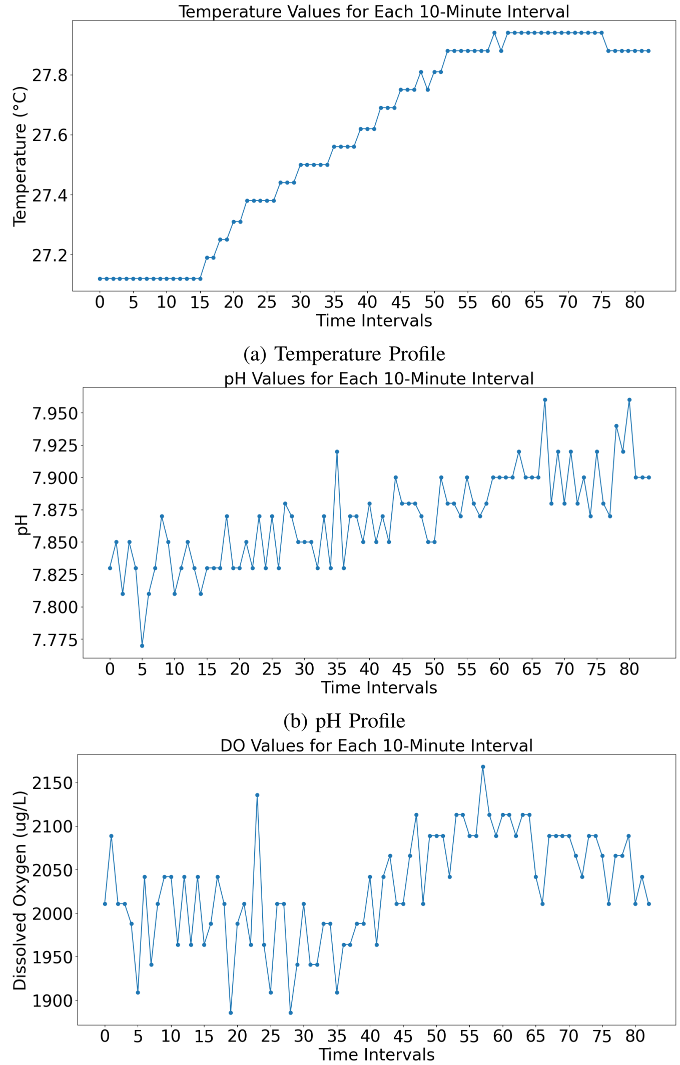
the other sensors were positioned in the same bucket. This phenomenon was still present when sequentially turning on the single sensors one-by-one, demonstrating some kind of interaction due to the different operating principles of the sensors. While this phenomenon requires further investigation, which will be carried out as part of our future work, to speed up the development of the monitoring platform we opted for the usage of two separate Arduinos: even if this choice considerably increases the overall energy consumption of the system, the final layout integrating low-power components is expected to fulfill the low-power requirement even with two MCUs. However, research is still ongoing to achieve the integration of all the sensors with a single MCU.

The last set of tests was devoted to the analysis of the operation of the integrated platform, with all the sensors positioned in salt water for a prolonged period of time. In particular, the system was continuously operating in the laboratory for two weeks. A sample of the acquisitions for three of the sensors for a period of 48 hours is shown in Figure 5. Since these tests were carried out without any modification in the water, the only parameter that may show some change is temperature (nevertheless, such value too is stable since the tests were carried out in a laboratory with almost constant temperature). Moreover, as shown in the figures, the sensors demonstrate a good stability along the 48 hours period. Moreover, the measured values are coherent with the standard values of that parameters for water.

B. Preliminary Field Test

A last set of tests was carried out to verify the effectiveness of the integrated system. In particular, these tests aimed at checking the buoyancy of the device as well as the actual effectiveness of the sensors while immersed in the water. This test was carried out in the Piovego canal, an artificial channel flowing around the city walls of Padova in Italy: the channel is a tributary of the Brenta river, which eventually flows into the Venice Lagoon. The deployment spot of the SENSWICH can be seen in Figure 5b: the platform was tied to a pole to prevent it from being carried away from the channel current. Together with this deployment, a LoRaWAN gateway was also positioned in the main building of the Department of Information Engineering of the University of Padova, at a distance of around 200 m.

While this experiment was not aimed at testing the long-term operation of the platform, but only to validate the effectiveness of the mechanical structure, the SENSIWCH was kept in the water for around 1 hour. During the deployment period, the structure demonstrated to perfectly float on the water, with a limited imbalance of the structure which was partially immersed in the water (around 5 cm): indeed, since the electronics was not placed in the centre of the structure, the portion of the structure holding it was heavier. However, such imbalance did not interfere with the operation of the system, thus he buoyancy was validated, opening the way for future long-term tests in the Venice Lagoon.



(a) Temperature Profile

(b) pH Profile

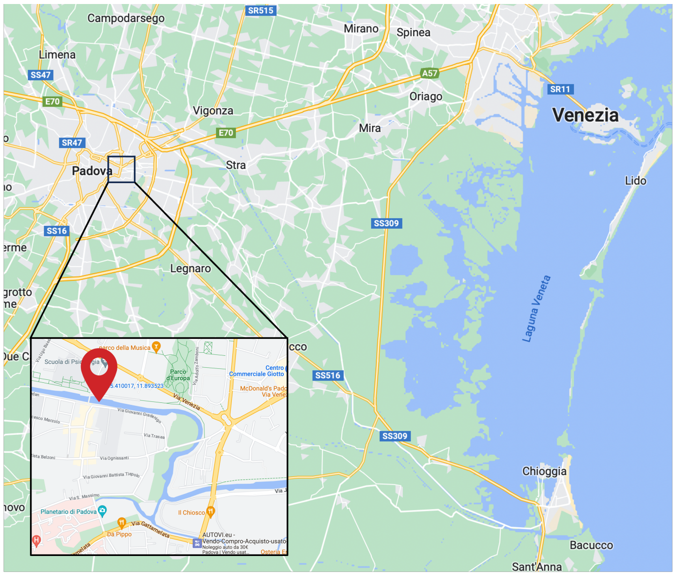
(c) Dissolved Oxygen Profile

Fig. 4: Sample Sensor Readings for a Period of Approximately 48 Hours: Temperature (a), pH (b), and Dissolved Oxygen (c).

VI. Conclusions

The aim of this paper was to present the architecture of a sensor node using LoRaWAN as the transmission technology, to be employed for the pervasive monitoring of the water quality of the Venice Lagoon. Together with the structure of the device, also a set of preliminary tests was presented. These experiments were not conducted directly in the Venice Lagoon, as their main goal was to test the correct operation of the single components as well as of the integrated system in a scenario simulating the final deployment conditions. To this aim, most tests were conducted in our laboratory, with a test performed in the field to validate the mechanical structure.

The positive outcomes of these preliminary tests are being used as a base for the final deployment of the first prototype. Research activities are also ongoing to optimize the functioning of the platform: the two main objectives of our future



(a) Map of the Area

(b) Positioning Site

Fig. 5: SENSWICH Testing Site: Map of the Area (a) and View of the Positioning (b) in the Piovego Canal, Padova, Italy.

work are the simultaneous use of all the sensors with a single MCU and the optimization of the architecture with the usage of low-power components. This last objective also has as a secondary target the reduction of the realization cost of the device, which is crucial to encourage a pervasive adoption of this technology.

Finally, future work will be the realization of a relatively large number of these devices, to set up a pervasive monitoring network throughout the Venice Lagoon, as well as to collect extensive data that may be employed to implement predictive models, e.g., exploiting machine learning algorithms.

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