# OPEN SENSING SYSTEM FOR LONG-TERM, LOW-COST WATER QUALITY MONITORING

**Jitta Jyothsna[1], B. Bhagya Sree[2]**

[1]PG Scholar, Department of DSCE, Shadan Women's College of Engineering and Technology, Hyderabad, jyothsna.sincere@gmail.com

[2]Assoc Professor, Department of ECE, Shadan Women's College of Engineering and Technology, bejjambhagyasree@gmail.com

## ABSTRACT

Water is a major preoccupation for our generation since it is crucial in keeping a healthy ecosystem and supporting biodiversity. The state of aquatic systems and water bodies needs to be continuously monitored to make informed decisions and trigger sanitation when necessary. However, observing and tracking the evolution of many water bodies without disturbing and polluting the biotopes is expensive, not scalable, and thus, infeasible. This article presents a way to make sustainable measurements using a new low-cost, open-source, and autonomous monitoring system deployable in a broad network. The smart buoy is deployed and controlled by a central unit that uses lab-graded sensors to measure ambient factors. The custom electronic board offers sustainable electronics integration emphasizing power path and network connectivity. The smart buoy showed an average power consumption of 1.8 mA and a cost of 932 euros per device. Currently, five spots have been monitored, which allowed the understanding of why biological events, such as a massive fish death, occurred. The system is easily expandable and can be used in various applications to increase the knowledge of the underwater ecosystem.

## 1. INTRODUCTION

Water is the most vital resource of life. Even if it is the most abundant resource on earth (75%), freshwater is less than 3%, and more than 65% of it is locked up in ice caps and glaciers, melting faster than ever due to the actual climate changes. Pollution is a primary concern for water quality. It comes from many sources, including agricultural runoff, sewage, and industrial waste. Pollution can contaminate drinking water and make it harmful for human consumption. It also harms aquatic ecosystems and reduces the quality of life for people who rely on them. Water quality is also threatened by overuse. This can happen when water is withdrawn from rivers and aquifers faster than it can be replenished or when too much water is used for irrigation, leading to soil salt build-up. Water is essential for life, and water quality is critical to support healthy ecosystems and sustain the economies based on them. Consequently, the optimal utilization of water resources and reliable monitoring of water quality is important, especially in the context of a possible future water shortage crisis. Unfortunately, there is still a need for more effective water quality monitoring systems that can provide data over an extended period and cover vast areas with minimum running costs. There are many ways to monitor water quality, but some methods are more effective than others. Classic methods rely on manual sampling and lab analysis, which offers the detection of an extensive range of substances but consumes resources. This is often combined with tools to monitor physical and chemical parameters but with manual sampling involving human supervision. For example, the EXO2 is a multi-parameter water quality sonde with seven sensor ports offering a dynamic range of smart sensors from chlorophyll from algae to fluorescent dissolved organic matter (fDOM). The sonde provides comprehensive multi parameter water quality data, with the SmartQC software ensuring proper calibrations. However, this solution is expensive and time consuming while the ecosystems are dynamic. Thus, it is not conceivable on a large scale. Another way to monitor water quality is to use remote sensing techniques, such as satellites, to detect changes in water quality. Nevertheless, current techniques for assessing water quality do not have enough spatial and temporal coverage. Moreover, specific measurement equipment is expensive, rarely wireless, and low-power. This makes it hard to update, improve and maintain the different devices. Hence, a significant contribution would consist in developing an autonomous, low-cost, wireless system that can monitor several water quality parameters while the measurements could be observed remotely. In the context of the Smart water project, we have developed an economically and energetically efficient smart buoy to monitor surface water bodies in Brussels and to asses in a sustainable way the quality of the aquatic ecosystems of Brussels. The collected data helps to identify those water bodies where action is required. The open-source system focuses on inexpensive and readily available components to reach a wider community. With large community support, the devices will easily be updated, improved, and maintained [1]. The system relies on sensors to detect a range of physical and chemical parameters and to spot substances that may be present in the water. The smart buoy can operate autonomously with minimal human supervision in remote, unmonitored water bodies. Our strong focus on low-power enables long-term operation, which is critical when many robots are deployed. The system contains multiple sensors. The current sensors measure water temperature, pH, dis solved oxygen (DO), electric conductivity (EC), and turbidity. A user interface is provided for data visualization and control. The system has been used to monitor the water quality of different water bodies in Brussels for several months. The data collected by the system has been used to identify trends in water quality and detect pollution events.

## 2. LITERATURE REVIEW

A previous study analyzed the Pandurucan river in San Jose, California [2]. The river was believed to be degrading. How ever, there was no substantial evidence of the water quality, and no scientific study had been carried out to investigate the characteristic of the water and its possible sources of contamination. The methodology consisted of taking samples manually every month. This method is work-intensive but could assess ten different water quality measurement parameters each time. The inconvenience is that the results are analyzed over multiple months and that if a major event occurs, resulting in biological alterations, one could only notice it one month after. The first step toward autonomous monitoring is using sensors in a stationary environment. It is commonly used in hydroponics, aquaculture, and freshwater systems to monitor water's amount of nutrients, salts, and impurities. For example, the more-free electrolyte the liquid contains, the higher the electrical EC. A significant advantage is that action can be delivered immediately after measuring. An example is an aquatic farm, which measures amounts of DO in the water [3], [4]. This shrimp farm located in Taiwan incorporated reaction mechanisms to increase shrimp survival. When the oxygen levels are too low, aerators or alarms are activated, and feeders are suspended. Another system relies on a station located on the river bank, taking hyperspectral images [5]. Now, one can see that taking images in the center of a lake or other aquatic bodies will be impractical, and it is an expensive tool that requires much processing and, thus, energy. Besides stationary measurement techniques, moving monitoring devices are increasingly used in environmental pollution studies. Another system relies on a drone to take a sample from water bodies [6]. However, the device only offers a flight time of 16 minutes if flight conditions are met, after which the sample must be tested. As in [2], the authors take samples one by one every month. This is not an adequate solution for every application. To monitor aquatic bodies adequately, more recurrent or continuous measurements are required. That is why a nearly five meters long solar-powered surface vehicle was developed [7]. It can navigate autonomously and continuously collect key water quality parameters and greenhouse gas emissions through a water column while the vehicle moves. Such measurement system is not conceivable for universal deployment since the vehicle can work autonomously for 24 hours maximum, after which the batteries must be charged or replaced. Other mobile water monitoring systems include satellites and other platforms, such as airplanes, to measure the amount of radiation reflected from the water's surface at various wavelengths [8]. These reflections can be used directly or indirectly to detect water quality indicators, such as total suspended solids (TSS), chlorophyll-a concentration, turbidity, temperature, and pH. Of course, the weather is a critical constraining factor, but this kind of solution can cover larger areas. The last kind of water quality monitoring device addresses underwater measurements [9]. A quick way of measuring deepwater is by pumping water into the robot, which then analyzes it before throwing the water back out. Other systems rely on underwater drones to obtain vertical water quality profiles and collect underwater images [10] [11]. This was done to monitor water quality and local ecosystems' con sequences of implementing large-scale floating solar panels. Autonomous Underwater Vehicles (AUVs) are typically deployed from a surface vessel and can operate independently from that vessel for several hours to several days. Static methods involve reduced costs and high accuracy but, in most cases, consume much power. Moving devices such as boats and planes and underwater robots cannot navigate over long periods unwatched. Those devices are often used for several hours before a charge is needed. Using satellites is not always feasible because it depends on the weather. In addition, covered areas may require much processing, and real-time imaging is often impossible. Ideally, those devices' advantages should be mixed, developing a remote, real-time, and low-power solution. Deploying many low-cost static devices into a wireless network could be adequate. However, Wireless Sensor Networks (WSN) introduce many problems to address, such as energy availability, which is critical when defining a network's lifetime. Other issues include the consideration of the right network to be employed (taking energy problems and cost into consideration), the lack of alternative power solutions, energy optimization techniques for efficient resource allocation and a sustainable network operation, choice of communication technology, the application runtime environment, and simplicity in setting up and configuring the application. Converging to an optimal solution implies carefully evaluating several deployments and runtime under different operational conditions. This is mainly due to the cost of the devices, and their Technology readiness levels (TRL) [12], [13]. Open-source technologies are publicly accessible and free to use and distribute. The proposed open-source technologies include both hardware and software. The advantages of using open-source technologies include that they are usually more cost-effective than proprietary technologies and allow for more collaboration and innovation. Open-source technologies also tend to be more reliable than proprietary technologies since the code is open to scrutiny by anyone. Additionally, with an engaged community, the technology can be spread much more effectively and at a lower cost, which is one of the key factors in such water quality monitoring networks. We have developed a low-cost, autonomous, wireless, water quality monitoring buoy to overcome the previously mentioned problems on scalability, power efficiency, cost, and more. The smart buoy takes measurements every 10 minutes. The data is remotely accessible; thus, issues can rapidly be noticed. Furthermore, the design can be easily adapted to match the target application. The paper is structured as follows: section III-A,III-B, III-C and III-D describe the sensing principles, including the indicator definitions, the electronics, including the main Printed Circuit Board (PCB) and peripherals, the communication system and the mechanical design, which includes the design constraints, requirements, and extensions. Results are discussed in section IV. The results include a cost-and-performance analysis, energy harvesting considerations, deployments in field conditions, and measurement accuracy analysis.

## 3. METHODOLOGS

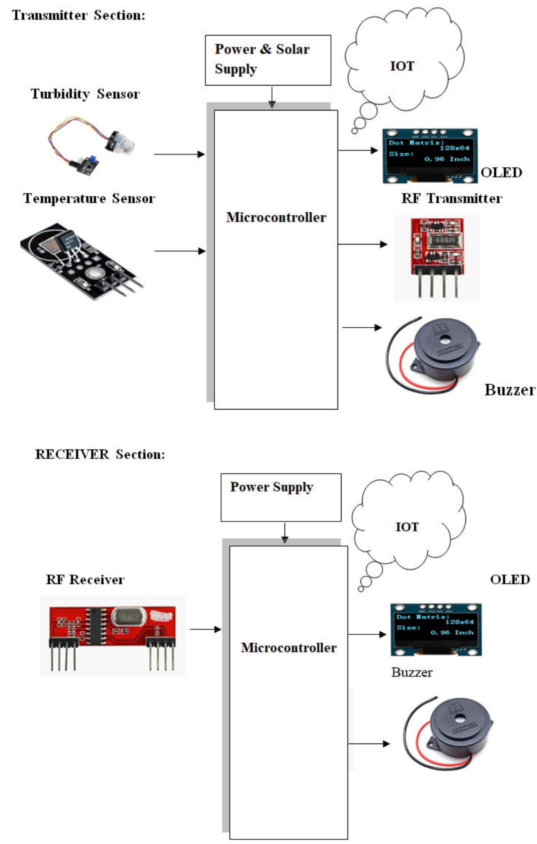
### 3.1 EXISTING SYSTEM

Multi-parameter water quality monitoring is crucial in resource-limited areas to provide persistent water safety. Conventional water monitoring techniques are time-consuming, require skilled personnel, are not user-friendly and are incompatible with operating on-site. Here, a multi-parameter water quality monitoring system (MWQMS) that includes an array of low-cost, easy-to-use, high-sensitivity electrochemical sensors, as well as custom-designed sensor readout circuitry and smartphone application with wireless connectivity. The system overcomes the need of costly laboratory-based testing methods and the requirement of skilled workers. The MWQMS system can simultaneously monitor pH, free chlorine, and temperature with sensitivities of 57.5 mV/pH, 186 nA/ppm and 16.9 mV/°C, respectively, as well as sensing of BPA with <10 nM limit of detection.

### 3.2 PROPOSED SYSTEM

This article presents a way to make sustainable measurements using a new low-cost, open-source, and autonomous monitoring system deployable in a broad network. The smart buoy is deployed and controlled by a central unit that uses lab-graded sensors to measure ambient factors.

### 3.3 BLOCK DIAGRAM




### 3.4 HARDWARE REQURIMENTS

#### 3.4.1 RASPBERRY PI PICO W

**Raspberry Pi Pico W** is **Raspberry Pi**'s first wireless microcontroller board, designed especially for physical computing. It is the successor of the popular **Raspberry Pi Pico** board. Like the Pico board, which we discussed earlier, the **Pico W** board is also built around the **Raspberry Foundation** in-house ARM chip RP2040. The main improvement is the addition .of Wi-Fi and Bluetooth functionality. **Raspberry Pi Pico W** incorporates an Infineon **CYW43439** wireless chip that supports IEEE 802.11 b/g/n wireless LAN, and Bluetooth 5.2.

**Raspberry Pi Pico Vs Raspberry Pi Pico W**

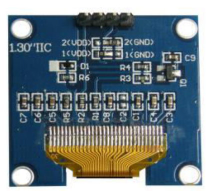
The main difference between the **Pico** and **Pico W** is the inclusion of Infineon's CYW43439 2.4-GHz Wi-Fi chip, which is responsible for Wi-Fi and Bluetooth. Another major change is with the power section. The new Pico W uses the **RT6154A** from **Richtek** as the power regulator instead of the **RT6150B** in the original Pico design. The debug port also moved near the SoC to make space for the Wi-Fi antenna.

**Raspberry Pi Pico W Specifications:**

The key features of Raspberry Pi Pico W are the following:

- **RP2040** microcontroller chip designed by Raspberry Pi in
- **Dual-core ARM Cortex M0+** processor, flexible clock running up to 133 MHz
- 264kB of **SRAM**, and 2MB of onboard Flash memory
- On-board single-band 2.4GHz wireless interfaces (802.11n)
- Castellated module allows soldering directly to carrier boards
- USB 1.1 Host and Device support
- Low-power sleep and dormant modes
- Drag & drop programming using mass storage over USB
- 26 multi-function GPIO pins
- 2×SPI, 2×I2C, 2×UART, 3×12-bit ADC, 16×controllable PWM channels
- Accurate clock and timer on-chip
- Temperature sensor
- Accelerated floating point libraries on-chip
- 8×Programmable IO (PIO) state machines for custom peripheral support

**3.4.3 OLED (Organic Light Emitting Diodes)**



OLED (Organic Light Emitting Diodes) is a flat light emitting technology, made by placing a series of organic thin films between two conductors. When electrical current is applied, a bright light is emitted. OLEDs are emissive displays that do not require a backlight and so are thinner and more efficient than LCD displays (which do require a white backlight).

OLED displays are not just thin and efficient - they provide the best image quality ever and they can also be made transparent, flexible, foldable and even rollable and stretchable in the future. OLEDs represent the future of display technology!

**Specifications**

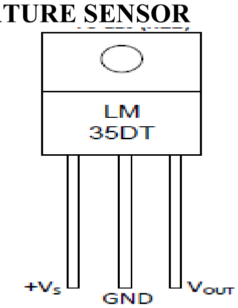
- ✓ Use CHIP No.SH1106
- ✓ Use 3.3V-5V POWER SUPPLY
- ✓ Graphic LCD 1.3” in width with 128x64 Dot Resolution
- ✓ White Display is used for the model OLED 1.3 I2C WHITE and blue Display is used for the model OLED 1.3 I2C BLUE
- ✓ Use I2C Interface
- ✓ Directly connect signal to Microcontroller 3.3V and 5V without connecting through Voltage Regulator Circuit
- ✓ Total Current when running together is 8 mA - PCB Size: 33.7 mm x 35.5 mm

**3.4.4 TURBIDITY SENSOR**

**Sensor Specification**

1. Operating Voltage: 5V DC
2. Operating Current: 40mA (MAX)
3. Response Time: <500ms
4. Insulation Resistance: 100M (Min)
5. Output Method: Analog
6. Analog output: 0-4.5V
7. Digital Output: High/Low-level signal (you can adjust the threshold value by adjusting the potentiometer)

**3.4.5 TEMPERATURE SENSOR**




**Pin Definition**

The definition of gray-scale sensor pin is

1. Signal Output
2. GND
3. Power

**Features Of Temperature Sensor**

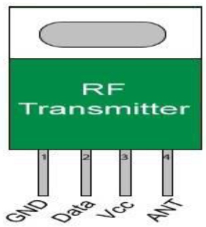
- Calibrated directly in Celsius (centigrade)
- $0.5^0$ C Ensured accuracy (at $+25^0$ C)
- Suitable for remote applications
- Operate from 4 to 30 V
- Low cost due to wafer-level trimming

**Specifications**

- Type: Analog
- Sensitivity: 10mV per degree Celsius
- Functional range: 0 degree Celsius to 100 degrees Celsius

### 3.4.6 RADIO FREQUENCY (RF) MODULE

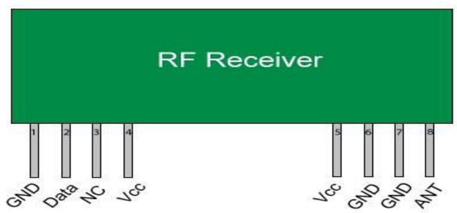
**RF TRANSMITTER**




**Pin Description of Transmitter**

- Pin 1: Ground (0v)
- Pin2: Input pin for data from encoder
- Pin3: Supply (+5v)
- Pin 4: Pin for external RF antenna

**RF RECEIVER**




**Pin Description of Receiver**

- Pin1: Ground (0v)
- Pin2: Output Pin For Digital Data Received
- Pin 3: Output Pin For Analog Data Received
- Pin4: Supply (+5v)
- Pin5: Supply (+5v)
- Pin6: Ground (0v)
- Pin7: Ground (0v)
- Pin 8: Pin For External RF Antenna

**RF Advantages:**

1. Not line of sight
2. Not blocked by common materials: can penetrate most solids and pass through walls
3. Longer range
4. Not light sensitive
5. Not as sensitive to weather/environmental conditions

**RF Disadvantages:**

1. Interference: communication devices using similar frequencies - wireless phones, scanners, wrist radios and personal locators can interfere with transmission
2. Lack of security: easier to "eavesdrop" on transmissions since signals are spread out in space rather than confined to a wire
3. Higher cost than infrared
4. Federal Communications Commission(FCC) licenses required for some products
5. Lower speed: data rate transmission is lower than wired and infrared transmission

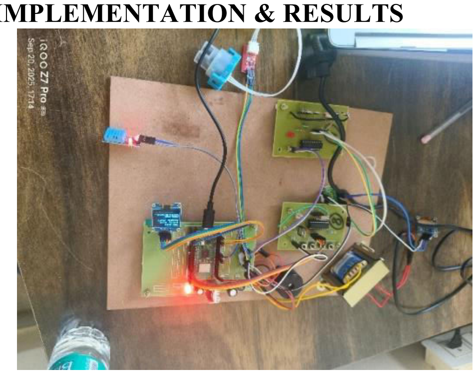
### 3.4.7 BUZZER

Fig. Buzzer

**USES**

- Annunciator panels
- Electronic metronomes
- Game shows
- Microwave ovens and other household appliances
- Sporting events such as basketball games
- Electrical alarms

## 4. IMPLEMENTATION & RESULTS



## 5. CONCLUSION

This paper presents a new low-cost, open-source, and autonomous water-quality monitoring system that can track the evolution of many water bodies without disturbing or polluting the biotopes. The smart buoy takes measurements every 10 minutes and can be produced easily (due to the open-source aspect) and massively (due to the low-cost aspect). Moreover, the results are remotely accessible; thus, issues can rapidly be noticed. Furthermore, the design can be adapted to match the required application. The system is expandable and can be used in various applications to increase our knowledge of the underwater ecosystem. This technology can be reproduced and reach a large community thanks to these characteristics. The goal is to help spot and sanitize where needed aquatic biotopes that we have mistreated for too long. The Smart Buoy has been deployed in the context of the Smart Water project. It is a collaborative (ULB, VUB, Brussels Environment, Brussels Marina, Brussels sewer museum, ...) and citizen project. It invites everyone to monitor the water quality of ponds and rivers in Brussels and thus contribute to its improvement. This paper describes the sensing principles, including the indicator definitions. Then describes the electronics, including the main PCB and peripherals. This is followed by the mechanical design, which includes the design constraints, requirements, and extensions. The results include a cost and-performance analysis, energy harvesting considerations, deployments in field conditions, and measurement accuracy analysis. One smart buoy cost 932 euros and can be deployed for six months (depending on the battery size, an average of 1.83mAh) without energy harvesting devices. The tested solar panels performed very well, averaging 239.8mWh, while the smart buoy requires approximately 6mWh. The smart buoy is fully functional but will benefit from regular updates from the Smart Water project and the emerging community. Some improvements include changing from sensor boards. The EZO sensor boards are not meant to be soldered by hand. Those are very fragile; manipulating them falsifies the results and even causes irreversible damage in some cases. The next smart buoy version will welcome two printed circuit boards instead of one to overcome this issue. The extra PCB will be populated with the isolator- and EOM boards (smaller, more affordable, and better characteristics). The shell's resistance will be further analyzed to estimate its lifetime, and an adapted solar installation will be proposed.

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