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# Development and Testing of an Autonomous Surface Vehicle for Real - Time Water Chemistry Monitoring in Freshwater Ecosystems.

**Abstract:** Water purity is essential for ecosystem health, pollution management, and public safety. Data collection delays, high costs, limited scalability, and poor real-time capabilities plague traditional water monitoring technologies. Static sensors and manual sampling are inefficient for large or dynamic water bodies. This paper suggests an IoT-enabled real-time water monitoring system to solve these challenges. Advanced sensors upload pH, temperature, turbidity, dissolved oxygen, and total dissolved solids data to the cloud for quick analysis. Multi-class categorisation using machine learning allows precise trend tracking and prediction. Mobile sensors provide more flexibility and dynamic coverage than static systems. Optimised hardware and cloud-based design decrease expenses and generate a predictive database for improved decision-making. Scalable, cost-effective technology promotes sustainable water management, pollution control, and environmental conservation, addressing gaps in prior techniques and helping global environmental objectives.

**Keywords**: *Quality of water; embedded systems; Internet of Things (IoT); water purity; pH; data analysis and unmanned surface vehicles (USV)*

## 1. Introduction

Water is one of the most essential natural resources for life. While there is enough water on Earth to meet everyone's needs, its availability is unevenly distributed across the globeThis uneven distribution, combined with the declining quality of water due to pollution and overexploitation, makes it difficult to access and utilize effectively. Addressing these challenges requires innovative strategies and sustainable management practices to ensure clean and equitable access to this vital resource. [1]. The need to protect water resources is growing in importance as the number of people on Earth increases. Water condition is determined by a number of factors, including the level of water, pH level, fluidity, and the saltiness of the samples.[2]

People have been working hard to make the best use of this valuable resource. It is important to keep track of supply so that you can meet people's changing quality and number needs [3]. The quality of water is based on its chemical, physical, and biological features. Freshwater supplies have been used up by industrialization [4]. Human activities and the exponential rise in human population have caused surface water pollution worldwide, particularly in rivers, lakes, and the ocean. Surface water supplies that are safe and clean are essential for the environment, economy, aquatic ecology, and general health and welfare of people. In order to assure that there is little to no pollution in the water sources, water monitoring is needed.[5]. There is an broadening need to establish a mechanism to improve the efficiency of current water standards assessment methods.[37]

Millions of people suffer from illnesses caused by consuming contaminated water. The availability of clean water sources is diminishing due to pollution from waste disposal, industrial discharge, and natural phenomena like acid rain [6]. In countries such as Bangladesh, where the garment industry dominates, the dumping of industrial waste into rivers and canals has reached critical levels [7]. This has led to a significant decline in water condition, threatening aquatic ecosystems and wildlife [8]. In an industrialized world, real-time water condition monitoring is essential to ensure an adequate supply of clean water for human consumption. A low-cost, self-assembled sensor with minimal power consumption and compact transmission capabilities is effective for potable water monitoring systems [9].

## 2. Motivation And Contribution To The Paper

A lot of study has been done on water pollution on different countries so that trends in water condition factors can be found. Based on the situation, we can say that we can safeguard water bodies around the globe from these

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kinds of accidents if the tracking process is made self-sufficient, cheap, and accurate. Monitoring the state of the water is the first step in managing water supplies. [10] The need for effective and approachable techniques of evaluating water is rising as worries about its quality rise.[11].

The technology and form of the tools used to check the quality of water have been changing a lot. To get the most information possible [12].The increasing need for automated platforms for inspection, surveillance, and monitoring has led to a constant growth in the requirement for Unmanned Surface Vessels (USVs) in recent years.[13]

Water systems must be continuously monitored to ensure their safety. A smart water monitoring system, utilizing the Internet of Things (IoT) framework, was developed to safeguard water resources and maintain purity in real-time [14]. Quality of water tracking programs look for problems' causes and guess what solutions might work. To save time on research, we might want to do an initial study using the public reports [15]. This lets us select out and collect only useful data. Before planning starts, a scouting study is done to look at the different sources of trash and how they affect the pollution, uses, and abstractions of water. If a geographic, A topographical study is done [16]. Right now, water samples are collected by hand from various locations and depths so that they can be tested in labs. Sensors put at different depths in the water are used for electronic tracking. These methods, on the other hand, are very expensive and take a lot of time. Our method is different because we use a USV, put sensors in different places, and take data automatically without using any water.

The remaining part of the article is as follows: The relevant work has been presented in Section 3. In the same vein, I have finalized Section 4, which pertains to the identification and problem statement. I have demonstrated the monitoring of water condition through infrastructure in Section 4.1, which is further elaborated upon in Section 4.2 as real-time water condition monitoring using sensors. System architecture and modeling were explained in Section 5. I have addressed the results and the subsequent discussion in Section 6. The lastsection we discussed about the conclusion and future work of the article.

## 3. Related Work

To make a good model, we looked at a number of different systems that had already been made by experts. Several writers have come up with different ways to check the quality of water by looking at things like temperature, pH, conductivity, and so on. Taking all of these things into account, we created a smart water monitoring system that can do all of these tracking tasks. Stephen Brosnan looked into a WSN to get water condition data (WQP) in real time. Quio Tie-Zhn created an online method for checking the grade of water using GPRS and GSM.[15]. This data was sent over a GPRS network, which allowed the WQP to be checked from afar. By using ZigBee and WiMAX networks, Kamal Alameh showed a web-based WSN for keeping an eye on water pollution. For real-time monitoring of water condition from far away, the system took measured data from sensors, processed it, and sent it to a web server through a ZigBee gateway and the WiMAX network. Ring a bell He created a WQM method using WSN.[16]. The instrument that was far away used the ZigBee network. WSN tried WQP and used GPRS to send info to the Internet. A virtual computer was used to gather information with the help of the Web. IoT devices are used in a low-cost system for real-time tracking of water condition. The sensors check many important physical and chemical factors of the water. [17]. Conditions of water can be tested, including its viscosity, temperature, pH, and dissolved oxygen conductivity. Within our project, we suggested using IoT to create a method for checking the quality of water.

## 4. Problem Statement And Multi-Layer Problem Formulation

The US Environmental Protection Agency (EPA) reports that in North America, approximately 47% of stream miles, 65% of lake acres, and 33% of bay and estuary square miles are too polluted for recreational activities such as swimming and fishing. [18].

A study from 2015 on the state of the environment in China said that the country's general water purity problem is "Average." Pollution in groundwater has been getting worseninig since 2011, going from "bad" to "very bad" in 2014. In 2014, 16.1% of groundwater was considered "very bad," up from 15.7% in 2013.

That is, the amount of water that was "unfit for human touch" rose from 28.3% in 2013 to 28.8% in 2014 [19]. In India, the highly crowded Ganga river is home to 37% of the country's people and covers eight states. From 1997 to 2013, records show that the average BoD amount was about 12 mg/liter [20].

The Matanza-Riachuelo River (MRR) in South America is also known as the Slaughterhouse River[36]. Every day, about 8.3 tonnes of oil and 82,000 cubic metres of industry waste mix with the river. 21% of the waste comes from dumping by the meat, tannery, and dairy industries.

The textile and paper industries, the metallurgical industry, and the food and beverage industry all give 14%, 11%, and 7%, respectively. The rest is made up of garbage, chemicals, and trash from cities [21].

In 2014, a study of the Buriganga River in Bangladesh found that the liquid oxygen level is zero at 4 of the 9 places along the river.For the last five, the average amount of liquid oxygen is 1.8. BoD of water is seen to be able to handle levels between 2 and 6. A study done by the BUET Civil Department in January 2007[22] found that the BoD in the Hazzaribagh area of Buriganga is 29. Among the most tainted rivers in the world, the Citarum River in Indonesia worries untreated industrial waste and home garbage. Every day the Citarum River receives 280 tons of industrial garbage in addition to 25000 cubic meters of home waste [23].

Southern Italy's Sarno River is among the most contaminated rivers in Europe.Although the river's higher extents remain less polluted, chemical foam and greasy scum infect lower raised areas. The river still mostly contributes polymers of aromatic chemicals (PAHs), the main carbon-based pollution in the Bay of Naples, from the industrial, agricultural, and municipal wastes.[24].

Monitoring water condition is essential for recognizing current and potential concerns. For instance, evidence shows that food manufacturing fertilizers increased globally nitrogen pollution in rivers by 20% in recent years.

The literature and data suggest that the Amazon, Uruguay, and Plata rivers are poisoned and dangerous. One aspect of water condition is the total amount of suspended particles (TSS) measure for silted rivers that carry harmful chemicals, reducing bioavailability. These rivers are very contaminated and require powerful technology to minimize toxicity and prevent additional harm [25-27]. Water condition data is used to establish pollution prevention and control strategies.

Monitoring is quite beneficial. Water condition objectives must be met by governments, communities, and companies. Pollution compliance is assessed using monitoring data. From oil spills and radiation leaks to flooding and widespread erosion, water condition monitoring is essential for emergency planning [28].

### 4.1 Infrastructure for Monitoring Water Condition

The majority of developing countries use manual labor. In addition, real-time sensor nodes are not widely used in wealthier countries. In order to assess exploitation and pollution, parameter values are contrasted with standard levels.

Different information is represented via parameters. Manual sampling involves acquiring water samples using containers from various points and depths. Samples are used in laboratory evaluations. Within two weeks, results are received. Following transmission of the reports, decisions are taken. In India, there is a vast network of 2500 stations for monitoring water condition. For surface rivers and lakes, monitoring is done every month or every quarter; for groundwater, it is done twice a year. There are 154 lakes, 25 channels, 45 drains, 78 ponds, 41 creeks/seawater, 10 water treatment plants (raw water), and 445 rivers in this network. In addition, there are 807 groundwater stations, 191 lakes, 44 drains, 42 canals, 13 tanks, 41 creeks/seawater, and 79 stations on rivers. The waterboard organizations use a manual method for collecting samples in these regions. [3] .

### 4.1.2 Water Standards Sensing Units

Several prosperous nations chose to use high-tech solutions to the issues that came up with tracking water condition by hand. First, they set up the "Real-Time Water Safety Tracking Network" across river basins using Wireless Sensor Networks, or WSN, [29,30] to check different aspects of water condition. pH, contamination, conductive properties, thermal levels, oxygen concentration, ammonia content, biological oxygen demand, chemical oxygen requirement, nitrate compounds, and chlorine salts are the factors that are monitored in real time [36].The central station collects data from all related stations, and the stations are functioning. A wireless sensor network, or WSN, gathers data from sensors submerged in water to monitor water condition, uphold use standards for water resources, and repair damaged water bodies. AWSN, which blends high-power distribution ZigBee-based technology with an IEEE802.15.4 compatible transceiver, is extensively utilized because to its simple implementation, cost-effective, power-efficient, dependable, and very scalable [31]. Each water condition tracking station operates as a GSM or GPRS gateway to make it easier to connect to the central receiving station. This station has software for gathering data, analyzing it, showing it, and making reports. The central receiving station provides the data to the board's zonal offices and pollution control boards**.**

### 4.2 Problem Formulation

Global water pollution statistics highlights alarming trends in rivers, lakes and ground-caused by industrial waste and agricultural run-off.In traditional monitoring methods , a number of drawbacks with this approach included random monitoring frequency, human error in the lab during sample collection and processing, inadequate dataset/survey, and an increased number of sampling sites. Additionally, in sensor based water monitoring there are a number of drawbacks to this approach, including low data variety, sensor node maintenance costs, and sensor node costs. The study focuses on addressing the limitations of traditional water condition monitoring systems by developing a cost-effective methodology that reduces substantial expenses. It seeks to design a system capable of traversing diverse water bodies and predicting their characteristics using advanced sensor technologies. Additionally, the study emphasizes analyzing and refining the proposed model through computational algorithms to ensure accuracy and efficiency. Finally, it aims to establish a pollution prevention and control framework by utilizing data collected from sensor-based monitoring systems.

## 5. Proposed Framework For Checking Real-Time Water Standards

Researchers have found that improvements in data processing can be used to keep an eye on water condition. Instead of just using traditional tracking methods like water sampling by hand and sensor node approaches using WSN, USVs (Unmanned Surface Vessels) and IoT (Internet of Things) could be used. [32]. Tracking and keeping an eye on the many aspects of water condition, such as pH, oxygen concentration, temperature, conductance, etc.), an engineering approach was presented. The suggested approach gave a thorough report on the quality condition of many geographically different locations of the water body under observation for a specific water body. Utilizing SVs has several benefits, the most important of which is the ability to examine the water surface quality in very remote and unreachable regions. Additionally, the likelihood of missing a specific river zone will be decreased by the USV-based technique [33].

To achieve this goal, this system used a combination of hardware and software technologies working together to build a standard integrated circuit. An unmanned surface vehicle (boat) was the technology that made up the embedded system. Data analytics was a component of the software back-end technological stack. The user or pollution control board was provided with a front-end portal that displayed all the high-quality data that came from the back-end portion. The three levels of functionality that made up the overall system were System directions, gathering and transmitting data, and producing reports on the water state [34,37].

During operation, they communicated with one another. This unit's parts included a brushless out runner with and electronics pedal controller that operated the system's throttle unit. This device supplies the system with the necessary level shifters at the various locations. The microcontroller APM 2.8 was used as the focal point for managing every operation inside the navigation unit. On the GCS (Ground Control Station), RF telemetry was utilized to maintain control and track system status. The system's localization and mapping were aided by the camera, IMU, GNSS, and magnetometer, which supported the semi-autonomous characteristics. The IoT and data gathering unit included all the required connectivity modules and sensors [35,36].

These subsystems gathered data on the pH, temperature, DO, turbidity, and other aspects of water condition. The primary server or cloud, which served as the data center, then received all of the real-time data that had been gathered. It was simpler to send the data in real-time using the Adafruit cloud service in this instance. Keeping the enormous quantity of data off-board was not always feasible, thus cloud storage provided an effective means of gathering and storing it. In addition, data security is maintained while facilitating simple data retrieval from the cloud. With appropriate level shifters installed where needed, the power supply unit ran the whole system.Here, a lithium polymer battery served as the primary powersource. The battery's state of charge was ascertained by use of sensors for voltage and current. When the battery level was crucial, the navigation was optimized by the intelligent battery monitoring device.

## 6. Results and Discussions

Figure 1 illustrates the approach used to achieve the stated goal. Real three-phase AC brushless motors were employed, controlled by an Electronic Speed Controller (ESC) with a trapezoidal wave generator. The ESC generated three distinct waves, one for each motor cable. The motor's speed was determined by the current's timing, with voltage and amperage having no direct effect. The ESC regulated rotational speed based on the trapezoidal wave's frequency by reversing the polarity of the phases, allowing alternate voltage flow through the windings. This "push-pull" effect created magnetic field changes, enhancing the motor’s power relative to its size. The motor's load affected the battery and ESC's amp draw.

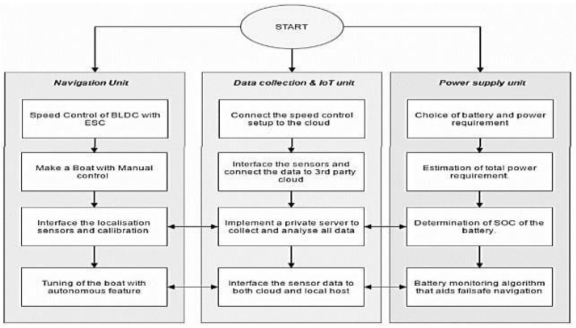


Fig.1. A methodical approach to deploying an automated water condition monitoring system

The motor's speed was controlled through a third-party cloud service using a 50 Hz PWM signal with varying duty cycles. The ESC operated within a range of 950 µs (maximum reverse), 1500 µs (halt), and 2500 µs (maximum forward).

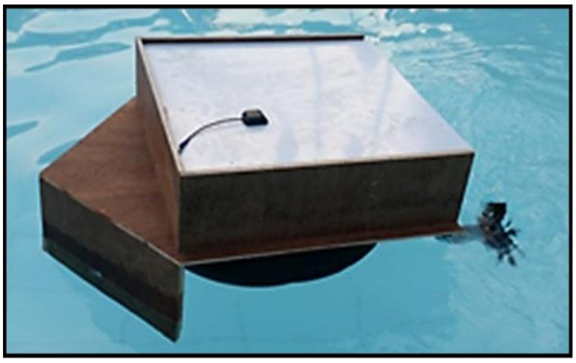


Fig 2. The wirelessly operated surface vehicle's first iteration

Design and Construction: Figure 2 illustrates the initial prototype system, which featured a two-way propeller design constructed using a 6 mm foam board and 2.5-inch diameter PVC tubing. This prototype utilized separate devices for data transmission, data collection, and navigation, with geotagging capabilities enabled by a GPS module.

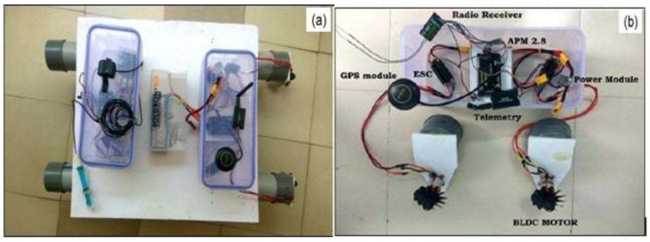


Fig 3. An first look at the suggested view from above the system., showing (a) the electrical system and (b) the parts

Figures 3a and 3b showcase the circuit layout and components of the fully functional system. Key features of this version included variable-speed propeller control, data transmission to a third-party cloud with geotagging, collection of pH and turbidity data, and Wi-Fi-based navigation in manual mode with a range of up to 3.4 km..

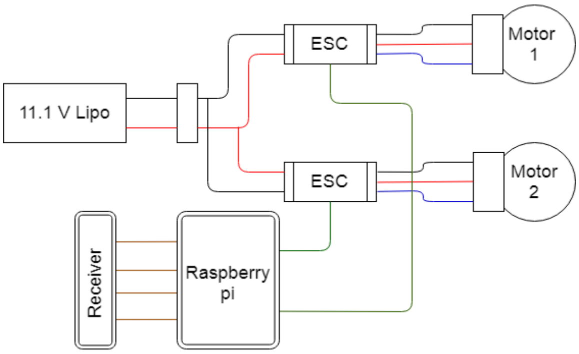


Fig 4. The unmanned system's navigation unit's circuit diagram.

Figure 4 exhibits the USV’s navigation unit circuit diagram.The navigation unit, powered by a Raspberry Pi 3, was selected for its superior clock speed, robust connectivity options, and overall ease of use.

Second Iteration of the System : The second iteration of the system, shown in Figure 5, was constructed using the same materials as the first prototype but featured several enhancements.

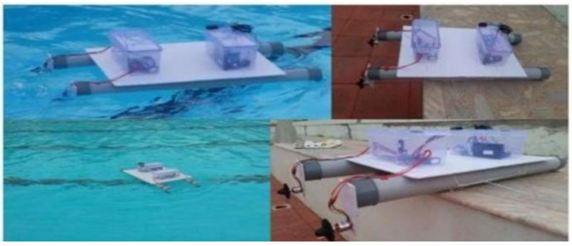


Fig 5. The wirelessly operated surface vehicle in its second iteration

This iteration incorporated distinct components for power supply, data retrieval, and navigation, along with support for a Ground Control Station (GCS). Key features included differential speed control for the propellers, data capture of temperature, pH, and telemetry using an ArduPilot-based GCS, geotagged data transmission to third-party clouds, and localization with wireless navigation in manual mode, covering distances of up to 4 km. The firmware was configured using the "Rover" setup to enable boat functionality, and Mission Planner was employed for calibrating sensors such as the GPS module, accelerometer, gyroscope, and magnetometer. Navigation in AUTO mode relied on an external compass integrated with the NEO-7M u-blox GPS module, allowing precise directional control. Up to three compasses could be connected, with one primary compass designated for navigation.

Testing and Results : The testing area included ten local ponds, where locals use the water for bathing cattle and washing clothes (Figure 6).

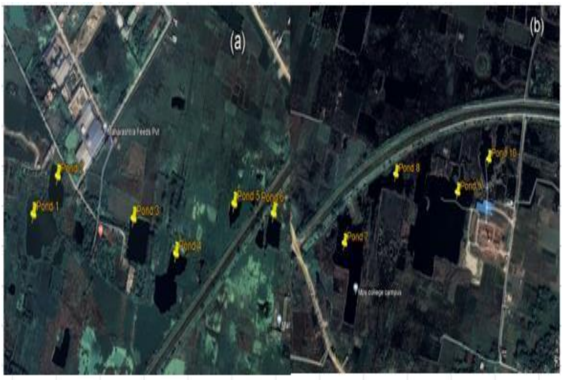
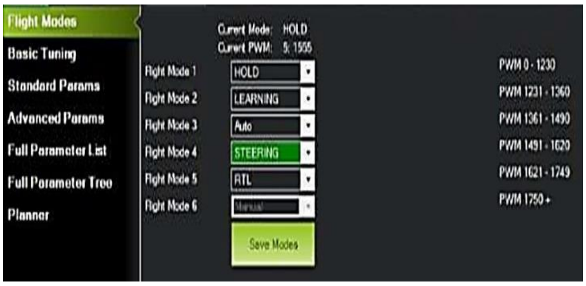


Fig 6. (a) Pond 1 to 6 (b) pond 7 to 10

The autopilot modes were managed via GCS, mission commands or a radio transmitter (Figure 7). The prototype development demonstrated a cost-effective solution, addressing both internal and external challenges.



Current Mode: HOLD
Current PWM: 5: 1555

| | | |
|---|---|---|
| Flight Mode 1 | HOLD | PWM 0 - 1230 |
| Flight Mode 2 | LEARNING | PWM 1231 - 1360 |
| Flight Mode 3 | Auto | PWM 1361 - 1490 |
| Flight Mode 4 | STEERING | PWM 1491 - 1620 |
| Flight Mode 5 | RTL | PWM 1621 - 1749 |
| Flight Mode 6 | Manual | PWM 1750 + |

Fig 7. Multiple methods of operation for the suggested boat navigation system.

Internal System Challenges:  Navigation consumed most of the energy. A twin-propeller system powered by two motors carried a maximum payload of 4 kg and had a runtime of up to 1 hour. While autonomous navigation was enabled by a combination of camera, GNSS, IMU, and ultrasonic sensors, the system still required manual intervention 30% of the time.

External System Challenges: The boat's speed was insufficient for large water bodies, and it lacked waterproofing, making it unsuitable for use in high-wind or high-wave conditions.

Data Collection and Mapping: Temperature and pH levels were tracked during tests in ten ponds (Figure 8.1.a and 8.1.b).

Fig 8.1: Temp map average value of ten pond is  31.23 ℃.

Fig 8.2: pH map – Average value of ten pond is 10.62

The route for the test ride is shown in Figure 9.

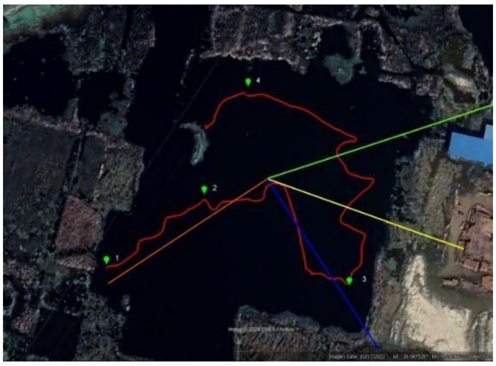
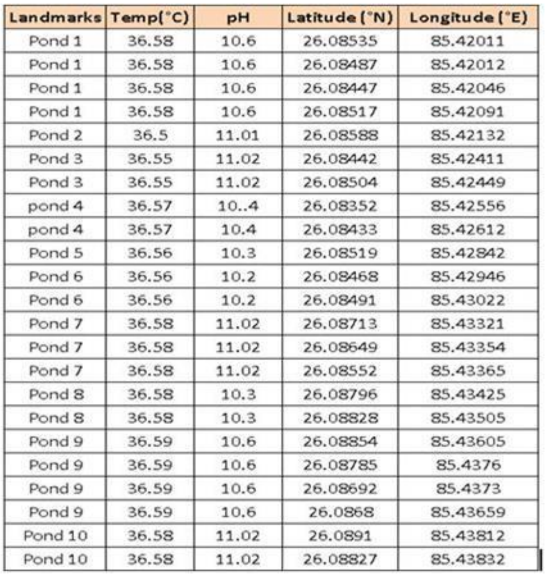


Fig 9: Performed a test drive of the self-sufficient water condition monitoring vehicle.

and the collected data, including latitude, longitude, pH, and temperature, is summarized in Table 1 below.

Table 1: The experimental system was deployed on the ten ponds located near my residence and college, and the parameters like temperature and pH were monitored. The original dataset that was downloaded from the cloud after the operation was finished.



| Landmarks | Temp(°C) | pH | Latitude (°N) | Longitude (°E) |
|---|---|---|---|---|
| Pond 1 | 36.58 | 10.6 | 26.08535 | 85.42011 |
| Pond 1 | 36.58 | 10.6 | 26.08487 | 85.42012 |
| Pond 1 | 36.58 | 10.6 | 26.08447 | 85.42046 |
| Pond 1 | 36.58 | 10.6 | 26.08517 | 85.42091 |
| Pond 2 | 36.5 | 11.01 | 26.08588 | 85.42132 |
| Pond 3 | 36.55 | 11.02 | 26.08442 | 85.42411 |
| Pond 3 | 36.55 | 11.02 | 26.08504 | 85.42449 |
| pond 4 | 36.57 | 10..4 | 26.08352 | 85.42556 |
| pond 4 | 36.57 | 10.4 | 26.08433 | 85.42612 |
| Pond 5 | 36.56 | 10.3 | 26.08519 | 85.42842 |
| Pond 6 | 36.56 | 10.2 | 26.08468 | 85.42946 |
| Pond 6 | 36.56 | 10.2 | 26.08491 | 85.43022 |
| Pond 7 | 36.58 | 11.02 | 26.08713 | 85.43321 |
| Pond 7 | 36.58 | 11.02 | 26.08649 | 85.43354 |
| Pond 7 | 36.58 | 11.02 | 26.08552 | 85.43365 |
| Pond 8 | 36.58 | 10.3 | 26.08796 | 85.43425 |
| Pond 8 | 36.58 | 10.3 | 26.08828 | 85.43505 |
| Pond 9 | 36.59 | 10.6 | 26.08854 | 85.43605 |
| Pond 9 | 36.59 | 10.6 | 26.08785 | 85.4376 |
| Pond 9 | 36.59 | 10.6 | 26.08692 | 85.4373 |
| Pond 9 | 36.59 | 10.6 | 26.0868 | 85.43659 |
| Pond 10 | 36.58 | 11.02 | 26.0891 | 85.43812 |
| Pond 10 | 36.58 | 11.02 | 26.08827 | 85.43832 |

Fig 10.1 : Average value of pond no. 9 with ph 10.6 and the four coordinations where the sample was collected.

Fig 10.2 : Average Temp value of pond no. 9 is 36.59(°C) and the four coordinations where the sample was collected.

For the ten ponds, average pH and temperature values were analyzed (Figures 10.1 and 10.2 is specifically for pond no 9). By the end of the mission, 3542 data points were collected. Using MATLAB, the data underwent a "creaming" process to generate concentration maps. The Google Earth Toolkit mapped the processed data, allowing visualization of parameter variations and pollution sources. For Pond 9, the mapped region measured 33 by 13 square meters.

The experimental system demonstrated significant potential but faced limitations, such as incomplete autonomy and occasional data loss. GPS localization had a 4-6 meter tolerance, and data transfer delays averaged 13 seconds. Despite these drawbacks, the prototype provided an economical solution for water condition monitoring and geo tagged data collection.

## 8. Conclusion and Future Work

An important part of protecting the environment and people's health is making sure that water quality is checked regularly and on time. People still use the old-fashioned way of checking water by hand, but it takes a long time and a lot of work. They don't always have the accuracy and regularity needed for frequent or large-scale tracking, which leaves room for mistakes and waste. Also, coverage is often limited in large or faraway areas of water, and accuracy is sometimes lost because of human error and problems with logistics. Nodal network methods have been looked into as a way to get around these problems. Sensor nodes are placed all over the body of water to collect and send data. This makes tracking the water state automatic. Nodal networks work well in some situations, but they have some problems too, like high start-up costs, hard to understand upkeep needs, and limited ability to grow in large water systems. This study suggested that an Unmanned Surface Vehicle (USV) could be a creative and useful way to deal with these problems. Internet of Things (IoT) technologies and high-tech devices are used by the USV to fully automate tracking of water conditions. The USV makes it easier, more accurate, and faster to get important water condition factors like temperature and pH levels without having to do it by hand.The study explained a system that was very good at keeping track of temperature and pH. All the data it collected was consistent and accurate. The design of the system made it possible for it to work on its own, even in difficult situations. This made it a reliable way to check on the water state. The USV-based method has a number of important benefits that make it an excellent choice for checking the state of water. In the long run, the method saves a lot of money because it cuts down on the need for people and resources. Its ability to connect to Internet of Things (IoT) technologies allows for real-time tracking, which gives you accurate information about the water's state and helps you make better decisions. The controlled structure of the system also makes it possible to cover big areas quickly and effectively, which isn't possible with traditional methods. It can also be expanded to cover more areas. The USV is also a reliable and repeatable tool for checking the state of water because it requires less human involvement, which improves the accuracy and regularity of data collection. The system's performance was completely tried in a number of different situations, and it was shown to work perfectly in all of them. The study showed that the USV has the ability to change the way water conditions are monitored, which makes it a very efficient and cost-effective way to control the environment in real time.As a next step, this study will create a way to test water quality and guess its features using IoT devices, which will then be checked for accuracy using computer programs. For real-time tracking, a pollution control plan based on data will be made. The collected data will also be used with machine learning methods to look at the water quality, find trends, and make better estimates. The method will be proven to work by showing that it is more cost-effective than other methods.

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