Grenze International Journal of Engineering and Technology, January Issue

IoT based Water Quality Monitoring System

Smita Bhagwat[1], Shantanu Jadhav[2], Shankar Jadhav[3], Pragati Jadhav[4], Prathmesh Jadhav[5] and Pritish Jadhav[6]
[1-6]Vishwakarma Institute of Technology, Pune, India
Email: smita.bhagwat@vit.edu, shantanu.jadhav24@vit.edu, shankar.jadhav24@vit.edu, pragati.jadhav24@vit.edu, prathmesh.jadhav241@vit.edu, pritish.jadhav24@vit.edu, aneesh.biyani241@vit.edu

***Abstract*—Water quality monitoring is a global challenge due to rapid urbanization and industrialization. Conventional laboratory testing is time-intensive and geographically restricted. This paper presents an IoT-enabled autonomous RC platform for real-time water quality monitoring. Equipped with pH, turbidity, and temperature sensors, the system performs dynamic sampling across diverse aquatic environments. Unlike previous works, this study introduces an error-aware calibration framework considering least count, absolute, and relative error, thereby enhancing measurement credibility. A dataset was collected from five distinct sites—college pond, local river, urban drainage outlet, agricultural canal, and industrial discharge. Results show significant differences across sites, with acidic contamination and high turbidity detected in urban and industrial regions. A Water Quality Index (WQI) was computed for each location, supported by error bars in graphical analysis. Finally, a predictive analytics framework for future deployment is proposed. The proposed system demonstrates a scalable, low-cost, and accurate solution for environmental monitoring.**

***Index Terms*— Arduino microcontroller, HC-05 Bluetooth module, Internet of Things (IoT), pH sensor, remote sensing, temperature sensor, turbidity sensor, water quality monitoring.**

I. INTRODUCTION

Freshwater resources are increasingly under stress due to rapid industrialization, urban expansion, and intensive agriculture. According to the World Health Organization (WHO), nearly 2 billion people worldwide are drinking contaminated water, which can cause serious health issues and negatively impact the economy [1]. This makes monitoring water quality—like measuring pH, turbidity, and temperature—essential for protecting human health, preserving ecosystems, and supporting sustainable development goals (SDGs). Traditional water quality monitoring methods rely on manual sampling and lab-based analysis. While accurate, these methods are time-consuming, limited to specific locations, and require resource-intensive laboratory setups, making them less suitable for real-time, large-scale monitoring [2]. To address these challenges, IoT-based water quality monitoring systems have emerged as cost-effective and scalable alternatives. These systems typically use embedded sensors, wireless communication modules, and data visualization tools, allowing real-time monitoring of water quality [3]. However, existing IoT solutions face several challenges. Most systems are static and limited to specific locations, such as rivers, reservoirs, or industrial effluents. Many studies also overlook sensor calibration and potential errors, which can lead to inaccurate readings affecting decision-making. Finally, while some research demonstrates the potential of IoT monitoring, only a few provide an integrated framework, like the Water Quality Index (WQI), which converts raw sensor data into actionable insights for policymakers. To overcome these challenges, this paper proposes an IoT-enabled autonomous RC platform for water quality

Grenze ID: 01.GIJET.12.1.48_1

monitoring, which introduces three key innovations: Mobile Sampling Framework: Unlike traditional fixed-node IoT systems, the proposed RC-based platform enables dynamic multi-site water quality assessment in real time. Error-Aware Calibration: A detailed analysis of least count, absolute, and relative errors is incorporated, enhancing the reliability of collected data. Integrated Water Quality Index (WQI): Sensor readings are aggregated into WQI values, providing an intuitive measure of water health for both technical and non-technical stakeholders.

The primary contributions of this work are therefore threefold: (i) design and deployment of a mobile IoT water monitoring platform, (ii) error and least count analysis for improved sensor credibility, and (iii) graphical and index-based comparative study of multiple aquatic environments.

II. LITERATURE REVIEW

Recent developments in unmanned surface vehicles (USVs) have enabled effective, low-cost water quality monitoring across various aquatic contexts. Early efforts focused on autonomous surface vehicles with real-time environmental sensing [1]. Power management and solar-based sustainability approaches, including dual-axis tracking, improved operational duration in remote areas [2]. Low-cost methods gained attention through RC boat platforms and wireless sensor networks enabling rapid deployment [3]. Microcontroller-based USVs (e.g., Arduino) emphasized simplicity, performance, and affordability [4]. Some systems combined sensing with cleaning for broader environmental management [5]. High-resolution water mapping became possible via georeferenced sensor-equipped USVs [6], while affordable designs expanded accessibility in rural and low-resource areas [7]. AI algorithms were later integrated for navigation, data analysis, and predictive modeling [8], with optimization techniques like multimodal PSO and federated learning improving monitoring efficiency [9].

IoT-enabled platforms now support remote control, cleaning, and parameter measurement [10]. Swarm-based USVs address large-scale aquaculture monitoring [11], while compact systems target real-time tracking with low hardware complexity [12]. Ensemble learning has improved large-area accuracy [13]. Further advances include portable, low-cost platforms [14], hybrid control architectures for navigation [15], and vision-based obstacle avoidance. Despite progress, challenges remain. Many studies lack sensor calibration and error analysis, reducing reliability across seasons. Budget USVs often record only basic parameters, rarely incorporating Water Quality Index (WQI) insights. Multi-environment testing is limited, restricting scalability. Real-time visualization, error-aware analysis, and modular architectures for expanding parameters (e.g., dissolved oxygen, conductivity, nitrate) are often missing.

This study addresses these issues by developing a compact Arduino-based USV with pH, turbidity, and temperature sensors, supporting MQTT-enabled wireless data logging for scalable, resource-constrained deployments.

III. METHODOLOGY: PROPOSED SYSTEM OVERVIEW

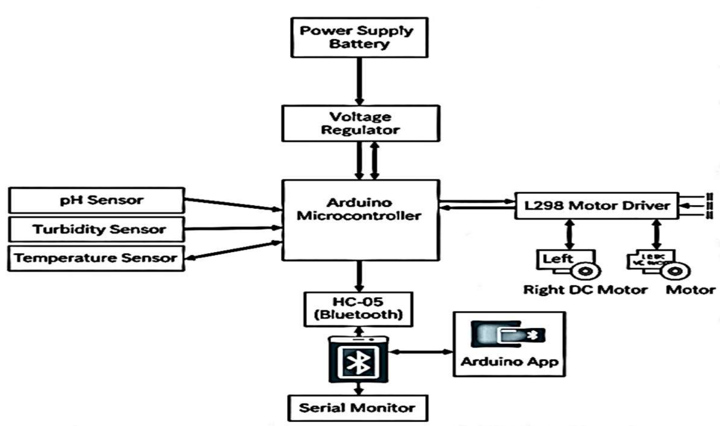

Fig.1 Block Diagram of Water Quality Monitoring using RC Boat

Expanding on recent work with low-cost and Arduino-based unmanned surface vehicles (USVs) focused on water quality monitoring [1], [4], [14], the proposed system uses a remote-controlled (RC) boat with water quality sensors and Bluetooth-based telemetry to deliver real-time information about environmental conditions.

This design emphasizes inexpensiveness, simplicity, and ease of operation in the field, in part to fill gaps around modularity and wireless telemetry identified in previous studies [7], [8]. An Arduino Uno microcontroller serves as an embedded CPU to read the sensor data, calibrate, and communicate. This builds upon previous work that demonstrated the practicality of using microcontrollers in water monitoring [4], [14]. The HC-05 Bluetooth module enables telemetry of the data to an Android-based monitoring application, which also facilitates easy operation in the field by users [10].
The sensing suite includes:

- pH sensor – measures the acidity or alkalinity of water.
- Turbidity sensor – provides an assessment of water clarity using suspended particles.
- Temperature sensor – to capture temperature, an important factor when analysing aquatic eco systems.

The block diagram of the proposed AI-assisted water quality monitoring system using a remotely operated RC boat is presented in Fig. 1. The system is powered by a rechargeable battery, which serves as the primary energy source. A voltage regulator ensures a stable and noise-free power supply to all electronic modules, maintaining operational reliability under varying battery conditions.
The sensing module integrates three primary water quality sensors:

- .pH Sensor – measures the acidic or alkaline nature of the water.
- Turbidity Sensor – detects suspended particles, indicating water clarity.
- Temperature Sensor – records water temperature, a critical parameter for aquatic ecosystem evaluation.

The sensor outputs are interfaced with an Arduino Uno microcontroller, functioning as the central processing unit. The microcontroller performs signal acquisition, sensor calibration, and preprocessing before data transmission.
For navigation, propulsion is provided by dual DC motors driven by an L298 motor driver. Independent motor control enables precise forward, reverse, and turning maneuvers, allowing targeted sampling at various locations. A HC-05 Bluetooth module establishes wireless communication between the microcontroller and an external monitoring platform. Real-time sensor readings are transmitted to an Android-based application and can also be logged for further analysis.
This architecture enables the RC boat to autonomously or semi-autonomously navigate water bodies, collect multi-parameter water quality data, and transmit it wirelessly, providing an efficient, scalable, and cost-effective solution for environmental monitoring.

B. Mathematical Modelling of Sensor Data

Temperature calculation:
The temperature sensor provides an output voltage vout(v)which is converted to temperature ttt using a linear relationship:

$$T = \frac{vout}{s} \qquad \ldots(1)$$

Output voltage from sensor, vout =1.365, Sensitivity of the sensor, s=0.05 v/∘c

$$T=\frac{vout}{s}=\frac{1.365}{0.05}=27.3∘C\ldots \qquad \ldots(2)$$

Result: The calculated temperature is 27.3°c, which is within the safe range for drinking water (10°c to 40°c).
Ph sensor calculation

$$Ph=phcal+\frac{vout\text{-}vcal}{slope} \qquad \ldots\ldots(3)$$

Measured sensor voltage: Vout=2.35 V, Phcal=7.0, Vcal=2.5V, Slope=−0.18 V/ph

$$Ph=Phcal+\frac{vout\text{-}vcal}{slope}\ldots \qquad \ldots(4)$$

$Ph=7.0+\frac{2.35\text{-}2.5}{-0.18}=7.0\pm\frac{0.15}{-0.18}=7.0+0.83=7.83$, which is within the safe range (6.5 to 8.5).

Turbidity value calculation:

$$T=a\cdot voutb \qquad \ldots\ldots(5)$$

Output voltage from turbidity sensor: Vout = 2.2v, Empirical constants from calibration: A=1.2, b=1.4
T = 1.2·(3.072)=3.69NTU Turbidity = 3.69 ntu, which is acceptable but not excellent (ideally <1 ntu).

C. Remote Navigation System

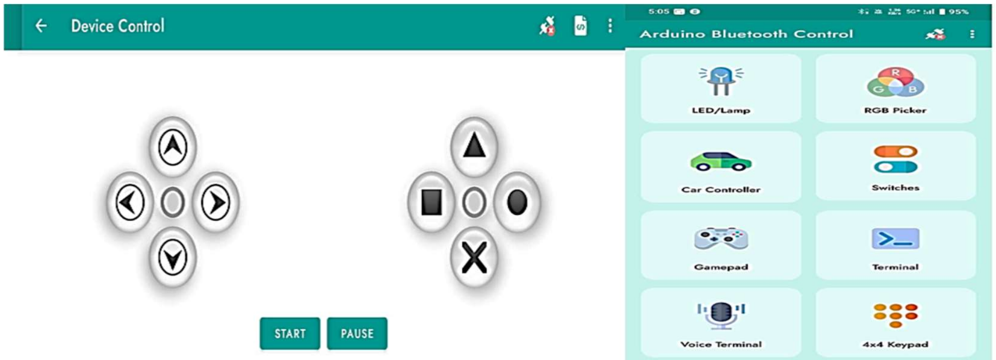

Fig.2 App interface and joystick module

The second phase of implementation involves integrating the rc boat with the HC-05 Bluetooth module and establishing communication with the joystick-based control interface, as illustrated in fig. 2. The operator uses the joystick to navigate the boat across the water surface. Sensor readings for temperature, turbidity, and Ph are continuously acquired by the Arduino uno, processed, and transmitted via Bluetooth to an existing serial monitoring application available on the google play store. This approach eliminates the need to develop a custom app, leveraging a readily available tool for real-time visualization of water quality parameters. Based on these readings, the water quality is assessed and categorized as fresh water, slightly polluted water, or polluted water.

IV. Results and Discussion

As shown in Fig. 3, to evaluate the real-time performance of the proposed water quality monitoring RC boat, extensive field testing was conducted across multiple aquatic environments, including college ponds, rivers, agricultural canals, and industrial discharge sites. The primary objectives were to: validate the accuracy of sensor readings and test the robustness of the wireless communication system.

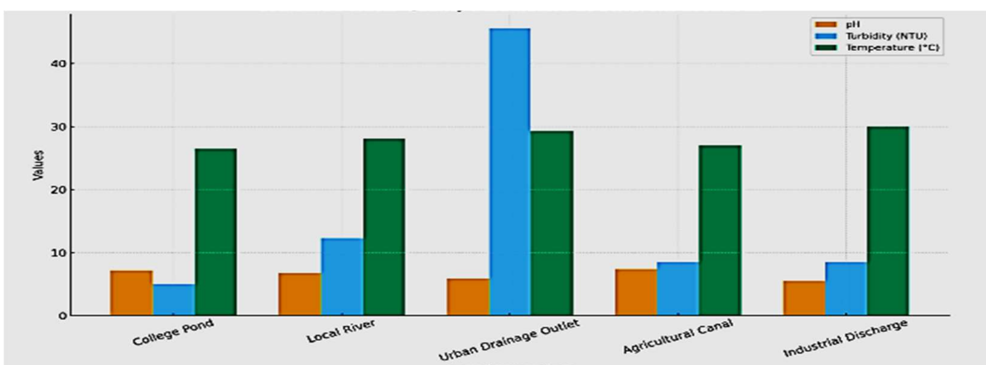

Fig. 3: Comparative Analysis of Water Quality Parameters Across Locations

Assess the viability of the boat's navigation mechanism. Sensor Performance Overview:
The RC boat system measured three critical water quality parameters—ph, turbidity, and temperature—and the data were compared against the standard thresholds defined by the World Health Organization (WHO) and the Bureau Indian Standards (BIS) for potable water

TABLE I: WATER QUALITY MEASUREMENT AND ANALYSIS

Location	pH	Turbidity (NTU)	Temp (°C)	QpH	QTurb	QTemp	WQI	WQL (approx)
College Pond	7.2	3.0	26.5	13.33	60	10	40.3	Good
Local River	6.8	12.3	28.1	-11.8	246	20.7	140.6	Medium
Urban Draining Outlet	5.9	45.6	29.3	-76	912	28.7	509.6	Poor
Agricultural Canal	7.4	3.0	27.0	26.67	60	13.33	45.15	Good
Industrial Discharge	5.5	8.5	30.0	-100	170	33	67.4	Poor

A. Site-Specific Inference

College Pond: The water quality is classified as good, showing a neutral pH of 7.2, very low turbidity (3.0 NTU), and moderate temperature (26.5°C). The calculated WQI of 40.3 falls under the Good category, indicating that the water is safe for drinking, recreational, and general domestic purposes.

Local River: The river water is slightly acidic with a pH of 6.8, while turbidity reaches 12.3 NTU, exceeding limits for direct consumption. The temperature of 28.1°C is within an acceptable range. A WQI of 140.6 categorizes the river water as Medium, suggesting that basic filtration or treatment is required before usage.

Urban Draining Outlet: This site exhibits poor water quality, reflected in a low pH of 5.9, very high turbidity of 45.6 NTU, and elevated temperature (29.3°C). The WQI of 509.6 indicates a Poor classification. Such water is unsuitable for drinking, irrigation, or domestic use due to significant pollution levels.

Agricultural Canal: The canal water demonstrates slightly alkaline pH (7.4), low turbidity (3.0 NTU), and moderate temperature (27.0°C). The WQI of 45.15 classifies it as Good, making it safe for irrigation and certain domestic applications, though it may require treatment for drinking purposes.I

ndustrial Discharge: Water from the industrial discharge point shows unsafe conditions with strongly acidic pH (5.5), moderately high turbidity (8.5 NTU), and higher temperature (30.0°C). The WQI of 67.4 places it in the Poor category, indicating it is unsuitable for drinking, agricultural use, or ecological purposes.

B. Communication and Navigation Performance:

- The HC-05 Bluetooth module provided stable and consistent data transmission to the mobile app in real-time.
- Manual and semi-autonomous navigation modes operated smoothly, demonstrating effective control and functional range in diverse environments.
- Data logging and visualization through the Serial Monitoring app enhanced usability and monitoring efficiency.

V. Future Scope

Future improvements to the water quality monitoring RC boat include adding GPS and GSM modules for real-time tracking and long-range communication, overcoming Bluetooth range limits and enabling use in remote areas. Incorporating advanced sensors—such as dissolved oxygen, conductivity, and heavy metal detectors—would enhance monitoring accuracy and provide a broader view of environmental health. Finally, integrating the system with cloud platforms like ThingSpeak or Firebase would enable automatic data storage, analysis, and visualization, supporting long-term, sustainable water quality management.

VI. Conclusion

As part of this project, we designed a portable, low-cost RC boat for real-time water quality monitoring. It is based on three sensors: pH, turbidity, and temperature, which read and transmit data wirelessly with the HC-05 Bluetooth module. We wanted to create a system that was as low-cost as possible but reliable in many real-world settings. Fieldwork was performed in lakes and rivers as well as with industrial discharge. The RC boat was able to obtain precise and stable measurements: the pH probe adequately reported differences in acidity and alkalinity, the turbidity probe detected differences in clarity in water, and the temperature probe reliably recorded changes in temperature. The data was visualized in a serial monitor application. The sensors in real-time and check for signs & patterns on-site. The boat could be operated fully manually or semi-autonomously to half access to larger areas to collect data. Reliability was improved considerably with calibration models in place to enhance sensor precision. The boat was very responsive as well, even in slightly choppy water. All in all, the project illustrated the capability of the RC boat for actual deployment in the field. The project exhibits how an inexpensive, Arduino-based RC boat can be both a valuable educational prototype and a viable way to monitor the environment. In addition, the system architecture has a lot of room for growth. Especially with GPS integration, cloud data storage, and additional sensor suites, all of which can further develop the prototype into a stronger platform for public policy, researchers, and local communities eager to monitor pollution and either/take action to manage water resources.

Acknowledgement

We sincerely thank everyone who supported our project on Water Quality Monitoring Using an RC Boat. We are especially grateful to Dr. Smita Bhagwat for her constant guidance and encouragement, and to Vishwakarma

Institute of Technology for providing lab facilities and resources. We also appreciate our teammates for their collaboration and dedication during testing and development. Special thanks to the professionals and individuals whose suggestions improved our work. Lastly, we express heartfelt gratitude to our families and friends for their unwavering support and motivation throughout the project.

REFERENCES

[1] Rashid, M. M., Roy, R., Ahsan, M. M., & Siddique, Z. (2022). Design and development of an autonomous surface vehicle for water quality monitoring. arXiv preprint arXiv:2201.10685.

[2] HAQUE, S.I., SIDDIKY, M.M., RAHMAN, M.A., SHAIKAT, M.H. and HASAN, R.R., 2023. IOT based Water Pollution Monitoring Multifunctional Boat using Solar panel with Dual Axis Tracker (Doctoral dissertation, Faculty of Engineering, American International University–Bangladesh).

[3] Chen, C.H., Shang, Y.J., Wu, Y.C. and Lin, Y.C., 2025. Development of Autonomous Electric USV for Water Quality Detection. Sensors, 25(12), p.3747.

[4] Huri, A.F.A.D., Nor, N.S.M., Saputra, H.M., Ismail, K., Zawawi, F.M. and Keyon, A.S.A., 2025. Real-Time In Situ Water Quality Monitoring: Experimental Validation using Unmanned Surface Vehicle (USV). Semarak International Journal of Applied Sciences and Engineering Technology, 5(1), pp.1-15.

[5] Chang, H.C., Hsu, Y.L., Hung, S.S., Ou, G.R., Wu, J.R. and Hsu, C., 2021. Autonomous water quality monitoring and water surface cleaning for unmanned surface vehicle. Sensors, 21(4), p.1102.

[6] Griffiths, N.A., Levi, P.S., Riggs, J.S., DeRolph, C.R., Fortner, A.M. and Richards, J.K., 2022. Sensor-equipped unmanned surface vehicle for high-resolution mapping of water quality in low-to mid-order streams. ACS ES&T Water, 2(3), pp.425-435.

[7] Tran, H.D., Nguyen, N.T., Cao, T.N.T., Gia, L.X., Ho, K., Nguyen, D.D., Pham, B.T. and Truong, V.N., 2024. Unmanned surface vehicle for automatic water quality monitoring. In E3S Web of Conferences (Vol. 496, p. 03005). EDP Sciences.

[8] Díaz, L.M., Luis, S.Y., Barrionuevo, A.M., Diop, D.S., Perales, M., Casado, A., Toral, S. and Gutiérrez, D., 2024. Towards an Autonomous Surface Vehicle Prototype for Artificial Intelligence Applications of Water Quality Monitoring. arXiv preprint arXiv:2410.05892.

[9] Kathen, M.J.T., Johnson, P. and Flores, I.J., 2022. AquaFel-PSO: A monitoring system for water resources using autonomous surface vehicles based on multimodal PSO and federated learning. arXiv preprint arXiv:2211.15217.

[10] Raj, B.S., Murali, L., Vijayaparamesh, B., Kumar, J.S. and Pragadeesh, P., 2021, June. IoT based water surface cleaning and quality checking boat. In Journal of Physics: Conference Series (Vol. 1937, No. 1, p. 012023). IOP Publishing.

[11] Li, M., Chai, J. and Li, C., 2024, March. Remote water quality monitoring: an IoT and USV-based study. In Ninth International Symposium on Sensors, Mechatronics, and Automation System (ISSMAS 2023) (Vol. 12981, pp. 921-926). SPIE.

[12] Qadir, M.I., Mumtaz, R., Manzoor, M., Saleem, M., Khan, M.A. and Charlesworth, S., 2024. Unmanned surface vehicle for intelligent water quality assessment to promote sustainable human health. Water Supply, 24(7), pp.2259-2270.

[13] Ryu, J.H., 2022. Prototyping a low-cost open-source autonomous unmanned surface vehicle for real-time water quality monitoring and visualization. HardwareX, 12, p.e00369.

[14] Vasudevan, S.K. and Baskaran, B., 2021. An improved real-time water quality monitoring embedded system with IoT on unmanned surface vehicle. Ecological Informatics, 65, p.101421.

[15] Mendoza-Chok, J., Luque, J.C.C., Salas-Cueva, N.F., Yanyachi, D. and Yanyachi, P.R., 2022. Hybrid control architecture of an unmanned surface vehicle used for water quality monitoring. IEEE Access, 10, pp.112789-112798.