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APPLIED RESEARCH

IoT-Enabled Advanced Water Quality Monitoring System for Pond Management and Environmental Conservation

JEETENDRA KUMAR[1], RASHMI GUPTA[1], SUVARNA SHARMA[2], TULIKA CHAKRABARTI[3], PRASUN CHAKRABARTI[4], (Senior Member, IEEE), AND MARTIN MARGALA[5], (Senior Member, IEEE)

[1]Department of Computer Science and Application, Atal Bihari Vajpayee University, Bilaspur, Chhattisgarh 495009, India
[2]Chitkara University Institute of Engineering and Technology, Chitkara University, Rajpura, Punjab 140401, India
[3]Department of Chemistry, Sir Padampat Singhania University, Udaipur, Rajasthan 313601, India
[4]Department of Computer Science and Engineering, Sir Padampat Singhania University, Udaipur, Rajasthan 313601, India
[5]School of Computing and Informatics, University of Louisiana, Lafayette, LA 70504, USA

Corresponding author: Rashmi Gupta (rashmigupta@bilaspuruniversity.ac.in)

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ABSTRACT The preservation of aquatic ecosystems and the availability of drinkable water sources depends on the protection of water quality. This is especially true about bodies of water such as ponds. Traditional monitoring techniques frequently require a significant investment of resources and have a restricted application, which has prompted the investigation of more effective technologies. We present a unique wireless acquisition system for monitoring real-time water quality that makes use of the Arduino (ESP32) microcontroller. This system allows us to collect data in real-time. This cutting-edge technology collects data from a variety of pond locations utilizing three individual sensors to perform remote measurements of three critical parameters: turbidity, TDS, and pH. The integration of the system with an aquatic boat enables complete sampling from the center as well as the sides of the pond, which is a significant step forward in terms of innovation. The collected information, which may include pH, turbidity, and TDS readings, is uploaded to the cloud so that it may be evaluated in real-time using the AquaSpecs app. The effectiveness of the proposed system has been proven by deployment in four ponds in Chhattisgarh; these ponds are named Birkona Pond, Budha Pond, Dagania Pond, and Kushalpur Pond. This deployment demonstrates the system's potential for effective water quality monitoring and management. Using the proposed water quality monitoring system, it was found that the Birkona pond was the cleanest pond having average values of pH, TDS, and Turbidity were 6.23,196.75 and, 8.83 respectively. Budha pond was found highly polluted pond having average values of pH, TDS, and Turbidity were 13.30, 544.18, and, 34.89 respectively. The proposed system is also compared with recent water quality monitoring systems and achieves a higher score. Sensor errors were also very low in the proposed system when compared with traditional approaches, which makes it suitable for monitoring water quality.

INDEX TERMS Aquatic boat, IoT, microcontroller, PCB, sensors.

I. INTRODUCTION

In the 21st century, there has been a rapid increase in technical progress, but at the same time, there has been a worrying escalation in pollution and global warming. The environmental difficulties we face have resulted in an increasing shortage of potable water. Real-time water quality monitoring encounters several obstacles in this particular situation, such as the effects of climate change, the pressure on scarce water supplies, and the growing world population [1]. As a result, it is of the utmost need to develop methods that are more resilient for the real-time monitoring of water

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quality indicators. Water, as a vital natural resource, has a crucial impact on our everyday existence. Monitoring the quality of water is an essential component of both environmental management and public health. Water quality assessment is a methodical evaluation of different physical, chemical, and biological factors to guarantee that water resources, whether from natural bodies of water or municipal supplies, satisfy accepted criteria for human consumption, industrial utilization, and ecological well-being [2]. This extensive procedure plays a crucial role in protecting the world's most valuable asset – water.

Water quality parameters [3], [4], [5] refer to a variety of fundamental characteristics and measures that are employed to assess the state and security of water sources. These factors can be classified into physical, chemical, and biological dimensions. Physical elements such as temperature, turbidity, and flow rate have an impact on factors like gas solubility and the existence of aquatic life. Chemical parameters encompass measurements such as pH, dissolved oxygen, nutrient concentrations, heavy metal content, and the presence of pollutants. These data are vital for evaluating the quality and safety of water [6]. Biological parameters primarily examine the presence and behavior of living creatures in water, including bacteria, algae, and macroinvertebrates. These species serve as markers of contamination and offer valuable information about the overall ecological well-being. Monitoring these metrics is essential for safeguarding public health, conserving ecosystems, and guaranteeing responsible water management [7].

Water quality is a crucial component of a well-balanced environment. Uncontaminated water is crucial for the sustenance of a diverse array of flora and fauna. Although first appearing inconsequential, human terrestrial activities significantly impact the water quality [8]. Chhattisgarh state is a very rich state in natural resources. Approximately 90,000 hectares of land in the state of Chhattisgarh is occupied by rural ponds. These ponds also maintain groundwater levels. Chhattisgarh also has water management difficulties. Overabstraction of water resources, rapid population and industry growth, unplanned urban development, and pollution are examples. Developing new infrastructure, maintaining and operating current infrastructure, and protecting the resource base from pollution and unplanned development that worsens droughts and floods are all difficulties [9].

Conventional techniques of water quality assessment involve the collection of water samples from various sources, which are then transported to a laboratory for analysis. Collecting samples from various sections of ponds can be a challenging task at times. This method requires a significant amount of time and additional exertion. By employing sensors, the real-time assessment of water quality in rural farms can significantly streamline the analysis process for pond water, thereby reducing the time and effort required. By employing an IoT-based methodology [10], [11], [12], [13], water quality monitoring may be conducted automatically through the utilization of sensors.

In the proposed work, we have developed an IoT-based wireless acquisition system for water quality monitoring in the center as well as side areas of ponds. With three sensors, the system gathers data from several pond areas. This water quality monitoring system delivers pond pH, turbidity, and TDS data to the cloud, where this data can be viewed in the mobile app. This device has been tested in four ponds of Chhattisgarh state.

II. REVIEW OF LITERATURE

Water quality monitoring systems have made substantial advancements, as demonstrated by a vast amount of literature. Researchers have explored novel methodologies and advanced technology, including Internet of Things (IoT) solutions and intricate sensor networks. These efforts seek to tackle the urgent requirement for efficient and immediate evaluation of water quality indicators. This study conducts a thorough examination of the current literature, exploring the development of water quality monitoring systems, their technological foundations, and the progress gained in comprehending and addressing water quality issues. In 2017, Das and Jain [14] suggested utilizing IoT to measure the quality of water immediately. They utilized temperature sensors, conductivity sensors, and pH sensors in their experiments. To transfer the data collected by the sensors, they utilized a Zigbee module. In addition to that, they utilized a proximity sensor to be notified whenever someone polluted the water. Their device monitors the contamination of the water in real-time. In 2017, Daigavane and Gaikwad [15] suggested the use of the Internet of Things to create a system for monitoring the water's quality. To accurately monitor the water's quality, they equipped the water monitoring system with sensors for temperature, pH, turbidity, and flow. In 2017, Parameshwari et al. [16] proposed a way to a method to evaluate the quality of the water. They made use of a level sensor, as well as sensors for temperature, pH, and turbidity. In 2017, Pasika and Gandla [12] proposed a water quality monitoring system using IoT. Their proposed system integrated sensors to measure pH, water turbidity, tank level, and environmental temperature/humidity. The sensors established a connection with a Microcontroller Unit (MCU), which analyzed the data before sending it to a Personal Computer (PC). By employing an Internet of Things (IoT) ThinkSpeak program, the analyzed data was transmitted to the cloud, facilitating the ability to remotely monitor the real-time quality of water. In 2018, Saravanan et al. [11] proposed a system that uses IoT to monitor the water's quality. They recommended integrating the Internet of Things with a supervisory control and data collecting system to create a real-time water quality monitoring system. They utilized flow sensors, temperature sensors, color sensors, and pH sensors in their research. The outcomes obtained by their system were superior to those produced by the approaches that were currently in use. Their platform was able to record information in real-time. In 2018, Kumar Koditala and Shekar Pandey [10] proposed lost cost water quality monitoring system. They used turbidity sensor and temperature sensor. Based on the model they achieved an R squared score of 0.933. Their system also has a heater and cooler to maintain water temperature. In 2018, Niswar et al. [13] devised a mechanism for monitoring the water quality to facilitate the farming of softshell crabs. Embedded devices, water quality sensors (pH sensor, temperature sensor, and salinity sensor), and a LoRA wireless interface were all utilized in the process of developing their system for monitoring water quality. In addition to that, they utilized a web-based monitoring system. Nearly 25 users were able to subscribe to their service without any problems. In 2018 Shirode et al. [17] proposed a method to measure water quality. They used pH sensor, conductivity sensor, turbidity sensor, and conductivity sensors. They used Arduino as a microcontroller. They just developed the system but no results were given in the research paper. In 2019, Mukta et al. [18] proposed IoT-based water quality monitoring system. They used four sensors i.e. temperature sensor, pH sensor, turbidity sensor, and conductivity sensor. For classification purposes, they used fast forest classifier. Using the fast forest classifier they were able to achieve 100% accuracy. In 2019, Simitha et al. [19] presented a water quality monitoring system based on the Internet of Things and wireless sensor networks. Their solution was economical, low-power, long-range, and scalable all at the same time. They employed a module that was based on LoRA, which is based on LoRaWAN. The temperature sensor, pH sensor, turbidity sensor, and DO sensor were all utilized by them. They discovered that their planned system operates quite successfully. In 2019, Chowdury et al. [20] proposed a water quality monitoring system using IoT. The authors introduced a water quality monitoring system that utilizes sensors, a microcontroller, a communication system, and a Wireless Sensor Network (WSN). The ability to retrieve data in real-time was accomplished by utilizing remote monitoring and Internet of Things (IoT) technology. The data obtained from an external location was analyzed using Spark streaming analysis, Spark MLlib, deep learning neural network models, and a Belief Rule Based (BRB) system. The results were then compared with standard values on a server PC. If the obtained value was beyond the predetermined limit, an automated SMS alert was sent to the appropriate agent. The paper's innovation was in the establishment of a water monitoring system characterized by high frequency, high mobility, and low power consumption.

In 2020 Pasika et al. [12] proposed an intelligent water quality monitoring system that utilized IoT in a cost-effective way.. They used a pH sensor, turbidity sensor, water level sensor, temperature sensor, and humidity sensor. They used an Arduino board as a microcontroller board. They found that their proposed framework works efficiently. In 2023, Bogdan et al. [21] proposed an inexpensive water quality monitoring system. They developed a low-cost Internet of Things (IoT) system that monitors the quality of different water sources and publishes its findings. The system consists of an Arduino UNO board and various sensors, is controlled through a mobile app. After monitoring five water sources in a rural area, the findings indicate that most were suitable for consumption, except for one where TDS values exceed the accepted limit of 500 ppm. In 2023, Razman et al. [22] proposed a water quality monitoring system. They proposed an Arduino-based system for monitoring and filtering water quality. They used Proteus software to simulate the design and ThingSpeak for real-time tracking. They compared various water quality parameters of tap water, lake water, and river water. When water quality wasn't good enough, a filtration device was turned on. Following international and state standards for water quality, tests were done to compare filtered and unfiltered water. For strong data validation, statistical tools like box plots and one-way analysis of variance were used. Using wireless fidelity, the real-time monitoring system made it easier for users to get info through ThingSpeak. Their study laid the groundwork for future research on systems that check for pollution in lakes and rivers, and it could be used to build bigger systems for main tanks in homes or workplaces.

III. METHODOLOGY

A novel wireless acquisition system that makes use of the Arduino (ESP32) microcontroller has been designed by us for the water quality monitoring system that we have presented. This cutting-edge instrument is designed to provide accurate remote measurements of important parameters relating to water quality, such as turbidity, Total Dissolved Solids (TDS), and pH. The system collects data from several locations throughout the pond by making use of three individual sensors. The fact that this system may be integrated with an aquatic boat is a significant advantage. This integration makes it possible to collect comprehensive samples from the pond's center as well as its sides, which improves the accuracy of water quality analysis as a whole. The proposed water quality monitoring system senses the data pH, Turbidity, and, TDS data of the pond and transfers data to the cloud can be assessed by the AquaSpecs app. Fig 1 shows the framework of the proposed water quality monitoring system. For testing purposes, this device has been tested in four ponds in Chhattisgarh i.e. Birkona Pond, Budha Pond, Dagania Pond, and, Kushalpur Pond.

A. PARAMETERS USED TO DETECT THE QUALITY OF WATER

For this experiment, we have utilized three parameters to evaluate the quality of water. These characteristics are important markers that offer vital information into the general health and condition of the water being studied. Every parameter has a unique function in assessing various aspects of water quality, enhancing a more detailed and comprehensive comprehension of its properties.

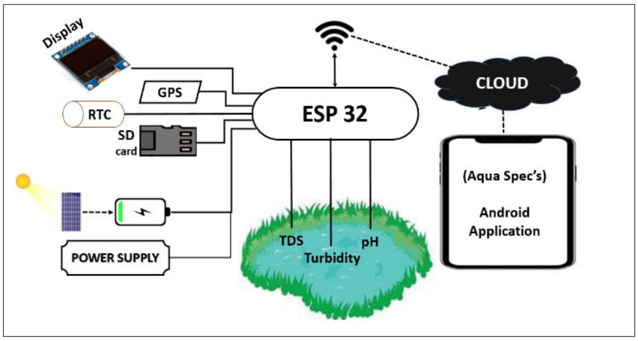

FIGURE 1. Proposed framework to detect the quality of water in ponds.

1) PH PARAMETER

The pH parameter is crucial, as it serves as an indicator of the concentration of hydrogen ions in water. It determines the acidity or alkalinity of water by measuring its pH value. Pure water has a pH value of 7, whereas values below 7 indicate acidity and values above 7 indicate alkalinity. The pH scale ranges from 0 to 14. The pH of drinking water should fall in the range of 6.5 to 8.5, according to WHO standards.

2) TURBIDITY

Turbidity measurement quantifies the presence of imperceptible suspended particles in water. A lower level of turbidity is indicative of cleaner water since it indicates that there is less sediment suspended in the water. Higher levels of turbidity are associated with an increased risk of waterborne infections such as cholera and diarrhea.

3) TOTAL DISSOLVED SOLIDS (TDS)

TDS measures water's total dissolved solids. These include minerals, salts, metals, cations, anions, and organic and inorganic compounds. TDS is usually measured in ppm or mg/L. Monitor TDS levels in water to monitor water quality because elevated TDS levels can suggest pollutants and affect taste, odor, and appropriateness for drinking and industrial use.

This system offers a technique for evaluating water quality that is both technologically advanced and accomplished in an instant, in contrast to more conventional methods of monitoring water quality, which rely on the collection of manual water samples. The Internet of Things (IoT), a relatively new idea in the field of software development, serves as the primary focal point of the overall system architecture. The hardware component includes an LCD for showing sensor outputs, an ESP32 for converting analog values to digital, sensors for real-time measurements, and Wi-Fi for creating connectivity between the hardware and the software. The software component requires the creation of a program that is written in embedded C language. This cutting-edge method offers a more effective approach to resolving the issues surrounding the quality of water all over the world in the 21st century.

B. COMPONENT/SENSOR UTILIZED

1) ESP32

The ESP32 is a single-chip combination chip that utilizes TSMC's ultra-low power 40 nm technology. It operates at 2.4 GHz and has Bluetooth connectivity. This chip is designed to accommodate a wide variety of power profiles and application types thanks to its meticulous craftsmanship, which aims to maximize power performance as well as RF performance, robustness, versatility, and dependability. The ESP32 requires less than ten external components and is marketed to the industry as the most integrated solution for Wi-Fi and Bluetooth applications currently available.

2) TP 5100 MODULE

The TP5100 is a voltage regulator integrated circuit that efficiently charges a single lithium battery by stepping down the input voltage from 8.4V to 4.2V. The QFN16 super compact packaging, along with its uncomplicated external circuit, makes the TP5100 an excellent choice for managing big current charging in portable devices. Additionally, the TP5100 includes many safety features such as built-in input overcurrent protection, under voltage protection, over temperature protection, short circuit protection, battery temperature monitoring, and reverse battery protection.

3) OLED DISPLAY

OLED is an abbreviation that stands for Organic Light-Emitting Diode, which is a type of flat panel display that emits light through the usage of organic components. As opposed to conventional LCDs, which are dependent on a backlight, organic light-emitting diode (OLED) panels produce light from each pixel, which results in darker blacks, more vibrant colors, and enhanced contrast. LCDs are not only thinner and lighter, but they also have a higher energy efficiency overall.

4) PCB BOARD

The term "printed circuit board" is the most commonly used for PCBs, Prior to the advent of PCBs, the process of constructing circuits involved a laborious technique of manually connecting individual points using wires. Consequently, numerous cases of wire junction failures and short circuits occurred as a result of the deterioration and cracking of wire insulation.

5) PH SENSOR

The concentration of hydrogen ions (H+) in a solution determines its pH. From 0 to 14, pH below 7 is acidic and neutral, and above 7 is alkalinity. Each whole number change is tenfold on the logarithmic scale. Mineral solubility, nutrient availability, and chemical reactions depend on pH in natural water systems. Different species thrive in different pH ranges, affecting aquatic creature health. The health of aquatic habitats depends on monitoring and regulating pH levels.

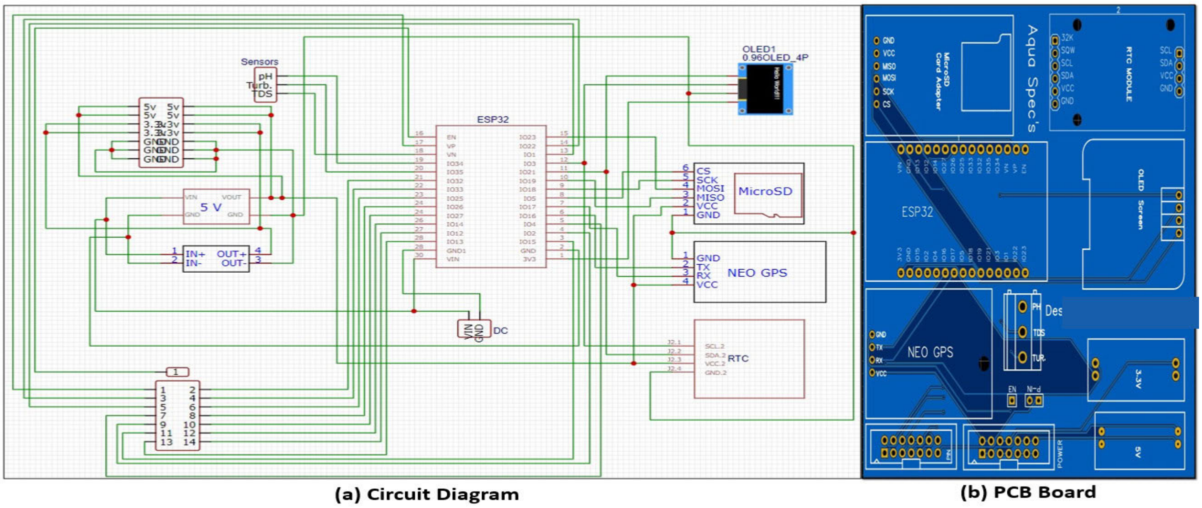

FIGURE 2. Design of (a) circuit diagram and, (b) PCB of the proposed system.

6) TURBIDITY SENSOR

Turbidity is a quantitative assessment of the level of opacity or haziness in water. Turbidity is a measure of the extent to which water loses its transparency. It is regarded as a reliable indicator of water quality. Turbidity obstructs the necessary light for submerged aquatic plants. Additionally, it can elevate surface water temperatures beyond the usual range due to the presence of suspended particles at the surface, which enhance the absorption of heat from sunlight.

7) TDS SENSOR

TDS sensor, which also goes by the name Total Dissolved Solids sensor, is a device that determines the number of soluble solids that are dissolved in water, more particularly in terms of milligrams per liter. Generally speaking, a higher TDS value implies a greater amount of soluble substances that have been dissolved in water, which ultimately results in less clean water. As a result, the value of the TDS can be utilized as an accurate indication to determine the degree to which water has been purified. This has applications in the evaluation and monitoring of water quality in a variety of settings, including hydroponics and domestic water systems, among others.

8) WI-FI

Wi-Fi, which stands for "Wireless Fidelity," is a system that lets devices talk to each other wirelessly using radio waves. Wi-Fi is a wireless local area network (WLAN) technology that comes from the IEEE 802.11 family of standards. This technology gets rid of the need for cables, so computers, smartphones, and tablets can connect and share info without any problems.

9) SOLAR BATTERY

A solar battery, which is also called a solar energy storage system or solar battery storage, is a gadget that saves the extra electricity that solar panels make when they're not in use. Through a process called photovoltaic effect, solar panels turn sunlight into power. But this energy production isn't always there, and the extra energy made when it's sunny needs to be saved for times when the sun isn't out, like at night or when it's dark.

10) REMOTE CONTROL AQUATIC BOAT

A remote-controlled aquatic boat is a particular type of watercraft that was created to be operated from a distance, most commonly through the use of a device known as a remote control. These boats come with a wide variety of features and functionality, which enables their owners to use them for a variety of different purposes. These boats can be outfitted with sensors to collect data from various points in a body of water, such as a pond or lake, making them ideally suited for use in water quality monitoring systems. This is one of the most noteworthy applications of this technology. The functionality of the remote control enables accurate navigation, which enables the boat to access particular places for data collecting without the requirement for a physical presence in such areas. The use of this technology improves the efficiency of water sampling and monitoring procedures. This is especially true in bigger bodies of water, where manually collecting samples could be difficult.

Fig 2 shows the circuit diagram and PCB board of the proposed system and Fig 3 shows pictures of the developed system. Fig 2(a) shows the circuit diagram of the proposed system. It visually represents the electrical circuit and line connection of various components like sensors, displays unit, wifi, ESP32 board, etc. We have also designed a specific PCB board to minimize the wired connections.

C. ALGORITHM OF WATER QUALITY MONITORING SYSTEM

In the developed system, two algorithms run. First algorithms run on the device side and the other at the mobile application.

FIGURE 3. Proposed water quality monitoring system.

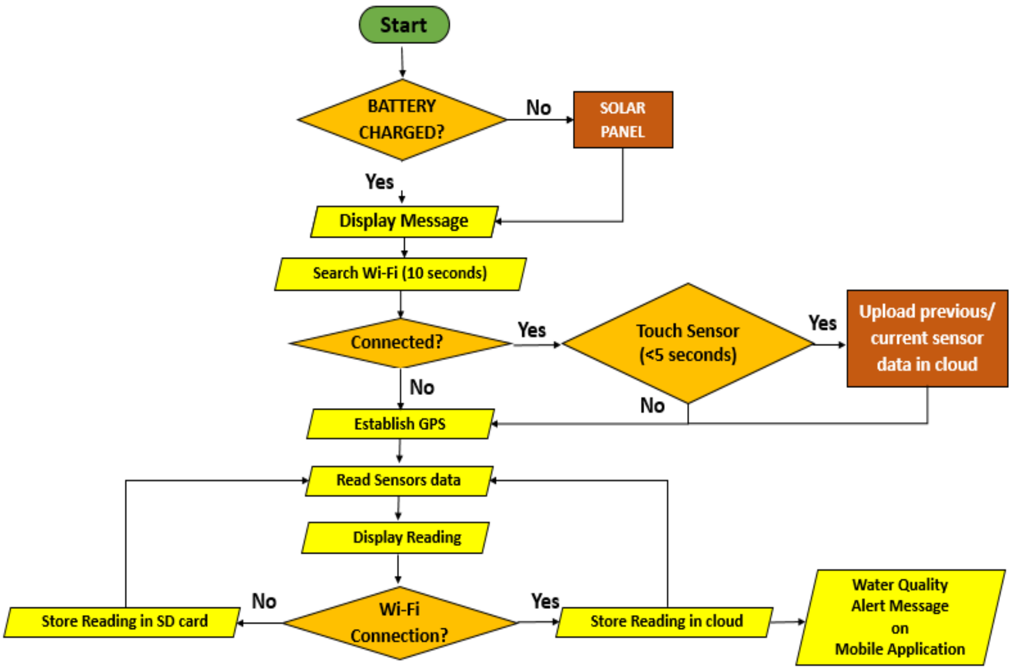

FIGURE 4. Flow chart of water quality monitoring system.

Fig 4 shows the flowchart of the proposed algorithm on the device side and cloud side.

1) ALGORITHM AT THE DEVICE

2) ALGORITHM ON MOBILE APPLICATION

The device-side algorithm initiates by examining the battery state. If the battery is not charged, the device transitions to utilizing the solar panel as an alternative power source. Subsequently, the 'Hello' message is exhibited, succeeded by a 10-second quest for Wifi. If the Wifi connection is established and the touch sensor is activated within a 5-second timeframe, the device will transmit past stored sensor data to the cloud. Subsequently, a GPS link is established, and data from pH, Turbidity, and TDS sensors is retrieved. The sensor values are exhibited on the LED display. The wifi connection is checked if it is not available then the data on SD card and if it is available then transfer the data to the cloud immediately. After this go to step 6 and read sensor values again.

Regarding the Mobile application aspect, cloud techniques are used to read the current and stored data obtained from the water quality monitoring device. This data includes the Device ID, Pond Name, Address, pH value, Turbidity, and TDS Sensor. Subsequently, it compares the sensor values with WHO water quality standards and subsequently presents a corresponding message i.e. water is drinkable or not on the application and the LED screen of the device. Show the message "Water is drinkable" on the mobile application and LED screen of the device if the pH is between the ranges of 6.5 to 8.5, the turbidity is below 50ntu, and the TDS is below 500ppm. Otherwise, show the message "Water is not drinkable". This guarantees the surveillance and transmission of data regarding the quality of water between the device and the cloud, accompanied by relevant feedback shown to users.

INPUT: NONE
OUTPUT: NONE

Step-1 : Start the system
Step-2 : If (Battery not charged?)
 Switch to solar panel
Step-3 : Display the 'Hello' message
Step-4 : Search for Wifi (For 10 Seconds)
Step-5 : If (Wifi connects?)
 If (Touch sensor is touched within 5 seconds)
 Upload current/previous sensor data to the cloud
Step-6 : Establish a GPS connection.
Step-7 : Read data of pH, Turbidity, and TDS sensors.
Step-8 : Display sensor values on the LED screen.
Step-9 : If (Wifi is not connected?)
 Store readings on SD card
 Else
 Store readings on the cloud
 Go to STEP [6]
Step-10 : Read the next values of sensors.

INPUT: (DEVICE ID, POND NAME, ADDRESS, PH VALUE, TURBIDITY, TDS SENSOR)
OUTPUT: MESSAGE "WATER IS DRINKABLE OR NOT"

Step-1 : Get data from the cloud (Device ID, Pond Name, Address, pH value, Turbidity, TDS Sensor)
Step-2 : If (pH value > 6.5 and pH value<8.5) and (Turbidity <50ntu) and (TDS <500ppm) the
Step-3 : Display the message "Water is drinkable" on the app and on the LED screen of the device
Step-4 : Else
Step-5 : Display the message "Water is not drinkable" on the app and on the LED screen of the device.

D. AQUA SPECS APP

Our Android app, called "AquaSpecs" is designed to present real-time and fire-store data in a tabular format. This app serves the sole purpose of displaying remote data and indicating the online state of the device. This program utilizes the Firebase database from a water specs monitoring device to provide us with the quality of pond water. The application provides real-time data updates at a frequency of one second. Additionally, it displays historical data from the cloud, including the date and time of each data entry. Viewing this data via an Android application enables us to gain awareness of the water quality near our location. Aqua Spec's is a vibrant application that is both user-friendly and engaging. This application may be effortlessly installed on any Android smartphone. This application will request internet access permission from the user and establish a direct connection to the Firebase cloud database. Once linked, it consistently retrieves data and displays it in a table. To modify the device name, simply tap on the device name and a pop-up window will appear, allowing you to make the desired changes. By selecting the address, we can conveniently get to the destination using the pre-installed Google Maps application on the Android system. Additionally, we can incorporate crucial information regarding the high standard of water quality as determined by the Indian government and the World Health Organization. Through this organizational reference, we can utilize three distinct metrics to assess water quality: pH, TDS, and Turbidity. Additionally, we can provide comprehensive information about these parameters on separate pages, including their respective measurement scales.

Fig 5 shows the screenshot of the AquaSpecs app. The details and addresses of various ponds are shown in Fig. These details include device_id, pond name, and address. Other screens of the app will display various sensor values and their WHO (World Health Organization) standard values. From this app graphs can also be viewed, and old data can be viewed. Data can also be downloaded in Excel format from this app.

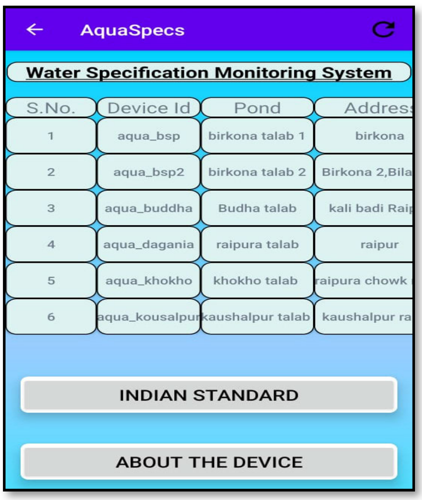

FIGURE 5. The screen of AquaSpecs mobile application locations data.

E. DEPLOYMENT

The designed water quality monitoring system has been used to measure water quality in four ponds namely *Birkona Pond(Pond 1), Budha Pond(Pond 2), Dagania Pond (Pond 3),* and, *Kushalpur Pond(Pond 4)* of Chhattisgarh state.Following Fig 6 shows the deployment of the proposed water quality monitoring system in different ponds.

At each pond, pH, TDS, and Turbidity data are collected and sent to the cloud. Fig 7, Fig 8, Fig 9, and Fig 10 show the graphs of pH, TDS, and Turbidity values of different ponds.

To improve data collecting efficiency, a small aquatic boat has been incorporated into the proposed water quality monitoring system. The decision to include this strategy is driven by the substantial disparities in water quality identified between the central and peripheral areas of ponds. Generally, the outskirts of ponds tend to have elevated pollution levels in

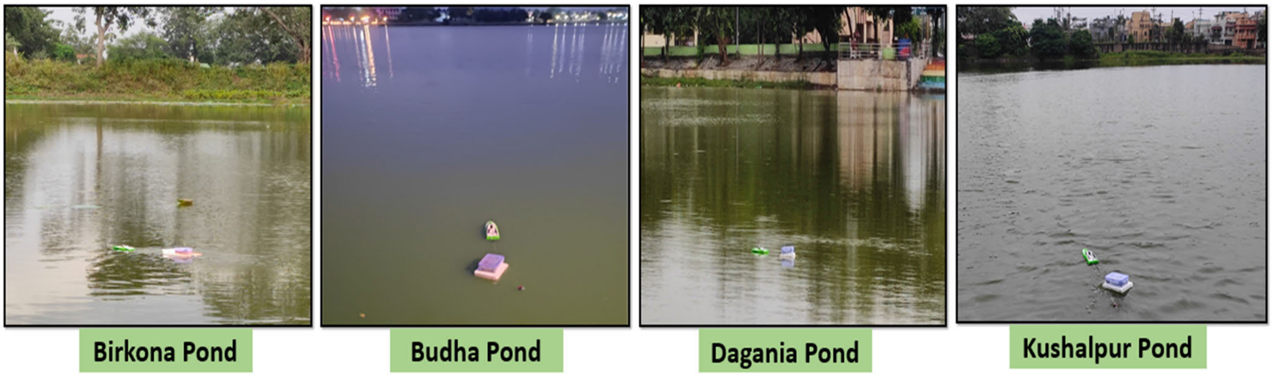

FIGURE 6. Deployment of proposed water quality monitoring system in different ponds.

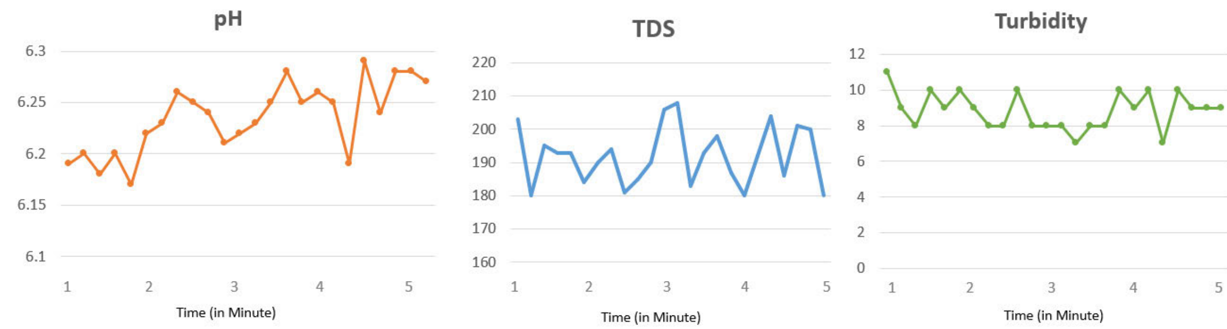

FIGURE 7. pH, TDS, and, Turbidity values at Birkona pond (pond-1).

comparison to the inner areas. This is because they frequently act as deposition sites for diverse contaminants that are dumped by persons. The watercraft enables the monitoring system to traverse both the periphery and middle of the pond, collecting data that accurately represents the various water characteristics available. The graphs depicted in Figures 6, 7, and 8 provide visual representations of different sensor parameter values, emphasizing the ever-changing characteristics of water quality. The oscillations in sensor values might be ascribed to the system's mobility aboard the boat, which allows for extensive data collection under various sea conditions.

In all four ponds, the proposed water quality monitoring system was deployed and tested one by one. We have collected and analyzed the average of sensor values during five minutes as shown in Table 1.

TABLE 1. Average values of pH, TDS, and turbidity in different ponds.

Pond Name	pH	TDS(ppm)	Turbidity
Pond-1	6.23	196.75	8.83
Pond-2	13.30	544.18	34.89
Pond-3	11.46	258.41	26.51
Pond-4	12.31	255.16	34.36

Following are standard values of pH, TDS, and Turbidity for drinking water.

pH - 6.5-8.5
TDS - 0-500 ppm
Turbidity - <50 ntu

In Pond-1, average values of pH, TDS, and Turbidity were 6.23, 196.75ppm, and 8.83ntu respectively. In this pond, values of pH, TDS, and Turbidity fluctuated between 6.17-6.29, 181-210, and, 7-11 respectively (Figure 7). All these values are in the standard range as mentioned above. So the water quality of this pond is acceptable and its water is drinkable. This pond was in a rural village in Bilaspur district and pollution was less. There was no outlet of sewage waste or industry waste was there. So water quality was good.

In Pond-2, average values of pH, TDS and Turbidity were 13.30, 544.18 ppm, and 34.89 ntu. In this pond, values of pH, TDS, and Turbidity fluctuated between 12.69-13.7, 508-597, and, 20-38 respectively (Figure 8). All three parameters of this pond were out of standard range. The water quality of this pond was not suitable for drinking.

In Pond-3, average values of pH were 11.46, 258.41ppm, and 26.51ntu respectively. In this pond, values of pH, TDS, and Turbidity fluctuated between 11.13-12.9, 246-272, and, 9-35 respectively(Figure 9). The water quality of this pond was not suitable for drinking but this water can be used for other home purposes.

In Pond-4, the average values of pH, TDS and Turbidity were 12.31, 255.16ppm, and 34.36 ntu. In this pond, values of pH, TDS, and Turbidity fluctuated between 11.82-13.26, 250-260 and, 16-52 respectively (Figure 10). The water quality of this pond was also not suitable for drinking but this water can be used for other home purposes

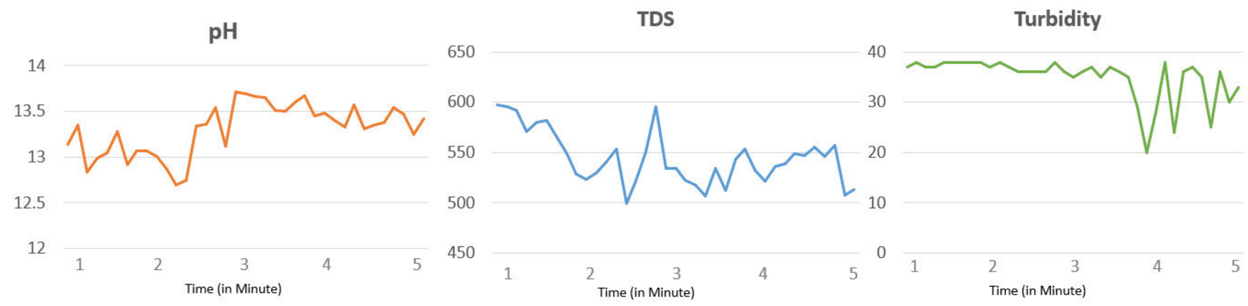

FIGURE 8. pH, TDS, and, Turbidity values at Budha pond (pond-2).

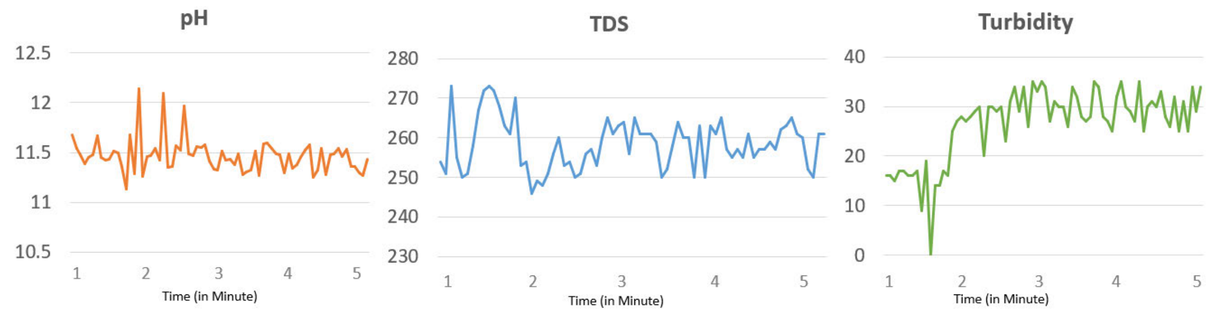

FIGURE 9. pH, TDS, and, Turbidity values at Dagania pond (pond-3).

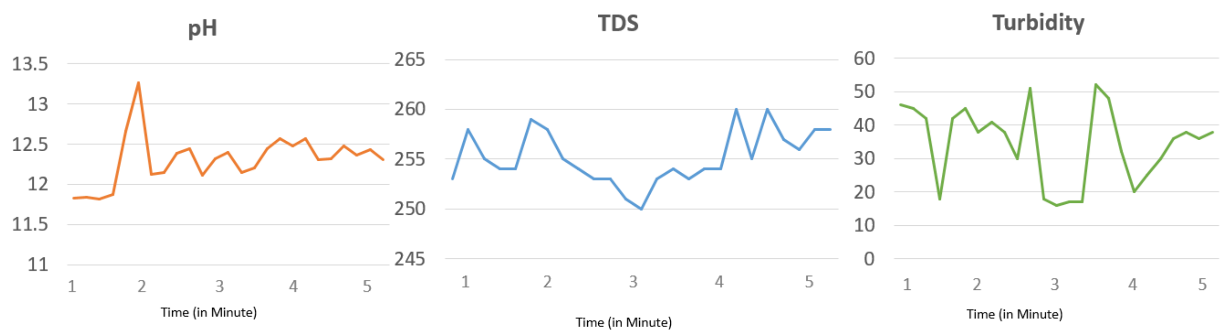

FIGURE 10. pH, TDS, and, Turbidity values at Kushalpur pond (pond-4).

Pond 1 was in rural area of Bilaspur district and found best pond. While Pond-2, Pond-3 and, Pond-4 were in Raipur district. Pond-2 was located in the industrial area with the outlet of sewage. This pond was found highly polluted pond. In Pond-3 and Pond-4, values of TDS and Turbidity were in range, and pH values were high which make this water high alkaline and not suitable for drinking. But their water can be used for other home purposes. The heightened values of pH, TDS, and Turbidity are attributed to the surrounding industrial areas, which introduce pollutants such as heavy metals into the water, consequently increasing TDS and Turbidity levels. The frequent fluctuation in sensor readings may be attributed to the continuous movement of all sensors within the pond via a boat. This movement can cause disturbances in the water, leading to fluctuations in the sensor readings as they encounter varying water conditions throughout the pond.

Moreover, the graphs illustrate the system's ability to accurately measure the subtle fluctuations in water quality, highlighting the need for a mobile monitoring method. This flexibility guarantees a thorough evaluation of the entire pond, allowing for a more precise depiction of the overall water quality conditions. The incorporation of an aquatic boat improves the system's capacity to collect varied data, yielding valuable observations on the ever-changing water quality attributes found in different sections of the pond.

Results received on Aquaspecs app as shown in figure 11. The app shows current values of pH, Turbidity, and TDS sensor as well as their standard values for drinking water.

We have also compared the working of our proposed system with some recently developed systems for water quality monitoring as shown in Table 2.

Where

D_A- Data Access (0- Offline1- Online)

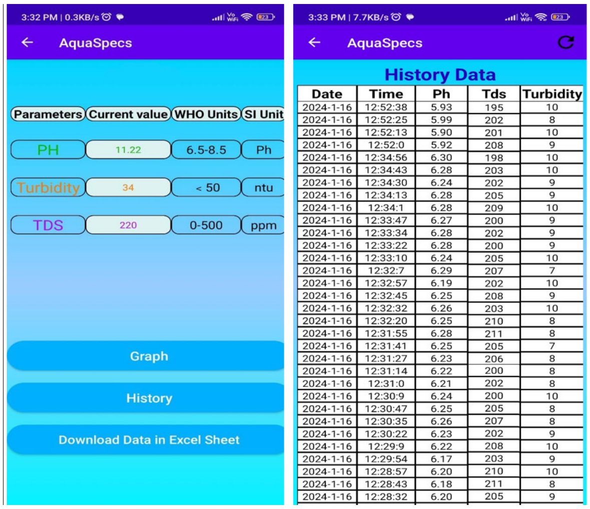

FIGURE 11. **AquaApp showing obtained values.**

TABLE 2. **Comparison of proposed approach with recent.**

Work	D_A	S_N	M_N	Dc	C	PC	Mw	S_P	L_t	Total Score
[23]	1	3	2	3	2	2	0	0	2	15
[24]	0	3	1	3	3	3	0	0	3	16
[25]	1	3	1	3	2	3	0	0	3	16
[26]	1	1	1	3	2	1	0	0	1	10
[27]	1	5	2	1	3	2	0	1	3	18
Proposed	1	3	1	3	3	3	1	1	3	19

S_N- Number of sensors used

M_N- No of MCU board used

D_C- Design complexity (1-High Complex, 2-Medium complexity,

3-Less Complexity

C - Cost (1- High Cost, 2- Medium Cost, 3-Less Cost)

PC- Power consumption (1- Less Power Consumption, 2- Medium Power

Consumption, 3- High Power Consumption)

M_W- Movable in water (0- No, 1 – Yes)

S_P - Solar Power enabled (0- No, 1- Yes)

L_t- Latency (1- High Latency, 2- Medium Latency, 3- Low Latency)

In Table 2, we have compared the performance of the proposed system with other recently developed water quality monitoring systems on the basis of data access method, Number of sensor used, Number of MCU board used, Design complexity, Cost, Power Consumption, Mobility in water, Solar power enabled, and Latency. All these factors play important role while designing a water quality monitoring system and every factor has given ranking according to their values. The sum of all rating have been calculated to find overall score of the system. After comparing the total score of all recent works, it has been found that the proposed approach is a good compromise between various factors for the task at hand. It achieves good performance while maintaining low complexity, moderate cost, and low power consumption.

As well as two main advantages of proposed approach are use of solar power and movable nature of device in water. Use of solar power allows the battery to work after exhaustion of battery power and movable nature of device in water allows the user the get sensor data from any area of the pond including center of the pond.

During the water quality monitoring, sensor accuracy also plays an important role. Sensors of the proposed system are also compared with traditional methods of measuring pH, turbidity, and TDS. When the water sample was tested with traditional methods and with sensors used in the proposed system, 0.3% error with pH sensor, 0.06% error with TDS sensor, and 0.9% error was Turbidity sensor were found. This less error shows the proposed system can accurately measure water quality.

IV. CONCLUSION

Water quality is essential to environmental balance. Clean water is essential for a diversified ecosystem. Water purity is essential to ecosystem health and resilience, thus it must be monitored and preserved to protect the complex web of life that depends on it. We have developed an effective Internet of Things (IoT)–based wireless water quality monitoring system that makes use of Arduino (ESP32) microcontrollers. The turbidity, Total Dissolved Solids (TDS), and pH may all be measured in real-time by using this device, which was developed specifically for ponds. The incorporation of an aquatic boat expands its versatility and makes it possible to collect comprehensive samples from a variety of locations inside the pond, which considerably improves the accuracy of the study. The *AquaSpecs* app's ability to send data to the cloud in real time enables the system to promote timely evaluations and decisions by allowing for the transmission of data. Our method has been successfully implemented in four ponds in Chhattisgarh, demonstrating both its practical relevance and its reliability. Using the suggested water quality monitoring system, the analysis revealed that the Birkona pond exhibited the highest level of cleanliness, with average pH, TDS, and Turbidity values of 6.23, 196.75, and 8.83, respectively. Conversely, the Budha pond was identified as the most polluted, displaying average pH, TDS, and Turbidity readings of 13.30, 544.18, and 34.89, respectively. When comparing the proposed system with recent water quality monitoring systems, the proposed system attains highest score. Sensors used in the proposed system also have very less error i.e. 0.3% error with pH sensor, 0.06% error with TDS sensor, and 0.9% error was Turbidity sensor, which makes it suitable for water quality monitoring This system provides an approach to environmental monitoring that is both cost-effective and scalable. This research contributes to the advancement of water quality monitoring procedures, and it has the potential for wider applications as well as the further examination of new parameters in studies to come.

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JEETENDRA KUMAR received the M.Sc. and M.Tech. degrees in computer science. He was an Assistant Professor with the Department of Computer Science and Application, Atal Bihari Vajpayee University, Bilaspur, Chhattisgarh, India, for the last ten years. He has completed two research projects sponsored by the State Planning Commission, C. G., and Commonwealth Media Centre for Asia (CEMCA) New Delhi, and Atal Bihari Vajpayee University. He has published various research articles in reputed journals and conferences, including topics such as sentiment analysis, fall detection using machine learning techniques, IoT applications, and automatic question generation. He has also contributed book chapters on topics related to neuroscience, smartphone applications, and fog computing in healthcare. He is a member of prestigious academic societies, such as the Indian Science Congress, the International Association of Engineers (IAENG), the International Computer Science and Engineering Society (ICSES), and the International Association of Academicians (IAASSE).

RASHMI GUPTA received the Ph.D. degree in computer applications from the National Institute of Technology, Raipur. Currently, she is an Assistant Professor with the Department of Computer Science and Application, Atal Bihari Vajpayee University, Bilaspur, Chhattisgarh. She has published more than 20 research papers, conference papers, and book chapters. She has also undertaken peer-reviewing responsibilities for esteemed publishers. She received grants from AICTE, to organize the ATAL Faculty Development Program; and the Science and Engineering Research Board, DST, for conducting high-end workshops and internships. Moreover, she has successfully organized numerous faculty development programs under the AIU-Academic and Administrative Development Centre, Atal Bihari Vajpayee University. Demonstrating her commitment to mentorship, she has guided over 30 PG and 20 UG students in their research-related major projects. She has served as a judge in the grand finale of Toycathon-21 and as an Evaluator in Hackathon-22, organized by the Ministry of Innovation Education Council, India. Additionally, she has been invited as a resource person to deliver lectures at various workshops and faculty development programs. With over ten years of teaching experience, her research interests include natural language processing, EEG signal processing, and human activity recognition.

SUVARNA SHARMA received the B.Sc. and M.Sc. degrees in computer science from Jiwaji University, Gwalior, Madhya Pradesh, in 2005 and 2007, respectively, and the M.Tech. degree from DAVV Indore, in 2013. Their Ph.D. degree was awarded by the Computer Applications Department, MANIT, Bhopal, in 2020. She is a seasoned academician and a researcher with a rich tapestry of experience in academia and industry. Dr. Sharma's contributions span various prestigious conferences and reputed journals, showcasing a dedication to advancing the field of computer science. With a focus on web crawling, data mining, and cutting-edge technologies, such as blockchain. Their work demonstrates a commitment to both theoretical exploration and practical applications and currently serving as an Assistant Professor with Chitkara University, Rajpura, Chandigarh, Dr. Sharma brings an extensive background in computer science and a fervent commitment to advancing knowledge in the field.

TULIKA CHAKRABARTI received the Ph.D. degree in science from Jadavpur University, in 2013. She is currently an Associate Professor with the Department of Chemistry, Sir Padampat Singhania University, Udaipur, India. She was an Academic Visitor with the GTE Laboratory, Asian Institute of Technology, Bangkok, in October 2019; a Visiting Scholar with the Logistics Institute-Asia Pacific–National University of Singapore, in April 2019; a Visiting Women Scientist with the Cyber Security Laboratory (N4.B2.c06), School of Computer Engineering, Nanyang Technological University, Singapore, in April 2019; and a Visiting Senior Women Scientist with the Faculty of Pharmacy and the Department of Biotechnology, Lincoln University College, Malaysia, in November 2018. She has more than 50 reputed publications, 41 international granted patents, eight Indian granted copyrights, and two books. She is a fellow of the Royal Society of Arts London, the Iranian Neuroscience Society, the Scientific Communications Research Group Egypt, the Nikhil Bharat Shiksha Parisad, and the International Society for Development and Sustainibility Japan.

PRASUN CHAKRABARTI (Senior Member, IEEE) received the Ph.D. degree in computer science and engineering from Jadavpur University, in 2009, and the D.Litt. degree from Sambalpur University, in 2022. In 2023, he has registered for another higher doctoral degree (D.Sc.). He is the Director, the Directorate of Research and Publications, and the Dean of International Affairs and Professor with the Department of Computer Science and Engineering, Sir Padampat Singhania University, India. He became a Full Professor at only 34 years and is one of the youngest Deputy Vice Chancellor of India at an age of only 41 years. On various research assignments, he has visited Waseda University, Japan, in 2012, availed prestigious INSA-CICS travel grant; the University of Mauritius, in 2015; Nanyang Technological University, Singapore, in 2015, 2016, and 2019; Lincoln University College, Malaysia, in 2018; the National University of Singapore, in 2019; the Asian Institute of Technology, Bangkok, Thailand, in 2019; and ISI Delhi, in 2019. He is a Visiting Senior Scientist with the National Kaohsiung University of Science and Technology, Taiwan; a Visiting Distinguished Research Fellow with Wales Institute of Digital Information, U.K.; an Honorary Adjunct Distinguished Professor with the Don State Technical University, Russia; a Visiting Professor with the Shiraz University of Medical Sciences, Iran; and an Honorary Visiting Distinguished Scientist with the PLANET Laboratory, Politecnico di Torino, Italy. He has more than 100 SCI/Scopus indexed publications, 11 books, 55 granted international patents, and 16 granted Indian copyrights. He has supervised 11 Ph.D. candidates successfully. He is a fellow of the Institution of Engineers, India; IET, U.K.; the Royal Society of Arts London; the Iranian Neuroscience Society; IETE; ISRD, U.K.; IAER, London; Nikhil Bharat Shiksha Parisad, Government of West Bengal; and the Scientific Communications Research Group, Egypt.

MARTIN MARGALA (Senior Member, IEEE) received the Ph.D. degree in electrical and computer engineering from the University of Alberta, Canada. He joined the School of Computing and Informatics, as a Professor and the Director, in August 2021. Before joining UL Lafayette, from September 2011 to July 2021, he was a Professor and the Chair of the Electrical and Computer Engineering Department, University of Massachusetts, Lowell, and the Co-Director of the Center for Smart Cyber-Physical Systems (SCyPS) (61 in Global Ranking in North America region; 13 in Global subject specific ranking Electrical and Electronic Engineering in North America region USNews) in the Spring of 1998. He is a Senior Member of ACM and SPIE with more than 50 journal and 200 peer reviewed conference publications in the areas of design for testability for energy efficient architectures and systems, high-performance reliable low-power architectures, and reconfigurable secure architectures and systems. He has directed 22 Ph.D. students and 19 M.S. students, many of whom currently hold leading positions in academia and industry. He has served on numerous program committees of international conferences and on workgroups (such as the International Technology Roadmap for Semiconductors) that have a great impact on the future direction of academia and industry.