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IoT-Based Real Time pH Monitoring of University of Mindanao's Chemical Laboratory Wastewater

Egi Joe Fran D. Morales[1,a] and Chosel P. Lawagon[2,b*]

[1]College of Engineering, University of Mindanao, Matina, Davao City, Philippines

[2*]Research and Publication Center, University of Mindanao, Matina, Davao City, Philippines

[a]egimorales@umindanao.edu.ph, [b*]clawagon@umindanao.edu.ph

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Abstract. Wastewater is a by-product of industrial and commercial facilities. If not treated, it could cause environmental and health problems. The proposed IoT-Based Real-Time pH Monitoring of wastewater can regulate the disposed waste through web browsers. The device has undergone several trials with wastewater from the chemical laboratory at different pH levels. It gave the signal to the solenoid motor to position either close when the pH level is more significant than pH 7.5 and less than pH 6.5 or open when the pH level is pH 6.5 to pH 7.5. The output's accuracy was measured using buffer solutions at different temperatures. It showed that the value of the pH level varied in temperature with significantly small changes. The system monitoring in the web browser captured the data every minute and saved it in a database for data comparison purposes. The device conformed to the Department of Environmental Natural Resources - Environmental Management Bureau (DENR-EMB) in the Philippines' standard permissible pH level (pH 6.0 to pH 9.0). Using an Arduino NANO microcontroller that served as a central processing unit and a Node MCU to connect the system to the internet, the equivalent output of an industrial pH meter was obtained, allowing the user to monitor the system at any time using a web browser.

Introduction

Wastewater is a costly pressing concern [1] that, if left untreated, poses environmental and health hazards, especially in developing countries [2], [3]. It is primarily generated from ordinary human activities like bathing, toilet flushing, laundry, and dishwashing, among others [4],[5]. Aside from domestic sources, it also includes industrial, commercial, agricultural, and academic activities [6],[7]. The common wastewaters generated from university chemical laboratories are acid and basic waste such as NaOH and KOH. The wastewater from the chemical laboratory was discharged from various laboratory activities, such as washing glassware and chemical waste from research and experimental educational activities. The discharged chemical liquid contains toxic chemicals, organic compounds, and heavy metals, which harm living organisms and the environment [8].

Every ecosystem relies on water in some regard, and when it is contaminated by sewage, toxic chemicals, or any number of other artificial forms of waste, the destruction of natural habitats and wildlife is imminent. Hence, several wastewater treatment practices, like physical water treatment [9], are used for screening, sedimentation, and skimming to remove solids. Biological water treatment [10] breaks down the organic matter in wastewater, such as soap, human waste, and food. In addition, using chemicals in water such as chlorine and oxidizing chemical commonly used to kill bacteria is one form of chemical water treatment [11]. These treatments require close supervision to prevent further environmental problems from persisting.

Although wastewater quality monitoring is required, some businesses need to apply it better because they need more technical resources and instruments [12]. Data on water quality and wastewater could be more reliable and organized. Due to increasing water quality concerns, monitoring water quality is likewise becoming a complex problem [13]. Consequently, a new paradigm is needed to manage water resources in the future. On the other hand, it's crucial to include cutting-edge technologies and new methods in conserving water resources. It enhances the performance of the network and processing facilities running within the region and resource consumption. Parameters affecting water quality must be regularly checked every day. For instance, monitoring of industrial wastewater includes dissolved oxygen, temperature, pH, ammonia, nitrate, nitrite, and salinity [16] as well as specific parameters (COD or TOC, AOX, suspended solids), single substance parameters, and BOD 5, NH4-N, and total N (sum of Kjeldahl-N, NO 2N, and NO 3-N) (heavy metals, nitrogen compounds and other). Usually, the parameter must be continuously observed, i.e., more than once every day. pH must be checked even after wastewater treatment to ensure it is safe to be released back into the environment [17], [18].

InoLab® 7110 and 7310 gadgets can measure and monitor wastewater's pH [19]. It cannot be observed online and only record measurement data, such as the date, time, and pH level [20]. On the other hand, real-time monitoring of the Internet of things (IoT) consists of a network of physical objects outfitted with software, sensors, and network connectivity to gather and share data[21]. Chemical laboratories can track the toxic liquid discharges from their equipment online and in real-time by using IoT monitoring [22].

The University of Mindanao Chemical laboratory (UMCL) generated wastewater is indefinitely stored in containers due to the lack of a government-accredited third-party chemical waste disposal facility in the region [23]. However, most of the waste generated in UMCL is alkaline and acidic; hence typical neutralization [24] can be done before safe disposal. To ensure that treated wastewater adheres to Department of Environment and Natural Resources (DENR) standards (pH = 6.5 to 8.5 from DAO No. 35) and is acceptable for safe discharge, the development of wastewater monitoring is necessary.

Hence, this study aims to monitor the quality of the treated wastewater online and assurance of water quality using sensors and microprocessors. Since wastewater monitoring is a system to ensure water quality, this can aid the university in guaranteeing clean and safe water for discharge, particularly for chemical laboratories and multi-test. Also, online monitoring allows the laboratory custodian to access and update anytime easily. Students are also safe from water contamination and risk of health problems.

The focus of this project is to design a system to monitor the quality of treated wastewater in terms of pH online in the University of Mindanao chemical laboratory only. The system will use a microprocessor and sensor to measure water quality. The microprocessor will send a signal through Wi-Fi and can be accessed online. The proposed method is limited only to android and laptops or computers.

Materials and Methods

A. *Materials*

The system's major components are the Node MCU (Express if Systems, 32 KiB instruction, 80 KiB user data, China), Arduino Nano (Arduino, eight analog inputs ports: A0~A7, China), Analog pH Sensor (DF Robot, Laboratory grade, pH 0~14, China), Analog Dissolved Oxygen (DF Robot, Galvanic Probe, 0-20mg/L, China), and Water Solenoid Valve (Ningbo Riyi Technology Co., Ltd, Actuating voltage: 12VDC, China).

An Arduino Nano serves as the system's central processing unit. All the system's components are controlled and processed by the Arduino nano. When connecting the system to a wireless network, the Node MCU comes in handy. It's also why the data in the system may be viewed through a web browser. The pH level of the wastewater influent and effluent is measured and monitored using an analog pH sensor/meter kit. An analog dissolved oxygen sensor/meter kit is used to measure and monitor the oxygen level in the wastewater influent and effluent. The water solenoid valve stops wastewater flow if the systems identify an undesirable pH level.

B. *Methods*

The IoT-Based Real-Time pH Monitoring flow chart of the system is shown in Figure 1. As the device turns on, the system checks to see if any buttons have been touched. The system will look for a Wi-Fi signal if no buttons are pressed. When the system identifies a known Wi-Fi network, it retrieves a threshold, begins monitoring, and sends data to the website. If the system is unfamiliar with the Wi-Fi signal, it will construct an Access Point (AP) and configure it through a web browser with an IP address of 192.168.4.1, after which it must be rebooted.

The system enters calibration mode if a button is pressed or can delete the previously saved data. Green, blue, and red are the three buttons. Each button has a distinct function. The green button activates calibration mode, the red button deletes the pH-calibrated value, and the blue button deletes the DO-calibrated value.

The system will enter calibration mode once the green button is pressed. "What button is pressed?" the system will question after it has entered calibration mode. The machine will exit calibration mode if it senses the green button. It will enter pH calibration mode if the blue button is pressed. If the red button is pressed, the system will enter Dissolved oxygen (DO) calibration mode and then restart the system.

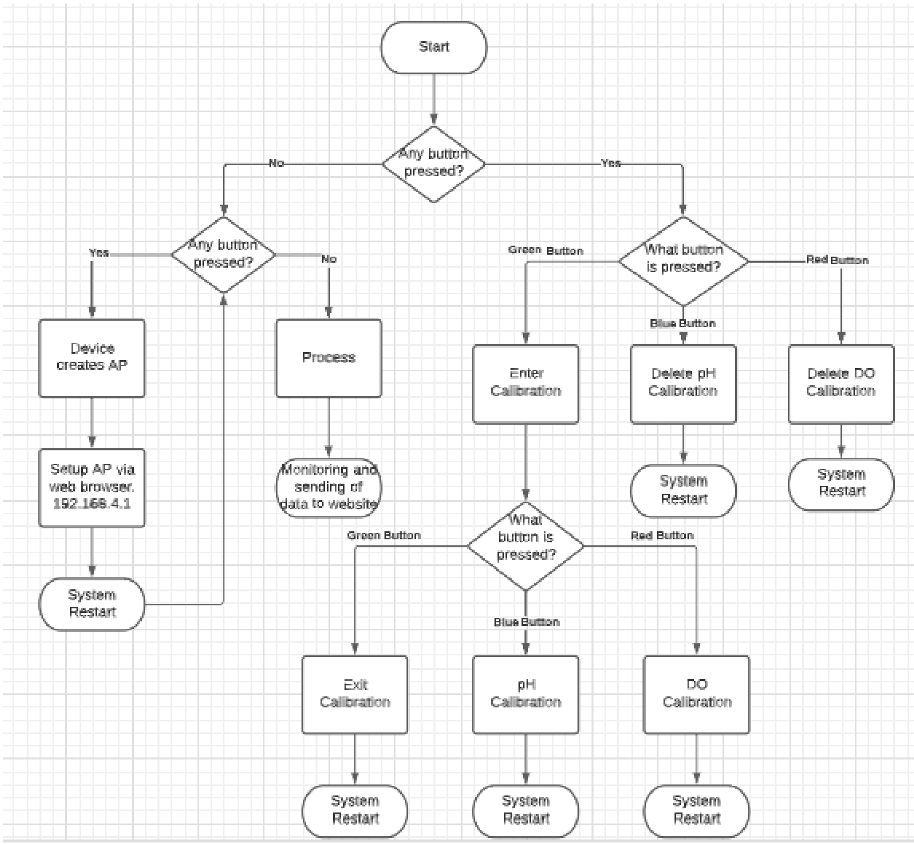

Fig. 1 IoT based real-time pH monitoring flow chart.

Results and Discussion

IoT-Based Real-Time pH Monitoring identifies the pH and DO levels and may be monitored online. IoT-Based Real-Time pH Monitoring detects pH and DO levels in analog sensors and saves the data online. The system's central processing unit, represented by the Arduino Nano in Figure 2, is responsible for processing sensor data before sending it to the Node MCU and LCD for monitoring.

IoT-Based Real-Time pH Monitoring, a functional block diagram of the system, is shown in Figure 3. The functions are shown above the blocks, and the required hardware is indicated inside the blocks. The purpose of this system is to monitor the pH level online and ensure effluent passes the environmental standard. The input command is wastewater. The pH and DO sensors convert the wastewater into a voltage.

Similarly, the feedback path's pH and DO sensor convert the threshold signal to a voltage. The Arduino nano boosts the difference between the input and output voltages. When the input and output match, the error will be zero, and the motor will not turn. Thus, the motor is driven only when the system detects if the feedback signal is within the threshold. The output of the Arduino nano always sends a threshold signal to Node MCU and LCD for monitoring.

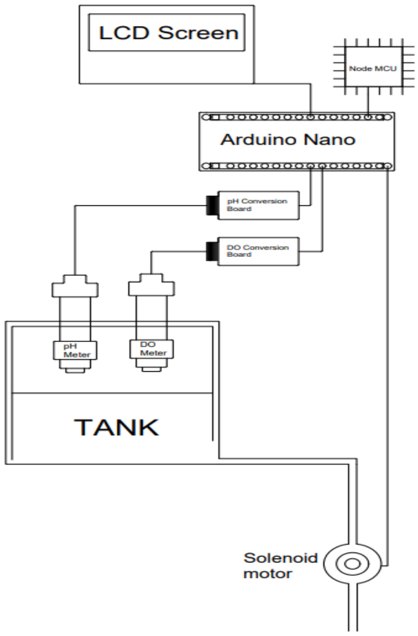

Fig. 2 IoT based real-time pH monitoring physical diagram.

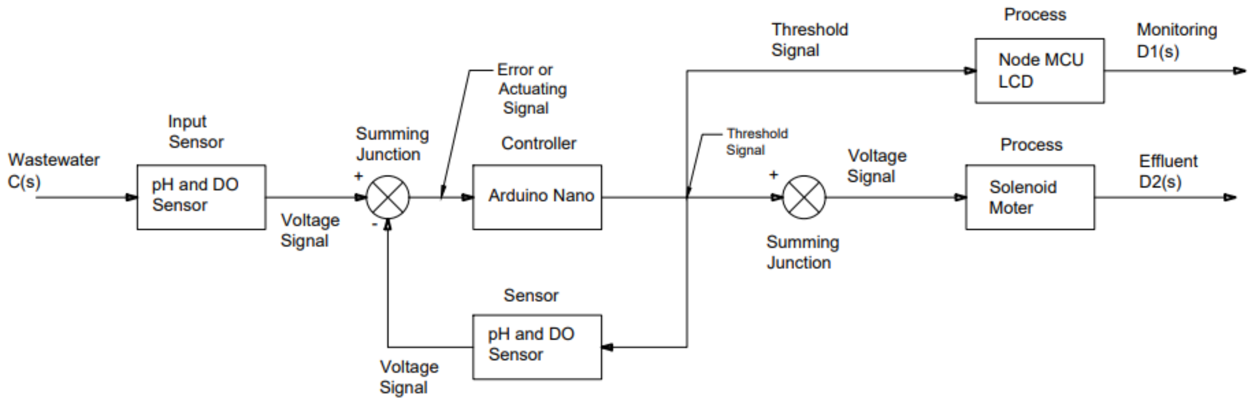

Fig. 3 IoT based real-time pH monitoring functional block diagram.

To test the accuracy of the device, a buffer solution was used at ten different temperatures (10 – 55 ℃). At pH 4 and 7, the value varies in temperature (Table 1), which is the expected trend [25], implying the device's reliability.

Table 1 IoT based real-time pH monitoring values of pH buffer 4 and 7 at different temperature for testing the accuracy of the system.

℃	pH Reading	
10	3.9	7.1
15	3.912	7.08
20	3.98	7.05
25	4.01	7.02
30	4.08	6.99
35	4.02	6.98
40	4.03	6.98
45	4.04	6.97
50	4.06	6.95
55	4.08	6.91

The system is set to pH 6.5 to pH 7.5, as is the acceptable wastewater pH for disposal back to the environment [26]. At this threshold, wastewater disposal is allowed and adjusted to any desirable pH level.

If the wastewater's pH is greater than pH 7.5, the status of the solenoid motor out of ten trials is 100% close (see Table 2). It is because the value of a pH level greater than pH 7.5 is set to close the solenoid motor from the program. It signifies that wastewater won't be thrown away unless it meets the designated threshold. This mechanism will ensure that only acceptable pH values will be disposed of, adhering to environmental standards and regulations [26]. InoLab® 7110 and 7310 gadgets can be used to measure and monitor the pH of wastewater [19] and dispose of the effluent to sewage once treated. It can't monitor online and can only record measured data [20] of wastewater.

Table 2 IoT based real-time pH monitoring solenoid motor status with pH level greater than 7.5 of the system.

pH Level	Solenoid Motor Status
8.03	Close
8.5	Close
8.00	Close
8.6	Close
9.06	Close
8.89	Close
8.9	Close
9.01	Close
9.03	Close
9.05	Close

The solenoid motor is open in all ten experiments when the pH is between 6.5 and 7.5 (see Table 3). The solenoid motor's configuration indicates that wastewater will be ejected when the pH level in the program is between pH 6.5 and 7.5. The established pH threshold complies with environmental legislation and guidelines, enabling the laboratory to dispose of treated effluent properly.

Table 3 IoT based real-time pH monitoring solenoid motor status with pH Level ranging from 6.5 to 7.5 of the system.

pH Level	Solenoid Motor Status
7.00	Open
7.03	Open
7.04	Open
7.4	Open
7.47	Open
6.6	Open
6.65	Open
6.57	Open
6.9	Open
6.97	Open

When the pH is less than 6.5, the solenoid motor is 100% closed (Table 4). If the pH level is less than 6.5, the solenoid motor will be shut, indicating that the wastewater will not be discarded. Wastewater's pH values are continuously monitored online, with the data gathered being saved in the database server.

Web browsers access the system's online monitoring (https://umindanaochemlab.com/). The online monitoring system dashboard (Figure 4) is on three levels. The blue line represents temperature, the green line represents pH, and the red line represents DO levels. The pH's upper limit from the dashboard can also be modified. A portion of the system had wastewater treated before being disposed of away. With the help of this technology, it is possible to examine previously acquired data, ensure that wastewater disposal in drainage is done by environmental standards, and monitor it online [27].

Table 4 IoT based real-time pH monitoring solenoid motor status with pH Level Less than 6.5.

pH Level	Solenoid Motor Status
6.48	Close
6.20	Close
6.19	Close
6.22	Close
6.17	Close
5.8	Close
5.78	Close
5.76	Close
575	Close
5.79	Close

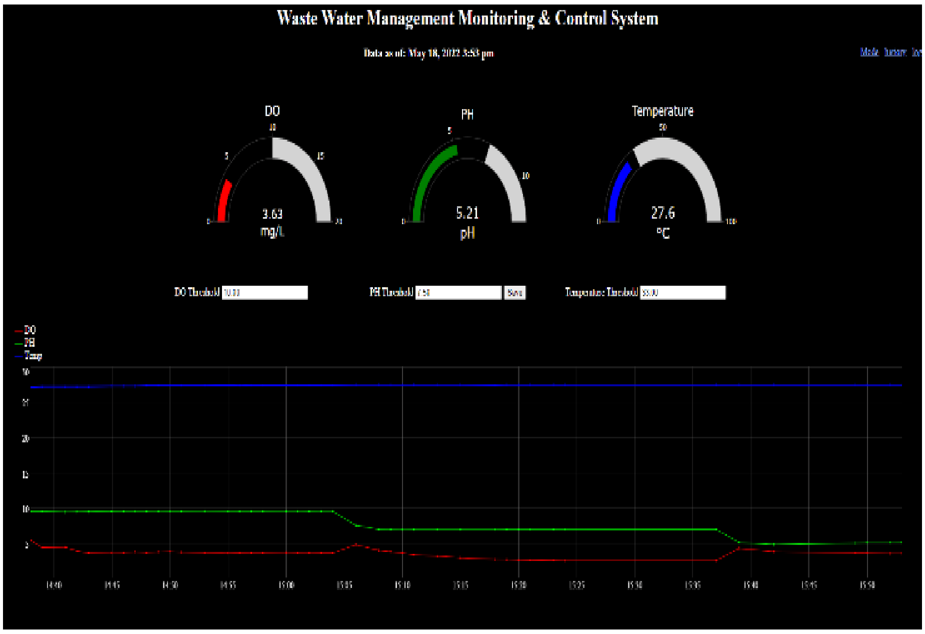

Fig. 4 IoT based real-time pH monitoring dashboard.

The temperature, pH, and DO level data obtained from the device were reflected in the online monitoring dashboard (Figure 4). The data was collected online and entered into the Origin Pro application to see the results.

The pH meter reads pH 9.6 to pH 9.66 for the first 30 minutes, pH 7.04 to pH 7.07 for the second 30 minutes, and pH 4.92 to pH 5.21 for the final 30 minutes of testing (Figure 5). It has been noticed that depending on the pH sensor employed, the pH level takes some time to stabilize its value. But such a device’s result is already acceptable given that only a shorter time (30 – 60 sec.) is needed to stabilize compared to other studies [28].

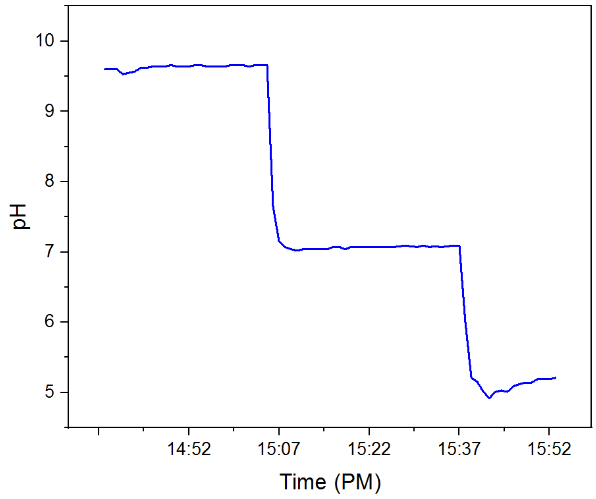

Fig. 5 IoT based real-time pH monitoring pH level measured online.

For the first 30 minutes of testing, the temperature swings from 27.31 to 27.56 degrees Celsius (Figure 6a) before settling at 27.63 degrees Celsius for the remaining hour. Because the temperature of the wastewater has yet to reach room temperature, on the other hand, the dissolved oxygen shows that it fluctuates every time the pH level changes and stabilizes as time passes by (Figure 6b). The oxygen level of water rises every time there's a motion in the water [29] which is the case herein.

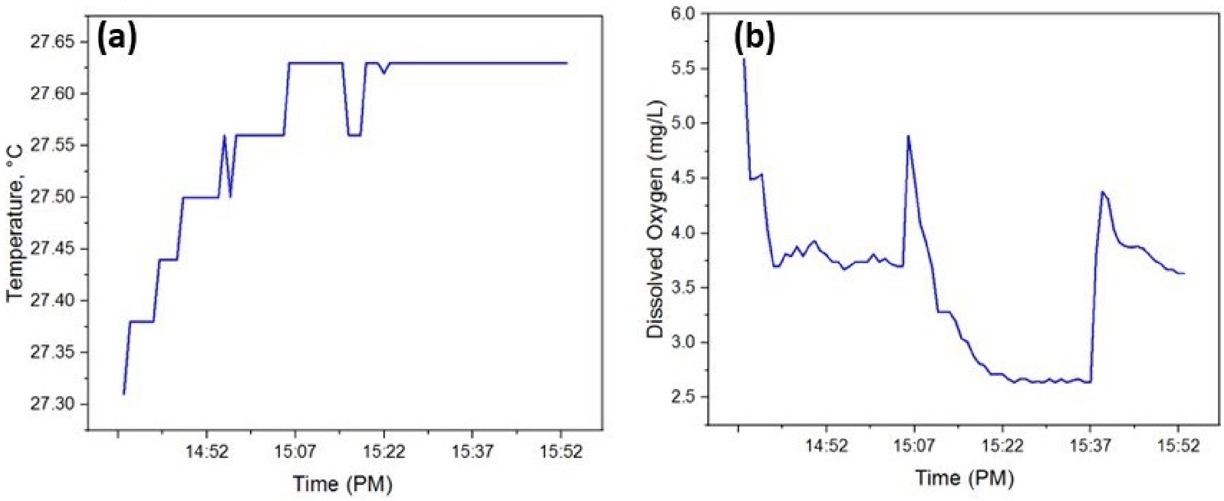

Fig. 6 IoT based real-time pH monitoring temperature (a) dissolved oxygen (b) level measured online.

Based on the system's output, the system is flexible in terms of the pH level that is allowable to be disposed of and monitored online via a web browser (https://umindanaochemlab.com/login.php) and onsite. It is an advantage as other studies only monitor the pH level of the water [30].

Conclusion and Future Works

The system was tested and operated with reliability up to 100% out of ten trials in the given objectives, taking into consideration of the following conditions: disposal of effluent when the pH level is within the range of pH 6.5 – 7.5 and holds the effluent that is greater than pH 7.5 and less than pH 6.5. The designed system used Arduino nano to monitor the pH level and ensure the safe disposal of effluents in The University of Mindanao chemical laboratory. IoT Based Real-Time pH monitoring can be installed in the laboratory and accessed on a website. Personnel can register on the website to access the monitoring dashboard. Compared to inoLab® 7110, which manually monitors the pH level of effluent, this study uses Arduino nano for processing the data gathered from the sensor. It sends it to node MCU and LCD screen for online monitoring and motor to dispose of effluent once the condition is true. The system developed is not limited to chemical laboratory applications but also any industry that may unintentionally dispose of harmful wastewater.

Furthermore, the dissolved oxygen for triggering solenoid DC motors and time delay detections from the system to online monitoring must be further explored. The time delay before it will be posted on the internet is 30 sec to 1 minute, depending on the speed of the internet. Finally, for ease of monitoring and better access, the creation of android and apple applications for better monitoring is recommended.

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