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Design of an Arduino-Based Water Quality Monitoring System

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ABSTRACT

In agricultural cultivation, water is a critical climatic element. It has an impact on the growth and development of plants. Their abundance or shortage can lead to a good harvest, a lower yield, or even failure. Water quality testing is an essential part of environmental monitoring. When water quality is inadequate, it has an impact on agricultural life as well as the biological system as a whole. The researcher decided to design, build, and test a device that would enable real-time water monitoring based on this concept. After five months of research and development at Eastern Samar State University Salcedo Campus, the device was finished. The Arduino-based Water Monitoring System is entirely functional and can detect sensor readings from four parameters, including temperature, pH, turbidity, and electrical conductivity. According to the experiment results and the system usability test, it can now be deployed. The gadget also has an ESP32 included in it, which can transfer data through WIFI and Bluetooth. The device was practical and usable because it complied with the specifications. When paired with the Water Quality Mobile Application, the device is compatible with a 5-volt power bank and works well. The researcher suggests that digital sensors be considered because the gadget employs analog sensors, and reading is completely dependent on the type of sensor used. Additional testing, such as monitoring the ammonia level and dissolved oxygen, can be done while considering the device power requirements and overall design.

Keywords: *Arduino Device, Water Quality Monitoring, developmental design, smart agriculture, Internet-of-Things*

I. INTRODUCTION

Background of the Study

Republic Act (R.A.) No. 9275 (2004), titled "An Act Providing for a Comprehensive Water Quality Management and Other Purposes," otherwise called the Philippine Clean Water Act of 2004 (CWA), was marked by previous President Gloria Macapagal-Arroyo on March 22, 2004. With its Implementing Rules and Regulation (IRR) contained in the Department of Environment and Natural Resources (DENR) Administrative Order (A.O.) No. 2005-10. The law applies to water quality administration in all water bodies. It essentially applies to the decrease and control of contamination from land-based sources. The water quality gauges and guidelines and the common obligation and punitive arrangements under the law will be upheld regardless of wellsprings of contamination.

Water is a major climatic factor in agricultural farming. It influences or affects plant growth and development. Their availability or scarcity may result in a successful harvest, reduced yield, or complete failure. According to FAO (2011), the number of crops cultivated in a single year increases from 1 to 2, which is usually double the irrigation yield of farmers.

However, the reaction of plants differs, and the importance of water varies according to the species of plants. Most plants are mesophytes, which means they are adapted to moderately wet conditions. Nevertheless, some water-based or water-based habitats are more suitable for dry conditions; others are called hydrophytes. The resurrection plants can remain almost complete. They can lose 90% and more of their cellular water and stay alive in their vegetative tissues. They can stay dry for a few years and seem a bit dead, but they unexpectedly come back to life when rehydrated (Le and McQueen-Mason 2006).

Water quality testing is a significant piece of ecological checking. When water quality is poor, it influences aquatic life as well as the encompassing biological system. Parameters that influence the nature of water in the earth can be physical, substance, or organic elements. Physical properties of water quality incorporate temperature and turbidity. Synthetic qualities include parameters, for example, pH and broke up oxygen. Organic markers of water quality incorporate green growth and phytoplankton. These parameters are applicable not exclusively to surface water investigations of the sea, lakes, and streams but to groundwater and mechanical procedures. Water quality observing can assist analysts with foreseeing and gain from characteristic procedures in the earth and decide human effects on a biological system (Fondriest Environmental Learning Center, n.d.).

International Environmental Technology (n.d.) affirms that water quality checking information is staggeringly valuable and is not in every case simple to accumulate. Pros utilize a scope of various methods to assemble results, including taking examples of concoction conditions, breaking down dregs, and utilizing fish tissue concentrates on discovering hints of metals, oils, pesticides, broke up oxygen, and supplements. Physical conditions, for example, temperature, disintegration, and stream, offer significant understanding, while organic estimations concerning plant and creature life show the wellbeing of marine biological systems.

As Myers (2020) described, water quality assesses water's physical, chemical, biological, and microbiological characteristics. Monitoring water quality in the 21st century is a growing challenge due to the vast number of chemicals used in our everyday lives and industry that can find their way into our waters. Methods of chemical analysis and knowledge of chemical toxicity are available for just a few thousand of the more than 80,000 chemical substances reported by EPA for commercial use in the United States.

According to the United States Environmental Protection Agency (EPA) (2012), water quality monitoring is characterized as sampling and analysis of water components and conditions, which can include: added toxins, such as pesticides, metals, and oils, and elements naturally present in water that can still be influenced by human sources, such as dissolved oxygen, bacteria, and nutrients.

Monitoring offers the credible information required to make rational decisions on water quality management both today and in the future. Water quality monitoring is used to alert us to existing, continuing, and emerging issues, assess compliance with drinking water requirements, and protect other beneficial uses of water. Monitoring data assessments help policymakers and water managers evaluate the efficacy of water policies, decide if water quality is getting better or worse, and devise new strategies to protect human health and the environment better.

A paper from Cloete et al. (2016) explains the design and implementation of a monitoring framework for water quality to inform users of specific water quality parameters. The device can calculate water quality physiochemical parameters such as flow, temperature, pH, conductivity, and oxidation potential. These parameters are used to identify water pollutants. They are physiochemical. The sensors are connected to a microcontroller-measuring node, which processes and analyzes the data based upon initial principles and implemented with signaling circuits.

From the preceding, the concept of developing a water quality monitoring is envisioned to be a help to the community. This study explicitly seeks to design and develop Water Quality Monitoring Technology compatible with agricultural use and provide a real-time water monitoring system for ESSU Salcedo.

Objectives of the Study

This study had the following objectives:

1. To design an Arduino-based water quality monitoring device compatible for smart agriculture.
2. To develop the Arduino-based water quality monitoring device, which will allow farmers to monitor the quality of water supply using four sensors in one device.
3. To the Arduino-based water quality monitoring device in terms of its functionality and general usability.

Significance of the Study

The water quality monitoring using IoT will be beneficial to the following:

The University. This study could be utilized for the smart agriculture project of the campus. It can also be an opportunity for the University to generate research-based technologies that are potential for patenting or, at the very best, for the utility models.

The Farmer Beneficiaries. This study would help farmers monitor water quality, thereby achieving optimal functionality of the device to the farm.

The Future researchers. This study could serve as a tool for researchers that need technology for monitoring water quality.

Scope and Delimitation

The study covers the design, development, programming, and testing of IoT-based water quality monitoring—a cost-effective water quality control system for IoT monitoring in real-time. The device consists of multiple sensors that can be calibrated in water to measure physical and chemical parameters. It includes turbidity (TU), electrical conductivity (EC), Temperature, and pH. The micro control device generates the calculated values from the sensors, and it will be forwarded to the application.

Moreover, four (4) identified water sources to be monitored, including the main water reservoir, tilapia fish pond, green hills water stream, and the Florida water stream.

Definition of Terms

The following terms were defined conceptually and operationally for easy understanding of the study.

Arduino Integrated Development Environment. It is an environment capable of allowing the programmer to send an instruction to the Arduino Microcontroller board. In this study, it was used to program the Arduino microcontroller.

Arduino: Microprocessor. It is an Arduino brand programmable electronic device that serves as the controller of the connected devices. This study was the device that was programmed to control the sensor, calculate the water's quality, and send it to the Arduino device.

Electrical Conductivity (EC). The degrees to which to specified material conducts electricity are calculated as the ratio of the current density in the electric field material that causes the flow of current. It is the reciprocal of resistivity (oxford dictionaries). In this study, it is a crucial parameter to be monitored using a sensor.

pH level. A range of ph 6.5 to ph 8.2 is optimal for most organisms. Most organisms have adapted to life in water of a specific ph and may die if it changes even slightly (www.fivecreeks.org/monitoring/pH.shtml). This study is used to recognize pH levels/organisms. In this study, it is a crucial parameter to be monitored using a sensor.

Turbidity (TU). The cloudiness or haziness of fluid is caused by large numbers of individual particles that are generally invisible to the naked eye. Similar to smoke in the air, the measurement of turbidity is a crucial test of water quality. In this study, this is the type of parameter that monitors the excellent quality of water. In this study, it is a crucial parameter to be monitored using a sensor.

System. It is a group of related parts that move or work together (Merriam Webster Inc., 2020). This term referred to the whole package upon implementing the Arduino-based Water Quality Monitoring System in this study.

Temperature. The physical property of matter that quantitatively expresses the common notions of hot and cold (cn.wikepedia.org) in this study refers to the hit index of water. In this study, it is a crucial parameter to be monitored using a sensor.

Acronyms

CCS	College of Computer Studies
EC	Electrical Conductivity
ESSU	Eastern Samar State University
IoT	Internet of Things
NTU	Nephelometric Turbidity Unit
pH	Power of Hydrogen
RAD	Rapid Application Development
TU	Turbidity

II. METHODOLOGY

The design and development of this project are divided into two main parts: hardware architecture and software details. In the hardware architecture, the creation of the circuit was constructed, and the prototype of the project was built. While in the software development, the whole complete prototype was operated via programming codes.

Hardware architecture

Because Arduino is the primary board, the ATmega328 microcontroller is the central controller to manage the circuit. It is a well-known open-source microcontroller-based kit for building digital gadgets and interactive tools that can interact with LEDs, LCDs, switches, buttons, motors, and speakers, among other things. The Arduino system provides a set of analog and digital pins connected to various boards and circuits to perform multiple tasks in a design. For loading programming from a computer, the Arduino board has a USB serial connection port. Arduino has developed its integrated development environment (IDE) software, fully supporting C and C++ programming languages. The Arduino Nano board is shown in Figure 1 and is utilized throughout the project.

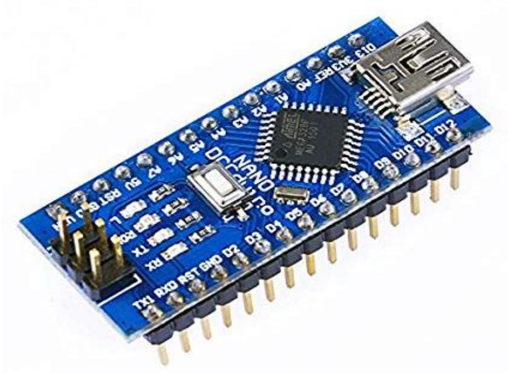

Figure 1. The Arduino Nano Board

Figure 2 shows the ESP32, a single 2.4 GHz Wi-Fi and Bluetooth combination chip made in TSMC's ultra-low-power 40 nm process. It is built to deliver the most incredible power and RF performance in various applications and power conditions, demonstrating resilience, adaptability, and dependability. ESP32 is a microcontroller used in mobile, wearable electronics, and Internet-of-Things (IoT) devices. It has cutting-edge low-power semiconductor capabilities, such as fine-grained clock gating, various power modes, and dynamic power scaling. For example, in a low-power IoT sensor hub application, ESP32 is woken up regularly and only when a specific condition is recognized. The chip's energy consumption is reduced by using a low-duty cycle. The power amplifier's output may also be adjusted, allowing for an ideal trade-off between communication range, data rate, and power consumption.

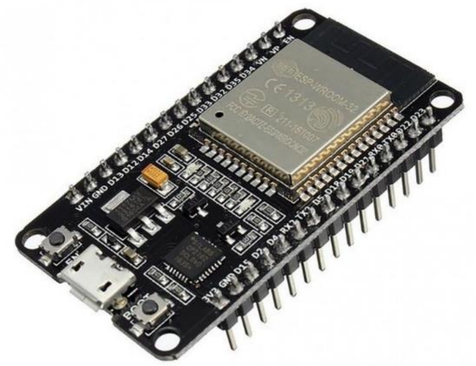

Figure 2. The ESP32 module to communicate with Arduino Board.

Other than the two main components mentioned, another essential element for this project includes three sensors: pH, temperature, turbidity, and electrical conductivity.

Figure 3 shows the pH sensor used in this project. The value of a solution is measured using an analog pH sensor, which displays the acidity or alkalinity of the material. It is widely utilized in various fields, including agriculture, wastewater treatment, industry, environmental monitoring, and many more. The module has an onboard voltage regulator chip that offers a wide voltage range of 3.3-5.5V DC, making it compatible with 5V and 3.3V control boards such as Arduino. The output signal is filtered with low jitter hardware. The pH scale is used to determine how acidic or basic a liquid is. It has values from 1 to 14, with 1 indicating the most acidic liquid and 14 indicating the essential fluid. A neutral material with a pH of 7 is neither acidic nor basic. pH is now necessary for our lives and is utilized in a variety of applications. It may be used to test the quality of water in a swimming pool, for example. pH measurement is also used in various applications, including agriculture, wastewater treatment, industry, environmental monitoring, and many more.

Figure 3. The pH-4502c sensor.

The analog DS18B20 1-Wire Temperature Sensor is a simple and affordable method to add temperature sensing to your Arduino project. These sensors are relatively accurate and do not require any extra components to function. You will be monitoring temperature in no time with only a few wires and some Arduino code. The DS18B20 temperature sensor is reasonably accurate and does not require any other components to function. It has a temperature range of -55°C to +125°C with an accuracy of 0.5°C.

Figure 4. The DS18B20 Temperature Sensor.

TDS (Total Dissolved Solids) refers to the number of milligrams of soluble solids dissolved in one liter of water. The higher the TDS value, the more soluble solids are dissolved in water, and the less pure the water is in general. As a result, the TDS value may be used as a single reference point for assessing the water's purity. It may test and monitor water quality in-home water, hydroponics, and other industries. TDS stands for Total Dissolved Solids in a Liquid, which refers to organic and inorganic compounds suspended in molecular, ionic, or micro-granular form. TDS is measured in parts per million (ppm) or milligrams per liter (mg/L) in most cases. TDS is proportional to water purity; the lower the TDS number, the purer the water. Reverse osmosis filtered water, for example, has a TDS of 0 to 10, but tap water has a TDS of 20 to 300, depending on where you reside in the globe.

Figure 5 shows the **TDS meter**, an **electrical charge (EC)** meter whereby two electrodes equally spaced apart are inserted into the water and used to measure the electrical amount. The result is interpreted by the **TDS meter** and converted into a ppm figure.

Figure 5. The Gravity Analog TDS (Electrical Conductivity) Sensor.

Figure 6 presents the turbidity sensor on the Arduino that detects water quality by measuring turbidity. It detects suspended particles in water by measuring light transmittance and scattering rate, which changes as the amount of total suspended solids (TSS) in the water changes. The amount of liquid turbidity rises as the TTS rises. Water quality in rivers and streams, wastewater and effluent measures, sediment transport research, and laboratory tests can benefit from turbidity sensors.

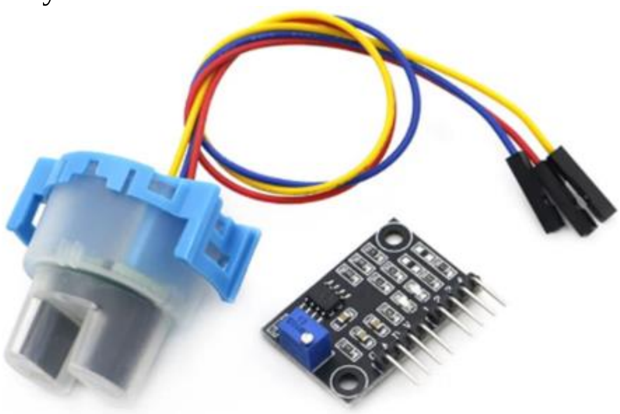

Figure 6. The Analog Turbidity Sensor.

Figure 7 presents a block diagram of the whole project. There will be three major subsystems, including:

- The Data Management Module requires an application that accesses the device environment and shows the same data to the end-user.
- The data transmission subsystem consists of a wireless communication interface with built-in security features that transmits data from the controller to the data storage server.
- The data collection subsystem consists of multi-parameter sensors and an optional wireless communication unit for transmitting sensor information to the controller. The controller gathers the data, executes the same data.

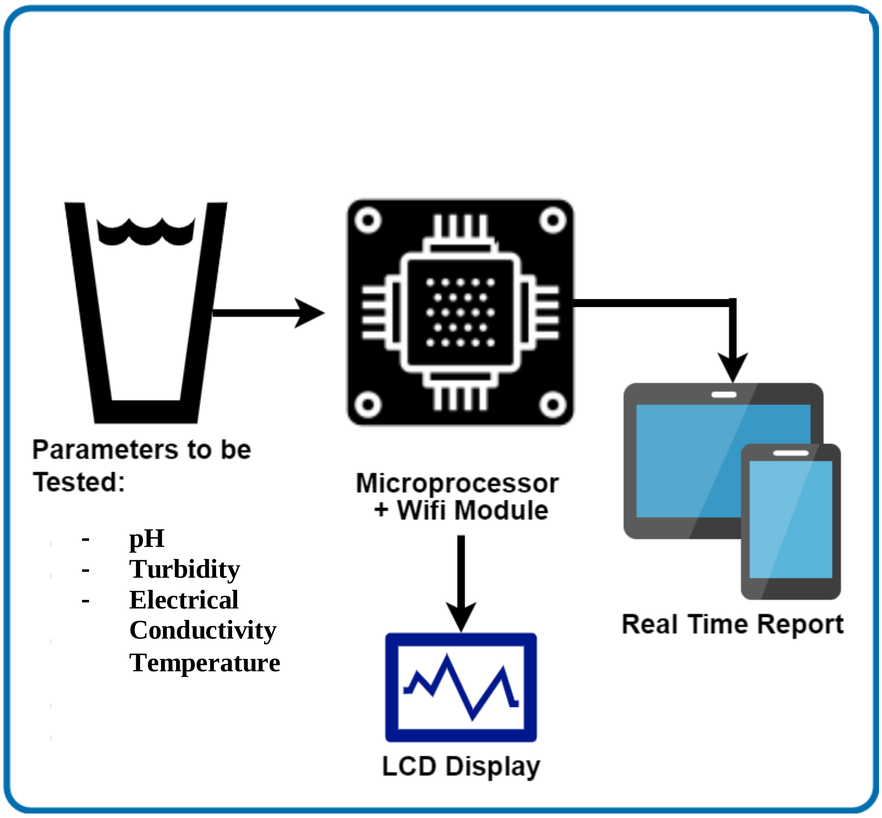

Figure 7. Data Flow Diagram of the Water Quality Monitoring System

Sensors form the bottom-most of the block diagram. Several sensors are available to monitor water quality parameters. These sensors are placed in the water to be tested, either stored water or running water. Sensors convert the physical parameter into equivalent measurable electrical quantity, inputting controllers through an optional wireless communication device. The controller's primary function is to read the data from the sensor, optionally process it, and send the same to the application using appropriate communication technology. The choice of the communication technology and the parameters to be monitored depends on the need of the application. The application includes the data management functions, analysis, and alert system based on the monitored parameters. This section further discusses the previous work carried out in each of the subsystems.

Based on the comprehensive tests performed by U.S. Environmental Protection Agency (USEPA), chemical and biological pollutants used have been found to affect a wide variety of water parameters, including turbidity (TU), electrical conductivity (EC), dissolved oxygen (DO), temperature and the pH (Theofanis et al., 2014).

Schematic Diagram

Turbidity (TU), Electrical Conductivity (EC), Dissolved Oxygen (EC), temperature, and pH are the main parameters controlled in the system. The overall project schematic diagram is shown in Figure 8.

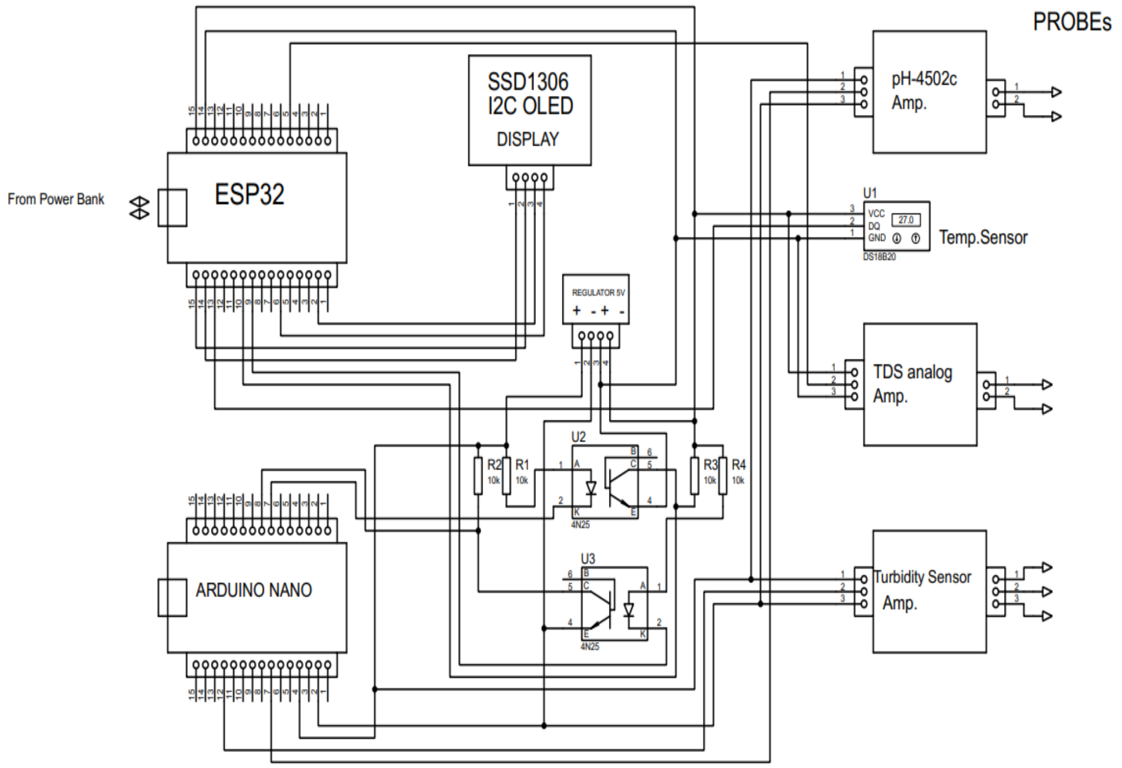

Figure 8. Project Schematic Diagram

An Arduino NANO microcontroller is the central component of the water quality monitoring system enabled by IoT. Most IoT-based device models use an external Wi-Fi interface. This design is economical, they are powerful, and they often lead to complex circuits.

Since the device function is to track water quality, sensors are immediately interfaced with the controller. The sensors like *Turbidity (TU)* and *Electrical Conductivity (EC)*, *Dissolved Oxygen (DO)*, *temperature* and *pH* are measured by inserting the sensor into the water. It can display the calculated parameters to the LCD. The sensor data are transmitted through the controller to the cloud. The threshold is determined in the cloud according to WHO guidelines. When the value exceeds the threshold, messages are sent from the cloud to mobile users. An application is built that displays the values obtained by each sensor in the cloud.

Turbidity is a measure of the cloudiness of the water. Optoelectronic devices such as LDR and LEDs are used to measure turbidity. Light is transmitted and reflected by suspended solids, and the sensors receive the reflecting light. The LDR is a high-resistance semiconductor. If the light falling on the device is of high frequency, the photons absorbed by the semiconductor give the bound electrons enough energy to jump into the conduction band.

The proposed system distance between the LED and the LDR is 9 cm. The resulting free electrons conduct electricity, thus lowering the resistance.

Conductivity is a measure of the ability to carry current solutions. This function is used to quantify salt in the water. The YL-69 is used for calculating water conductivity in the proposed configuration. There are two electrodes, which are proportional to conductivity when immersed in water. The calculation is in dimension per unit. The range of conductivity is appropriate between 300 and 800 μ per cm.

Temperature is a critical quality of water because it regulates the maximum dissolved oxygen concentration and influences chemical and biological reactions. Temperatures should not exceed 89 degrees Fahrenheit in warm water streams). Coldwater streams shall not exceed 68 degrees (Fahrenheit).

The pH measures the amount of acid or base in the solution. Three in 1 pH meter with inverting operational amplifiers are used to measure pH. Op-amp switching is used to boost voltage from mV to voltage range. The pH sensor consists of the reference electrode and the pH electrode, also known as the measuring electrode. When placed in a solution, the pH electrode develops a pH-proportional potential. The value ranges from 0 to 14. The acceptable pH range for drinking water is 6.5 to 8.5.

Software Development

The project's software is based on a flowchart in Figure 9. The developed device needs to be connected in 5 volts of power to start its operation. Once connected, the device will automatically initial its connections between the controller and microprocessor. Initialization is complete once the OLED display will continuously displays the sensor readings. A separate application had been developed to check the device's functionality.

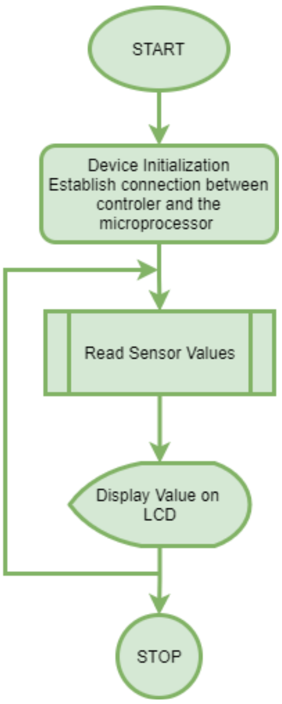

Figure 3. Flow Chart for Water Quality Monitoring System

III. Results and Discussion

The study aimed to design an Arduino-based water quality monitoring system for smart agriculture. All the modules were created, and all the components were assembled.

Figure 4 presents the map showing the water samples used in the experiment. It includes four water sources: the main water reservoir, Tilapia Fish Pond, Greenhill's Village water stream, and Florida village water stream.

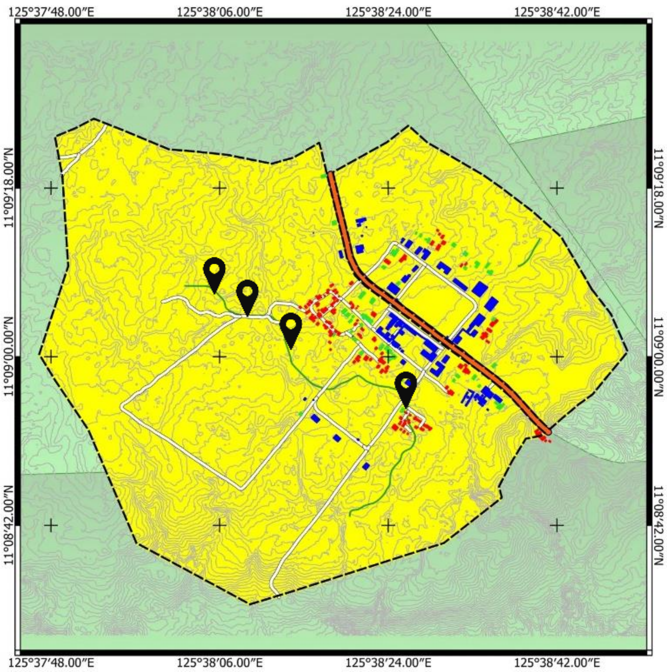

Figure 4. Location of Water Samples

Table 1 presents the results obtained in the experiments. The testing of each module was carried out successfully in a controlled environment using five samples. Thus, there is a need to conduct further investigations in an environment similar to actual water conditions.

Table 1. Water Sample Result

Water Sample	Module Data Result			
	pH	**Temperature**	**TDS**	**Turbidity**
a. Main Water Reservoir	7.93	25.37 °C	0 PPM	1527.32 NTU
b. Tilapia Fish Pond	7.88	25.44 °C	0 PPM	1638.29 NTU
c. Greenhills Village Water Stream	7.80	25.50 °C	0 PPM	1552..35 NTU
d. Florida Village Water Stream	7.71	25.44 °C	22 PPM	1514.73 NTU

During the experimental testing, observations were done to check the system's performance. All tests were completed by using the designed hardware for the water samples. Figure 4 presents the OLED display during initialization. It displays the name of the school and the device name. Figure 5 shows the OLED display during sensor reading. Found on the display are the four sensor reading values: temperature, pH, turbidity, and electrical conductivity.

Figure 4. OLED Display During Initialization

Figure 5. OLED Display During Sensor Reading

Usability Testing

After the experimental testing, the usability test followed to guarantee that the developed device meets the requirements and is ready for implementation. The respondent used the System Usability Scale (SUS) by the (Digital Equipment Corporation, 1986), which measures how well a product allows users to accomplish their goals. The SUS Scale is generally used after the respondents had an opportunity to use the system being evaluated before any debriefing or discussions take place.

To calculate the SUS score, first sum the score contributions from each item. Each item's score contributions will range from 0 to 4. For items 1,3,5,7 and 9, the score contribution is the scale position minus 1. For items 2,4,6,8 and 10, the score contribution is the scale position minus 5. Multiply the sum of the scores by 2,5 to obtain the overall value of the SUS. A SUS score of 68 is considered above average, and anything below it is below average.

The evaluators of the system usability tests were three faculty members from Eastern Samar State University and three farm operators in the Municipality of Salcedo. During the testing, the respondent uses the Water Quality Monitoring System Mobile Application (Chica et al., 2021) to furtherly check its usability in terms of its ease in interconnecting with other technology.

Table 2 displays the summary for system usability on the quality of the Arduino-based Water Quality Monitoring System that was done on the second week of September 2021. It represents the overall score of the 10 item statements. It obtained an overall SUS score of 73.75. It implies that the developed device is usable and now ready for implementation.

Table 2. System Usability Results on the Quality Attributes of the Arduino-based Water Quality Monitoring System

Criteria	Mean	SUS Score
1. I think that I would like to use the device frequently	3.80	**2.80**
2. I found the device unnecessarily complex	1.00	**4.00**
3. I thought the device was easy to use	3.50	**2.50**
4. I think that I would need the support of a technical person to be able to use the device	2.50	**2.50**
5. I found that the various functions in this device were all integrated	3.75	**2.75**
6. I thought there was too much inconsistency in this device	1.00	**4.00**
7. I would imagine that most people would learn to use this device very quickly	4.00	**3.00**
8. I found the device very cumbersome to use	2.00	**3.00**
9. I felt very confident using the device	3.75	**2.75**
10. I needed to learn many things before I could get going with this device	3.00	**2.00**
	SUS Score	**29.30**
	Overall SUS Score (SUS Score x 2.5)	**73.75**

IV. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

This part presents the summary, conclusion, and recommendations of the study.

Summary

The device aimed to monitor water quality primarily for smart agriculture by designing, developing, and testing the Arduino-based Water Quality Monitoring Device. Several processes were used to accomplished this goal.

The first was designing the device. Analysis of the data gathered was made to conceptualize the communication between the different sensors to the overall function of the device. The development phase followed after the designing stage. It primarily involves the programming of Arduino Uno microprocessors to control the pH, temperature, turbidity, and electrical conductivity sensors. Since this study focuses on real-time water quality monitoring to its beneficiaries, the researcher also includes an OLED to display its sensor reading for easy recording.

After the development phase comes to the testing phase of the device, the testing phase consists of two-phase in a controlled environment. The first phase was the experimental phase, wherein the device was used to monitor the water samples. It was noted that to facilitate onsite testing; the devices should run using a battery.

The final test was done was the usability test to measures the ease of using the device. It was done before any briefing about the device was made, it was participated by selected faculty of ESSU Salcedo Campus and farmers in the Municipality of Salcedo, Eastern Samar, which gave the study a SUS score of 73.75 that was interpreted as above average, meaning the device was ready to be implemented and ready for use. Proper packaging of the device was suggested for it to look formal.

Conclusion

Based on the findings and evaluation of the device, the researcher came up with the following conclusions:

1. The Arduino-based Water Monitoring Device had been successfully designed, developed, and tested. It was supported by faculty members of the Eastern Samar State University Salcedo Campus and farmers beneficiaries of the study.

2. The Arduino-based Water Monitoring Device was practical and usable since it has met the requirements that had been specified. The device is compatible with 5 volts power bank and works well if paired by the Water Quality Mobile Application (Chica, 2021).

Recommendation

Based on the findings of the study, the researcher had drawn the following recommendation:

1. Since the device uses an analog type of sensors, and reading depends solely on the type of sensors used, the purchase of digital sensors could be explored.
2. Further testing adding more sensors such as monitoring the ammonia level and dissolved oxygen can be included bearing in mind the power requirement and the device's overall design.

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