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IoT-Based Monitoring System for Turbidity and Mercury Concentration of Rivers in Ghana: Detecting Illegal Mining (Galamsey) Sites and Evaluating Environmental Impact

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Abstract- Illegal mining, also known as "galamsey," is a significant environmental issue in Ghana, specifically due to its negative effects on the country's river ecosystems. The government has implemented several measures to assess the environmental impact and identify illicit mining locations. This research paper introduces an IoT-based system for monitoring water quality of rivers. The system is designed to detect and assess illegal mining activities along rivers, specifically focusing on turbidity and mercury concentration as indicators of pollution. The proposed system leverages the LoRa technology by sending turbidity and mercury sensor data processed by a microcontroller to a server through the LoRa gateway. The system has integrated a fuzzy logic-based model to make accurate predictions about pollution levels and detect the presence of an illegal mining site along the stretch of the river. The designed system passed simulations and tests to confirm that the system is capable of delivering precise and prompt water quality data. The system provides local authorities, environmental agencies, and communities with the necessary information to quickly and efficiently address environmental risks.This IoT-based system aims to protect Ghana's water resources and promote environmental awareness and responsible resource management.

Key Words- Fuzzy Logic, LoRa Technology, Turbidity Sensor, Mercury Sensor

I. INTRODUCTION

The rivers of Ghana have played a vital role in the sustenance of the nation for many centuries, providing support to people, ecosystems, and agricultural activities. The rivers play a crucial role in the everyday lives of the local population, serving as vital sources of supplies andcontributing to the aesthetic appeal of the region. Nevertheless, Behind the calm exterior of these waterways is a pernicious and escalating problem: the unlawful extraction of minerals, commonly referred to as "Galamsey" within the local context (Darkwa&Acquah, 2022).The illicit behavior in question is not only detracting from the scenic beauty of Ghana's landscapes, but also posing a substantial threat to the overall health and sustainability of its waterways (Suglo et al., 2021).The primary worries revolve on the escalation of turbidity, which is the level of cloudiness or muddiness in the water, as well as the amplified presence of dangerous mercury in the rivers (Darko et al., 2023). The presence of these contaminants presents significant risks to both the ecological integrity and the socio-economic welfare of the populations that depend on these rivers for their livelihoods and survival (Mallongi et al., 2020).Numerous Galamsey operators opt to conceal themselves inside the wooded regions of Ghana, therefore carrying out their operations in secluded locations beyond the observation of both vigilant individuals and governing bodies.

(Mensah &Tuokuu, 2023) In light of the urgent environmental crisis and the difficulty in detecting illicit miners concealed within forested regions, our research initiative aims to propose a novel approach that leverages contemporary technology, specifically the Internet of Things (IoT), and employs sophisticated data analysis using fuzzy logic. The primary objective of this technology is to function as a vigilant guardian, offering authorities and environmental activists the capability to ascertain the levels of turbidity and mercury content in rivers. Thus providing evidence of illicit mining operations occurring along the riverbanks. This study aims to provide a framework for the design of a system that combines Internet of Things (IoT) technology with fuzzy logic.

II. RELATED WORKS

The incorporation of Internet of Things (IoT) technology has significantly transformed the field of environmental monitoring, especially in relation to the evaluation of water quality, throughout the past few years. The utilization of Internet of Things (IoT) enabled devices and sensors has become more significant in the realm of real-time data gathering, analysis, and management pertaining to water quality metrics. This section provides a thorough examination of important studies and research endeavors that emphasize the use of the Internet of Things (IoT) in the monitoring of water quality.

Chandana Urs et al., 2017 proposed the creation of an affordable device for real-time water quality monitoring in the context of the Internet of Things (IoT). The system used multiple sensors to measure water's physical and chemical parameters. Water parameters like temperature, pH, turbidity, and conductivity were measured. Arduino Uno model functioned as a core controller, Wifi module for data transmission, and LCD screen for value display. Sensor data was stored in the cloud for water quality monitoring by the water department.

Kamal et al., 2019 suggested an IoT-based Early Warning Framework (EWF) for monitoring River Nile water quality with minimal cost and effort. Launched a prototype to monitor pH, turbidity, and temperature at a test site in Egypt's Nile. In this research his focus was to reduce the cost involved in monitoring the quality of water remotely.

Lestari et al., 2019 employed an IoT-based river water quality monitoring system leveraging LPWAN communication technology to monitor Citarum watershed monitoring stations in real time and log monitoring data in the server. Used four nodes and one gateway with LoRa transceiver and Arduino boards (LPWAN communication method) to test for communication range to exchange hardware information and implement network mesh topologies to expand software monitoring points.

Shahrani et al., 2021 introduced an autonomous robot equipped with real-time sensors for pH, temperature, voltage, and garbage detection. In the context of water quality monitoring, the sensors transmitted data through Wi-Fi to a mobile application developed by using MIT App Inventor, where it is subsequently stored on a cloud-based platform. River water robots utilized solar cells and wind turbines as sources of energy for their operation. While these studies provide valuable insights into the broader applications and potential of IoT technology in environmental monitoring, it is essential to acknowledge the unique context and focus of the present research. The present study is specifically positioned within the context of Ghana, where the problem of illicit mining, commonly referred to as "Galamsey," has developed as a notable environmental issue. The presence of a special geographical setting has stimulated the creation of a monitoring system based on the Internet of Things (IoT), which has been designed with distinct goals in mind to tackle the issue of illegal mining.

III. MATERIALS AND METHODS

1. System Architecture

The system as depicted in figure 1 consists of a turbidity sensor and a mercury sensor, both of which continually gather data on water conditions.

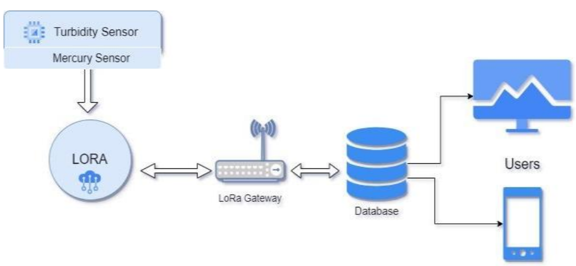

Figure 1: Turbidity and Mercury Concentration Monitor System Architecture

The data is subsequently processed by a control board that has a LoRa (Long-Range) module, with the ATmega328P serving as its microcontroller, therefore facilitating wireless communication. The sensor data which is collected at hour intervals is transferred via LoRa technology to a central LoRa gateway and thereafter routed to a central online database server for the purpose of storage.The moving average algorithm is used to calculate the average of the sensor data collected using a window size of 20 and a sampling interval of 30 seconds. This statistical method was chosen to ensure accurate and precise sensor data and it is computationally less intensive for the microcontroller.

The Moving Average, denoted as MA is defined as

$$MA = \frac{1}{W}\sum_{i=1}^{W} X_i$$

Where W denotes the window size and X_i represents the turbidity or mercury concentration value at position i where i ranges from 1 to W.

The data is accessed by users using a web application, allowing for real-time presentation and analysis of the parameters being investigated.The design is influenced by a deliberate selection of components. One objective is to provide a continuous power supply in places that are geographically isolated, while simultaneously upholding optimal operational efficiency. The primary function of the main board is to contain the microcontroller and LoRa module, therefore acting as the central processing unit and communication hub. The decision to choose this option was based on two primary factors: the need for effective data processing and wireless transmission, as well as the desire to minimize power consumption. This decision not only guarantees dependable data transmission but also preserves energy, a critical factor when functioning in distant areas where consistent access to power may be restricted.

The incorporation of a solar panel as seen in the monitoring device in figure 2 is for the purpose of generating power which is in accordance with our dedication to promoting sustainability and addressing the requirement for self-reliance in distant deployments. Solar energy is a dependable and sustainable kind of electricity, highlighting the need for continuous system functionality in regions where regular power supply is difficult. Furthermore, the incorporation of a battery system for the purpose of energy storage.

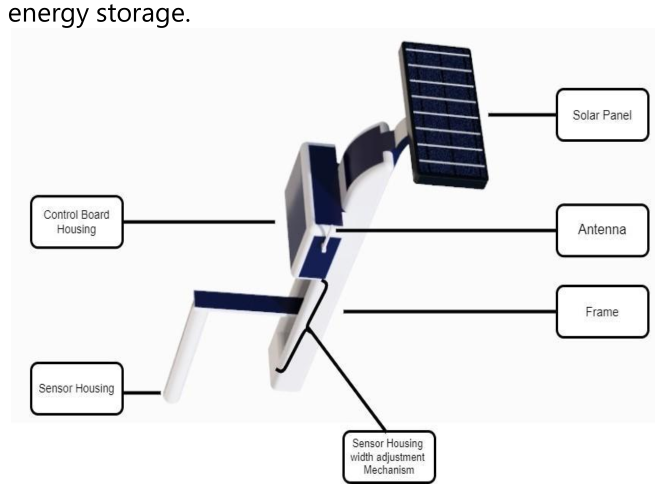

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Figure 2: Turbidity and mercury concentration monitoring device.

2. System Hardware

As seen in Figure 3, the hardware configuration comprises five primary units, including the microcontroller, power unit, sensor unit, LoRa unit, and motor. The three-dimensional representation can be observed in Figure 4, while the circuit schematic is depicted in Figure 6.

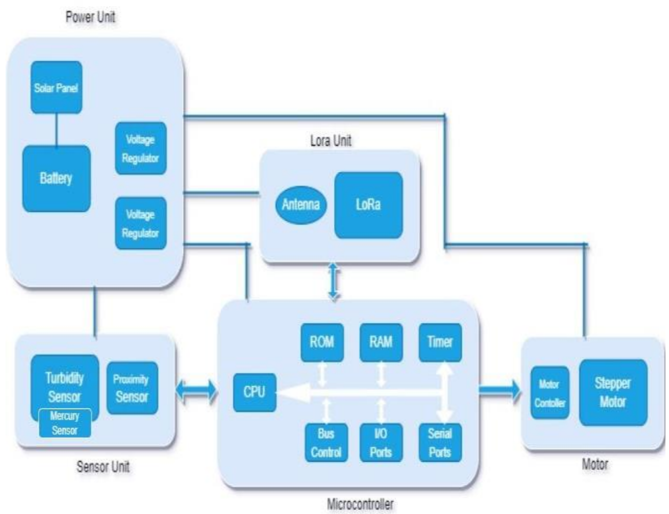

Figure 3: System functional block diagram.

2.1. Microcontroller Unit

The microcontroller serves as the core processing unit in the system, performing a vital purpose in the processing of sensor data. The functions of this entity involve the collection of data, wherein it establishes connections with sensors to gather unprocessed data, which is then parsed and arranged in an ordered manner. The microcontroller does preliminary duties to eliminate noise and anomalies, as well as carries out data fusion in cases when numerous sensors are engaged. Furthermore, it has the capability to compress and bundle the data into a highly efficient format suitable for transmission through the LoRa module. This microcontroller effectively oversees the whole communication process, guaranteeing the transfer of data that is both dependable and precise, while also ensuring that it is sent in a timely manner.

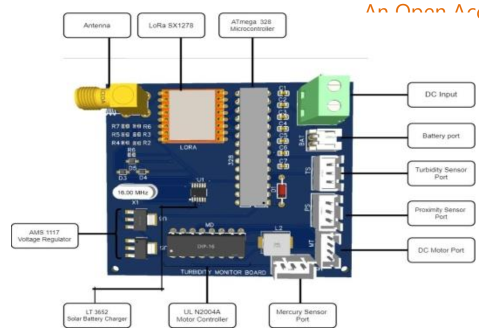

Figure 4: PCB design of the control board

2.2. The LoRa Unit

The LoRa (Long-Range) module serves crucial purposes, particularly focused on the wireless transfer of data. Functioning as the major hub for communication within the system, it facilitates the effective and extensive transfer of processed sensor data from distant monitoring sites to a central gateway or server. The purpose of this unit is to establish and effectively manage communication to the LoRa gateway, hence assuring the reliable flow of data. Significantly, it utilizes the intrinsic energy efficiency of LoRatechnology, rendering it highly suitable for remote and low-power applications, thereby enhancing the overall performance and sustainability of the water quality monitoring system.

2.3. The Sensor Unit

The three sensors in the system provide independent yet interrelated functions. The turbidity sensor and mercury sensor serve as the principal instruments for data collection, consistently measuring and monitoring many parameters related to water quality. These sensors communicate the recorded results for further analysis, facilitating the ability to monitor turbidity levels and mercury concentrations in real-time. Concurrently, the proximity sensor, strategically located in close proximity to the submerged sensors, functions as a watchful protector. The proximity sensor instantly identifies and initiates notifications upon physical touch or close approach by an aquatic organism or a foreign material which can affect the sensor data. This feature serves as a critical intrusion detection mechanism, guaranteeing the continuous functioning of the sensors and protecting against any tampering.

2.4. Motor

The inclusion of a motor inside the system serves a crucial function in preserving the integrity of the sensors and guaranteeing the acquisition of dependable data. The motor is activated by the proximity sensor when it detects physical touch or the presence of a foreign substance in close proximity to the monitoring sensors. The response of the motor may be described as having two components. Firstly, it elevates the sensors above the water surface to safeguard them against any interference or contact with the material traversing over them. After the sensors have been securely raised, the motor activates a timer, usually programmed for a duration of one minute. During this short duration, the sensors are maintained in a heightened state in order to prevent any disruptions. Following the passage of time, the motor effectively repositions the sensors back to their initial submerged state, therefore recommencing the process of data collecting. The implementation of this automatic motor reaction serves the dual purpose of safeguarding the monitoring equipment and facilitating uninterrupted data gathering, thus achieving a harmonious equilibrium between sensor protection and continuous water quality monitoring.

The motor employed in the system employs sliding mode control, which is a resilient and adaptable method, in order to immediately and precisely respond to the readings of the proximity sensor. This ensures that the sensors are elevated when required for protection and lowered for data gathering purposes. Simulink is utilized for the purpose of simulating the functioning of the motor as shown in figure 5, providing a platform for the modeling, testing, and optimization of its response to different situations and sensor inputs. The utilization of this simulation methodology facilitates the enhancement of the control algorithm for the motor, guaranteeing its precise execution of intended activities, such as the accurate manipulation of the sensors to detect and respond to intrusions or disturbances.

The sliding mode control equation is giving by:

$$f(u) = K \cdot \frac{s}{|s| + \delta}$$

Where δ is a small positive constant called the timing parameter and K is a positive constant.

The sliding surface is defined as:

$$S = \frac{dw_e(t)}{dt} + C.w_e$$

C is the strictly positive constant that that determines the bandwidth of the system and w_e is the rotation error signal.

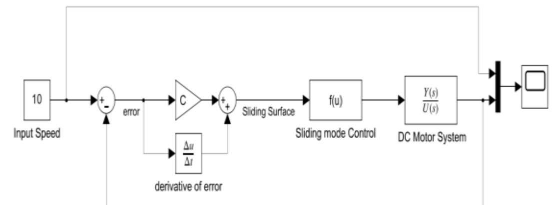

Figure 5 Stepper motor control using Sliding mode control

2.5 The Power Unit

The power unit has been specifically engineered to effectively regulate energy resources, ensuring uninterrupted and dependable functionality. The fundamental principle of this system is the utilization of the AMS 1117 voltage regulator, which serves the purpose of ensuring a consistent and controlled voltage output. This functionality is crucial in protecting delicate electronic components from any disruptions caused by voltage variations, hence preserving the overall integrity of the system. The LT3652 battery charger operates in conjunction with a solar panel to efficiently capture and utilize the generated energy, hence enhancing the charging procedure and facilitating the storage of energy in a 12V 24Ah rated battery. The solar panel rating and the battery capacity calculations is defined as follows;

$$Operating\ Voltage = 12V$$
$$Operating\ Current = 1.5A$$
$$Power = 12V \times 1.5A = 18W$$
$$Daily\ Energy\ requirement, E_r = 18W\ \times 24h$$
$$E_r = 432Wh$$
$$Energy\ to\ be\ generated\ by\ the\ solar\ panel, S_E$$

$$S_E = 18W\ \times 8h = 144Wh$$
$$Taking\ a\ solar\ panel\ efficiency\ of\ 15\%$$
$$Solar\ panel\ rating, SR\ is\ defined\ as$$
$$SR = \frac{1}{Panel\ Efficiency} \times Energy\ generated$$

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$$SR = \frac{144Wh}{0.15} = 960\ Wp$$

$$Battery\ capacity, BC\ is\ defined\ as$$
$$BC = E_r - S_E$$
$$BC = 432Wh - 144\ Wh$$
$$BC = 288Wh\ or\ 24\ Ah$$

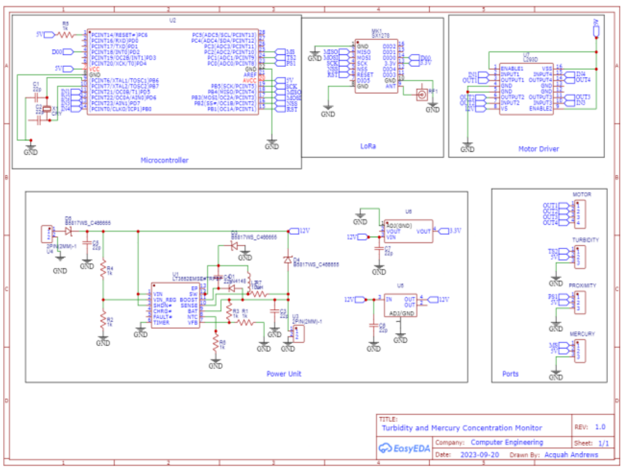

Figure 6: System hardware schematic diagram

3. System Software

3.1 Web Application

The user interface of the web application shown in figure 7 provides a user-friendly and instructive experience. The system integrates the display of real-time data with essential information on turbidity and mercury concentration, therefore offering users a full understanding of water quality and environmental safety.

The core of the interface comprises dynamic graphs that exhibit historical patterns and current variations in turbidity and mercury content. These graphs facilitate the monitoring of water quality fluctuations over a period of time, allowing users to discern trends and detect irregularities. The inclusion of a graphing tool facilitates a comprehensive examination of the data, hence assisting in the timely identification of any water quality concerns.

In addition to its graphing capabilities, the online program has a separate window that functions as an early warning system. The current system employs fuzzy logic as a means of evaluating the probability of galamsey operations occurring in the vicinity of the monitored river. The system offers users a distinct indicator of probable instances of illicit mining in the surrounding area, based on predetermined thresholds and patterns. The indication included in this panel serves as a means of identifying potential galamsey activities, enabling users to promptly respond to environmental hazards.

Figure 7: Web application interface.

3.2 Database

The Firebase Real-time Database serves as a data storage solution. Firebase is a comprehensive cloud-based platform offered by Google that encompasses a variety of services, including real-time database functionality, authentication capabilities, and cloud storage solutions. The primary subject of our discussion is the Firebase Real-time Database, which offers a NoSQL data storage solution based on the JSON format.

The database has two nodes, labeled "Mercury" and "Turbidity," each containing two sub-nodes labeled "value" and "timestamp." The node labeled "Turbidity" records both turbidity values and their corresponding timestamps. Similarly, the node labeled "Mercury" stores mercury concentration values together with their respective timestamps.

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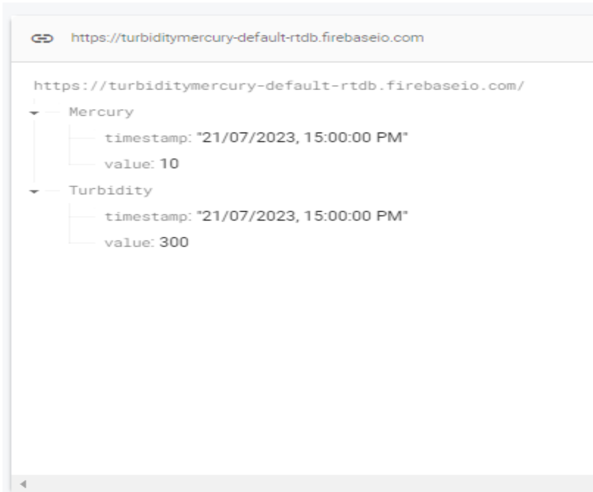

Figure 8: Firebase Real time database.

3.3 Fuzzy Logic

In the code sample provided in figure 9, fuzzy logic is employed for pollution detection by defining linguistic variables and membership functions to represent the relationships between input parameters, namely turbidity and mercury concentration, and the output parameter, pollution level. Fuzzy rules, such as "If turbidity is low and mercury concentration is low, then pollution level is low," are established to capture the complex and imprecise nature of environmental data. By computing the degree of membership in these linguistic terms and evaluating the rules, the fuzzy logic system generates a pollution level estimation that considers the interplay of turbidity and mercury concentration, providing a nuanced and context-aware assessment of water quality, which is crucial for detecting potential pollution. The pollution level gives an indication of probable illegal mining sites closer to the river.

```
fuzzy.py

#  Fuzzy rules
rule1 = ctrl.Rule(turbidity['low'] & mercury_concentration['low'], pollution_level['low'])
rule2 = ctrl.Rule(turbidity['low'] & mercury_concentration['medium'], pollution_level['low'])
rule3 = ctrl.Rule(turbidity['low'] | mercury_concentration['high'], pollution_level['medium'])
rule4 = ctrl.Rule((turbidity['high'] & mercury_concentration['low'], pollution_level['medium'])
rule5 = ctrl.Rule((turbidity['high'] & mercury_concentration['medium'], pollution_level['high'])
rule6 = ctrl.Rule((turbidity['high'] & mercury_concentration['high'], pollution_level['high'])
rule7 = ctrl.Rule((turbidity['medium'] & mercury_concentration['low'], pollution_level['medium'])
rule8 = ctrl.Rule((turbidity['medium'] & mercury_concentration['medium'], pollution_level['high'])
rule4 = ctrl.Rule((turbidity['medium'] & mercury_concentration['high'], pollution_level['high'])

pollution_ctrl = ctrl.ControlSystem([rule1, rule2, rule3, rule4, rule5, rule6, rule7, rule8, rule9])

pollution_sim = ctrl.ControlSystemSimulation(pollution_ctrl) # simulate

turbidity_value = ref.child('Turbidity').get()  # fetching turbidity values from Firebase
mercury_value = ref.child('Mercury').get()      # fetching turbidity values from Firebase
pollution_sim.input['turbidity'] = turbidity_value
pollution_sim.input['mercury_concentration'] = mercury_value

pollution_sim.compute() # output
```

Figure 9: Fuzzy Logic code for evaluation and prediction

IV. RESULTS AND DISCUSSION

1. Static Stress Analysis of the Turbidity and Mercury Concentration Monitoring Device.

In order to assess the robustness of the system, a series of tests were conducted. The simulation was conducted on the monitoring device made of steel as depicted in figure 10 and figure 11 in order to determine the safety factor and displacement of the sensor housing under a force of 1000N. The safety factor was determined to be 12.74, indicating a high level of structural integrity. Additionally, the displacement of the sensor housing by 0.1123mm suggests that the system possesses sufficient strength to withstand the forces exerted by river tides.

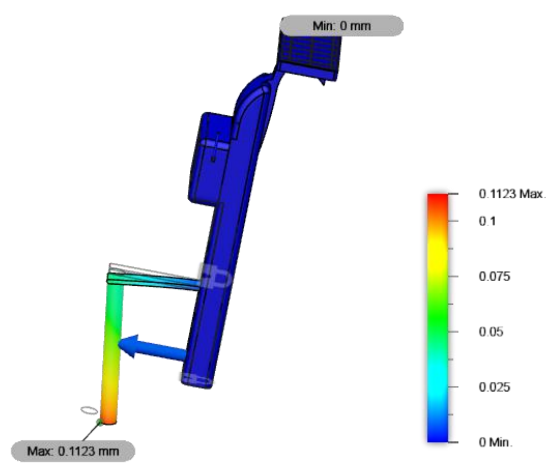

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Figure 10: Displacement analysis of the turbidity and mercury concentration monitoring device.

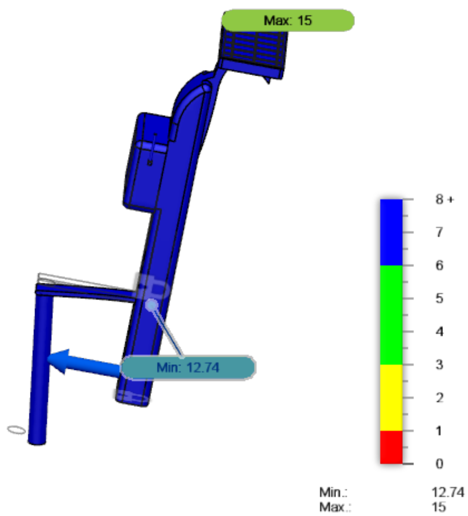

Figure 11: Safety factor analysis the turbidity and mercury concentration monitoring device.

2. Motor Control Simulation Analysis

The graph in Figure 12 shows the response curve of the adjustable system which has the motor when using sliding mode control.It is evident from the graph that the use of sliding mode control results in a short response time of 1.3 seconds. Additionally, there is no overshoot observed in the system's response. The settling time of the system is approximately 1.3 seconds.

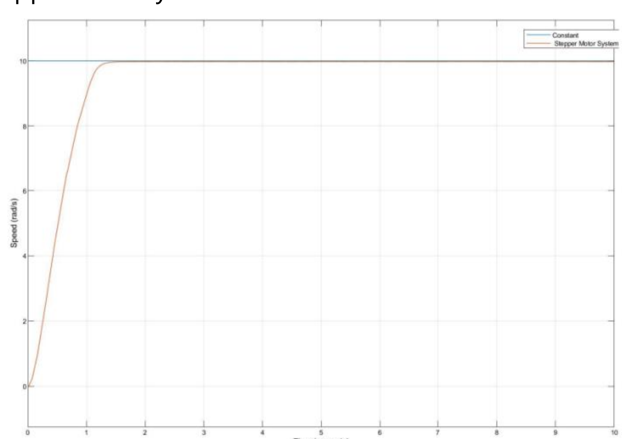

Figure 12: Response curve of the stepper motor controlled with sliding mode control.

3. System prototyping

A prototype environment was set up in figure 13 to simulate the system mainly consisting of Arduino Uno, LCD, Turbidity sensor and the Mercury sensor.

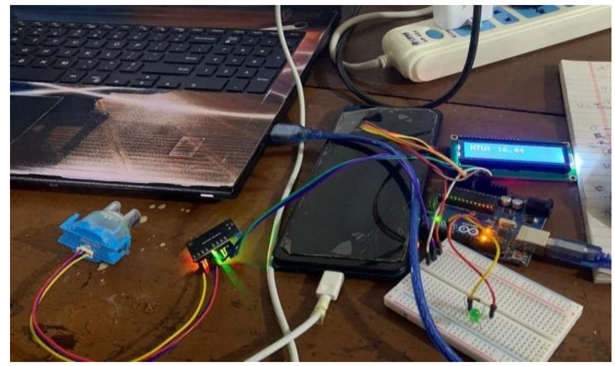

Figure 13: Hardware prototyping using Arduino Uno

V. CONCLUSION

In the present study, a water quality monitoring system based on the Internet of Things (IoT) has been designed with the objective of identifying instances of illicit mining (often referred to as "galamsey") in Ghanaian rivers, while concurrently evaluating their ecological consequences. The system integrates many components, such as turbidity and mercury sensors, LoRa communication technology, and a pollution level forecast mechanism based on fuzzy logic. By conducting extensive simulations and tests, we have successfully showcased the system's efficacy in delivering real-time water quality data and detecting probable instances of contamination. This initiative signifies a substantial advancement in the efforts to tackle the urgent problem of illicit mining in Ghana and its adverse environmental consequences. In order to validate and gather data under various environmental circumstances, the system will be implemented in real river areas being affected by galamsey activities. Furthermore, it is imperative to prioritize ongoing research and development endeavors aimed at enhancing scalability and power efficiency.

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