DESIGN, DEVELOPMENT AND VALIDATION OF AN ARDUINO-BASED GLOBAL SYSTEM FOR MOBILE COMMUNICATION PROTOTYPE FOR REMOTE WATER LEVEL MONITORING

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A Project thesis submitted in partial fulfillment of the requirements for the award of the degree of Master of Applied Information Technology in the Department of Computer and Information Technology and the School of Science and Technology of Africa Nazarene University.

April 2024

DECLARATION

DECLARATION

I declare that this document and the research that it describes are my original w
they have not been presented in any other university for academic work.

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DEDICATIONS

I dedicate this research study to my nuclear family and my friends: My dear loving Mum Jecinta Matu, my industrious daughter Esther Blessing, my cherished wife Mary Blessing, my adorable son Prince Joseph and my friend Mr. Anthony Osome for their prayers and moral support.

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ABSTRACT

Amidst global research on IoT-based water level monitoring devices, questions persist about sensor dependability and accuracy, especially in real-world scenarios. The research main objective was to design, develop and validate the Arduino-based Global System for Mobile Communication (GSM) prototype that utilizes a JSN-SR04T waterproof ultrasonic sensor in remote water level monitoring that meets the requirements of accuracy and reliability. Two theoretical frameworks were used in this research study to bring out the relationship between the predictor and outcome variables: The ultrasonic wave reflection principle and the Piezoelectric Effect. The research method employed in this research was mixed methods research comprising of explanatory and predictive statistical approaches of gathering and analyzing data to ascertain whether there was a significant difference between the means of data obtained from the IoT-based monitoring system and those from the manual gauge. Linear and Multiple regression were used to analyze the effect of air temperature variations on ultrasonic sensors under different locations. One (1) Arduino-based GSM water level monitoring prototype that utilized a JSN-SR04T waterproof sensor was developed and used to collect sensor datasets. The research study used stratified sampling techniques and had the following sample sizes: 48 manual gauge readings, 48 sensor readings and 15 tests of GSM efficiency. Data was visualized in the Arduino serial monitor, the ThingSpeak Server application and in Excel using graphs and charts. The research study found that the developed and validated Arduino-based GSM water level monitoring prototype was very accurate and reliable for application in water reservoir level monitoring. The IoT prototype achieved a water level accuracy of 98.92 percent in a lab setting environment and an accuracy of 95.083 percent in an outdoor simulation. The ANOVA test confirms the lack of significance for the location effect on accuracy with a p-value of 0.09099. While the sensor demonstrates high accuracy, reaching 100% in certain temperature ranges during outdoor testing, there are instances of lower accuracy, particularly noticeable at 23.44°C and 42.97°C. The impact of temperature on accuracy is evident, with fluctuations noted, and a distinct decrease in accuracy observed at higher temperatures. The research study concludes that while temperature significantly affects the accuracy of outdoor readings, the location of the sensor, whether indoors or outdoors, does not significantly influence accuracy. These findings provide valuable insights for optimizing sensor use in various environmental conditions. The significance of this research study is that it adds to the existing knowledge on effective water resource management through the implementation of IoT water level monitoring systems.

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DEFINITIONS OF TERMS

Accuracy: The error-to-full-scale output ratio or the error-to-output ratio, as specified, expressed in percentage.

Arduino-based GSM: The use of Arduino microcontrollers in conjunction with GSM (Global System for Mobile Communications) technology is referred to as Arduino-based GSM.

Error: The discrepancy between the displayed and actual measured values is called an error.

Full-scale output: The algebraic difference between the outputs at the specified upper and lower range limits.

GSM: Global System for Mobile Communications is a widely used digital cellular network technology that allows for global mobile communication. It offers voice and data services, allowing users to use their mobile devices to make calls, send text messages, and browse the internet. GSM operates on a variety of frequency bands and allows for seamless connectivity and roaming between networks and countries. GSM ensures secure and reliable communication through its digital modulation techniques and encryption algorithms. It serves as the foundation for advanced mobile technologies such as 3G and 4G, and the GSM SIM800L module in the aforementioned project allows communication between the Arduino board and the mobile network for remote monitoring (Dange, 2019).

Internet of Things (IoT): The networked connection of commonplace items, including equipment, vehicles, buildings, and other things, that are equipped with sensors, software, and network connectivity to gather and exchange data. By enabling communication between items and the internet, this technology establishes a network of interconnected devices. The Internet can be accessed by IoT devices using a variety of connections, including Wi-Fi, Bluetooth, cellular networks, and satellite connections (Costa & Emanuel, 2020).

Linearity: The closeness of a calibration curve to a specified straight line is known as linearity.

Microcontroller Unit: A microcontroller unit (MCU) is referred to as a "true computer on a single chip" when it contains all required peripherals. This device can readily read data from sensors, manage, safe and modify output displays, and communicate data to other machines and devices as needed (Jan et al., 2022).

Piezoelectric Effect: The Piezoelectric Effect is a phenomenon in specific materials, like crystals and ceramics, where applying mechanical stress generates an electric charge, and applying an electric field causes deformation. This bidirectional relationship between stress and charge is unique to piezoelectric materials, relying on certain crystals' ability to exhibit internal electric polarization in response to external forces. This leads to the generation of an electric potential across the material. Piezoelectric materials find common applications in sensors, actuators, and various electronic devices, serving to convert mechanical energy into electrical signals and vice versa (Xu et al., 2023).

Reliability of IoT system: The reliability of an IoT (Internet of Things) system pertains to its capacity to consistently execute designated functions and provide reliable and precise outcomes consistently. It encompasses aspects such as resilient connectivity, steadfast data precision, compliance with performance criteria, and the system's resilience against diverse environmental conditions and potential obstacles (Moore et al.,2020).

ThingSpeak Server: it is an open-source IoT analytical platform for real-time data processing and visualization. It facilitates the visualization of data transmitted from an Arduino UNO to the ThingSpeak channel.

Ultrasonic Water level sensor: A device that utilizes ultrasonic technology to determine the depth of water or other liquids is called an ultrasonic water level sensor. Typically, it is made up of a receiver that picks up the reflected waves and a transducer that sends out ultrasonic waves (Petru et al., 2023).

Water Level: It gauges the water depth in a river at a particular spot. River stage is another term for the measurement of a river's water level at an arbitrary location.

Water Resource Users Association: An organization of water consumers, owners of riparian land, and other interested parties who have formally and voluntarily joined together to cooperatively share, manage, and conserve shared water resources is known as a Water Resource Users Association (WRUA) (Bertule et al., 2018).

ABBREVIATIONS AND ACRONYMS

AFD:	Android Flood Detection
ANOVA:	Analysis of Variance
AWD:	Alternate Wetting and Drying
EUR:	Euro
FS:	Full Scale
GSM:	Global System for Mobile Communications
IDE:	Integrated Development Environment
IoT:	Internet of Things
IWRM:	Integrated Water Resources Management
KPA:	Kilo Pascal
LCD:	Liquid Crystal Display
LoRa:	Long Range
MEMS:	Microelectromechanical system (MEMS) Technology
NACOSTI:	National Commission for Science, Technology, and Innovation
NB-IoT:	Narrow Band-Internet of Things
RMSE:	Root Mean Square Error
SDG:	Sustainable Development Goals
SIM:	Subscriber Identity Module
SMS:	Short Message Services
TTN:	The Things Network
Wi-Fi:	Wireless Fidelity

WRUAs: Water Resource Users Associations

WSNs: Wireless Sensor Networks

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CHAPTER ONE

INTRODUCTION AND BACKGROUND OF THE STUDY

1.0 Introduction

This chapter introduces the background of the research study that has the goal of designing, developing and validating an Arduino-based Global System for Mobile Communication (GSM) prototype for remote water level monitoring. Other sections in this chapter include the statement of the problem, objectives, research questions, study significance, scope, limitations, delimitations, assumptions, theoretical and conceptual framework.

1.1 Background of the Study

According to Jan et al. (2022), global warming, urbanization, and industrial growth are contributing to water scarcity, with many facing difficulties in obtaining fresh water for necessities. Water is stored in tanks, but manual procedures in developing countries lead to waste and leaks. IoT technology offers effective monitoring, leak detection, and automatic tank refilling, providing real-time input for experts and end users. Bertule et al. (2018) assert that a major barrier to achieving the targets outlined in Sustainable Development Goal (SDG) 6 by 2030 is the lack of comprehensive national data regarding ecosystems related to water.

According to Chepyegon and Kamiya (2018), the surface water resources in Kenya are estimated to account for 22,564 million cubic meters, which constitute 91.5 percent of the overall available water resources, with ground water making up the remainder. The

yearly water demand in 2010 was 14% of the total resources available, with groundwater providing 16% of this need, demonstrating the dependence on both surface and groundwater sources. Remarkably, although the irrigation industry accounts for about half of the water demand, it only covers 17% of the land that could be used for irrigation, and issues like poor investment and scarce water prevent it from growing.

Kenya experienced water scarcity indices as of 2010, with freshwater resources expected to be accessible at a rate of 1093 m3/capita/year and water resources at a rate of 586 m3/capita/year. According to the study, Kenya's water sector administration faces a variety of difficulties in its efforts to increase the country's water supply coverage, including social, financial, and technical ones. The sector management can be made better by adopting basic technical standards for water supply institutions to secure their long-term viability, closely monitoring water resources and services, and including impacted communities throughout the entire water supply development process. For Kenya to manage its water resources sustainably, it is essential to address issues including transboundary water management, scarce groundwater knowledge, and lack of water (Chepyegon & Kamiya,2018).

At the core of all these issues are disputes over water resources and how they affect the farming and pastoral communities in Laikipia County (Lesrima, 2019). Given that 97% of abstracted water is used for agriculture, putting policies in place to stop these abstractions during dry seasons might greatly lessen water stress among those living in the lower river lengths. There would be more water available for residential use if agricultural water extraction were to be reduced by just 1.5% (Mwangi et al, 2023).

As the organization with the most control over the Naro Moru catchment's water resource management, the Naro Moru Water Resource Users Associations (WRUA) must also get real-time discharge data. Techniques for monitoring the water level of rural rivers are simple and affordable, but they are neither accurate nor trustworthy. The idea of remote data collection and sharing needs to be presented to provide the Naro Moru WRUA with access to the most recent river discharge data (Mwaura et al, 2021).

According to Cherqui et al. (2020), regarding the sustainable management of the watersheds, understanding the water levels in waterways is essential. This is especially true for estimating river discharges, preventing floods, and designing hydraulic projects. Technological improvements in low-cost sensors give new monitoring possibilities, enabling a greater spectrum of water infrastructure to be monitored successfully. This offers issues like sensor reliability and data administration, but it also opens opportunities for creative solutions and preventative maintenance procedures. Despite limits, low-cost systems enable real-time monitoring, prompt maintenance actions and improved data resolution.

Water level sensors use many measurement approaches, including pressure, capacitance, ultrasonic, radar, and laser-ranging sensors (Jan et al., 2022). Ultrasonic, capacitive, and inductive sensors are among the low-cost water level monitoring options (Andang et al., 2019).

Cherqui et al. (2020) state that since choosing the best sensor involves the construction of new, extensive monitoring networks, it is important to take the supply chain's security and cost into account. Practical factors may also be considered when choosing a sensor,

such as using Water depth sensors that don't require contact to lessen the need for frequent site inspections for sensor maintenance and cleaning. Finding inexpensive, dependable sensors that produce correct data is the biggest challenge, though.

Water resources in the Mount Kenya region are getting harder to get by, according to Wamucii et al. (2023). Future land use and climate change challenges may compound the problems associated with water management. The input data is the largest limitation. In mountainous catchments, the patterns of rainfall are highly erratic and challenging to measure using a monitoring network. Though the amounts are only estimates, 80–100% of the naturalized dry season discharge is accounted for via abstractions from rivers.

When it comes to areas where water resources are limited or susceptible to variations in weather and human activity, monitoring water levels is an essential part of effective water resource management (Camara et al., 2020). A water level detecting system's purpose is to make it easier for people to gather real-time data on water levels.

Mulwa et al. (2021) point out that in numerous parts of the globe, rising needs for water as well as a scarcity of water have become significant obstacles to day-to-day living. Urbanization, population increase, water supply pollution, and inadequate resource management have all exacerbated the water crisis. Along with the severity of climate change, the general population is concerned about the potential implications of water scarcity on food security, economic activity, health, and education.

According to Ahmed et al. (2020), techniques for assessing water quality in addition to water depths are among the most important instruments for making sure that the appropriate condition of water is preserved and the amount of water used is controlled

to avoid situations like the complete depletion of water from a given level, which could result in an unwanted water crisis. By assessing the quantity and rate at which water resources are being depleted at reservoirs and dam sites, resource managers at those locations can apply conservation practices that are best relevant to their circumstances.

Water resource management may be enhanced and decision-making made easier with the use of more accurate, consistent, and timely data that might be obtained by the application of IoT technology to water level monitoring (Videnov and Staykova, 2019). This discusses how to manage water resources sustainably for the Naro Moru sub-catchment region, taking into account the effects of global warming, modifications to land use and disagreements over water issues.

The development of wireless communication technology was intended to be a key component of contemporary society (Alves et al., 2019). One area of contemporary life where wireless communication technology has great promise is food production. This is particularly true in terms of identifying and transmitting pertinent agricultural data, like weather, crop development, water quality and levels, and other elements that would enable to help agriculturalists make better, rapid and precise farming judgments (Siddiquee et al., 2022).

Naro Moru Water Resource Users Associations (WRUAs) oversee the administration of resources related to water, and The Internet of Things (IoT) usage in water level monitoring can give them the information they need to manage their resources more effectively (Mwaura et al.,2021).

Monitoring river water levels is a crucial part of water management since it gives helpful information for decision-making in several scenarios, including flood prediction and early warning systems, water resource management, and hydroelectric power generation. Building cost-effective, low-powered Internet of Things-based river-level monitoring systems is now possible thanks to the growth of the Internet of Things and recent developments in sensor and connectivity technologies (Mdegela et al., 2023).

The goal of this project was to design, develop and validate an accurate and reliable Arduino-based GSM prototype utilizing a JSN-SR04T waterproof ultrasonic sensor for remote water monitoring.

1.2 Statement of the Problem

Amidst global research on IoT-based water level monitoring devices, questions persist about sensor dependability and accuracy, especially in real-world scenarios (Jan et al., 2022). Existing studies lack comprehensive understanding due to a focus on lab settings and a lack of sensor reliability validation (Moore et al., 2020). Environmental factors like air temperature, humidity, and silt's impact on system accuracy remain unexplored, contributing to uncertainty sources in IoT-based water level monitoring (Manupiya, 2021).

There is a strong correlation between the extreme water shortage that the Naro Moru sub-catchment region is facing and the lack of a reliable and timely water level monitoring system. 30,000 pastoralists and subsistence farmers have suffered as a result of the continuous over-abstraction in the upper Naro Moru River (Mulwa et al., 2021). The Center for Integrated Research and Training in Arid and Semi-arid Lands

Development (CETRAD) has attempted to monitor water levels using water loggers and manual measurement systems, but these methods have proven to be unsafe, unreliable, and ineffective, leading to incomplete and delayed information on river water flow levels. This shortage often worsens disputes over water supplies and also contributes to careless resource extraction (Mwangi et al., 2023).

This study aimed to fill these gaps by designing, developing and validating an Arduino-based GSM prototype that utilizes the JSN-SR04T sensor in remote water level monitoring. Understanding the causes of data uncertainty, especially those impacted by environmental conditions, was the goal of the research project (Manupiya, 2021). Despite its reputation for precision, ultrasonic sensors have issues with air temperature and detecting range constraints that affect their accuracy in real-world applications (Hasna Iftinan Apsari et al., 2022).

This study extensively examined and evaluated water level monitoring prototypes especially the ones developed using ultrasonic sensors and, in the process, narrowed the gap by identifying and resolving the limitations of IoT in water resource management (Gao et al., 2021). The goal is to improve knowledge and offer practical solutions, particularly in the field of groundwater resource management. The designed, developed and validated prototype was reliable, easy to use, simple to install, and capable of sending out real-time water level messages.

1.3 Research Objectives

The main objective of this research study was to design, develop and validate an Arduino-based Global System for Mobile Communication (GSM) prototype that

utilizes JSN-SR04T waterproof ultrasonic sensor in remote water level monitoring that meets the requirements of accuracy and reliability.

1.4 Specific Objectives

By the end of this project, the research is expected to:

1. Develop an IoT prototype that utilizes a JSN-SR04T waterproof ultrasonic sensor in remote water level monitoring.
2. Evaluate the performance of an IoT prototype that utilizes a JSN-SR04T waterproof ultrasonic sensor for remote water level monitoring that meets the requirements of accuracy and reliability.
3. Validate the IoT prototype by assessing the influence of air temperature variations on the performance of the JSN- SR04T waterproof Ultrasonic sensor in remote water level monitoring.

1.5 Research Questions

1. What are the key design considerations for developing an IoT prototype for remote water level monitoring that meets the requirements of accuracy and reliability?
2. How can the performance of the IoT prototype that utilizes the JSN-SR04T waterproof ultrasonic sensor be evaluated to ensure it meets the requirements of accuracy and reliability?
3. What is the influence of the variations of air temperature on the performance of the IoT prototype that utilizes the JSN SR-04T waterproof Ultrasonic sensor, and how can this be validated for remote water level monitoring?

1.6 Significant of Study

With special reference to the Naro Moru Sub-catchment in Laikipia County, Kenya, this study is significant because it contributes to the existing knowledge base on environmental monitoring and communication systems in remote locations. Real-time data on water levels is highly needed in this region for efficient management of water resources, flood prediction, and disaster mitigation. To answer this, an Arduino-based global system for mobile communication water level monitoring was developed and validated. In addition to improving our knowledge of how to create trustworthy Internet of Things solutions for monitoring water levels, this research offers insightful information on how environmental elements like temperature affect sensor performance. Better decision-making and sustainable water resource management techniques will be aided by the study's practical implications for local populations, environmentalists, and legislators.

The research study targeted to close the gap that exists between ultrasonic sensor applications in theory and real life. Focusing on accuracy and reliability, the study helps to address practical issues in water resource management. Experimenting with the sensors' precision and developing prototypes that are immediately usable to meet community requirements are crucial.

1.7 Scope of Study

The research concentrated on the development and validation of an Arduino-based GSM water level monitoring system, specifically examining the feasibility and performance

of the JSN SR-04T ultrasonic sensor in comparison to the traditional manual measuring tools.

Experimental investigations took place at Dedan Kimathi University Engineering laboratory and Kingongo flats in Nyeri, serving as locations for a controlled environment and outdoor environment simulations, respectively. The experiments aimed for meticulous and precise assessments, ensuring the reliability of results within the specific contexts of these two locations.

The evaluation of GSM's efficacy in sending and receiving water level messages was conducted in the confined settings of Dedan Kimathi University Engineering laboratory. The analysis of the datasets was done at the County Government of Laikipia offices. While the findings offer valuable insights, their implications and applicability are limited to controlled experimental settings and may not necessarily extend to broader geographical areas.

1.8 Limitations of the Study

Several constraints within the study warrants acknowledgment. The study's surroundings, which included controlled laboratory settings at Dedan Kimathi University and outdoor environment simulations at Kingongo Flats in Nyeri, Kenya, limited the research's applicability to real-world field conditions in water catchment areas other than the Naro Moru Sub-catchment area.

Furthermore, the study's time frame was constrained, which might have made it more difficult to record the monitoring system's flexibility or long-term performance. Also,

the study's focus was mostly on the technical features of the JSN SR-04T ultrasonic sensor and the Arduino-based GSM water level monitoring system, ignoring any potential logistical, socioeconomic, or legal issues that might come up during actual use.

These drawbacks highlight the necessity for more studies and field testing to handle practical issues to guarantee the system's suitability for the Naro Moru Sub-catchment area.

1.9 Delimitations of the Study

The study had specific limitations that shaped its scope and constraints. First, the research was delimited to the design, development and validation of the Arduino-based GSM prototype that utilized a JSN-SR04T waterproof sensor in remote water level monitoring. A lot of emphasis was given to the evaluation of the effect of air temperature variations on JSN-SR04T sensor. It did not encompass a comprehensive analysis of broader environmental or ecological factors that may impede the accuracy of the JSN-SR04T sensor such as humidity and siltation.

The research did not involve an extensive evaluation of the logistical or economic aspects of implementing the monitoring system in the real-world context of the Naro Moru Sub-catchment. Additionally, the study did not account for potential long-term maintenance or calibration requirements of the monitoring system beyond the scope of the experiment.

These delimitations were strategically implemented to uphold the study's concentration on the technical facets of the system, encompassing laboratory-based testing and

outdoor environment simulations. It is acknowledged that further research and field testing are imperative to address a more extensive array of factors and practical considerations.

1.10 Assumptions of the Study

The research study's assumptions encompass:

a) The JSN SR-04T waterproof Ultrasonic water level sensor is assumed to be a feasible and reliable option for water level measurement, and its specifications as provided by the manufacturer are accurate.
b) It is assumed that the environmental conditions in the outdoor environment simulations at Kingongo Flats and the experiment in the laboratory setting at Dedan Kimathi University are representative of conditions within the Naro Moru Sub-catchment area.
c) Weather conditions and other environmental factors will remain within reasonable parameters, and extreme events such as severe storms or flooding will not disrupt the study.
d) The study assumes that the budget allocated for the research will be sufficient to cover all the expenses related to the development, validation and data collection activities.

1.11 Theoretical Framework

1.11.1 Ultrasonic Wave Reflection Principle

The Ultrasonic Principal concept was developed in the late 1800s by Scottish engineer and physicist Sir John Ambrose Fleming (Kanth et al., 2023). Fleming is famous for having designed the first functional radio transmitter and receiver. He was also the first to demonstrate the use of ultrasonic waves for non-destructive testing and material inspection. The foundation for the discipline of ultrasonic engineering was laid by his contributions, which are still significant today.

The theoretical underpinning of ultrasonic sensors is based on their fundamental mode of operation (Dou et al., 2019). These sensors emit short, high-frequency sound pulses that are spaced regularly and move through the atmosphere at the speed of sound. When these sound pulses come into contact with an object, they are reflected to the sensor (Wang et al., 2021).

The sensor converts electrical energy into ultrasonic waves in essence. This conversion process makes use of piezoelectric crystals. High frequencies of oscillation occur when electrical energy is supplied to piezoelectric crystals (Xu et al., 2023). It is also true in reverse. When these piezoelectric crystals sense ultrasonic waves, they will produce electrical impulses. These sensors can transmit ultrasonic waves to an item and then receive the echo produced by this object. The current depth is shown on an LCD or control circuit that processes the electrical energy from the echo to determine what to do next.

Based on how long it takes for sound pulses to reach an item and return as echoes, the sensor then assesses how far away the target object is. This time-of-flight measurement approach effectively avoids the impacts of background interference and ensures accurate distance measurement because the sensor functions based on time rather than sound strength. Ultrasonic sensors are flexible in that they can detect a wide range of materials that reflect sound, regardless of color (Aliew, 2022). This extends to translucent materials and even thin foils, making them appropriate for a variety of uses.

Moreover, ultrasonic sensors function even in challenging environments such as dusty air and ink mists. Even with little deposits on their sensor membranes, they can continue to operate normally. Innovative applications such as fill level monitoring in microtiter plate wells, small bottle identification in the packaging sector, accurate detection of thin wires are made possible by this adaptability in conjunction with sensors that have narrow beam spreads and minimum blind zones. Subali et al. (2019) examined the applications and advancements of ultrasonic sensors in a variety of sectors, from industrial automation to agriculture, emphasizing the technological significance in numerous domains.

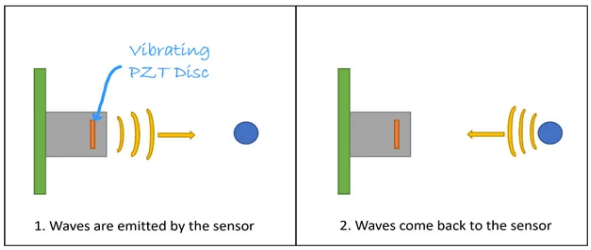


Figure 1.1: Ultrasonic wave reflection principle (Researcher,2023)

1.11.2 Piezoelectric Effect

Applicable in many domains, especially in sensors and actuators, the piezoelectric effect is demonstrated by crystalline materials such as ceramics, quartz, and Rochelle salt (Pan, 2023). As a result of mechanical stress, like compression or tension, these materials produce an electric charge on their surfaces, which is the characteristic that defines this effect. In contrast, materials subjected to an electric field experience deformation and change in shape. The high-frequency response and varied device design options of ultrasonics make the piezoelectric effect an enabling technology, and these two phenomena are closely related to each other.

Ultrasonic applications such as testing, measuring, and monitoring heavily depend on piezoelectric components. Ultrasonic level measurement, which is frequently employed for jobs involving liquids or powders, is one noteworthy application. Sound is produced when particles in solids, gases, or liquids vibrate due to the application of the piezoelectric effect. Electrical energy can be converted into mechanical vibration and vice versa, and this phenomenon serves as the foundation for ultrasonic technology (Kanth et al., 2023).

The piezoelectric effect plays an important part in the generation and detection of ultrasonic waves within the domain of ultrasonic sensors for detecting water levels. The transmitters and receivers of these sensors are piezoelectric crystals. Sound waves of high frequencies are produced when an electric voltage is given to the crystal, causing deformation due to the piezoelectric action. In the direction of the water's surface, these waves flow through the air. Upon encountering the water surface, certain waves are reflected as echoes,

triggering mechanical vibrations in the piezoelectric crystal. Via the piezoelectric effect, these vibrations produce an electric charge (Espinoza-Ortiz et al., 2023).

The time it takes for the sound wave to be released, reach the water's surface and return as an echo must be measured precisely. The resultant measurement makes it easier to compute the distance that exists between the sensor's position and the outermost layer of the water. Accurate distance measurement and water level computation are made possible by taking advantage of information about the sound speed in the air. These sensors are perfect for water level monitoring applications since the piezoelectric effect is seamlessly integrated into the sensor to enable the effective generation and detection of ultrasonic waves. Due to their exceptional precision, dependability, and flexibility in different environmental settings, they are invaluable for monitoring water levels in real-time, protecting infrastructure related to water, assisting with flood forecasting, and assisting with environmental management initiatives (Subashini et al., 2022).

1.12 Conceptual Framework

The interconnection between the predictor and outcome variables through a visual diagram is referred as a conceptual framework, which Singh (2023) refers to as the research's foundation. The development of the Arduino-based GSM prototype for remote water level monitoring (IoT hardware and software components), manual water level monitoring tools (ruler measurement) and validation of the IoT system (indoor testing, outdoor testing and investigations of GSM efficiency) are the independent variables for this research study while the dependent variables are accuracy and reliability of IoT prototype.

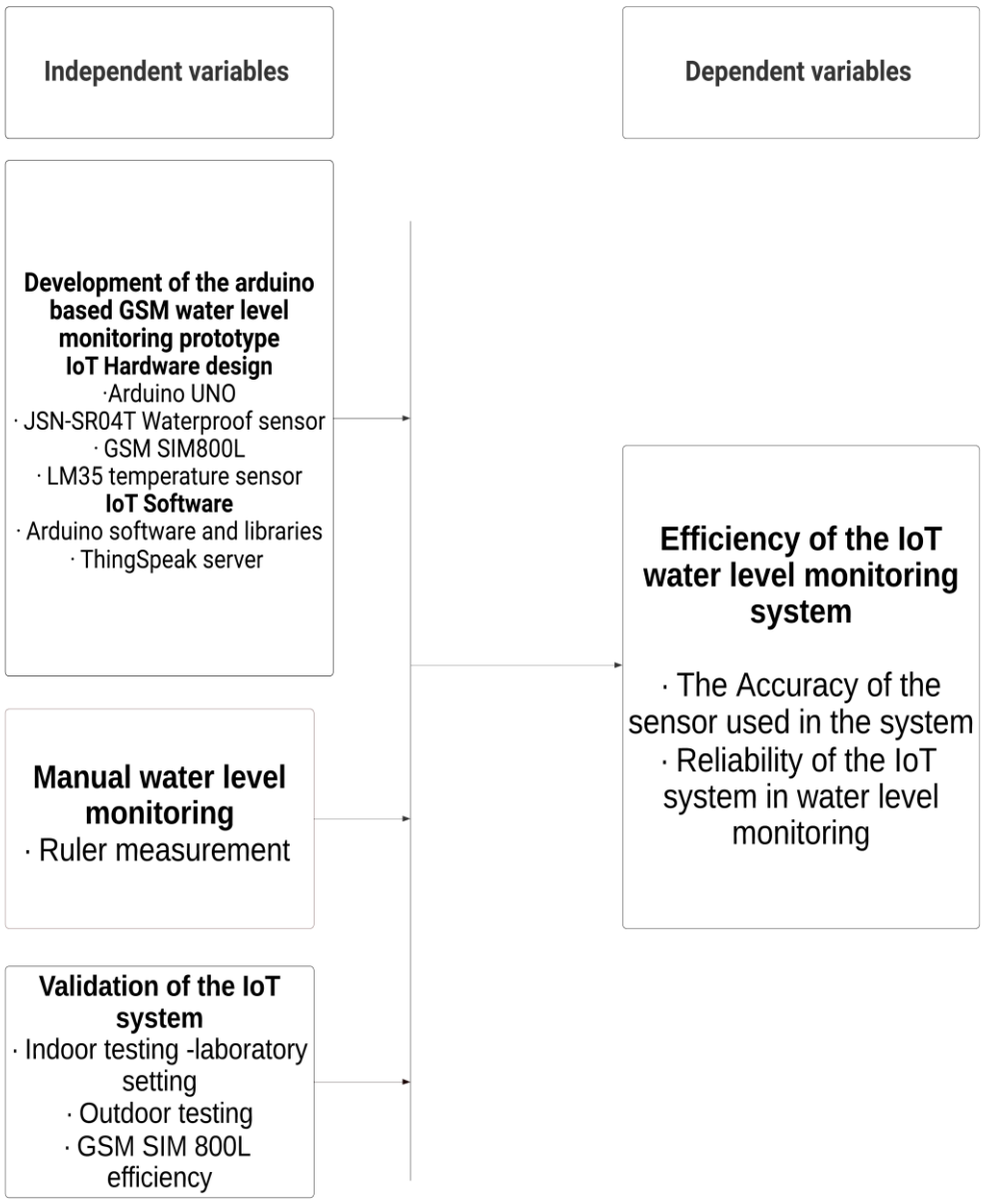


Figure 1.2: Conceptual Framework for development of the IoT Prototype (Researcher, 2023)

1.13 Summary of Conceptual Framework

Table 1.1: Conceptual Framework for development of the IoT Prototype

OBJECTIVE	INDEPENDENT VARIABLES	DEPENDENT VARIABLES
1. To develop an IoT prototype that utilizes JSN-SR04T waterproof ultrasonic sensor in water level monitoring	Type hardware used in the IoT. Type of IoT Software GSM SIM 800L Efficiency of sending and receiving data.	The accuracy of the sensor readings. The assessment of GSM SIM800L data transmission efficiency focused
2. To evaluate the performance of the IoT prototype that utilizes the JSN-SR04T waterproof ultrasonic sensor for remote water level monitoring that meets the requirements of accuracy and reliability	The number of testings of Indoor testing (laboratory setting) and Outdoor simulations.	Accuracy validation Performance in adverse conditions
3. To validate the IoT prototype by assessing the influence of air temperature variations on the performance of the JSN SR-04T waterproof Ultrasonic sensor in remote water level monitoring	Temperature sensitivity analysis Temperature range testing	Accuracy deviation assessment Correlation analysis

Source: Researcher (2023)

The research study that focused on the development and validation of an Arduino-based GSM prototype that utilized JSN-SR04T waterproof ultrasonic for remote water level monitoring had various variables playing distinct roles in shaping the investigation. The predictor variables in this research study encompassed the components of the IoT system itself, including hardware and software elements. These consisted of the design and development aspects of the IoT infrastructure that ranged from the selection and integration of IoT devices (sensors, communication modules) to the development of software components responsible for data processing and transmission.

The instruments used for manually measuring water levels, particularly the ruler method, represented an additional set of independent variables. These technologies provided a baseline for IoT system comparison which enabled a thorough assessment of its efficacy in remote water level monitoring. In addition, the validation protocols used for both indoor and outdoor research, as well as the evaluation of GSM efficiency, represented other independent variables. The overall comprehension of the functioning and output of the IoT system under a number of climatic circumstances is aided by these tests.

The outcome variable in this research investigation was centered around the effectiveness of the IoT in water level monitoring. Various factors were considered when evaluating its effectiveness, including the accuracy of water level readings, the real-time monitoring capability of the system, and the dependability of data transmission across GSM networks. Changes in the independent variables had an impact on outcomes and performance indicators, which were effectively reflected in the dependent variable.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter reviews the existing literature on IoT water monitoring technologies and their effectiveness in water resource management. The chapter highlighted these sections: Introduction of literature reviews, development of IoT prototypes for remote water level monitoring, evaluation of the performance of ultrasonic sensors in remote and validation of the influence of air temperature variations on the performance of ultrasonic sensors in remote water level monitoring. In conclusion, the research study examined the summary and gaps in the body of knowledge that justify this study. The study objectives serve as a basis for the literature review themes.

2.2.0 Objective 1: Development of an IoT prototype

This section highlights the literature review thematic areas elements under the research objectives one (1): To develop an IoT prototype for remote water level monitoring that utilizes JSN-SR04T waterproof ultrasonic sensor in water level monitoring. The sections are traditional water level monitoring systems, IoT concept, sensors and technology for detecting water levels, systems for remotely monitoring water levels and flood early warning systems.

2.2.1 Traditional Water Level Monitoring

Conventional tools like bubble gauges, staff gauges, wire gauges, and float gauges provide practical and dependable results, but they also pose issues because of their mass and high costs associated with development, deployment, and maintenance (Wu et al., 2023). These features make it difficult for conventional measuring devices to be widely used, especially when considering the ecological importance of different streams. Large systems' immobility makes remote monitoring even more challenging. These traditional instruments also don't have telemetry capabilities, which means that they must rely on manual recording and run the risk of human error.

Traditional water level monitoring systems, as defined by Jan et al. (2022), are historical and contemporary methods that use conventional techniques to measure and track water levels in various water bodies. These techniques precede contemporary innovations like sophisticated Internet of Things (IoT) and wireless sensor networks. As part of these systems, staff gauges or float-operated devices are used to physically measure the water levels by personnel. Manual measuring has several disadvantages, including being labor-intensive, time-consuming, and not providing real-time data, despite being straightforward and requiring little equipment.

Float gauges, which are buoyant instruments attached to permanent structures, provide round-the-clock monitoring, although they are only suitable for certain areas, are prone to damage, and need constant maintenance. Staff gauges are less suitable for remote places due to their reliance on human readings. Staff gauges are made up of vertical rulers along water bodies and are cost-effective. Although piezometers are useful for monitoring

groundwater levels, they may not provide a complete picture of surface water levels and need to be maintained regularly (Moreno et al., 2019).

Since conventional methods of estimating river discharge rely on factors like water flow velocity and cross-sectional area, they are sometimes complicated and time-consuming. While some traditional systems use telemetry to enable remote data transfer, manual readings are still a common practice. Many disadvantages of these conventional methods include labor-intensive processes, the possibility of human mistakes, limited coverage in large or remote areas, and high maintenance needs in difficult settings. Many places are switching to automated, more advanced water level monitoring systems as technology develops, especially ones that make use of the IoT. These emerging technologies offer immediate data, enhanced efficacy, and precision in managing water resources (Ahmed et al., 2020).

2.2.2 IoT Concept

The Internet of Things (IoT) is a concept centered around objects that may transmit data via the Internet without requiring direct human interaction, as noted by Ashtikar (2019). On the Internet of Things world, commonplace items become "Things," such as smart garbage cans that notify users when they are full, sensors that warn drivers of low tire pressure, and cardiac implant monitors.

Palermo et al. (2022) state that the physical, network, and application layers make up the three layers of the Internet of Things architecture. Data is collected via sensors at the physical layer, which is processed and stored at the network layer in the cloud. Specific services are provided by the application layer. The use of IoT in water management results

in increased productivity, decreased expenses, reduced human involvement, better asset use, and expanded commercial opportunities. The development of self-monitoring, self-communicating, and self-administering smart infrastructures is being fueled by factors such as resource management, sustainability, and technical breakthroughs.

The usage of the Internet of Things (IoT) has progressively increased, embracing a variety of devices, software, applications, and communication protocols (such as Wi-Fi, Ethernet, and Bluetooth). This extension makes it possible to offer a range of services via cloud servers. There are more chances for people now that there are a lot of connected IoT and non-IoT devices available (Costa and Emanuel, 2020).

The Internet of Things is intimately tied to machine communication (Barzegar et al., 2023). Gadgets and controllers with actuators and sensors, such as Raspberry Pi, Arduino-based CPUs, Intel Edison, and Intel Galileo, are commonly used to support it. These boards allow for the remote monitoring and control of sensor data via the Internet. IoT in the future will involve gathering a variety of sensor data for business reference, market insights, and research.

IoT devices provide communication and interaction among devices, machines, objects, animals, or humans without requiring external intervention, as emphasized by Siddiquee et al. (2022). These gadgets are important to the IoT ecosystem's data provision (IDE). Enhancements in safety, mobility, and dependability can be achieved through comprehensive studies carried out with a large and varied dataset.

2.2.2.1 Benefits of IoT systems in water resource management

IoT systems in irrigation offer several advantages, contributing to more sustainable and effective agricultural operations, as described by García et al. (2020). The decrease in total water consumption is one important advantage. IoT systems minimize water waste by automating the irrigation process so that only the required amount is used. A significant amount of water was wasted in the old manual irrigation techniques when human interaction was crucial. Intelligent irrigation systems minimize or do away with the need for human intervention, maximizing water resources to match exact specifications. This solves water scarcity-related environmental issues in addition to improving efficiency.

Cost-effectiveness is yet another important benefit of IoT-based irrigation, as noted by García et al. (2020). The decrease in water consumption, when combined with improved irrigation process accuracy, results in lower overall costs. This feature is essential for companies with limited resources because it highlights how important cost control is. In line with this goal, smart irrigation enables effective operations at reduced costs. The deployment of IoT-based irrigation systems leads to a significant decrease in energy usage. The overall energy usage is decreased by maximizing machine runtimes and putting planned intervals into place. This is in keeping with cost-cutting strategies as well as environmental sustainability.

Plants and crops only receive the required amount of water thanks to IoT systems' increased efficiency in irrigation and water management. This tailored method decreases crop wastage, eliminating concerns related to both under and over-provision of water, as

underlined by Pizarro et al (2023). IoT use in irrigation offers several advantages overall, including increased crop productivity, economic effectiveness, and resource conservation.

2.2.2.2 Microcontrollers and Communication Modules

Petru et al., (2023) investigate how communication modules and Arduino microcontrollers can be integrated into Internet of Things-based water level monitoring devices. To facilitate smooth real-time data transfer, the study evaluates the performance of Arduino boards, their suitability for a range of sensors, and the effectiveness of communication technologies including GSM, Wi-Fi, and LoRa. Using an Arduino board is a cost-effective and versatile solution that supports many forms of communication (SPI, I2C, and Serial), allows for a broad variety of operating voltages and has low-power capacities.

Development boards such as the HC-SR04 sensor module, NodeMCU ESP8266 and Arduino Uno were used in the research study's prototype. The tank's water management system serves three primary purposes: level control, level monitoring, and mobile phone-based remote control of the water supply pump for customers. Programming these applications in the Arduino IDE programming environment was part of the research project.

2.2.3 Water Level Monitoring Technologies and Sensors

Water level measurement is essential for several applications, including industrial water use, pollution monitoring, and the assessment of climate change. The complexity of this seemingly basic characteristic is highlighted by the nomenclature used about the water

level, which changes depending on individual applications. Examples of such terminology include depth, gage height, tide gage, and hydraulic head (Galli et al., 2022).

There are two varieties of sensors for measuring water level: touch and non-contact. They use different measurement concepts, including pressure, capacitive, ultrasonic, radar, and laser range sensors. With the help of linked devices, real-time monitoring systems have evolved to provide fast data access (Pizarro et al., 2023).

The use of low-cost GNSS antenna arrays, video surveillance, inexpensive sensors, and unmanned aerial vehicles has resulted in the proposal of several in-situ water level measurement devices in recent years. Finding affordable, reliable, portable, easy to assemble and disassemble, and adequately accurate equipment is still difficult, nevertheless (Dange, 2019).

Dange (2019) introduces a wireless system that monitors water levels remotely by using the Global System for Mobile Communication (GSM) network. With an open-access platform like Arduino serving as the primary controller, the system makes use of web infrastructure and ultrasonic sensing apparatus to provide remote access to data from any place. The device notifies the appropriate authority of the river's water level continuously and sounds an alert when the water level drops too low or floods. The suggested system is noteworthy for its capacity to enable field equipment setups online, which improves its adaptability and usage in a variety of climatic circumstances.

2.2.4 Remote Water Level Monitoring

IoT water monitoring has become a well-liked and effective way to protect water resources, with applications in a variety of fields including intelligent ecosystems, logistics, and healthcare. This strategy maintains the water cycle while reducing water waste and promoting economic success. According to Colaco and Lohani (2020), technological developments have made water level monitoring a remote and telemetrically enabled procedure instead of a periodic, human one.

Telemetric devices provide more frequent and precise recording of water levels by remote monitoring of water levels. The capacity to transfer the gathered data over long distances improves response times and usability in general. Other advantages of this move to real-time sensor technologies include increased accuracy and a lower chance of human error (Aliew, 2022).

The increasing use of water level sensors, particularly in coastal areas where watercourses meet, has given societies the ability to receive instantaneous data on water depths. Instead of depending just on one offshore tide gauge, a network of dispersed water level sensors can provide precise and in-depth information about water levels, improving the ability to identify flood hazards (Tien et al., 2023).

Water level sensors must be positioned strategically throughout a neighborhood to yield the greatest possible value. Although the goal is to monitor as much ground as possible, resource constraints force careful consideration of sensor location. To thoroughly evaluate flood risk in coastal areas, Tien et al. (2023) presents a method for properly placing real-

time water level sensors while taking into account a variety of factors, including some that aren't typically taken into account in such decision-making processes.

2.2.5 Flood Early Warning Systems

Floods are a common and devastating natural calamity that have posed serious risks to human life as well as considerable economic losses on a global scale. It has become clear that integrating advances in information and communication technology (ICT) can significantly lessen the effects of floods on people and property (Maspo, 2018). ICT-based tools and solutions have demonstrated efficacy in augmenting readiness, reaction, and recuperation endeavors, thus mitigating the unfavorable outcomes linked to flood occurrences.

Early warning systems for flooding are essential for sending out timely notifications about approaching floods. To identify possible floods, these systems use a variety of techniques, including tracking river flows, water levels, and rainfall. When a flood is identified, warning systems notify residents in impacted areas to evacuate using sirens, text messages, or public address systems (Maspo, 2018). Living close to riverbanks and downstream regions is especially important since early warnings give residents more time to prepare and evacuate, which eventually lowers the number of fatalities and property losses (Brindha et al., 2022).

Effective flood detection devices have been developed thanks to several investigations. A system with ultrasonic sensors to detect water depth and a sensor used to gauge the velocity of water flow was presented by Indrasari et al. (2018). The wireless and GSM-based communication infrastructure proved successful in monitoring water level levels at the

Katulampa Dam in Bogor. Using a GSM connection, Satria et al. (2019) created a real-time location-based flood disaster information system that includes ultrasonic sensor-equipped flood detectors and a server system for data processing. The technology proved effective in sending data on flood height remotely via SMS services.

Siddiquee et al. (2022) did, however, draw attention to some important factors for IoT-sensor-based flood monitoring systems. Because of the limits of battery-powered sensors, they may not be appropriate for wide regions even though they are consistent, affordable, and portable. These results highlight how crucial it is to take energy economy and system scalability into account when implementing flood monitoring systems.

2.3.0 Objective 2: Evaluation of the performance of IoT prototype

This section highlights literature review elements under research objective two (2): to evaluate the performance of the JSN-SR04T waterproof ultrasonic sensor for remote water level monitoring that meets the requirements of accuracy and reliability. The sections under this research objective are ultrasonic water level sensor, sensor accuracy, laboratory testing techniques for IoT prototypes in water level monitoring and comparative analysis of data transmission methods in water level monitoring.

2.3.1 Ultrasonic Water Level Sensor

The ultrasonic water level sensor offers different advantages, as outlined by Panagopoulos et al (2021). One significant benefit is that the sensor is immune to the impacts of contaminated water, floating debris, and aquatic life because no component of it comes into touch with the liquid. It is also useful for monitoring rivers and lakes because it is not

influenced by high flow rates. Long-term dependability, resistance to frigid conditions, and minimal maintenance needs are further advantages. Through testing the ultrasonic sensor at various preset distances and obstacle forms Kusuma et al. (2023) were able to provide important insights into how the sensor performed in various scenarios.

Omac and Perin (2022) highlights the use of an Arduino Uno to turn on the ultrasonic sensor system, which is intended to be used for measuring reservoir water levels. These sensors are especially well suited for high accuracy and resolution low-range monitoring applications. They function using sound waves of elevated frequencies that are transmitted and received, which permits non-contact measurement without causing any disturbance to the water's surface. By using a non-contact methods, the chance of sensor damage from encountering tainted or corrosive water is decreased (Pereira et al., 2022). They may, however, be less accurate because of their sensitivity to ambient elements like humidity and temperature. Additionally, errors may be introduced by reflection wave interference with good obstructions (Wang et al., 2021).

Ultrasonic sensors have drawbacks despite these benefits, such as a measurement range that is usually only a few meters. Given that the sound waves may weaken as they descend, they may not be employed in deep boreholes (Aderemi et al., 2021). The sensors measure the time between emission and reflection to compute distances. They do this by both producing and detecting sound waves. Because of the high frequency and human inaudibility of the sound released, concentrated and accurate measurements are guaranteed (Luo et al., 2023). According to Carreira-Casais et al. (2021), ultrasonic sensors work based on ultrasonic vibrations, which are normally over 20 kHz. The circuit package for an ultrasonic sensor consists of transmitter and receiver modules. Ultrasonic waves are

produced by the transmitter; when they encounter an item, they bounce back and are picked up by the receiver module.

Because of its affordability, resilience, and accessibility, the JSN-SR04T-2.0 sensor is frequently utilized in real-world applications (Andang et al., 2019). The sensor, which is positioned above a fixed height over a river, detects variations in river height by calculating the distance between the surface of the river and the installation site. Battery usage is determined by the sampling interval; 15-minute intervals are advised for best battery saving. For timely measurements, more regular intervals, such as every minute, can be used in high-flood-risk locations (Indrasari et al., 2018).

2.3.*2* Sensor Accuracy

The use of ultrasonic sensors to measure sound wavelengths, especially at close ranges, was examined by Subali et al. (2019). Nevertheless, the study neglected to assess distance-detecting accuracy.

In order to detect water depth, Sze et al. (2022) compared the HC-SR04 and JSN-SR04T sensors. The JSN-SR04T sensor displayed a lower average deviation of 1.28 percent, indicating greater accuracy, in comparison to the HC-SR04 sensor, which had an average error of 2.48 percent. Despite these encouraging findings, the research did not proceed to the point where a community-ready prototype, such as river location testing, which may have provided insightful information for community applications, could be developed.

Suryana & Yudono (2023) used an ATmega328P microprocessor with a JSN-SR04 sensor to detect the water level, flow rate, and volume of water in a horizontal pipe. When testing

5000 cc of well water in an 11 cm diameter pipe, the findings showed errors of 1.7 percent for water level measurement, 4.2 percent for water flow rate measurement, and 0.8 percent for water volume measurement.

Siswanto et al. (2019) created a program to control and monitor the water level in rainwater storage ponds utilizing HC-SR04 sensor, Arduino Uno R3 microcontroller, and DHT-22 temperature and humidity sensors. The device was said to be quite successful at controlling the water level in real-time.

Alam & Maulana (2020) used ultrasonic sensor and Arduino Uno to design a prototype automobile with automated braking. The accuracy rate of the system was 95.83 percent, with an average error of 4.17 percent. It was unfit for use in automobiles, though, and it stayed in the research stage.

The application of linear regression with the JSN-SR04T sensor for water depth detection in a water tank via Antares was investigated by Hasna Iftinan Apsari et al. (2022). Even though the JSN-SR04T initially produced measurements that were not reliable, the linear regression technique was used to improve measurement accuracy. After applying linear regression, test results showed increased accuracy, indicating that the procedure greatly improves the measurement data's accuracy over its initial state.

2.3.3 Laboratory Testing Techniques for IoT Prototypes

Pramono et al. (2023) created a river water level detecting system utilizing ESP32 and the Internet of Things (IoT). The aim was to acquire proficiency in utilizing ultrasonic sensors and ESP32 for ground water level monitoring and employing technology to enhance early

flood disaster reduction. The primary objective was to facilitate easier flood management for the community, enabling more prompt, accurate, and effective responses to mitigate the impact and losses associated with flood disasters. The research concluded that the system performed effectively, as evidenced by the accuracy of the sensor in measuring water levels during testing with the Arduino IDE. The ESP32, functioning as a microcontroller, processed data from ultrasonic sensors, which operated based on sound wave reflection principles to determine distances. The findings suggest that this system can be employed for accurate river water level monitoring and as part of a flood disaster mitigation system.

According to Morawska et al. (2018), to develop best practices and ensure quality assurance in metrology, testing sensors and monitors in both laboratory and field settings is crucial. They support the creation of uniform testing procedures and platforms, particularly for inexpensive water level sensors. The testing and use of an affordable MEMS-based pressure sensor for water level monitoring is presented in this work. The sensor demonstrated reliability across various in-situ and laboratory conditions with 031 percentage accuracy in the entire scale.

A study on a low-cost pressure sensor (0–689 kPa range) for Internet of Things and MEMS technology for water level monitoring was carried out by Barzegar et al. in 2023. In both laboratory columns and in situ settings, the sensor's performance—including accuracy, precision, repeatability, and temperature—was evaluated. The MEMS sensor demonstrated a 0.31 percent full-scale accuracy in trustworthy monitoring, according to the results.

Selva Kumar, (2022) research project goal was to create a low-cost, highly accurate water level monitor and controller using an Arduino Uno and an ultrasonic sensor. The

system's objectives were to accurately calculate the water level in a reservoir or a tank and to automatically manage the flow of water. Because of its inexpensive cost and easy installation, the system is ideal for usage in rural areas, small enterprises, and residences. It calculates the distance between the ultrasonic sensor and the water's surface. Next, the Arduino Uno uses this distance measurement to calculate the water level and manage the water flow using a motor or solenoid valve. The accuracy, reliability, and response time of the system are the three primary criteria used to evaluate its performance. Temperature and humidity are examples of climate variables that are included throughout the evaluation process. The study's findings demonstrate that the water level indicator and controller—which uses an Arduino Uno and ultrasonic sensor—is an affordable and dependable approach to water management. The device can help eliminate water wastage in addition to cutting water expenses and guaranteeing a steady supply of water. The research article offers helpful information about the creation of high-precision, inexpensive water depth indicator and controller systems, as well as possible uses in water management.

2.*3.4* Communication technologies in water level monitoring

Wireless communication technologies used in water level monitoring include GSM (Global System for Mobile Communications) and LORA (Long Range). GSM is surpassed by LORA, designed for IoT, in terms of transmission range, power efficiency, and data transfer speed (Kabi et al., 2023). Although GSM is more widely used, its data speeds and battery consumption are slower. The system application requirements determine which of LORA and GSM to use. Early flood alerts are made possible through the utilization of wireless sensors, which include communication modules. The aforementioned devices facilitate connection between the server and water level sensors in the monitoring region.

With 60% of the world's population owning one, mobile phones are a common means of communication. SMS has gained popularity due to its speed and affordability since GSM was introduced in 1991. (D. Kumar, 2022). To overcome network coverage restrictions in remote locations, a comparative analysis examines data transmission technologies, including GSM, Wi-Fi, and LoRa, taking into account factors like reliability, data rate, and range.

For agricultural truck tracking, Soy (2023) assesses LoRa and NB-IoT technologies, highlighting their limitations in terms of transmission in various settings. LoRa offers affordable cloud access, but NB-IoT has better coverage, making it appropriate for agricultural applications. ZigBee is a low-power communication standard for personal and corporate devices that is based on IEEE 802.15.4. (Biswal et al., 2021). ZigBee devices, which have a low power consumption and can operate for up to a year with just one battery installation, are used as wireless controllers or sensors.

2.3.5 Validation of the Water Level Monitoring Systems

A flood monitoring system was developed by Dswilan et al. (2021) using the GSM SIM900A and JSN-SR04T ultrasonic sensors. The components of the system included solar panels for power generation, a JSN-SR04T sensor, flood information sender, SIM 900A and a water depth detector. The test findings showed that the JSN-SR04T could detect distances between 20 and 600 cm. The data from water level indicated a regression value of 0.9996 and a sensitivity of 5.0314 mV/cm. Thus, there was a comparable 5.0314 mV change in voltage for every 1 cm change in water level. Furthermore, the regression value approaching 1 cm indicated that the sensor was operating as intended. However,

when tested in the field, measurements without a buoy can reduce errors. The test findings also showed that employing a buoy decreased the proportion of mistakes compared to not using one. measurement mistake caused by increases in water discharge caused by rain, which could obstruct the buoy's communication with JSN SR04T. The community can monitor river flow and floods more easily because the test can determine water levels, conditions at certain levels, and communicate data.

Andang et al. (2019) conducted a follow-up study to evaluate the JSN-SR04T ultrasonic sensor's capacity to identify floods depending on water levels in rivers. The research investigation highlighted that Higher accuracy is obtained when the JSN-SR04T sensor, which has a 6-meter range, is used. The study recognized that the JSN-SR04T be positioned at higher locations to enhance safety during rainfall as the control and sensor systems are located in separate enclosures. The study’s limitations persist due to data collection occurring under dry weather conditions and on uniform riverbed surfaces. Wavy water surfaces may also influence the levels of water in rivers.

The requirement for affordable wireless sensors for real-time water level monitoring when applying the alternating wetness and drying (AWD) irrigation technique in lowland rice fields is addressed by Cruz et al. (2022). Cruz created a low-cost wireless sensor with a PVC cap-enclosed Wi-Fi-enabled microprocessor, waterproof temperature, humidity, and ultrasonic depth sensor. Tested in the lab, pseudo-field, and real field settings, the sensor demonstrated good agreement with manual measurements, with RMSE of 5.0 mm to 13.5 mm and errors ranging from 5.2% to 6.6%. Since The inexpensive sensor performed on par with high-end sensors, it was an economical choice for lowland crop production systems' successful irrigation water management.

An IoT sea level monitoring device was introduced by Kusuma et al. (2023) to accurately measure sea levels and transmit real-time data. The device was made up of a battery, an MS5803-14BA sensor, a GSM module, and an ESP32 microcontroller. It was all constructed on a PCB board and kept out of the water in a waterproof case.

2.4.0 Objective 3: Validation of the IoT prototype

This section outlines the literature review thematic areas under research objective three (3); To validate the IoT prototype by assessment of the influence of air temperature variations on the performance of the JSN-SR04T waterproof Ultrasonic sensor in remote water level monitoring. The sections under this objective are factors affecting ultrasonic water level sensors, effects of air temperature on the accuracy of ultrasonic water level sensors and assessment of JSN-SR04T waterproof sensor.

2.4.1 Factors affecting the accuracy of ultrasonic sensors

For ultrasonic sensors, measurement accuracy often refers to the precise precision of the analog output value (Silva et al., 2020). The accuracy of an ultrasonic sensor's measurement, as indicated by the echo transit time, depends on several physical parameters, including both internal tolerances and external elements like air qualities.

Ultrasonic sensors work using the echo transit time method, which measures distance by measuring the interval between an ultrasonic pulse being sent out and a measurement of the echo that is returned. The speed of sound in air at ambient temperature, or roughly 344 m/s, is the basis for this computation. This speed can, however, change by around 0.17

percent for every degree Celsius of temperature change. These changes influence the transit time and may lead to errors in the computed distance (Dou et al., 2019).

Manupiya (2021) states that in the absence of temperature correction, a 20°C temperature shift might result in measurement errors of +7.65 cm at -25°C and -8.5 cm at 70°C when measuring 100 cm.

Numerous ultrasonic sensors have temperature probes added to monitor temperature changes and adjust the distances measured. With ultrasonic sensors, measurement accuracy is guaranteed within -25°C to +70°C, the entire operational temperature range, with an approximate error margin of ±1.5 percent (Aliew, 2022).

2.4.2 Effects of air temperature variations on ultrasonic sensors

Sze et al. (2022) underlined that air temperature variations have a substantial influence on how well ultrasonic sensors work. Temperature variations have an impact on sound speed, a crucial factor in accurate distance measurements. Shorter ultrasonic wave travel durations are the result of rising temperatures speeding up sound. On the other hand, lower temperatures result in a slower speed of sound, which extends the duration of ultrasonic wave propagation. Ultrasonic sensors often use temperature sensors or temperature compensation algorithms to lessen these temperature-related impacts. These steps are taken to recalibrate sensor readings, guaranteeing accuracy and consistency over a wide range of temperatures. To guarantee accurate and consistent measurements, it is essential to take the sensor's operating temperature range into account.

The majority of ultrasonic sensors can be adjusted and work in the -40°C to +70°C temperature range thanks to an inbuilt temperature sensor. The drawbacks of internal temperature compensation sensors include the possibility that they will not be near the temperature in the actual measurement channel, such as inside an enclosed tank, and that external heating or cooling sources may affect them (Khanan & Ashari, 2020).

Although ultrasonic leak detection techniques are useful, they should be used in conjunction with other approaches to avoid false alarms and environmental interference (Gautam et al., 2020). To identify pipe deterioration, researchers have integrated piezoresistive and ultrasonic sensors (Wang et al., 2021). The accuracy of the measurements is however affected by these methods' susceptibility to variables like temperature, air conditioning, and pipe cleanliness (Manupiya, 2021). Furthermore, ultrasonic procedures require a significant amount of electricity.

Because of its affordability, lack of moving parts, ability to estimate distances despite moderate amounts of dust, smoke, and humidity, and generally tiny and unobtrusive design, ultrasonic range sensors are a good fit for use in underground mines (Dou et al., 2019).

2.4.3 Assessment of the JSN-SR04T waterproof ultrasonic sensor

Tawalbeh et al. (2023) state that the JSN-SR04T ultrasonic sensor, which consists of an electronic circuit, a lengthy probe, and a waterproof transducer, uses a single transducer for both sending and receiving ultrasonic waves. This sensor's waterproof construction, small size, precision, high resolution, low power consumption, and variety of output modes are among its noteworthy features.

Andang et al. (2019) have highlighted that the JSN-SR04T type is widely used for river-level detection because of its excellent accuracy, which lowers analytical mistakes. This sensor's wide reach, which spans from 25 cm to 4.5 m, allows for positioning at higher locations while ensuring protection from submerged conditions. Utilizing an IO port TRIG and a minimal output level of 5μs, the JSN-SR04T sensor operates at a frequency of 40 KHz through transmission. It processes return signals, then at the IO port ECHO, it generates high-status signals. There is a particular equation that is used to calculate the variation in signals returned from the output.

Utilizing the JSN-SR04T sensor, Andang et al. (2019) effectively designed and tested an Arduino-Uno-based flood elevation detecting system. The technology exhibited an error measurement of 0.74 percent compared to manual measurements. Manual methods, which used a metric tape measure, were hampered by things like uneven water surfaces and swaying from water flow, which led to mistakes made by people and natural interference. In all 37 experiments, communication between the Arduino Uno and sensors was seamless, and the Atmega328 processor processed the data without any delays.

The incorporation of ultrasonic sensors, specifically the JSN-SR04T, has shown to be quite advantageous in an Internet of Things water level monitoring system. This device was coupled with ESP8266 NodeMcu V3 Board for real-time water level measurement. The ThingSpeak IoT platform wirelessly received the ultrasonic sensor data, which allowed for user monitoring and information access via cloud-based internet platforms on mobile devices and PCs. When the water level rose above a set point, the microcontroller set off an alarm that included a flashing red LED and a buzzer (Oo, 2019).

2.5 Summary and Knowledge Gaps

There are clear research needs in the areas of network growth and sensor placement in the context of IoT for water level monitoring. Important concerns including flood danger, socioeconomic vulnerability, and the exposure of vital infrastructure are frequently ignored in current studies. Studies in the field suggest improving accuracy and portability by tweaking current prototypes. Furthermore, they support additional research into ultrasonic technology, emphasizing its potential for a wide range of uses beyond water level monitoring (Palermo et al., 2022).

Sarma et al. (2023) state that there are still significant research gaps even with the IoT-based monitoring systems promising potential. Because different tools and systems have distinct data formats and communication protocols, interoperability and data standardization present problems that impede the smooth integration of various tools and systems. Because IoT devices are vulnerable to hacks and breaches that compromise the confidentiality of collected data, security and privacy considerations are of utmost importance. Effective security measures and privacy-preserving techniques are needed to close this gap. It will take careful study to ensure that IoT-based monitoring systems are user-friendly and acceptable, particularly in the agricultural sector, to meet the needs and preferences of stakeholders and farmers. To fully realize the potential of IoT-based monitoring systems for agricultural environment and security monitoring, it is imperative to address the critical research gap regarding the cost-effectiveness of implementing and maintaining these systems. This includes finding ways to lower the cost of these systems, particularly regarding resource-constrained small-scale farmers.

The effectiveness of Internet of Things operations is heavily dependent on communication technologies, and the selection of these technologies must take the application's environmental context into account. Low-energy nodes for short-distance data transmission and high-energy-consuming devices for long-distance data transmission are the two types of IoT technologies for irrigation. Popular wireless technologies with differing benefits and drawbacks include Wi-Fi, GSM, LoRa, and MQTT. Nevertheless, there are still gaps in the IoT environment, such as expensive proprietary equipment, few case studies, and a lack of end-to-end solutions for water resource management applications (Ashtikar, 2019).

Successful sensor systems must enable long-range communication, accommodate numerous sensor kinds, be dependable in inclement weather, and use minimal power. Promising prototypes and effective field demonstrations notwithstanding, cost and energy efficiency issues still exist, requiring additional optimization. Research reveals that wireless sensor networks have drawbacks, especially in places with erratic connectivity, environmental elements that affect data accuracy, expensive implementation costs, and security issues (Moreno et al., 2019).

Limitations regarding IoT cloud servers include financial ramifications, possible threats to data security, and communication lag. Licensing fees can be expensive for small-scale developers, and using third-party data management raises security issues. IoT applications' real-time responsiveness may be impacted by unwanted communication latency. Adoption barriers for IoT include low awareness and access among farmers in poor nations, interference and security concerns, and the requirement for enhanced dependability and robustness in outdoor farming settings. Compatibility problems and power-related

obstacles add to the complexity of implementing IoT. Finally, resolving privacy and data security issues in Internet of Things systems necessitates continued study as well as the use of cryptographic techniques and access keys (Colaco & Lohani, 2020).

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Introduction

This chapter outlines the research methodology that was considered during the research study. It contains details about the research design, research site, target population, study sample size, data collection and analysis methods, ethical and legal considerations regarding the research investigation.

3.2 Research Design

This research method employed a mixed method research methodology. It involves both quantitative and qualitative methods of data collection and analysis in one study (Dawadi et al., 2021). The following research designs are evident in the study under the following research objectives:

Objective 1: Development of an IoT prototype

Prototyping Design

This research study adopted a prototyping research design in the development of an Arduino-based GSM water level monitoring system. The prototyping process involved gathering the requirements, quick design, building the prototype, initial evaluation, refining the protype and implementation through data collection in the indoors and outdoors. The IoT water level monitoring prototype that utilized JSN-SR04T waterproof sensor was tested for accuracy and reliability in water level monitoring in the controlled indoors

environment and simulation in the outdoor environment. The design involved crafting a functional prototype capable of transmitting data via Global System for Mobile Communication (GSM) protocols.

Objective 2: Evaluation of the performance of the IoT prototype

The research designs under this study objective were:

Experimental Design

The study utilized an experimental design to evaluate the performance of an IoT prototype that utilizes a JSN-SR04T waterproof sensor for remote water level monitoring that meets the requirements of accuracy and reliability. The IoT was designed to capture real-time changes in water levels during both indoor and outdoor testing. The experimental setup allowed for controlled testing conditions to evaluate the performance of the IoT prototype.

Quantitative Research Design

This research study employed a Quantitative research design in numerical data collection methods and statistical analysis of the water level monitoring process. This included measuring water levels using Arduino-based GSM water level monitoring prototype that utilized JSN-SR04T sensor, recording data on air temperature variations and analyzing the relationship between the air temperature variations and sensor accuracy. Quantitative research allowed for identification of trends and patterns, and evaluation of the IoT water level monitoring prototype's accuracy and dependability. Additionally, quantitative methods were used to evaluate the reliability of GSM in sending real-time water level messages.

Observation research design

Observational research design is a research methodology where the participants or phenomena are observed in the natural setting. In this research study, indoor and outdoor observations of the performance of the Arduino-based GSM water level monitoring prototype were used. Incorporating a manual gauging system featuring a staff gauge enabled a comparative assessment thus ensuring that the accuracy and reliability of the Arduino prototype were juxtaposed with conventional methods. The observation of the IoT prototype in real-time and continuous manner enabled capturing water level changes and enabled understanding of its effectiveness in water level monitoring.

Objective 3: Validation of the IoT prototype

This research objective utilized two research designs namely the experimental research design and correlational research design. To start with, experimental research design was used where the sensor's performance was subjected under different temperature scenarios, with data collected and analyzed to assess any correlations between air temperature variations and sensor accuracy. By systematically varying air temperatures and observing their effects on the performance of the sensor, the investigation was able to make inferences about the influence of air temperature variations on the accuracy of the sensor in remote water level monitoring.

The correlation research design was used to validate the research Objective three (3). This involved data collection on air temperature variations and sensor performance in natural settings without experimental manipulation. The observations were made and changes in air temperature recorded with their corresponding fluctuations in the accuracy of the JSN-

SR04T sensor readings. Subsequently, to evaluate the strength and direction of the correlation between sensor efficacy and changes in air temperature, statistical analysis was done. This research design facilitates the identification of correlations between variables and infer potential causal relationships.

3.2.1 System Architecture

This study outlines the development and validation of an Arduino-based Global System for Mobile Communication (GSM) prototype that utilizes a JSN-SR04T waterproof ultrasonic sensor in remote water level monitoring that meets the requirements of accuracy and reliability.

The IoT prototype gathers water level datasets, transfers data to a gateway, permits data to be sent from the gateway to a cloud server, and allows data to be displayed on a mobile app and at LCD. The entire system is managed by an Arduino UNO microprocessor. The GSM module, ThingSpeak server, and JSN-SR04T waterproof sensor are all interfaced with it. After the calculated water level is compared to the predetermined threshold, the microcontroller allows SMS alerts to be sent to users via the GSM module.

3.2.2 Features of the prototype-Arduino-based GSM water level monitoring system

This section highlights the features of the Arduino-based GSM prototype. The hardware components utilized are the JSN-SR04T waterproof sensor, GSM SIM800L, Arduino UNO and LCD. The prototype components and their specifications are well outlined in this section. The section also depicts how the JSN-SR04T Waterproof sensor is interfaced with

an Arduino board, LCD and GSM module. The Bill of materials for the prototype is also discussed in this section.

3.2.3 Block Diagram of the IoT Prototype

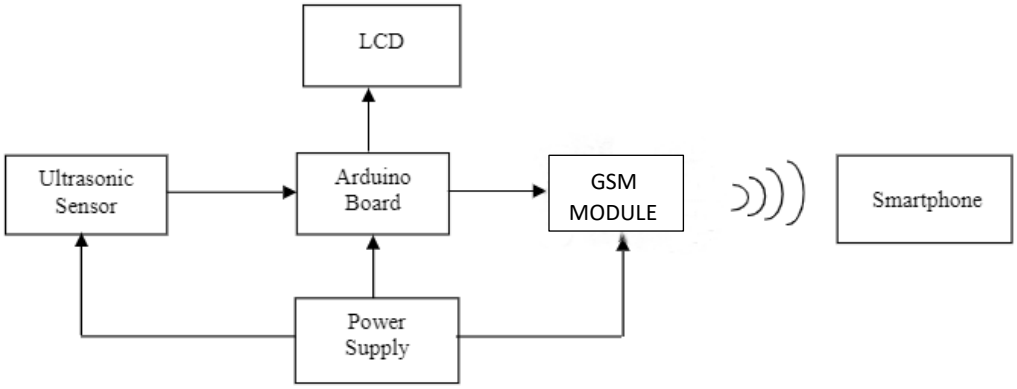


Figure 3.1: IoT System Block diagram

The Arduino-based GSM water level monitoring system operates as follows: The ultrasonic sensor gauges the distance from the sensor to the water surface by emitting sound waves, which are subsequently transformed into an analog signal readable by the Arduino board. This data is then showcased on the LCD screen for easy visualization of the water level information. Additionally, the Arduino board is configured to transmit this water level data to a mobile phone using GSM (Global System for Mobile Communications) technology. This functionality enables continuous monitoring of the water level and triggers alerts should the water drop below a predefined threshold.

3.2.4 Components of Arduino-based GSM Water Level Monitoring Prototype

A breadboard, jumper wires, LM35 temperature sensor, JSN SR-04T Sensor, Arduino UNO, 16*2 LCD and other essential parts make up the Arduino-based GSM water level monitoring prototype.

The prototype's specifications are based on the following requirements: it must be able to detect surface water, allow wireless data transmission every 15 minutes via GSM SIM800L, be affordable, robust, and reliable, provide ease of design and maintenance, and maintain energy self-sufficiency during indoor and outdoor water level monitoring sessions. The water level monitoring system is made more useful and effective by the combined use of certain parts and standards.

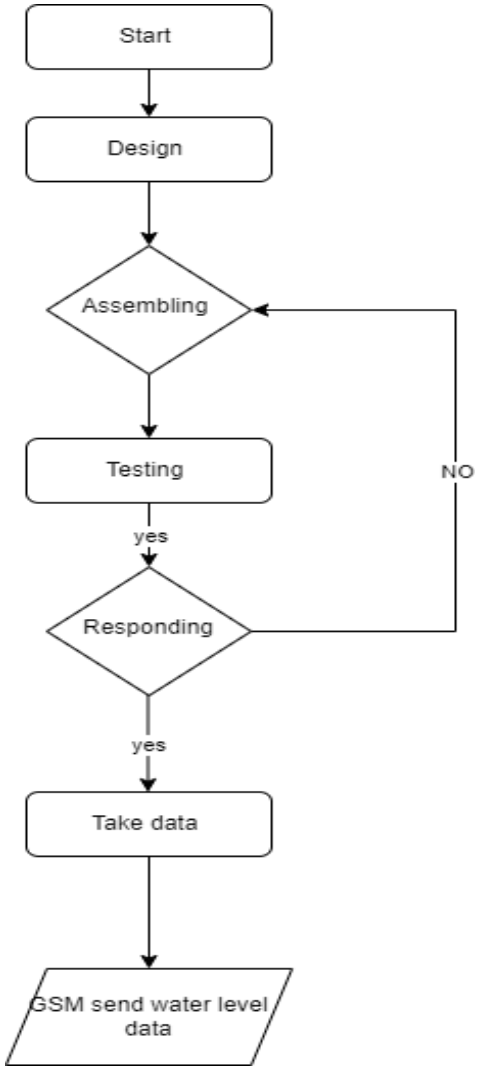


Figure 3.2: Prototype process workflow (Researcher,2023)

The process workflow for the Arduino-based GSM water level monitoring prototype begins with the startup of the Arduino, which includes configuring the necessary pins and modules. The SIM800L and the Arduino then communicate with each other when the Arduino sends the AT command, which turns on the GSM module. The Arduino instructs the JSN SR04T water level sensor to begin taking readings as soon as the GSM module is turned on. After that, the gathered water level data is combined with further data, such as sensor IDs or time stamps. Lastly, the GSM module receives another AT commands from

the Arduino, telling it to transmit the gathered data to a specified server or platform so that it can be thoroughly monitored and analyzed.

3.2.5 Interfacing JSN-SR04T waterproof ultrasonic with Arduino

Connecting the JSN-SR04T sensor to designated pins on the Arduino board is the first step in integrating it with the Arduino platform. The pinout procedure usually entails determining which pins on the Arduino and sensor are critical and making the appropriate connections. The JSN-SR04T sensor typically contains pins for power (VCC), ground (GND), trigger (TRIG) and echo (ECHO). The TRIG and ECHO pins connect to digital pins for signal triggering and reception, the VCC pin links to a 5V output on the Arduino shield, while the GND pin connects to the ground. Properly setting these connections ensures successful communication between the sensor and Arduino, allowing Arduino to read and interpret the ultrasonic data from the JSN-SR04T sensor.

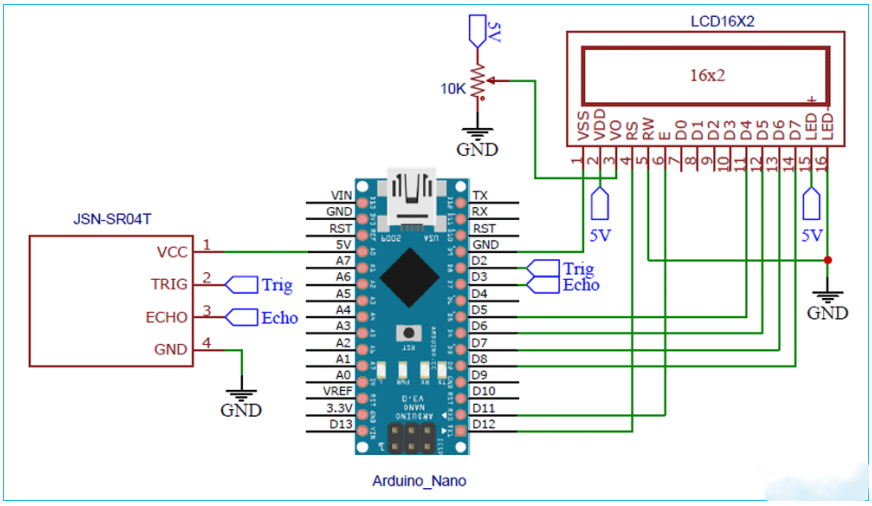


Figure 3.3: Interfacing JSN-SR04T waterproof ultrasonic sensor with Arduino (Researcher,2023)

3.2.5.1 Bill of Materials

The Arduino-based GSM Water Level Monitoring Project requires the following components:

Table 3.1: Bill of Materials for the prototype

NUMBER	COMPONENTS	QUANTITY	COST (KSHS)	PURCHASE AREAS
1	Arduino UNO R3 Board	1	1400	Pixel Electronics
2	GSM Module SIM800L	1	1500	Ktechnics
3	Jump wires	6	200	Ktechnics
5	LM2596 Buck Converter	2	200	Ktechnics
6	JSN-SR04T Sensor	1	1000	Ktechnics electronic
7	USB cable type A/B	2	200	Pixel electronics
8	LMF35	1	500	Pixel electronics
	Total		**5000**	

Source: Researcher (2023)

3.2.6 Hardware Components Requirements

3.2.6.1 Arduino UNO

It is an open-source microcontroller created by Arduino.cc. Arduino UNO is based on Atmega328 microcontroller chip. It operates on a programming language known as C++. It contains massive libraries of preset tutorials and codes. The device has an operating voltage of 5V. It contains 14 digital input/output pins and 6 of them can be used as PWM outputs. Other elements of this device include a USB port, an ICSP header, a power jack, a 16 MHz crystal oscillator, 6 analog inputs and a reset button.

The Arduino UNO includes all the essential components for powering the microcontroller and providing necessary support and this can be done by connecting it to a computer using a USB cable.

The UNO board differs from its predecessor in that it does not utilize the FTDI USB-to-serial driver chip. Instead, it features the Atmega8U2 with a USB-to-serial convertor application. The term “UNO” meaning “one in Italian was chosen for the upcoming Arduino 1.0 release. As the base model for the Arduino platform, the Uno is the most recent in a line of USB Arduino boards.

The Arduino shield’s specifications include an Atmega328 microcontroller, which has an operating voltage of 5V, a recommended input voltage range of 7–12V (with limits between 6–20V), 14 digital I/O pins, six analog input pins, 40 Ma DC per I/O pin, 50 Ma DC for 3.3V pin, 32 KB of flash memory (of which 0.5 KB is used by the bootloader), 2 KB of SRAM, 1 KB of EEPROM, and a clock speed of 16 MHz. These specs lay out the features and restrictions of the Arduino shield and supply the details required to incorporate it into projects and applications.



Figure 3.4: Arduino Shield (Pixelelectronic.com)

3.2.6.2 JSN-SR04T Waterproof Ultrasonic Sensor

Notable improvements have been made to the HC-SR04 sensor module with the JSN-SR04T sensor module. The use of an external 2.5-meter wire in place of a soldered transducer offers an important benefit of placing the elements used in sensing farther away from the control circuitry.

The sensor's potential for outside deployment in bad weather is further increased by its waterproof cover. It is advised that the sensor's drawbacks be evaluated during the research investigations. The JSN-SR04T has a minimum measuring distance of 20cm in contrast to the HC-SR04T's minimum of 20cm. Due to its single transducer for both transmission and reception, the JSN-SR04T is limited in that it takes time to switch between modes. Notwithstanding this, the JSN-SR04T has exceptional specifications: The device operates at a voltage of DC 5V, with a static working current of 5mA and a working current of 30mA. It emits acoustic waves at a frequency of 40kHz and has an operating range of 25cm to 4.5m, with a cable length of 2.5m.



Figure 3.5: JSN-SRO4T Sensor (pixelelectronic.com)

3.2.6.3 GSM Module -SIM800L

For GSM/GPRS connectivity, the SIM800L GSM Module is a reasonably priced, small cellular module. It is compatible with 2G SIM cards worldwide and operates on quad-band frequencies of 850/900/1800/1900MHz.

The module can transmit and receive SMS messages, engage in audio conversations with an external speaker or headset, and send and receive GPRS data for use with TCP/IP and HTTP, among other functions. It's important to note that while it's not GPS-based, it can its location via GSM (GPRS).

The module supports 3GPP TS 27.007, 27.005, and SIMCOM-enhanced AT instructions and interfaces with a microcontroller via the UART port. It needs an input voltage of between 3.7V and 4.2V during sleep mode, when its power consumption drops to 1Ma. A 3A power source is advised because the module's transmission current can reach up to 2 amps. A high-power buck-to-buck converter module is used with the SIM800L to guarantee appropriate power management.



Figure 3.6: GSM SIM800L (pixelelectronic.com)

3.2.6.4 16×2 Liquid Crystal Display

A 16-by-2 LCD is a type of liquid crystal display that has two rows, each containing 16 characters. Numerous technological projects and gadgets frequently employ this type of alphanumeric display. A communication protocol called the I2C (Inter-Integrated Circuit) interface makes it simple and effective for microcontrollers and peripheral devices to communicate with one another.

Compared to a direct parallel connection, connecting an LCD via the I2C interface usually requires fewer pins, which makes it more practical for projects where the microcontroller has limited accessible pins.

The communication protocol used by the I2C interface is master-slave. The LCD module is a slave to the microprocessor, which functions as the master. Several devices with separate addresses can be linked to the same bus thanks to the I2C interface.

The address of the LCD module with an I2C interface is predetermined by the manufacturer. Usually, this address is listed in the documentation or can be located with an I2C scanner application.



Figure 3.7: LCD 16x2 Yellow backlight /w I2C (pixelelectronic.com)

3.2.6.5 LM 35 Analog Temperature Sensor

The LM35 analog temperature sensor produces an electrical output that is proportionate to the temperature (measured in degrees Celsius). It can operate between -55°C and 150 °C. Since the scale factor is 0.01V/°C, the voltage obtained at my temperature of 27°C will be 0.27V. Without the need of calibration from the external sources, it sustains an accuracy of ±0.4°C at ambient temperature and ±0.8°C within the 0°C to 100°C range. The readout remains unchanged at the modest self-heating temperature of 0.08°C.

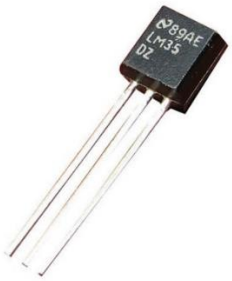


Figure 3.8: LM35 Precision Temperature Sensor (pixelelectronic.com)

3.2.7 Software Components Requirement

3.2.7.1 Arduino IDE

Writing, creating, and uploading code to the Arduino board is made easier with the help of the Arduino IDE, a software tool. Arduino developers frequently utilize it, and it is available for Linux, Mac, and Windows operating systems (Purwandani et al., 2021).

One can write Arduino programs using the code editor included in the Arduino IDE. To facilitate and speed up the coding process, it offers syntax highlighting, auto-completion,

and indentation. The Arduino platform offers a variety of functions and libraries that can be used for writing programs in the C/C++ Arduino programming language.

The Arduino IDE converts written code into machine code that is compatible with the Arduino board’s microcontroller. A customized version of the GNU Compiler Collection (GCC) created especially for AVR microcontrollers, the AVR-GCC compiler is used by the IDE.

After compilation, the code is uploaded to the Arduino board using a USB connection. The Arduino IDE facilitates board communication and transfers the compiled code to the microcontroller's flash memory. The code launches instantaneously upon uploading, enabling users to interact with the project via the connected devices.

The Arduino IDE comes with a serial monitor that is used to monitor and visualize the data sent or received over the serial connection. This aids in debugging and troubleshooting codes as well as output display and input from external devices.

The Arduino IDE has tools to help to choose the right Arduino board and configure the connection port. It works with a variety of Arduino boards, including the well-known Arduino Uno and more sophisticated boards like the Arduino Mega or Arduino Nano.

Writing, compiling, and uploading code to the Arduino board is made easy and convenient with the help of the Arduino IDE, which is an indispensable tool in the development process.

3.2.7.2 ThingSpeak Server

The term “ThingSpeak Server” generally refers to the ThingSpeak open-source Internet of Things (IoT) platform, which is intended to make it easier to gather, process, and display data from various IoT sensors and devices. ThingSpeak provides several noteworthy benefits when used with an ultrasonic water level monitoring system (Sabanci et al., 2018).

The data from the ultrasonic sensors may be safely saved in the cloud and accessed from any location with an internet connection thanks to its primary function as a centralized hub for data collecting and storage. Second, it allows continuous water level monitoring, which is crucial for applications like flood prediction, environmental management, and the security of water-related infrastructure. This is made possible by the sensors’ ability to communicate data to the platform in real time (Viegas et al., 2021).

Data visualization is another area in which ThingSpeak shines. It provides tools for building personalized dashboards that include graphs and charts that make data interpretation and analysis easier. Furthermore, the platform facilitates alerts and notifications, enabling users to set up warnings for when water levels surpass thresholds. This feature is highly valuable for early warning systems in the event of possible flooding or significant fluctuations in water levels.

Understanding the behavior of water levels over time and long-term trend analysis depends on users being able to compute and extract insights from the data that has been gathered, which ThingSpeak makes possible (Diriyana, 2019). Furthermore, the platform’s open API guarantees simple integration with a wide range of IoT gadgets and programming languages, increasing its adaptability and researcher and developer accessibility. Users can

create an ultrasonic water level monitoring system to meet their unique monitoring and analysis needs, set up their sensors to send data to the platform, and make use of ThingSpeak's extensive feature set by integrating the system with it. In the end, this integration improves ultrasonic water level monitoring systems' usefulness.

ThingSpeak extends the functionality of the platform by providing several tools for managing data flow. React is one such tool that, when stored data satisfies predetermined criteria, sets off events. For example, when a certain field on a certain channel reaches a predetermined threshold, it can be configured to run a script or send a remote message over HTTP. TimeControl is an additional resource that works similarly to a software timer by scheduling operations to be performed once at a certain time or regularly. React and TimeControl both support the same activities.

Additionally, ThingHTTP acts as a vital tool for remote calls over HTTP, permitting contact with other entities like devices, websites, and online services. When used in tandem, these tools enable users to effectively manage and regulate the data flow within the ThingSpeak platform.

3.2.8. Prototyping procedure

3.2.8.1 JSN-SR04T with Arduino UNO Connection

An easy wiring setup is used to link the Arduino UNO and the JSN-SR04T sensor. Because the JSN-SR04breakout T's board and the HC-SR04 have the same pinout, they may be simply swapped out (A. Kumar et al., 2023). Connecting the sensor's cord to the breakout board's rear connector ensures a secure and appropriate connection with the Arduino UNO.

For best results, this configuration ensures that the JSN-SR04T sensor is correctly interfaced with the Arduino UNO.

Table 3.2: Wiring JSN-SR04T with Arduino 768x362

Component	Pin name	Arduino uno Pin
JSN-SR04T Sensor	VCC	+5V
JSN-SRO4T Sensor	GND	Arduino Board GND
The Sensor Trig	Trig	Pin 12
The Sensor Echo	Echo	Pin 11

Source: Researcher (2023)

3.2.8.2 IoT Prototype Build Instructions

A methodical approach was taken in designing the Arduino-based GSM water level monitoring prototype. First, all of the required parts were assembled, including the JSN-SR04T Waterproof Ultrasonic Sensor, Arduino Nano, 162 LCD, Breadboard, Jumper Wires, LM35, and GSM Module (SIM800L). The Arduino Uno was then linked to the GSM Module with the correct jumper wires, guaranteeing the correct power supply and communication. After that, the JSN-SR04T Sensor was connected to the Arduino Uno by following the supplied pinout for the proper connections of power, ground, and signal. The 16X2 LCD was linked by the recommended pinout to display the water level and pertinent information in real-time. The LM35 temperature sensor was included to monitor the temperature.

To enable the reading of sensor data, communication with the GSM module, and display on the LCD, an Arduino sketch was created and uploaded. Extensive testing and debugging were carried out in a regulated setting to guarantee peak performance and resolve any

problems with sensor data, GSM transmission, or visual display. Energy-efficient choices were taken into consideration when implementing the power supply for the complete system, especially for extended monitoring sessions. The parts were firmly attached for outdoor use and contained in an enclosure that took the deployment environment into account. To communicate with the ThingSpeak server for monitoring and analysis, data transmission via the GSM module was set. Accuracy was ensured by calibrating the sensors, and the system was optimized for dependable data transfer and energy efficiency. Complete documentation was maintained throughout the process, offering valuable insights for troubleshooting and future use. This included wiring schematics, descriptions of the code, and specific settings.

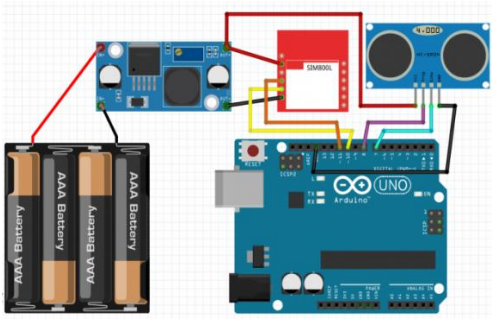


Figure3.9: IoT Prototype setup (Researcher,2023)

3.3 Research Site

The social, cultural, and geographic context in which a study is being conducted is defined as the research site (Sheppard, 2020). Along with the physical features of the site, such as its location and natural surroundings, a study site also contains the social and cultural context of the surrounding area, which includes the population, history, and cultural norms

of the community. The study site was in Kingongo Flats in Nyeri and the laboratories of Dedan Kimathi University.

3.4 Target Population

Willie & Willie (2023) cited that population is the total set of people, events, or things that research is going to look into. The target population in research is important because it establishes the scope and relevance of the investigation. It helps identify the population's key characteristics and determine the ideal sample size for the research.

The 188 square kilometer Naro Moru sub-catchment, which is a portion of the larger Ewaso Ng'iro North catchment basin, is home to around 65,000 households (S. Mwaura et al., 2020). The Naro Moru Water Resources Users Association (WRUA), whose goal is to manage and conserve the sub-catchment for the benefit of all users, was founded in 2002 to lower water-related conflicts and ensure equitable access to the resource. There are 50 kilometers in the Naro Moru River. The Naro Moru Water Resource Users Association's organizational structure influenced the target population selection. The target demographic is mostly agriculturalists who depend on the Naro Moru River for both home and agricultural use (Mwangi et al.,2023).

Bertule et al. (2018) state that in addition to ensuring a minimum flow of thirty percent in the river at the end of their area of influence, Water Resources Users Associations (WRUAs) carry out their mandate to manage and conserve water resources by acting as a forum for conflict resolution and cooperative management of water resources. Establishing upstream water storage facilities to help augment flow during droughts, conducting water abstraction surveys, educating users about their unique circumstances, acting as a liaison

between users and the Water Resources Management Authority (WRMA), offering guidance and training on rainwater harvesting and water conservation, and organizing open-field days for members to visit other Water Resource Users Associations and other users on the same river are just a few ways to achieve this.

3.5 Study Sample

The sample size is the total number of items selected from a population to create a sample for scientific analysis. The sample size should not be excessively large or small; rather, it should be suitable for the research objective and the characteristics of the population. Because it influences how exact and reliable the results will be, sample size is a crucial factor in study design. It needs to be representative of the population and large enough to be under control (Ward, 2022).

In statistical analysis, sampling involves the act of choosing or selecting a predefined number of observations taken from a broader group or a collection of individuals. Depending on the kind of study being done, the technique for selecting a sample from a broader population may involve either systematic or basic random selection (Roco et al., 2021).

The principal aim of sampling is to obtain a representative sample, which is composed of a limited number of examples or units selected from a significantly larger group or population. As a result, the smaller group may be analyzed by the research study, enabling reliable conclusions about the larger population to be made. Researchers often concentrate on procedures that provide samples displaying comparability to enhance the trustworthiness of their findings (Rahman, 2023).

This research study made use of stratified sampling. The campaign's goal is to determine which sampling approach to use. The water level was measured multiple times and categorized into multiple strata. Stratified sampling is a sampling technique used in statistics and research to ensure that a sample accurately represents the characteristics of a population. It works by first dividing the population into subgroups, or strata, based on predetermined criteria. Next, a random sample is selected from each stratum. This method is especially useful in heterogeneous communities, which are made up of several subgroups with differing characteristics (Rahman, 2023).

JSN-SR04T waterproof sensor has a 20cm minimum measuring distance with 25cm to 4.5m operating range, and 2.5m cable length (Andang et al., 2019). The sensor range used in the experiment was 25–150 cm, arranged into discrete strata with uniform intervals and measurement ranges. These intervals included: Stratum 1, which included four measurements at 25 cm; Stratum 2, which included four measurements at 50 cm; Stratum 3, which included four measurements at 75 cm; Stratum 4, which included four measurements at 100 cm; Stratum 5, which included four measurements at 125 cm; and, lastly, Stratum 6, which included four measurements at 150 cm.

All strata had the same sample size, which is the number of measurements made for every water level inside the indicated stratum. Over an hour, each water level was measured four times at 15-minute intervals, yielding a consistent sample size of four for each water level. This is consistent with Siris et al. (2019) concept of the BeSmart data collection framework factors driven by data accuracy, time, energy and privacy.

3.6.0 Data Collection

This section emphasizes the data collection instruments and the pilot testing of the research tools, ensuring their validity and reliability for gathering data.

3.6.1 Data Collection Instruments

The study utilized a variety of data collection tools, including an IoT-based water level monitoring prototype designed and developed to capture changes in water depths and air temperature during indoor and outdoor testing. Additionally, a manual gauging system, utilizing a staff gauge, was employed for both indoor and outdoor sensor testing to facilitate a comparative analysis between IoT-based monitoring devices and manual measurements.

The accuracy and reliability of the IoT prototype were assessed about contemporary water level monitoring systems. A GSM water level monitoring prototype, based on Arduino technology, was crafted to collect data on water level changes and wirelessly transmit this information for analysis. Before being deployed, the sensor was rigorously tested for accuracy and reliability and calibrated to gather data at intervals of every 15 minutes.

Excel and R Studio were used to evaluate the data collected from IoT-based monitoring devices and manual gauging methods to determine how effective each system was in tracking water levels. The Dedan Kimathi University laboratory and the Kingongo flats in Nyeri County, Kenya, served as the sites for the data collection, which took place between November 1 and November 17, 2023.

3.6.2 Pilot Testing of Research Instruments

A pilot study is essentially a small-scale inquiry carried out to evaluate research procedures, test data collection tools, examine sample recruitment strategies, and enhance other research methodologies in preparation for a larger study (Lowe, 2019).

Pilot testing is crucial to the research process since it may be used to find and fix problems with research instruments and guarantee their validity and reliability (Oktavia et al., 2018). By this process, the Arduino-based GSM prototype underwent a pilot test. By putting the prototype in an outdoor environment and gathering data beforehand of the actual data collecting day, it was possible to assess the device's operation and pinpoint any flaws, such as mistakes or technical issues. On October 28, 2023, a trial test was conducted at Kingongo Nyeri to evaluate the Arduino-based water level monitoring system before the actual day of data collecting was implemented.

3.6.3 Instrument Reliability

An essential element of research methodology is the reliability of the instruments. This ensures consistency and stability of measurements tools over time. It assesses how consistently a research instrument yields dependable and uniform results when deployed repeatedly under similar conditions. The reliability of the data collection instruments employed in this research study, the manual gauging method and IoT-based water level monitoring equipment, were carefully evaluated (Oktavia et al., 2018).

Assessing the reliability of the IoT prototype in remote water level monitoring, an array of tests and measurements were conducted. These assessments aimed to verify the

repeatability and accuracy of the prototype in measuring water levels. The reliability testing process involved subjecting the Arduino-based prototype to various conditions and scenarios, including changes in environmental factors, to observe its performance consistency.

Additionally, by taking repeated measurements with the staff gauge, the manual gauging system's dependability was investigated. The reliability of the manual gauging system was highlighted by readings that remained consistent across several trials. To make sure the manual gauging system was reliable, any discrepancies or deviations in measurements were duly logged and examined.

The reliability evaluation of the manual gauging system and the Internet of Things prototype adds to the overall robustness of the research findings by fostering trust in the precision and consistency of the data that was gathered. Comprehensive assessment of instrument dependability improves the reliability and validity of the study findings.

3.6.4 Instrument Validity

In research, instrument validity is vital because it measures how well a research tool captures the targeted constructs (Pandey & Snigdh, 2021). Several aspects of instrument validity were systematically investigated in this study.

First, content validity evaluated how well the research instruments fit the study's questions and were relevant to them. It particularly focused on how well the questions about IoT-based water level monitoring systems conform to the objectives of the research, highlighting the systems' effectiveness in managing water resources.

Second, by comparing the results of the research instruments to an external criterion—manual river gauging systems—criterion-related validity validated the validity of the instruments. This required a direct comparison between the accuracy of IoT-based water level monitoring devices and manually operated measuring techniques that were carried out at the same site at the same time.

Thirdly, construct validity ensured that the research instruments precisely assessed intended constructs by scrutinizing their relationship with other pertinent variables, such as the reliability and accuracy of the IoT-based water level monitoring system, establishing construct validity through these associations.

Concurrent validity entailed contrasting data from instruments measuring the same concept and utilizing comparable water level monitoring systems to evaluate the accuracy and dependability of IoT-based water level monitoring sensors. By taking a thorough approach to instrument validity, the study findings are strengthened overall and the desired elements in the field of water level monitoring are faithfully captured.

Mavrogiorgou et al. (2018) claim that many people are ignorant of what reliability entails. There's more to achieving a certain degree of satisfaction than just taking tests again and again. Four key characteristics help to define reliability more precisely. These dependability requirements, according to Moore et al. (2020), stipulate that devices must: carry out a certain task, operate without error, operate in predefined scenarios, and endure for a given period. This means that a comprehensive grasp of the expected usage scenarios, the criteria for appropriate operation, and the requirements for describing a failure are important for the reliability definition.

Moore et al. (2020) presented three non-standard reliability measure definitions to observe the real-time quality of data acquired from devices in IoT contexts. The three defined parameters were validity, availability, and currency.

3.6.5 Data Collection Procedures

According to Pratiwi and Fikri (2023), data-collecting procedures are the strategies or tactics used to obtain data for scientific investigations. These approaches necessitate systematic and well-planned measures to guarantee that the gathered data is reliable and precise, accurately representing actual occurrences in the field.

The research study used multiple processes to collect data in a thorough manner using a systematic methodology. The IoT-based water level monitoring system, which was painstakingly built for both indoor and outdoor testing, served as the main instrument for this task. Real-time data collection on changes in water level was made easier by this technology. A wireless communication aspect was added with the deployment of the Arduino-based GSM water level monitoring prototype, enabling the transfer of water level data at predefined intervals. The prototype was calibrated to record data every 15 minutes.

A manual gauging system was also used in conjunction with the Internet of Things system to provide meaningful comparisons between the manual measurements and the IoT-based monitoring devices. The accuracy and dependability of the IoT prototype were evaluated using the staff gauge as a baseline for both indoor and outdoor sensor testing.

To guarantee accurate data gathering, the Arduino-based GSM water level monitoring prototype underwent a thorough calibration procedure before deployment. The system’s

functionality was further evaluated through pilot testing, which took place at Kingongo Nyeri in an outdoor environment. This stage made it possible to find any errors or technical issues that needed to be fixed.

The gathered data, which included measurements from IoT-based monitoring devices as well as manually operated gauging equipment, was thoroughly analyzed using R Studio and Excel. These analytical instruments were essential in determining how well the two systems monitored water levels.

The Kingongo flats in Nyeri County, Kenya, and the Dedan Kimathi University laboratory served as the sites for the data collection, which ran from November 1 to November 17. The research aimed to acquire accurate and comprehensive data on changes in water levels by carefully implementing these data-collecting procedures. This allowed for a detailed analysis of the performance of the IoT-based water level monitoring system compared to manual gauging methods.

3.7 Data Processing and Analysis

To derive significant insights from the gathered data, data processing and analysis are essential elements of this study project (Barrocas et al., 2023). The processing and analysis of the water level data from the manual gauging system and the Internet of Things-based monitoring system in this study were led by a methodical methodology.

The process included several important steps. The primary goal of data cleaning was to improve the dataset's dependability for ensuing studies by addressing mistakes, outliers, and inconsistencies present in raw data. Then, using descriptive statistics that is the mean

and range measurements, a thorough analysis of the water level readings was provided, highlighting trends and patterns. ANOVA and t-tests were used in a comparative analysis to evaluate the IoT prototype performance versus manual gauges, and the results showed a significant difference between the two approaches. Multiple regression was also used to analyze the influence of air temperature variations on the JSN-SR04T waterproof ultrasonic sensor.

Relationships between variables were investigated using correlation analysis, with a focus on the agreement or disagreement between water level readings from the IoT-based system and manual gauging. Regression analysis examined modeling relationships, including how the position of sensors affects the accuracy of the Internet of Things system. Graphs and charts are examples of visual representations that were created to make difficult information easier to understand. Throughout these phases, R-Studio and Excel, two statistical software programs, were used to perform in-depth analyses and extract insightful insights from the dataset.

3.8 Legal and Ethical Consideration

To preserve the rights and welfare of research participants and guarantee adherence to relevant laws and regulations, this study placed a high priority on legal and ethical issues. The National Commission for Science, Technology, and Innovation (NACOSTI), the Kenyan government agency in charge of supervising and approving research projects, received the application for the research study and approved the data collection. This action was done to make sure the study complied with ethical and regulatory requirements.

An Internet of Things-based water level monitoring project aimed at effective water resource management in Laikipia County underwent several procedures to address ethical and legal concerns. These procedures were put in place and consistent with the recommendations of Ward (2022). First, informed consent was acquired from the Center for Integrated Research and Training in Arid and Semi-arid Lands Development (CETRAD), and the responsible director gave his approval after being made aware of the idea. To preserve participant privacy and confidentiality, secure data transmission and storage techniques as well as data anonymization were applied. Additionally, the research study made sure that all relevant laws and rules such as those that deal with data protection, privacy, and environmental protection were followed. The procedure for gathering the data was secure, trustworthy, and accurate.

CHAPTER FOUR

DATA ANALYSIS AND FINDINGS

4.1. Introduction

This chapter presents research data analysis and findings from a study that was to design, develop and validate an Arduino-based Global System for Mobile Communication (GSM) prototype that utilizes a JSN-SR04T waterproof ultrasonic sensor in remote water level monitoring that meets the requirements of accuracy and reliability.

The data analysis is centered on the research objectives of the study, which were to develop an IoT prototype for remote water level monitoring that utilized a JSN-SR04T waterproof ultrasonic sensor in water level monitoring. Secondly, to evaluate the performance of the IoT prototype that utilized the JSN-SR04T waterproof ultrasonic sensor IoT prototype for remote water level monitoring that meets the requirements of accuracy and reliability. Thirdly, to validate the IoT prototype by assessing the influence of air temperature variations on the performance of the JSN-SR04T waterproof Ultrasonic sensor in remote water level monitoring

The research method employed was a mixed research method that utilized qualitative and quantitative approaches in data collection and analysis. Manual ruler readings and water level sensor readings via LCD were both observed and recorded in Excel. GSM SIM800L transmitted the data to a mobile phone. ThingSpeak Server was used to visualize the sensor reading datasets. Data analysis was done in an Excel workbook and R studio. The research objectives and the findings were then presented using tables, graphs and charts.

4.2 Objective 1: Development of an IoT prototype

The initial step in the prototyping process involved assembling the parts and wiring them according to the circuit design. After that, the board was updated with the ready-made Arduino code. The water level sensor was mounted and water levels were adjusted to test the device and ensure measurement accuracy. To guarantee accuracy, the temperature values were cross-checked against a known temperature source. Verifying the water level and temperature readings are displayed accurately was used to test the LCD's operation. By triggering and sending messages of measured water level to the specified recipient, the GSM functioning was tested.

4.2.1 Hardware Design

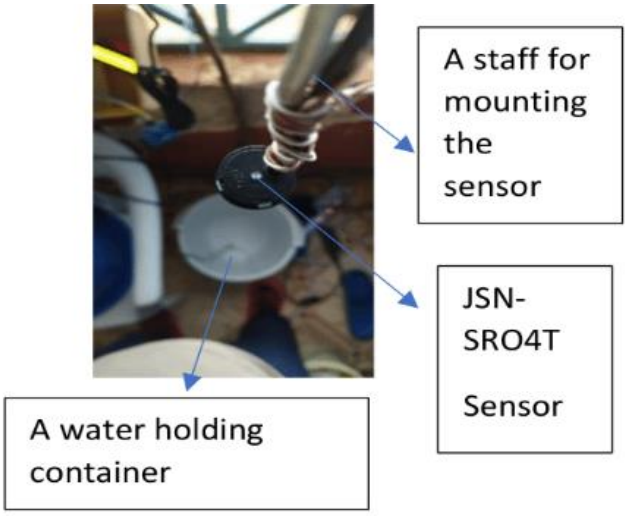


Figure 4.1: Data collection in the indoor environment (Researcher,2023)

4.2.2 Circuit Description

The prototype circuit consisted of the following elements namely the Arduino Shield, the JSN-SR04T level sensor, GSM modem SIM800L, a 16X2 LCD, LM35 temperature sensor and a breadboard. A 9V supply providing at least 1A of current was used to power the entire circuit. The GSM SIM800L has an operating voltage of 3.7V-4.2V and an operating current of 1-2.5 Amps. Therefore, a back converter was used to scale down the voltage for GSM consumption. The Arduino can alternatively be powered by the 9V supply through the Vin pin or the DC jack.

A grounding connection between the Arduino board and GSM board is established ensuring that the Arduino's Tx and Rx correspond to the GSM's Rx and Tx, respectively. Arduino's PINs 2 and 3, respectively, are linked to the trigger and echo pins. The Arduino 5V output pin supplies power to the ultrasonic sensor JSN-SRO4.

4.2.3 Step 1: Hardware Assembly

The connection between the Arduino and the JSN-SR04T sensor is the focus of the hardware assembly in the initial processes. This calls for a methodical approach to guarantee appropriate functioning and connectivity. The VCC pin of the sensor is attached to the 5V port on the Arduino, establishing the power connection. The sensor is simultaneously grounded by connecting its GND pin to the GND port of the Arduino.

The trigger pin of the sensor is linked to a specific digital pin on the Arduino, such as D2, to enable communication between the sensor and the Arduino. Furthermore, the sensor's Echo pin is connected to another digital pin on the Arduino, such as D3. This careful

connection design serves as the cornerstone for the hardware assembly, resulting in a networked system that is prepared for further data collecting and programming duties.

4.2.4 Connecting the I2C 16x2 LCD

Connecting the SDA pin to the Arduino's A4 pin for data transmission and the SCL pin to the A5 pin for clock synchronization allows the system to incorporate the I2C 16x2 LCD Display. To establish the required power connections, the GND and VCC pins of the display are connected to the GND and 5V ports on the Arduino shield, respectively. Moving on to the GSM SIM800L Module, its integration entails attaching the VCC pins and GND to the Arduino's GND and 5V ports.

Additionally, to facilitate communication between the GSM module and the Arduino, the GSM module's RX pin is linked to the Arduino's TX pin (digital pin 1), and the GSM module's TX pin is connected to the RX pin (digital pin 0). Lastly, powering the Arduino shield and the GSM board is emphasized as a means of ensuring operational power. This ensures a reliable and effective power source for the entire system and can be accomplished with an external power supply or by using a USB connection to a computer.

4.2.5 Step 2: Code Development

Developing the Arduino code was a critical component of the project. It centered on obtaining distance measurements from the ultrasonic sensor, sending data to the ThingSpeak Server via the GSM module, and displaying the outcomes on the LCD. The required libraries had to be added for the ultrasonic sensor, GSM module, and LCD for this code to function.

Properly enabling connection between the GSM module and the mobile network required setting up the SIM800L module. For this, it was necessary to connect to the mobile network and configure the module to send HTTP queries to the ThingSpeak Server. The Access Point Name (APN) and network settings were appropriately set up based on the specifics of the SIM card.

Concurrently, it was necessary to set up a ThingSpeak account. Creating a ThingSpeak channel dedicated to receiving, logging, and visualizing the water level data was the next step after creating the account. This channel acted as the allocated repository for the transmitted data, which made it simpler to store the data for processing in an ordered fashion. The coordinated execution of these steps, which incorporated hardware, software, and network configurations, ensured the full functionality of the IoT prototype.

4.2.6 Step 3: Calibration

The setup of the IoT prototype in the laboratory involved strategically positioning the JSN-SR04T sensor to ensure accurate measurement of water levels. An essential component of this setup was the calibration process, which relied on a known reference point. Calibration aimed to establish a correlation between the sensor readings and the actual water levels by measuring the distance from the sensor to the water surface under two distinct conditions: when the container was empty (representing 0% water level) and when it was full (representing 100% water level). This calibration process enabled the mapping of sensor readings to specific water levels, providing a basis for accurate and meaningful interpretation of the collected data in the subsequent stages of the project.

4.2.7 Step 4: Data Collection and Monitoring

For data collection and monitoring, the Arduino with the connected hardware was powered on in the laboratory setting. The Arduino was programmed to periodically determine the water depth using the JSN-SR04T sensor, display the obtained data on the LCD, and transmit the data to the designated ThingSpeak channel through the GSM module. This automated process allowed for continuous and real-time monitoring of water level fluctuations. By accessing the ThingSpeak channel online, the collected water level data was observed and analyzed to gain insights into the dynamics of the monitored system.

4.2.8 Step 5: Troubleshooting and Maintenance

The IoT prototype was tested to ensure that it was providing accurate readings and displaying them correctly on the LCD. The GSM module's connectivity was monitored to ensure that it was sending data consistently to the ThingSpeak server. Subsequently the hardware and power supply maintenance were performed to ensure continuous operation.

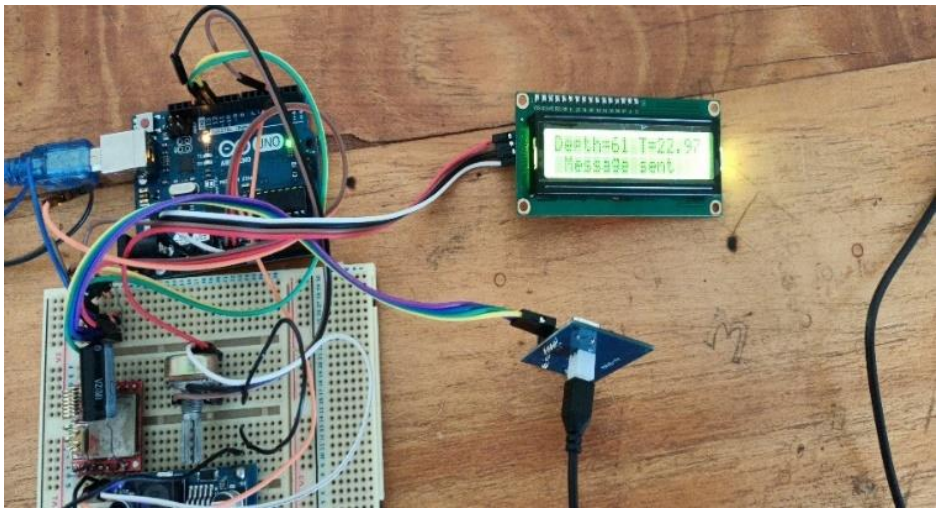


Figure 4.2: IoT water level monitoring system (Researcher,2023)

4.2.9 Working of JSN-SR0T

By utilizing the IO port TRIG to initiate a trigger with a minimum of 10 microseconds, the module autonomously emits an 8-40kHZ square wave and checks for the presence of a returning signal. If a signal is detected, the IO port ECHO outputs a high-level signal with the duration of this high signal representing the time taken for the ultrasound signal to travel from emissions to reception.

Once the distance measurement is completed, the module is activated. If the echo signal is not received, the ECHO port will automatically switch to a lower state after 60 milliseconds indicating the end of measurements regardless of its success. The LED indicator, which is not powered, will receive a signal once the module is illuminated, indicating that it is operational.

4.2.9.1 Connecting JSN-SR0T and Arduino UNO

An organized method was followed to connect the JSN-SR04T sensor to the Arduino Uno. Initially, a consistent and stable power source was established for dependable sensor operation by connecting the Arduino's 5V output to the JSN-SR04T sensor's VCC (Voltage Common Collector) pin. The Ground (GND) terminal of the JSN-SR04T sensor was connected to the Arduino Ground Port to establish a common ground reference for both parts. After that, the JSN-SR04T sensor's trigger pin was linked to pin 11 on the Arduino UNO. The ultrasonic signal used to assess distance was more easily transmitted with this arrangement.

Finally, the echo pin of the JSN-SR04T sensor was coupled to digital Pin 11 on the Arduino, allowing the Arduino to receive and analyze the echoed signal, enabling precise measurement of the distance to the sea surface. Water level measurements in the planned system are accurate and efficient because of the flawless connection between the Arduino Uno and the JSN-SR04T sensor made possible by this built-up configuration.

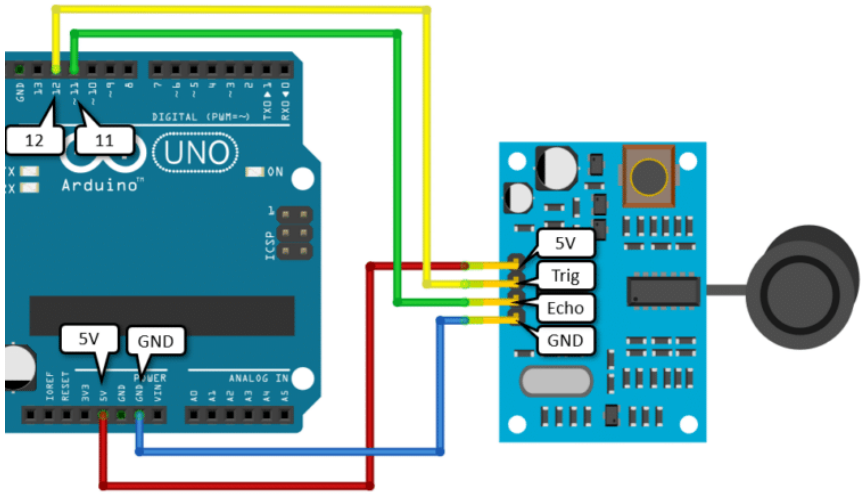


Figure 4.3: Schematic diagram for the IoT prototype (Researcher,2023)

4.2.10 ThingSpeak Server

Data was uploaded using an Arduino and the ThingSpeak library after the channels were created and configured. Through the use of pertinent functions, such as ThingSpeak, and channel details configured in the Arduino code, data was transmitted to the channels by the system via writeField(). Customization, including various time ranges and display options, was possible while viewing the data on ThingSpeak. The fact that the channels were made public underscored the security of the data and API keys.

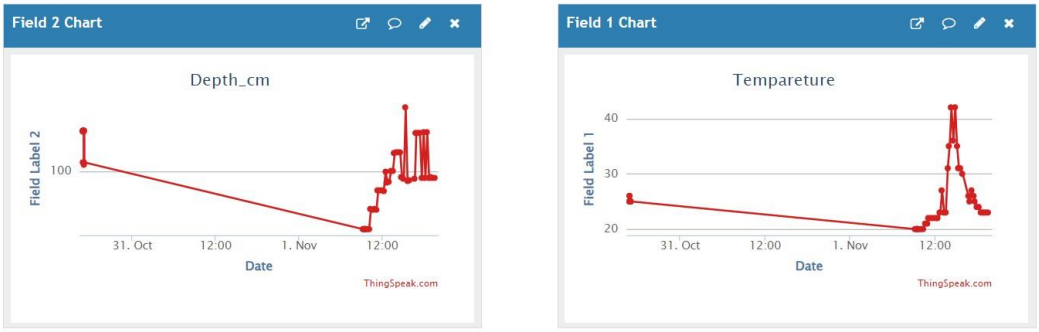


Figure 4.4: Data Visualization at ThingSpeak Server (Researcher,2023)

4.3 Objective 2: Evaluation of the Performance of the IoT Prototype

The performance of the IoT prototype that utilizes the JSN-SR04T waterproof ultrasonic sensor was evaluated for accuracy and reliability. Accuracy is the difference between the ultrasonic sensor's measured output value and the target's actual distance. The IoT system output was first visualized in the Arduino serial monitor and then broadcasted by GSM SIM800L. Later the visualization was through the ThingSpeak Server. This section looks at the evaluation of the accuracy of the IoT prototype that utilizes the JSN-SR04T waterproof ultrasonic sensor in the indoor environment (laboratory setting) and simulation of the outdoor environment and each of the accuracies evaluated. To evaluate the reliability of the IoT prototype, tests were performed to determine the time it takes to send and receive an SMS generated from the IoT prototype via the GSM module.

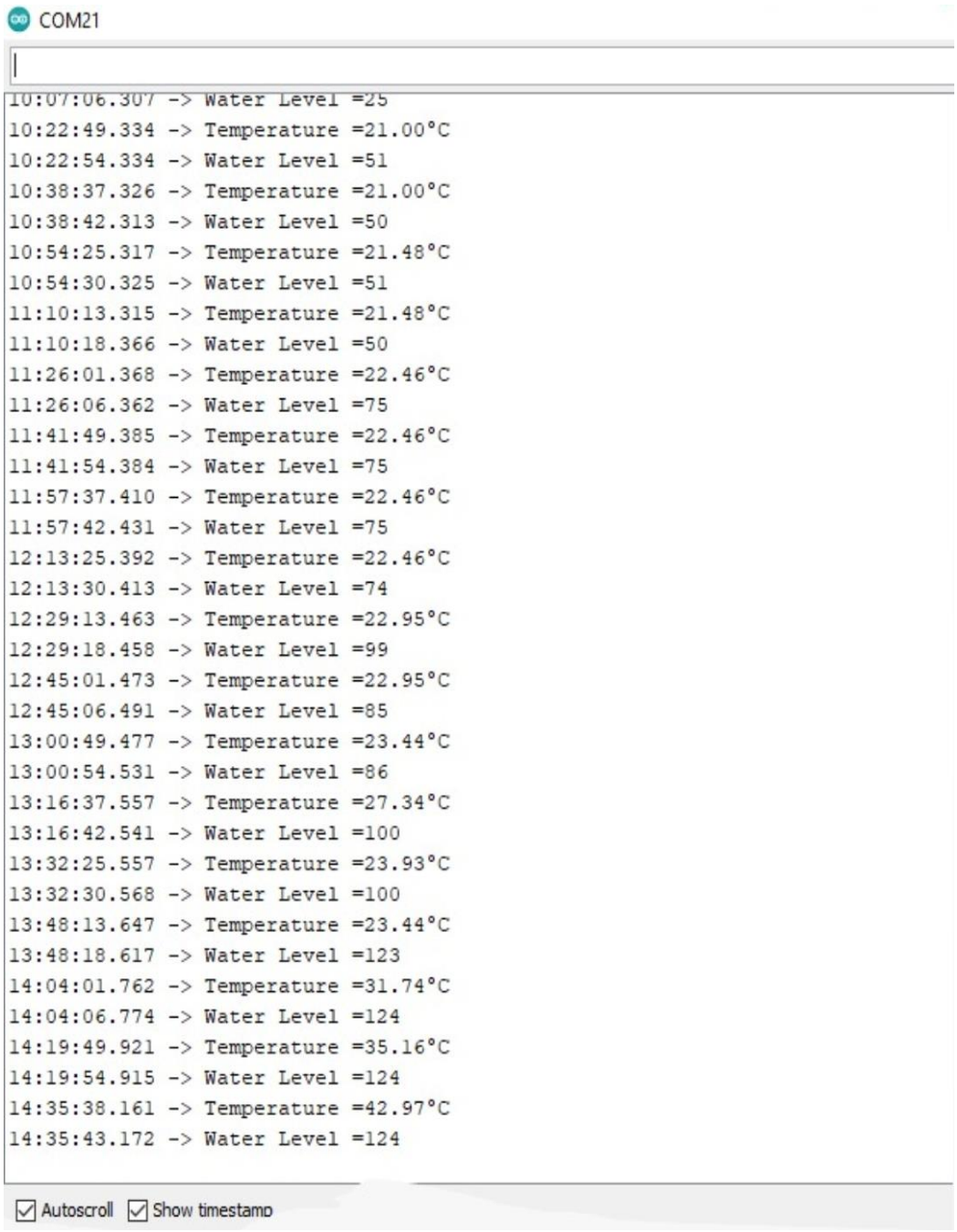


Figure 4.5: Serial Monitor water level data (Researcher, 2023)

4.3.1 Indoor Testing

Several experiments were conducted in laboratory settings that featured JSN-SR04T ultrasonic sensor measurement outputs and ruler measurements concurrently with temperature recordings. The purpose of these trials was to ascertain the IoT prototype's

accuracy in comparison to manual water level measurements made with a ruler. The indoor experiments were done in one day and the results tabulated in Table 4.1 are shown below.

Table 4.1: Indoor testing of the accuracy of JSN-SR04T Waterproof sensor

Time	Temperature	Ruler Measurement	Sensor Recording	Error	Percentage Error	Percentage Accuracy
12.36 pm	21.00	25	25	0	0	100
12.51 pm	21.00	25	25	0	0	100
1.12 pm	21.00	25	25	0	0	100
1.26 pm	21.48	25	25	0	0	100
1.28 pm	21.00	50	49	1	2	98
1.45 pm	21.48	50	49	1	2	98
2.01 pm	21.48	50	50	0	0	100
2.17 pm	21.48	50	50	0	0	100
2.32 pm	22.46	75	74	1	1.333	98.667
2.48 pm	21.48	75	74	1	1.333	98.667
3.04 pm	21.48	75	74	1	1.333	98.667
3.20 pm	21.48	75	74	1	1.333	98.667
3.36 pm	21.48	100	98	2	2	98
3.51 pm	21.48	100	98	2	2	98
4.07 pm	21.48	100	98	2	2	98
4.23pm	21.48	100	98	2	2	98
4.39 pm	21.97	125	123	2	1.6	98.4
4.55 pm	21.48	125	124	1	0.8	99.2
5.10 pm	21.48	125	124	1	0.8	99.2
5.26 pm	21.00	125	124	1	0.8	99.2
5.42 pm	21.48	150	149	1	0.667	99.333
5.58 pm	21.00	150	148	2	1.333	98.667
6.13 pm	21.00	150	148	2	1.333	98.667
6.28 pm	21.48	150	148	2	1.333	98.667
Mean					**1.083**	**98.917**

Source: Researcher (2023)

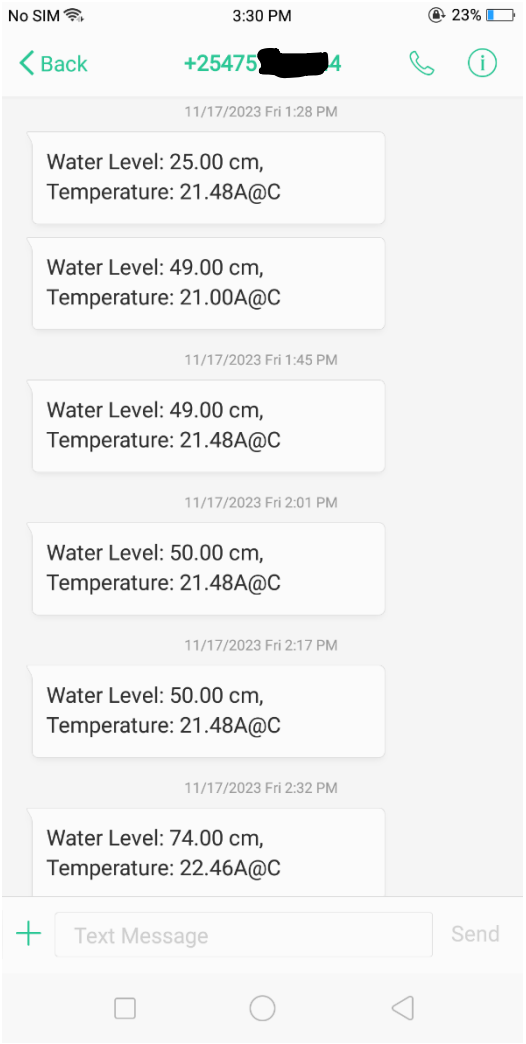


Figure 4.6: Indoor testing output via SMS (Researcher, 2023)

The JSN SR04T waterproof sensor achieved an accuracy of 98.917% in the indoor setting.

4.3.2 Outdoor Testing

To replicate the unpredictable conditions anticipated in real-world, the system underwent testing at an outdoor facility where temperature and humidity fluctuated throughout

accompanied by winds and vibrations. The water levels remained consistent and the measurement angle and surrounding environment closely resembled the ideal conditions.

The experiment was done in a real-life situation to observe the behavior of the sensors. The JSN-SR04T waterproof ultrasonic sensor and the LM35 temperature sensor were tested and results recorded. The outdoor experiment was done in one day and the results were tabulated on a table.

4.3.2.1 Outside Testing Procedure

The outdoor tests were conducted by transporting the IoT system, which included the sensor, Arduino, GSM module, and power source, to an outdoor location. The system was disassembled for transportation and then carefully reassembled at the outdoor test site, ensuring secure positioning for accurate outdoor water level measurements.

The setup included verifying the suitable placement of the sensor for effective outdoor data collection. Subsequently, the same Arduino sketch was executed, enabling the JSN-SR04T sensor to read water levels, display the readings on the LCD, and send the data, along with the current outdoor temperature, to the designated ThingSpeak channel. Attention was given to ensuring the GSM module's network connectivity at the outdoor location.

The system ran at specified intervals, capturing data points of water level and outdoor temperature, which were diligently recorded for later analysis on a computer. This systematic approach facilitated the collection and analysis of data to explore the impact of air temperature on the JSN-SR04T waterproof sensor's accuracy in both controlled and outdoor settings.

Table 4.2: Outdoor testing of JSN-SR04T waterproof sensor Accuracy

Time	Temperature	Ruler measurement	Sensor recording	Error	Percentage error	Percentage accuracy
9.21am	20.51	25	25	0	0	100
9.36am	20.51	25	25	0	0	100
9.51am	21.00	25	25	0	0	100
10.07am	21.00	25	25	0	0	100
10.23am	21.00	50	51	1	2	98
10.38am	21.48	50	50	0	0	100
10.54am	21.48	50	51	1	2	98
11.10am	22.46	50	50	0	0	100
11.26am	22.46	75	75	0	0	100
11.42am	22.46	75	75	0	0	100
11.57am	22.46	75	75	0	0	100
12.13pm	22.95	75	74	1	1.333	98.667
12.29pm	22.95	100	99	1	1	99
12.45pm	23.44	100	85	15	15	85
1.01pm	27.34	100	86	14	14	86
1.16pm	23.93	100	100	0	0	100
1.48pm	31.74	125	123	2	1.6	98.4
2.04pm	35.16	125	124	1	0.8	99.2
2.20pm	42.97	125	124	1	0.8	99.2
2.35pm	36.62	125	124	1	0.8	99.2
5.42pm	42.97	150	91	59	39.333	60.667
5.58pm	35.16	150	150	0	0	100
6.14pm	31.74	150	91	59	39.333	60.667
6.29pm	31.25	150	150	0	0	100
Mean					**4.917**	**95.08333**

Source: Researcher (2023)

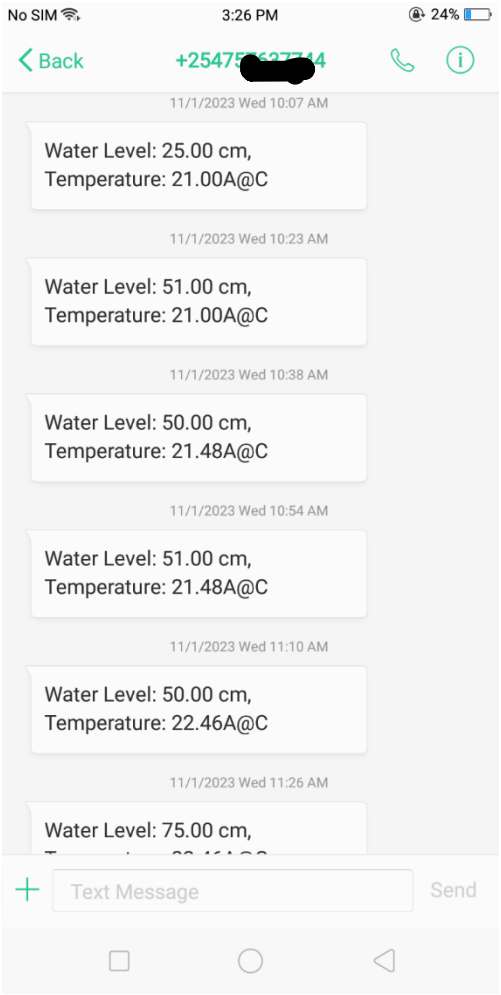


Figure 4.7: System-generated data sent by SMS (Researcher,2023)

The Arduino-based GSM water level monitoring prototype achieved an accuracy of 95.083% in the outdoor setting.

4.3.3 Evaluation of the efficiency of GSM SIM800L

The assessment of GSM SIM800L data transmission efficiency focused on the speed and reliability of sending and receiving data (H. Hassan et al., 2020). Calculating the average time taken for the module to receive a message involved summing the individual test durations, yielding a total time of 69.39 seconds across 15 tests.

The average time was determined by dividing the total time by the number of tests, resulting in an average of approximately 4.626 seconds (rounded to three decimal places). This calculated average time serves as a metric to gauge the efficiency of data transmission for the GSM SIM800L in the conducted tests.

Table 4.3: Message transmission time

GSM EFFICIENCY	TIME TAKEN FOR GSM TO RECEIVE THE MESSAGE ONCE IT IS SENT (SECONDS)
TEST I	4.43
TEST 2	5.57
TEST 3	4.84
TEST 4	5.21
TEST 5	4.86
TEST 6	4.75
TEST 7	5.32
TEST 8	4.87
TEST 9	4.71
TEST 10	5.42
TEST 11	4.71
TEST 12	5.04
TEST 13	5.16
TEST 14	4.47
TEST 15	4.53
Mean	**4.926**

Source: Researcher (2023)

4.4 Objective 3: Validation of the IoT prototype

4.4.1 Effects of air temperature variations on the Accuracy of IoT prototype

To compare the effects of temperature on the accuracy of the IoT prototype that utilizes the JSN-SR04T sensor in indoor and outdoor testing data was organized through a simple analysis. This was done by calculating the average accuracy for each temperature range in both indoor and outdoor scenarios.

4.4.2 Organizing the sensor Data for outdoor and indoor scenarios.

In the initial step of the analysis, the data was systematically organized for both indoor and outdoor testing scenarios, listing temperatures for each. For indoor testing, temperatures included 21.00°C, 21.48°C, 22.46°C, and 21.97°C. Outdoor testing temperatures encompassed 20.51°C, 21.00°C, 21.48°C, 22.46°C, 23.44°C, 27.34°C, 31.74°C, 35.16°C, 42.97°C, and 36.62°C.

In the second step, the average accuracy for each temperature range in the indoor testing data was calculated. This involved a methodical approach, considering the number of occurrences for each temperature and the associated accuracy, divided by the total occurrences. These steps facilitated a structured assessment of how varying temperatures influenced the average accuracy of the JSN-SR04T sensor in indoor testing conditions (Andang et al., 2019).

4.4.2.1 Effects of temperature variations on IoT Prototype that utilizes JSN-SRO4T Waterproof sensor in outdoor testing

Table 4.4: Effects of outdoor air temperature variations on JSN-SRO4T sensor

RANGE OF TEMPERATURE	ACCURACY
20.51	100
21.00	99.33
21.48	99
22.46	100
22.95	98.83
23.44	85
23.93	100
27.34	86
31.25	100
31.74	87.23
35.16	99.6
36.62	99.2
42.97	78.93
Mean	**95.083**

Source: Researcher (2023)

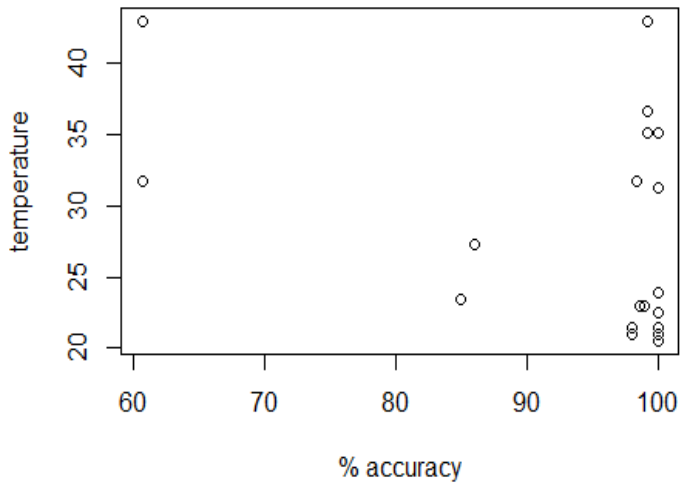


Figure 4.8: Effects of outdoor air temperature variations on JSN-SR04T sensor (Researcher,2023)

4.4.2.2 Regression Modelling: Data Analysis using R-Studio for outdoor scenarios.

Model 1, represented by the linear regression model Outdoor_reading.lm (% accuracy~temperature), reveals key insights into this relationship. The outdoor equation is y= 112.7724-0.6582X.

The intercept of 112.7724 signifies the estimated percentage accuracy when the temperature is zero, while the temperature coefficient of -0.6582 suggests a decrease of approximately 0.6582 units in sensor accuracy for every one-unit increase in temperature.

Both coefficients show statistical significance with a temperature p-value of 0.0422, indicating a significant relationship between outdoor temperature and sensor accuracy. The model's fit, assessed by the R-squared values, indicated that approximately 17.46% of the variability in percentage accuracy can be explained by the linear relationship with

temperature. The residuals, with a spread from -31.216 to 14.709, offered insights into the model's accuracy and areas for improvement.

The F-statistic of 4.653 with a p-value of 0.04218 confirmed the overall statistical significance of Model 1. The analysis demonstrated a statistically significant negative correlation between outdoor temperature and sensor accuracy, providing valuable insights into environmental factors influencing outdoor sensor performance and guiding optimal sensor use in similar conditions.

4.4.2.3 Effects of air temperature on JSN SRO4T Waterproof sensor in Indoor scenario

Table 4.5: Effects of indoor air temperature variations on JSN-SRO4T sensor

Range of Temperature	Accuracy
21.00	99.22
21.48	98.83
21.97	98.4
22.46	98.67

Source: Researcher (2023)

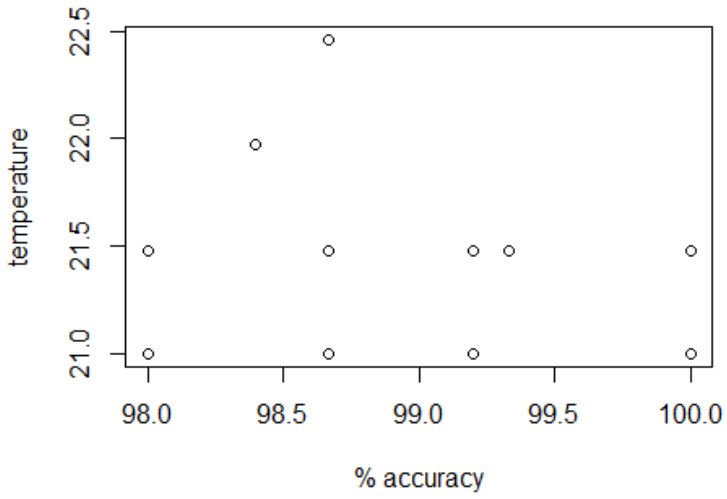


Figure 4.9: Effects of indoor air temperature variations on JSN SRO4T sensor (Researcher,2023)

The accuracy seems to be generally high across the temperature ranges, with a slight decrease as the temperature increases. The sensor performed consistently well across the provided temperature ranges, with accuracies above 98%. There isn't a significant drop in accuracy within the provided temperature ranges, suggesting that the sensor maintains good performance across these indoor temperatures.

The JSN-SR04T sensor demonstrates high accuracy for indoor testing, and there isn't a clear pattern of decreasing accuracy with increasing temperature within the specified range. The IoT prototype appears to be reliable across the given indoor temperatures. In the real world, conditions may vary.

4.4.2.4 Regression modeling: Data Analysis using R-studio for indoor scenario.

Model 2 focuses on indoor temperature readings and investigates the relationship between temperature and the percentage accuracy of sensors. The linear regression model, denoted

as indoor_reading.lm, is expressed as % accuracy~temperature, where % accuracy represents the accuracy of the indoor sensors, and temperature denotes the corresponding temperature readings. The indoor equation is y=111.0786-0.55683X.

Model 2, which explores the relationship between indoor temperature and sensor accuracy, reveals key insights across various aspects. The coefficients in the model, with an intercept of 111.0786 and a temperature coefficient of -0.5683, indicate the estimated percentage accuracy when the temperature is zero and the decrease in accuracy with each one-unit increase in temperature, respectively.

However, the significance test with a p-value of 0.229 suggests that the effect of temperature on indoor sensor accuracy is not statistically significant. The model's fit, evaluated through R-squared values, indicates that approximately 6.52% of the variability in indoor sensor accuracy can be explained by the linear relationship with temperature. Despite a negative relationship suggested by coefficients, the non-significant p-value implies that indoor sensors may not be significantly impacted by temperature changes, distinguishing them from outdoor sensors in this regard.

4.4.3 Combined model

The combined model, assessing the influence of sensor location on accuracy, exhibits a lack of statistical significance with a p-value of 0.09099. This implies that whether the sensor is placed indoors or outdoors does not have a significant impact on accuracy. The coefficient for "test_typeoutdoor" in the model is -3.833, indicating that, on average, outdoor readings have 3.833 units lower accuracy compared to indoor readings.

The ANOVA test, which evaluates the overall significance of the model, aligns with these results, reiterating the lack of significance for the location effect on accuracy with a p-value of 0.09099. In conclusion, while temperature significantly affects the accuracy of outdoor readings, the location of the sensor, whether indoors or outdoors, does not significantly influence accuracy. These findings provide valuable insights for optimizing sensor use in various environmental conditions.

4.5 Analysis of the JSN-SR04T sensor's accuracy

The analysis of the JSN-SR04T sensor's accuracy under varied temperature conditions reveals noteworthy patterns. While the sensor demonstrates high accuracy, reaching 100% in certain temperature ranges during outdoor testing, there are instances of lower accuracy, particularly noticeable at 23.44°C and 42.97°C.

The impact of temperature on accuracy is evident, with fluctuations noted, and a distinct decrease in accuracy observed at higher temperatures consistent with the findings of Manupiya (2021). To delve deeper into this relationship, a comprehensive analysis was undertaken. Similar analyses were undertaken by Hasna Iftinan Apsari et al. (2022) and Andang et al. (2019).

The collected indoor and outdoor datasets were compared to assess trends and variations in sensor accuracy concerning temperature changes. Statistical measures, including mean analysis, were calculated and compared to quantify the temperature's impact on accuracy. Visualizations, in the form of graphs and charts, were employed to illustrate the nuanced relationship between temperature and sensor accuracy. The goal was to draw conclusive

insights into the sensor's performance under different temperature conditions and ascertain whether the outdoor test data aligns with the outcomes obtained in the controlled lab.

CHAPTER FIVE

DISCUSSIONS, CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

The primary findings are covered in this chapter, along with conclusions, recommendations, and ideas for further research. The introduction, discussions, summary of main findings, conclusions, research recommendations, and areas of further studies are the sections that make up this chapter. The sections were written with consideration for the goals of the study.

5.2 Discussions

This chapter explores the discoveries made during the research investigations. This portion is grounded in the particular objectives outlined in the study, which included the development of an IoT prototype for remote water level monitoring that utilizes JSN-SR04T waterproof ultrasonic sensor in water level monitoring, evaluation of the performance of IoT prototype that utilizes JSN-SR04T waterproof ultrasonic sensor for remote water level monitoring that meets the requirements of accuracy and reliability, and validation of the IoT prototype by assessing the influence of air temperature variations on the performance of JSN- SR04T waterproof Ultrasonic sensor in remote water level monitoring.

5.2.1 Objective 1: Development of the IoT prototype

The findings show that IoT water level monitoring prototypes outperform manual river gauging systems in several ways. To start with, the IoT prototype collects data in real-time, allowing for more accurate and timely monitoring of water levels. This is critical for the early management of water resources. Meticulous IoT prototype calibration increases the accuracy and reliability of remote water level monitoring. The developed IoT prototype shows promise for remote water level monitoring. The results are consistent with Djalilov et al. (2023) who created a water level measurement and control system designed for versatile applications such as managing water levels in dams to prevent flooding, addressing water loss in reservoirs supplying specific areas, and serving various industrial purposes. The system's minimal requirements and straightforward installation process make it suitable for widespread use in large-scale water management facilities.

5.2.2 Objective 2: Evaluation of the performance of an IoT prototype

The study was successful in creating an IoT prototype that was specially made to satisfy the accuracy and reliability of remote water level monitoring. A GSM SIM800l, an Arduino UNO R3, an LM35 temperature sensor, an LCD, and a waterproof ultrasonic sensor JSN-SRO4T are all included in the prototype. The waterproof JSN-SR04T sensor was performed with 98.92 percent accuracy in a lab setting free from external environmental disturbance. The sensor obtained an accuracy of 95.083 percent when it was replicated outside to match actual field testing.

The high accuracy of the JSN-SR04T waterproof sensor is consistent with the findings of Andang et al. (2019) who investigated the performance of the JSN-SR04 ultrasonic sensor

for flood elevation detection with system tests done beneath a bridge in a river. The sensor captured water surface levels, and the outcomes were displayed on a Liquid Crystal Display. 37 scenarios that represented different river water surface conditions were included in the research test. Subsequently, the results of the system's measurement were compared to manual measurements. The analysis revealed a measurement error of 0.75%, aligning with the sensor's datasheet, which specifies a maximum resolution of 0.5 cm for the JSN-SR04T sensor. The utilization of ultrasonic sensors for river level detection is prevalent due to their heightened accuracy, minimizing errors in analysis. In contrast to the PING ultrasonic sensor, which has a measurement range of 3 cm to 3 m and a measurement error of 1 cm, the JSN-SR04T sensor expands its range from 25 cm to 4.5 m. This extended range enables the placement of the JSN-SR04T sensor at elevated locations, ensuring greater safety against submersion.

The outcomes align with the discoveries of (Rozaq, 2018). Evaluation outcomes reveal that Static Ultrasonic Ping sensors exhibit an average error of 2.16% and achieve an accuracy rate of 97.83%. Similarly, the Dynamic Ultrasonic Sensor Ping testing results indicate a mean deviation of 1.97%, accompanied by an accuracy level of 98.03%.

The assessment of GSM SIM800L data transmission efficiency showed that the GSM had an average of 4.626 seconds of the time taken for the GSM module to receive a message across 15 tests. Hassan et al. (2020) tested the efficiency of GSM in the transmission of flood messages in the Malaysia region and found GSM module used achieved an average efficiency of 12.58 seconds.

5.2.3 Objective 3: Validation of the IoT prototype

The impact of air temperature on the accuracy of the JSN-SR04T waterproof sensor is evident, with fluctuations noted, and a distinct decrease in accuracy observed at higher temperatures. To delve deeper into this relationship, a comprehensive analysis was undertaken.

The collected lab and outdoor test data were compared to assess trends and variations in sensor accuracy concerning temperature changes. Statistical measures, including mean analysis, were calculated and compared to quantify the temperature's impact on accuracy.

The JSN-SR04T sensor demonstrates variable accuracy in outdoor testing, with some temperatures showing high accuracy and others showing lower accuracy. The impact of temperature on accuracy is more pronounced in outdoor testing compared to indoor testing. Understanding these trends can help in optimizing sensor use and making informed decisions based on environmental conditions. The observations made by Dswilan et al. (2021) supported the notion that achieving high accuracy in training an ultrasonic sensor within the millimeter range is contingent upon obtaining the instantaneous speed of sound. The research emphasized the significance of factoring in parameters such as temperature to meet the accuracy requirements.

5.3 Summary of Main Findings

The research study’s primary results indicate that the IoT-based water level monitoring tools are more effective than manual river gauging systems. The designed IoT prototype for remote water level monitoring meets the accuracy and reliability requirements. The

evaluation of the IoT prototype that utilizes the JSN-SR04T waterproof ultrasonic sensor in water level monitoring showed that it had 98.92 percent accuracy in an indoor setting free from air temperature variations. The sensor obtained an accuracy of 95.083 percent when it was replicated outside to match actual field testing.

The analysis of the JSN-SR04T sensor's accuracy under varied temperature conditions reveals noteworthy patterns. While the sensor demonstrates high accuracy, reaching 100% in certain temperature ranges during outdoor testing, there are instances of lower accuracy, particularly noticeable at 23.44°C and 42.97°C.

The impact of temperature on accuracy is evident, with fluctuations noted, and a distinct decrease in accuracy observed at higher temperatures. The findings add to the body of knowledge on the use of IoT for water resource management. These findings are also exemplified by Kabi et al. (2023) who developed a river water level data collection system using LoRa technology at Muringato River in Nyeri County, Kenya.

5.4 Conclusions

The designed and tested Arduino-based GSM water level monitoring prototype is very accurate, reliable and cost-effective for application in water reservoir level monitoring. There is a variation in the distance between the measuring device and the ultrasonic sensor while testing the JSN-SR04 ultrasonic sensor. The discrepancy is regarded as erroneous. The test findings indicate that, although having an error value when compared to the calibration measuring instrument, the JSN-SR04 ultrasonic system is fairly accurate. Testing under pseudo-field conditions shows that the sensor's accuracy is worse than it is in the laboratory’s-controlled environment. The sensor operated in the hydraulic

measurements beneath the laboratory. In conclusion, the JSN-SR04 performs admirably and is quite accurate; nevertheless, when used outdoors, it is influenced by outside variables such as air temperature. These results support Manupiya (2021) and Dswilan et al. (2021) findings that air temperature has an impact on ultrasonic sensors.

5.5 Recommendations

Based on the results obtained, the study proposes the following suggestions. To begin, Water Resource Users Associations (WRUAs) should consider implementing an Arduino-based GSM water level monitoring prototype in their catchment areas. This implementation would allow for more accurate and timely monitoring of water levels, resulting in better water resources.

A comprehensive comparison of current measurement methods and sensor readings should be performed to assess the financial implications of implementing IoT-based systems. This analysis would provide insights into long-term costs and help water regulators make informed decisions about alternative energy investments and budget allocation.

In addition, more research might be done to evaluate the viability and affordability of automated river water level monitoring devices. A thorough investigation should be conducted into aspects like cost concerns, maintenance requirements, and scalability to promote the general adoption and implementation of these systems. Research studies can examine the long-term costs, robustness, and operational efficiency of different monitoring methods, enabling stakeholders to make educated decisions.

Ultrasonic sensor accuracy standards come in a variety of values, and some are not quite clear about the exact conditions of their collection. Most good ultrasonic sensors can often achieve 1-3 percent accuracy, while the most accurate ultrasonic sensors can reach 0.1–0.2 percent of the reported range under optimal conditions. When selecting an ultrasonic sensor in circumstances where precision is critical, consider factors other than the specified accuracy level. Furthermore, ultrasonic sensors should have temperature compensation to improve their performance. If the sensor is intended for outdoor usage, it is advisable to inquire with the manufacturer about available reference target adaptors or other options for temperature adjustment. The water level monitoring prototype should be placed above the height of any predicted snowfall, kept well away from exhaust vents, and have a significant space between the ground and the sensor (Andang et al.,2019).

5.6 Areas for Further Studies

Subsequent research endeavors may examine the amalgamation of Internet of Things-driven water level monitoring systems with extraneous environmental factors including temperature, precipitation, and water quality. This all-encompassing method would yield a more thorough comprehension of river ecosystems.

The JSN-SR04T waterproof sensor's performance and efficacy can be evaluated through comparative research in a variety of settings and seasons, including winter, summer, fall, and spring. It was noted that JSN-SR04T was unstable between 150 and 200 cm. The cause of the sensor's instability in such ranges requires more investigation.

Studies including long-term monitoring can be carried out to examine the patterns and trends in changes in water level over time. This would help with more precise forecasting models and advance our knowledge of hydrological processes.

5.7 Summary of the Findings

Table 5.1: Summary of the Research Findings

Research objective	Findings
Objective 1: To develop an IoT prototype that utilizes a JSN-SR04T waterproof ultrasonic sensor in remote water level monitoring.	The developed prototype was very stable and performed well under the controlled conditions of the laboratory and pseudo-field conditions. The GSM SIM800L module upon being tested for efficiency performed very well.
Objective 2: To evaluate the performance of an IoT prototype that utilizes a JSN-SR04T waterproof ultrasonic sensor for remote water level monitoring that meets the requirements of accuracy and reliability.	The waterproof JSN-SR04T sensor was performed with 98.92 percent accuracy in a lab setting free from external environmental disturbance. The sensor obtained an accuracy of 95.083 percent when it was replicated outside to match actual field testing. It was observed that it took an average of 4.9 seconds to receive a text message from the IoT prototype. This will enable real-time water level monitoring in the Naro Moru sub-catchment area.

Objective 3: To validate the IoT prototype by assessing the influence of air temperature variations on the performance of the JSN SR-04T waterproof Ultrasonic sensor in remote water level monitoring	The JSN-SR04T sensor demonstrates variable accuracy in outdoor testing, with some temperatures showing high accuracy and others showing lower accuracy. The impact of temperature on accuracy is more pronounced in outdoor testing compared to indoor testing. Understanding these trends can help in optimizing sensor use and making informed decisions based on environmental conditions. The combined model, assessing the influence of sensor location on accuracy, exhibits a lack of statistical significance with a p-value of 0.09099. This implies that whether the sensor is placed indoors or outdoors does not have a significant impact on accuracy. On average, outdoor readings have 3.833 units lower accuracy compared to indoor readings. The ANOVA test, which evaluates the overall significance of the model, aligns with these results, reiterating the lack of significance for the location effect on accuracy with a p-value of 0.09099. In conclusion, while temperature significantly affects the accuracy of outdoor readings, the location of the sensor, whether indoors or outdoors, does not significantly influence accuracy. These findings provide valuable insights for optimizing sensor use in various environmental conditions.

Source: Researcher (2023)

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APPENDICES

APPENDIX 1: Letter of Authorization

AFRICA NAZARENE
UNIVERSITY

P.O. Box: 53067 - 00200 Nairobi, Kenya.
Tel: 020 252 7170/1 - 5
Email: vc@anu.ac.ke
www.anu.ac.ke

13th March 2023

BENARD M. MATU
18S03DMIT006,

Dear Mr. Matu,

RE: PROPOSAL DEFENSE FEEDBACK

Following the 2nd of February 2023, School of Science & Technology board meeting during which you defended your research proposal entitled "**DESIGN AND IMPLEMENTATION OF AN ARDUINO-BASED LORAWAN WATER LEVEL MONITORING SYSTEM AND ITS EFFECTIVENESS IN WATER RESOURCE MANAGEMENT AT NARO MORU RIVER IN LAIKIPIA COUNTY**", the board of examiners concluded that you **pass with major corrections**. Besides, you have been allocated a new primary supervisor, i.e., **Dr. Mageto Victor and Dr. Ombui Edward will be your Secondary Supervisor**. You are required to work closely with your supervisors to address the attached recommended corrections.

Further, I am pleased to inform you that the board approved your proposal for data collection as part of your Master's program. Once you incorporate the feedback given from the external examiners and the board, your proposal will be more refined and shows great potential for contributing to the topic of study.

I would like to draw your attention to the need for ethical clearance in cases where human subjects will be used in your data collection. It is important to ensure that your research is conducted in an ethical and responsible manner that protects the rights and welfare of the participants. Therefore, I recommend that you obtain ethical clearance from the relevant Institutional Review Board (IRB) or Research Ethics Committee (REC) before beginning your data collection. The clearance certificate will demonstrate that your research has been reviewed and approved by an appropriate body and that it meets the required ethical standards.

Additionally, it is also necessary to obtain a clearance certificate from the National Commission for Science and Technology (NACOSTI) where applicable. This will confirm that your research meets the necessary legal and regulatory requirements and is authorized to proceed. Therefore, I strongly advise that you prioritize obtaining these certificates before commencing your data collection.

Council Prof. John Marangu (Chair), Dr. Daniel Miller (Vice Chair), Dr. Stanley Makhosi Bhebhe (Vice Chancellor), Dr. David Busic,
Members Dr. Daniel Gomis, Dr. Verne Ward, Rev. Donald Gardner, Rev. Gabriel Benjiman, Mrs. Madeleine Mansaly Sarr, Mrs. Sibongile Ncala

Overall, I am confident that your project will make a significant contribution to the field, and I wish you all the best in your research efforts. Please let me know if there is anything further I can do to support you.

Please feel free to contact me via email on hodcit@anu.ac.ke in case of any questions.

Sincerely,



Edward Ombui, PhD.
Head of Department, Computer and Information Technology

APPENDIX 2: Research Permit

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

Ref No: **373675**

Date of Issue: **04/April/2023**

RESEARCH LICENSE



This is to Certify that Mr.. benard MUNYIRI matu of Africa Nazarene University, has been licensed to conduct research as per the provision of the Science, Technology and Innovation Act, 2013 (Rev.2014) in Laikipia on the topic: DESIGN, IMPLEMENTATION, AND EVALUATION OF AN ARDUINO-BASED LORAWAN WATER LEVEL MONITORING SYSTEM FOR NARO MORU RIVER WRUAS IN LAIKIPIA COUNTY for the period ending : 04/April/2024.

License No: **NACOSTI/P/23/24642**

373675

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See overleaf for conditions

APPENDIX 3: Consent Request Form

COUNTY GOVERNMENT OF LAIKIPIA

21st March,2023

To

The sub-region Manager
Upper Ewaso Nyiro Sub-basin Area
Water Resource Authority,
P.O.BOX 1331-10400,
Nanyuki.

Dear Sir,

REF: REQUEST FOR MANUAL WATER LEVEL DATASETS FOR NARO MORU RIVER

The above subject refers.

This is to humbly request for your approval for academic research data collection exercise in terms of:

- ✓ **Manual gauging datasets for the dates (27th march 2023- 31st march 2023.**
- ✓ **Connection with personnel collecting manual dataset along.**
- ✓ **To engage the Naro Moru WRUAs in data collection.**

I look forward to more engagements with you.

Regards

Benard Matu
Senior ICT Officer
County Government of Laikipia

APPENDIX 4: Project Code

```
#include <SoftwareSerial.h>
#include <Wire.h>
#include <LiquidCrystal_I2C.h>

#define SIM800_TX_PIN 2
#define SIM800_RX_PIN 3

SoftwareSerial sim800(SIM800_TX_PIN, SIM800_RX_PIN);

// Set the LCD address to 0x27 for a 16 chars and 2 line display
LiquidCrystal_I2C lcd(0x3F, 16, 2);

// Define pin numbers for the ultrasonic sensor and analog temperature sensor
int trigPin = 12; // Trigger pin for the ultrasonic sensor
int echoPin = 11; // Echo pin for the ultrasonic sensor
int lm35Pin = A0; // Analog input pin for the LM35 temperature sensor

float celsius = 0; // Variable to store the incoming data
long duration, cm, inches; // Variables to store ultrasonic sensor measurements

void setup() {
  Serial.begin(9600);
  sim800.begin(9600);
  pinMode(trigPin, OUTPUT);  // Set the trigger pin as an output
  pinMode(echoPin, INPUT);   // Set the echo pin as an input

  delay(10000); // Wait for SIM800L to initialize
  Serial.println("AT");
```

```
  delay(2000);
  sim800.print("AT\r\n");
  delay(1000);
  sim800.print("AT+SAPBR=3,1,\"Contype\",\"GPRS\"\r\n");
  delay(2000);
  sim800.print("AT+SAPBR=3,1,\"APN\",\"safaricom\"\r\n"); // Replace 'yourAPN' with your
APN
  delay(2000);
  sim800.print("AT+SAPBR=1,1\r\n");
  delay(2000);
  sim800.print("AT+HTTPINIT\r\n");
  delay(2000);


  lcd.init(); // Initialize the LCD with a 16x2 display
  lcd.backlight();


  sim800.println("SIM800 is ready to send/receive SMS"); // Use sim800 instead of Serial
  sim800.print("AT+CMGF=1\r"); // AT command to set SIM800 to SMS mode
  delay(100);
  sim800.print("AT+CNMI=2,2,0,0,0\r"); // Set the module to send SMS data to serial out upon
receipt
  delay(100);


  sim800.println("AT+CMGF=1"); // Replace x with the mobile number
  delay(1000);
  sim800.println("AT+CMGS= \"+254712828124\"\r"); // Replace * with the mobile number
  delay(1000);
  sim800.println("System is On"); // The SMS text you want to send
  delay(100);
  sim800.println((char)26); // ASCII code of CTRL+Z
}
```

```
void loop() {
  // Print temperature in Celsius to the serial monitor
  Serial.print("Temperature =");
  Serial.print(celsius);
  Serial.println("°C");
  delay(5000);

  // Ultrasonic sensor measurements to determine water level
  digitalWrite(trigPin, LOW);
  delayMicroseconds(2);
  digitalWrite(trigPin, HIGH);
  delayMicroseconds(10);
  digitalWrite(trigPin, LOW);
  pinMode(echoPin, INPUT);
  duration = pulseIn(echoPin, HIGH);
  cm = (duration / 2) / 29.1; // Measurement in centimeters
  Serial.print("Water Level =");
  Serial.println(cm);
  lcd.clear();
  lcd.setCursor(2,1);
  lcd.print("Depth = ");
  lcd.setCursor(12,1);
  lcd.print(cm);

  delay(5000);
  // Read temperature from LM35 sensor
  celsius = readTemperature();

  // Send temperature and water level to ThingSpeak
  sendToThingSpeak(celsius, cm);
```

```
  delay(15000); // Delay for 15 seconds


}

float readTemperature() {
  int rawValue = analogRead(lm35Pin);
  float milliVolts = (rawValue / 1024.0) * 5000;
  float celsius = milliVolts / 10;
  lcd.setCursor(2, 0);
  lcd.print("Temp  =");
  lcd.setCursor(10, 0);
  lcd.print(celsius);
  return celsius;
}


void sendToThingSpeak( long waterLevel,float temperature) {
  sim800.print("AT+HTTPPARA=\"CID\",1\r\n");
  delay(2000);

sim800.print("AT+HTTPPARA=\"URL\",\"http://api.thingspeak.com/update?api_key=8SVSJ
AA08SAGD7EX&field1=");
  delay(500);


  sim800.print(waterLevel);
  sim800.print("&field2=");
  sim800.print(temperature);
  sim800.print("\"\r\n");
  delay(2000);
  sim800.print("AT+HTTPACTION=0\r\n");
  lcd.clear();
  sendSms(cm, celsius);
  delay(15000); // Wait for the action to complete
```

```
}

void sendSms(float cm, float tempC) {
  sim800.println("AT+CMGF=1"); // Set the SMS mode to text
  delay(1000);
  sim800.println("AT+CMGS=\"+254712828124\"\r"); // Replace with the desired phone number
  delay(1000);
  sim800.print("Water Level: ");
  sim800.print(cm);
  sim800.print(" cm, Temperature: ");
  sim800.print(celsius);
  sim800.print("°C");
  sim800.write(26); // End AT command with Ctrl+Z
  delay(1000);
  lcd.setCursor(0, 4);
  lcd.print("Message sent");
  delay(900000);

}
```

APPENDIX 5: Model 1 Validation

```
# Linear Models
# Model 1
Outdoor_reading.lm<-lm(`% accuracy`~temperature, data=Outdoor_reading)
summary(Outdoor_reading.lm)

##
## Call:
## lm(formula = `% accuracy` ~ temperature, data = Outdoor_reading)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -31.216   0.386   1.349   3.862  14.709
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) 112.7724     8.4769  13.304 5.35e-12 ***
## temperature  -0.6582     0.3051  -2.157   0.0422 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 10.52 on 22 degrees of freedom
##   (1 observation deleted due to missingness)
## Multiple R-squared:  0.1746, Adjusted R-squared:  0.1371
## F-statistic: 4.653 on 1 and 22 DF,  p-value: 0.04218
```

Outdoor equation: ***y= 112.7724-0.6582X***

APPENDIX 6: Model 2 Validation

```
indoor_reading.lm<-lm(`% accuracy`~temperature, data=indoor_reading)
summary(indoor_reading.lm)

##
## Call:
## lm(formula = `% accuracy` ~ temperature, data = indoor_reading)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -1.1447 -0.5765 -0.1993  0.5599  1.1281
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) 111.0786     9.8212  11.310 1.23e-10 ***
## temperature  -0.5683     0.4589  -1.238    0.229
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.749 on 22 degrees of freedom
##   (22 observations deleted due to missingness)
## Multiple R-squared:  0.06518,    Adjusted R-squared:  0.02268
## F-statistic: 1.534 on 1 and 22 DF,  p-value: 0.2286
```

Indoor Equation: ***y=111.0786-0.55683X***

APPENDIX 7: Combined Validation Model

```
# Combined model
Outdoor_reading$test_type<-"outdoor"
indoor_reading$test_type<-"indoor"

combined_df<-rbind(select(indoor_reading,c("temperature","% accuracy","test_t
ype")),select(Outdoor_reading,c("temperature","% accuracy","test_type")))
combined_model<-lm(`% accuracy`~test_type, data=combined_df)
summary(combined_model)

##
## Call:
## lm(formula = `% accuracy` ~ test_type, data = combined_df)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -34.417  -0.250   1.083   4.117   4.917
##
## Coefficients:
##                 Estimate Std. Error t value Pr(>|t|)
## (Intercept)       98.917      1.571  62.944   <2e-16 ***
## test_typeoutdoor   -3.833      2.222  -1.725    0.091 .
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 7.857 on 48 degrees of freedom
##   (21 observations deleted due to missingness)
## Multiple R-squared:  0.05836,    Adjusted R-squared:  0.03875
## F-statistic: 2.975 on 1 and 48 DF,  p-value: 0.09099

anova(combined_model)

## Analysis of Variance Table
##
## Response: % accuracy
##           Df  Sum Sq Mean Sq F value  Pr(>F)
## test_type  1  183.68  183.68  2.9751 0.09099 .
## Residuals 48 2963.52   61.74
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

There is no significant effect on the location of the sensor on accuracy, this means that whether the sensor is outdoors or indoors the accuracy remains the same.

Combined model equation: ***y=98.917-3.833x***

APPENDIX 8: IoT Prototype

