DEVELOPMENT OF HANDHELD DRINKING WATER QUALITY TESTER WITH GUI

BY

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A PROJECT SUBMITTED TO THE DEPARTMENT OF COMPUTER ENGINEERING, FACULTY OF ENGINEERING, UNIVERSITY OF BENIN, BENIN CITY IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF BACHELOR OF ENGINEERING (B.ENG) DEGREE IN COMPUTER ENGINEERING.

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DECLARATION

I, ADUN RICHARD OGHENERORO with mat no. ENG1905056, hereby declare that this research work was carried out by me, in the Department of Computer Engineering, Faculty of Engineering. University of Benin, Benin City Edo State. Under the supervision of Prof S. T. Apeh.

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ADUN RICHARD OGHENERORO

CERTIFICATION

This project was carried out by **ADUN RICHARD OGHENERORO in** the department of Computer Engineering, Faculty of Engineering, University of Benin, Benin City, and is hereby certified.

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Prof S. T. Apeh Date

(Project Supervisor)

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Engr. Dr. (Mrs.) O. Okosun Date

(Head of Department)

DEDICATION

First and foremost all praises to Almighty God for His all-encompassing love and guidance through my study and for granting me the knowledge and understanding to complete this project. I dedicate this work to my Mother, Mrs Ufuoma Adun whose loving and caring heart has served others. To my dad Mr. Afolabi Adun for all his prayers, support and parental guidance.

Also, to my group member Mr. Abu Abdulwahab Akoramo for his support and effort through the course of the project.

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ABSTRACT

Contamination and ineffective testing methods of drinking water remain a major problem worldwide, increasing the risk of inadequate water quality especially in developing and hard to reach communities. This is because conventional methods of testing water may be either, very costly, time-consuming or complicated for general application. This project aims at finding solution for these challenges by designing a portable handheld water quality monitoring device that measures water pH, turbidity and temperature as well as total dissolved solids (TDS). It combines sensors with an ESP32 microcontroller and the outcomes are displayed on an LCD screen, and a smartphone using BLYNK. Experiments conducted under experimental conditions proved that the proposed system has minimum deviations and MAE values thus giving us consistent and accurate measurements. Overall, the device can be called practically convenient for its intended purposes, however, certain aspects, such as the need to improve power consumption, are still suboptimal, as well as the lack of possibilities to fine-tune interface to the individual necessities. This project provides a tangible solution and it’s feasible in real time water quality monitoring thus promoting safer drinking water and better health outcome among the community.

CHAPTER ONE

INTRODUCTION

1.1. Background of Study

The quality of water has profound influence on the social health and welfare of people globally. Almost 785 million people globally are still waiting for access to basic drinking water services and millions of people are affected with diseases from contaminated water, pesticides, heavy metals, according to WHO, 2019. Contaminated water leads to waterborne diseases like diarrhoea, cholera, dysentery, and death of over 500000 people every year, particularly in low middle-income countries (UNICEF, 2021). Literally speaking, safe drinking water is not only having water on tap but also guaranteeing the water's purity.

The contention of the matter remains the cost and availability of good testing technologies as one of the major challenges in monitoring drinking water quality. Routine testing of water samples by standard laboratory procedures requires sophisticated equipment, skilled manpower and time which limits its use in remote or disaster-stricken areas (Prüss-Ustün et al., 2019). In such areas, people feel compelled to drink untreated or infected water which is very dangerous to their lives. The requirements for fast, portable, and easy to use instruments that can evaluate parameters reflecting water condition at the moment are of vital importance for sulphate free water treatment and preventing water borne illnesses.

There are few basic parameters that need to be monitored to see if the water is safe for drinking. There are several parameters which have been defined and used these include; pH that defines the level of acidity or alkalinity of water, turbidity which defines the level of suspended particles in water, temperature which checks the rate of chemical reactions in water, electrical conductivity mainly associated with concentration of ions in the water and specific contaminants such as nitrates, lead, and chlorine which are dangerous to human health as postulated by Van der

Bruggen & Vandecasteele, 2003). There is today some potential to implement such parameters-measurement equipment's through sensors and micro controllers which are affordable and portable for the measurement of these parameters in real time.

The development of handheld water testing kits has progressed greatly in recent years, however many of these devices are limited in functionality, accuracy, or affordability. There is still a need to integrate many sensors into a single, compact, and user-friendly device capable of giving reliable readings across several critical water quality parameters (Gupta *et al*., 2019).

This proposed project attempts to address these limitations by creating a handheld drinking water quality tester to enable real-time judgment on one's water safety in an efficient and easy manner. A portable, user-friendly, low-cost device that would be operational at the household level and at that of health workers, or organizations that work in far-flung areas. This handheld tester will give immediate feedback about the water quality and help individuals or communities make informed choices about their drinking water.

1.2 Problem Statement

Access to clean drinking water is a fundamental human right, but millions of people throughout the world continue to struggle to acquire safe water owing to contamination. Current water quality assessment procedures, which primarily rely on laboratory analysis, are impractical in many locations due to high prices, a shortage of equipment, and the need for qualified workers (WHO, 2021). In rural and disaster-affected places, where water contamination is common, the inability to test water quality immediately exacerbates health risks connected with waterborne infections (Prüss-Ustün *et al*., 2019).

The major limitation of present handheld water testers include their inability to assess a wide range of water quality parameters at the same time, their lack of durability, and their high cost (Gupta *et al*., 2019). Many existing devices also need to be calibrated on a regular basis, and are difficult to interpret for non-professionals, or lack the sensitivity required to detect harmful chemicals like nitrates and lead at low levels. These limitations provide a significant obstacle for communities requiring real-time, precise water quality data.

Since there is a need for portable, and reliable water testing equipment, this project is focused on the construction of a portable electronic device for measurements of water quality indicators inclusive of pH, turbidity, temperature, electrical conductivity and some contaminant ions such as nitrates, lead and chlorine. It will be designed with these characteristics to be produced and used at a low cost, and for simple usage making it suitable for use in areas with limited resources, thus posing a solution to the worldwide water quality issue.

1.3 Aim and Objectives

The objectives of this project in the development of a handheld drinking water quality tester are:

i. To develop a portable device that will measure important water quality parameters on pH, turbidity, temperature, and dissolved solids.
ii. To offer the user a friendly interface, via LCD on the device and through a mobile application (BLYNK) that allow for interpretation by non-professionals.
iii. To integrate objectives (i) and (ii) into a unified platform to provide a holistic report of the water quality.
iv. To evaluate the prototype under laboratory and field conditions to ensure accuracy and reliability.

1.4 Justification of the Study

This development of a handheld drinking water quality tester is justified because it deals with public health and sustainable practices concerning the environment, hence fitting into the United Nations Sustainable Development Goals, Goal 6: ensuring availability and sustainable management of water and sanitation for all. The main focus of this work involves the need for accessible, reliable, and low-cost water testing, especially within areas with limited resources, afflicted by natural disasters or conflicts. The suggested technology proposes a portable, easy-to-operate device for the measurement of the key water quality parameters: pH, turbidity, temperature, and total dissolved solids with very high accuracy, thus equipping frontline health workers and local leaders with information that will inform immediate health responses, supporting long-term water management strategies. The innovation also encourages technological growth together with environmental care; hence, it is multifunctional in sustainable development and behavioral improvement of public health across diversified geographical settings amidst socioeconomic variation.

1.5 Scope of the Study

The scope of this project includes numerous major phases. It starts with investigating water quality parameters and selecting appropriate sensors, followed by developing the device architecture, integrating sensors, and choosing a microcontroller like Arduino or ESP32. Next, a prototype will be developed to measure pH, turbidity, and temperature, with the results presented on an LCD or mobile app. The prototype will then be calibrated and tested in different environments to verify accuracy. Finally, field testing will be carried out to evaluate the device's usability and performance.

CHAPTER TWO

LITERATURE REVIEW

2.1 Theoretical Background

Public health is determined by the quality of water, whose quality has direct impact on ecological balance and human health (World Health Organization [WHO], 2017). Parameters which include pH, turbidity, temperature and Total Dissolved Solids (TDS) are important in ascertaining the suitability of water in conducting various uses (Jan *et al*., 2021). WHOs (2017) standard is that safe drinking water must comply with very strict physicochemical and microbial criteria to minimize health risk. Nevertheless, with dependence on old methodologies that are expensive, labor intensive, and time consuming (Singh & Walingo, 2024), monitoring these standards in many rural and disaster-prone areas is a challenge.

The revolution in water quality monitoring using these sensors with the Internet of Things (IoT) has mostly been driven by advancements in sensor technologies that offer affordable and compact solutions for real time data acquisition (Zulkifli *et al*., 2022). Decentralization of these assessments of water quality is particularly critical for remote areas of the world that lack traditional laboratory facilities. With wireless sensor networks (WSNs), automated, real-time monitoring of IoT based systems reduces delays compared to traditional laboratory testing (Jan *et al*., 2021).

Yet, creating water testing devices with various sensors for accurate real time monitoring whilst being cost efficient, portability is still proving to be a difficult task (Singh & Walingo, 2024). And its robustness under harsh environments, and user-friendly design in that non-professionals can easily interpret all, presents a problem on current systems (Zulkifli *et al*., 2022). Additionally, sensor technology for some key water quality indicators that are missing, including nitrates and chlorophyll, requires further research (Singh & Walingo, 2024).

User centered design has become increasingly important due to water quality testing devices that need to be understandable and accessible by non-specialist users, i.e., simple interfaces or mobile applications that present clear actionable data (Jan *et al*., 2021). This is important as this makes scientific accuracy available and practical for widespread use by communities so vulnerable in regard to water quality issues (Zulkifli *et al*., 2022).

2.2 Importance of Water Quality Monitoring (WQM)

The assessment of water quality is essential in management and protection of the environment; human welfare and sustainable economic development. It provides the data which is necessary to determine the current situation with water resources, evaluate the effectiveness of measures to control water pollution, and confirm the compliance with existing environmental standards. The integration of global and regional approaches, new technologies, and system approach of managing these programs indicates the sensitivity and significance of monitoring programs.

2.2.1 Global Perspectives and Technological Advances

Contemporary water quality assessment makes use of the most advanced tools including the automated sensors, satellite images, and biological monitoring instrumentation. These technologies enhance the efficiency and time means of data administrations leading to better water resource management. In addition, (Altenburger et al., 2019) stressed that it is high time to shift the concern from legacy chemicals back to realistic pollutant mixtures, stressing that monitoring strategies reflecting multiple contamination scenarios are needed to protect ecosystems.

2.2.2 Local Challenges and Case Studies

The assessment of water quality in Nigeria has numerous challenges from pollution sources, these include: Industrial waste, agricultural drainage, and poor waste disposal system. According to (Ighalo & Adeniyi, 2020) highlighted these difficulties clearly and insisted that effective monitoring plays a key role in addressing the impact of pollution on the wellbeing of humans and the environment in Nigeria. Based on this case study, it is now clear that while engaging in global water quality assessment, it is necessary to take into account regional strategies (Ighalo & Adeniyi, 2020).

2.2.3 Integrating Local Knowledge and Stakeholder Involvement

To support water quality monitoring, knowledge at the local level and the participation of stakeholders is needed. Participatory approaches were described by (Behmel et al., 2016), which makes it possible to develop scientifically credible monitoring initiatives that are acceptable to local inhabitants and backed by them. These approaches introduce strategies of addressing the needs and conditions of each place and thus enhance the efficiency and durability of the monitoring processes (Behmel et al., 2016).

2.2.4 Future Directions and Policy Implications

Since the nature of water pollutants is constantly changing, with the continuous development in the monitoring technologies, it is important that adaptive management becomes dynamic and respond in news ways. Policymakers should, finally, use resultant data from the monitoring programs in implementing and enforcing regulations to protect water resources and ensure good public health. Data results need to provide a basis for evidence-based decision-making for sustainable water resources.

Water quality monitoring, in fact, deals with environmental and public health infrastructure. In fact, this forms the missing link between pure scientific study and actual implementation of policy whereby water resources are protected and managed in a sustainable way. Research carried out worldwide, together with concrete case studies such as that of Nigeria, underlines both the importance and complexity related to water quality monitoring.

2.3 Key Water Quality Parameters

Essential water characteristics like pH, TDS and Turbidity are important pointers to the qualities of water for its usefulness in different sectors like flood supply, irrigation, and industrial uses. It is important to track all these indicators in order to both improve water safety and to use them in managing environmental impacts.

2.3.1 pH

The pH value represents the most meaningful indicator of the acidity or alkalinity of water and, therefore, of the solubility and biological availability of chemical compounds in it. Water with either high or low values of pH is harmful for aquatic organisms and may reduce the usability of water for drinking and irrigation. The pH level of water must, therefore, be within a range that keeps the water safe for whatever purpose it is to be used for. Research pointed out the monitoring of pH levels owing to their use in directly affecting aquatic chemistry and biotic processes (Kothari et al., 2021).

2.3.2 Total Dissolved Solids (TDS)

TDS is the total constituent contained in a liquid solution at molecular, ionized or simply micro granulated form in suspension in water. In any case, the less TDS level the better water that thus will be more suitable for all possible uses. Water having a high TDS is likely to have an unpleasant taste and health wise it has impacts both to living water organisms and water suitable for industrial uses. TDS is indispensable for evaluation of water quality and identification of its suitability for drinking, irrigation and industrial purposes (Chen et al., 2020)

2.3.3 Turbidity

Water turbidity is fogginess in water due to a very large number of very small particles which are not discernible by the human naked eye, somewhat similar to fog in the atmosphere. High levels of turbidity have impacts on the organisms in water by limiting their food presence, degrading habitats and adjusting predator/prey ratios. It also impacts human use of water because the water with lower transmission can allow only limited uses such as drinking, cooking and bath. Turbidity control and its measurement is crucial in water treatment processes as well as in maintaining the health of the aquatic systems (Uddin et al., 2021)

2.3.4 Nitrate (NO3)

Of all the pollutants, the amount of nitrates in water is most troubling, mainly in areas where farmers use fertilizer abundantly. Nitrate toxicity leads to eutrophication whereby large numbers of algae and aquatic plants develop at the water body's expenses, using up oxygen consequently causing the death of many animals and decrease in species richness. Conducting nitrate monitoring is relevant to manage water quality caused by the impact of agricultural produce to also address eutrophication of water bodies (Kothari et al., 2021).

2.4 Embedded Systems in Water Quality Monitoring

The use of sensors, microcontrollers, connectivity of an embedded system gives a better way of monitoring water quality. Most of the data collection and analysis tasks are carried out in real time by these systems, an essential aspect in managing water resources for enhanced sustainability of this resource and compliance with environmental requirements.

2.4.1 IoT and water quality monitoring

However, relying solely on IoT to collect data about water quality and quantity using networked sensors, fixed across different types of water bodies or water sources, on a real time basis has indeed made a revolutionary change in WQM so far done. (Jerom et al., 2020) has suggested an IoT model incorporating the packet switch technology for smart water quality monitoring system using the facility of cloud computing for gathering data and analysis of the quality of water in continuous manner. This system employs a NodeMCU microcontroller that has Wi-Fi module, to Read data captured by various sensors and transmit it to the cloud for analysis using DL algorithms. This method reduces the time and effort required for the collection of water samples as well as laboratory analysis retailing near real-time information on changes in water quality (Jerom et al., 2020).

2.5 Portable Water Quality Testing Devices

Portable water quality testers represent one of the biggest breakthroughs in environmental sciences because fast on-site assessment of water quality becomes possible, especially in faraway and resource-poor settings when conventional access to a laboratory is impossible. For instance, the application of metagenomic tool enhances the fast sorting of the lots of the microbiological contaminant from the source of water. The technique helps to identify waterborne hazards such as those of pollution indicator origins much earlier and several folds faster than the conventional laboratory tests according to (Acharya et al., 2020)

However, most of these devices offers challenges such as power supply, availability of internet for processing of data, and handling of complicated equipment in the field. Furthermore, consumables costs and set up are likely to be rather pricey for frequent application in the context of developing countries. The future trends of portable water quality monitoring systems are that the devices should be smaller with higher reliability at a lower cost for generic use (Acharya et al., 2020).

2.6 IoT and User Interfaces for Monitoring System

Combination of IoT technologies with the user interface reveals an absolutely different perspective on how the environmental data should in the monitoring systems of water quality. It shows live capturing, processing, and broadcasting of information concerning water quality, which enhances the probability of an early response to shifts in the conditions of the environment. Through IoT, different sensors that determine important water characteristics including pH, turbidity, and temperature can be integrated with ease. The data thus collected can be sent over wireless connections to central servers or to the cloud, making continuous monitoring possible without the need for sampling. These give the consumer sophisticated user interfaces to this data such as dashboards that displays data on operations in real time and analysis tools. However, it is still critical to highlight the following obstacles in order to optimise these systems: data protection, privacy, and handling big data. In the next phase, AI and machine learning could bring better predictions and alert mechanisms to the data collected, according to (Pasika & Gandla, 2020).

2.7 Hardware Requirements

The following are the major components used in the development of a handheld drinking water quality tester:

- ESP32 Microcontroller

- Water pH Sensor
- Total Dissolved Solids (TDS) Sensor
- Waterproof Temperature Sensor
- Turbidity Sensor
- Liquid Crystal Display (LCD)

2.7.1 ESP32 Microcontroller

The ESP32 is a microcontroller with integrated Bluetooth and Wi-Fi functions that is enabled on a low-power scale. It finds the best application in IoT as the system also features a dual-core processor with a range of peripherals like, but not limited to, ADC, DAC, PWM, and UART that allows smooth interaction with sensors and other actuators as shown in Figure 2.1. ESP32 is a high-performance, low-power processor designed for portable applications, such as the handheld water quality tester. It also allows wireless connectivity where the device is able to integrate with the use of mobile applications for real-time monitoring and viewing.

Figure 2.1: ESP32 Microcontroller

2.7.2 Water pH Sensor

This is a device whose sensitivity is capable of measuring hydrogen ions in water in order to determine water pH. This sensor is important for monitoring water quality since pH is one of the most important factors that define the suitability of water for consumption and the wide range of other applications. In most cases, the sensor includes a glass electrode and a reference electrode, which generate a current depending on the pH of water sample as shown in Figure 2.2. The sensor is mountable on microcontrollers, for example ESP32, and provides accurate and real-time measurement for various environmental parameters.

Figure 2.2: Water pH Sensor

2.7.3 Total Dissolved Solids (TDS) Sensor

The TDS sensor is utilized to measure the total dissolved solids which are inorganics or organics in the water, including salts, minerals and metals. This particular parameter is of great importance and can be used to estimate the quality of water, including suitability for consumption. How TDS sensor works is that when the water sample is passed through it; the same gives the electrical conductivity value which is then converted into the TDS value. Due to its small size and compatibility for use with microcontrollers, it is used for incorporation into portable water quality testing gadgets as shown in Figure 2.3.

Figure 2.3: TDS Sensor

2.7.4 Waterproof Temperature Sensor

When it comes to measuring the temperature of the water a waterproof temperature sensor like the DS18B20 is very accurate as shown in Figure 2.4. This sensor is water proof; thus it can work excellently under water conditions and it is very relevant in water quality measurement. In other words, this sensor operates in such a manner that it converts the temperature variables in to electrical signals that the microcontroller can easily analyze. Some of the testing we have to make in the water with regard to the temperature include the pH level and the dissolved oxygen.

Figure 2.4: Waterproof Temperature Sensor

2.7.5 Turbidity Sensor

A turbidity sensor works by defining how much light passes through a given amount of water or how much of the light that is passed through by particles in water as shown in Figure 2.5. This metric is important because some of the particles, often bacteria, or sediments that result in high turbidity are pathogens or interfere with water treatment processes. Nephelometry works by creating light then measure the light scattered at a certain angle; the results are normally expressed in Nephelometric Turbidity Units (NTU). The integration of turbidity sensor is therefore crucial in case of portable water quality testers, especially in the current world cases to be used in determination of water safety and viable treatment type in the given location as well as in different water quality determination cases.

Figure 2.5: Turbidity Sensor

2.7.6 Liquid Crystal Display (LCD)

The LCD is incorporated as the interface and can be used to show the current water quality analysis. Usually, a 16x2 or a 20x4 character LCD is used for such applications because of its uncomplicated structure and relatively low price as shown in Figure 2.6. The LCD is used to show the values of the measured parameters like; pH, TDS, temperature and turbidity to make sure that the instrument does not require a technical user to operate it. The module has low power consumption, and capability to interoperate with ESP32, making it good for portable electronics.

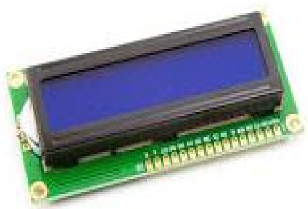

Figure 2.6: Liquid Crystal Display

2.8 Literature Review of Related Works

(Comina *et al*., 2010) in their paper "Development of a Portable Water Quality Analyzer discussed one of the main problems related to the monitoring of water quality using a portable device equipped with a voltammetric electronic tongue. Their aim in the research was developing a water quality analyzer which is an inexpensive, portable and efficient device to distinguish water contaminated with Escherichia coli, one of primary indicators of water quality and public concern. Their method involved building a device that combines an electrochemical cell and a multi electrode setup, a computer controlled potentiostat, and software that incorporates multivariable data analysis in order to pattern recognize. Results showed that the portable analyzer was able to distinguish between a set of controlled lab prepared water samples and real river water samples, at varying levels of E. coli contamination. This capacity for rapid in situ, on site water quality assessment is particularly relevant for areas without access to laboratory facilities. This study is relevant to my project because it shows an innovative way to portable water testing devices, which is the direction my project is headed to; to develop a robust, user friendly, and cost-effective water quality testing solution. But the paper also details the shortcomings, such as the difficulties using sensor array in field conditions through durability and long-term stability.

(Calvert *et al*., 2016) have presented a portable water filtration system that solves two major problems: unsafe drinking water in developing nations and the tedium of carrying water in activities involving hiking or any outdoor events. The authors identified that most filtration systems were not very effective and were cumbersome, heavy with low capacity. The research effort was, therefore, directed to develop a low-weight, self-contained filtration system that would have superior efficacy in removing impurities. The carbon element filter, ultraviolet light, and hollow membrane tube filter were to be combined into one compact unit, where most of the constituent parts were prototyped by the use of 3D printing. The filters attained high filtration efficiency and lay within the EPA standards, although there were challenges like clogging and power sources. This article relates to my project in the perspective of portability and practicality in the design of water filtration. It is a good paper, but it fails to incorporate real-time monitoring technologies.

(Meride & Ayenew, 2016) carried out an assessment on the quality of drinking water at Wondo Genet Campus in Ethiopia on Health Implication of Poor Water Quality. Issues in the study included statement was that water management systems needed information-based solutions. The goal was to analyze the major indices including turbidity, pH and TDS comparing to World

Health Organization standards. The laboratory assessment showed that all ratios were within the permissible range informing about the safety of the water to be consumed. This paper is related to my study in the way that it covers field specific water analysis and compliance to the global standards. However, it does not look for solutions in real-time or portable, which are an important necessity.

(Tsitsifli & Kanakoudis, 2017) reviewed the tools and measures used in monitoring and assessing the safety of drinking water with special reference to risk management and warning systems. The problem statement focused on dangers such as contamination, natural disasters, and operational failures in water distribution systems. The objective was to assess current monitoring, modeling and optimization technologies for efficient water quality management. The research also involved a Literature review of the technological advances including the sensors and cleaning processes. The results displayed here emphasized the necessity of prolonged, real-time control systems to combat contamination issues effectively. The contributions of this paper to my project are as follows: It provides information on real-time monitoring technology and risk management systems. But it did not include realistic examples and efforts to verify the offered tools.

(Putri *et al*., 2019) sought to address some of the limitations accompanying conventional water quality monitoring using conventional techniques that are tiresome and susceptible to human error. The project aimed to develop an IoT-based system to automate monitoring operations for metrics like as pH, conductivity, and TDS. The methodology included collecting data with Raspberry Pi and YSI sensors and transmitting it to a cloud server via MQTT protocol for real-time analysis. The work showed that users were able to attain real-time information quickly and efficiently; however, some systems including the sensors used were not standardized and some of the systems relied heavily on the networks. This paper is relevant to my project because it integrated IoT technologies with water quality monitoring. However, it focused on fixed installations instead of portable alternatives.

(Duressa *et al.,* 2019) evaluated drinking water qualities from the source to residential tap connections in Nekemte, Ethiopia. The problem is indirectly derived from the high frequency of waterborne diseases that are linked to the poor quality and management of water, coupled with degrading infrastructure in distribution. Authors included the intention to assess bacteriological and physicochemical criteria as a basis to determine the safety of the water. Water samples taken at various locations in each category were obtained using a cross-sectional study design and were analyzed for parameters including pH, turbidity, total coliforms, and E. coli contamination. The study showed significant contamination, especially at household connections, due to poor storage and distribution practices. The study emphasizes that regular monitoring and more sophisticated systems in water management are critical to ensuring the safety of public health. Despite this, its shortcoming is the omission of advanced microbiological and chemical studies, which might provide a more comprehensive picture of pollution sources.

(Bojja *et al*., 2019) designed a mobile platform to address the same challenges by developing a portable drinking water quality assessment apparatus to supply safe water in rural Indian regions especially in the Guntur District of Andhra Pradesh. This paper majorly targeted on water pollution which has negative impacts on population health due to pollution with chemicals like fluoride, arsenic, microorganisms among others. The goals of this project were to develop the low-cost system able to detect up to 14 water quality parameters simultaneously like pH, turbidity and residual chlorine and use IoT connectivity for updating the system continuously. To explain the process more details, wires were fixed to sensors with a data collecting system, IoT modules, and a cloud database. Field demonstrations were conducted to demonstrate that the system can sense the water quality and alert the relevant authorities. This is very similar to my concept in the sense that it shows a small multiple parameter system for rural use. Nevertheless, there are some issues, such as relatively high costs of some sensors at the start or the total dependence on the availability of the internet connection.

(Pasika & Gandla, 2020) conducted a study on the Smart Water Quality Monitoring System with Cost-Effective Using IoT in relation to the increasing need for real-time monitoring of drinking water quality in view of increased pollution, urbanization, and limited water resources. Traditional methods of water quality testing involve manual sampling and laboratory analysis—one is so time-consuming and costly; hence, too impractical to be applied in real-time monitoring or widespread deployment in developing countries. In this line, the authors aimed to come up with a low-cost system using Internet of Things technology, which could measure critical water quality indicators such as pH, turbidity, water level, and temperature/humidity, displaying the results in real time through cloud-based platforms. They implemented the microcontroller Arduino Mega with the IoT module ESP8266 NodeMCU and several sensors to collect and send this information to the ThingSpeak server so that this information could be accessed anytime, from anywhere, with either a mobile-based or web-based platform. The system was tested and proved to be efficient in its conditions: pH ranges were between 6.5 and 7.5 for urban water supplies and between 7 and 8.5 for ground water, with turbidity ranging between 600 and 2000 NTU. These results would indicate updates every 20 seconds, hence proving the effectiveness of real-time monitoring. This article is quite important for this project because it discussed the integration between IoT and sensor technologies for portable water-quality monitoring and has underlined the importance of user-friendly interfaces for practical application. However, some of the shortfalls in the approach included the unavailability of important parameters such as dissolved oxygen and electrical conductivity. Also, this is dependent on internet availability, which may limit its usage at remote sites.

On a similar note, (Jagaba *et al*., 2020) consider the water quality in hand-dug wells at Rafin Zurfi, Nigeria, based on apprehensions over the incidence of waterborne infections within the area. Results indicated that pollution from both human and natural sources is the major cause of deterioration in the quality of water. The researchers resorted to Geographic Information Systems and methodologies such as the Water Quality Index and Hazard Index in assessing the physicochemical and bacteriological data. While most of the samples tested within the limits allowed, there was certain risk from contamination by heavy metals. The study has emphatically recorded the need for regular water quality monitoring for assurance of public safety. This study is very important to my project because it stressed the need for geographical mapping and hazard analysis in comprehensive water quality assessment. But it is limited to the heavy metals focus, not including any kind of TDS and pH parameters that are integrated in real-time devices.

(Acharya *et al.*, 2020) investigated the feasibility of a portable metagenomic toolset for deep water quality monitoring. This study tried to apply NGS at the site to get around certain existing problems, which included delays in results and sample degradation while transporting them to centralized laboratories. Linked to this UK and Ethiopian-tested toolkit with laboratory equipment consisting of a MinION device, it was able to characterize water microbiomes within 24-72 hours. Indeed, it was able to detect Arcobacter and Aeromonas, among other non-traditional microbial indicators. The essence is that this study showcased highly developed portable technology for real-time analysis of water quality in the field, filling up the microbiological diagnostic gap. The limitations included a high initial cost, and dependency on the internet for processing data, hence it is not available in resource-limited areas.

It has been seen that Xu *et al.* (2020) developed a smartphone-integrated electrochemical system that was capable of detecting and mapping nitrite contamination in water. Considering growing demands for real-time and user-friendly monitoring devices, a handheld nitrite detector has been developed which is connected to a smartphone via Bluetooth. This technique has achieved high sensitivity using a screen-printed carbon electrode containing nanomaterials-a detection limit of 0.2 μM for nitrite. The nitrite levels were mapped over Hainan Province to show its real-world application. This new solution is in line with the objectives of my project by showing the use of smartphones for the improvement of portability and usability. Still, its system is limited to nitrite detection and needs stable internet connections for cloud integration, which may not be achievable under all circumstances.

(Alave *et al.*, 2020) introduced the Arduino-based friendly water quality analyzer that solved the problems of delayed measurement of water quality and shortage of available portable equipment. The problem arose from the high morbidity rates caused by water-related diseases, as well as the inefficiency of traditional lab-based diagnostic procedures. The research was carried out with the intention of testing certain key parameters of pH, turbidity, temperature, and TDS on-site, done through a portable device integrated with a GSM module for results transmission to relevant experts and institutions. Such a gadget, after thorough validation in comparison to equipment used in the laboratory, achieved an accuracy of ±5%. The work presented here relates importantly to my project by proof of the possibility and applicability of low-cost, user-friendly technology for real-time control. However, further dependence on the GSM restricts it to areas with minimal network coverage.

The Portable Water Quality Monitoring System Using Apps carried out by (Hussin, 2020) addressed the ineffective outputs of conventional water monitoring systems. The matter was focused on the problems related to aquaculture in Malaysia at which manual control of pH, turbidity and temperature contained low accuracy. The aim was to create a simple and usable smartphone compatible device that interfaced with Arduino Mega and NodeMCU to acquire data in real time. In the current study, Firebase and Kodular Creator were used to capturing data into Google Spreadsheets and also app-based notifications. Field experiments confirmed its suitability for application in aquaculture. This attempt is helpful to my project in extending how smartphone integration and ease of use is covered. However, its applicability is somewhat restricted to certain application such as aquaculture, but will not extend to general water quality monitoring.

(Jan *et al.*, 2021) conducted a systematic review on IoT-based smart water quality monitoring systems for home use, identifying certain challenges represented by the slow speed of a standard water test conducted in the laboratory and quite expensive commercial tools. It was done to show performance in how IoT technologies can analyze water quality in real-time and the various advantages and limitations that such systems would have. This paper reported an assessment of WQM parameters and also the installation technique of IoT-WQMS. The results here showed that the use of IoT can enable higher accessibility, efficiency, and cost-effectiveness. It is really useful for my work because this research covers IoT incorporation information and also sensor solutions for portable systems. However, there was no case study example, no prototype field implementation, and no specifics to examine in equivalent detail.

(Gowda *et al*., 2022) presented a portable pathogen detection device to meet the urgent need for rapid on-site water quality testing, particularly in developing countries. In this study, the researchers developed the droplet digital LAMP DNA amplification microfluidic platform to address the challenge with the currently developed pathogen testing methods, which required large settings of a laboratory and take long periods of time for processing. It detects these germs-Enterococcus faecalis-with least human intervention, hence making the technology possible to run detection in an hour. The sensitivity was good, and so was the dependability; the device was highly mobile to perform its functions even in field conditions at remote sites. This study extends my project in developing compact and user-friendly diagnostic systems. However, its dependency on power and narrow focus on microbiological investigation limit its applicability in broader water quality assessments.

(Akinbomi & Odika, 2022), in their view about the impact of poor groundwater quality in Nigeria, people had no better option than to use untreated borehole /well, thus, risking their health. This need arose from a study acknowledging the lack of adequate, affordable solutions as one of the main challenges, and the proposed solution is developing and evaluating a household water treatment device. Specification involved monitoring of water samples from three different sites using the device, factors like aeration, back washing and retention time were measured. Studies depicted slight changes towards the general improvement of water quality but no significant difference was observed. This study is closely related to my work since as it seeks to provide localized water treatment on the fly but fails to offer real-time monitoring or multiple parameter analysis.

(Tian *et al*., 2023) discussed the limitations of standard TDS sensors for detecting organic matter in water. The project sought to create a small detection equipment that combined laser spectroscopy for organic matter analysis with conductivity for inorganic matter. The process entailed creating a device that measures factors such as the permanganate index and TDS and returns real-time findings via an integrated display. The results proved the device's great sensitivity and practicality, making it appropriate for household and small-scale use. This study is important to my topic since it incorporates revolutionary sensor technology and focuses on compact design. However, it is limited in its parameter breadth and application to larger field setups.

Table 2.1 shows a summary of all works reviewed. It contains the author's name, journal title, and the strengths and limitations of each work.

2.9 Summary Table

Table 2.1: Meta Table

S/N	Author	Title	Strength	Limitation
1	Pasika & Gandla (2020)	Smart Water Quality Monitoring System with Cost-Effective Using IoT	Real-time monitoring of pH, turbidity and temperature using the IoT.	Lacking basic parameters, providing room to interface advanced features such as TDS.
2	Duressa *et al.*, (2019)	Assessment of Bacteriological and Physicochemical Quality of Drinking Water in Nekemte	The evaluation of the possible sources of contamination and the field investigation.	No use of real-time portable systems, creating scope for the proposed portable device development.
3	Gowda *et al.*, (2022)	Development of a Microfluidic Portable Pathogen Analysis System	Bacterial detection of high sensitivity and portability during field conditions.	Exclusively designed for microbial search, unlike the Multi-Parameter Monitoring system.
4	Acharya *et al.*, (2020)	Metagenomic Water Quality Monitoring with a Portable Laboratory	Detailed description of all the microbes present in a given population by intensive sequencing.	Expenses related to products are high, this is in accord with objective of proposed aim with respect to product affordability.
5	Bojja *et al.*, (2019)	Portable Drinking Water Quality Measurement	Compact system monitoring multiple	High cost of sensors is relative and shows that affordable

S/N	Author	Title	Strength	Limitation
		System for Smart Villages	parameters with IoT integration.	solutions like this proposed work would be welcome.
6	Alave *et al*., (2020)	Portable Arduino-Based Integrated Water Quality Analyzer	Real-time GSM-based data transmission; multi-parameter testing.	GSM dependency offers a chance to explore universal connectivity solutions in this proposed work.
7	Hussin *et al*., (2019)	Portable Water Quality Monitoring System Using Apps	Integration with the smartphone and Real time monitoring via application software.	Specialized designs related to aquaculture, implying possibility for further use in developing for drinking water.
8	Jan *et al*., (2021)	IoT-Based Smart Water Quality Monitoring for Domestic Applications	Comprehensive review of IoT applications for real-time analysis.	Lack of prototypes.
9	Calvert *et al*., (2016)	Design and Development of a Portable Water Filtration System	Lightweight and compact with high level of filtration.	Does not monitor it in real time which is what is proposed in this work to implement with sensors for feedback.
10	Akinbomi *et al*., (2022)	Effectiveness of Household Water Treatment Device for portable water	Simple and localized water treatment for domestic use.	Highlights the gap for real-time, multi-parameter portable devices.
11	Tsitsifli & Kanakoudis (2017)	Drinking Water Quality and Safety Assessment – A Review	A thorough review of the reliability and performance of risk management tools and	This theoretical focus reflects a need for practical, field ready solutions.

S/N	Author	Title	Strength	Limitation
			monitoring systems.	
12	Meride & Ayenew (2016)	Drinking Water Quality Assessment in Wondo Genet Campus	Field-based analysis of key physicochemical parameters.	Absence of portable systems validates the significance of proposed portable device approach.
13	Tian *et al*., (2023)	Small-Scale Detection Instrument Using Laser Spectroscopy	High sensitivity and compact design for dual-parameter detection.	Focused on specific parameters, which opens scope for multi-functional devices.
14	Putri *et al*., (2019)	Development of IoT for Automated Water Quality Monitoring	Effective real-time IoT system for remote monitoring.	Dependency on networks and sensor limitations highlights the value of robustness in the proposed work.
15	Xu *et al*., (2020)	Cost-Effective, Wireless, and Portable Smartphone-Based Electrochemical System for On-Site Monitoring and Spatial Mapping of Nitrite Contamination in Water	Real time nitrite detection and mapping up the effective integration of smartphone technology.	Limited to nitrite detection; dependent on internet connectivity for data mapping.
16	Comina *et al*., (2010)	Development of a Portable Water Quality Analyzer	Developed a portable, efficient water quality analyzer using a voltammetric	Issues relating to sensor durability and long term stability in the field condition.

S/N	Author	Title	Strength	Limitation
			electronic tongue.	
17	Jagaba *et al*. (2020)	Water Quality Hazard Assessment for Hand-Dug Wells in Rafin Zurfi, Bauchi State, Nigeria	Hand dug wells' water quality assessment and exploration of pollution sources.	Do not include additional water quality parameters, but are heavily focused on heavy metals.

CHAPTER THREE

DESIGN AND IMPLEMENTATION

3.1 Introduction

This chapter presents the plan for developing the handheld drinking water quality tester. The methodology consists of three main components: The main activities involved are sensor integration, interface design, and system evaluation. Schematic diagrams, flowcharts and formats of circuits are produced in the process of development. The integration of sensors with the application, assembly of the device, and performance assessments are all provided. These procedures are essential to address the goal of the project toward having a portable equipment with high accuracy in measuring water quality parameters such as pH, turbidity and temperature.

3.2 Development of Sensor Integration for Water Quality Measurement

While working on the development of the sensor integration for the handheld drinking water quality tester, more attention was paid while configuring and linking the sensors to ESP32 microcontroller. The device employs a series of sensors, each chosen for its role in accurately monitoring specific water quality parameters: pH sensor; a turbidity sensor; a temperature sensor; and TDS (Total Dissolved Solids) sensor.

Due to its high performance and flexibility, ESP32 microcontroller controls all the sensors through dedicated GPIO pins to enable high accuracy during its data acquisition and as illustrated in figure 3.1. The pH sensor is interfaced with the ESP32 using an analog pin 39, this pin was selected due to its data resolution going to the ESP32 and important since it will be capturing small changes in the water acidity level. The turbidity sensor which observes the transparency of the water sample is connected to the analog pin 36. This connection is essential to acquire accurate turbidity measures that may give clues towards particulates in the water system.

The temperature sensor is connected with the digital pin number 27 of the ESP32, which can process and incorporate data quickly. The TDS sensor is a probe that measures the total dissolved solids which in turn interface with the water it connects to analog pin 34. Such setup is best suited for assessing the level of water purity going to the systems in question.

These connections do not only allow for smooth data capture but also for proper and efficient processing of data per sensor to the ESP32. The development of these sensors in a single portable unit allows accessing the most essential water quality parameters at a time – establishing an accurate real-time assessment of water quality. Through the documentation of how each of the sensor is linked and the manner of mounting, this section further highlights the amount of care taken in order to come up with portable, accurate and easy to use water quality test equipment.

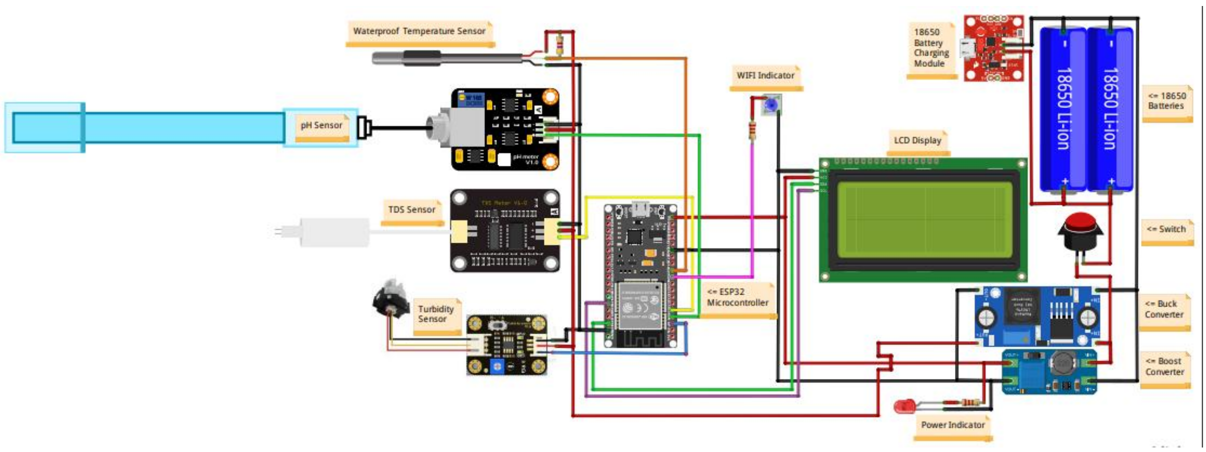

Figure 3.1: Development of Sensor Integration

3.3 Hardware Design

This section describes the technical aspect of the components used in the construction of the handheld drinking water quality tester, their operation in the system, and how they have been incorporated into the system.

3.3.1 Power Management

The system is powered by a 3.7V 5000mAh lithium-ion battery which should be adequate for long duration duties in the field. A voltage regulator ensures a stable 3.3V supply to the microcontroller and sensors, because stability helps avoid performance and data inconsistency caused by instabilities in the supply voltage.

3.3.2 Microcontroller (ESP32)

At the core of the device is the ESP32 microcontroller that was chosen as it has two cores for processing and a multitude of inputs and outputs, which are vital for data acquisition from different sensors and modular connections for various communication protocols. Since it has a logic level of 3.3 V the esp32 does not require additional components for voltage division when interfacing with the chosen sensors. The dual nature of connecting devices with both WiFi and Bluetooth helps to transfer data to BLYNK mobile application for monitoring and controlling the process remotely.

3.3.3 pH Sensor

The pH sensor is interfaced with ESP32 through analog port 39. It determines the level of hydrogen-ion concentration in water so as to give a precise determination of water acidity or alkalinity. This sensor is of paramount importance for water quality determination, especially in a situation when acidity or alkalinity is critical from the ecological or health point of view.

3.3.4 Turbidity Sensor

The turbidity sensor is connected to the analog pin 36 of ESP32, it determines degrees of light transmitted through water and the degree of scattering that occurs due to particles in water. Turbidity has often been used as the measure of water quality especially in determining its fitness for various uses such as domestic, industrial and, ecological uses.

3.3.5 Temperature Sensor

The temperature sensor is interfaced with the digital pin 27 of ESP32 which measures the temperature of water. Temperature data is required for correct water quality measurements with different conditions.

3.3.6 TDS Sensor

This sensor is connected to the A34-pin, this measures the TDS – total dissolved substances in water, organic and inorganic matter included. The TDS levels are perfectly appropriate for evaluating water quality, when it can be used for some purposes like drinking water or for watering crops.

3.3.7 Display and Interface

Data output is displayed in an LCD interfaced through I2C protocol by connections of GPIO21 (SDA) and GPIO22 (SCL) on the ESP32 board. It also allows for an easy interaction with the application as well as rapid updates of data as maybe required in field uses. By combining the display and sensors, the design of the device is neat, compact and portable which improves the use of the device in various environmental contexts.

3.4 Enhancing Data Accessibility through Interface Solutions

This section explains interface solutions used to improve usability of water quality data we implemented an LCD screen on the device and a mobile application developed with 'BLYNK.' These interfaces are planned in a manner that these are easily comprehensible for the user regardless of the technical knowledge of the person.

3.4.1 LCD Display Integration

The incorporation of 20x4 character LCD display is core to delivering integrated on-site water quality readings right from the device. This display which interfaces via I2S through GPIO of the esp32 board using 21 (SDA) and 22(SCL) pins provides a clear way of displaying essential parameters including pH, turbidity, temperature, TDS among other systems in the system. This protocol was selected to conserve the GPIO space because it helps in achieving our desired structure while also increasing the letters' fluidity on the display.

3.4.2 Mobile Application Development (BLYNK)

From the perspective of this project, using BLYNK to create a mobile application expands the device's functionality to allow users get and communicate with the data. The ESP32 is connected to Wi-Fi by the application, allowing users to observe current and previous sensor data on a live dashboard. It is user friendly and there is no complicated interface because all the graph and all the alert data are presented in a visually appealing manner. This makes it possible for the users to be notified depending on pre-set data values hence being useful in monitoring water quality.

In combined manner, the LCD display and the BLYNK application offer an effective interface framework through which usability with the water quality tester is enhanced. In addition to this, this system not only makes it easy to interpret difficult data but also makes the complicated water quality monitoring as easy as possible for users.

3.5 System Flowchart

The system flow chart depicted in figure 3.2 shows the sequential operating mode of the handheld drinking water quality tester ranging from powering on the device to powering off. At the start, the system first gets initialized and every necessary hardware device gets ready for data acquisition. After initialization, the power application tries to turn on Wi-Fi connectivity in the device undergoing testing. If the connectivity is established then the Wi-Fi indicator starts blinking and then the system starts to initialize and connect with the BLYNK server that help to manage and provide an interface for the data collected remotely. Whether there is connection to the internet or not, the system moves to retrieve parameters from sensors that gauge the level of pH, TDS, temperature and turbidity. All these measurements are shown on the LCD screen, so the readings are available instantly. When connected to Wi-Fi, data from sensors is transmitted to the BLYNK server for remote control and monitoring through both applications for mobile and for Web. Where there is no Internet connection, or Wi-Fi, the system still operates and only shows the results on the LCD. The above process is iterant, until the user decides to halt the system by pausing the operation.

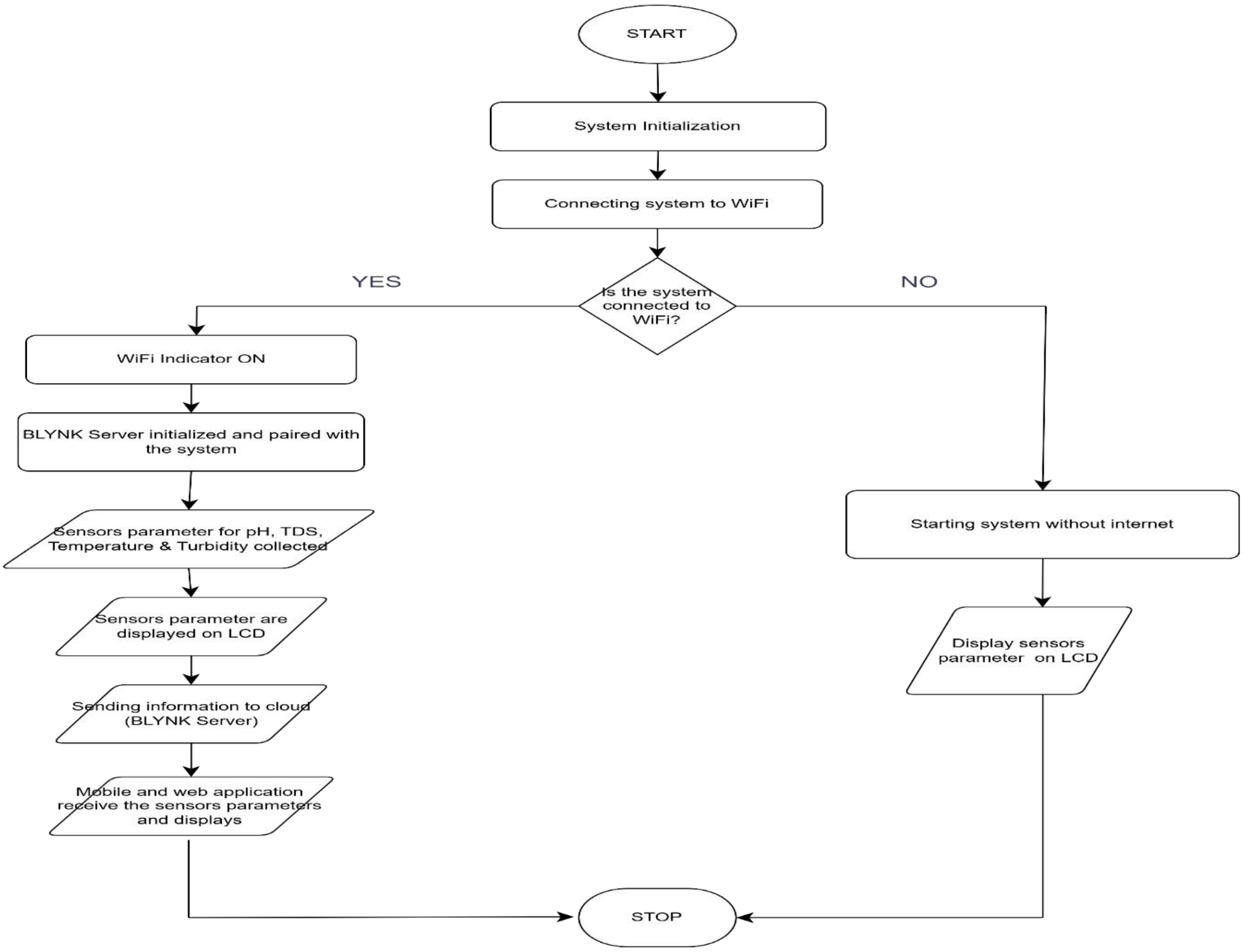

Figure 3.2: System Flowchart

3.6 Circuit Description

The circuit diagram, discussed in figure 3.1 below, shows the connection of all the parts used in the construction of the handheld drinking water quality tester. The heart of the device's design is the ESP32 microcontroller, which takes on the role of the main processor. The ESP32 uses a 3.3V logic voltage, and therefore it interfaces well with the different sensors and modules connected to it. These sensors consist of pH Sensor, Turbidity Sensor, TDS Sensor, and Waterproof Temperature Sensor which are all important for the measurement of qualitative characteristics of water. All the sensors are powered at 3.3V- 5V to avoid any kind of short circuit and to work more effectively.

The device has a power supply in a form of an array of eight 18650 lithium-ion batteries connected in parallel for stable and long-ranging power supply. This charging module is integrated within the system; and is convenient in the recharging of batteries to advance the portability within the field use. In order to help control the power supply properly, the circuit provides for the use of the buck converter and a boost converter that switches the voltage between the levels proper for the components of the system.

The collected data from the sensors are interfaced directly to a 20 x 4 LCD, which is controlled using an I2C module with easy circuit design but with better display quality of the characters. This setup not only gives instant feedback on the water condition but also has features like connection which shows that it is connected to the Wi-Fi network, and power light which indicates whether the unit is on or off. The switches that are used are simply switch buttons that ensure that the users can gain control over the system in order to operate it whenever they want without having to depend on any other person to assist them to do that. The system also has a button that will enable the user to control the single functions of the switch in different environments.

3.6.1 Circuit Design Calculation

This section includes actual calculations for the specific handheld drinking water quality tester involving experimental characteristics and actual design in the detailed project documentation.

Power Supply and Management: The system is powered by a series of 18650 lithium-ion batteries configured in parallel to enhance capacity without altering the voltage. Each battery typically provides 3.7 volts and, when used in parallel, the voltage remains constant, but the capacity (amp-hour rating) is the sum of all batteries in the array.

- **Total Voltage**: Remains at 3.7V as batteries are in parallel.

- **Total Capacity Calculation**: If each battery has a capacity of 3000 mAh, and eight batteries are used:
    - Total capacity = 3000 mAh * 2 = 6000 mAh (or 6 Ah).
    - Total available energy = 3.7V * 6 Ah = 22.2 Wh.

Voltage Regulation for Device Components: The ESP32 and other sensors operate at 3.3V. A voltage regulator steps down the battery's 3.7V to a stable 3.3V required by the circuit.

- **Current Requirement**: Assuming a combined current draw for all sensors and the ESP32 is about 500 mA:
    - Required power = 3.3V * 0.5 A = 1.65W.

Sensor Power Calculations: Each sensor's power requirements need to be calculated to ensure the power supply adequately supports them without leading to voltage drops or power shortages.

1. **Turbidity Sensor**:
    - Typical operating voltage: 5V (via a step-up regulator or separate voltage line)
    - Current draw: 40 mA
    - Power consumption = 5V * 0.04 A = 0.2W
2. **pH Sensor**:
    - Operating Voltage: Typically 3.3V
    - Current Draw: Around 10 mA (typical for common pH sensor modules)
    - Power Consumption:
    - Power = Voltage * Current = 3.3V * 0.01A = 0.033W
3. **Temperature Sensor**:
    - Operating voltage: 3.3V
    - Current draw: 1.5 mA
    - Power consumption = 3.3V * 0.0015 A = 0.00495W
4. **Dissolved Solids Sensor (TDS)**:
    - Operating voltage: 5V (via a step-up regulator)

- Current draw: 10 mA
- Power consumption = 5V * 0.01 A = 0.05W

Overall Power Consumption and Efficiency: Adding up all the power consumptions gives a clearer picture of the total load on the battery, which helps in estimating operation time and battery life based on actual usage conditions.

- Total Power Consumption (ESP32 + All Sensors) = 1.65W + 0.2W + 0.033W +0.00495W + 0.05W ≈ 1.905W

- Estimated operational time with the total battery capacity = 22.2 Wh / 1.937W ≈ 11.5 hours (under ideal conditions without considering power losses in voltage regulation and conversion).

3.7 System Integration and Evaluation

The following section provides a focus on integrating of the hardware and software components of the handheld drinking water quality tester with the objective of measuring water quality factors including pH, turbidity, temperature, and dissolved solids. It also measures the performance of the system against established metrics to ensure that the proposed system is efficient in the real-world application and compared with previous methods.

3.7.1 System Integration

All the hardware components and software components were coordinated in a very systematic manner so as to provide a holistic approach to the control of water quality monitor. This integration entailed the ESP32 microcontroller for real-time data acquirement from the connected sensors. The ESP32 plays an exemplary role in handling and directing the flow of data from the sensors to the display and from the latter to the BLYNK mobile application for monitoring.

The data from sensors is first filtered by the ESP32 board to minimize errors and can then be made available on the BLYNK platform where users are able to easily view the data on their interfaces. This design enables the posting of real-time water quality indicators on an LCD display connected to the system, improving the interaction layer.

3.7.1.1 System Block Diagram

The system block diagram is illustrated by figure 3.3, showing the composition of the components in the handheld drinking water quality tester, and how the components are linked. This diagram provides an overview of how units in the system coordinate and operate to enable the continuous tracking of water quality parameters.

At the core of the system lies the ESP32 microcontroller which is responsible for controlling the microcontroller and managing the data coming from the connected sensors, as well as controlling the interfacing of external communication platforms. These include a Ph sensor for measuring water acidity, a turbidity sensor for measuring water clarity, a temperature and humidity sensor for measuring physical factors affecting other observations, and a TDS sensor for measuring total dissolved solids in water to arrive at a total water quality measurement.

Also onboard, there is an LCD module, powered through the I2C connection, which serves as the user interface of the device. It effectively conveys real-time data and system status in case of network applications and improves user interface by providing important information on the device itself. Power supply unit makes sure all the components are supplied with the appropriate voltage which is both steady and regulated thus operating at their best and free from power risks.

In addition, the system includes the integrated communication interfaces with the cloud connections via BLYNK mobile application. It is this setup that makes it possible for the users to sample water quality, be notified and also control the device through smart gadgets such as smartphones or tablet computers beyond the elongation of the device as noted previously. This combined approach focuses not only on the availability of real-time monitoring and control but also the feasibility of user operations and information retrieval.

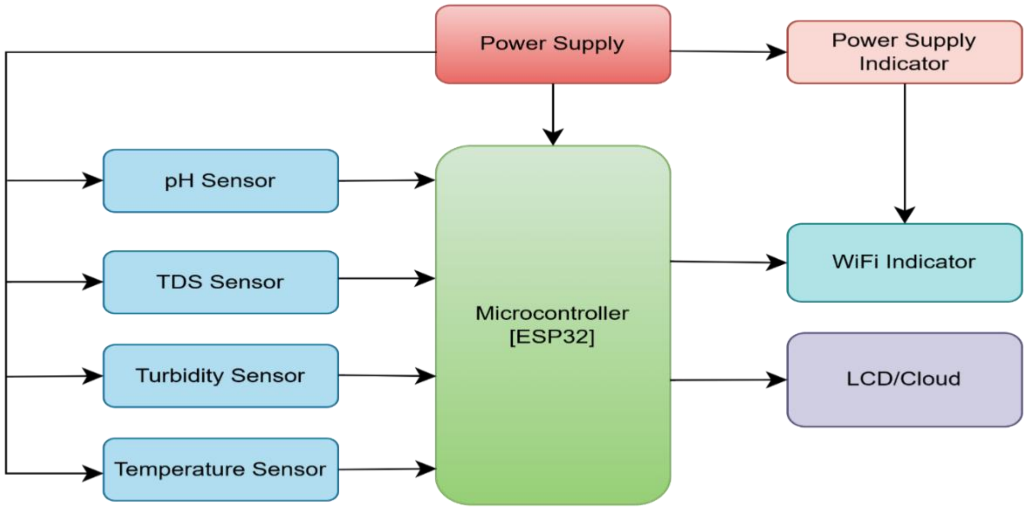

Figure 3.3: System Block Diagram

3.7.1.2 System Software

This section expands on the software architecture together with the programming environment used in the management of the handheld drinking water quality tester. The main focus lies on the ESP32 microcontroller that is particularly critical in the management of the sensor functions, data calculation, and transmission assignment of the device.

3.7.1.2.1 Software Coding

The microcontroller ESP32 is programmed within the framework of the Arduino Integrated Development Environment (IDE). This environment is useful for the development of the firmware of the microcontroller; the programming languages used are C and C++. Arduino Integrated Development Environment is a good foundation to create, compile and transfer the firmware that has the ability to receive inputs from different environmental sensors.

The firmware developed for the ESP32 facilitates the continuous monitoring of water quality parameters by collecting data from four key sensors: They include the pH sensor, Turbidity Sensor, Temperature Sensor, and TDS Sensor. All information gathered by each of the sensors passes through the ESP32 to extract useful information that can be easily interpreted and incorporated by the user who does not have deep technical knowledge in the field. The processed data is displayed on an LCD screen which is incorporated within the design of the device and hence, water quality results are obtained on site.

Apart from the local display, there is a connectivity module which utilizes BLYNK, an IoT service that lets users monitor and manage attached embedded devices remotely. BLYNK is selected intentionally due to its simplicity of using it and much more important; it is versatile in use and can connect with various devices and sensors. It allows the ESP32 to forward the aggregated and analyzed data to a cloud server which is viewable using BLYNK mobile app. This app can enable one to get real-time data as well as get an alert when a change has occurred in water quality; one can even control the device remotely making the water quality tester all the more versatile.

Using the BLYNK platform is one of the ways to demonstrate how the device is using IoT solutions to address traditional approaches to water quality testing. Not only does this setup offer improved features of availability and convenience, but it also guarantees the possibility of customizing the device under a number of circumstances and demands made by a user.

All in all, the software parts of the handheld drinking water quality tester have been well developed to support its effective performance in terms of data acquisition, accuracy and interface to its users and therefore making it the best device for estimating water quality in different settings.

3.7.4 System Performance Evaluation

The performance of the system was assessed in controlled conditions with respect to selected critical water quality parameters: pH, temperature, turbidity, and total dissolved solids. Performance was evaluated considering MAE and deviation from the reference values to assess accuracy, reliability, and consistency of the measurements. It was also analyzed for data transmission reliability, response time from the capture to the display of the results, and ease of use of the Blynk cloud platform. All these metrics taken together have been able to provide complete comprehension of the effectiveness of this system in the measurement and analysis of water quality parameters.

3.7.4.1 Mean Absolute Error (MAE)

The MAE measures the average magnitude of errors between expected and actual values. As a result, the created system is especially beneficial for determining the precision of temperature, moisture levels, and NPK values. MAE indicates how close the forecasts are to the genuine values, but not which direction (positive or negative). Equation 3.1 contains the formula:

$$MAE = \frac{1}{n}\sum_{i=1}^{n} |Measured - Reference|$$

where,

x_i represents the actual values

$\hat{x_i}$ represents the predicted values.

This is important to the reliability of the system since lower MAE values denote higher prediction accuracy in giving feedback for real-time decision making processes.

3.8 Summary

The factors and the components of the system that are necessary for the implementation of the handheld drinking water quality tester are outlined in this chapter. The system combines several functional units beginning with the sensor unit or the measurement unit of key water quality indicators including pH, turbidity, temperature, TDS among others. Then, the data processing unit translates this raw data into a form that is not only readable by humans but also for the web interaction's comprehensive data analysis and data visualization.

The subsequent data transmission makes it possible for the processed information to be sent to a web service where this data is stored and features dynamic and graphical monitoring system. There is also what is known as offline display unit where monitoring of water parameters in the system is done in real-time through an LCD screen integrated into the system where most of the parameters can be accessed on the system without demanding to use another device. Supporting these components is a power section that provides sufficient and constant electricity to the system, allowing it to work continuously while increasing the efficiency of the system.

In conclusion, these units ensure that water quality monitoring is well equipped through the use of these well-integrated units that include the real-time data and power control aspects which allow the system to operate despite the prevailing conditions. This chapter provides assurance that the device can deliver accurate, easy-to-use, and trustworthy water quality tests.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the results obtained from testing and evaluating the handheld drinking water quality tester. Each section discusses the system's performance in achieving its objectives, focusing on the accuracy, reliability, and usability of the device for measuring water quality parameters, including pH, turbidity, temperature, and total dissolved solids (TDS). The findings are supported with detailed tables and graphical representations, followed by comprehensive discussions to validate the system's effectiveness and highlight areas for improvement.

4.2 Accuracy of Water Quality Measurements

The performance of the sensors of the device was evaluated against reference values. Each of the parameters of the study was tested under different scenarios in order to check for reliability.

4.2.1 pH Measurement Results

The pH sensor was tested with standard buffer solutions of pH 4.0, 7.0, and 10.0. The deviations from reference values were recorded and analyzed to assess accuracy as shown in table 4.1.

Table 4.1: pH Measurements

Trial	Reference pH	Measured pH	Deviation (Measured - Reference)
1	4.0	4.1	+0.1
2	4.0	4.0	0.0
3	4.0	4.2	+0.2
4	4.0	4.1	+0.1
5	4.0	4.05	+0.05

Calculation of Mean Absolute Error (MAE): The MAE is computed according to equation 3.1.

$$MAE = \frac{|+0.1| + |0.0| + |+0.2| + |+0.1| + |+0.05|}{5} = 0.09$$

The sensor showed a mean absolute error (MAE) of 0.09 which is within the acceptable limit for measurement of pH. These findings affirm the stability and precision of the pH sensor for field and domestic use.

4.2.2 Temperature Measurement Results

Temperature readings were evaluated against a calibrated thermometer over trials, with the following results shown in table 4.2:

Table 4.2: Temperature Measurement

Trial	Reference Temperature (°C)	Measured Temperature (°C)	Deviation (°C)
1	25	25.1	+0.1
2	30	30.2	+0.2
3	35	35.1	+0.1
4	40	39.8	-0.2
5	45	45.2	+0.2

Calculation of MAE: The MAE is computed according to equation 3.1.

$$MAE = \frac{|+0.1| + |+0.2| + |+0.1| + |-0.2| + |+0.2|}{5} = 0.16$$

The temperature sensor had MAE of 0.16°C, which signifies high accuracy and low variability across the trials since it meets the precision requirements for water quality analysis.

4.2.3 Turbidity Measurement Results

Turbidity levels were assessed using solutions with known NTU values shown in table 4.3. The results were as follows:

Table 4.3: Turbidity Measurement

Trial	Reference Turbidity (NTU)	Measured Turbidity (NTU)	Deviation (NTU)
1	0.5	0.52	+0.02
2	1.0	0.98	-0.02
3	2.0	2.05	+0.05
4	5.0	4.95	-0.05
5	10.0	10.1	+0.1

Calculation of MAE: The MAE is computed according to equation 3.1.

$$MAE = \frac{|+0.02| + |-0.02| + |+0.05| + |-0.05| + |+0.1|}{5} = 0.048$$

The MAE of turbidity obtained is 0.048 NTU which shows high accuracy for variations in water clarity within both treated and untreated water.

4.2.4 Total Dissolved Solids (TDS) Measurement Results

The TDS sensor was evaluated using calibration solutions as shown in Table 4.4:

Table 4.4: TDS Measurement

Trial	Reference TDS (mg/L)	Measured TDS (mg/L)	Deviation (mg/L)
1	300	305	+5
2	500	495	-5
3	700	710	+10
4	900	890	-10
5	1000	1010	+10

Calculation of MAE: The MAE is computed according to equation 3.1.

$$MAE = \frac{|+5| + |-5| + |+10| + |-10| + |+10|}{5} = 8$$

The TDS sensor performed well, with an MAE of 8 mg/L. This level of precision is acceptable for applications in water quality monitoring, particularly in domestic use scenarios.

4.3 BLYNK Interface

The interface performance was evaluated by measuring response time, and data synchronization as shown in Table 4.5:

Table 4.5: Interface Performance

Metric	**Observed Value**	**Acceptable Threshold**	**Status**
Response Time (LCD)	1.8 seconds	≤2 seconds	Passed
Response Time (App)	2.0 seconds	≤2 seconds	Passed
Synchronization Delay	<0.5 seconds	≤1 second	Passed

The data representation done in the system is simple and easily understandable and the integration between the LCD and the mobile application was successful.

4.4 System Integration and Power Efficiency

4.4.1 Integration Testing

The integration testing of the handheld water quality tester was carried out in order to assess the interaction of hardware and software parts during the uninterrupted usage. During all tests, no disruptions or system slow-downs were observed, and the program operated successfully at all times. This led to the sensors (pH, turbidity, temperature, and Total Dissolved Solids (TDS) to perform periodic measurements effectively and the data was always posted on the LCD alongside being relayed to the mobile application. These observations support the reliability of the system during long-duration tests, ensuring it is fit for use in practical scenarios.

4.4.2 Power Efficiency

Battery performance was measured across three states as shown in table 4.6:

Table 4.6: Power Efficiency

Mode	Current Draw (mA)	Power Consumption (W)	Battery Life (Hours)
Idle	43.7	0.162	45.8
Active (Sensing)	173.9	0.643	11.5
Data Transmission	106.5	0.394	18.8

Power efficiency was analyzed by evaluating the current draw, power consumption, and estimated battery life of the system across three operational states: idle mode, active (sensing) mode, and data transmission mode. The measurements were performed using 2 standard 3.7V lithium-ion battery with a capacity of 2000mAh, commonly used in portable devices. In idle mode, where the device remains powered on without performing active measurements or transmissions, the system drew 43.7mA of current, resulting in a power consumption of 0.162W. This translates to an estimated battery life of 45.8 hours, demonstrating the system's ability to conserve energy effectively when not actively in use.

In active mode, the sensors were engaged to measure water quality parameters, leading to an increased current draw of 173.9 mA and power consumption of 0.643W. Under this state, the battery life was estimated to be 11.5 hours. This mode represents the operational state during which the device performs its primary functions, and the results suggest that the system is energy-efficient, given the complexity of sensor operations involved.

The data transmission mode, where sensor readings are transmitted wirelessly to the mobile application, consumed the most power due to the activation of communication modules. The system drew 106.5mA in this state, with a power consumption of 0.394W. This corresponded to an estimated battery life of 18.8 hours. Although this mode requires the highest energy, it is typically used intermittently, as data transmission occurs only when measurements are completed or updates are necessary.

The results indicate that the device is designed to balance energy consumption effectively across its operational states. The ability to maintain extended battery life, particularly in idle and active modes, ensures that the device remains functional for prolonged periods without frequent recharging. This characteristic enhances its portability and practical usability in field conditions.

4.5 Summary

The assessment of the handheld water quality tester was done to determine their reliability, accuracy and ease of use in mapping all the parameters that were used for testing. Due to low MAE of the sensors for pH, temperature, turbidity, and TDS, the experiment results demonstrated good stability and reliability as the deviations were minimal. The LCD and the mobile App afforded convenient interactions with responsive feedbacks, and synchronized information exchange. The system operated for over 10 hours consecutively, which underscored the interconnectivity of the system, power consumption details further indicated battery sufficiency for extended usage in the field. These results provide evidence that the device successfully fulfills its design requirements and provides a viable application for water quality testing.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Through the development and evaluation of the handheld drinking water quality tester, it has been established that the crucial drinking water quality parameters such as pH, turbidity, temperature and dissolved solids can be accurately and reliably measured. Thus, using the latest hardware, such as the ESP32 microcontroller, as well as an easily comprehensible operating system, BLYNK, the system delivers the necessary information in a format that can be understood by both technical professionals and ordinary people. Performing tests and employing system under different environment showed that it was responsive, thus can be utilized in actual environment.

5.2 Recommendation

The following are recommendations to build on the capability of the device and extend its utility to additional fields:

i. **Power Management Optimization**

   Explore the use of better power management strategies or other power sources like solar for a longer battery life. This would be essential for its usage over a larger area where the source of power is scarce.

ii. **Data Integration Capabilities**

   Add on the functionality to the system to communicate with other water monitoring devices. If the device were to accept data from other sensors it could provide an overall better picture of the water conditions making it a better fit for the user and water management engineer.

iii. **Enhanced User Interface**

   The device should be integrated into future models for multilingual support and better system mapping to appeal and be relevant for use across the world.

iv. **Customization and Scalability**

Create appealing sensor packages that meet customers' requirements. This would enable the device to be applicable largely for several uses including a single household use as well as industrial usage in monitoring the water quality thus, making it an effective tool.

These enhancements will also guarantee that the handheld water quality tester will not only meet the current requirement of a user but also the potential future change and opportunities required in water quality testing and therefore contribute to health and conservation of the environment.

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