UNIVERSITY of RWANDA

Research and Postgraduate Studies (RPGS) Unit

ACEIoT

Thesis Title:

Development of IoT based solution for small sailing boat monitoring and tracking: A case of Zanzibar

Student's Name: Asya Suleiman Mgeni

Ref.: 219013171

Collage of Science and Technology

School of African Center of Excellence in Internet of Things

Master of Science in IoT-Wireless Intelligent Sensor Network

2018 - 2020

UNIVERSITY of RWANDA

Research and Postgraduate Studies (RPGS) Unit

ACEIoT

Development of IoT based solution for small sailing boat monitoring and tracking: A case of Zanzibar

By

Asya Suleiman Mgeni

Reference Number: 219013171

A dissertation submitted in partial fulfilment of the requirements for the degree of

Master of Science in Internet of Things

With Specialization in Wireless Intelligent Sensor Network

In the College of Science and Technology

Main Supervisor: Dr Abuubakar Diwani

Co-Supervisor: Dr Pierre Bakunzibake

Submission date: May 2021

Declaration

I, **ASYA SULEIMAN MGENI,** hereby declare that this thesis submitted by me under the University of Rwanda is my own and has not been submitted to any other University, College or Institution or published earlier.

Name. ASYA SULEIMAN MGENI

Signature. 

Date. 30/11/2020

Bonifide certificate

This is to certify that the project entitled" Development of IoT based solution for small sailing boat monitoring and tracking: A case of Zanzibar" Is a record of original work done by Asya Suleiman Mgeni with registration number 219013171in partial fulfilment of the requirement for the award of masters of sciences in Internet of Things in College of Science and Technology, University of Rwanda, Academic year 2018/2020

This work has been submitted under the guidance of Dr Abuubakar Diwani and Dr Pierre Bakunzibake

Supervisor:

Dr. Abubakar Diwani Bakari 17.02.2021

(School of Computing Communication and Media Studies, The State University of Zanzibar, Tanzania)

Co-Supervisor:

Dr. Pierre Bakunzibake 15.02.2021

(College of Science and Technology, University of Rwanda)

The Head of Masters and Trainings

Names: Mukanyigira Didaciene

Signature: …………………….

Acknowledgments

To begin with, acknowledgments are reserved to my supervisors Dr. Abuubakar Diwani and Dr. Pierre Bakunzibake, for their guidance, support, and supervision. My thanks go to my sponsor Inter-University Council for East Africa (IUCEA), to enable me financially to the competition of my study. Many thanks to all the interviewed company representatives for providing information and sharing their experiences with me. Special thanks to my family, who made it possible for me to study. Finally, I would like to thank all the people who supported and encouraged me during my studies, especially my friends and lecturers.

Abstract

Globally, IoT applications are emerging exponentially with various functionalities to automatically monitor, control the environment, and manage various tasks. This research aims to address various challenges facing marine small sailing boat transportation in Zanzibar by establishing an IoT solution to track and monitor sailing boats at Zanzibar seashore. Zanzibar people use the Indian Ocean for transportation, entertainment, fishing, and tourism activities, and the most popular sailing vessels they use are boats that are traveling in various maritime areas. The interviews with Zanzibar maritime authority (ZMA) officials and the ICT Manager revealed that ZMA does not have a proper monitoring and tracking system for small boats and other local vessels. The existing tracking system based on global AIS only focuses on tracking and monitoring big ships traveling locally and abroad. Hence, the absence of a smart monitoring and tracking system for small sailing boats may increase unwanted consequences that could also jeopardize the lives of those inside the boats once the accident or malicious activities happen like collision and leakage in the boat. Therefore, this research project proposed an IoT-based system that will address the existing challenges.

The proposed platform envisaged to facilitate a safe environment for both passengers and the boatmen by providing an early warning before a collision occurs, alert message in case of water leakage, and transmitting real-time about the boats' movement. The following technologies are used to design this system, GPS, water detector sensor, ultrasonic sensor, buzzer, Arduino UNO, Bluetooth, and GSM module. This project's output is an IoT system, which will continuously monitor a moving boat and report its status. For doing so, the Arduino Uno interfaced with sensors together with a buzzer and Bluetooth. The Bluetooth is used to send collected data to GSM using peer to peer communication. The water sensor detects the presence of water inside the boat, once the water is detected, the system automatically sends an alert message to the user. The user will also view the position of the boat through a mobile device. The system also uses an ultrasonic sensor for measuring the proximity between the boat and obstacle; if the boat approaches the obstacle, the buzzer starts to ring until the boat is in a safe position. The GSM used GPRS and TCP/IP protocol to send data in a database at the same time to send alert messages to the mobile

Phone. The designed IoT system simulated using the Proteus design suite, and then the prototype was developed using physical devices. A mobile app named “ZMA APP” is also part of the physical experimental setup. A user uses this app to receive an alert message once the boat gets leakage. Overall, the proposed system will enhance the efficiency of ZMA, especially on tracking and monitoring small boats and communication between boat and marine port authority.

Keywords

Internet of Things

Small boats

Maritime environment

Tracking

Monitoring

Real-time system.

List of Acronyms

AIS: Automatic Identification System

IoT: Internet of Things

GPS: Global Position System

GSM: Global System for Mobile communication

ZMA: Zanzibar Maritime Authority

GPRS: General Packet Radio Service

TCP/IP: Transmission Control Protocol/ Internet Protocol

ICT: Information Communication Technology

VTS: Vessels Traffic Services

MSSNs: Maritime Surveillance Sensor Networks

Table of Contents

List of Tables

List of Figures

Chapter 1

Introduction

This thesis attempts to develop an IoT based smart solution for tracking and monitoring small boats for Zanzibar port. The system is envisaged to facilitate a safe environment for traveler transmitting critical information in real-time about the boats' movements and reporting any information concerning collision and water leakage in the boat. This chapter presents background information, motivation, and problem statement. The chapter also proceeds with the study objectives, study scope, and significance of the study. Finally, the study's organization is presented.

1.1 Background

Globally, Internet of things (IoT) applications are emerging exponentially with various functionalities to monitor automatically, control, and manage various tasks in different sectors. Internet of Things (IoT) is defined as the connection of everything embedded with electronics, software, and sensors to the Internet, enabling the collection and exchange of data without requiring human interaction [1]. IoT facilitates several advantages in the day-to-day world, including minimizing human effort, efficient resource utilization, saving time, enhancing data collection, and improving security [2]. Researchers and practitioners widely use IoT to develop an affordable wireless system with less power [26], to solve societal problems in various sectors such as health, agriculture, environment, and others [3][4][5][6][7][8][9].

The potential of IoT technology is also highly recognized in the maritime transportation sector. In recent years, researchers and practitioners have innovated various smart solutions for managing maritime transportation [10], including smart tracking and smart monitoring of the marine vessels, smart environmental and weather monitoring, and others[11][22]. Smart tracking and minoring of maritime vessels have many benefits in maritime transportation. Includes increasing the passengers' security, reducing accidents in the environment like collisions, sinking of the vessels, avoiding boat disappearance, and improving communication between captain and port officer [10].

Ships and boats are the common transportation vessels used in maritime. It is known that big ships are working in the deep sea. Today, the contemporary big ships were manufactured with an automatic computerized system to track and monitor their dynamic status. The common system used in the big ships is called the Automatic Identification System (AIS). However, small boats are mainly working within the coastline of either island or mainland. Most of these vessels are locally made and miss intelligent systems like AIS, especially in developing countries, including Tanzania.

Zanzibar is the semi-autonomous part of Tanzania in East Africa. It is an archipelago that consists of many small islands and two large ones: Unguja and Pemba. Since the Zanzibar territory is surrounded by the Ocean, tourism, and fishing are the main economic activities performed by many people. In these activities, the most popular maritime transportation used is locally made small boats [12]. However, according to Zanzibar maritime authority (ZMA) officials, the small boats used to carries passengers at the Zanzibar coastline have no proper system for monitoring and tracking their condition at the seashore. Hence, the absence of a smart monitoring and tracking system for small sailing boats may increase unwanted consequences that could also jeopardize the lives of those inside the boats once the accident or malicious activities happen like collision and leakage in the boat. Therefore, this research project proposed an IoT-based system for tracking and monitoring small sailing vessels that will be used to address the existing challenges at Zanzibar port.

The tracking and monitoring system has been studied by several researchers [11], [14]–[24]; however, their studies have not addressed the issues of collision detection and water leakage detection. In the previous studies, a web application has been very common for visualizing real-time information compared to a mobile application. Since the mobile application is easy and affordable, a mobile application was considered an interface for information visualization in this study. Similarly, the use of mobile devices for data visualization is also requested by ZMA officers. Besides, the majority of the reported IoT solutions were designed for tracking and monitoring the big ships. There is not much attention in designing IoT solutions for the small boat that are commonly used for small fish farmers, tourist, or maritime entertainers, especially in the East Africa coastal area. Hence, the current study proposed an IoT solution that consists of anti-collision applications and leakage detection applications, and location tracking. The proposed system uses IoT components to monitor and track the small boats in Zanzibar port. The system is fitted inside the boat that provides effective real-time information on a dangerous situation such as collision and boat leakage. The system includes hardware and software components that help to track and monitor the boats. Users use a mobile app named "ZMA APP" to view data from the database. Moreover, the user will receive an alert message once the boat gets leakage. This solution will solve critical maritime communication problems in Zanzibar.

1.2 Motivation

Tourism and fishing are among the main economic activities performed by many people in Zanzibar, and these sectors are contributing a large to the economics of this country. Since the Ocean surrounds 100% of the Zanzibar territory, an ocean is often used for transportation and other economic activities. In these activities, the most popular transportation used is small sailing boats /vessels [13]. Those boats always travel in various areas of maritime. For instance, in tourism, one of the most dazzling places tourists visit once they are in Zanzibar is a Prison Island, which lies about 30 minutes sailing from the coastline. To move from Seafront Stone Town to Prison Island, a group of up to 12 tourists has to hire a local sailing boat with one boatman and sailing to its prison's shore.

The responsible for maritime transportation and related issues in Zanzibar is called Zanzibar Maritime Authority (ZMA). ZMA was established under act number 3 of 2009 of the Zanzibar government constitution. It is responsible for monitoring, regulating, and coordinating all matters relating to the maritime industry in Zanzibar [13]. It also monitors, regulates, and coordinates all activities on shipping in sea waterways in Zanzibar to make sure navigation safety. Ensuring it provides better navigation safety, information, and communication technology has been considered an essential aspect of communication between boat/ships and the maritime authority, which is why there is a particular unit for ICT services at ZMA. Among the ZMA ICT unit's responsibilities is to manage, administer, and control the operations of the ICT infrastructure and systems in ZMA and ensure the best use of technology and practices [13]. ICT makes possible information exchange between ship/boat and port operator. However, currently, ZMA is facing challenges in tracking and monitoring small sailing boats because there no automatic monitoring system that can transmit real-time critical information about boat situations in the sea environment. Lack of tracking and monitoring system increases unwanted consequences that could also jeopardize the lives of those who are inside the boats once the accident or malicious activities happen like collision and sinking [13]. According to ZMA's ICT manager, there is currently a system for tracking big ships called Automatic Identification System (AIS). This system lacks monitoring components. This system is only used for tracking big ships/boats and not small sailing boats.

Therefore, the problem facing the port authority and small boat users has motivated the researcher to propose a system that would reduce frequent accidents. They are currently using traditional methods to track boats that are not efficient and safe for users. Thus, in this study, using new technologies, an IoT-based system was proposed. It is believed that this system will help to provide safe transportation at the coast of Zanzibar and help to reduce frequent accidents. This system will also improve the marine transportation system's efficiency and sustainable management of sailing boats in Zanzibar marine port. Besides, the solution will increase trust for tourism travelers, and many of them will opt for a small boat. As a result, the local people will increase their income as well.

1.3 Problem Statement

The integration of IoT based systems in Maritime vessels (ship, boat) tracking and monitoring in the sea environment is a relatively small phenomenon in the world. It is in the growing stage of development and utilization. That shows, more studies are needed in this context. Various studies in this area have been done and propose IoT solutions for monitoring and tracking maritime vessels [14][15][11][16].

However, most of them propose IoT solutions for big ships and not for small sailing boats. On the other hand, there is a need for such a system in the least developed countries like Tanzania. Small sailing boats are common in maritime transportation for local movement, fishing, and tourism, especially in the coastal line. For example, in Zanzibar Islands, it has been reported that there is an unreliable sailing boat monitoring system. As a result, when there is calamity at sea, the information cannot be quickly shared with the port authority. According to Zanzibar maritime port officials, the Zanzibar maritime authority currently does not have a system that can monitor and track small sailing boats or local vessels. The existing system (AIS) only focuses on tracking big ships traveling both locally and abroad. If any calamity happens while the boat is in motion, there is no proper communication between the landside and the seaside. For example, it is difficult to monitor and provide alerts when there is damage on the boat, like when the boat gets leakage. Another weakness of the current system is boat disappearance, no means to identify the boat's Location. Besides, in case of fog and boats fail to see ahead, there is no direct communication between vessels, and it might cause collision between the boats. In addressing those challenges, this study designed, simulated, and developed an IoT-based prototype to monitor and track small sailing boats. The developed prototype consists of a collision detection application, water leakage detection application, and application to track boat location.

1.4 Study Objectives

1.4.1 General Objective

This project's main objective was to develop an IoT-based smart system to track and monitor sailing boats that enhance maritime communication and alleviate frequent maritime accidents.

1.4.2 Specific Objectives

1. To identify and determine the IoT technologies, cloud technology, and other wireless technologies suitable for tracking and monitoring maritime boat
2. To propose a design for IoT based tracking and monitoring system which can prevent collision between boats, detect water leakage, and track boat position.
3. To build a prototype of the designed system using physical devices.

1.5 Study Scope

This research focused on proposing an IoT-based system to track and monitor small sailing boats in Zanzibar marine port. The system consists of a wireless sensor network capable of detecting leakage, measuring proximity between the boat and obstacle, and determining the boat position. The proposed system is based on the alert. Users can receive a notification once the leakage is detected in the boat, and receive an alert when the boat gets closer to another boat or any obstacle. An ultrasonic sensor is used for measuring the proximity between the boat and obstacle, GPS for determining the boat location, and a water detector for detecting the presence of water. All sensors are fixed in the boat with a microcontroller and GSM module. The successful development of the proposed system could dramatically transform the port's economics and ultimately improve tourists' and fish farmers' serviceability. The developed system consists of a network of low-cost sensors fixed in the boat, which collect data from the boat environments and are processed by a microcontroller.

The system is capable of continuously monitoring and tracking the boat movement. Hence the collected data from the boat are sent to the cloud via the GSM module. Meanwhile is sent to end-users through short message services. Users can view all data and receive a notification if there is a leakage in the boat through their phone. Not only that, but also captains of the boats can receive an alarm if they are approaching any obstacle.

1.6 Significance of the Study

The proposed IoT solution for sailing boat monitoring and tracking will help to mitigate accidents in the maritime environment. It is also envisaged to facilitate a safe marine environment for both tourists and fish farmers by transmitting critical information in real-time about the boats' movements and other safety parameters. The system will also improve the marine transportation system's efficiency and sustainable management of sailing boats in Zanzibar marine port. The solution will also increase trust for tourism travelers, and many of them will opt for this boat sailing. As a result, the local people will increase their income.

1.7 Organization of the Study

The following chapters depict the work that has been accomplished and the output of introducing the IoT system to track and monitor small boats in Zanzibar port. The second chapter gives a literature review relating to tracking and monitoring IoT systems in maritime and different technologies that have been used. The third chapter describes all methods that are used in this study. The fourth chapter introduces the system analysis and design. The fifth chapter describes the working of the system and the results obtained from the system. The sixth chapter consists of a conclusion and future work.

Chapter 2

Literature Review

In this study, literature studies were done by reading different papers about this topic to obtain data, technologies, and theories related to this study. This chapter gives an overview of previous work on how they solved marine problems using different methods. It also describes the gaps which are found through works done by previous scholars.

2.1 Related Work

IoT in maritime is a new and growing area of research in computing. It is in the infant stage in research. Some studies can be used as the basis for this work. In this section, the researcher reviewed previous literature that has been conducted on the design, development, and implementation of IoT systems for tracking and monitoring marine vessels. This study aimed to develop an IoT-based system for tracking and monitoring small boats for improving marine transport services on the coast of East Africa, whereby the tracking and monitoring parameters are water leakage, proximity, and Location.

Rifandi et al. [17] developed an IoT-based system for monitoring the boat's position and condition. The system's benefit is to help the port officers monitor the ship's position and find out the last ship's position in the event of an accident by using a web-application. The monitoring parameters are Location and the number of people on board. This system was tested in Indonesia.

In 2012, Ahmad et al. [15] designed a wireless sensor network for environmental safety monitoring at the Port of Brisbane, Australia. In this system, the gateway retrieves data from the sensor network and sends them to the database. The user can access sensor data by using the Google map interface. The parameters used are Location, measuring hazard events, including fire, smoke, and toxic gases.

In 2018, Iborra et al. [11] designed a system for tracking and monitoring boats and presented the result through a web-based dashboard. The system helped to inform the port authority, the state, and the position of the boat. Sudheera et al. [18] also proposed a GPS tracking device for fishing boats. In this system, a GPS device determines the Location of the boat. The system also records all activities within the boat from the beginning until the end of the journey. The main objective was to minimize illegal unreported and unregulated fishing for sustainable fishing. Reggiannini et al. [19] described the IoT-based platform for sea surveillance. The system can detect and identify illegal marine traffic. This system is capable of detecting target vessels in an input map. Also, the system is proving the prediction of each vessel's forthcoming route. The user of the system can visualize results in a dedicated web GIS interface. This platform represents a novel tool to counter unauthorized fishing and tackle irregular migration.

Moreover, Lingling et al. [16] proposed a sailing monitoring system in the marine environment using Lora as communication technology. However, this solution focuses on transmission performance, monitoring parameters in this system include speed, the direction of winds and boat, and GPS location. Margarit et al. [20] designed a ship monitoring system working with synthetic aperture radar images. This system aims to give authority to a system that controls all shipping operations and allows them to verify compliance. The system also provides follow-up to transportation strips, monitoring illegal immigration, and ensuring sustainable economic development. It is a web-based system. Claramunt et al. [21] design and implement a system for monitoring small ships and boats. It consists of the database server and mobile navigation client. It is oriented towards vessel traffic services (VTS) based on a radar system and AIS to monitor vessel movements and improve navigation safety. In this system, a client access information through the web application interface.

Pramunanto et al. [14] reported the Cost panic system, which is embedded in marine vessels. With a system, the captain can press a panic button whenever there is an emergency condition on the ship/boat. The harbor officers can be notified about the emergency/accident on their mobile-based application. XU et al. [22] also designed an IoT-based system using a wireless sensor network to monitor the marine environment. This system measures physical parameters, such as temperature, humidity, pressure, wind speed, wind direction, and chemical parameters like salinity, turbidity, pH, nitrate, chlorophyll, and others. Yang et al. [23] proposed a simulation framework based on OMNeT++ discrete event simulator, and the energy model is discussed for simulating Maritime Surveillance Sensor Networks (MSSNs). Technology like ZigBee and wireless networks is used as a data link. The system recognizes data acquisition for information such as dynamic ship states, marine environmental protection, and other significant resources. Zainuddin et al. [24] apply wireless communication in the marine area to support the Vessel Monitoring System. The system can transmit vital information related to shipping activities such as vessel positions.

The author of the current study has identified some gaps from the previous literature presented above—first, the collision detection when there is any obstacle around the marine vessel. Also, water leakage detection has not been addressed in previous studies. The inclusion of these components in the proposed system will add more parameters to monitoring missing in the previous IoT solutions, including water and movement. The web application has also been very common for visualizing real-time information compared to a mobile application. The mobile application is easy and affordable, so a mobile application was considered an interface for information visualization in this study.

Similarly, it is requested by ZMA the system be mobile-based. It is also possible as currently, there is a high proliferation of mobile devices in developing countries like Tanzania. Besides, most reported IoT solutions were designed to track and monitor big ships and medium-size boats. There is not much attention in designing IoT solutions for the small boat that is commonly used for small fish farmers or maritime entertainers, especially in the East Africa coastal area. Therefore, the existing gaps in the literature and the lack of literature on IoT in maritime in the East African context suggest a need for more studies. Hence, the current study will develop an IoT solution with anti-collision detection applications, leakage detection applications, and location tracking.

Chapter 3

Research Methodology

The research methodology describes the method used to solve a problem and also required data so that research can be carried out. In addressing this study's problem, the researcher used a literature review, interview to gather user needs, and a system development approach. This chapter describes the system development process, including hardware and software components used in this research, in which each component used in the research is explained. This chapter also proceeds with the algorithm used in the research and finally indicates the sequence diagram used.

3.1 System development

The proposed system consists of a microcontroller, and it is interfaced with sensors, including a water detector, ultrasonic sensor, and GPS, which are the input of the system. The GSM module is used to send data to the cloud. F**igure 1** below shows the block diagram of the system.

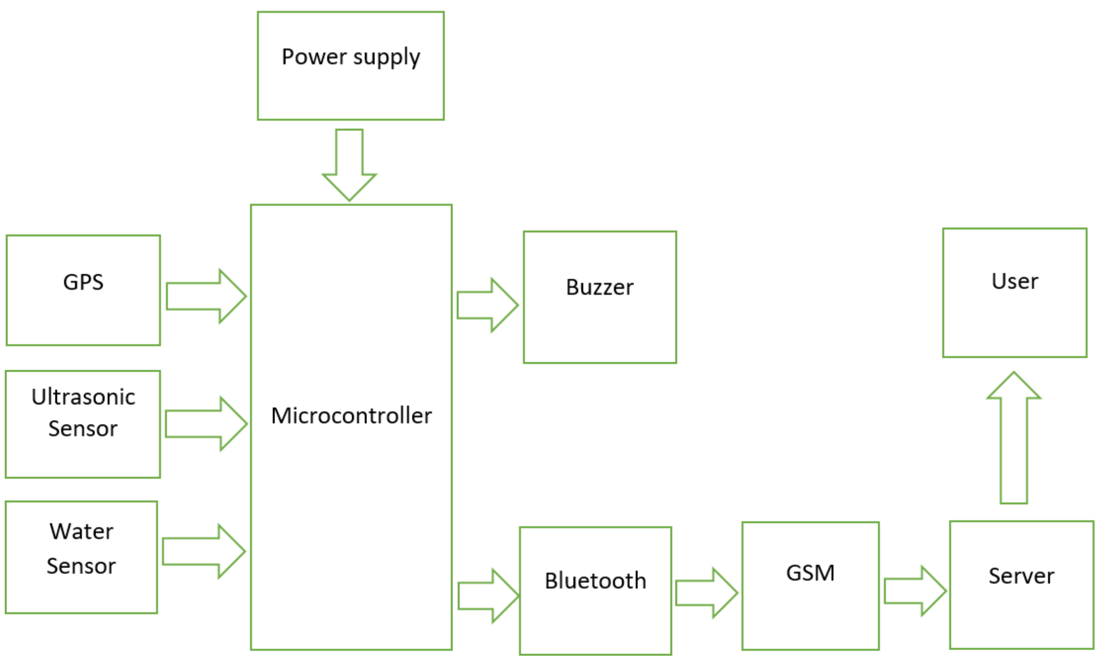

Figure 1 Block diagram of the proposed system

The block diagram of the proposed system shows how our system works. The system unit embedded with sensors is installed inside the boat that is to be tracked and monitored. The sensors collect data when the boat is in motion, a microcontroller captures the data for processing, then the Bluetooth sends data to GSM, and GSM sends them to the cloud. The system can alert the user through messages once the water is detected in the boat. The water is sensed using a water detector sensor. The system can also alert users via buzzer sound once the boat approaches an obstacle, which may help avoid a collision in the sea environment. The data obtained is processed using a microcontroller and sent to the Bluetooth, then GSM sends data to the cloud. A cloud database is set up to store the data obtained for future reference. **Figure 2** shows a conceptual diagram of the system.

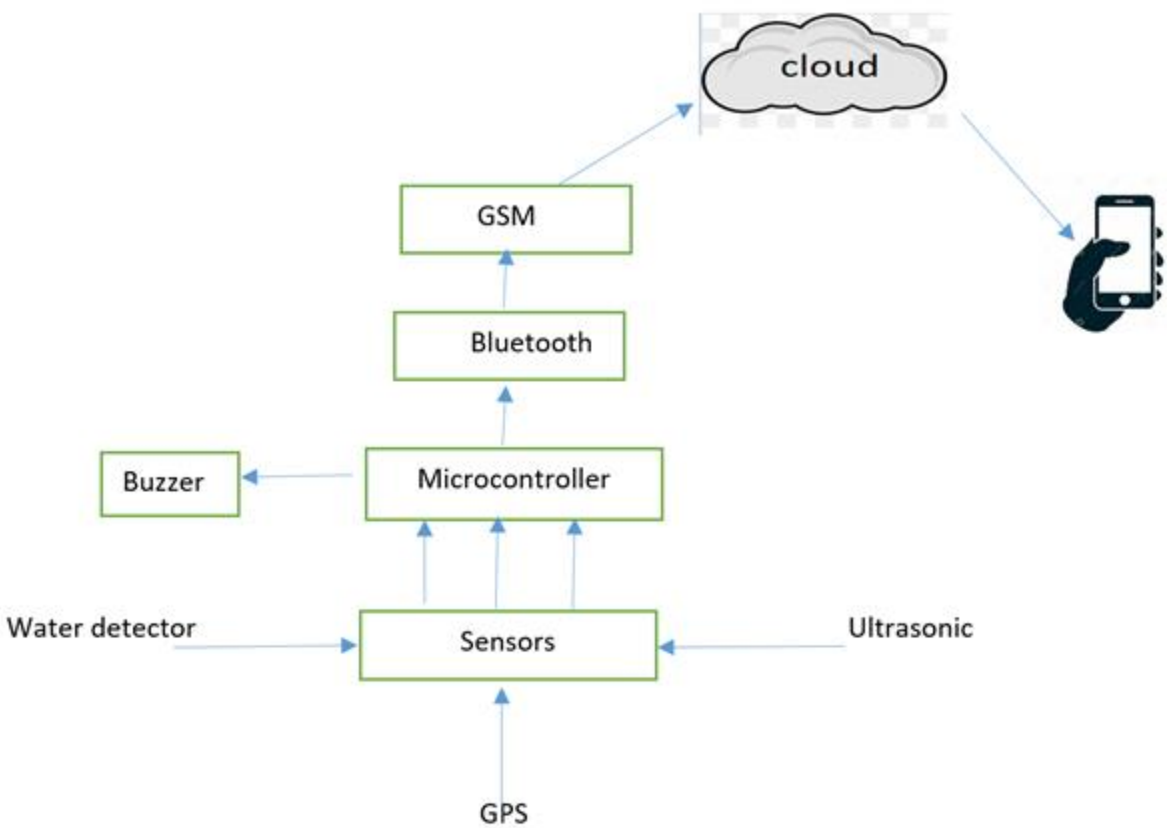

Figure 2. Conceptual diagram

3.2 Description of hardware Components

For the effective implementation of the proposed system, the following are the hardware components used. The heart of the system is the microcontroller in which, for this case, Arduino Uno was used. The water detector sensor is also used to detect water inside the boat, while GPS is used to determine the boat's position. Another component is an ultrasonic sensor for measuring the proximity between the boat and the detected obstacle. The buzzer is also used to generate sound (alert) to the captain once the boat approaches an obstacle. Moreover, Bluetooth is used to send the captured data to the GSM. Then the GSM sends data to the cloud.

Water detector sensor.

A water detector is a device that detects the presence of water, often by measuring the electrical conductivity of the water present and completing a circuit to send a signal. In this research, the water sensor was used to detect the presence of water inside the boat. Hence if the water was detected, the system automatically sends alert messages to the port officers for immediate action. **Figure 3** shows the picture of the water sensor, source [25].

Figure 3. Water sensor

Ultrasonic sensor

The ultrasonic sensor is a device used to measure the distance to an object using ultrasonic sound waves. It sends and receives pulses that relay back information about an object. It can handle collision avoidance for an object. In this study, the ultrasonic was used to measure the proximity between the boat and the obstacle. If a specific parameter threshold is reduced, the buzzer produces a sound that alerts a captain. It may help to avoid collisions between boats in the sea area. **Figure 4** shows the picture of an ultrasonic sensor, source [26].

Figure 4 Ultrasonic sensor

GPS

A global position system (GPS) is a device used to determine an object's ground position. The GPS signal can give accurate information to estimate the Location and Location of an object. In this research, the GPS was used to determine the boat's position**. Figure 5** shows the picture of the GPS source [27].

Figure 5. GPS

Buzzer

A buzzer is a device that can generate beeps and tones. It uses piezo crystal, a material that changes shape when voltage is applied to it. A buzzer is an actuator. This research used a buzzer to alert the captain of the boat when the boat approaches an obstacle. **Figure 6** shows the picture of the buzzer, source [28].

Figure 6. Buzzer

Arduino UNO

Arduino UNO is a microcontroller board with input and output pins, USB connection, a power jack, reset button, and others. It is based on ATmega328. It is used for building electronics projects. An Arduino UNO plays a significant role in this research. It is like the heart of the system since all components are connected to Arduino. It collects all sensor data and sends them to the GSM via Bluetooth. **Figure 7** show the picture of arduino UNO, source [29].

Figure 7 Arduino UNO

Bluetooth

Bluetooth is a wireless technology that allows data to be exchanged between devices. It is robust, low power, and low cost, and the fact that it has become a universal standard for exchanging data amongst a range of fixed and mobile devices. Bluetooth wireless technology can simultaneously handle both data and voice transmissions. The range can be up to 100m for class one, up to 10m for class two, and even up to 1m for class three Bluetooth. Every Bluetooth device has a transmitting and receiving antenna [30]. The Bluetooth uses peer to peer communication to send data to the GSM in this research.

GSM

GSM stands for Global System for Mobile Communication. It is a technology used to transmit mobile voice and data services. GSM is the most accepted standard in telecommunications, and it is globally implemented. It operates on the mobile communication bands 900 MHz and 1800 MHz in most parts of the world. GSM was developed using digital technology. It can carry 64 kbps to 120 Mbps of data rates [31]. The GSM in this research was used to send data to the cloud database and send messages to the user's phone.

3.3 Software Components

In this study, the following software tools were used to develop the system. These are Arduino IDE, Firebase database applications (Cloud software).

Arduino IDE

In the development of this system, the programming language was necessary. Thus the microcontroller had been programmed by using Arduino IDE software. Arduino IDE software is an open-source software introduced by Arduino to edit, compile, and upload the Arduino codes [33]. Arduino IDE software is open-source software that is used for compiling the program into the microcontroller. In this software C- programming language has been used for code. The coding primarily has two parts, the void setup () that is identified as preparation for the program, and it runs only once. Another part is a void loop () that is identified as the execution of the program. **Figure 8** shows the Arduino IDE interface where all codes are typed here and then after compilation is uploaded to an Arduino device.

Figure 8 Arduino IDE interface

Cloud Server

It is a cloud server, which is used for data storage and processing. The cloud data are being sent to the user for notification and visualization through mobile applications via the Internet. In this study, the Firebase Realtime database application was used for storage. It is a cloud-hosted database that enables to store and sync data between users in real-time. It makes an easy for users to access the data from any devices, web, or mobile, and it helps users collaborate. Whenever update the data in a real-time database, it stores the data in the cloud and simultaneously identifies all end devices.

The Firebase also provides cloud messaging, that part is for messaging and notifications for Android, IOS, and web application [34]. The researcher has used Firebase because it is cost-effective and easy to connect with other system components [34]. **Figure 9** shows the firebase interface.

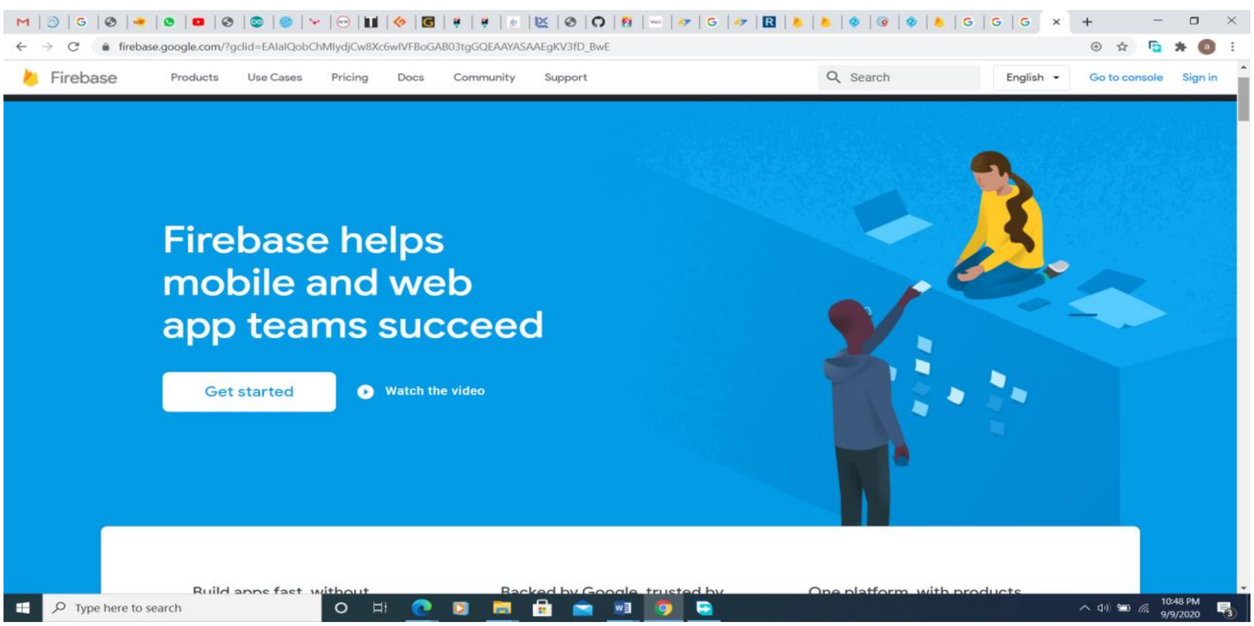

Figure 9 Firebase interface

3.4 Flow chart of the proposed system

This flowchart is a graphical representation of the proposed system's flow, as shown in **figure 10**.

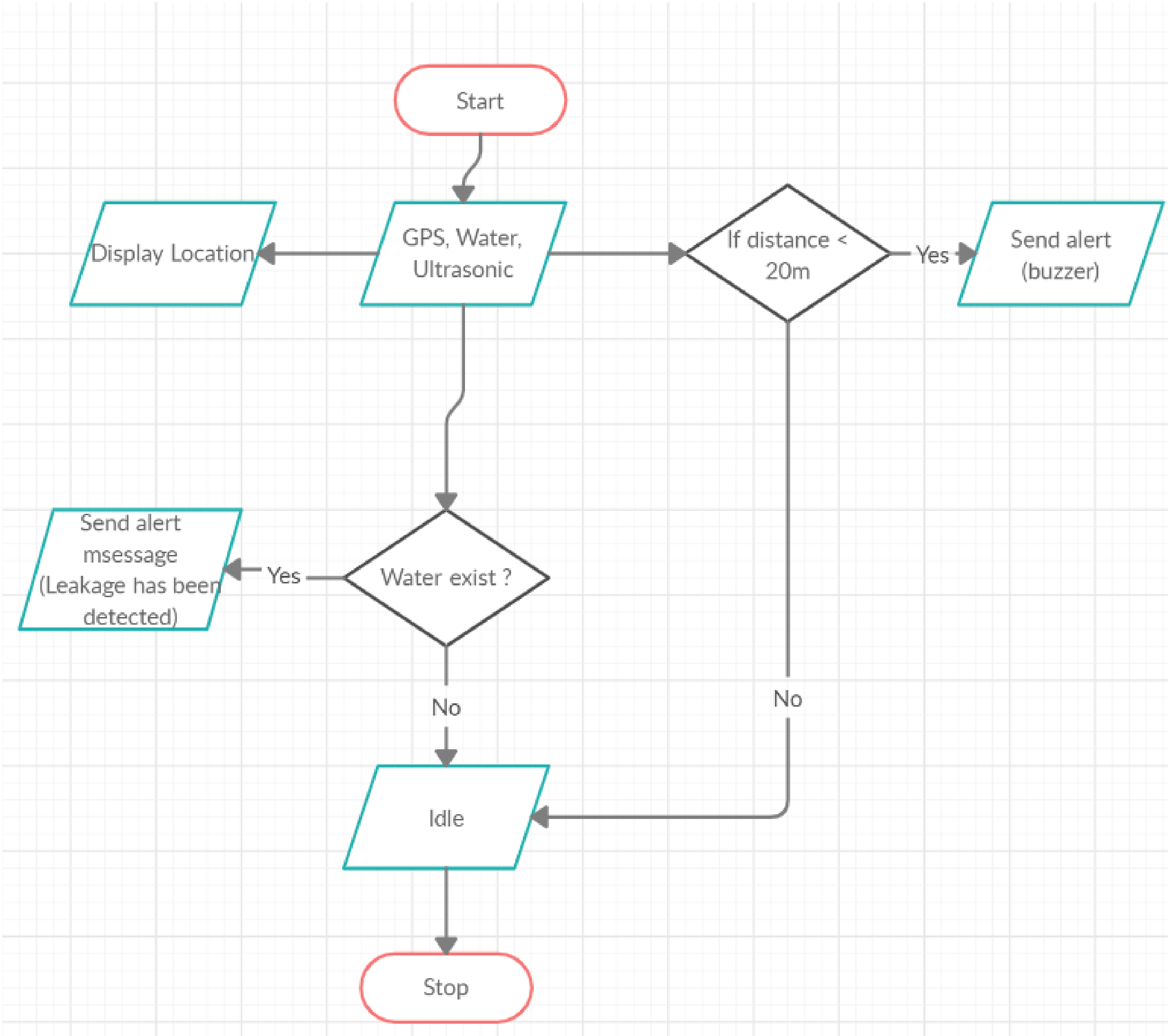

Figure 10 Flow chart of the proposed system

On the other hand, in **figure 11**, the author of this study designed a sequence diagram of the proposed system, which shows the system operation's activities. This diagram describes the interaction between objects and system processes of the IoT based monitoring and tracking system for sailing boats, developed for enhancing marine transportation in Zanzibar port.

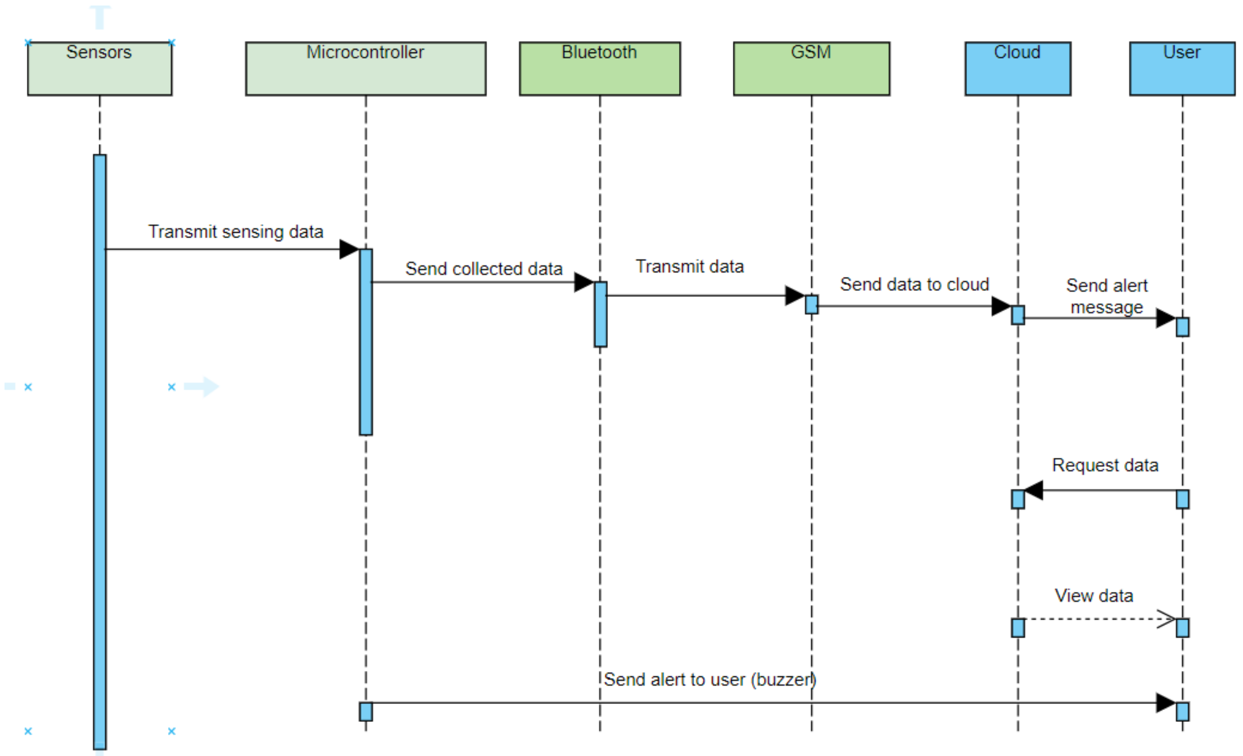

Figure 11 Sequence diagram of the proposed system

Chapter 4

Introduction

In this research, the simulation was used to validate the designed system before developing a prototype using a physical device. This chapter explains the simulation designed in this thesis and describes each module used in the simulation. This chapter also includes the results obtained by the simulation.

4.1 Simulation of the proposed system

The proposed system has been simulated in PROTEUS simulation software before creating the actual physical prototype. This simulation is a virtual prototype. For this purpose, Arduino 1.8.9 and Proteus 8.7 versions were used. The circuit includes an ultrasonic sensor, a water detector, a GPS module, an LED controlled by the Arduino Uno microcontroller, and a virtual monitor for displaying the results. Using the Proteus environment makes the designer validate the whole system's behavior before the actual implementation. Proteus is a software used for simulation and design developed by Lab center electronics for electrical and electronic circuit design. It has a wide range of components in its library, including sensors, microcontrollers, resistors, and others [32]. **Figure 12** shows the Proteus simulation model for the proposed system. The water leakage, proximity, and Location (Longitude and latitude points) are the parameters simulated in the proteus software. The threshold value of the distance between the boat and an obstacle was set at a minimum of 700 centimeters. As the boat approaches an obstacle to less than 700 centimeters, the buzzer generates the tone until the captain takes action. We used a test pin obtained in the device module for data collection (see **Table 2**) and collected data saved to the excel file. While the alert message is being displayed on the black screen, the black screen here is assumed as the mobile phone interface. **Table 1** shows the monitored parameters with sensors used in the simulation environment.

Table 1 Monitored parameters

SNo	Monitored parameters		Sensor Used
1	Water	With the presence of water inside the boat, the system will send an alert message to the black screen	Water detector
2	Movement/Collision	Distance between the boat and an obstacle should be above 700 centimeters to avoid a collision. If it is below 700 centimeters, the system should turn on a sound.	Ultrasonic
3	Position	Identify longitude and latitude after every specified time.	GPS

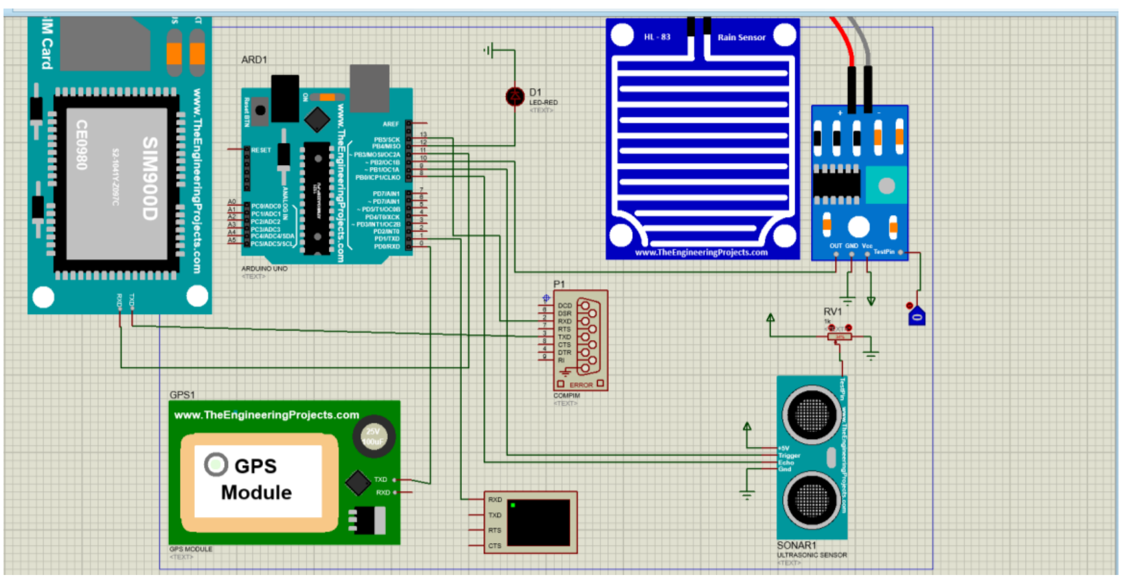

Figure 12 Proteus simulation model for the proposed system

Table 2 below shows some critical setup used for collecting data during the simulation.

Table 2 Data collection test pin

SNo	Sensor	Data collection test pin
1	Water detector	If Test pin = 1, there is water leakage If Test pin = 0, there is no water leakage
2	Ultrasonic	Test pin used to adjust the distance. When the distance is below the threshold value, the LED in PROTEUS will turn **ON** red light.
3	GPS	Latitude and longitude are automatically shown on a black screen.

4.2 Simulation results

Figure 13 shows the GPS sensor and water sensor results, in which longitudes and latitudes of the boat position are displayed on a virtual screen. Also, an alert message called "**Leakage has been detected"** is displayed on the black screen. It happened when the test pin in the water detector was set to 1. Besides, the GSM module is also used for sending data to the server.

Figure 13 Proteus simulation model with GPS and water leakage results

Regarding the result of the collision detection scenario, when the ultrasonic sensor has detected the distance below the threshold value, the red light turns ON, as seen in **figure 14**. The light means that the boat is approaching an obstacle.

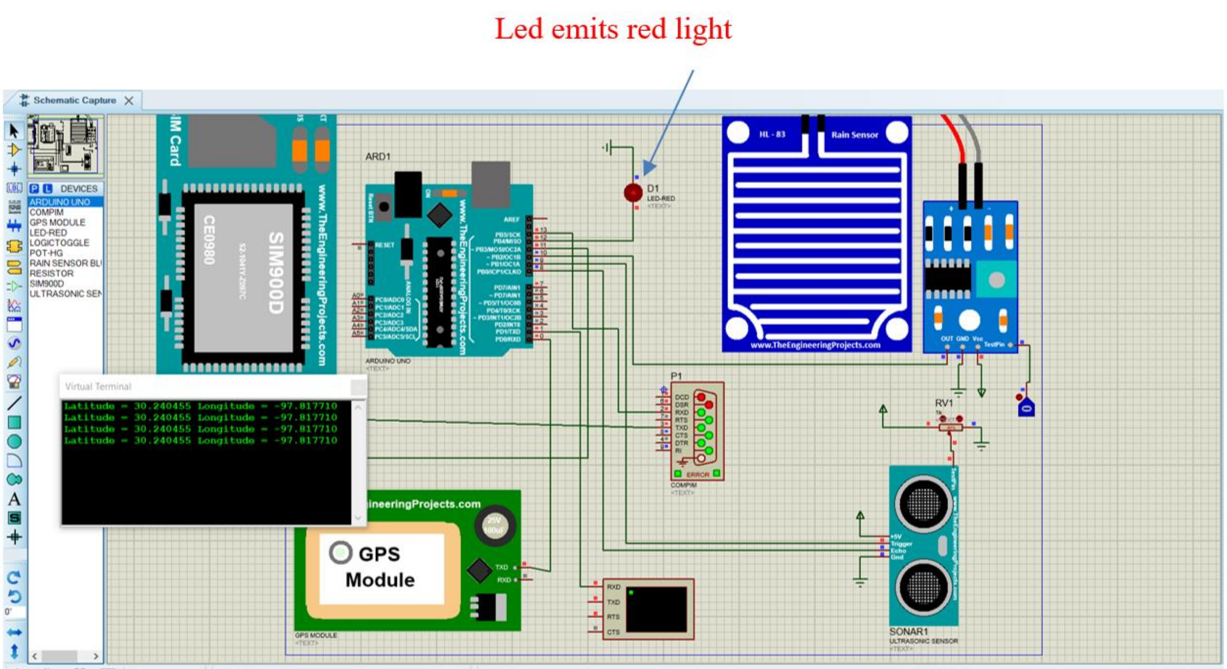

Figure 14 Collision detection simulation

Chapter 5

Introduction

In this thesis, the prototype of the proposed system also was built by using physical devices. The devices used are Arduino Uno, ultrasonic sensor, water detector, GPS, and smartphone. This chapter describes the experimental setup of the system, finally showing the results of the system.

5.1 System prototype

After the simulation, the researcher built a prototype by using physical devices. The simulation programs' codes were transferred to real Arduino board hardware for the prototype's real development. The program uploaded into the Arduino Uno is written in the C programming language. Arduino IDE software is used for Uploading programs into Arduino. Furthermore, a simple mobile app called ZMA app was designed as the user interface for information visualization and reception of alert messages.

Figure 15 shows the experimental setup of an IoT based system for tracking and monitoring the small boats. The setup contains a Microcontroller that is an Arduino UNO, also sensors which are ultrasonic and water detector sensor, there is an actuator that is a buzzer. Other devices are Bluetooth device which is interfaced with Arduino, GPS, and GSM. In this system, Arduino UNO sends the sensor information to the Bluetooth then sends it to the cloud server using the GSM module. The data of these sensors are sent to the mobile app with the boat location. The sensors are interfaced with the Arduino UNO and are given a power supply. The Arduino UNO reads values from the sensors, and this microcontroller posts the information to the cloud server through the GSM module. When the water is detected in a boat, the system automatically sends an alert message to the user through a mobile application. Similarly, as the boat approaches an obstacle less than 700 centimeters, the buzzer generates the tone until the captain takes action.

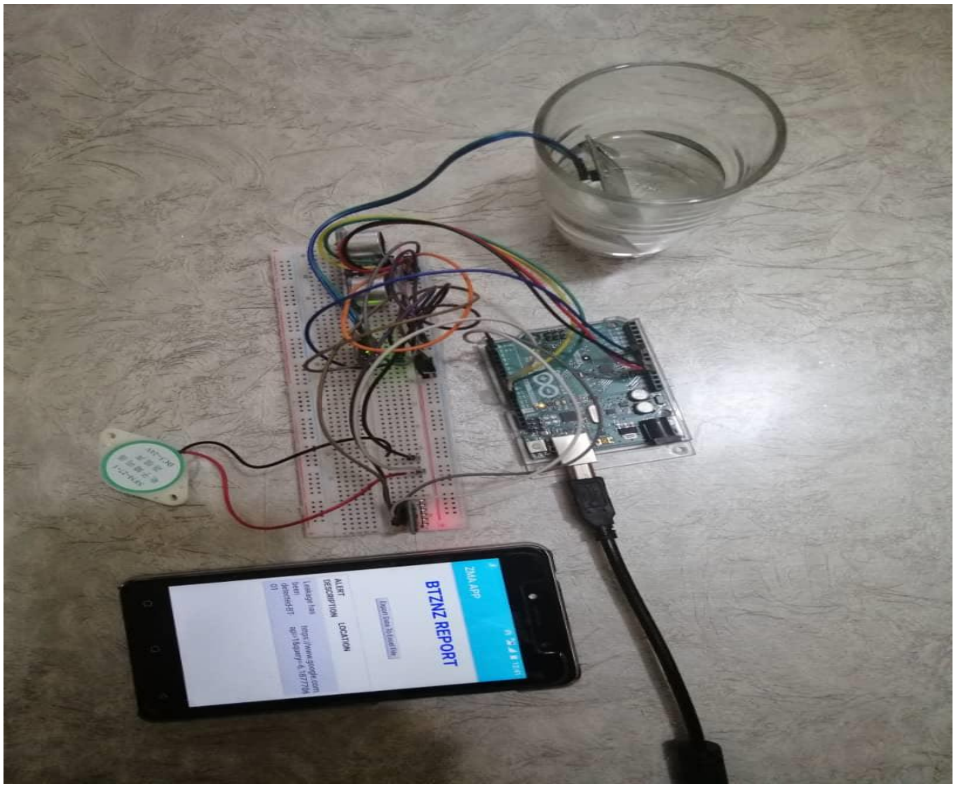

Figure 15. Experiment setup

5.2 System results

An android app developed using Android Studio is used to view the boat's report through the user's mobile phone. The application is called the ZMA app, and the ZMA app interface can be viewed in **figure 16**.

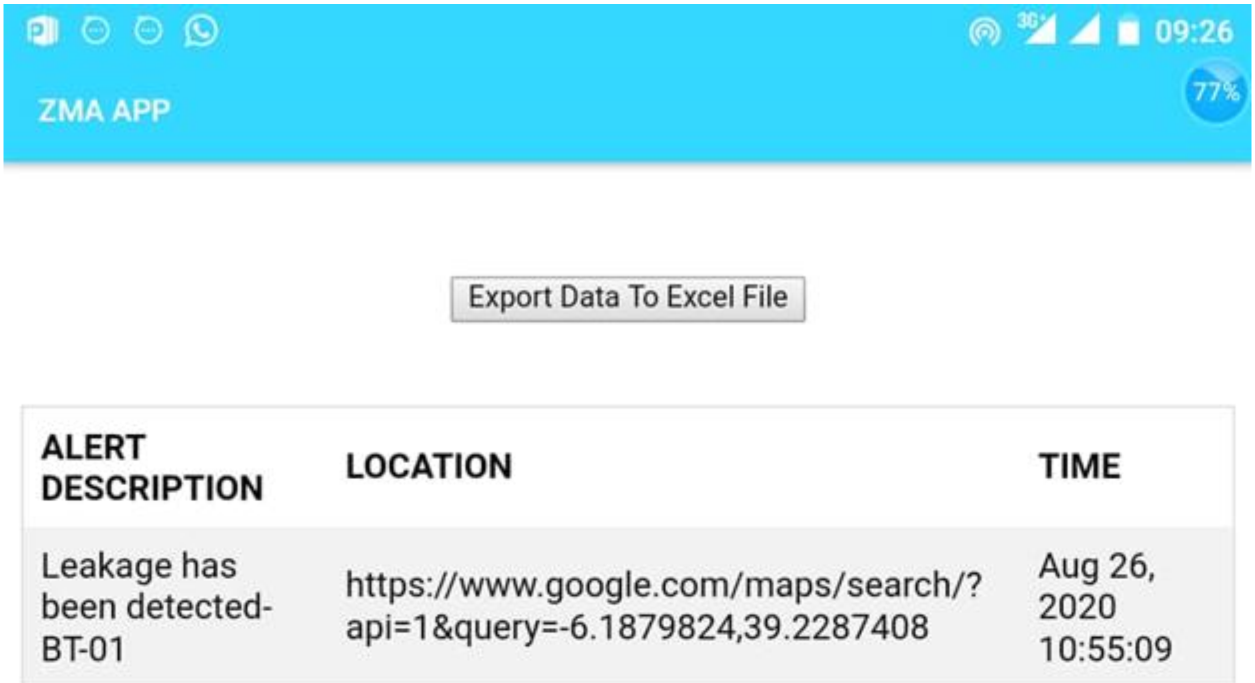

Figure 16. Android app

This project's final output is the functional IoT-based prototype for tracking and monitoring small sailing boats, as shown in **figure 15**. **Figures 17** and **18** show the graphs from the serial plotter, which shows the distance readings from the ultrasonic sensor and water detection reading from the water detector. Besides, **Figure 20** shows the position of the boat on the map.

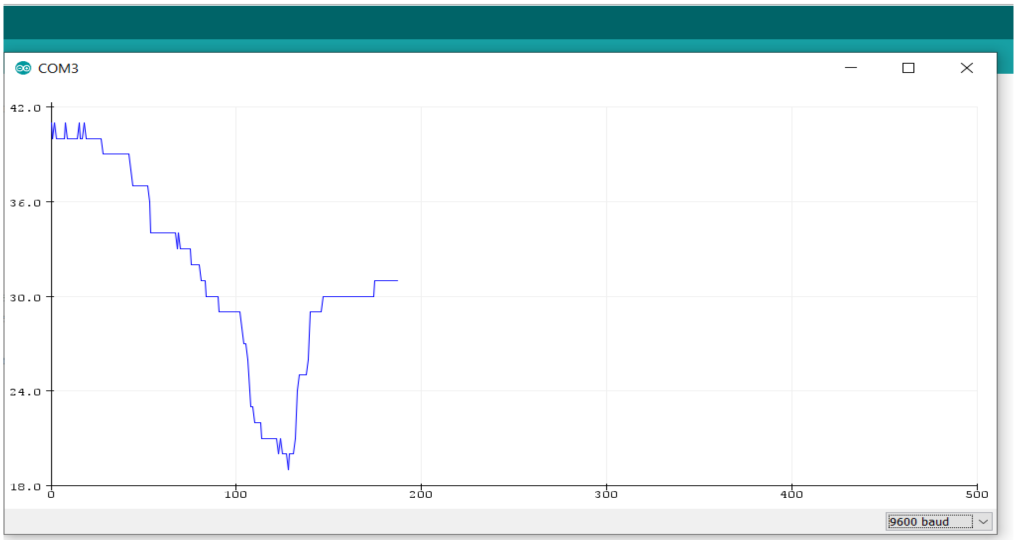

Figure 17. Distance reading from Ultrasonic sensor

In **figure 17**, the vertical line indicates the value of distance, and the horizontal line indicates time. As the graph goes down, it means that the boat approaches an obstacle. In **figure 18**, the horizontal line indicates the water sensor's value, and the horizontal indicates time. Therefore when the graph goes down, it means that the water is detected in the boat.

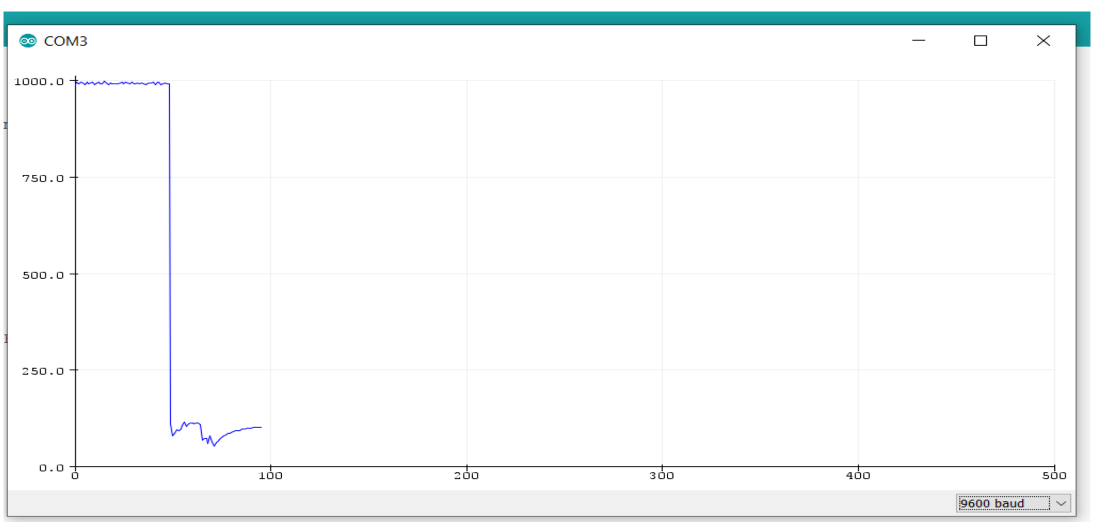

Figure 18. Water detection reading

Moreover, **Figure 16** shows the boat's report that includes an alert message, Location of the boat, and event time, on the mobile app. Similarly, if the user needs a manual report, he/she can export the data to an excel file.

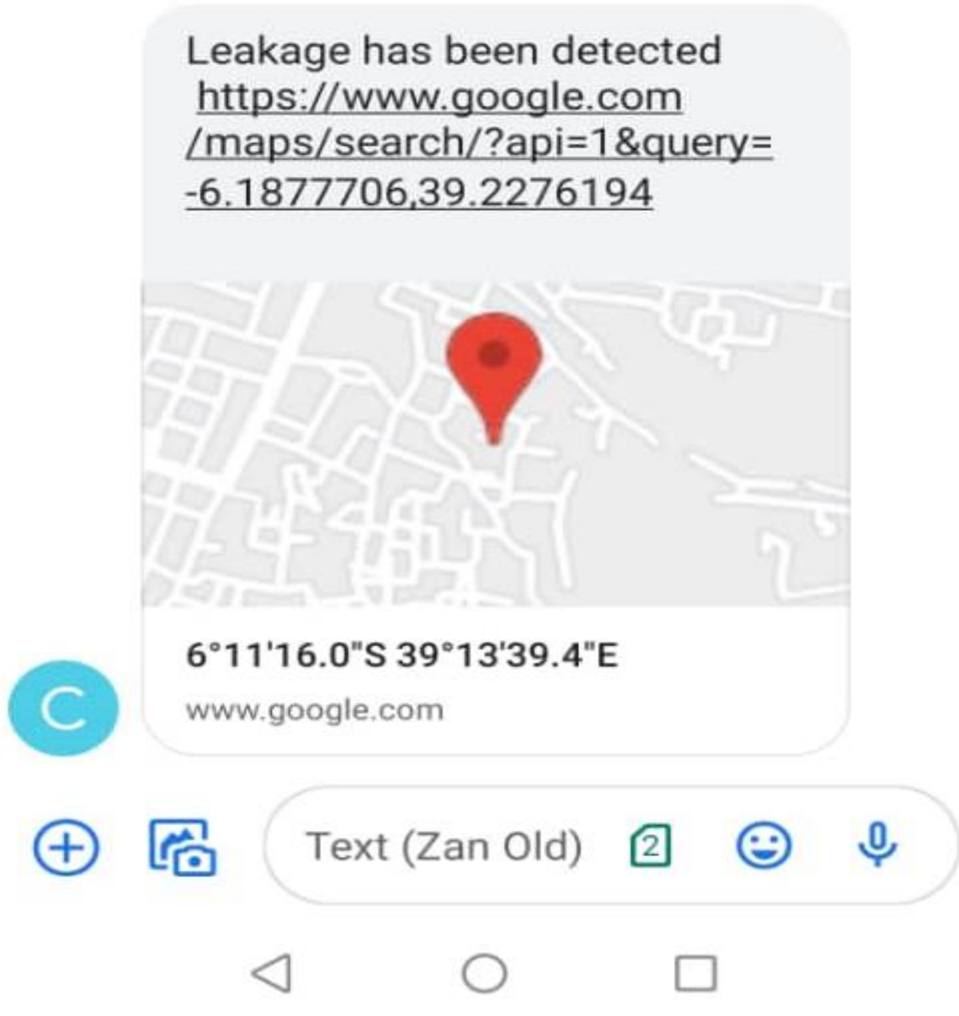

Figure 19 Alert message "leakage has been detected."

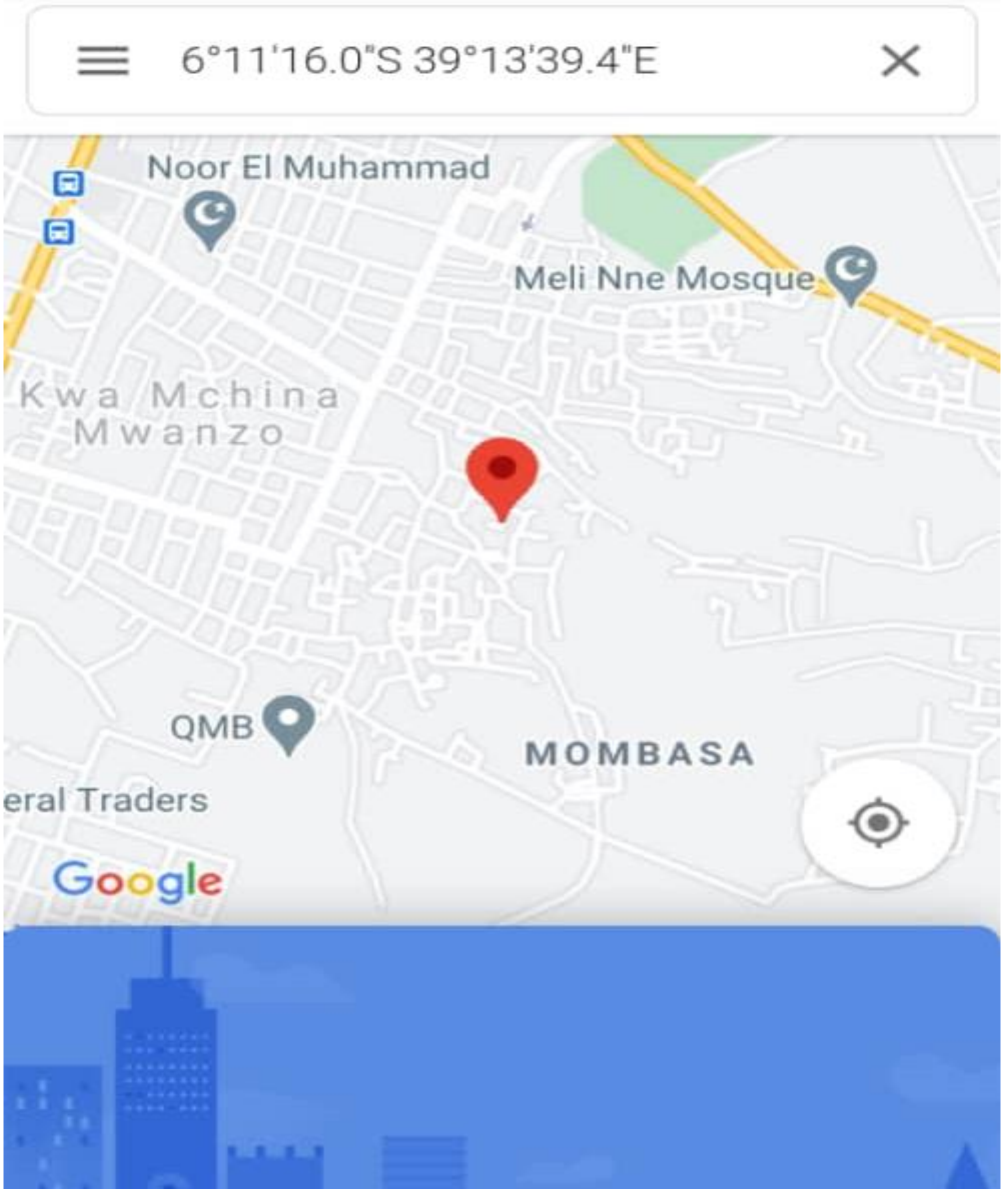

Figure 20 Position of the boat: Results from GPS

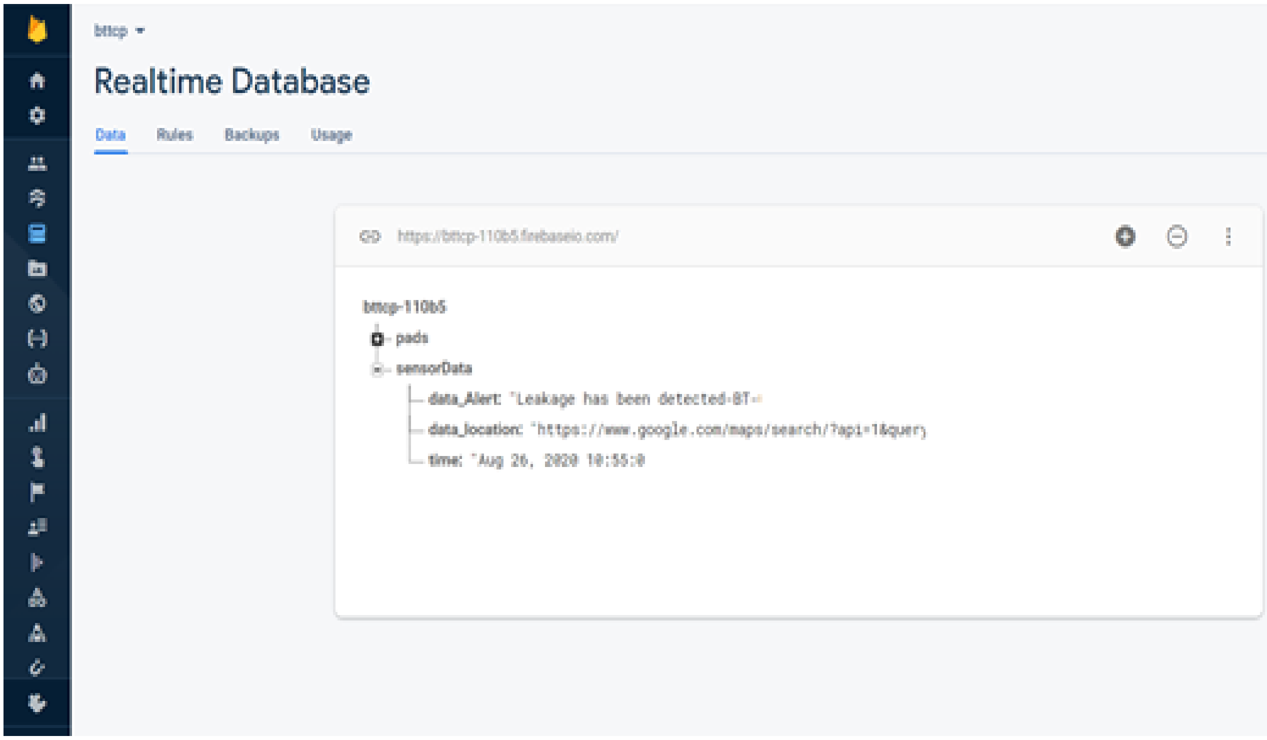

Figure 21. Real-Time cloud database

Figure 21 shows the database which stores all information about the boats, including the alert message, Location, and time. It is a cloud database, which is a real-time database.

Chapter 6

Conclusion and Future work

This chapter summarizes all the contributions of this study, and finally, some recommendations for future work have been pointed out.

6.1 Conclusion

This project explores the use of the Internet of things in maritime transportation. The project's works include requirement analysis, literature review, system design, simulation, and experimental work of the IoT-based prototype to monitor and track small sailing boats. The proposed prototype will improve the marine transportation system's efficiency and sustainable management of small sailing boats in Zanzibar marine port. It will be envisaged to facilitate safe marine transportation travelers and also increase traveler’s trust. The proposed prototype development includes a microcontroller called Arduino UNO, a water detector, ultrasonic sensor, GPS and buzzer, GSM, and Bluetooth as communication technology, cloud Server, and Firebase database application for data processing and storage. The Internet is also used for linking cloud platform and mobile application users. The developed prototype should be tested and implemented in a real situation in the field however, that part was not covered in this work. This study has been lengthy. It enables us to explore and gain a comprehensive understanding of IoT and other emerging technologies, including cloud computing.

6.2 Limitations and future work

This thesis's main focus was to develop an IoT-based smart system for tracking and monitoring small sailing boat for Zanzibar port. However, the developed system was for completion of the author’s Master's degree studies. Thus, there are some limitations from this research project that needs to be addressed in future studies. This proposed prototype should be validated in the

Zanzibar coastline's real environment to be improved. The system should also be implemented using cost-effective communication technology like LoRaWAN technology instead of GSM technology. GSM is a good option as it is reliable and covers long-range, but for actual usage, especially in the least developing countries, Lora is the best.

List of References

[1] K. K. Patel, S. M. Patel, and P. G. Scholar, “Internet of Things-IOT: Definition, Characteristics, Architecture, Enabling Technologies, Application & Future Challenges,” *Int. J. Eng. Sci. Comput.*, vol. 6, no. 5, pp. 1–10, 2016, doi: 10.4010/2016.1482.

[2] A. Reddy, “Reaping the Benefits of the Internet of Things,” *Cognizant*, no. May, p. 10, 2014.

[3] M. K. Hasan, R. Z. Rusho, T. M. Hossain, T. K. Ghosh, and M. Ahmad, “Design and simulation of cost effective wireless EEG acquisition system for patient monitoring,” *2014 Int. Conf. Informatics, Electron. Vision, ICIEV 2014*, pp. 1–5, 2014, doi: 10.1109/ICIEV.2014.6850797.

[4] F. Vannieuwenborg, S. Verbrugge, and D. Colle, “Designing and evaluating a smart cow monitoring system from a techno-economic perspective,” *Jt. 13th CTTE 10th C. Conf. Internet Things - Bus. Model. Users, Networks*, vol. 2018-January, pp. 1–8, 2017, doi: 10.1109/CTTE.2017.8260982.

[5] A. R. Al-Ali, I. Zualkernan, and F. Aloul, “A mobile GPRS-sensors array for air pollution monitoring,” *IEEE Sens. J.*, vol. 10, no. 10, pp. 1666–1671, 2010, doi:10.1109/JSEN.2010.2045890.

[6] A. S, D. Nair, R. K. Sampath, and G. S. Nair, “IOT Based Smart Gas Monitoring System,” *IOSR J. Electr. Electron. Eng.*, pp. 2278–1676.

[7] R. Sriram, M. Shafaf, V. K. T, and K. Vidhya, “Environmental Condition Monitoring System for the Industries,” no. April, 2016.

[8] M. Duarte *et al.*, “Application of swarm robotics systems to marine environmental monitoring,” *Ocean. 2016 - Shanghai*, pp. 1–8, 2016, doi: 10.1109/OCEANSAP.2016.7485429.

[9] G. Singh, N. Bisht, P. Bisht, and P. Singh, “Iot Based Flood Monitoring and Alerting System with Weather Forecasting,” no. 6, pp. 559–563, 2020, doi: 10.35940/ijitee.F3854.049620.

[10] T. Xia, M. M. Wang, J. Zhang, and L. Wang, "Maritime Internet of Things: Challenges and Solutions," *IEEE Wirel. Commun.*, vol. 27, no. 2, pp. 188–196, 2020, doi: 10.1109/MWC.001.1900322.

[11] R. Sanchez-Iborra, I. G. Liaño, C. Simoes, E. Couñago, and A. F. Skarmeta, "Tracking and monitoring system based on LoRa technology for lightweight boats," *Electron.*, vol. 8, no. 1, pp. 1–18, 2019, doi: 10.3390/electronics8010015.

[12] "Zanzibar Island." [Online]. Available: https://www.tanzaniatourism.go.tz/en/destination/zanzibar-island. [Accessed: 19-Feb-2020].

[13] "ZMA Seminor and Work." [Online]. Available: https://www.zma.go.tz/national_workshop_15-19_2012.php. [Accessed: 19-Feb-2020].

[14] E. Pramunanto, M. Ulfa, and A. Kurniawan, "Coast Panic-Emergency Situation Monitoring System on West and East Sailing Lane of Surabaya Using LORAWAN Technology," *2018 Int. Conf. Comput. Eng. Netw. Intell. Multimedia, CENIM 2018 - Proceeding*, pp. 100–105, 2018, doi: 10.1109/CENIM.2018.8710908.

[15] A. Ahmadi, A. Bigdeli, M. Baktashmotlagh, and B. C. Lovell, "A wireless mesh sensor network for hazard and safety monitoring at the Port of Brisbane," *Proc. - Conf. Local Comput. Networks, LCN*, pp. 180–183, 2012, doi: 10.1109/LCN.2012.6423601.

[16] L. Li, J. Ren, and Q. Zhu, "On the application of LoRa LPWAN technology in Sailing Monitoring System," *2017 13th Annu. Conf. Wirel. On-Demand Netw. Syst. Serv. WONS 2017 - Proc.*, pp. 77–80, 2017, doi: 10.1109/WONS.2017.7888762.

[17] J. D. Bandung, "DEVELOPMENT OF PROTOTYPE TRADITIONAL SHIP PASSENGER MONITORING SYSTEM Teknik Informatika – Universitas Komputer Indonesia," 2017.

[18] K. L. K. Sudheera, G. G. N. Sandamali, W. N. D. C. Sandaruwan, and N. D. Jayasundere, "Offline tracking system for deep sea going vessels using GPS and GPRS," *2015 8th Int.*

Conf. Ubi-Media Comput. UMEDIA 2015 - Conf. Proceeedings, pp. 55–60, 2015, doi: 10.1109/UMEDIA.2015.7297428.

[19] M. Reggiannini *et al.*, “Remote sensing for maritime prompt monitoring,” *J. Mar. Sci. Eng.*, vol. 7, no. 7, 2019, doi: 10.3390/jmse7070202.

[20] G. Margarit, J. A. B. Milanés, and A. Tabasco, “Operational ship monitoring system based on Synthetic Aperture Radar processing,” *Remote Sens.*, vol. 1, no. 3, pp. 375–392, 2009, doi: 10.3390/rs1030375.

[21] C. Claramunt and T. Devogele, “Information Fusion and Geographic Information Systems,” *Inf. Fusion Geogr. Inf. Syst.*, no. May 2014, 2007, doi: 10.1007/978-3-540-37629-3.

[22] G. Xu, W. Shen, and X. Wang, “Applications of wireless sensor networks in marine environment monitoring: A survey,” *Sensors (Switzerland)*, vol. 14, no. 9, pp. 16932–16954, 2014, doi: 10.3390/s140916932.

[23] X. Yang, K. Liu, Y. Cui, and J. Zhang, “Modeling and simulation for maritime surveillance sensor networks,” *Isc. 2010 - 2010 10th Int. Symp. Commun. Inf. Technol.*, pp. 215–219, 2010, doi: 10.1109/ISCIT.2010.5664841.

[24] Z. Zainuddin, Wardi, and Y. Nantan, “Applying maritime wireless communication to support vessel monitoring,” *Proc. - 2017 4th Int. Conf. Inf. Technol. Comput. Electr. Eng. ICITACEE 2017*, vol. 2018-Janua, pp. 158–161, 2017, doi: 10.1109/ICITACEE.2017.8257695.

[25] “Arduino - Water Detector / Sensor.” [Online]. Available: https://www.tutorialspoint.com/arduino/arduino_water_detector_sensor.htm. [Accessed: 30-May-2020].

[26] “Ultrasonic Sensor Module HC-SR-04 by Robokart.” [Online]. Available: https://www.amazon.in/Ultrasonic-Sensor-Module-HC-SR-04-Robokart/dp/B00ZNB01HI. [Accessed: 30-May-2020].

[27] “NEO 6M GPS Module.” [Online]. Available: https://www.indiamart.com/proddetail/neo-6m-gps-module-19819679162.html. [Accessed: 30-May-2020].

[28] “Buzzer, piezo-electric, DC.” [Online]. Available: https://www.homesciencetools.com/product/buzzer-piezo-electric-dc/. [Accessed: 30-May-2020].

[29] “Arduino Uno Rev. 3.” [Online]. Available: https://www.generationrobots.com/en/401867-arduino-uno-rev-3.html. [Accessed: 30-May-2020

[30] “What is Bluetooth Class?” [Online]. Available: https://www.lairdconnect.com/support/faqs/what-bluetooth-class. [Accessed: 16-Sep-2020].

[31] “GSM - Overview.” [Online]. Available: https://www.tutorialspoint.com/gsm/gsm_overview.htm. [Accessed: 15-Sep-2020].

[32] “Proteus PCB Design and Simulation Software – Introduction.” [Online]. Available: http://www.circuitstoday.com/proteus-software-introduction. [Accessed: 17-May-2020].

[33] M. Fezari and A. Al Dahoud, “Integrated Development Environment ‘ IDE ’ For Arduino,” *ResearchGate*, no. October, pp. 1–12, 2018.

[34] “Firebase Realtime Database.” [Online]. Available: https://firebase.google.com/docs/database. [Accessed: 09-Sep-2020].

Appendices

Appendix 1: Programming code

```
const int trigPin = 8;

const int echoPin = 9;

long duration;

int distance;

void setup() {

 pinMode(A0, INPUT);

Serial.begin(9600);

pinMode(trigPin, OUTPUT);

pinMode(echoPin, INPUT);

pinMode(11,OUTPUT);

}

void loop() {

ultrasonic();

rain();

}

void rain(){

int x=analogRead(A0);

  if(x <=155){
```

```
    Serial.print("leakage has been detected-BT-01");
    delay(5000);
  }
}
void ultrasonic(){
digitalWrite(trigPin, LOW);
delayMicroseconds(2);
digitalWrite(trigPin, HIGH);
delayMicroseconds(10);
digitalWrite(trigPin, LOW);
duration = pulseIn(echoPin, HIGH);
distance= duration*0.034/2;
delay (1000);
if (distance < 20){
  tone(11, 1200);
    delay(100);
    noTone(11);
    delay(100);
  }
  else {
```

```
    noTone(11); }
}
```