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of

Master of Engineering in the faculty of Electrical Engineering

SMART IRRIGATION SYSTEM FOR FARM APPLICATION USING LORA TECHNOLOGY

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Declaration

I, Alfredo Pequeno Duda, declare that the contents of this dissertation/thesis represent my own unaided work, and that the dissertation/thesis has not previously been submitted for academic examination towards any qualification. Furthermore, it represents my own opinions and not necessarily those of the Cape Peninsula University of Technology.

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Signed **Date**

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- Special thanks and gratitude goes to my parents and family in Angola for their support and encouragement throughout my studies.

Abstract

In terms of information generation for future goods and services, the Internet of Things is now one of the most promising fields. One of the uses for the Internet of Things is smart farming, which automates irrigation systems and monitors agricultural fields to save water therefore, this work presents an intelligent irrigation system for farm application using LoRa technology which will help farmers in the optimisation and management of water for irrigation of crops and prevent water loss and minimizing the cost of labour. The system consists of two main hardware, the LoRa sensor node and LoRaWAN gateway. The system employs smart sensors, LoRa communication device, smart control and cloud-based monitoring and control. The smart sensors modules employed on the LoRa node consist of temperature and humidity sensor, capacitive soil moisture sensor, rain sensor and passive infrared sensor. At the same time, the sensors gather the environmental data, which are then transmitted to the LoRa gateway via LoRa communication using Serial Peripheral Interface protocol. Moreover, a cloud monitoring system has been developed for real-time data monitoring, alarm and pump control.

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GLOSSARY OF TERMS

Abbreviations

LoRa	Long Range
IoT	Internet of things
BSU	Base Station Unit
TN	Terminal node
MQTT	Message Queue Telemetry Transportation
RF	Radio Frequency
GSM	Global System for Mobile Communications
DC	Direct current
IDE	Integrated Development Environment
MCU	Microcontroller
LPWAN	Low Power Wide Area Network
PCB	Printed circuit board
RF	Radio Frequency
db	Decibel
WSN	Wireless network
SPI	Serial peripheral interface
UART	Universal Asynchronous Receiver Transmitter
LNA	Low noise amplifier
PLL	Phase Lock Loop
PA	Power amplifier
CRC	Cyclic Redundancy Check
LDO	Low Dropout
VSWR	Voltage standing wave ratio

CHAPTER 1

Introduction

Water is one of the source of life for every living and also needed for growth as example the agriculture sector (Ragab, 2022). Traditionally, irrigation system was done manually by making water available to crops without knowing the appropriate amount of water need for the crops. These old systems have been source of water waste in agriculture resulting in the destruction of crops. By introducing automation in irrigation, it assists the farmers in monitoring the amount of water being used which avoids over saturated crops and improving yields and cost-effectiveness (Rehman A, 2022), (Chethan.R, 2018).

The created irrigation system, which is microcontroller-based, will function permanently for indeterminate basic measure, even in certain abnormal circumstances, for the purpose of reading and performing at remote locations (G.Ravi kumar, 2018).

1.1 Statement of the research problem

Irrigation has been the major feature in agriculture and different irrigation systems have been developed over the past years. However, many irrigation systems that are used today do not fulfil the process of applying controlled amount of water to crops at the needed interval and revegetate disturbed soil in dry areas and water optimization during less rainfall period. Many of the systems being time consuming, inefficient mechanism of regulation, requires intense labour as well as overwatering that eventually result in water wastage (Ahmad Din, 2022).

1.2 Background to the research problem

Over thousands of years, Human race have been relying on agriculture for food production and irrigation for watering their crops. Agriculture is the use of land for the breeding of animals and the growing of crops to produce food, medicinal herbs, and other goods that support and improve life (Singh, 2022). Irrigation involves the process of watering land or oil to assist with the growth of crops, landscape maintenance and revegetation of damaged soil in dry areas and during period of inadequate rainfall (A.M Rasyid, 2015).

Irrigation is still a crucial component of effective agricultural practices everywhere in the world. Irrigation system utilization, however, is not very common in many regions of the world. For watering plants or crops, they still use human labour. Additionally, the current irrigation systems use inefficient pressure and flow rates that waste water.

A problem that many regions of the world are dealing with is water scarcity. For instance, Southern Africa experiences severe water shortage issues as a result of recurrent droughts, the degradation of surface resources, and rising water demands in agriculture, which must fulfil the rising demand for food from an expanding population (Greenwell Matchaya, 2019).

The fundamental growth of plants requires water. Plants will become stressed and perish, lowering the quality of the plants, when there is not enough water available. In order to solve this issue, an intelligent, automated irrigation system is required. In order to decrease water waste, reduce the amount of labour required for watering, and ultimately save time, a smart irrigation system will be in charge of effectively watering the crops (R.PRATHIPA, 2021).

The two most important components of irrigation are timing and quantity of watering. It is possible to automatically predict when plants might require water by using sensors and other techniques. The system will be made up of sensors that measure the amount of soil moisture, and it will turn on the pump automatically when the amount of moisture falls below the threshold required for healthy plant growth. When the device achieves the appropriate level of soil moisture for the given time, it will automatically shut off. The smart irrigation system's microcontroller will function as the system's brain, and it will also be built using dependable components at affordable prices.

The algorithm that controls an irrigation system is what gives it intelligence. creating highly precise, cost-effective, and computationally efficient algorithms for the best crop output (Supreme Ayewoh Okoh, 2021).

1.3 Hypotheses or research questions.

In order to design and build a Smart irrigation system using LoRa technology, many questions were addressed which are:

- What are the agricultural climate factors and their influence in the development process of agricultural products?
- What kind of sensor technologies will be used in the design of the system?
- How will module integration be and design specification achieved?
- What hardware and software will be needed to achieve best results?
- Which are the existing LoRa technologies and why LoRa?
- Is it possible to create a system that accommodates all possible agricultural scenarios, regardless of the user?
- What is the impact of smart irrigation in water saving strategy?

1.4 Objectives of the research.

1.4.1 Aim:

This research aims to design and implement a Smart irrigation system for farm application using LoRa technology which will help the farmers in the optimization and management of water for irrigation of crops and prevent water loss and minimizing the cost of labour.

1.4.2 Objectives:

The objectives of this research are the following:

- Design and implement a Smart Irrigation System capable of sensing agricultural parameters such as Ambient temperature, humidity, moisture content of the soil etc.
- Transferring sensor data from crop field to the control station for decision making.
- Monitoring water level in the reservoir, control the water pump valve and provide the ability to set the timer of the irrigation period.

- Formulate the Smart irrigation algorithm based on the data obtained from the sensors.
- Implement the algorithm above mentioned and evaluate the performance of the system.

The following aspect will be considered in the choice of the final design solution:

- Water-saving.
- Human intervention.
- Reliability.
- Installation cost and power consumption of the system.

1.5 Significance of the research

This study will be a significant endeavour in saving water for the environment and also beneficial mostly in agriculture field with the following advantages:

- It will help to minimal wastage of water and save money on unnecessary water costs.
- It will help to minimize human effort, labour and time.
- It will help to achieve precision agriculture.
- It will assist in the healthy growth of the plants and crops.

1.6 Structure of this thesis

The thesis is structured as follows:

Chapter 2 consider the requirements to develop the system described in this chapter.

Chapter 3 discuss literature review and previous work done in similar field.

Chapter 4 covers the theory and hardware selected for use in this project.

Chapter 5 covers the hardware design of the LoRa sensor node and LoRaWAN gateway.

Chapter 6 describe the software design for the LoRa sensor node and LoRaWAN gateway.

Chapter 7 analyses measurements and results from field tests.

Chapter 8 recommendations to investigators that wish to further pursue this research.

Chapter 9 covers the conclusion of the research.

CHAPTER 2

This chapter presents the requirements to develop the Smart Irrigation System for farm application using LoRa technology. A LoRa Sensor Node and a LoRaWAN gateway will be deployed to achieve those requirements.

2.1 Requirements to develop the system described in this chapter

The purpose of the smart irrigation system using LoRa technology, is to monitor the soil moisture content, temperature, humidity, rain as well as the intrusion of the LoRa sensor node in real time. It has strict power requirements and therefore, during normal period, the LoRa sensor node is expected to transmit data every 10min. if the module detects a critical situation as the intrusion detection, it will transmit the PIR data immediately.

The LoRa module antenna will be situated within the PCB on the top left position, which is mounted onto the antenna mounting hole on the PCB. This mounting technique provides better signal range which allows better connectivity between the nodes and gateway.

The data transmitted by the LoRa sensor node will differ depending on the distance and signal strength. Therefore, a payload with 50-bytes size is expected. The communication between the LoRa sensor node and LoRaWAN gateway is bidirectional.

The solution must also consider the challenges posed by the outdoor environment in which the LoRa Sensor node will be deployed. the system is expected to be deployed in farms where line-of-side is achieved which allow a long range communication, in addition, the solution will therefore need to be energy self-sufficient.

Due to the low number of messages and small amount of data sent from the LoRa sensor node, the system will not have to focus on high throughput therefore, the communication from LoRa sensor node may need to take place over extended ranges. The choice of operating frequency and RF module have a large impact on the range over which their system could communicate. Therefore, an operating frequency and RF module will need is chosen, with a focus on long range rather than high bandwidth.

The lack of formal electricity supply in farms, the sensor nodes must be battery powered, Therefore, all sensors attached to the LoRa sensor node must be running at low-power mode.

2.2 Summary

In this chapter, a smart irrigation system for farm application using LoRa technology was presented as a way to deliver data from the crop to the cloud or base station. The project consists of LoRa sensor node and LoRaWAN gateway which links private network to the public network.

CHAPTER 3

Literature Review

This chapter introduces LPWAN, describe the LoRa technology, its features, LoRaWAN, its network architecture and discuss previous studies which implemented LPWAN to monitor environmental contents and smart irrigations.

3.1 LPWAN

LPWAN technologies such as LoRa, Sigfox, LTE Cat M1 and MB-IoT have arisen to empower a large portion of the development of IoT market and applications that they are used, differ from each other in their requirements and their usage (Ayesha Siddique, 2019), (Tu, 2022). Given the enormous market chance and advantages to businesses and consumers, there is significant interest in IoT and multiple approaches to deal with the trending market.

	Cat-1	Cat-0	eMTC	NB-IoT	EC-GSM	LoRa	Sigfox
Specification	3GPP	3GPP	3GPP	3GPP	3GPP	Open	Private
Spectrum	Licensed	Licensed	Licensed	Licensed	Licensed	Unlicensed	Unlicensed
Channel BW	1.4MHz to 20MHz	1.4MHz to 20MHz	1.4MHz	180KHz	200KHz	7.8 to 500KHz	100Hz
System BW	1.4MHz to 20MHz	1.4MHz to 20MHz	1.4MHz	180KHz	1.4MHz	125KHz	200KHz
Peak Data Rate	UL: 5Mbps DL: 10Mbps	UL: 1Mbps DL: 2Mbps	UL: 1Mbps DL: 800kbps	UL: 204.8kbps DL: 234.7kbps	UL: 74kbps DL: 74kbps	180bps~37.5kbps	UL: 100bps DL: 600bps
Max. number of Messages per day	unlimited	unlimited	unlimited	unlimited	unlimited	50000(BTS)	140(Device) 50000(BTS)
Device Peak Tx Power	23dBm	23dBm	23dBm	23dBm	26dBm	14dBm	14dBm
MCL (Maximum Coupling Loss)	144dB	144dB	156dB	164dB	164dB	UL: 156dB DL: 168(SF12, BW7.8) 132(SF6, BW125)	UL: 156dB DL: 147dB
Device Power Consumption	Medium	Medium	Low-Medium	Low	Low	Low-Medium	Low

TABLE 1: LPWAN Technologies and their key aspects.

LPWAN is becoming one of the fastest growing technology in the internet of things ecosystem since 2013 and is helping to drive such technological movement. LPWAN is a great solution for mobile devices that has to send data over long ranges while keeping the battery life longer (SEMTECH, 2017).

Due to the high replacement costs resulting from nodes being dispersed over broad geographical areas, having a long battery life is essential in agriculture. When compared to competing technologies (such GSM, 3G, and LTE) (Bišćan J, 2022), (GAITAN, 2022), LPWAN technologies offer battery savings that guarantee nodes are constantly available and can maintain a relatively high output power (Esma Kökten, 2020).

3.2 LoRa technology and LoRaWAN

LoRa is a spread spectrum technology developed by Semtech and standardized by the LoRa Alliance 2015. To enable bidirectional communication, this LPWAN technology modulates the signal using chirp spread spectrum in the sub-GHz range. Additionally, it renders the modulated signal resistant to channel noise and interference.

LoRaWAN is an open standard network stack which uses the characteristic of LoRa physical layer, aiming of providing devices and sensors the ability to transmit and receive data frames within minimum data rate, long distance transmission and distinct time duration during the transmissions (HENNA DAVID, 2020), (Chaudhari BS, 2020).

LoRaWAN is established in a star-of-stars network architecture, provides long-range, bidirectional communication, and runs in unlicensed spectrum. End nodes are not connected to a single gateway but instead transmit data to numerous gateways that are in its range. Tens of thousands of sensor nodes can be supported separately by each gateway. In order to reduce power consumption and maximize network capacity, LoRaWAN data rates are scalable and employ an adaptive data rate algorithm.

3.3 LaRaWAN network architecture

Since the LoRaWAN network has a star-of-stars topology, end nodes do not need to be connected to a single gateway in order to access the network. Since a gateway logically functions as a link-layer relay, end devices are directly connected to a network server. In this two-way connection, uplink transmission from the end device to the network server has always been encouraged. End devices, gateways, network servers, and application servers make up the LoRaWAN architecture.

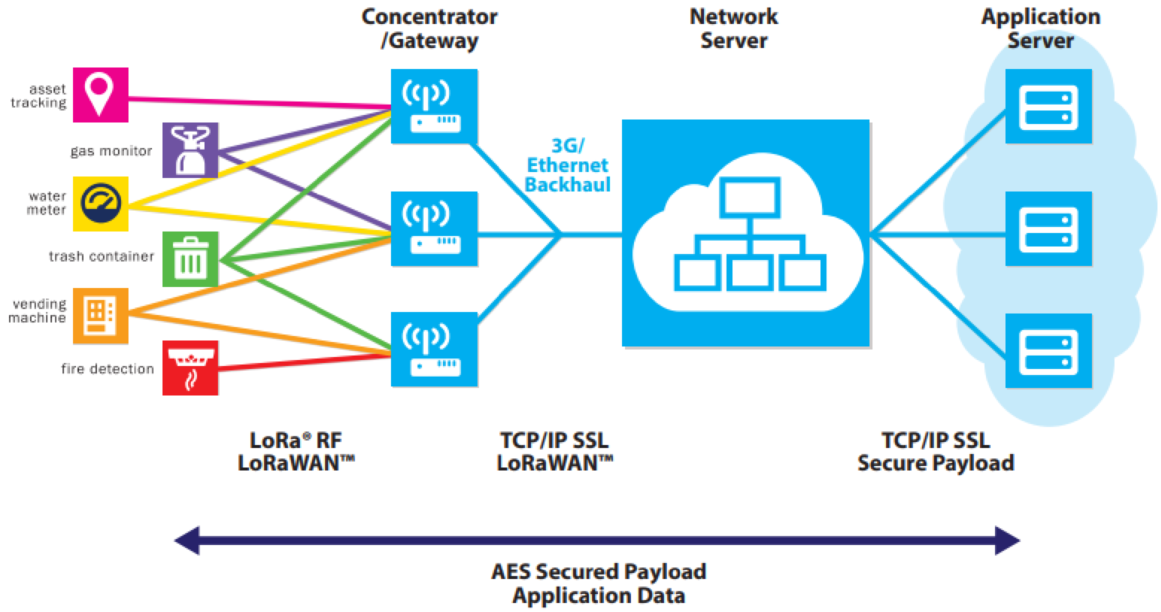

FIGURE 1: LoRaWAN network architecture.

End Device:

The end node are devices within a network that are equipped with sensors to gather data then communicate with gateway over LoRa radio module. The End node are usually low power with embedded microcontrollers to perform processing operations.

Concentrator / Gateway:

Gateway are the intermediate devices between the end node and network server. In LoRaWAN network, there can be more than just one gateway and the data transmitted to them can be received or transmit to network servers by multiple gateways.

Network Server:

The network server is responsible to ensure security and reliable packet routing within the network. The network server act as bridge between the end nodes, gateways and application server. It is the brain of the network that ensures reliable operation, managing acknowledgment, decoding and duplicating packets.

Application Server:

The appropriate application server receives packets from the network server and processes them before providing relevant data and handling the client application. This aids users in tracking assets, reducing costs, and improving operational efficiency. Through a web-based application dashboard, the user may also set up rules to act in response to particular events or a combination of events. It is quick and easy to set up and manage a LoRaWAN network because of the availability of highly integrated application servers and dashboards. The IoT applications for smartphones and desktops are designed to have easy configuration with a simple visual interface because the majority of business owners and end users are searching for simplicity of use and dependable data that they can act on (SEMTECH, 2017).

Device Classes

End devices serve many applications having different requirements. The end node devices can be used into different classes according to the application profiles. These device classes have their trade off when it comes to battery life versus network downlink communication latency. The downlink communication latency is an important matter when it comes to control or actuator type application.

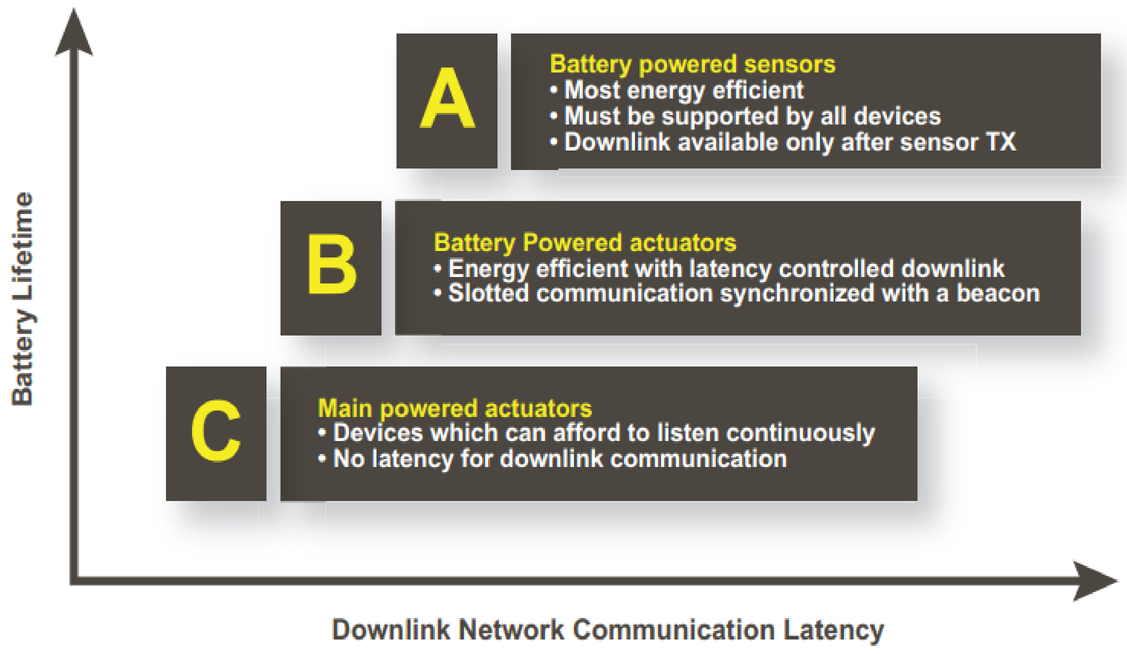

FIGURE 2: LoRaWAN device classes.

Class A: Bi-directional end-devices.

End node devices in class A provide bidirectional communication by allowing each End node device to transmit uplink data followed by two brief downlink receive windows. The transmission slots arranged by the End node device is based on its communication requirements with a little fluctuation within random time basis.

For applications that only need downlink communication with immediately after the End node device has sent an uplink transmission, a class A is the better solution as it is the lowest power demand system. Any other moment, will require the servers downlink communications to wait until the next scheduled uplink happens (Alliance, 2015).

Class B: Bi-directional end-devices with scheduled receive slots.

Class B devices open additional receive windows in addition to the Class A random receive windows at predetermined intervals. The end node device gets a time-synchronized beacon from the gateway, which uses to open its receive window at the appointed moment. As a result, the server can determine when the end node device is listening (Alliance, 2015).

Class C: Bi-directional end-devices with maximal receive slots.

End node devices of Class C is demands more power as they have almost continuously open receive windows that only closed when they are in transmitting mode (Alliance, 2015).

3.4 Features of LoRa technology

Low Power:

LoRaWAN was developed to minimize the power demands of connected sensors and increase their battery life. It employs an asynchronous communication technique in the lowest power mode, allowing the nodes to be in sleeping mode at all time and only wake up when they have data to broadcast before returning to power saving mode immediately or after the transmission has been acknowledged (Bouguera T, 2018).

LoRaWAN systems also features adaptive data rate algorithms intelligence which permit the end node to readjust its data rate to best perform and to suit the environment within it. A node will operate at higher data rates, consume less power, and spend less time on the air if it is close to a gateway. On the other hand, nodes placed at the distant sites would require more power and transmit data more slowly. Contrastingly, competitive LPWAN technologies do not allow adaptive data rate and employ a fixed data rate regardless of the environment, in contrast to cellular-based systems that continuously ping the network to stay in sync (SEMTECH, 2017).

LoRaWAN sleep mode current consumption are in nano amp range while actively receiving data even when placed in hard to reach places as example in elevator shafts, basements, behind walls and the transmit current consumption are at low as in milliamps range, which enables applications such as smart meters to last longer up to 20 years on a single battery (SEMTECH, 2017).

LoRaWAN's low power characteristic increases sensor battery life and makes it suitable for applications in smart buildings. Applications for smart buildings can cut insurance costs, eliminate time spent manually monitoring facilities, prevent property damage, and speed up reaction to issues like water leaks or heating failures (SEMTECH, 2017).

Robust Long-Range Coverage:

LoRaWAN can cover a long range distance up to 48km in rural areas or line of site and more than 3km in urban areas having link budget from 158dB to 168dB depending on the environment and any obstructions in presence. Such coverage distance, it can compete with the existing cellular technologies. This LoRaWAN is enabled by LoRa’s unique spread-spectrum modulation scheme. The spread-spectrum techniques compared to narrowband schemes, it is more robust in very noisy channel conditions and better at mitigating interference (SEMTECH, 2017).

Security:

Any LPWAN must consolidate security. LoRaWAN incorporate two security layers, one for the application and the other for the network as a whole. The network security guarantees validation and authenticity of the end node device while the security layer on the application layer ensures that the network operator has limited access when it comes to user's application data. AES encryption is utilized with the key trade using an IEEE EUI64 identifier. Every technology choice has its trade off however LoRaWAN features security, scalability for capacity, device classes and optimization for a wide range of application in IOT (SEMTECH, 2017).

3.5 Previous studies on similar field

Alhasnawi, B.N, Jasim, B.H. and Issa, B.A proposed an Internet of things for smart precision agriculture to predict the irrigation requirements of crops using parameters such as temperature, moisture along with the weather forecast information from the internet. The system focused mainly in water wastage that has been a major concern in nowadays. The system allows the user to monitor the data using a web browser and emails. The proposed system consists of hardware and software. The hardware consists of BSU and several TN. The software consists of Wi-Fi network and the system protocol and MQTT broker which was built on the BSU and TU board (Naji Alhasnawi, 2020).

Olugbenga K.O, Abiodun E.O, O.G Adegboro Presented Smart Irrigation System: A Water Management Procedure able to control the water pump installed in the irrigation site based on soil moisture content acquired from moisture sensor as well as monitoring the water level in the reservoir with the help of ultrasonic sensor. The data acquired from the sensors are sent to the Arduino microcontroller for control and decision making. The system has to decide to irrigate by determining the amount of pumps to be activated at any instance and at a specific location where they are installed, this way, the crops could be irrigated depending on their water requirement and needs. For this system to be implemented, a laboratory prototype model was developed with a farm setting with water reservoir, DC pump and the control unit. Experimental results revealed the efficiency and performance making the system development a suitable tool for future studies (Olugbenga Kayode Ogidan, 2019).

Shinde, S. and Gohil, V developed Automated irrigation system using WSN and Wi-Fi module which encourage the water saving and managements practice which help optimization in water usage which help to keep the crops healthy. the system was developed in such a way that is microcontroller based having distributed wireless network, control station and a user interface. The system sensor node consisted of temperature and humidity sensors and soil moisture sensor. they were placed in the crops and were battery operated devices. The base station gathered all sensor data with the help of RF transceiver for later process. An algorithm was developed to help monitoring the temperature, soil moisture to control the water level (Sharad Shinde, 2017).

Gutiérrez, J. Villa-Medina, Nieto-Garibay, and Porta-Gándara has designed an automated irrigation system that used wireless sensor network and GPRS module which optimizes the water use for agriculture crops. The system consisted of distributed wireless network with soil moisture, temperature sensors placed in the fields. The WSN uses Zigbee for its communication network. It consists of base station which receives all the sensor data which then actives the actuators within a threshold value of the temperature and soil moisture content. The system used GSM modem which allowed web application to be remote monitoring. The system was tested and managed to save water up to 90% comparing to traditional irrigation practice (J. Gutiérrez, 2014).

k. Abhinayalalitha, P. Ramadoss proposed Arduino Based Agricultural Monitoring System in Mobile Application which consisted of two functional components which were the moisture sensor and the motor/ water pump. The system used Arduino as the brain of the control system. The moisture sensor sensed the moisture of the soil then sent the data to the database to be stored therefore, it sent it to the android phone through GSM port. This method was used to avoid data loss while sending the sensor data from device to device. The Arduino board was programming on the Arduino IDE. The moisture sensor measured the level of moisture in the soil and provided the data to the Arduino which then decided if watering was needed or not (K. Abhinayalalitha, 2017).

Samarth Mehta, Namrata Saraff, Sahil Sawant Sanjay, Shaily Pandey Designed Agriculture monitoring and controlling using HC-05 Module which was based on microcontroller ATMEGA328. The system was equipped with temperature sensor, light and moisture sensors. Each sensor sense the respective parameter and send the data to the user through HC-05 Bluetooth module. The user gets to know the status of parameters via Bluetooth module directly on the smartphone without going into the field directly. When the moisture content reached below the desired level according to the user, he could switch on the water pump (Samarth Mehta, 2018).

M. Safdar Munir, Imran Sarwar Bajwa, M. Asif Naeem and Bushra Ramzan Proposed the implementation of IOT system in smart irrigation for tunnel farming where the system was designed to be able to make smart decision in irrigation of plants with the help of weather condition content, humidity and soil moisture level. The system focussed on efficient energy consumption as the sensors were periodically turn on and off as needed. The system was based on Arduino microcontroller, extended sensors like humidity, light, temperature and moisture sensor, an IoT server, cloud storage and gateway support (Munir, 2018).

Abhishek Kumar and Magesh.S Automated irrigation system based on soil moisture using Arduino. This system used sensors to sense the soil moisture content and automatically control the pump when the power is on. A proper usage of this types of systems, it is necessary due to the shortage of reserved water because of lack of Rain, spontaneous use of water causes a large amount water to be wasted. For this reason, the automatic irrigation and soil moisture system was used. the system was developed in India where most people depend on agriculture harvesting and it is also the source of employment of the majority of people and has a huge impact on the India's economy (Abhishek Kumar, 2017).

Jehangir Arshad proposed The implementation of LoRaWAN based smart agriculture decision support system for optimum crop that gathers input parameters based on real-time monitoring to maximize the yield that accomplishes sustainability by increasing per-hectare production and reducing water seepage wastage in agriculture business. An intelligent sensor module, a smart irrigation system, and a controlled fertilizer module make up the three fundamental components of the proposed model. The system integrates sensors, decision support layers that use the cloud, and networking-based DSS to suggest cautions for the best sustainable production.

The intelligent sensors module includes a temperature and humidity sensor, an NPK sensor, a soil moisture sensor, a soil conductivity sensor, and a pH sensor. These sensors use the Serial Peripheral Interface (SPI) communication protocol to send statistics to the cloud over the internet via Long Range (Arshad J, 2022).

Literature review was conducted to understand the technologies and techniques available for the research, apply, and improve on techniques and technologies researched.

CHAPTER 4

Hardware selection and communication protocol

This chapter describes the selection of the hardware and sensors that was selected for this project which consist of LoRa Sensor Node that is the end Node device and the LoRaWAN Gateway.

The LoRa Sensor nodes will be self-powered and will rely only on battery for power. Therefore, it was decided to choose low power components to be use in the design. Furthermore, Sleep mode was used for the sensors that are not in use continuously.

The LoRa sensor node and LoRaWAN gateway will consist of a power supply, MCUs, RF module, sensors, battery, display and more.

LoRa sensor node and LoRaWAN gateway

Both LoRa sensor node and LoRaWAN gateway form part of the wireless network able to transmit and receive messages via LoRa communication. Both devices will share almost same main hardware. Using the same main components such as microcontroller, display and LoRa module for both devices, lowers the complexity of the design and therefore the cost as a whole while also simplifies longer-term maintainability.

4.1 Choice of RF module

A LoRa module was required to satisfy the requirement of being able to deploy the gateway to a remote location without access to a wire connection. Many LoRa modules are not available to operate in south Africa due to the ISM band region and some of these modules were expensive due to capabilities and range. It was decided to search a module that is allowed to operate within a 433MHz ISM band which is allowed in South Africa and a module that can significantly has small footprint size, versatile, cheap and have a decent range for communication.

Electronics shops in South Africa such as Communica based cape town and Botshop based in Pretoria sells wide range of RF modules. This means obtaining a module and technical support, if required, would be greatly simplified satisfying the requirement of using locally available components. It was decided to investigate the SX1278 LoRa module which was suitable for use in this study.

4.1.1 SX1278 LoRa module

The SX1278 transceivers include the LoRaTM long range modem which offers ultra-long range spread spectrum communication and high interference immunity while minimizing current consumption. The module uses a half-duplex communication system, allowing it to send and receive signals on the same medium but not simultaneously (Semtech, 2015).

The SX1278 LoRa module uses the SPI communication protocol, which is appropriate for devices and controllers that only support SPI communication. It is one of the newest RF technology and long-range modules (Poonam S. Jakhotiya, 2021). It uses a variety of modulations for data communication that are selectable and have a range of up to 5 KM to 10 KM, making it the best for long-distance communication (Semtech, 2015).

4.1.2 Basic functionality components of the SX1278

The SX1278 transceiver module initially amplifies the RF signal it receives using an LNA when it receives a signal. To enhance the second order linearity and harmonic rejection after the LNA inputs, differential conversion is performed. The mixer step subsequently reduces the signal to components that are in phase and quadrature (I&Q) at the intermediate frequency (IF). A pair of sigma delta ADCs then perform data conversion, with all subsequent signal processing and demodulation performed in the digital domain (Semtech, 2015).

Two oscillators built into the SX1278 generate the local oscillator frequencies for the transmitter and receiver, respectively. The lower UHF bands (up to 525 MHz) are covered by one generator, and the upper UHF bands by the other (from 778 MHz onwards). The Phase Lock Loops (PLL) are designed for quick auto-calibration and short lock time. Within the PLL bandwidth, frequency modulation is carried out digitally during transmission. The bit stream can optionally be pre-filtered in the PLL to enhance spectral purity. (Semtech, 2015).

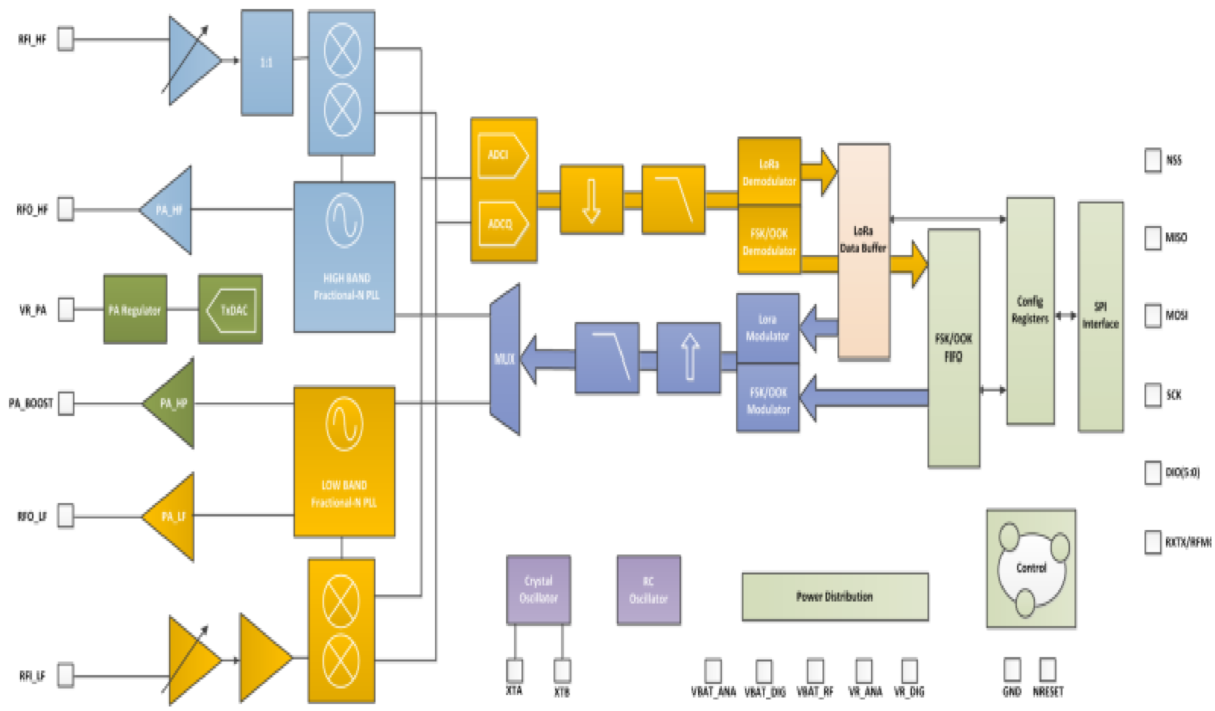

FIGURE 3:Block diagram of sx1278 transceiver.

The sx1278 is equipped with three RF power amplifiers. Two of those can be connected directly to their respective RF receiver inputs through a pair of passive components and have a maximum output of +14 dBm each. Together, they can form a single antenna port high efficiency transceiver by being unregulated for high power efficiency. Utilizing a specific matching network, the third power amplifier may produce up to +20 dBm. The frequency bands that the frequency synthesizer targets are all covered by this high-stability power amplifier, as opposed to the high efficiency power amplifier (Semtech, 2015).

Cyclic Redundancy Check (CRC) and Forward error correction (FEC)

The sx1278 includes an integrated CRC error checking procedure that, before transmission, appends the polynomial check to the end of a payload and, after reception, removes it to carry out the data integrity check. If the current transmission link needs any kind of error correction, it could be determined using this built-in technique. But at the moment, our solution does not make use of the CRC check.

Additionally, a forward error correcting method for transmissions is integrated within the SX1278. The user-defined value of 4/8 has been set as the FEC's code rate. Accordingly, an additional 4 bits are added for error correction for every 4 bits of data sent by the user, total 8 bits. Code rates ranging from 4/8 to 7/8 can be adjusted by the user.

4.1.3 Power supply for the SX1278

ow ripple voltage and well-regulated power quality are required for the SX1278 power supply. The RF module's power supply voltage is post-regulated to achieve this low ripple voltage. By filtering out any frequency components connected to the DC-DC converter switching frequencies, this assures that they are all eliminated. A switching DC-DC converter and the object to which power is being provided are connected via a post-regulation procedure that employs a low dropout (LDO) linear regulator.

4.1.4 RF module parameters setup

During setup, the following settings were programmed into the SX1278 module. The module was configured with an output power of 20 dBm. With 512 chips / symbol as the spreading factor, the bandwidth was set to 31.25 kHz. A 4/8 coding rate for cyclic redundancy checks was chosen.

4.2 Antenna

A crucial component of the RF chip is the antenna. The frequency band used by LoRa devices, such as LoRa nodes and LoRaWAN gateways, is also in the radio frequency band, making the antenna selection even more crucial. Since the LoRa sensor node and LoRaWAN gateway share the same LoRa module, a Pig tail cable antenna was chosen which allow the mounting easier onto the PCB.

FIGURE 4:The Antenna 433MHz with pig tail cable.

The antenna has a male SMA connector and can be used with any SMA female connected as the one connected to the included cable. The Antenna 433MHz with pig tail cable support frequency of 433MHz with a gain of 3dbi, input impedance of 50 Ohm and VSWR < 1.5.

4.3 Choice of MCU

The ESP32 microcontroller by Espressif Systems was selected for use in the LoRa sensor node and LoRaWAN gateway design as it incorporates the peripheral features required to fulfill the specification of this study.

The ESP32 is a highly integrated chip designed for mobile devices, wearable electronics, and Internet of Things applications. It includes built-in antenna switches, RF baluns, power amplifiers, low-noise receive amplifiers, filters, and power management modules.

Through power-saving features including fine resolution clock gating, several power modes, and dynamic power scaling, ESP32 achieves extremely low power usage.

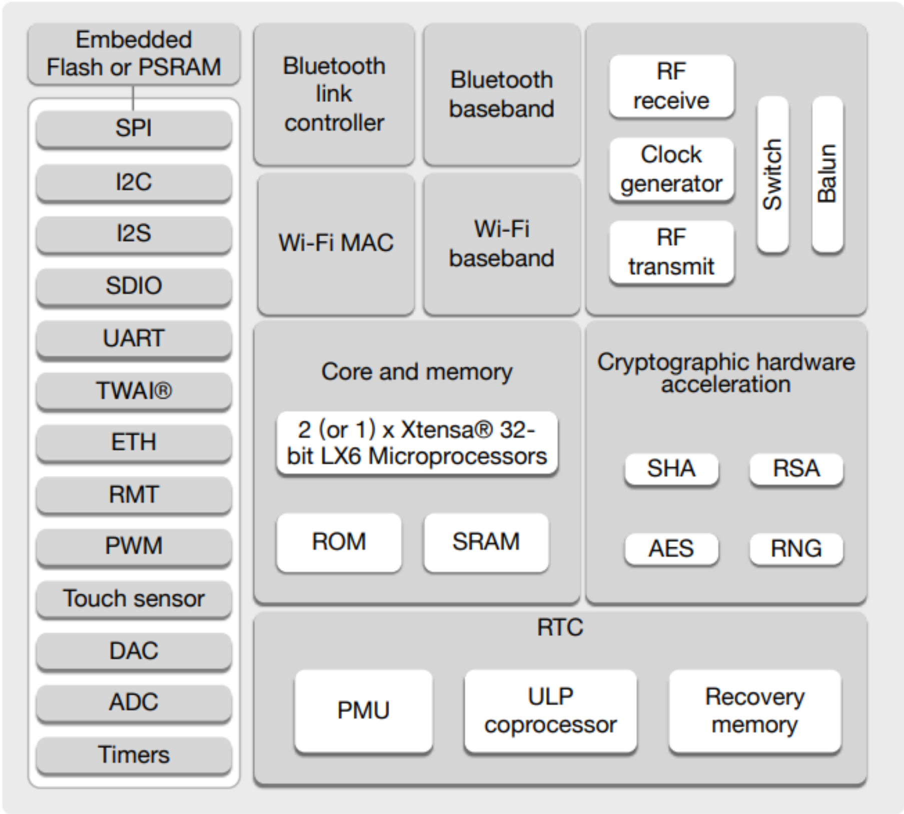

FIGURE 5:ESP32 functional block.

The ESP32 WROOM-32 has two independently controllable CPU cores, and its CPU clock frequency ranges from 80 MHz to 240 MHz. A low-power co-processor is another feature of the ESP32 chip that can be used in place of the CPU to conserve energy when carrying out tasks that do not need a lot of processing power, including peripheral monitoring.

A wide number of applications may be targeted with the module's integration of Bluetooth, Bluetooth LE, and Wi-Fi, which also makes it future-proof. While Bluetooth enables the user to easily connect to the phone or broadcast low energy beacons for its detection, Wi-Fi offers a wide physical range and direct internet access through a Wi-Fi router.

The ESP32 chip's sleep current is less than 5 A, making it appropriate for battery-operated and wearable electronics applications. With 20.5 dBm output power at the antenna and a data throughput of up to 150 Mbps, ESP32 enables the greatest physical range. As a result, the chip provides the best performance for connection, range, power consumption, and electronic integration, which are all industry-leading criteria (Espressif, 2022).

4.3.1 Peripheral

Esp32 features a wide range of peripherals which facilitate the deployment of it in a lot of applications and project. Those peripheral are: capacitive touch, ADC, DAC, I2C, UART, CAN 2.0, SPI, I2S, RMII, PWM and more.

4.3.2 CPU Clock

The default CPU clock is set to an external crystal clock source upon reset. Additionally, a PLL is connected to the external crystal clock source to create a high-frequency clock typically 160 MHz. ESP32 also includes a built-in 8 MHz oscillator. The inbuilt 8 MHz oscillator, the PLL clock, or an external crystal clock can all be chosen by the application as the clock source. Depending on the application, the chosen clock source may drive the CPU clock directly or after division. (Espressif, 2022).

4.3.3 RTC Clock

The esp32 RTC clock consist of five possible sources which are internal 8MHz oscillator, external low speed 32KHz crystal clock, internal 31.25KHz clock derived from the internal 8MHz oscillator with prescaler of 256 and 150KHz internal oscillator. (Espressif, 2022).

The application can select either the internal 8 MHz oscillator or the external high-speed crystal clock when the chip is operating in normal power mode and a faster CPU access is required. The application selects either the internal 31.25 kHz clock, the internal RC clock, or the external low-speed (32 kHz) crystal clock while the chip is operating in the low-power mode. (Espressif, 2022).

4.3.4 CPU and internal memory

The esp32 is equipped with two low-power 32-bit LX6 microprocessors, as well as internal memory that includes 448KB of ROM for booting and core functions, 520KB of on-chip SRAM for data and instructions, 8KB of SRAM in RTC, and 1 Kbit of eFuse, of which 256 bits are used for the system (MAC address and chip configuration), and the remaining 768 bits are reserved for customer applications, such as Flash-Encryption and Chip ID (Espressif, 2022).

4.3.5 RTC and low- power management

With the use of advanced power management technologies, ESP32 can switch between five power modes as shown in the table below:

Power mode	Description	Power consumption
Modem-sleep	The CPU is powered on.	Max speed 240 MHz: 30 mA ~ 50 mA
		Normal speed 80 MHz: 20 mA ~ 25 mA
		Slow speed 2 MHz: 2 mA ~ 4 mA
Light-sleep	-	0.8 mA
Deep-sleep	The ULP co-processor is powered on.	150 μA
	ULP sensor-monitored pattern	100 μA @1% duty
	RTC timer + RTC memory	10 μA
Hibernation	RTC timer only	5 μA
Power off	CHIP_PU is set to low level, the chip is powered off	0.1 μA

TABLE 2: ESP32 Power modes.

4.3.6 WIFI

In ESP32, TCP/IP and the complete 802.11 b/g/n Wi-Fi MAC protocol are implemented. It supports the Distributed Control Function's STA and SoftAP operations for the Basic Service Set (BSS) (DCF). In order to shorten the active-duty period, power management is managed with little host input (Espressif, 2022).

4.3.7 Bluetooth

The chip incorporates a Bluetooth link controller and Bluetooth baseband, which perform baseband protocols and other low-level connection operations like modulation and demodulation, packet processing, bit stream processing, frequency hopping, and more (Espressif, 2022).

4.4 Communication protocol

Communication between different sensors and modules will be needed in this project, therefore an overview of different communication protocols will be done as well as how they differ to one another. These protocols are SPI, I2C, USART and USB.

4.4.1 SPI

SPI, also known as serial peripheral interface, is one of the most used interfaces between microcontrollers and peripheral ICs such sensors, ADCs, DACs, shift registers, SRAM, and others. The implementation of the Ra-02 LoRa module required a deep understanding of the SPI protocol, therefore it was necessary for this thesis.

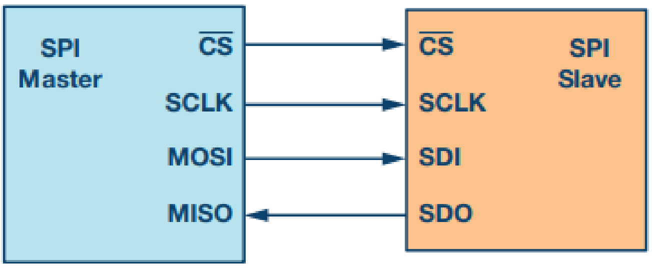

FIGURE 6: SPI configuration with master and a slave.

The SPI communication was developed by the Motorola in 1972 (Anon., 2014). SPI is a hierarchical synchronous communication full-duplex protocol used by electronic equipment. It transmits data signals in both ways, uses separate lines for clock and data, and maintains synchrony on both sides.

There are four key pins that make up the SPI interface namely Clock (SCLK), Master out slave in(MOSI), Master in Save out (MISO) and chip selector (CS).

The master device in an SPI configuration is the one that produces the clock signal. Data exchanged between the master and slave is synced with the master's clock. In comparison to I2C connections, SPI devices support substantially higher clock frequencies.

Data transmission:

To Start a communication between devices using SPI interface, the master must send the clock signal and select the slave by enabling the CS signal. Usually chip select is an active low signal hence, the master must send a logic 0 on this signal to select the slave (Dhaker, 2018).

Since SPI is a full-duplex interface, both the master and the slave can transfer data simultaneously over the corresponding MOSI and MISO lines. During SPI communication, the data is simultaneously broadcast (shifted out serially onto the MOSI/SDO bus) and received (the data on the bus (MISO/SDI) is sampled or read in). The shifting and sampling of the data are synchronized by the edge of the serial clock (Dhaker, 2018).

Clock Polarity and Clock Phase

In SPI, the clock polarity and phase can be chosen by the master. During the idle state, the CPOL bit controls the polarity of the clock signal. The time between the start of the transmission, when the CS is high and transitioning to low, and the end of the transmission, when the CS is low and migrating to high is referred to as the idle state. The clock phase is chosen by the CPHA bit. The data is sampled and/or shifted using either the rising or falling clock edge, depending on the CPHA bit. In accordance with the requirements of the slave, the master must choose the clock polarity and phase. There are four SPI modes that can be selected depending on the CPOL and CPHA bit setting. Table 1 displays four SPI (Dhaker, 2018).

SPI Mode	CPOL	CPHA	Clock Polarity in Idle State	Clock Phase Used to Sample and/or Shift the Data
0	0	0	Logic low	Data sampled on rising edge and shifted out on the falling edge
1	0	1	Logic low	Data sampled on the falling edge and shifted out on the rising edge
2	1	1	Logic high	Data sampled on the falling edge and shifted out on the rising edge
3	1	0	Logic high	Data sampled on the rising edge and shifted out on the falling edge

TABLE 3: SPI Modes with CPOL and CPHA

A communication sample in four SPI modes is shown in Figures 7 through Figures 10. The MOSI and MISO lines are used in these instances to display the data. The dotted green line indicates the beginning and conclusion of the transmission, while the orange and blue edges of the sampling and shifting edges are shown (Dhaker, 2018).

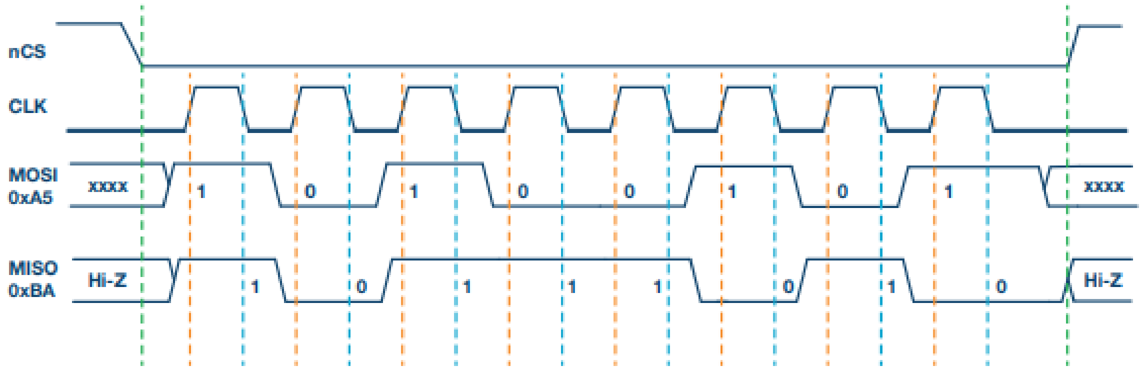

FIGURE 7: SPI Mode 0, CPOL = 0, CPHA = 0: CLK idle state = low, data sampled on rising edge and shifted on falling edge.

The timing diagram for SPI Mode 1 is shown in Figure 7. In this mode, the clock polarity is 0, indicating a low idle condition for the clock signal. The data are sampled on the falling edge of the clock signal (shown by the dotted orange line) and are shifted on the rising edge (represented by the dotted blue line) in this mode since the clock phase is 1 (Dhaker, 2018).

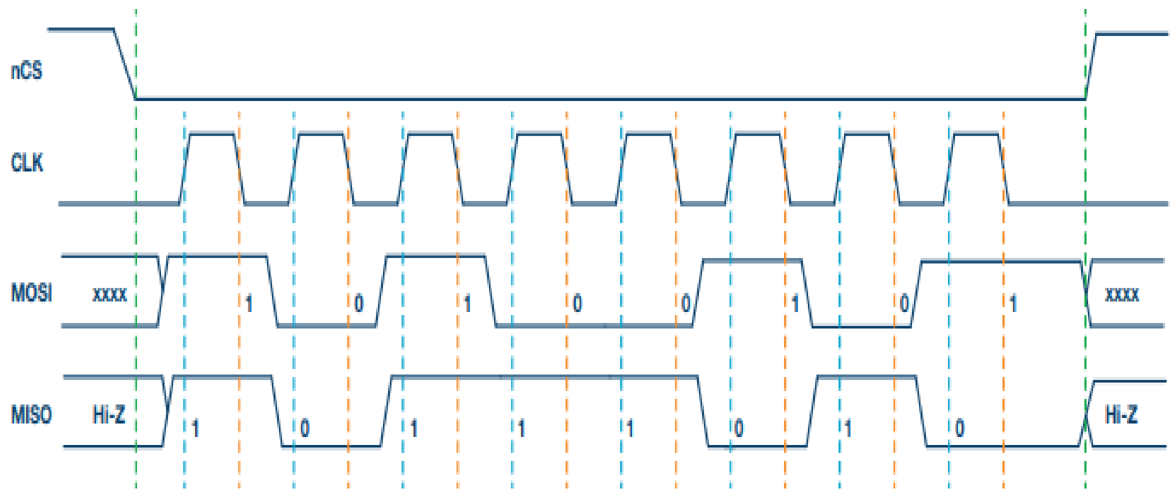

FIGURE 8: SPI Mode 1, CPOL = 0, CPHA = 1: CLK idle state = low, data sampled on the falling edge and shifted on the rising edge.

The time diagram for SPI Mode 2 is displayed in Figure 8. The clock signal's idle state is high when the clock polarity in this mode is 1, which denotes. The data is sampled on the falling edge of the clock signal (shown by the dotted orange line) and is shifted on the rising edge (represented by the dotted blue line) in this mode since the clock phase is 1 (Dhaker, 2018).

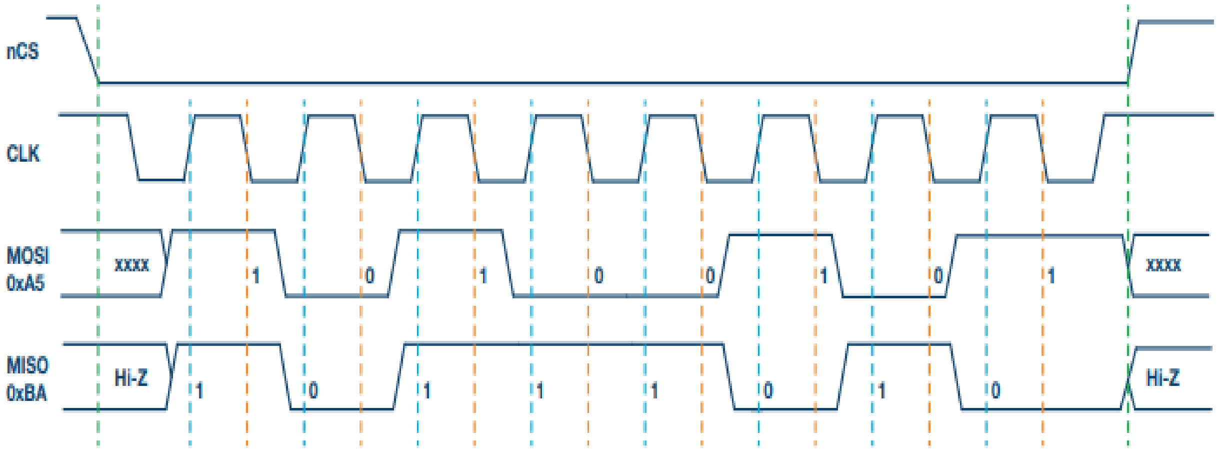

FIGURE 9: SPI Mode 2, CPOL = 1, CPHA = 1: CLK idle state = high, data sampled on the falling edge and shifted on the rising edge.

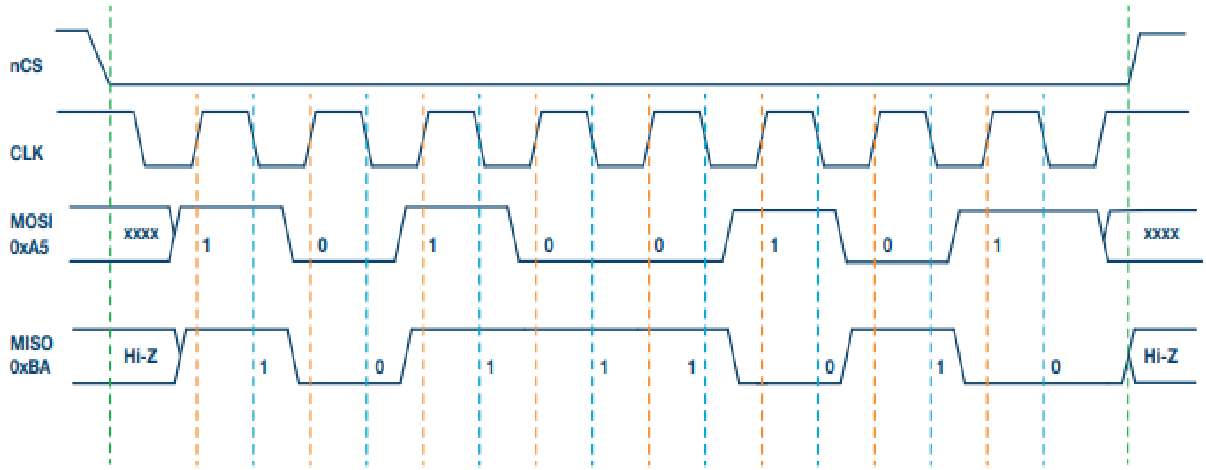

FIGURE 10: SPI Mode 3, CPOL = 1, CPHA = 0: CLK idle state = high, data sampled on the rising edge and shifted on the falling edge.

The timing diagram for SPI Mode 3 is displayed in Figure 10. The clock signal's idle state is high when the clock polarity in this mode is 1, which denotes. The data is sampled on the rising edge of the clock signal (shown by the dotted orange line) and is shifted on the falling edge (represented by the dotted blue line) in this mode since the clock phase is zero (Dhaker, 2018).

Multi-slave Configuration

Multiple slaves can be used with a single SPI master. The slaves can be connected in regular mode or daisy-chain mode.

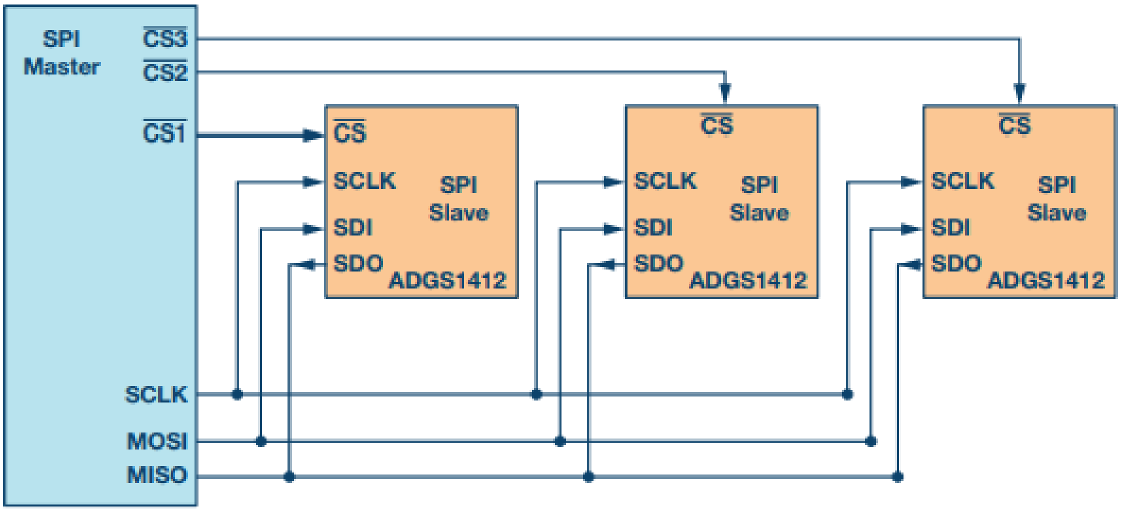

FIGURE 11: Multislave SPI configuration.

Regular SPI Mode:

Regular mode requires the master to provide a unique chip choose for each slave. The clock and data on the MOSI/MISO lines are available for the chosen slave as soon as the master enables (pulls low) the chip select signal. The data on the MISO line becomes garbled if numerous chip select signals are active because the master is unable to determine which slave is transmitting the data. Figure 6 shows that as the number of slaves rises, so do the number of chip select lines from the master. This may quickly increase the amount of inputs and outputs required from the master and reduce the number of available slaves. In standard mode, more slaves may be added using a variety of methods, such as by creating a chip select signal with a mux (Dhaker, 2018).

Daisy-chain mode:

According to this strategy, the number of clock cycles needed to transfer data increases proportionally to the slave position in the daisy chain as data is propagated from one slave to the next.

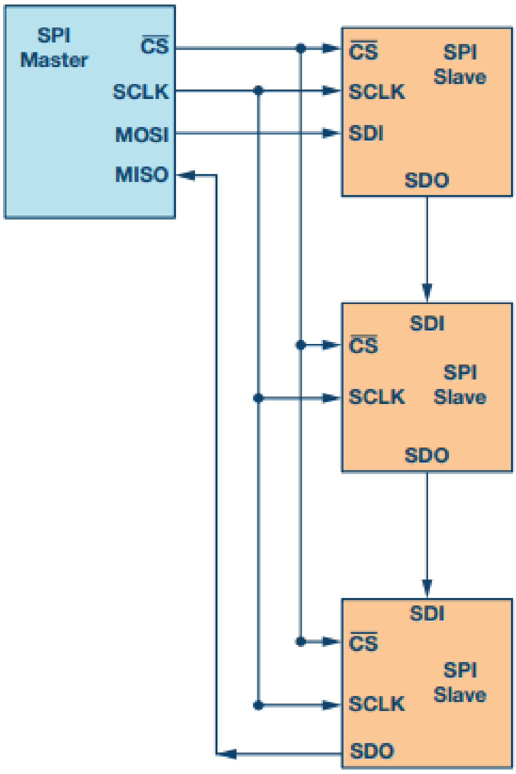

FIGURE 12: Multislave SPI daisy-chain configuration.

For instance, in Figure 12, an 8-bit system needs 24 clock pulses instead of the eight required in conventional SPI mode for the data to be available on the third slave. Figure 8 depicts the clock cycles and data transmission in a daisy chain. Not all SPI devices automatically support daisy-chain mode (Dhaker, 2018).

4.4.2 I2C

I2C, also referred to as Inter-Integrated Circuit, is a bus interface connection protocol used by devices for serial communication. The I2C was first created by Philips Semiconductor in 1982. It is now a widely used short-distance communication protocol and is also known as the two wired interface (Bill, 2010).

Two bi-directional open-drain channels called serial data (SDA) and serial clock are used in I2C communication for data transmission (SCL). These two lines need to be raised. While the SCL transmits the clock signal, SDA permits the transfer of data. There are two different configurations for the I2C communication protocol: master mode and slave mode.

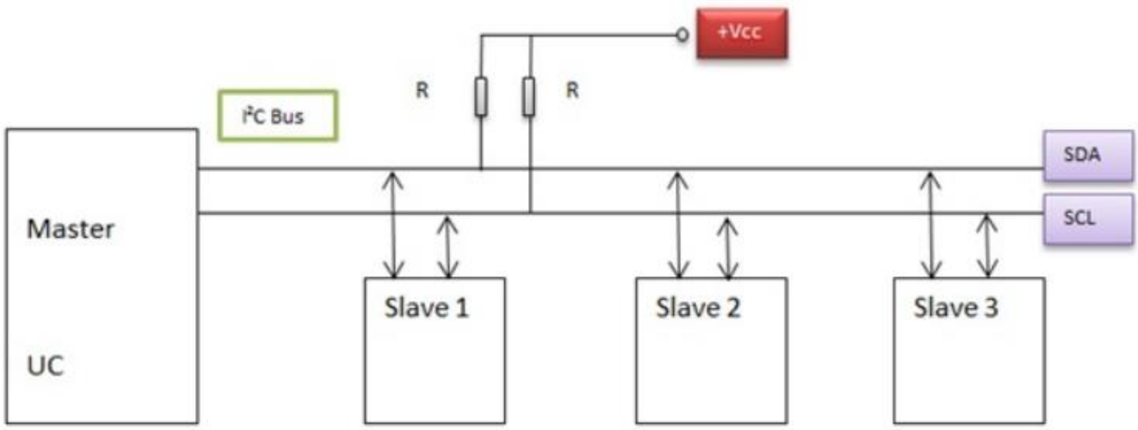

FIGURE 13: I2C bus with single master and three slaves.

Every I2C instruction that is started by the master device has a START condition at the beginning and a STOP condition at the end. SCL must be high for both situations. SDA transitions from high to low are referred to as START and transitions from low to high as STOP. The bus is deemed to be in use after the Start condition and can only be used by another master once a Stop condition is discovered (SLR, 2021).

The master can generate a repeat Start after the Start condition. Repeated start is equivalent to a conventional START and is usually followed by the slave I2C address. It involves issuing one additional START condition without issuing a STOP condition. SDA and SCL are both released following the STOP condition, putting both in a pull-up state (SLR, 2021).

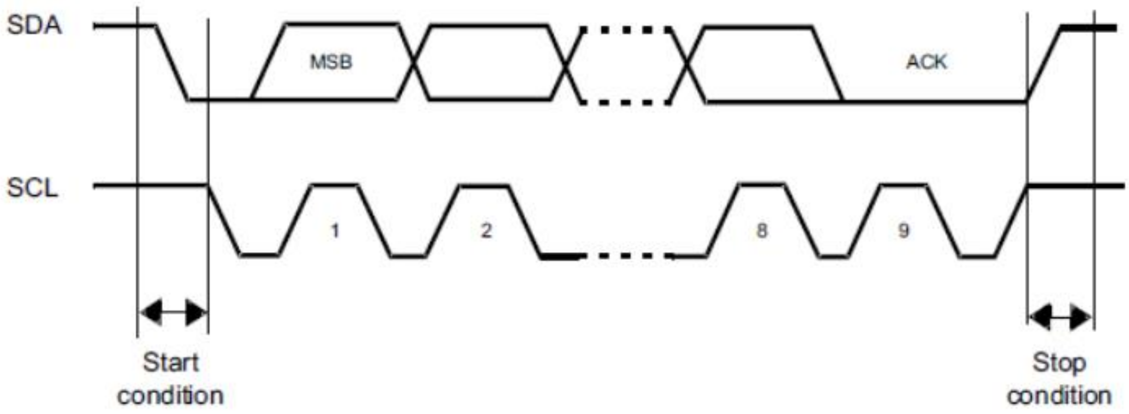

FIGURE 14: I2C bus protocol.

Software determines the start and stop circumstances in master mode. Following the START condition, the bus is deemed to be full, and following the STOP condition, the bus is deemed to be empty once more. Another master may have the opportunity to use the bus for data communication when it is available.

If many START conditions are generated instead of a STOP condition, the bus remains busy. I2C peripherals on most microcontrollers support both master and slave modes. Because the mode automatically switches to master mode with the generation of the START condition and back to slave mode upon the generation of the STOP condition by the peripheral.

Data is sent as packets when using the I2C communication protocol. These packets are 9 bits long; the first 8 bits are used for the SDA line and the final bit is set aside for the ACK/NACK signal.

4.4.3 USART

USART, also referred to as universal synchronous and asynchronous receiver and transmitter, is a serial communication system that uses two different protocols. Utilizing clock pulses as the reference, this protocol is used to send and receive data bit by bit on a single wire.

The USART was initially used in the 1960s. Although USB has nearly completely supplanted the protocol, it is still extensively supported and understood because of its age. New systems can be easily integrated using straightforward RS-232 to USB converter adapters. This protocol allows for data transfer rates of up to 1Mbits/s.

UART converts incoming and outgoing data into a serial binary stream as part of its function. Serial to parallel conversion is used to transform 8-bit serial data received from a peripheral device into parallel form, and serial to parallel conversion is used to transform parallel data received from the CPU. This information is in the form of modulation and is transmitted at a specific baud rate (Anon., 2021).

4.4.4 USB

The original purpose of the universal serial bus was to replace outdated ports with a single, universal port and connect peripherals to a single master. Through multiplexing, one master can have up to 127 connected slave devices.

With standardized ports and cables, the protocol is plug-and-play compatible. The purpose of USB has been fulfilled by its availability on almost all PCs. When hooked into a master, devices configure themselves. Signals from different protocols can be converted to USB using widely accessible USB converters.

USB is getting more and more common as a result of widespread device integration that has reduced costs and improved the protocol. There was only USB 1.0 initially, but now there is now USB 2.0 and USB 3.0. Each advancement in the protocol allowed for better communication speeds and more power to be made accessible to the slave devices (Ghosh, 2007).

4.5 Choice of sensors

The LoRa Sensor Node was designed to be capable of interacting with four different sensors such as temperature and humidity sensor, Moisture sensor, PIR sensor and Rain sensor which gathers the environment conditions then later communicate the data gathered to the LoRaWAN gateway.

4.5.1 Temperature and humidity sensor:

The sensor node makes the use of the SHTC3 sensor module to gather the temperature and humidity of the environment then send the data to the microcontroller via I2C communication for processing.

In order to meet present and future requirements, the SHTC3 was specifically built to surpass traditional constraints for size, power consumption, and performance to price ratio.

A module incorporating the SHTC3 was obtained from Sparkfun. This module has built-in in pull-up resistor that allows the I2C communication too take place, two connectors to allow desi chain mode and the also a header to connect the required IO pins to the MCU.

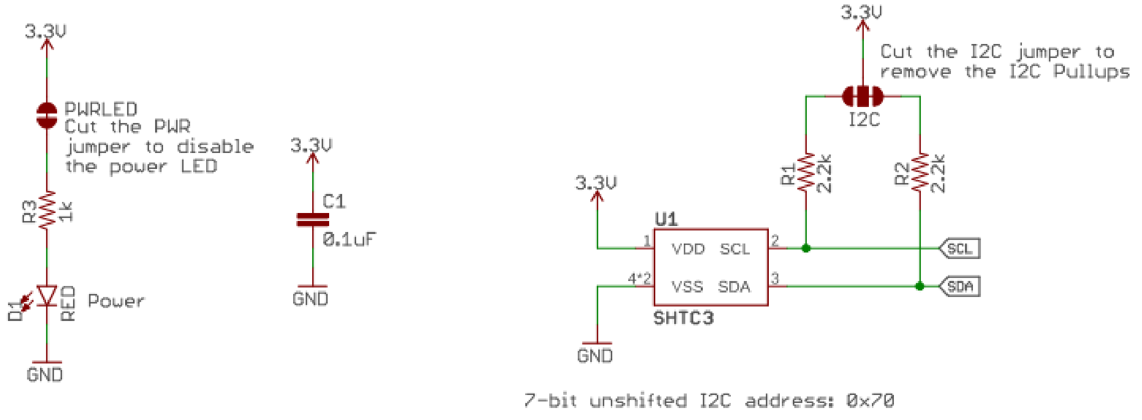

FIGURE 15: Complete schematic of the SHTC3 with the pullup resistors and power led indicator.

The SHTC3 covers a humidity measurement range of 0 to 100 %RH and a temperature measurement range of - 40 °C to 125 °C with a typical accuracy of ±2 %RH and ±0.2°C. The broad supply voltage of 1.62 V to 3.6 V and an energy budget below 1 µJ per measurement make the SHTC3 suitable for mobile or wireless applications powered by batteries.

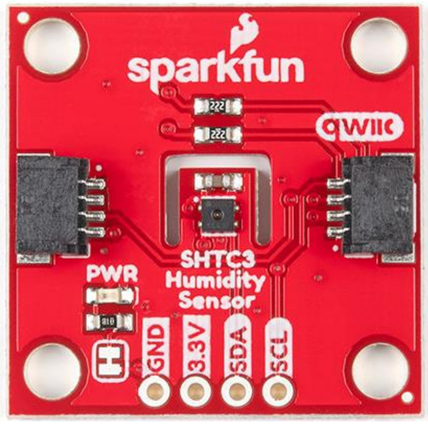

FIGURE 16: SHTC3 humidity/ temperature sensor module.

The SHTC3 provides the best performance-to-price ratio thanks to Sensirion's humidity and temperature sensors, which have a reputation for quality and dependability in the market and consistent accuracy over a wide measurement range. The SHTC3 is suited for high-volume applications because to its tape and reel package and compatibility with conventional SMD assembly procedures. (Sensirion, 2019).

4.5.2 Moisture sensor

Measuring soil moisture is important for agricultural applications to help farmers manage their irrigation systems more efficiently. Knowing the exact soil moisture conditions on their fields, not only are farmers able to generally use less water to grow a crop, they are also able to increase yields and the quality of the crop by improved management of soil moisture during critical plant growth stages.

For the LoRa sensor node to monitor the moisture content of the soil, a capacitive moisture sensor is used.

Capacitive moisture sensor

By monitoring variations in capacitance, the capacitive soil moisture sensor gauges the moisture content of the soil. The capacitive soil moisture sensor measures soil moisture using capacitance rather than resistance. The standard fork type resistance sensor's main drawback is that it requires conductive bare metal probes to be put into the soil, and over time, the modest electrical current that runs between them causes the probes to corrode through electrolysis (Supplies, 2019).

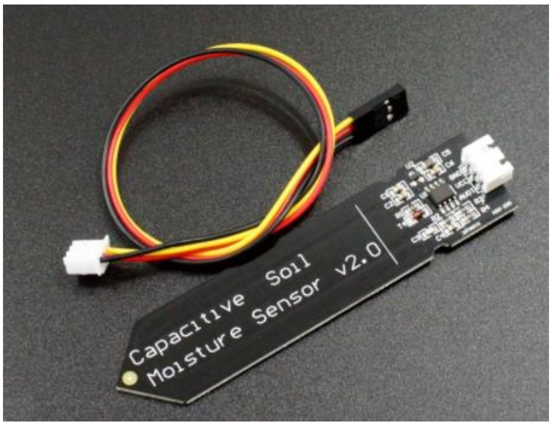

FIGURE 17:Capacitive soil moisture sensor module V2.0

The module generates a 1.5MHz clock using a TL555I CMOS timer. The TL555I is comparable to the well-known NE555 but uses more recent CMOS technology that has improved frequency capability in addition to other features (Supplies, 2019).

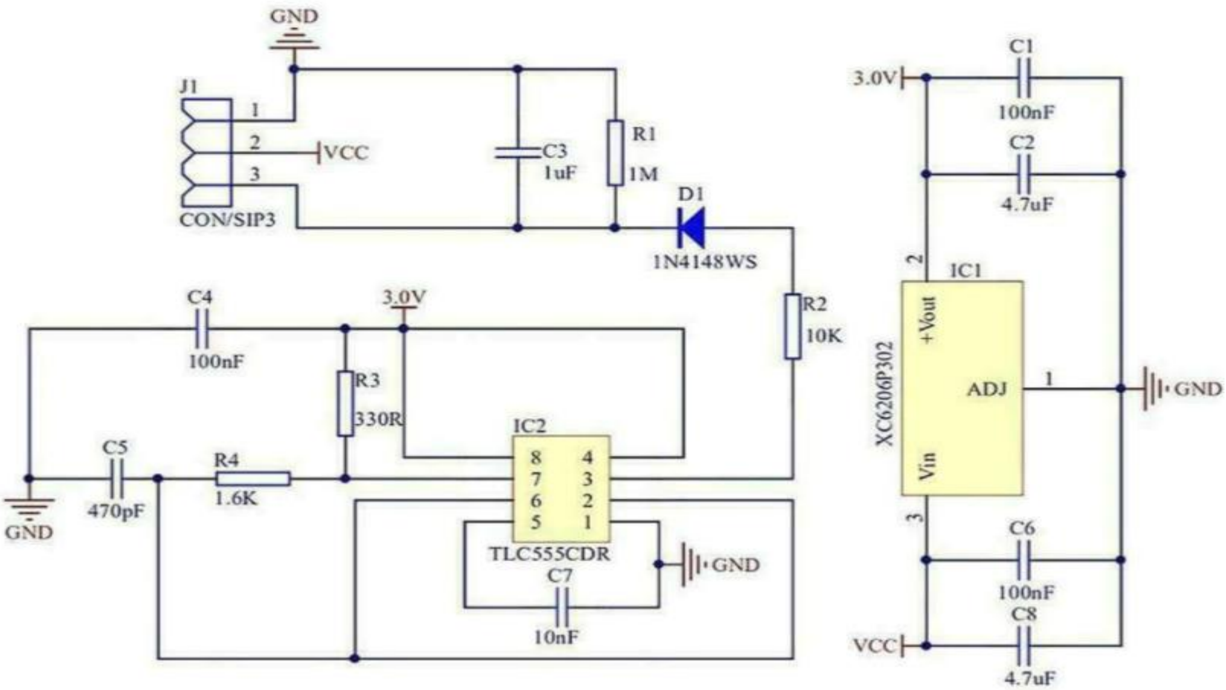

FIGURE 18: A complete schematic of capacitive soil moisture sensor V2.0

The waveform from the TL555I is converted by a peak voltage detector into a DC voltage that can be read by the ADC input of a microcontroller (Supplies, 2019).

The capacitance of the circuit, which in turn influences the peak amplitude of the signal and consequently the DC voltage output that is being monitored by the MCU, is affected when the probe is exposed to moisture. Lower DC voltage output corresponding to greater moisture (Supplies, 2019).

4.5.3 Passive infrared sensor

An electronic sensor that measures the infrared light emitted by objects in its range of vision is known as a passive infrared sensor. The PIR-based motion detectors, security alarms, and automatic lighting applications are where they are most frequently employed.

Due to farms lack of security, PIR motion sensor was used on the LoRa node to alert the LoRaWAN gateway from intrusion.

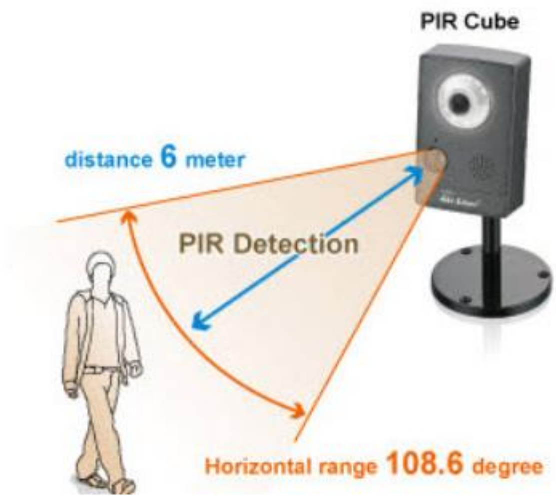

FIGURE 19: Example of PIR sensor detection.

4.5.4 PIR sensor

Theory of operation

The components of pyroelectric devices, like the PIR sensor, are comprised of a crystalline substance that produces an electric charge when exposed to infrared light. An on-board amplifier measures the voltages produced as a function of variations in the amount of infrared energy striking the element. The infrared impulses are focused onto the element by the device's Fresnel lens, a specific filter. The on-board amplifier trips the output to signify motion as the ambient infrared signals fluctuate quickly.

FIGURE 20: PIR sensor module.

The PIR module used in this project was obtained from Robokits world. The module can work from 5V to 9V DC and gives digital output. It requires 10-60 seconds of settling time before starting its operation. It consists of pyroelectric sensor that detects motion by measuring change in the infrared levels emitted by the objects. It can detect motion up to 6 meters.

4.5.5 Rain Sensor

In order to detect a rainfall, a rain sensor was diploid. A rain sensor is one kind of switching device which is used for detecting rainfall. There are two types of output a rain sensor can deliver which are digital and analogue. The digital rain sensor works in a principle of a switch, whenever there is rain the switch will be normally close whereas the analogue rain sensor can measure the intensity of the rain.

FIGURE 21: Rain sensor module used in LoRa sensor module.

The sensor is composed of a rain detection plate with a LM393 low voltage comparator that manages intelligence. The sensor detects water that comes short circuiting the tape which act as a variable resistance that will increases its resistance when the sensor is wet and decrease when the sensor is dry.

The module includes a variable resistor which adjust the rain detection sensitivity. If the knob is turned in clockwise, the sensitivity of the rain sensor will be enhanced. If it is rotated anticlockwise, then the sensitivity of this sensor will be reduced.

4.6 USB to TTL Serial Converter

In order to flash the esp32 microcontroller, the USB to TTL serial converter was used. The converter is based on FT232R which is a USB to serial UART interface device which simplifies USB to serial designs and reduces external component by having an integrated EEPROM, USB termination resistors and an integrated clock circuitry that does not requires any external crystal oscillator into the device.

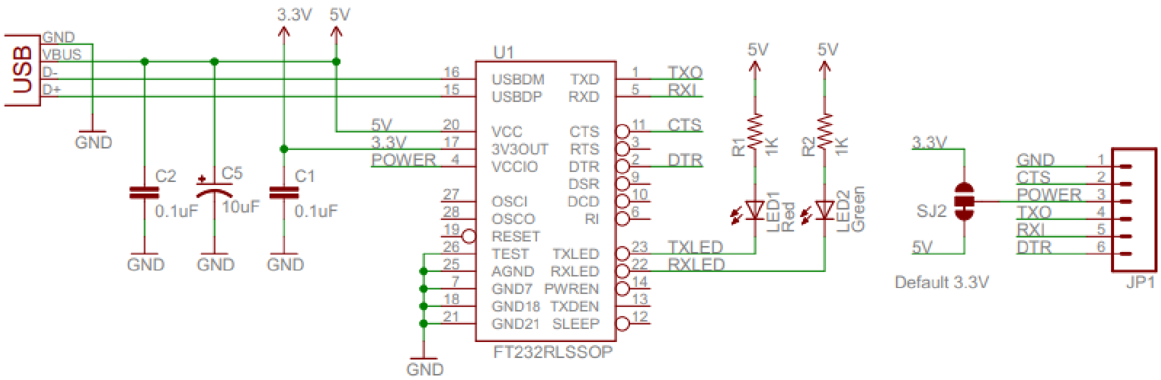

FIGURE 22: Complete Schematic of FT232R USB to TTL Serial Converter module.

The FT23R features two new functions comparing to the previous version making it a 3-in-1 chip for many application areas, its internal generated clock can also be used to drive an external logic or a microcontroller (International, 2020).

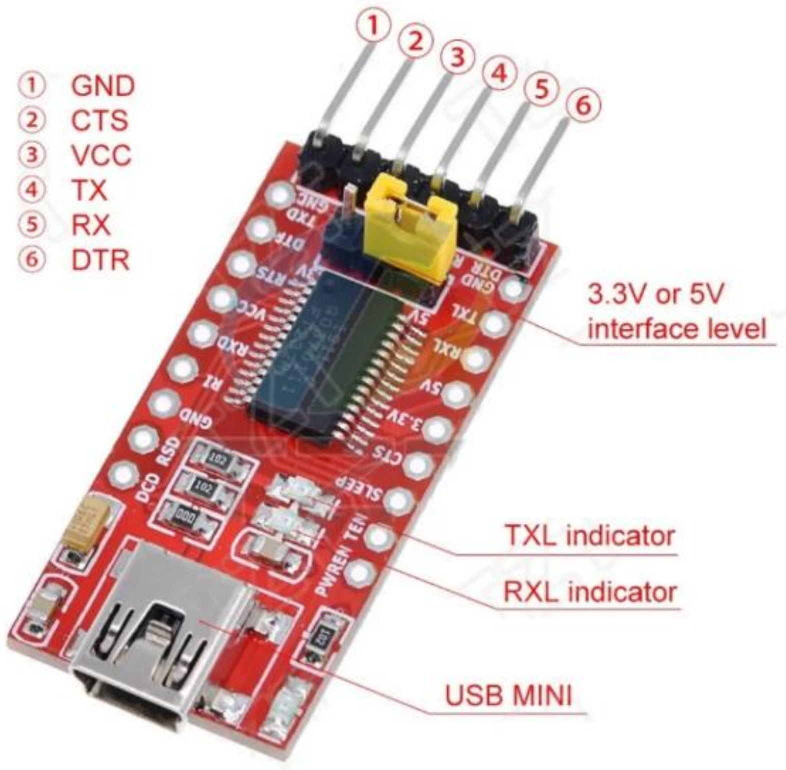

FIGURE 23: FT232R USB to TTL Serial Converter module.

Asynchronous Bit Bang Mode with RD# and WR# Strobes.

The FT232R supports the bit-bang mode of the previous chip version of FTDI. The eight UART lines can be changed from the standard interface mode to an 8-bit general purpose I/O port in bit-bang mode. The device's internal timer regulates the rate at which data packets are transmitted sequentially to the interface (International, 2020).

Synchronous Bit Bang Mode.

The synchronous bit bang mode is supported by the FT232R. The interface pins are only read in this mode—unlike asynchronous bit bang mode—when the device is being written to. Due to the data being returned being synchronous with the output data, it is now simpler for the controlling program to measure the response to an output stimulus (International, 2020).

The brand-new FTDIChip-IDTM security dongle functionality is also available on the FT232R. Each device can have a distinct number burned into it during manufacturing thanks to the FTDIChip-IDTM function. This number cannot be reprogrammed. This number serves as the foundation for a security dongle that may be used to prevent the copying of any customer application software. It can only be read through USB. This enables the FT232R to be used as a dongle for software licensing. Additionally, when combined with additional data, the FTDIChip-IDTM number can be used to construct a renewal license system (International, 2020).

Parameter	Description	Minimum	Typical	Maximum	Units	Conditions
VCC1	VCC Operating Supply Voltage	4.0	---	5.25	V	Using Internal Oscillator
VCC1	VCC Operating Supply Voltage	3.3	---	5.25	V	Using External Crystal
VCC2	VCCIO Operating Supply Voltage	1.8	---	5.25	V	
Icc1	Operating Supply Current	---	15	---	mA	Normal Operation
Icc2	Operating Supply Current	50	70	100	μA	USB Suspend
3V3	3.3v regulator output	3.0	3.3	3.6	V	

TABLE 4: Operating voltage and current.

The FT232R runs on a voltage supply between +3.3V and +5V, with a nominal operational mode current of 15mA and a nominal USB suspend mode current of 70uA. In order to meet the USB suspend mode current restriction of 2.5mA, there is more room for peripheral designs. An integrated level converter within the UART interface allows the FT232R to interface to UART logic running at +1.8V, 2.5V, +3.3V or +5V (International, 2020).

4.7 OLED Display:

In order to display the sensor data, LoRa sensor node and LoRaWAN gateway were equipped with the 9.6-inch OLED display which update its data every second.

FIGURE 24: 6-inch OLED display.

The OLED display is built on the SSD1306 single-chip CMOS OLED/PLED driver and controller for organic / polymer light emitting diode dot-matrix graphic display system. There are 64 commons and 128 segments in it. This IC is intended for OLED panels of the Common Cathode kind (SYSTECH, 2008).

In order to reduce the amount of external components and power consumption, the SSD1306 integrates a contrast control, display RAM, and oscillator. The brightness may be adjusted in 256 steps. General MCUs provide data and commands via hardware configurable Parallel Interface, I2C Interface, or Serial Peripheral Interface that is compatible with the 6800/8000 series. Numerous small, portable apps, such the calculator, MP3 player, and sub-display for mobile phones, are ideal for it (SYSTECH, 2008).

Features of 9.6-inch OLED

The 9.6-inch OLED display has a 128 x 32-dot resolution, an on-chip oscillator, 256-step contrast brightness, an embedded 128 x 32-bit SRAM display buffer, programmable frame rate, multiplexing ratio, scrolling functionality in both the horizontal and vertical directions, I2C communication, and it can operate within the 1.65V to 3.3V range for IC logic (SYSTECH, 2008).

SSD1306 has to recognize the slave address before transmitting or receiving any information by the I2C-bus.

4.8 Power supply

The power supply is responsible for providing constant voltage to the component supply rail in a hardware design and ensuring that the hardware is protected against reverse polarity connections from the main power source.

The following section describe the maximum power requirement of the LoRa sensor node and LoRaWAN gateway.

Since the LoRa sensor node will be located in an open field, it must be self-sufficient in terms of energy requirements. To achieve this, the LoRa sensor node will be equipped with 6.1V battery, battery charger, regulator and can also support solar panel.

4.8.3 Voltage regulator

MP1584

The MP1584 DC-DC switching regulator by Monolithic power is used to regulate the voltage from charger or any other power source to a stable voltage for battery charging in the LoRa sensor node. The regulator is a high frequency step-down which was used to convert the voltage down to 6.2V from 12V adapter. The MP1584 support The wide 4.5V to 28V input range accommodates a variety of step-down applications, including those in an automotive environment. A 100µA operational quiescent current allows use in battery-powered applications (MPS, 2011).

LM317

For The constant-current battery charger circuit, the LM317 was chosen to provide a constant current limiting to charge the battery at a slow pace in the LoRa sensor node.

The LM317 is an adjustable three terminal regulator capable of deliver a positive voltage from1.25V to 37V range with a maximum current of 1.5A.to be able to set the output voltage, two external resistors are needed between its output terminal, ground and adjust pin. The device features a line regulation up to 0.01% and a typical load regulation of 0.1% while also features current limiting, thermal overload protection, and safe operating area protection (Instruments, 2020).

MC7805

The MC7805 Linear regulator by on semiconductor is used in the LoRa sensor node and LoRaWAN gateway to power sensors that their power source is 5VDC. MC7805 belong s to the family of linear regulator designed as fixed voltage regulators widely used in many applications. It features internal current limiting protection, thermal shutdown and safe area compensation. By adding an adequate heatsink, they are able to deliver output current up to 1A although designed primarily as fixed voltage regulators and they can also be added external components to provide adjustable voltage and current to a system (Industries, 2019).

Lt1117-3.3 LDO

The LDO LT1117-3.3 by Linear Technology was used to regulate the 5v from mc7805 to 3.3v suitable for the MCU, LoRa module, OLED display and other sensors that utilized 3.3v in the LoRa sensor node and LoRaWAN gateway. The LT 1117 is a positive low dropout regulator designed to provide up to 800mA of output current.

The Lt1117-3.3 has a dropout voltage at maximum 1.2V at current of 800mA which decrease at lower load currents. The on chip trimming adjust the output voltage at about ±1% and the current limit is also trimmed to help minimize the stress on both power source and the regulator under overload conditions.

The low profile surface mount SOT-223 package allows the device to be used in applications where space is limited. The LT1117 requires a minimum of 10μF capacitor on its output for stability. In most regulators design, such output capacitors are always needed.

4.9 Battery

The battery will be used to power the LoRa sensor node. The 6.1V lead acid type of battery was chosen which is able to provide capacity that is sufficient to sustain the LoRa sensor node in reasonable conditions.

CHAPTER 5

Hardware development

This chapter discusses the development and implementation of the final hardware design based on the requirements and specification listed in chapter 2.

The design of the system is divided into two modules which are the LoRa sensor node and the LoRaWAN gateway which are discussed in detail in this chapter, then concludes with details related to the layout and production of the printed circuits boards required for the study.

5.1 LoRa sensor node

The LoRa sensor node was required to gather information from environment, process the information and communicate with the LoRaWAN gateway. it is divided into power supply unit, processing unit and communication unit.

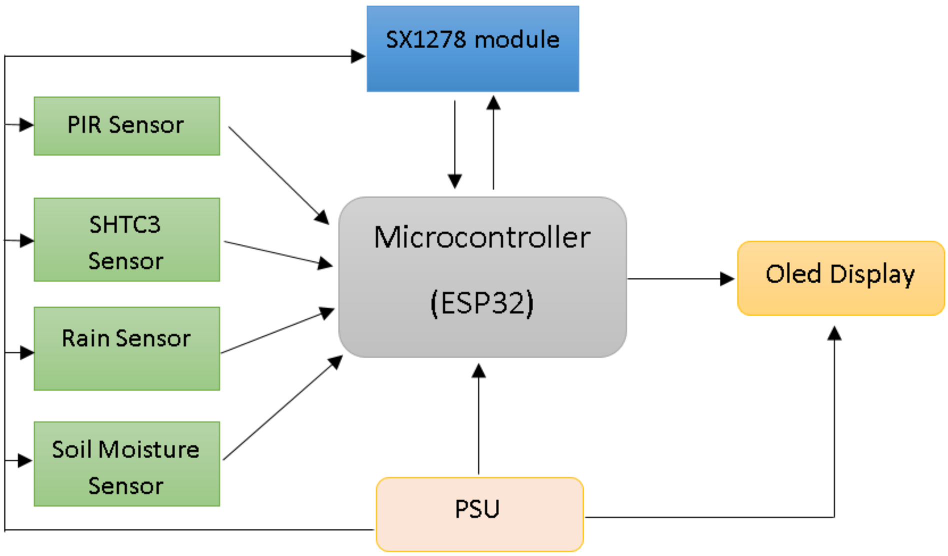

FIGURE 25: The complete block diagram of the LoRa sensor node.

The LoRa sensor is divided into three units as follow:

- Power supply unit

- Processing unit
- Communication unit

5.1.1 Power supply unit

The LoRa sensor node power supply unit was required to provide stable DC voltage to charge the battery and power all modules and sensors used. The power supply unit operate over an input DC voltage range of 8V to 24V allowing a wide range of power source that can be used and support reverse polarity protection in case of a reversed supply connection.

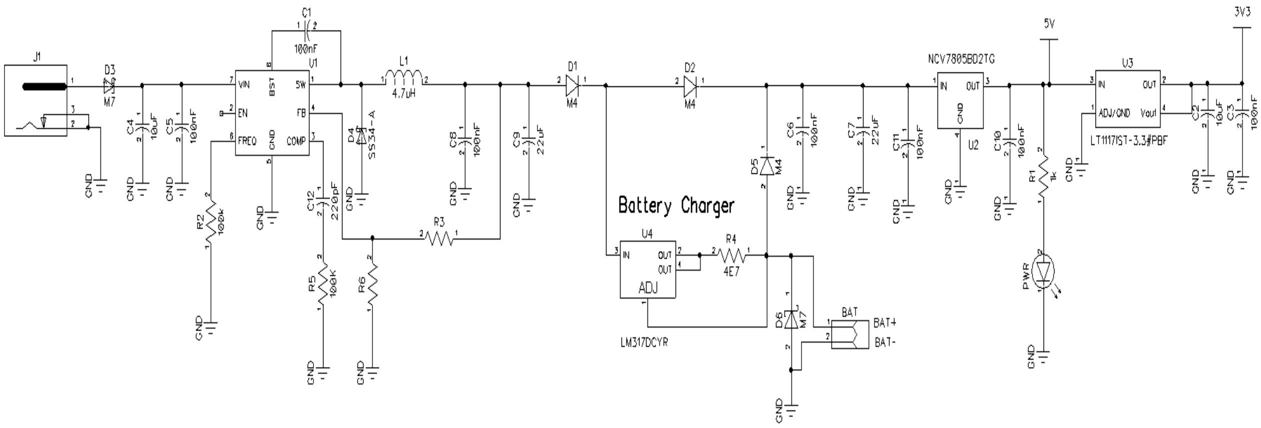

FIGURE 26: The complete power supply unit schematic of the LoRa sensor node.

The PSU consist of three stages to reduce power losses over the required input voltage range.

- Pre- regulation stage
- Battery Charger stage
- Regulation stage

Pre- regulation stage

Pre-regulation stage was implemented to reduce the ripple voltage from the input source and to minimise the power dissipation of the regulator which will then reduce heat generation in the post regulation stage and improves regulation as voltage change at the input is less. The MP1584 DC-DC converter integrated circuit was used as the pre- regulator as they dissipate less power than an equivalent linear regulator during rising of the input voltage or loading conditions.

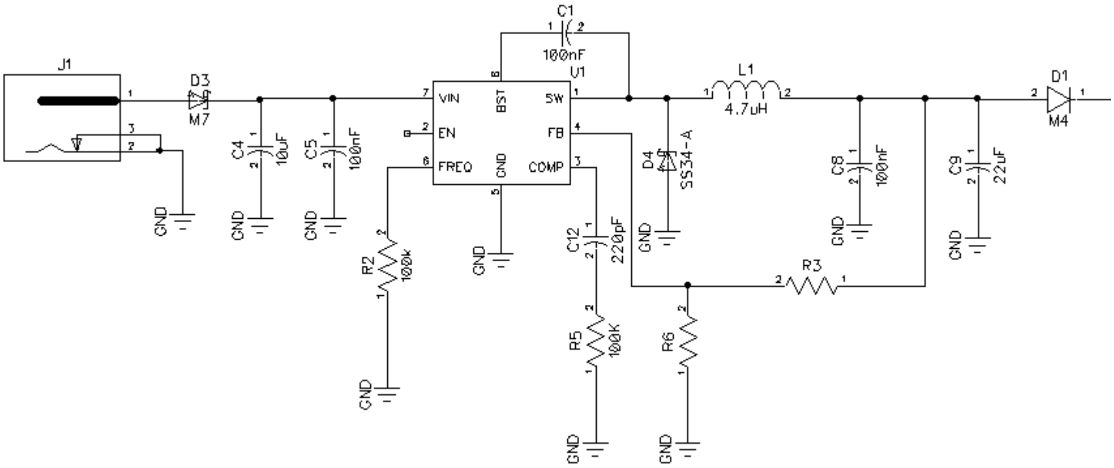

FIGURE 27: Pre- regulation stage circuit of the LoRa sensor node.

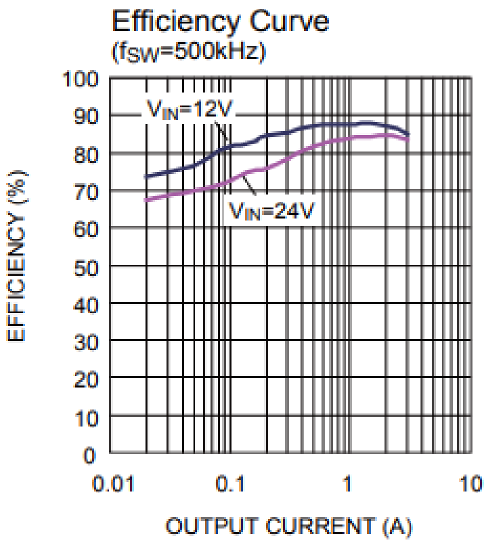

FIGURE 28: MP1584 efficiency versus the output current.

Pre-regulation stage operation

The input voltage is supplied from the DC jack connector which is then is in series with D3 which is a protection diode responsible for reverse polarity protection followed by filtering capacitors C4 and C5 used to improve and smooth the input voltage. L1 was used to provide constant and stable output to the output while being driven by the switched input voltage and the D4 supplies the current to the inductor when high-side switch Is off. The C8 and C9 were used to stabilize and filter the output voltage.

The output voltage was set using a resistive voltage divider from the output voltage down to the feedback voltage by:

$$Vfeedback = Vout \left(\frac{R6}{R3 + R6}\right) \tag{5.1}$$

Therefore, the output voltage is set to:

$$Vout = Vfeedback\left(\frac{R3 + R6}{R6}\right) \tag{5.2}$$

Battery Charger stage

The charger stage consists of LM317 configured in precision current-limiter mode which is used to trickle charge the battery at a fixed current and battery reverse protection diode.

Battery charger stage operation

The charger circuit is powered by the pre- regulator circuit. D2 and D5 were used to prevent the battery voltage from reversing it back to the pre-regulator circuit while the D6 were used to protect the system from a reverse connector of the battery.

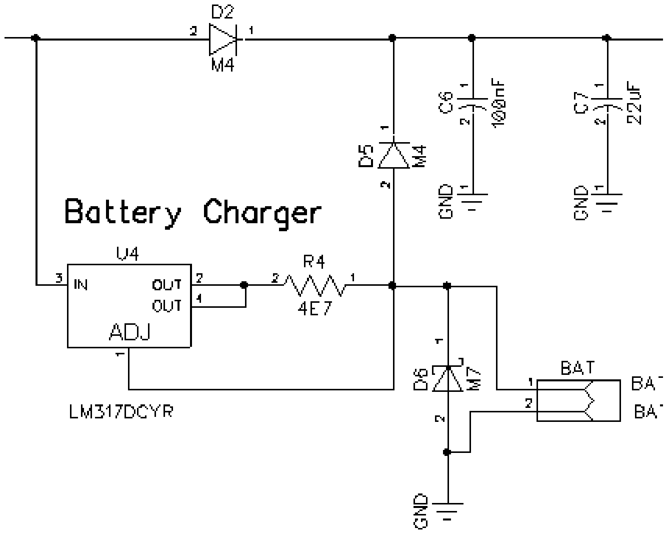

FIGURE 29: Battery Charger stage circuit of the LoRa sensor node.

The battery is charged with a current of 125ma as shown in the calculation bellow allowing slow charge when solar panel is used to provide power for charging.

$$Icharging = \frac{1,25V}{R4} \qquad (5.3)$$

$$Icharging = \frac{1,25V}{4.7} = 265,96mA$$

And the power rating of the resistor was calculated by:

$$P.res = Vref * Icharging \qquad (5.4)$$

$$P.res = 1.25V * 265,96mA = 332,35mA \qquad (5.5)$$

Regulation stage

Regulation unit was implemented to maintain a relatively constant output voltage even though the input voltage may be highly variable.

Two low dropouts (LDO) linear regulation were required to provide the required voltage to power the ESP32 microcontrollers and modules. The MC7805 provided a fixed 5V output while the LT1117 – 3.3V provided the 3.3V.

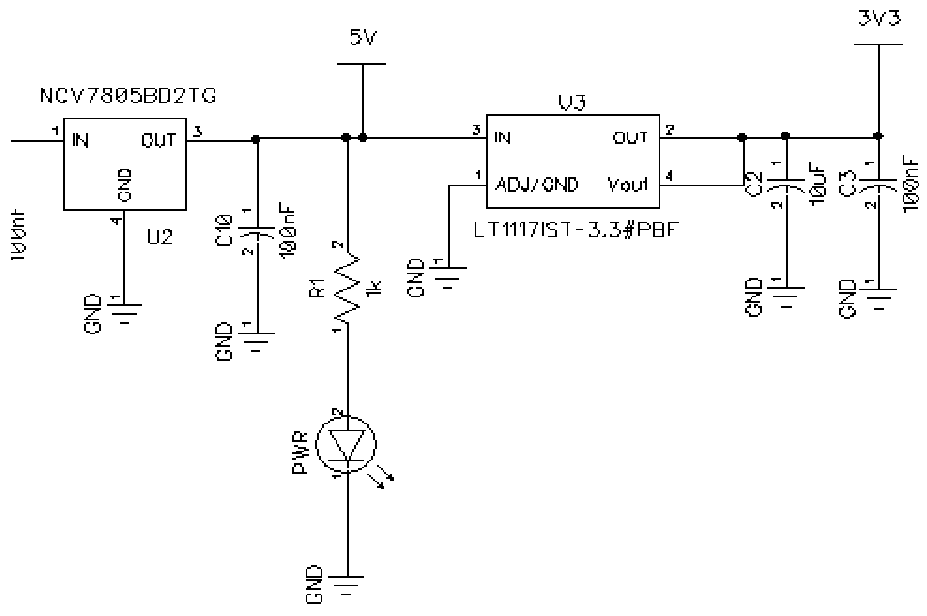

FIGURE 30: Post regulator circuit for the LoRa sensor node.

Regulation stage operation

The voltage supplied from the battery is then fed to the fixed positive regulator L7805 regulating the 12V to 5V which is then fed to the LDO LT1117-3.3V and the Pwr LED indicator which indicate whether the system is power. The LDO LT1117-3.3 regulator requires an output capacitor as part of the device frequency compensation therefore a 12uF and 100nF ceramic capacitors were implemented to fulfil the compensation frequency.

5.1.2 Computing unit:

Processing unit of the LoRa sensor node is responsible for gathering all the sensor data then process it into a readable data.

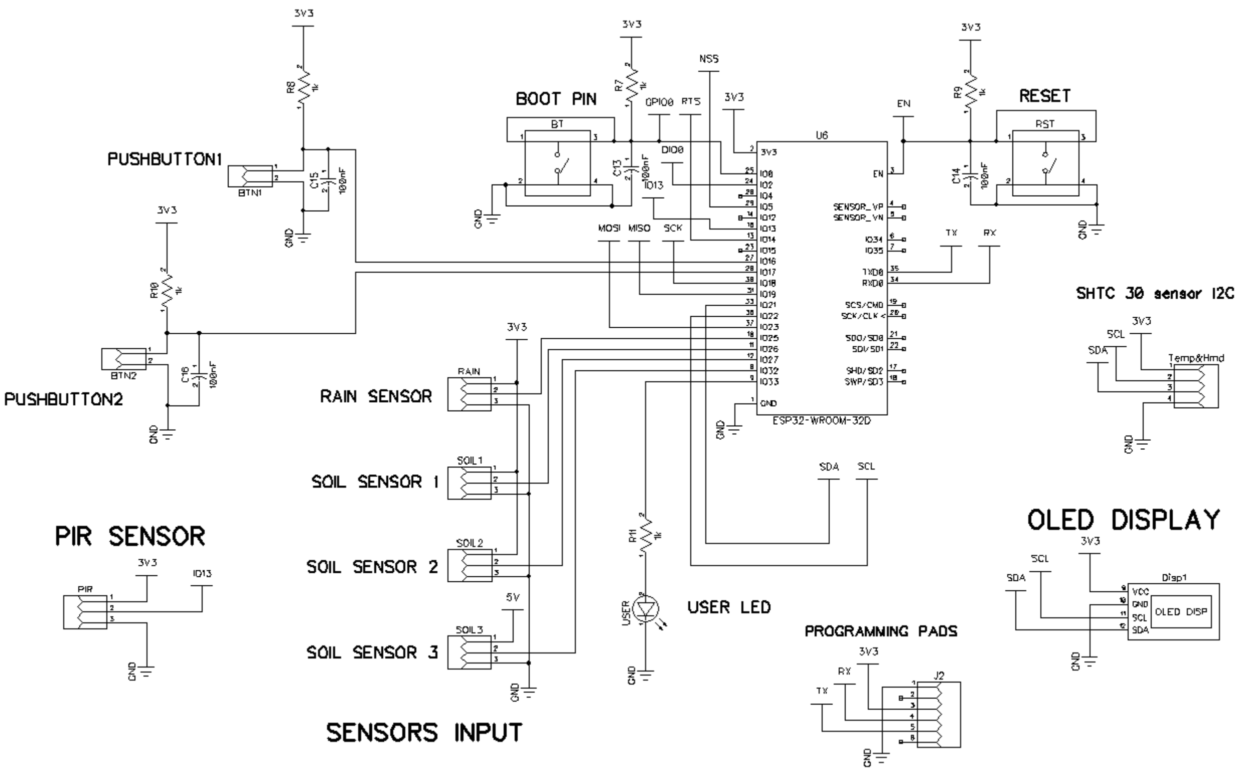

FIGURE 31: Complete block diagram of the LoRa sensor node computing unit.

The computing/processing unit is made up of esp32 microcontroller, BOOT pushbutton which enables the esp32 into a programming mode, reset pushbutton, one connector terminal for rain sensor, one connector terminal for PIR sensor, one connector terminal for SHTC3, three connector terminal for soil moisture sensor, one user led, programming pin headers, one OLED display pin header and two additional terminals for user pushbutton.

5.1.3 Communication unit

The Sx1278 LoRa transceiver module, by semtech was selected for this study as discussed in chapter 4. The module interface with the LoRa sensor node PCB through 16 female pin header with pitch of 2.54mm.

The module is installed on the board using SPI communication protocol allowing the computing unit to communicate with the communication unit.

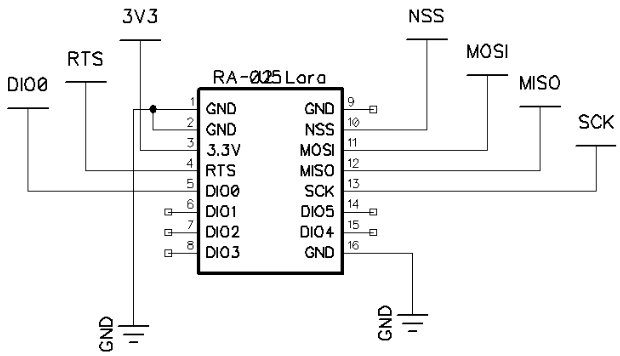

FIGURE 32: Communication unit of the LoRa sensor node.

5.2 LoRaWAN gateway

The LoRaWAN gateway is the base station for the LoRa sensor node. It is responsible to create the communication between the private network to the internet and cloud.

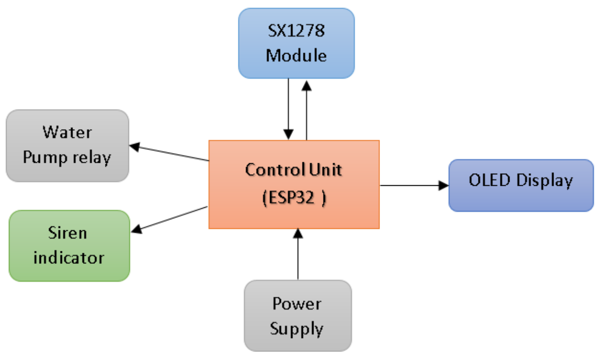

FIGURE 33: A complete block diagram of LoRaWAN gateway.

The LoRaWAN gateway consist of power supply, control unit, water pump control, siren indication, communication module and OLED display.

5.2.1 Power supply unit:

The voltage supplied from 12V DC adapter or 12V battery is filtered by C3, C4 and C5 to remove unwanted noise, then is fed to the fixed positive regulator L7805 regulating the 12V to 5V which is then fed to the LDO LT1117-3.3V and the PWR LED indicator which indicate whether the system is power.

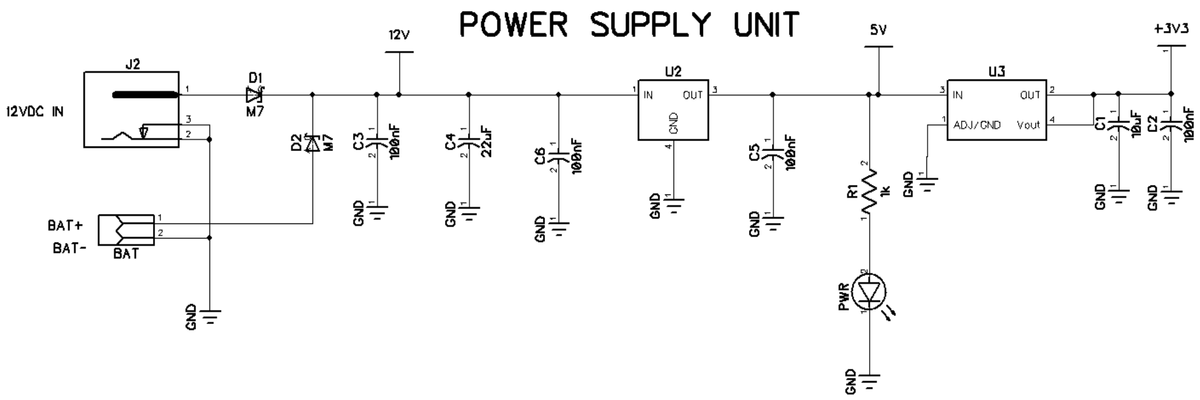

FIGURE 34: A complete power circuit of the LoRaWAN gateway.

The regulator 5V was used to power the water pump relay while the 3.3V was used to power the esp32 microcontroller, OLED display, SX1278 LoRa module.

5.2.2 Control unit

The control unit controls the pump switch, the siren, the irrigation timer and transmit the data gathered from the LoRa sensor to the network server.

The control unit consist of esp32, OLED display pin header, irrigation timer setting pushbuttons, siren on/off pushbutton, programming pads BOOT pushbutton and reset pushbutton.

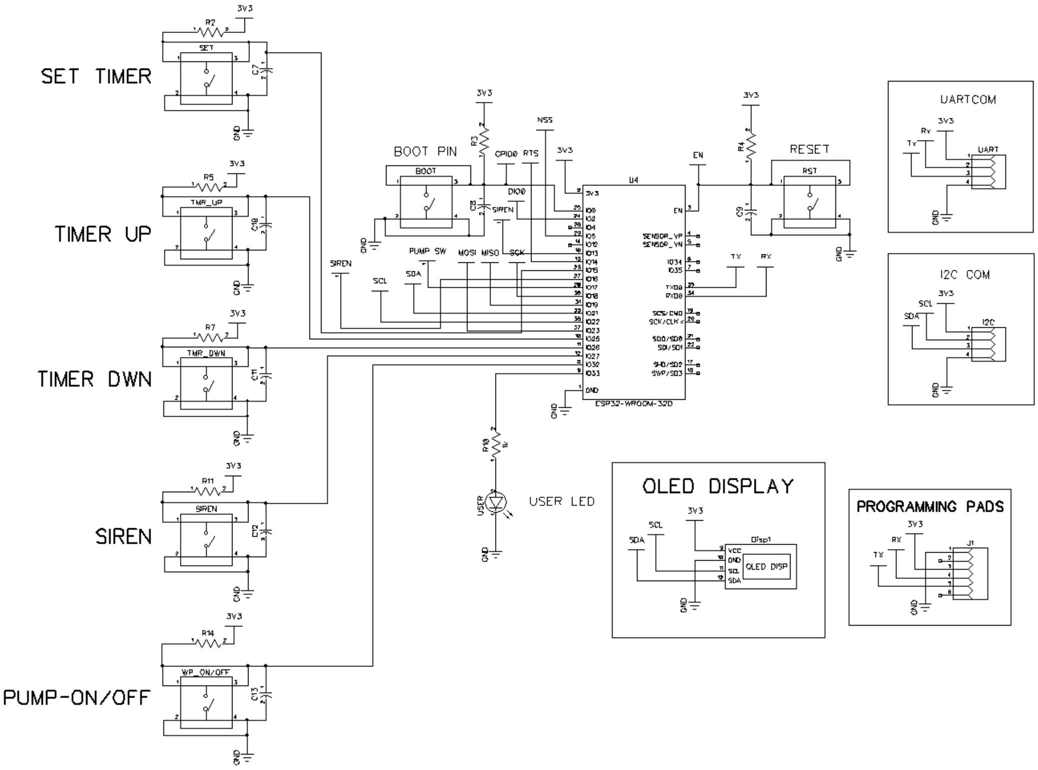

FIGURE 35: A complete schematic of the control unit of the LoRaWAN gateway.

Siren indicator

The siren indicator was design to report when here is an obstacle around the LoRa sensor node. This was used to detect and identify possible threats to a system, and to provide early warning to system in the event that an attack is able to exploit a system vulnerability.

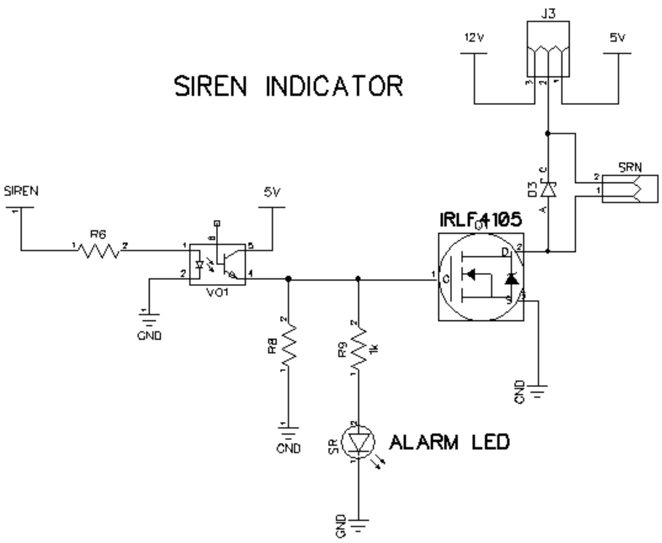

FIGURE 36: Siren indicator circuit of the LoRaWAN gateway.

Water pump replay

Water pump relay was Implemented to allow the irrigation to be controlled in combination with the soil moisture sensor.

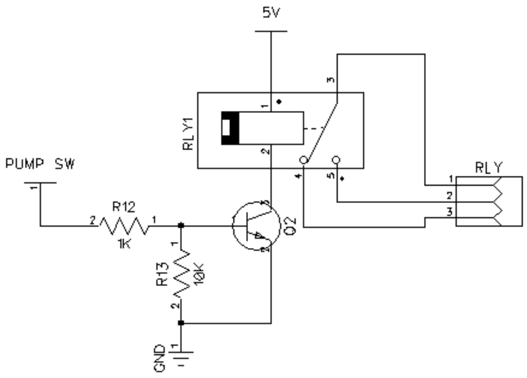

FIGURE 37: Water pump relay circuit of the LoRaWAN gateway.

The pump controller relay operates in such a way that when the LoRa sensor node reports that the moisture content of the soil is at a level where it is considered as dry, the pump controller switch on the pump for a certain time set by the user for the irrigation time then the pump goes off when the moisture sensor detects that the soil moisture content is at desired state considered as wet.

5.2.3 Communication unit

the LoRaWAN gateway shares the same communication module with the LoRa sensor node as discussed in chapter 4. The module is mounted in the LoRa gateway PCB through 16 female pin header with pitch of 2.54mm.

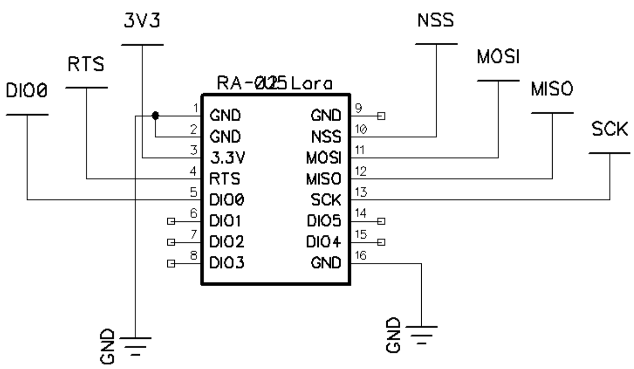

FIGURE 38: Communication unit of the LoRa sensor node.

The module is installed on the board using SPI communication protocol allowing the computing unit to communicate with the communication unit.

5.3 PCB Design

Two printed circuit boards were design for this project, the LoRa sensor node and the LoRaWAN gateway. Diptrace was used to achieve a proficient and good quality PCB and schematic for this project.

DipTrace is a software use for creating schematic diagrams and printed circuit board layouts.

DipTrace has four modules: schematic capture editor, PCB layout editor with built-in shape-based auto router and 3D preview, component editor, and pattern editor.

The PCBs were designed for prototype. Therefore, all modules are connected to the board with headers and can be easily be replaced if they break or if new module is required.

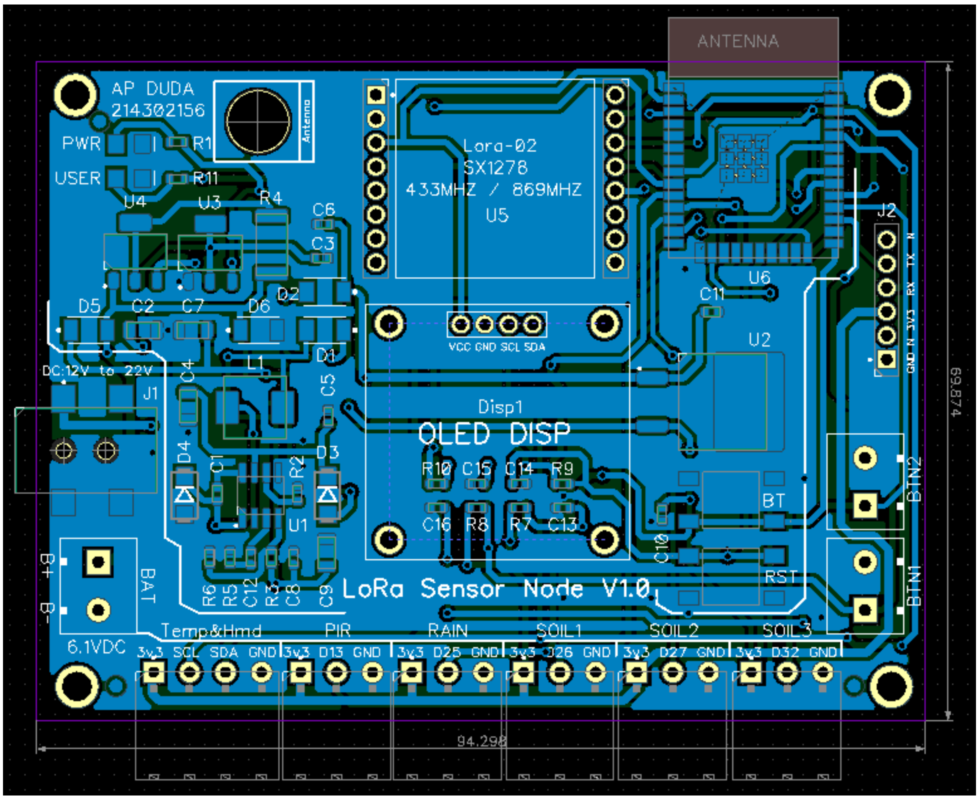

FIGURE 39: PCB layout of the LoRa Sensor node.

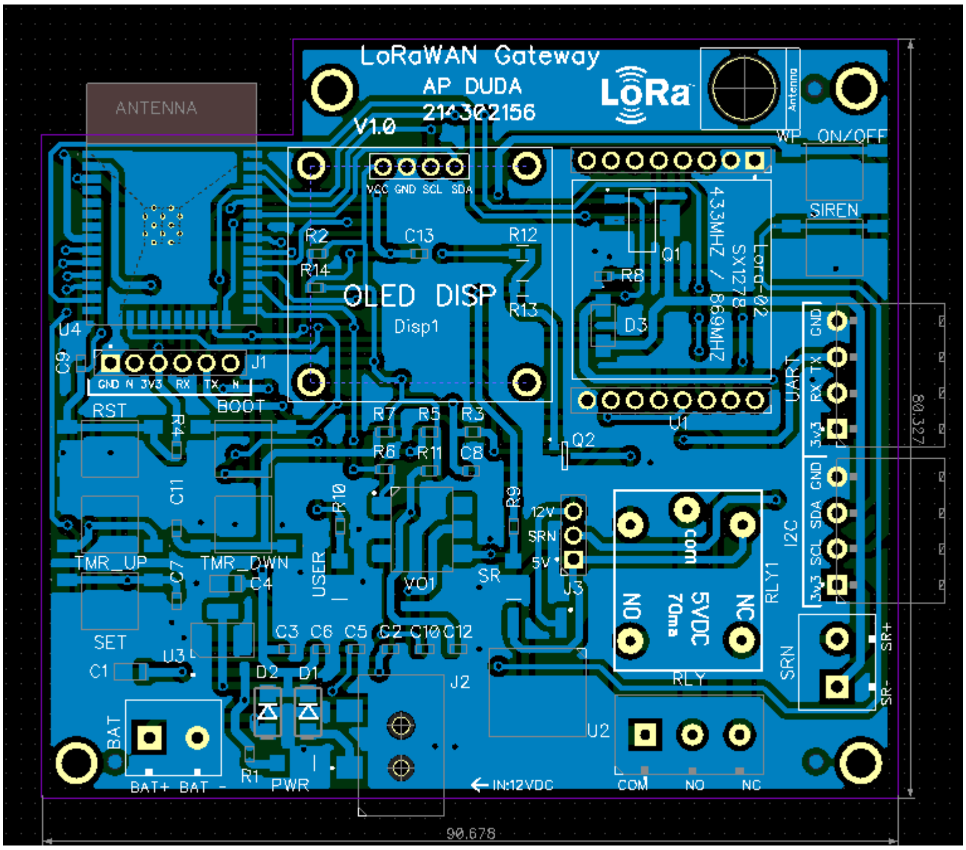

FIGURE 40: PCB layout LoRaWAN gateway.

5.4 PCB manufacture

There are several PCB substrate laminates available such as FR-2, FR-4, Polyimide and Teflon. FR-4 is a flame retarding composite consisting of woven fibreglass matting impregnated with an epoxy binder and is a very common substrate material used in PCB laminates. It is cost effective, exhibits an acceptable Relative Dielectric Constant over a wide frequency spectrum and is mechanically stable in dry and humid conditions. FR-4 was the material used for PCBs for this study due to these properties.

Electroless Nickel Immersion Gold was applied to the copper traces and ground planes to:

- Improve the surface planarity to assist with the optional placement of SMD components.
- Reduce trace oxidation occurring after a prolonged exposure to the atmosphere thereby improving the ability to solder the components to the PCB.
- To bring the finished thickness of the traces and ground planes to 35um.

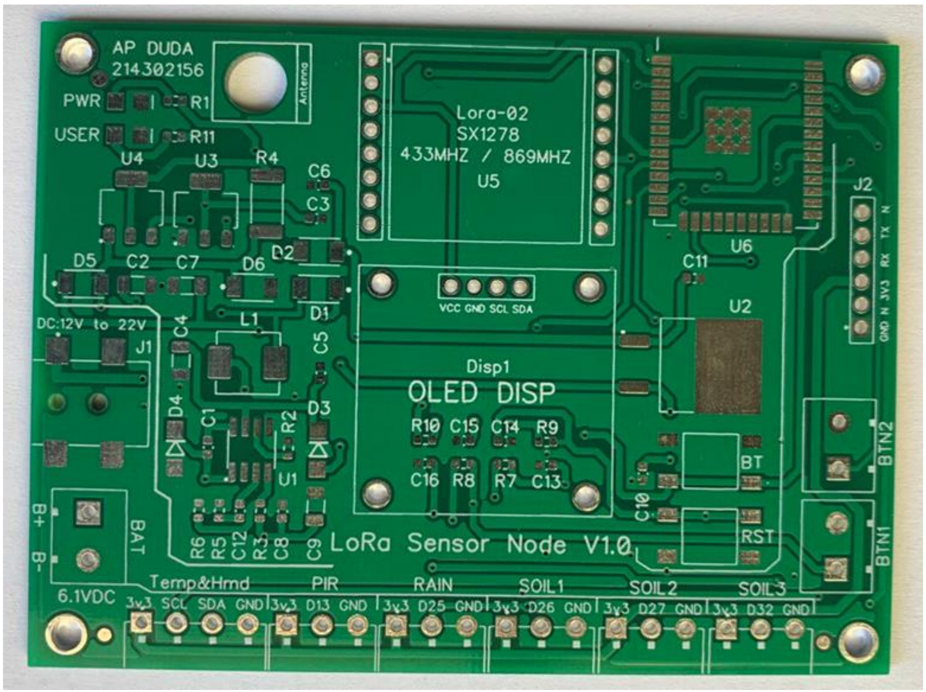

FIGURE 41: Completed LoRa sensor node bare PCB made with FR4, white silk screen and green solder mark.

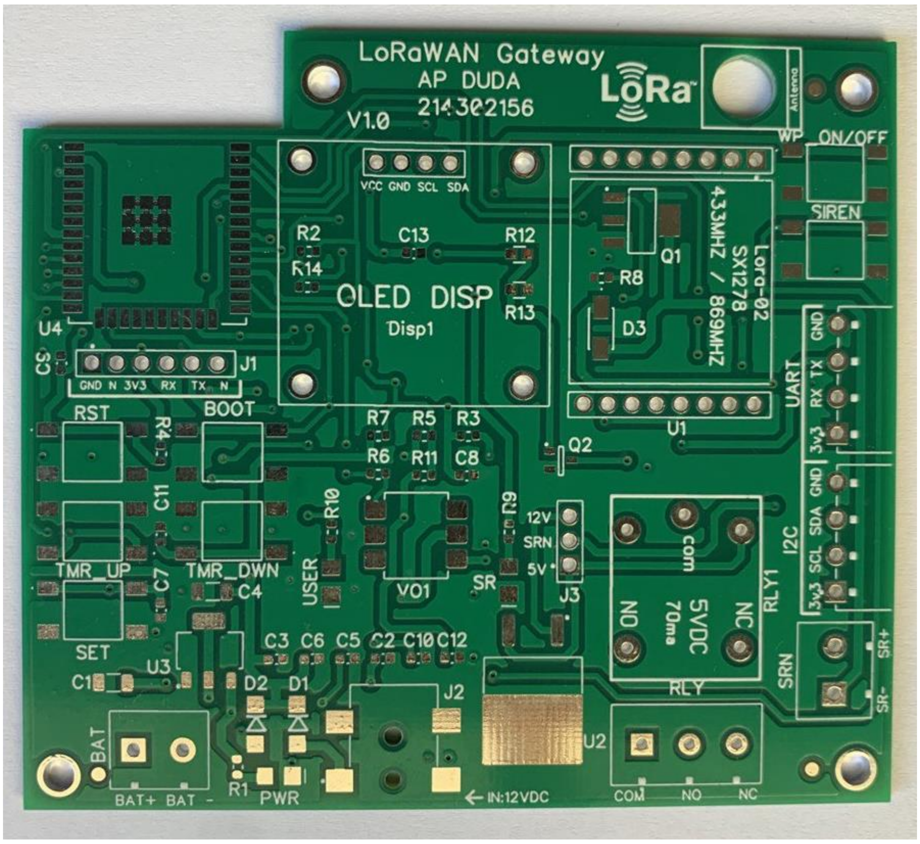

FIGURE 42: Completed LoRaWAN gateway bare PCB made with FR4, white silk screen and green solder mark.

The PCBs were finished with green solder mask and white silkscreen legend on the top layer. A flying probe test was performed on the PCBs to ensure that the trace nets were electrically continuous.

5.5 PCB assembly

The Printed Circuit Board Assembly process has a number of steps, some of these are automated and some are manual.

In the assembly process of this project, two different components mounting technologies were used which are surface mount and through-hole.

Surface mount technology is useful for small, sensitive components such as resistors, diodes, capacitors etc.

The main advantages of surface mount technology include:

- It is cost-effective
- It offers better performance when the environment is subject to vibrations.
- It lends itself to automated production and soldering.
- It takes care of high component density.

The through-hole technology is useful when components are to be mounted on the board through a process of inserting them through holes on the board. When there are large components, this technology is preferable. The other advantages that accrue with Through-hole technology include:

- It creates strong bonds between the components and the board. In applications
- like transformers, for example, where there is high heat, these work best.
- The components can be swapped out, so it lends itself to testing and to prototypes.

Preparatory Steps for Printed Circuit Board Assembly

Solder Paste

The first stage begins with the Solder Paste. Essentially this means applying a solder paste on the board. Jet printer MY700x was used to fulfil this step. Solder paste is a mix of solder with flux which needs to be applied to the board at the correct places.

Pick and Place

The next step is what is known as Pick and Place. The My9 Pick and Place machine was used to mount the surface mount components on the printed circuit board. These are then soldered to the board.

Reflow Soldering

This process ensures that the solder paste solidifies and that components are affixed to the board. Essentially, after pick and place the PCB board was moved to a conveyor belt. It is here that the board is heated to about 250 degrees Celsius, which melts the solder. then it moved to cooler heaters where the solder cools and solidifies.

Quality Control

After Reflow Soldering, comes the very important process of inspection. It is important to check to see that the connection isn't poor and that there are no shorts as a result of misplaced components. Manual inspection methods were used in this process.

Functional Test

After quality check, comes the final inspection to test for functionality. A 12Vdc was power to through the PCBs at this stage, its electrical characteristic such correct voltage out of the voltage regulators were tested.

This completes the PCB Assembly process. However, soldering can make the process messy. What is therefore extremely important, was to wash the boards after the soldering process. For this, an ultra-sonic washing apparatus was used, where the PCB boards were washed in deionized water.

Washing was then followed by a drying process which was then followed by testing process.

It was also important to note that there are some differences between THT Assembly, SMT Assembly and Mixed Technology Printed Circuit Board Assembly.

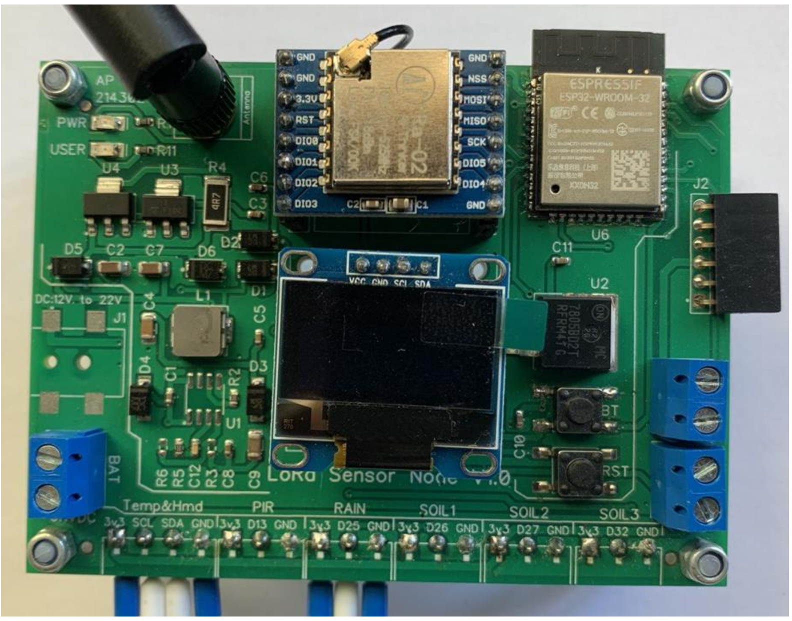

FIGURE 43: Completed LoRa Sensor node PCB with all surface mount and through hole components assembled.

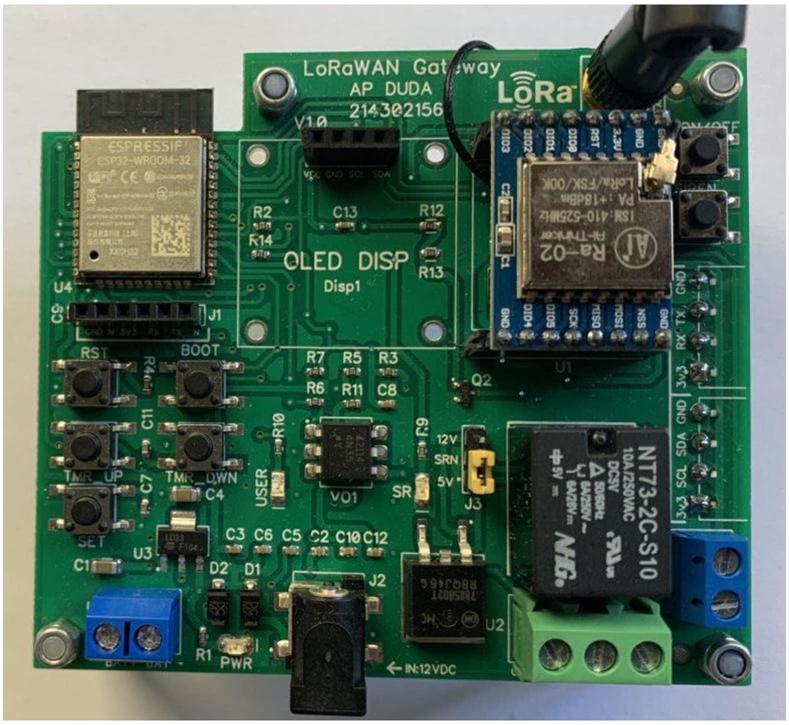

FIGURE 44: Completed LoRaWAN gateway PCB with all surface mount and through hole components assembled.

CHAPTER 6

This chapter deals with the design and implementation of the software aspects integrated with the hardware described in Chapter 5. Its functionality and detailed design are of vital importance to meeting the objectives of this dissertation.

Software design implementation

In the process of the software development, software such as Visual studio code, platformIO IDE, Arduino IDE, putty and notepad++ were used to develop the firmware for the LoRa sensor node and LoRaWAN gateway.

PlatformIO is professional tool ,cross-platform ,cross-architecture and multiple framework used in embedded systems to develop firmware for embedded products (PlatformIO, 2014).

One of the advantage of PlatformIO in the embedded market is to provides developers with a modern integrated development environment such as Cloud & Desktop IDE that works cross-platform that supports SDKs or Frameworks, and includes debugging, testing, automated code analysis and remote management (PlatformIO, 2014).

The second software that played a very important role in this thesis is PuTTY which is an open source terminal simulator, serial port and also support many network protocol including Telnet, rlogin, SCP, SHH and raw socket connection (Tatham, 1998).

PuTTY was used for software debugging and it provided an easy interface to use the UART com port which the data from the microcontroller could be printed in real time.

Notepad++ was used to compare codes regarding to the changes done. it allows the process of the code changes without recreation of the same code.

Notepad++ is a source code and text editor for Windows platform. It also supports tabbed editing functionality which allows a user to work on multiple open files in a single window (Yllemo, 2020).

The development of the firmware and algorithm for the microcontroller used is a major part of this thesis.

Two different firmware were developed for this project, the first software was developed for LoRa sensor node and the other for the LoRaWAN gateway.

The development of the firmware was driven by the flowchart. This facilitated the firmware development as a whole by being broken into smaller manageable sections.

6.1 LoRa sensor node

The first system designed is the LoRa sensor node which is outlined and validated in this section.

6.1.1 Overview

The LoRa sensor node software is designed in such a way that it can operate in two different Modes based on the signal provided from the PIR sensor.

This section discusses two the program routines that provided a fast response and efficiency for the LoRa sensor node hardware developed in chapter 5 which are the start-up routine as well as the continuous routine. The continuous routine consists of Normal mode and Alert mode.

6.1.2 Design

A flowchart was developed to describe the LoRa sensor node program routines. The integration of the firmware was done in the Visual studio code in the platformIO integrated development environment.

6.1.3 Program routine of the LoRa sensor node

Figure 2 and 3 presents the design of the LoRa sensor node along with its Modes.

Start-up Mode

When the sensor node is switched on or restarted, it first includes the libraries used, initialise the GPIOs and global variables, initialize the peripheral hardware before arriving at the main loop. The setting up of the GPIOs, initialisation of peripherals is known as the sensor node start up routine.

The nodes begin by including libraries for the hardware, initialising the ports, global variables and functions, then checks which devices are connected and whether they are functioning. If they are not, the user is alerted via a message to the UART and display After that, the LoRa module is then set up according to the parameters given in subsection. Once the LoRa module is fully functional, the node start-up routine is complete and the program continues to the main loop.

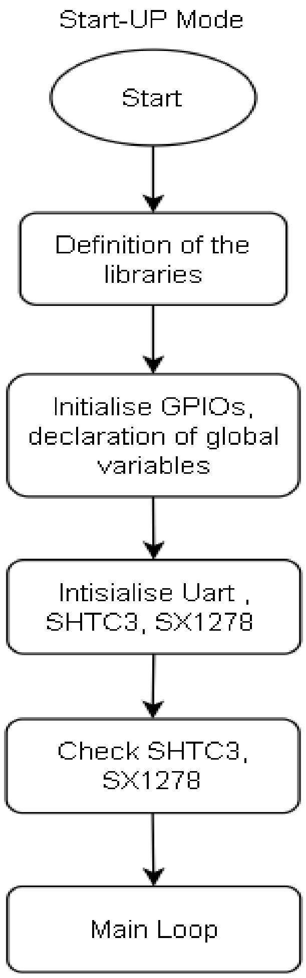

FIGURE 45: Startup mode for the LoRa sensor node.

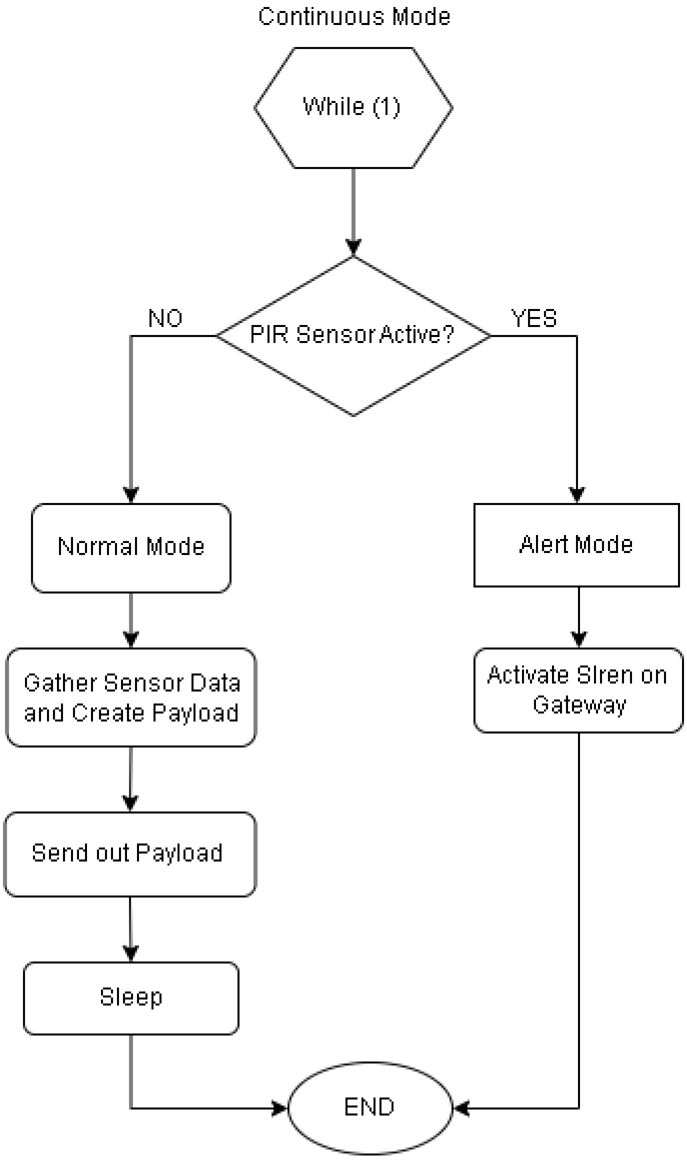

FIGURE 46: A complete Software design flowchart of the LoRa sensor node.

Continuous Mode

The main loop takes place inside a continuous loop. The sensor node gather data for each sensor, then all the data gathered is packed into variable message then sent to the gateway address, after that the module goes to sleep. After 5min, the MCU wakes up, gather the data then goes to sleep MCU. In a case where the PIR sensor actives, the MCU wakes up and only send the PIR message alerting the view.

6.1.4 Implementation

The firmware implementation of the flowchart can be found in Appendix. The next section verifies the output of the implementation.

6.2 LoRaWAN gateway

6.2.1 Overview

The LoRaWAN gateway firmware was designed in such that in run three different tasks simultaneously. In order to achieve this, a Real Time Operating System was used.

A real time operating system (RTOS) is an operating system used in embedded systems ore in systems where real time situation is critical. Their main objective is to ensure that a system respond to events deterministically.

By using a real time operating system, it allows a written application to be set as independent tasks and also assigning priorities to each tasks. The real time operating system is responsible for ensuring the highest priority task is able to run first. As example if a task is not able to run include when a task is expecting an external event to occur, or when a task is waiting for a fixed time period.

In this project, the RTOS which was chosen for the esp32 microcontroller was the FreeRTOS which is a real-time kernel on top of which embedded applications can be built to meet their hard real-time requirements. In FreeRTOS, Applications can be organized in collection of independent threads of execution. Only single thread can be executed at the time on processors that has only one core. The kernel decides which thread should be executed by examining the priority assigned to each thread by the application designer. In other words, the application designer could assign lower priorities to threads that implement soft real-time requirements and higher priorities to threads that implement hard real-time requirements. This would ensure that hard real-time threads are always executed ahead of soft real-time threads, but priority assignment decisions are not always that simplistic (Barry, 2016).

The FreeRTOS kernel is a real-time operating system that supports numerous architectures for building embedded microcontroller applications which are:

• A multitasking scheduler.

• Multiple memory allocation options (including the ability to create completely statically-allocated systems).

• Inter-task coordination primitives, including task notifications, message queues, multiple types of semaphore, and stream and message buffers.

• Support for symmetric multiprocessing (SMP) on multi-core microcontrollers.

FreeRTOS features:

FreeRTOS has the following standard features such as Pre-emptive or co-operative operation , Very flexible task priority assignment, fast and light weight task notification mechanism, Queues, Binary semaphores, Counting semaphores, Mutexes, Recursive Mutexes, Software timers, Event groups, Tick hook functions, Idle hook functions, Stack overflow checking, Trace recording, Task run-time statistics gathering, Full interrupt nesting model, A tick-less capability for extreme low power applications, Software managed interrupt stack when appropriate.

LoRaWAN gateway

The firmware for the LoRaWAN gateway is discussed in this section. Arduino integrated development environment was used.

6.2.2 Design

A flowchart was developed to describe the LoRaWAN gateway program routines. The integration of the firmware was done in such a way that three different tasks has to be run simultaneously.

The description of the tasks is described below:

Task1: Receive the data from LoRa sensor node and transmit the data to cloud.

Task2: Display the sensor data to the OLED display.

Task3: Timer control for the irrigation and control the siren.

6.2.3 Program routine of the LoRaWAN gateway

The LoRaWAN gateway features start up mode and continues mode. when the LoRaWAN gateway is powered or restarted, the sequence begins by including the libraries, initialise the GPIOs and global variables and the peripheral hardware before arriving at the main loop. The setting up of the GPIOs, initialisation of peripherals is known as the LoRaWAN gateway start up routine.

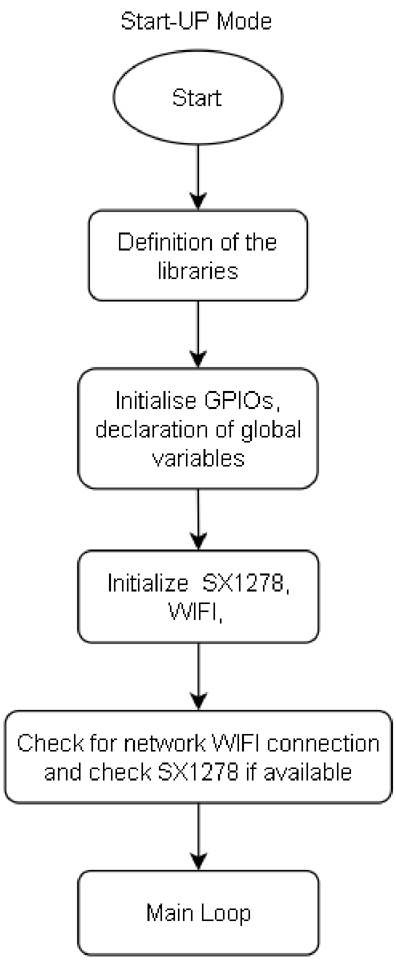

FIGURE 47: Software design flowchart for the startup routine of the LoRaWAN sensor node.

Task 1 routine flowchart:

The Task1 routine is responsible for sending out the data received from the LoRa sensor node to the cloud for storage. it is also responsible for controlling the water pump relay which switching on/ off the valve for water flow.

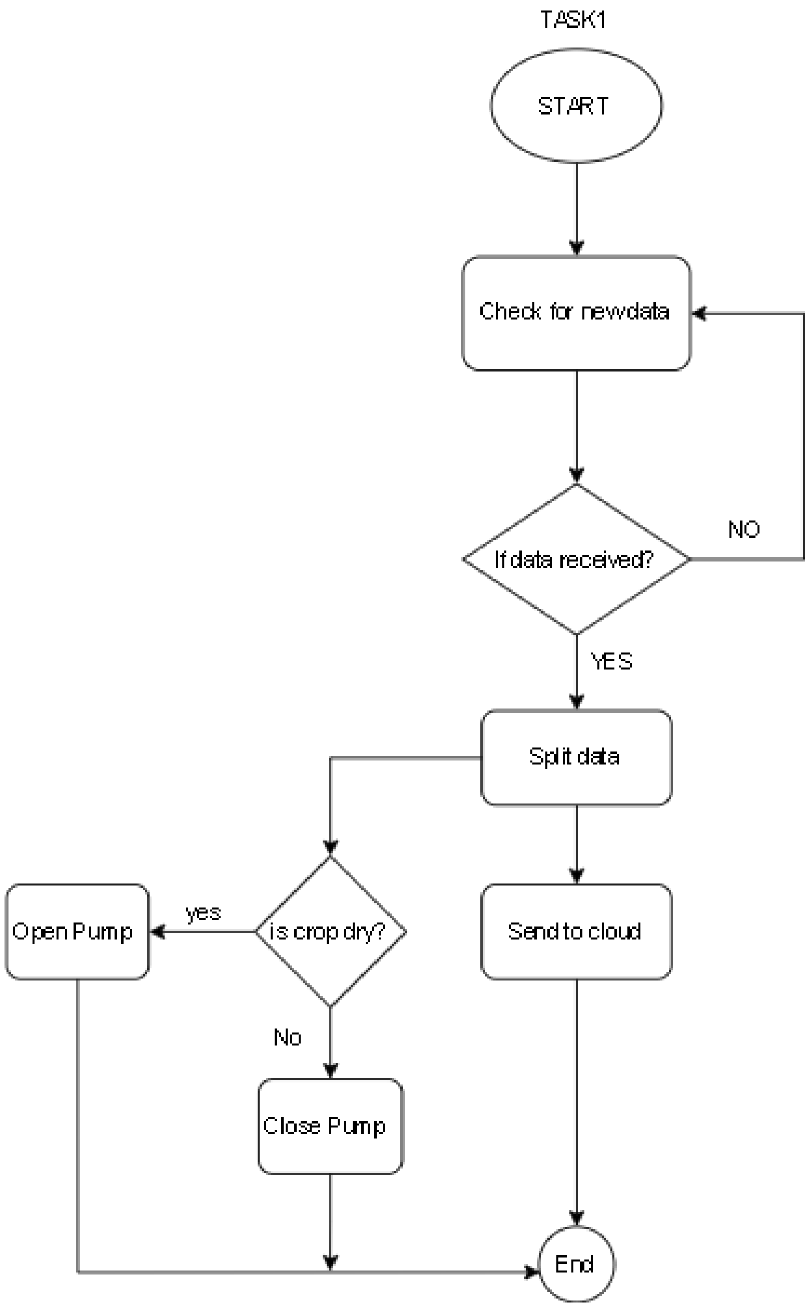

FIGURE 48: Software design flowchart for the Task1 routine of the LoRaWAN sensor node.

When the LoRaWAN gateway is powered or reset, the start-up routine begins, once the start-up is completed, task 1 begins by constantly checking for incoming payload, once new payload is received, the payload is separated into humidity, temperature, moisture and PIR data which is then transmitted to could one by one, also it checks if the crop is dry by using the moisture data to control the water pump valve. In this way, the task1 is running simultaneously with task2.

Task 2 routine flowchart:

Figure bellow presents the task2 flowchart of the LoRaWAN gateway along with its PIR controller.

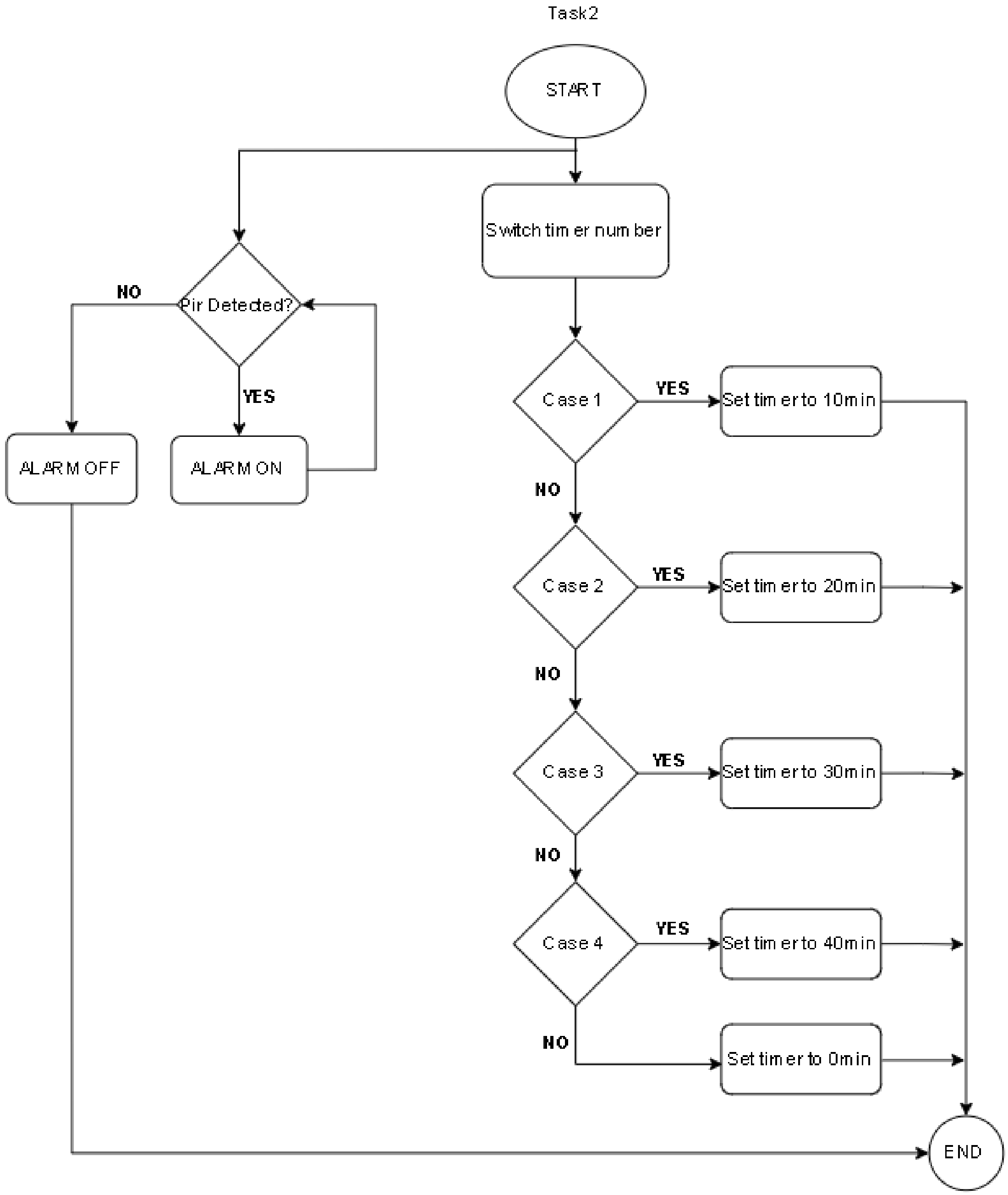

FIGURE 49: Software design flowchart for the Task2 routine of the LoRaWAN sensor node.

Task 2 is responsible for setting up the irrigation time and indicate whether the LoRa sensor node is safe. The LoRaWAN gateway consist of four cases which set the irrigation time from fifteen minutes up to forty minutes.

6.2.3 Implementation

The firmware implementation of the flowcharts can be found in Appendix. The next section discusses the results of the combination of the hardware and software developed in chapter 5 and 6.

CHAPTER 7

Results

This chapter describes the results done from several tests which were performed on the hardware, software and communication of the LoRa gateway and the LoRa sensor node. To guarantee that the hardware and software function as intended, tests were run. The results from all these tests and conclusions derived from each will be explained in this chapter.

7.1 Power Supply Test

A 12VDC @ 2A adapter was used to test functionality of the power supply unit for both hardware. The adapter was connected to the LoRa sensor node PCB after that, measurements were taken. The same test was done for the LoRaWAN gateway PCB.

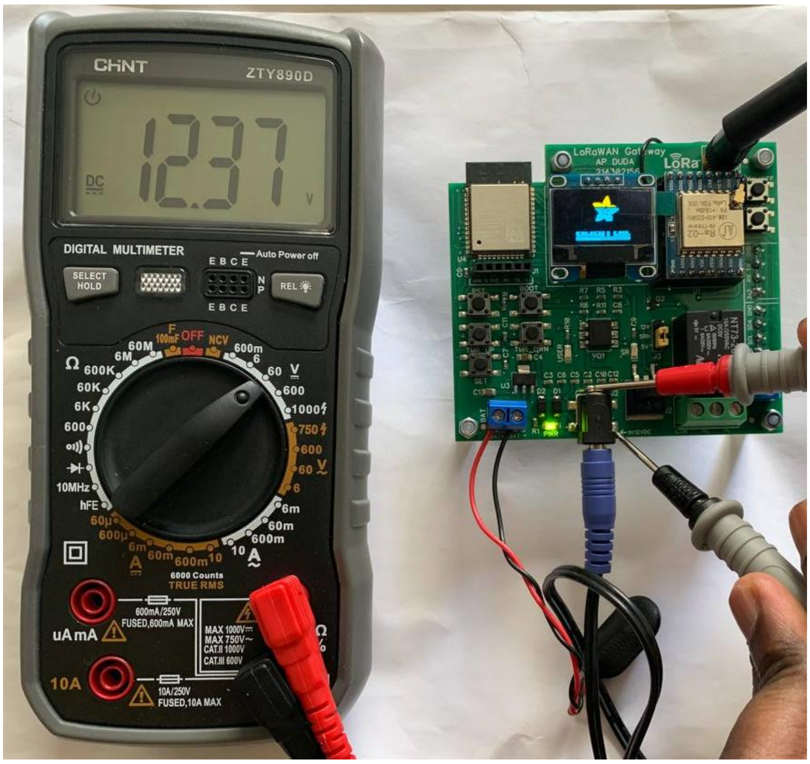

FIGURE 50: LoRaWAN gateway input voltage measurement with multimeter.

Firstly, the test of the input voltage with the multimeter was conducted which measured 12.37V as shown in figure 50, then the 5V regulator was tested which measured 5.03V as displayed in figure 51.

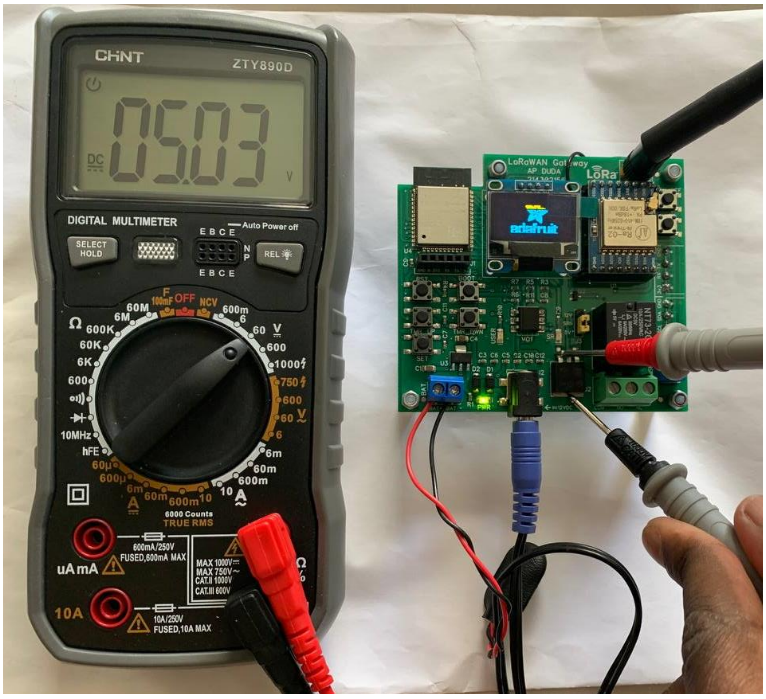

FIGURE 51: LoRaWAN gateway 5V regulator output measurement with multimeter.

After the 5V regulator was successfully tested, the test proceeded with the 3.3V regulator which measured 3.315V as shown in figure 52.

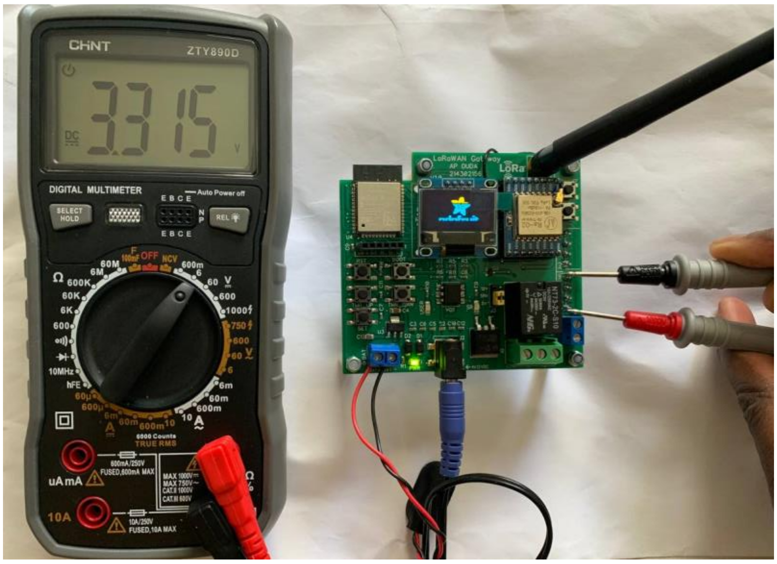

FIGURE 52: LoRaWAN gateway 3.3V regulator output measurement with multimeter

After the power supply test of the LoRaWAN was completed. The same tests of the three points were done onto the LoRa sensor node where the input voltage measured 12,20V as shown in figure 53, the 5V regulator which measured 5.043V and 3.3V regulator which measured 3.314V and results were recorded in table 10.

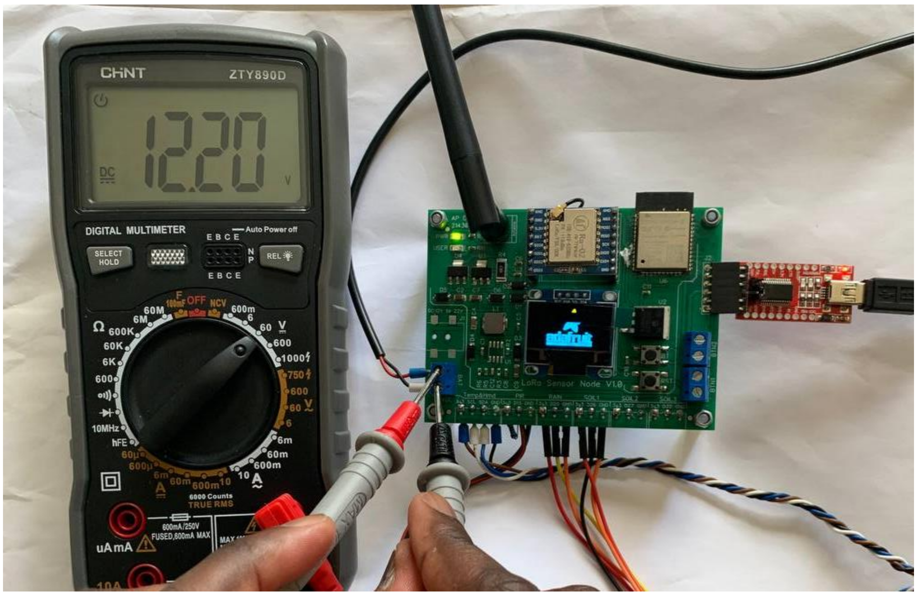

FIGURE 53: LoRa sensor node input voltage measurement with multimeter

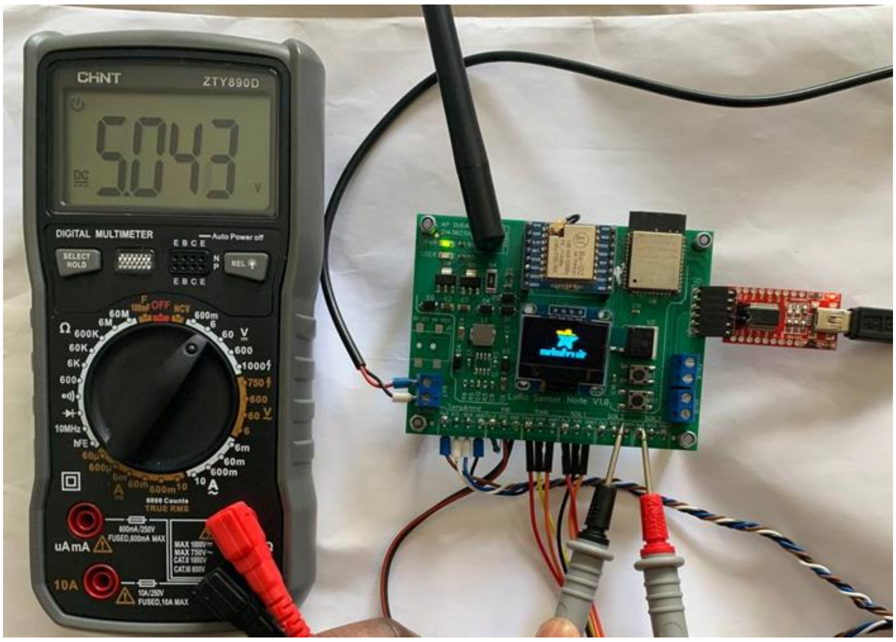

FIGURE 54: LoRa Sensor Node 5V regulator output measurement.

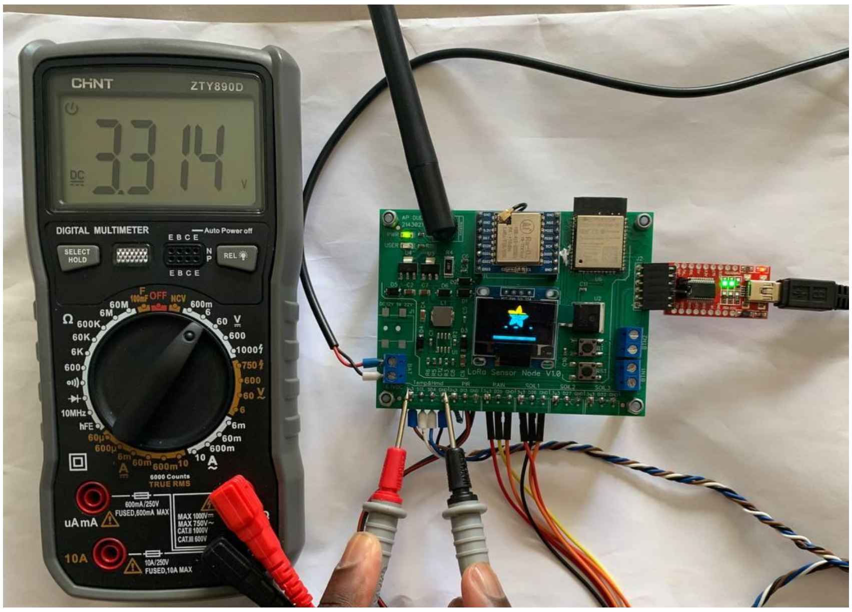

FIGURE 55: LoRa Sensor Node 5V regulator output measurement.

LoRa Sensor Node 5V and 3.3V regulators result.	LoRaWAN gateway 5V and 3.3V Regulators result.
5.043V	3.314V
3.314V	3.315V

Table 5: Output voltage of the Power supply units for the LoRa sensor node and LoRaWAN gateway.

The table above shows that the output voltage of the regulators was functioning properly and they provided the fixed voltages that powered the sensors, esp32 microcontroller and other devices on the system.

The temperature of the pre-regulator components on both PCBs were checked manually to ensure that none of them were generating excessive heat which would indicate the presence of a possible fault with the regulator or PCB. None of the components were hot to the touch and power supply did not register any current being drawn during the tests.

7.2 Communication range test

A location in Cape Town, particularly in Somerset West was chosen as the testing site as it resembles the environment in which the network can be tested. Measurements were possible over distances varying between 0 to 1500 meters in steps of 50 meters' distance. Figure 56 demonstrate a range test between the modules over a distance of 1.08km.

FIGURE 56: Measurement location for the range test.

7.2.1 Testing Protocol

The objective of this test was to determine how well the signal for communication between the LoRa sensor node and LoRaWAN gateway will be. The LoRaWAN was placed at a stationary location with its antenna at a fixed height at about 3 meters above ground level while The LoRa sensor node, the mobile station, was moved to many different points and tests were conducted and its antenna was place15cm low and 4 meters high above ground level. At each point, 10 packets of data were sent from the mobile station to the base station. Each time a packet was received at either station the received signal strength indicator, packet number as well as the data sent was stored.

7.2.2 RSSI Measurements

In wireless communications, the measurement of the power present in a received radio signal is known as the Received Signal Strength Indicator (Balakrishnan A, 2022), (Anand S, 2022). The RSSI provides a measurement of the communication quality between two radios that are attempting to communicate with one another. It is measured in dBm, with values closer to 0 dBm indicating a better communication quality and more negative values referring to a worse communication quality (Kavetha S, 2022).

Figure below displays the RSSI readings for the radios over the test area. The distance at which a radio was unable to establish communication can be viewed from the figure as the point where the RSSI reached -120dBm.

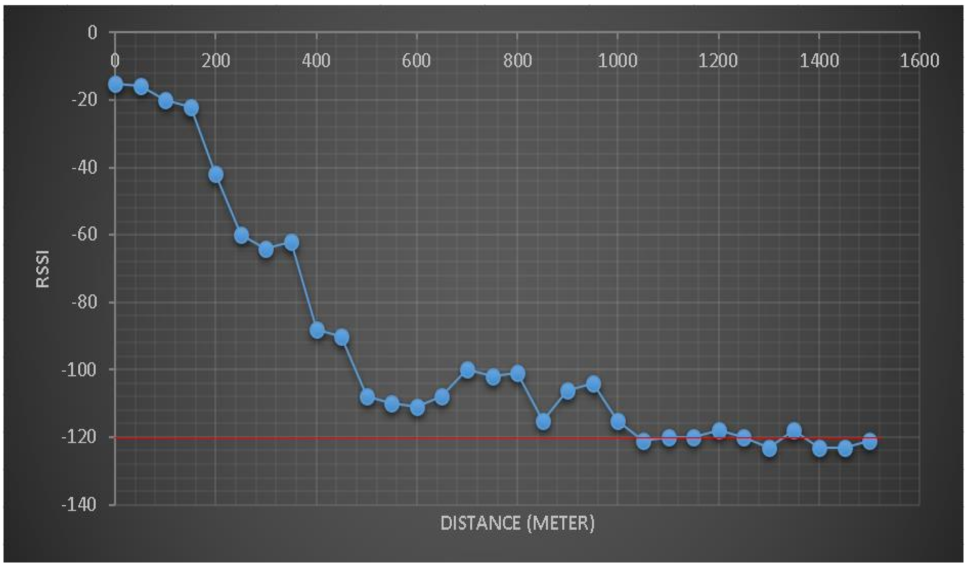

FIGURE 57: The RSSI measurements at each waypoint from 0m to 1500m distance.

The RSSI decreased as the distance between the two radios increased. This is expected because as the distance between the radios increases, the signals between them suffer from greater free space losses. The signals are also gradually distorted and refracted by environmental objects or absorbed by the soil and vegetation.

in summary The LoRa sensor node and LoRaWAN gateway were able to transmit packets without error over a distance up to 1km in an area with busy roads, flat type buildings and trees. After this, packet transmission approached 0%.

7.3 Environmental monitoring test

In this section, various test case was done such as temperature reading, humidity, rain checking, moisture and pump commands. The tests were performed on the basis of the output carried out by the system. Different test cases such as Unit and System testing with different sub heading have done with specific objective and the end results.

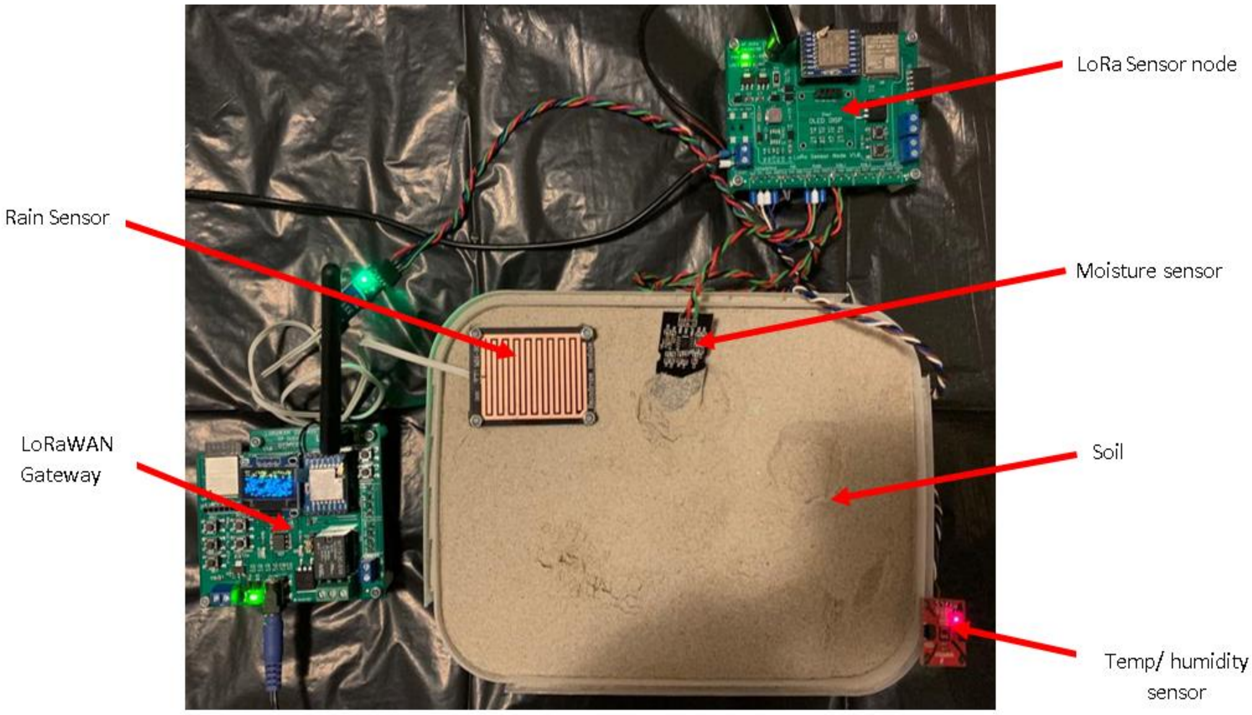

FIGURE 58: Setup of the system for the environmental monitoring test.

The first test conducting for the environmental condition were humidity and temperature. The data was collected within eight days during the winter season. The relationship between the humidity and temperature is that they are inversely proportional.

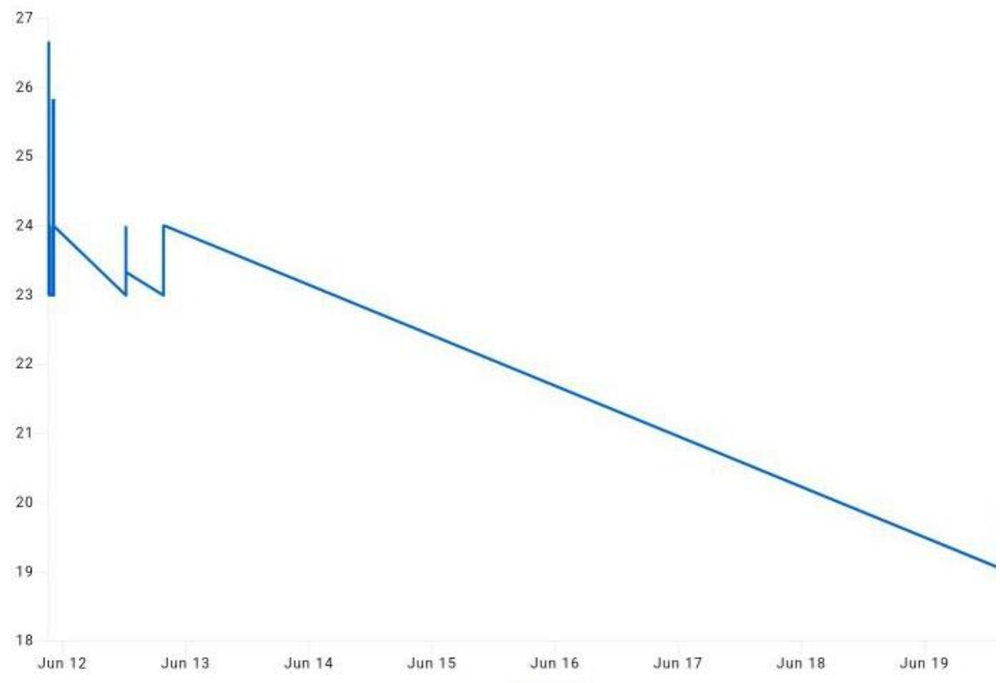

FIGURE 59: Temperature graph monitoring during eight days' period

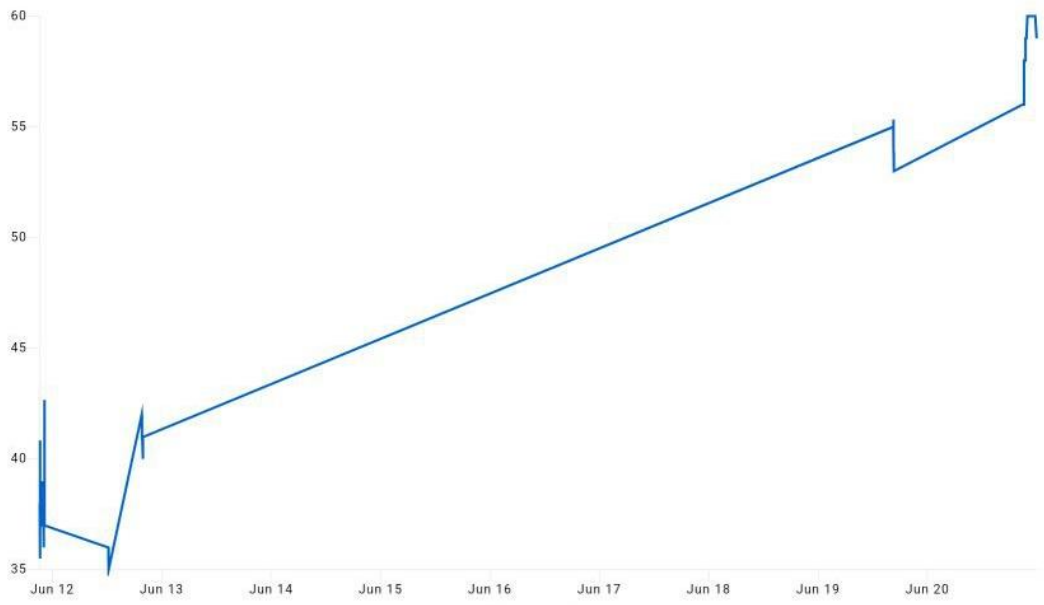

FIGURE 60: Humidity graph monitoring during eight days' period.

Figure 64 shows the decrease in temperature during the testing period while the figure 65 shows increase in humidity during the same period. The system was able to keep track of the humidity and temperature contents for later review by means of AdafruitIO cloud service.

Moisture content was monitored in period of three hours. The series1 in blue line represents the moisture while the orange line series2 represent the water pump which was either 0% meaning the pump is off and 100% meaning the pump is on.

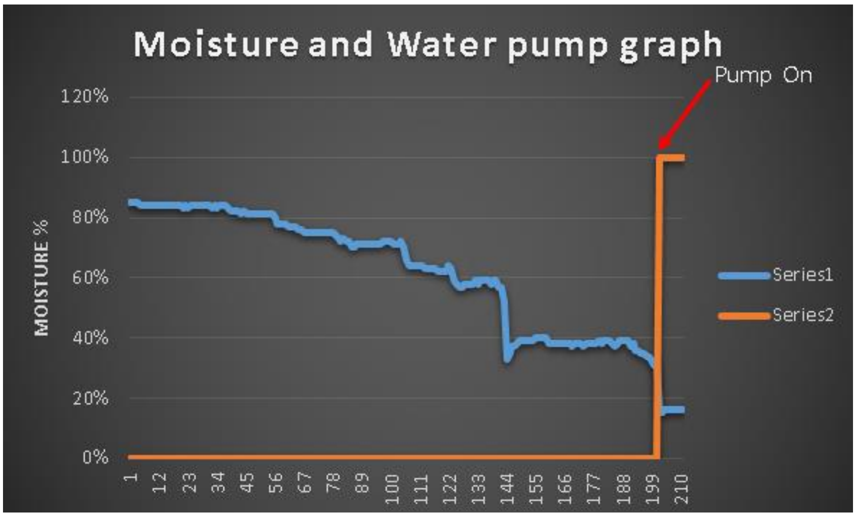

FIGURE 61: Graph representing decrease on moisture level.

The graph shows a slowly decrease in moisture over a period of time, once moisture reached around 20% the water pump switched on watering the soil till its wet state which was set to 100% while the dry state was set to 20%.

The environmental conditions can be easily and accurately monitored with the help of sensors. This methodology has a capability of sensing the moisture, humidity, temperature and obstacle. These values can be used in an efficient and effective way to take all necessary steps and automate the process to agriculture.

7.4 Web user interface

In order to allow the user to interact with system remotely and to facilitate the logging of data, AdafruitIO was used. AdafruitIO allows the system to be monitored in real-time and also provide the ability to control the siren and pump motor switch. The interface allows you to view the temperature in degrees Celsius, humidity, rain, moisture in percentage as show in figure 1. It also provides the temperature, humidity and moisture graphs.

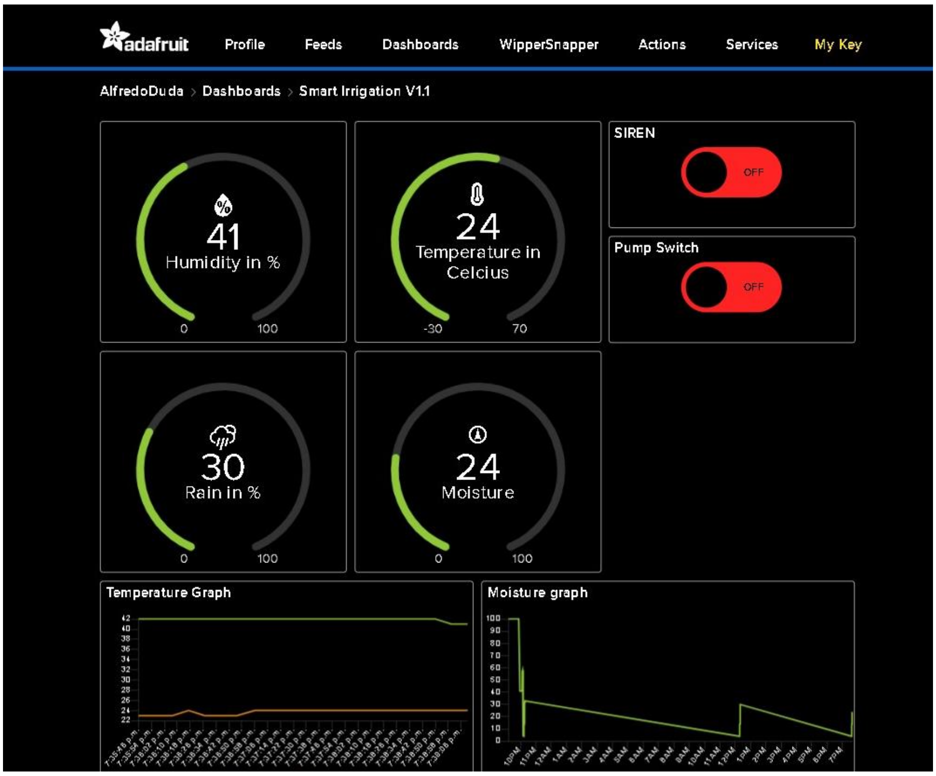

FIGURE 62: Dashboard of the smart irrigation system with the environmental monitoring on AdafruitIO.

CONCLUSION

This investigation presented a smart irrigation system for farm application using LoRa technology to reduce water wastage and labour in agriculture by combining LPWAN technology, cloud computing and optimization. The system successfully provided significant results and fast communication by deploying low-cost sensors to sense variables of interest such as humidity, temperature, rain, soil moisture and obstacle around LoRa sensor node. The system demonstrated that optimization into irrigation help reduce the water consumption, improve the quality of crops and also reduce labour.

The research questions have been answered and the problem statement has been addressed. The phases of problem definition were completed successfully. Literature analysis, hardware design, software design, implementation, testing, presentation of results was all addressed and implemented. The dissertation is thus concluded.

Recommendations and Future Work

- The following are recommendations for future work by which to improve and continue the research undertaken during this project:
- Future implementations of solar panel to charge the LoRa sensor node battery must be taken into consideration in order to further increase the battery life.
- Future work should be considering the mounting of the LoRa sensor node into a pole to facilitate the communication between the gateway and the LoRa sensor node.
- Future replacement of the microcontroller for the LoRa sensor node to a cheaper microcontroller will be considered.
- The sx1278 LoRa module offers an eight-bit cycle redundancy check (CRC) code that is transmitted at the end of each serial transfer. This can be used to compare against a calculated CRC from the received data. If the sent CRC and the calculated CRC match, the data was sent correctly. Implementation of this code would allow for reliable data transfer, especially in noisy environments, or where the modules are in a closed area.
- Future work with the Sigfox LPWAN will also be taken into account.

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Appendices

Appendix A: Regions

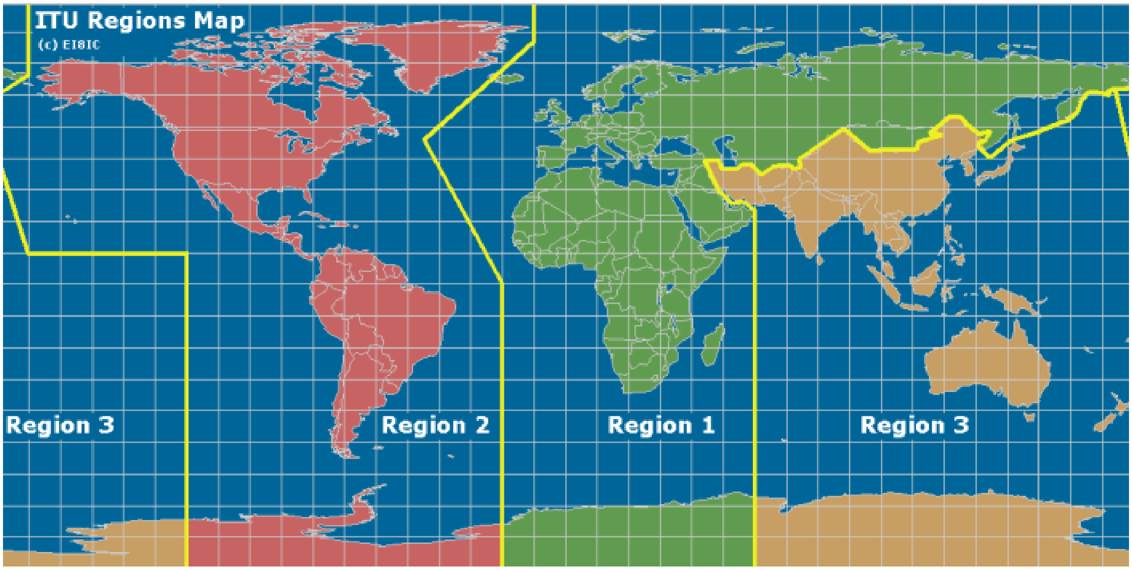

Figure 63:This figure shows the regions in world in which standard ISM bands are the same. For region 1 the 433MHz band is reserved as an ISM band (Kaijage, 2012)].

Appendix B: Bill of materials

Bills of material of LoRa Sensor Node:

#	Quantity	RefDes	Value	Name	Manufacturer
1	3	BAT, BTN1, BTN2		OSTTB022161	On Shore Technology
2	2	BT, RST		TS04-66-43-BK-160-SMT	
3	12	C1, C3, C5, C6, C8, C10, C11, C12, C13, C14, C15, C16	100nF	CAP_0603_N	
4	4	C2, C4, C7, C9	10uF	CAP_1206_N	
5	3	D1, D2, D5	SS56-HF	SS56-HF	DIODE RECT C=A 1KV 1A SQUARE M-4
6	1	D3	M7	M7	
7	1	D4	SS34-A	SS34-A	
8	1	D6	M7	Diode 1A	
9	1	Disp1		Oled display	
10	1	J1		PJ-002AH-SMT-TR	CUI INC
11	1	J2		PPTC061LFBN-RC	Sullins
12	1	L1	4.7uH	IHLP2525CZER4R7M8A	Vishay
13	5	PIR, RAIN, SOIL1, SOIL2, SOIL3		ELVM03900	Amphenol
14	2	PWR, USER		LED_SMD1206	
15	10	R1, R2, R3, R5, R6, R7, R8, R9, R10, R11	1k	RES_0603_N	
16	1	R4	4E7	RES_2512_N	
17	1	Temp&Hmd		ELVM04900	Amphenol
18	1	U1		MP1584	Analog Devices
19	1	U2		NCV7805BD2TG	ON Semiconductor
20	1	U3		LT1117IST-3.3#PBF	Linear Technology
21	1	U4	LM317DCYR	LM317DCYR	ON Semiconductor
22	1	U5		Lora - 02	
23	1	U6		ESP32-WROOM-32D	

Bill of material of LoRaWAN Gateway:

#	Quantity	RefDes	Value	Name	Manufacturer
1	2	BAT, SRN		OSTTB022161	On Shore Technology
2	7	BOOT, RST, SET, SIREN, TMR_DWN, TMR_UP, WP_ON/OFF		TS04-66-43-BK-160-SMT	
3	2	C1, C4	10uF	CAP_1206_N	
4	11	C2, C3, C5, C6, C7, C8, C9, C10, C11, C12, C13	100nF	CAP_0603_N	
5	2	D1, D2	M7	M7	
6	1	D3	M7	B240A-13-F	
7	1	Disp1		Oled display	
8	2	I2C, UART		ELVM04900	Amphenol
9	1	J1		PPTC061LFBN-RC	Sullins
10	1	J2		PJ-002AH-SMT-TR	CUI INC
11	1	J3		PPTC031LFBN-RC	Sullins
12	3	PWR, SR, USER		LED_SMD1206	
13	1	Q1	nCHAN_SOT223	MFET IRFL4105	International Rectifier
14	1	Q2	MMBT2222ATT1	Trans NPN SMD 600ma	ON SEMI
15	12	R1, R2, R3, R4, R5, R6, R7, R8, R9, R10, R11, R14	1k	RES_0603_N	
16	2	R12, R13	1K	RES_0603	
17	1	RLY		282836-3	TE Connectivity
18	1	RLY1	NT73-C-S10-DC5V	Relay NT73	
19	1	U1		Lora - 02	
20	1	U2		NCV7805BD2TG	ON Semiconductor
21	1	U3		LT1117IST-3.3#PBF	Linear Technology
22	1	U4	ESP32-WROOM-32D	ESP32-WROOM-32D	
23	1	VO1		4N35SR2VM	ON Semiconductor