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Development of industrial IoT based monitoring and control system for radio broadcasting network in Tanzania: a case of Tanzania broadcasting corporation

Msimbe, Hamisi

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DEVELOPMENT OF INDUSTRIAL IoT BASED MONITORING AND CONTROL SYSTEM FOR RADIO BROADCASTING NETWORK IN TANZANIA: A CASE OF TANZANIA BROADCASTING CORPORATION

Hamisi J. Msimbe

A Final Project Report Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science in Embedded and Mobile System of the Nelson Mandela African Institution of Science and Technology

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ABSTRACT

The radio towers must be constructed in sharp elevations or mountains to ensure the maximum radio wave propagation and long-distance coverage of the radio station programs. Due to the sharp elevation positioning of radio towers, the tower operators or technicians are required to climb up every day to be able to take readings of the equipment. Strenuous and daily effort is needed to access these sharp locations either on foot or by car. A need to develop and implement a system that will monitor and send earlier notifications information on the status of the transmitter to the responsible tower operators. Therefore, this project aims to develop an IIoT-based monitoring and control system for terrestrial broadcasting networks with outdated technology of Fm transmitter equipment which is still used in Tanzania. As a result, the solution will effectively and timely assist tower operators to monitor, collecting information understanding and the existing problems that are happening at the radio towers without physically climbing to the radio towers. In addition, the system is cost-effective and collect information in real-time based as it is integrated with a mobile application in a smart device that is linked to the embedded system which is installed in a specific tower to monitor parameters such as forward power, reflected power, electrical units, fuel level, temperature, humidity, and smoke. This study has used a mixed-design approach of quantitative and qualitative methods using focus group discussions with 20 stakeholders to evaluate the developed system. The result of the evaluation shows that 90% of the respondents agreed that the developed system is robust and appropriate to manage the existing challenges at the radio towers.

DECLARATION

I, Hamisi J. Msimbe, do hereby declare to the senate of the Nelson Mandela African Institution of Science and technology that this dissertation is my original work and that it has neither been submitted nor being concurrently submitted for degree award in any other institution.

Hamisi J. Msimbe		31/07/2022
Name of the Candidate	**Signature**	**Date**

The above declaration is confirmed by:

Dr. Judith Leo		01/08/2022
Supervisor 1	**Signature**	**Date**

Dr. Michael Kisangiri		
Supervisor 2	**Signature**	**Date**

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CERTIFICATION

The undersigned certify that they have read and found the dissertation titled, "Development of Industrial IoT Based Monitoring And Control System For Radio Broadcasting Network In Tanzania: A Case Of Tanzania Broadcasting Corporation" to qualify for acceptance by the Nelson Mandela African Institution of Science and Technology (NM-AIST) in Arusha, in partial fulfillment of the requirements for the degree of Masters of Science in Embedded and Mobile Systems of the Nelson Mandela African Institution of Science and Technology.

Dr. Judith Leo		01/08/2022
Supervisor 1	**Signature**	**Date**

Dr. Michael Kisangiri		
Supervisor 2	**Signature**	**Date**

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DEDICATION

I devote this work to the loving memory of my late mother, Maimuna Hamisi for her encouragement until I have reached this stage. Also, I devote this work to my three loving sons Hafidh, Nazzeer, and Niran.

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LIST OF ABBREVIATIONS AND SYMBOL

ADC	Analog to Digital Converter
AM	Amplitude Modulation
App	Application
ARM	Advanced RISC Machines
BDD	Block Definition Diagram
DC	Direct Current
DHT	Digital Humidity and Temperature Sensor
DSM	Dar es Salaam
ECG	Electrocardiogram
EMW	Electromagnetic Wave
ESP	Electronic Stability Program
FM	Frequency Modulation
FPGA	Field Programmable Gate Array
GHz	Gigahertz
GN	Government Notice
GPRS	Global Packet Radio System
GPS	Global Positioning System
GSM	Global System of Mobile Communication
HD	High Definition
HTML5	HyperText Markup Language Version 5
I2C	Inter-Integrated Circuit
ICT	Information and Communication Technology
IIoT	Industrial Internet of Things
IoT	Internet of Things
ITU	International Telecommunication Union
KW	Kilowatt
LAN	Local Area Network
LCD	Liquid Crystal Display
LW	Long Wave
MCU	Microcontroller Unit
MHz	Megahertz

MP	Megapixel
MW	Medium Wave
NAS	Network Attached Storage
NBS	National Bureau of Standard
RFA	Radio Free Africa
TuT	Taasisi ya Utangazaji Tanzania
OCR	Optical Character Recognition
OS	Operating System
OSHA	Occupational Safety and Health Authority
PCB	Printed Circuit Board
RAM	Random Access Memory
RF	Radio Frequency
RP	Reflected Power
RTD	Radio Tanzania Dar es salaam
SDIO	Secure Digital Input/Output
SIM	Subscriber Identity Module
SMS	Short Messaging Service
SPI	Serial Peripheral Interface
SW	Short Wave
TANESCO	Tanzania Electricity Supply Company Ltd
TBC	Tanzania Broadcasting Corporation
TCRA	Tanzania Communication Regulatory Authority
TV	Television
UART	Universal Asynchronous Receiver Transmitter
UML	Unified Modelling Language
UPS	Uninterrupted Power Supply
USB	Universal Serial Bus
VSWR	Voltage Standing Wave Ratio
WIFI	Wireless Fidelity
WSAN	Wireless Sensor Actuator Network

CHAPTER ONE

INTRODUCTION

1.1 Background of the Problem

A radio broadcasting network is a telecommunication system composed of towers deployed on mounted land surfaces for transmitting audio and video programs from a single transmitter to numerous receivers. Transmission systems of radio broadcast depend on the power of the transmitter, gain of the antenna, and height of propagating antenna (TekoBroadcast, 2021). For that reason, the radio towers must be constructed in sharp elevations or mountains to transmit for longer distance coverage. The mounted land, large buildings of the city, hill, or uphill mountains are required for ensuring the maximum radio waves propagation and great coverage of the radio station programs as the technique employed for both television and radio programs broadcastings. The broadcasting tower consists of equipment such as a transmitter, generator, uninterrupted power supply (UPS), feeder cable, and pair of Antennas (Lowe, 2016). Each radio station has its number of radio towers deployed on the land surface depending on the demand for broadcasting coverage of such stations. Some of the radio stations may have national, regional, or district operating licenses, in consequence, they differ in the number of transmitting towers owned.

Internet of Things (IoT) is the set of technologies that allow uniquely recognized objects in the network to make interconnections among them (Asghari *et al.*, 2019). Internet of Things technology facilitates remote accessibility of information with internet-enabled devices connected all over the world remotely (Brous *et al.*, 2020). Broadcasting as the means of communication, its technologies grow proportional with internet-enabled capabilities that are IoT applications. For this reason, the integration of IoT and Broadcasting systems is important. The proposed solution is applicable for existing terrestrial broadcasting of Fm transmitter equipment with outdated technology which are still used in Tanzania. The aim is to assist the companies to incorporates old transmitter which do not internet-enabled features with IoT technology instead of performing rapid installation of latest technology at high cost.

Figure 1 is a combined approach of terrestrial and satellite Broadcastings for purpose of long-distance broadcasting which can cover the size of the country, in which the radio stations transmit their programs from the Studio to the satellite via an uplink Amplifier which propagates the wave at its uplink frequency in GHz.

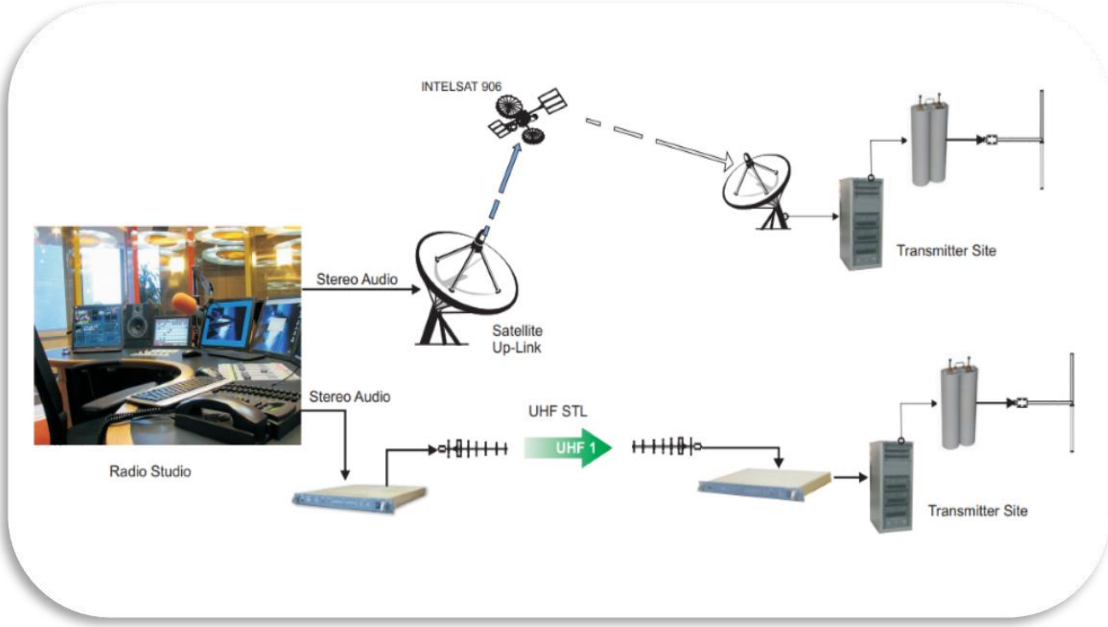

Figure 1: Transmission of programs from studio to Radio station transmitter via satellite and STL

Figure 1 shows audio program from the studio is transmitted in two ways either using Direct to Satellite (DTS) or via Studio to Transmitter Link (STL). For the large area coverage like a nation and region, DTS is used while for small area coverage like district or wards, coverage STL system is used Uplink transmission.

In the DTS system, Stereo Audio Programs from the studio are transmitted toward the uplink satellite dish. It projects a more powerful signal with assigned bandwidth frequency towards the satellite named Intelsat 906. Subsequently, according to Nice and Harris (2002), numerous land surface satellites installed in various regions of a country are integrated with digital receivers or decoders to pick up the signal from the satellite via downlink frequencies assigned by the communication regulatory authority as shown in Fig. 2. The Satellite Downlink dish receives the signal from the satellite with help of a digital receiver which decodes high-frequency signals in MHz to lower frequency signals. It decodes the modulated signal to acquire the original signal from the studio at the transmitter site which can be located in any place in Tanzania. With help of an Exciter and RF amplifier built-in within the transmitter itself, the signal is modulated and broadcasted in the assigned frequency by the authority (TCRA) from a range of 87 MHz -108 MHz. Figure 2 shows more deployment of the DTS system such that 128 kbps or 256 kbps stereo audio program from the studio with left and right channels are combined with 512 KBS video signal collectively by Meg II encoding equipment

(400 KW), It transmits upwards to the satellite from Headquarters of TBC known as mikocheni, Dar es salaam. Then the Downlink dishes located in various regions of Tanzania decode the high signal into lower signal frequency. According to Admin (2019) and Frank (2021), the lower signal is sent to the FM transmitter for processing and broadcasting at specific a frequency assigned by the regulatory authority in specific areas or regions of the country as shown in Fig. 3. Re-transmission of the audio signal to the specific frequency assigned by the authority (TCRA) can be 87.7 MHz or 89.7 MHz, 2 KW (2000 W) FM transmitter is used to broadcast for maximum distance coverage within the city or district with a large population extension and 250 W FM transmitter is used for small distance coverage within small towns.

In the STL system, there is a broadcasting studio that is located at any place within a district usually a flat land environment. The studio is equipped with an STL transmitter attached to a Yagi-Uda antenna which propagates audio signal from the studio via a UHF link towards an STL receiver equipped with a Transmitter on the top of high mountains or high buildings. The STL transmitter and receiver communicate in one way communication system along the line of sight. Transmitter equipment process the received signal from the studio and broadcasts it to the assigned frequency by the authority. In the STL system, there is no communication link involved with the satellite.

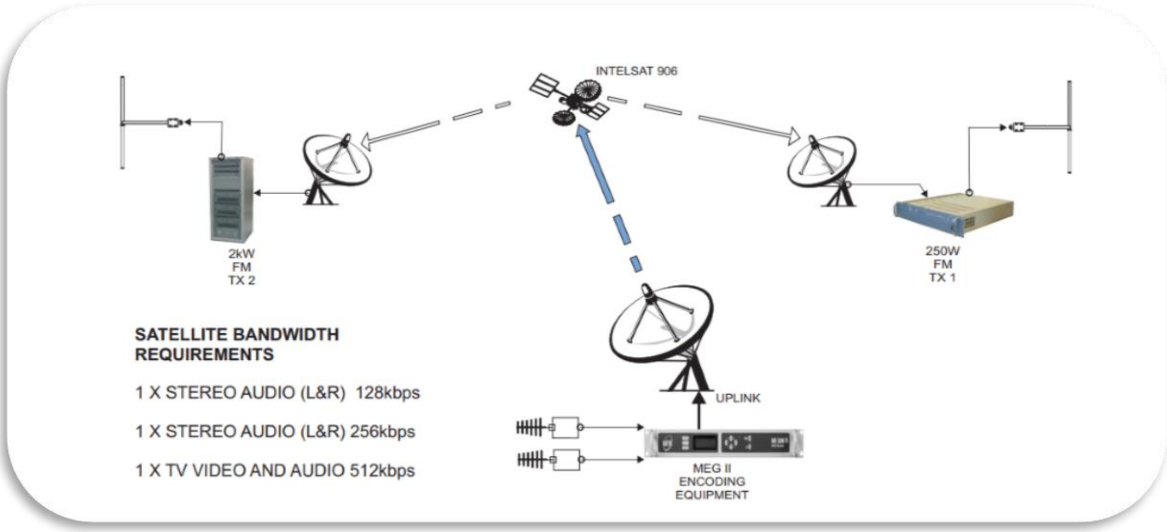

Figure 2: Reception of programs from satellite to three downlink dishes located at three different locations or regions

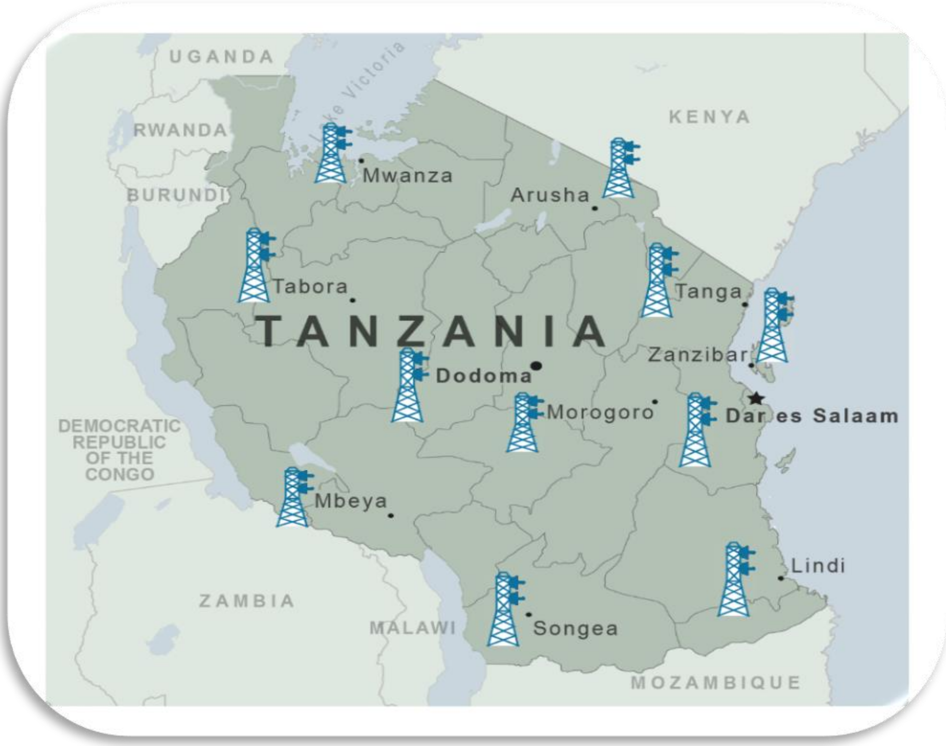

Figure 3: Deployment of radio towers at various regions and districts in Tanzania

1.2 Statement of the Problem

The daily operation of the broadcasting system is composed of many radio towers which require the teamwork of technicians or engineers who attend physically to radio towers to take readings of the basic parameters of the transmitters. Whereby, they observe and collect readings are later on used to estimate the status of the equipment and notify the rest of the team if there is a need for maintenance and repairing. Mostly the remote and rural locations are selected for installing broadcasting equipment.

Broadcast systems indicated in Figs. 4 and 5, indicate the locations consist of dense forests which require strenuous and daily effort to accomplish the data collection process. The process of taking readings and operating conditions of broadcasting equipment, as well as writing reports of the equipment, is performed by the technician on duty every day. Technicians climb up the mountain by car or on foot to read the operating readings including forwarding power, reflected power, temperature, humidity, generator fuel level, electrical energy balance units, etc. Sometimes it becomes difficult for the technician to climb up and down frequently to the mountain after detecting the problem to search for the electronic accessories needed. The technician spends a lot of time climbing up a mountain and descending to the flat earth's surface.in general, the process is manual-based, hence There is a necessity for an automated system that will provide earlier notification or information (readings) of the transmitter to the technicians and engineers without the need for them to climb up the mountain.

In addition, according to the literature, there is a very limited study that has deployed IoTs and embedded technologies to solve these challenges (Farhan *et al.*, 2017). Furthermore, the operation of most of the existing systems is very expensive to the organization which leads to continuous payment of staff salaries, insurance, pension funds, daily fuel for the vehicles, for each radio station. These excessive operating costs lead to the failure of extending broadcasting services in some districts in Tanzania and East Africa. Moreover, the existing system cannot provide information in real-time based when required due to workers writing information within a logbook hence, such a situation hinders the technical manager who resides at the headquarter in Dar es salaam to detect timely the status of the transmitters from all 27 regions in Tanzania.

Figure 4: Radio broadcasting tower located in uphill mountains with grassland

Figure 5: Radio broadcasting tower located in uphill mountains with forest reserve

Therefore, this project aims to design and develop the IIoT-based monitoring and control system for radio broadcasting networks in Tanzania that will effectively and timely assist tower operators to monitor, and collecting information. Through group discussion with stakeholders seven basic parameters namely forward power, reflected power, temperature, humidity, generator fuel level, fire, and electrical units were selected to be monitored and controlled. The purpose of selecting these parameters is to narrow and reduce the complexity of the research study by understanding the existing problem.

Previous works have not been explored in the broadcasting sectors, literature works based on the monitoring of industries, homes, environment, and health, therefore to eliminate the challenges, IoT based monitoring and control system has been designed and implemented in radio broadcasting towers to monitor two additional parameters known as forwarding and reflected powers which have never been explored other studies. As a result, Expenses incurred during traditional operations have been escaped because the systems are integrated with the internet and reported directly to the cloud in which all the data can be captured from the server, for that reason a reduced number of employed and salaried people.

1.3 The Rationale of the Study

The study will provide an alternative and foremost mechanism for gathering the operating status of each radio tower located at different locations in a real-time and cost-effective manner by employing the designed system. Tremendous motivation is to eliminate the existing problem which oppresses 172 radio station operators (TCRA, 2021) or broadcasting radios operating in Tanzania. The proposed system will facilitate public and private radio stations to invest in many areas of the country at a low cost due to the minimized expenses. In normal Circumstances of the current system, two technicians including a driver with one car serve one tower one technician can serve more than five towers. For that reason, more deployment of radio towers in various districts can be extended using the cost-effective system and short time of operation.

1.4 Research Objectives

1.4.1 General Objectives

The main objective of the study is to design and implement the IIoT-based monitoring and control system for radio broadcasting networks in Tanzania as a solution to technical challenges facing the broadcasting sectors.

1.4.2 Specific Objectives

(i) To collect requirements for the development of the Industrial IoT-based monitoring and control system for radio broadcasting networks.

(ii) To develop an integrated mobile application and embedded system for monitoring and controlling information of broadcasting towers

(iii) To validate the developed system.

1.5 Research Questions

(i) What are the functional requirements and correct methodologies for the Design and Implementation of the IIoT-based monitoring and control system for radio broadcasting networks in Tanzania?

(ii) What features should be designed and implemented in the proposed solution for the IIoT-based monitoring and control systems?

(iii) Is the developed system vigorous in monitoring and controlling towers?

1.6 Significance of the Study

The major consequences after the installation of the proposed system are both for the society, companies, and government. The companies may undergo minimized operating expenses hence motivated to expand their communication capabilities and offer more services to the listeners. Installation of new radio towers in non-beneficial Rural and remote areas will be done. Listeners are offered the ability to receive information through radio programs such as music, interviews, news, comedy, and entertainment. Lastly, the government through its agents collects revenues through the installation of licensed towers, On-air advertisements, and other radio services in these newly installed districts.

1.7 Delineation of the Study

The study conducted on this project assumed that all the radio towers installed in uphill mountains have access to internet services either by using a GSM network or ethernet cable installed within the building. The internet connection exists for enabling the transfer of data between embedded systems installed within the towers and Blinky mobile applications installed on smartphones of duty technicians. Additionally, Basic parameters such as forward power, reflected power, VSWR, electrical unit balance, generator fuel level, temperature, and humidity are monitored and controlled remotely. To narrow the study, Secondary parameters are not considered which include VSWR, DC voltage level, Audio level, detection of EMW radiation, switching on/off of the transmitters, remote insertion of electrical units in energy meters, and theft detectors can be introduced. This reduced the complexity of the work and enhanced the efficiency and effectiveness of the proposed system. Parameters knowns as EMW radiation are measured by an institution known as OSHA which oversees the security of the workplace. OSHA advises the specific media about the excessive measures to be taken after detecting that maximum radiation is emitted. Hence EMW detection was not advised to be implemented in the study.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

The usable range of radio frequency spectrum addressed by ITU is 3 kHz up to 300 GHz. In brief, ITU is responsible for assigning various frequencies of communication for different fields (ITU, 2021). The current radio broadcasting technology is propagated within the RF range in frequency of 87.5 MHz up to 108 Mhz employing FM propagation techniques (ITU, 2017). In FM broadcasting, a single powerful transmitter propagates electromagnetic waves to numerous distributed receivers over the land surfaces. Broadcasting as the means of communication, its technologies grow proportional with internet-enabled capabilities that are IoT applications. This chapter describes parts of the proposed system that are necessary for enhancing the performance and functionality of the state of art broadcasting technologies.

2.2 Evolution of Radio Broadcasting

Initially, around the 1920s the RF spectrum was divided based on wavelength resulting in Short Wave (SW), Medium Wave (MW), and Long Wave (LW). Amplitude modulation broadcasting services were the earliest technology mainly covering MW and LW, the audio and music programs were transmitted as mono with less audio quality compared with Frequency modulation broadcasting. Frequency modulation was designed for long-distance transmission approximately the whole continent or beyond, Unlike FM which is limited to small area coverage in a range of a few kilometers, especially district coverage but it has better sound quality on reception. Frequency modulation reception quality varies depending on weather conditions such that during the day there is a high quality of reception rather than nighttime after sunset due to signal fading or distortion. The FM reception does not depend on clear skies and fine weather (BBC, 2019).

2.3 Radio Broadcasting Penetration in Tanzania

Earlier in Tanzania few local radios provided radio services using AM technologies which incorporated expensive and high-power consumption RF transmitters and Antenna. The Tanzania government initiated RTD as the first AM broadcaster followed by Radio one Stereo founded by IPP media. The cost of operation was very expensive in AM broadcasting which involved RF transmitters up to 100 KW, for that reason few broadcasters existed. All over Tanzania country, there were three radio stations until the mid-1990s when private mass media underwent rapid growth. Unlike contemporary and less power usage of FM broadcasting transmitters with maximum forward power of 2 KW. The switchover from AM to FM broadcasting provided opportunities for other shareholders to invest in the broadcasting industry due to the low cost of operation and investment.

The advancement of ICT infrastructures has facilitated the availability and provision of information to residents. It is the result of the information and broadcasting policy enacted by the government for the first time in 1993. The number of television media increased up to thirty including the Television ya Taifa which was founded in 2000. Furthermore, in 2003 the government of Tanzania formed the authority known as TCRA which controls and regulates other radio stations. Starting from the 2000s there are more than 30 radio stations with national broadcasting licenses provided by TCRA to operate in the whole of Tanzania from only one government station known as RTD which started operating earlier after independence in 1961 (Habari, 2014).

In addition, some local government authorities, municipal councils, and private companies have installed radio stations to operate in the districts and town council levels. The cost of operation of these stations is covered by themselves. The radio broadcasting sector in Tanzania has more than 172 licensed radio stations that operate (TCRA, 2021) in national, regional, and district-level broadcasting services. In Tanzania mainland, about 76 percent of male and female-headed households accept that the availability of electrical energy near their premises has contributed to the accessibility of mass media through Tv and radio programs (NBS, 2016). In conclusion tee, the current distribution of radio services is greater than earlier after independence.

2.4 Overview of Existing Broadcasting Technology Used in Tanzania

The FM Broadcasting technology is currently used in the whole of Tanzania country in which all local and national licensed radio stations use assigned and changeable frequencies to broadcast to different regions of the country (TCRA, 2021). Frequency modulation broadcasting technology needs many powerful transmitters to be constructed in various areas to increase the radio coverage. in this technology Exciter, Rf Power Amplifiers, DC, and power supplies are connected to transmit RF waves through feeder cables up to propagating antenna installed in the high-level tower. The RF transmitting range starts from 50 W up to 5000 W (TBC, 2019). Each radio station has its unique frequency which cannot be provided to other stations to avoid electromagnetic interference. Radio stations that broadcast at the nearest frequencies use a device known as a Cavity filter combiner to prohibit interference with other stations.

2.5 Benefits of the Internet of Things

Latest services and opportunities emerged due to technological change after the connection between devices themselves using the internet (Sisinni *et al.,* 2018). With the assistance of sensors or actuators, information is easily obtained from different scenarios and complex actions are performed. In combination with the cloud paradigm, The IoT technologies have the following advantages in smart technologies applications:

2.5.1 Monitoring of Data

The major advantage of IoT is to facilitate remote observation of data that are not easily collected traditionally. In Tree (2014), a device from any part of the world can be viewed once connected to the internet using a heterogeneous or homogeneous sensor network. The latest network architecture allows heterogeneous equipment to lengthen the operating spectrum for WSN and deployed sensor nodes to keep a check over the regions. The impulse of the detected phenomenon (heat, pressure. Humidity, etc.) is reported to the base stations for further processing. In Akyildiz and Vuran (2010), heterogeneous WSN, the deployment of relay nodes to ensure fault tolerance with a higher network connection is conveyed.

2.5.2 Easy, High Performance, and Real-Time Accessibility of Information

IoT provides simplified ways to view and manage computerized devices with faster execution at a specific period (Güngör & Hancke, 2013). The data that is continuously taken from the field with help of WSN are being reported and stored in the cloud. Mostly software and hardware are designed to enhance faster response and fulfillment of complex action with efficient energy utilization. Taking consideration of hardware design to enable microprocessor chips to control performance of sensor, radio, and sensor signal conditioner accordingly. Computation processes enhance the easy acquisition of information about contemporaneous events occurring either preceding or simultaneously (Samanthula *et al*., 2013).

2.5.3 Reduction of Operation Cost

Expenses incurred during an operation can be escaped because most systems integrated with the internet can report directly to the cloud where all the data can be captured from the server, for that reason a reduced number of employed and salaried people (Sen & Yamin, 2021). Furthermore, the acquisition of a wireless sensor-actuator network (WSAN) is installed systems whereby data can be observed and analyzed. Retrieval of information in the network by inserting queries and collecting results in large area coverage rather than physical attendance to every point in the field (Stojkoska & Trivodaliev, 2017). It is possible because of the large number of sensor nodes deployed. Delay-aware sensor networks are suggested to decrease data collection procedure which in turn elongates the network lifetime.

2.5.4 Enhanced Automation, Security, Privacy, and Control Capability

Every internet-enabled device undergoes self-operation without man intervention and at any time command can be inserted to change the mode of operation remotely over the web, mobile app, or other software (Carri *et al.*, 2021). Physical attendance to the system is unnecessary with increased security and privacy of the information within a network (Lin *et al.*, 2017).

2.6 Influence of IoT on Monitoring and Control Systems

A monitoring and control system enables remotely viewing of data and management of the intended system. The capability of automation, easy accessibility, as well as real-time monitoring of intended information, make IoT useful to many operations (Formisano *et al.*, 2015). The technological advancement resulted due to the IoT features, industrial revolution 4.0, security systems, and surveillance systems also are the output of IoT (Ni *et al*., 2017).

The impact of IoT does not only rely on technological advancement but also on the social welfare of society. Currently, internet banking, telemedicine, e-payment, e-government, and distant learning facilities have contributed to the well-being of the whole society (Asghari *et al*., 2019).

2.7 Other Related Works

The presence of real-time features of the IoT enables the applications of monitoring and control systems in different fields. IoT application enhances the reliability, performance, and efficiency of the system (Jadhav *et al.*, 2016), some Different studies have been explored the monitoring and control systems in various fields.

In one of the studies, an industrial-standard Field-Programmable Gate Array (FPGA) embedded controller installed Linux operating system (OS) is programmed to gather readings such as voltage, real power, reactive power, circuit breaker status, and transformer temperature data with various sampling speeds in real-time. The IIoT-based monitoring system for a power substation was developed in the FPGA-embedded controller. All the critical parameters at the substation, involving voltage, frequency, power, circuit breaker status, and transformer temperatures are monitored in real-time. The controller transfers the recorded data to a NAS in the network. Industrial-Standard GPS is applied to provide high-resolution timestamps and synchronization functions. With the IoT platform, storage and transferring of the data through the LAN is possible. System operators can remotely retrieve the data in real-time and access the data from the NAS on the network (Zhao *et al*., 2019). Transfer of data between inside substation components is through ethernet cables. The design did not allow real-time retrieval of information using wireless devices.

Another study is monitoring the production lines in an industry employing wireless sensor networks. The Production monitoring system collects and distributes unadulterated production information at all levels along the production process without human intervention resulting in reducing regular inspection. The significant data is captured utilizing a real-time production monitoring system. With the captured data, realistic production goals can be attained when a suitable analysis is performed and implementation is executed. Monitoring of operation parameters including temperature, voltage, and current sensors with the assistance of a microcontroller and GSM module is performed in which there a is relay acting like a switch to monitor the production line (Sumithra *et al.*, 2018). Information on the production lines can be accessed using PCs or mobile phones using GSM SIM cards for sending short messages. The WSN employing multi-hop techniques has limitations on transmission distance of some 10m from every hop to a base station on the field. The identified fault which occurs to the induction motor is monitored and solved in time after performing extra operations and evaluating of machinery condition (Hou & Bergmann, 2012).

In another study in which the Proposed system monitors and processes data such as temperature, humidity, smoke, and fire sensors for security purposes by a raspberry microprocessor. All the sensors' data will be posted to the server for wireless security monitoring with the assistance of ESP8266 which incorporates a raspberry pi processor. Buzzer module notifies the employee in the industry of security. The study improved worker security using necked eye checking concerning any industrial emergency (Shalini & Prakash, 2020).

In another study, Zhao *et al.* (2019) proposed an IoT-based online monitoring system for continuous steel casting that is capable of processing huge amounts of data, and the proposed framework design offers sufficient flexibility to coordinate advanced hardware equipment and computer program functionalities. The proposed architecture consists of four sections namely the sensing layer, network layer, service resource layer, and application layer. This innovation can be well connected to other comparative manufacturing situations for genuine-time observation. The proposed framework needed a few strategies of mobile internet and big data analytics to enhance the performance and functionality of the proposed framework.

Another study in the field of health, Spanò *et al.* (2016), introduced a Low-power wearable ECG monitoring system for multiple-patient remote monitoring in which non-experts use them to observe the health of the patients in the household. The design has three major sections: the sensor and actuator networks, the IoT server, and the user interfaces used to visualize and manage the system. An authenticated user can retrieve the ongoing sensor information and observe data in real-time using the proposed ECG sensor, based on high-level performance ADC and a microprocessor-radio combo chip which perform better in case of energy utilization than numerous proposed frameworks based on an intentionally designed front-end chip.

From the discussion above which explores the application of the internet of things in various monitoring and control systems for different fields and the technologies applied, this study is going to explore the application of monitoring and control systems for another field of communication known as radio broadcasting network based in Tanzania. Weakness from other studies like the use of the mobile application in retrieving the information from the indoor sensors has been incorporated.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

The materials and methods employed in this project as well as the advancement of the proposed solution are presented in this chapter. The chapter provides explanations about the project case study area, sampling techniques, data collection data analysis methods, requirement analysis, and architectural design. Additionally, the section on the development of a mobile application for monitoring and control of radio networks is explained.

3.2 Project Case Study Area

Tanzania is one of the countries situated along the East Africa region with a total dimension of 945 087 square kilometers (NBS, 2017), it is approximately the whole territory of Tanzania is constructed with radio broadcasting towers situated on uphill land surfaces, mountains, high buildings, or elevations. Currently, Tanzania has 31 regions in which the frequency spectrum is divided by TCRA among broadcasters for them to operate. For that reason, the project study is based on the whole of Tanzania due to the presence of radio broadcasting networks throughout the country. Furthermore, the data collection for the proposed solution is collected among ten regions specifically requiring strenuous efforts to access the broadcasting masts caused by the arduous geographic environment of the land surface. Regions include Tanga, Tabora, Arusha, Lindi, Dodoma, Dar es salaam, Mwanza, Shinyanga, Singida and Katavi.

Furthermore, TCRA (2021) Tanzania has 172 radio broadcasting stations and every station has its own assigned frequency to broadcast in licensed regions which can be districts, municipalities, or other whole Tanzanian domains. The paramount operators with national licenses of broadcasting are provided to eight investors namely TBC FM, TBC Taifa, Radio one, Radio free Africa (RFA), East Africa radio, E-FM, Wasafi Media, and Clouds entertainment (TCRA, 2021), Others remaining investors have only regional or district content broadcasting licenses. The project study is based on the government broadcasting corporation known as TBC although all other media operate likewise. The addressed problem and solution apply to all other radio stations.

The Tanzania Broadcasting Corporation (TBC) is the Public Service Broadcaster established by Government Order in 2007 and became operational on the 1st of July 2007 replacing the then Tanzania Broadcasting Services -Taasisi ya Utangazaji Tanzania (TUT) Government Notice (GN) 186 under the Public Corporations Act as its parent law. Tanzania Broadcasting Corporation has 33 FM broadcasting transmitters in 102 districts of Tanzania except for 52 remaining districts. All these transmitters are operated and monitored by a technical department consisting of 135 employees (TBC, 2020). Currently, TBC is constructing 25 radio FM radio broadcasting towers in various districts of Tanzania including the ones that do not have FM radio services since independence.

The probability sampling technique is selected to determine a specific number of sample sizes in which selected broadcasting stations are chosen for data to be collected. Effectively, with systematic sampling techniques applied to the study, a number of populations are 33 representing the total number of radio stations belonging to TBC in the whole Tanzania territory. Furthermore, the required number of sample sizes is 10, taking 33/10=3.3 approximately to 3 which is selected as the interval for a suitable sample size. Arranging all stations in alphabetical order and assigning them with numbers starting from 1 up to 33. Each station that accepts a multiple of 3 is selected for every increase of interval 3.

3.3 Data Collection

During the time of data collection which takes place for two months from July 2021 to August 2021, different methods are used to obtain the primary and secondary data about the study. Primary data techniques employed to gather information at the broadcasting stations include Observation, Questionnaires, and interviews, in case of secondary data techniques employed from already published books, articles, journals, and online portals.

Through observation the nature of the working environment of the radio towers acquired. It details the whole operation of broadcasting programs from studio to audiences or listeners. Also, structured questionnaires were assigned to technical staff to answer some open-minded questions to acquire their responsiveness to the study. Lastly, a combination of structured and unstructured meetings and discussions were conducted with technical department staff to acquire their suggestion about the proposed project and solution to TBC.

Finally, the explanation from books, articles, journals, and online portals detailed a comprehensive understanding of radio communication. Online content which is available in government publications, public records, technical manuals, and different organizational Annual reports was used.

3.4 Requirement Analysis

It involves the procedure of explaining, understanding, and documenting the user's expectation for the proposed system to be implemented. In the intended monitoring and control system for radio broadcasting networks, several identified tasks shown in Table 1, Table 2, and Table 3 have been addressed to accelerate system design and performance of the system after getting the approval of technicians and managers. The UML diagrams have been used to differentiate the functional and non-functional requirements of the proposed system.

Table 1: Functional requirement of the electronic system

No.	Requirement
1.	The system should have sensors to measure operating temperature, humidity, and smoke within the Transmitter room
2.	The system should have a sensor for generator fuel level outside the Transmitter room
3.	The system should transfer data from the broadcasting room to the smart devices remotely
4.	The system should have sensors to capture forward and reflected powers propagated by transmitter equipment
5.	The system should have a sensor to capture the electrical energy balance of the energy meter

Table 2: Functional requirements of the Mobile App

No.	Requirement	Description
1.	Add Station,	Already existing and newly installed broadcasting towers/stations can be added
2.	Register Managers, Technical Staff	Registration of credentials of all users of the organization
3.	Login (Seniors, supporting staff)	Provision of authentication capability to access their accounts already created
4.	Log out	Sign out features for the users to keep their accounts safe and privacy
5.	Forget password	Option allowing to retrieve the account information failed to be remembered by the user
6.	Display of Operating status	Show the real-time status of transmitters including forwarding power, reflected power, Electrical unit balance, generator fuel level, etc.
7.	Print Report on operating status	Showing graphs, and charts on the trend of data received from the prototype

Table 3: Non-functional requirement of the proposed system

No.	Requirement	Description
1.	Performance	High-speed data transfer should be displayed from the embedded circuit to the mobile app user instantaneously
2.	Security	Ensuring the data from all stations are kept safe from intruders' interaction
3.	Usability	The appearance of the Mobile App together with its embedded circuit should support interaction with staff through the user interface
4.	Scalability	The system should support new installations of new radio broadcasting stations that should be established later
5.	Supportability	The system should assist the regional transmitters operators
6.	Reliability/Availability	The system should operate 24/7

3.5 System Development Approach

The rapid application development approach is used for the development and designing of the proposed system allowing various functionalities of the project to be developed concurrently. The superiority of RAD over other methodologies is that it ensures incrementally analysis, design, implementation, and testing of the prototype, for this reason, RAD is a less expensive approach, flexible, and high productivity due to the application of code generators and code reuse instead of manual coding since the proposed has hardware section and software section. Timeboxing allows the implementation of a working prototype after passing through four phases shown in Fig. 6.

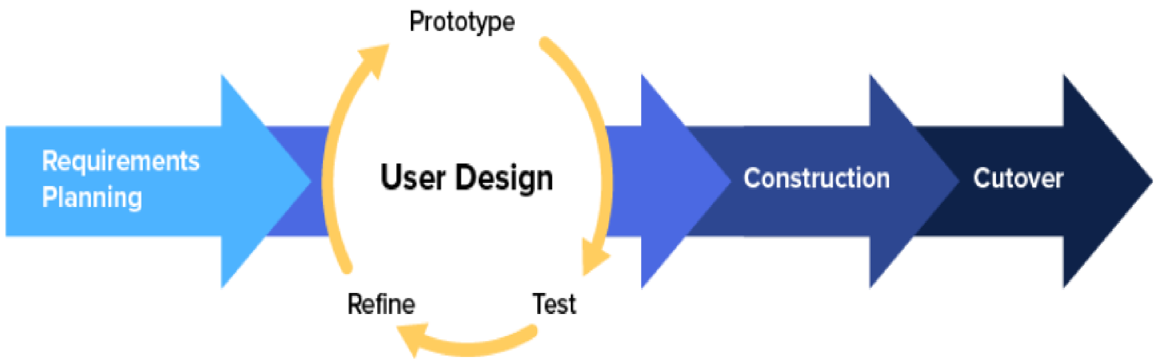

Figure 6: Four phases of Rapid application development (Kissflow, 2021)

3.6 System Modeling

The outline of modeling and analysis of the functional requirements of the proposed system is done based on unified modeling language, UML dynamic tool such as use case diagram which explains the system externally by elaborating actors against the services provided by the system. With the Use case diagram system functionalities are easily detailed by associating entrants to the set of events or actions accomplished by the system. Furthermore, a context diagram is used to show the interaction of various actors with the system in its environment. Context diagrams are modeled using a static tool called block definition diagram (BDD).

3.7 Context Diagram

Figure 7 shows applying of composition relationships shows all actors are strongly dependent and controlled to a larger extent by the system, with a multiplicity of any number of technicians and technical managers involved in controlling the system. Once the system is constructed only one actor known as the system inspector is involved in approving and authorizing the safety condition of the system. Also, disposal of the system may happen or not as well as system production depending on the need by the time.

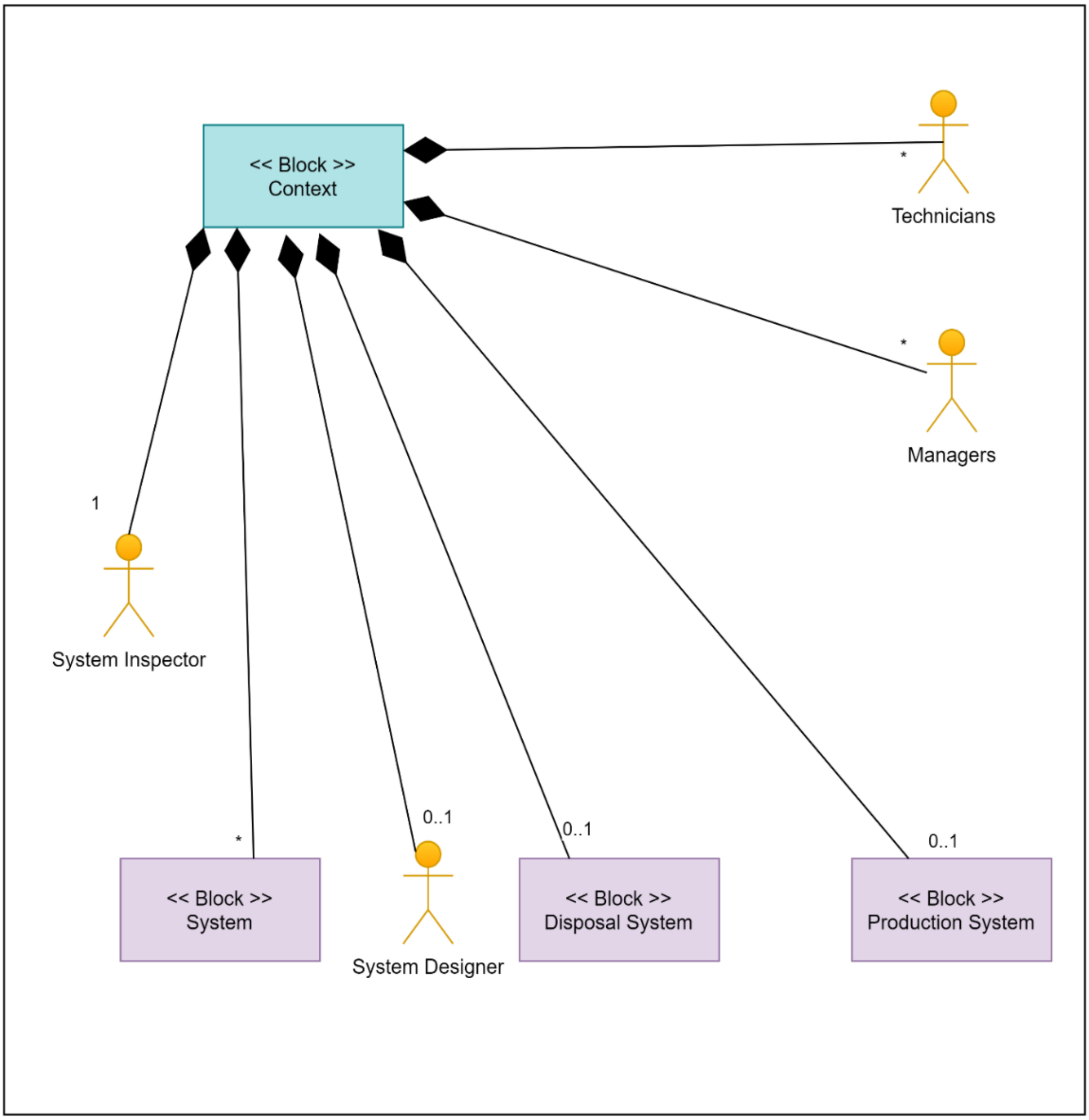

Figure 7: Context diagram illustrating the interaction of the system and its environment

3.8 Use Case Diagram

With the use case, the basic system functionalities are presented, and the basic parameters to be monitored are shown in Fig. 3. parameters to be monitored include forward power, reflected power, VSWR, Temperature and humidity, generator Fuel level, and electrical unit balance on the prepaid energy meter. With the help of an internet connection, remote monitoring using a mobile app installed on a smartphone is performed. Additionally, actors (Technicians or managers) view the status of the transmitters through the mobile application.

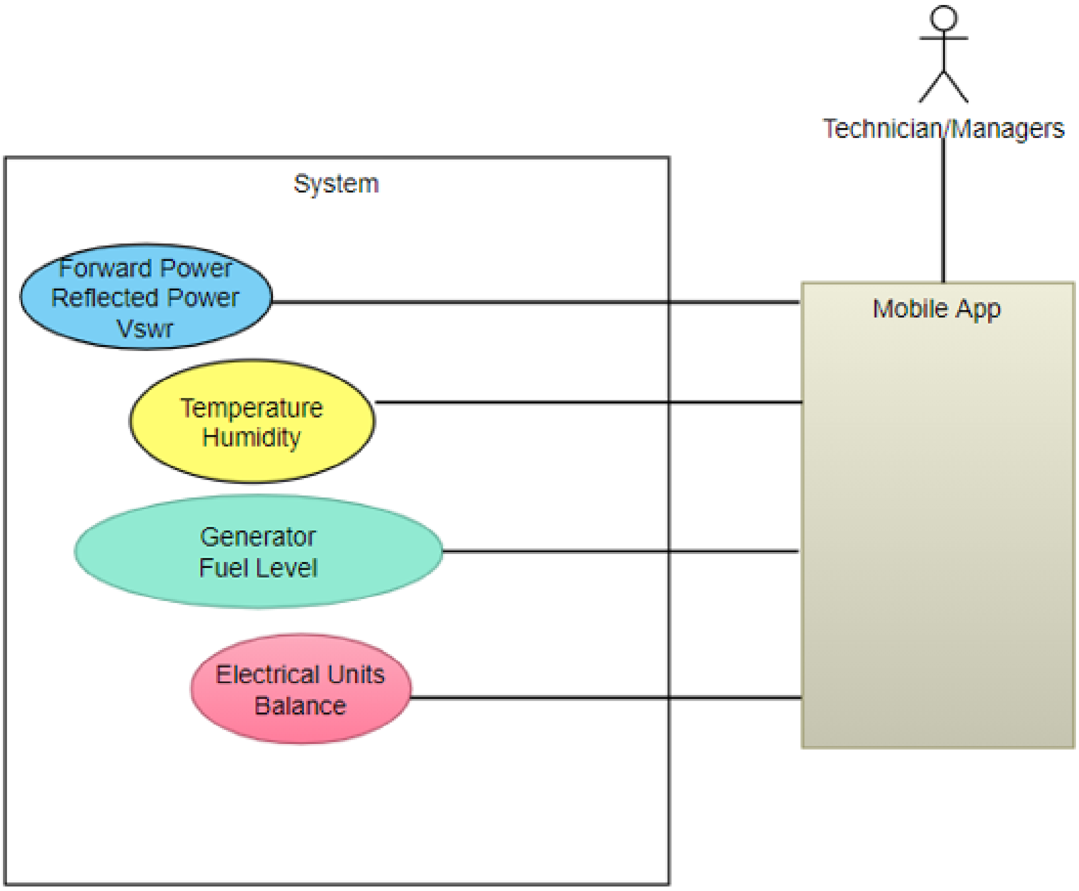

Figure 8: Use case diagram of basic system functionalities to be monitored remotely

3.9 System Implementation

The system shown in Fig. 9 is composed of embedded devices/sensors installed in each broadcasting tower and a user-friendly mobile app. The system will be integrated such that all the data from all regional transmitters of Tanzania mainland will be visible through a mobile App. The sensors monitor the operation of the transmitter and send notifications to local technicians using WIFI, if WIFI services are not available also the information can be sent to headquarters using GSM. Each technician/ engineer is given a username and password to log in through a mobile App and he/she will be able to fill out and report the data according to the region it belongs to. The technical director will be able to see the information of all 27 regions on his mobile phone and respond accordingly. The entire communication framework is illustrated in Fig. 10.

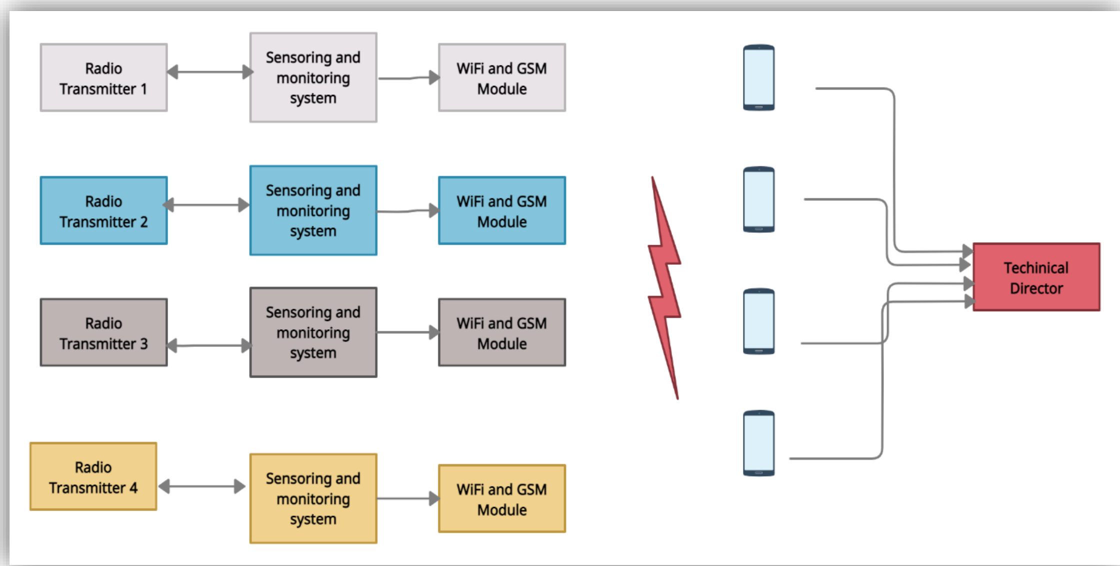

Figure 9: Architecture of the proposed radio broadcasting network

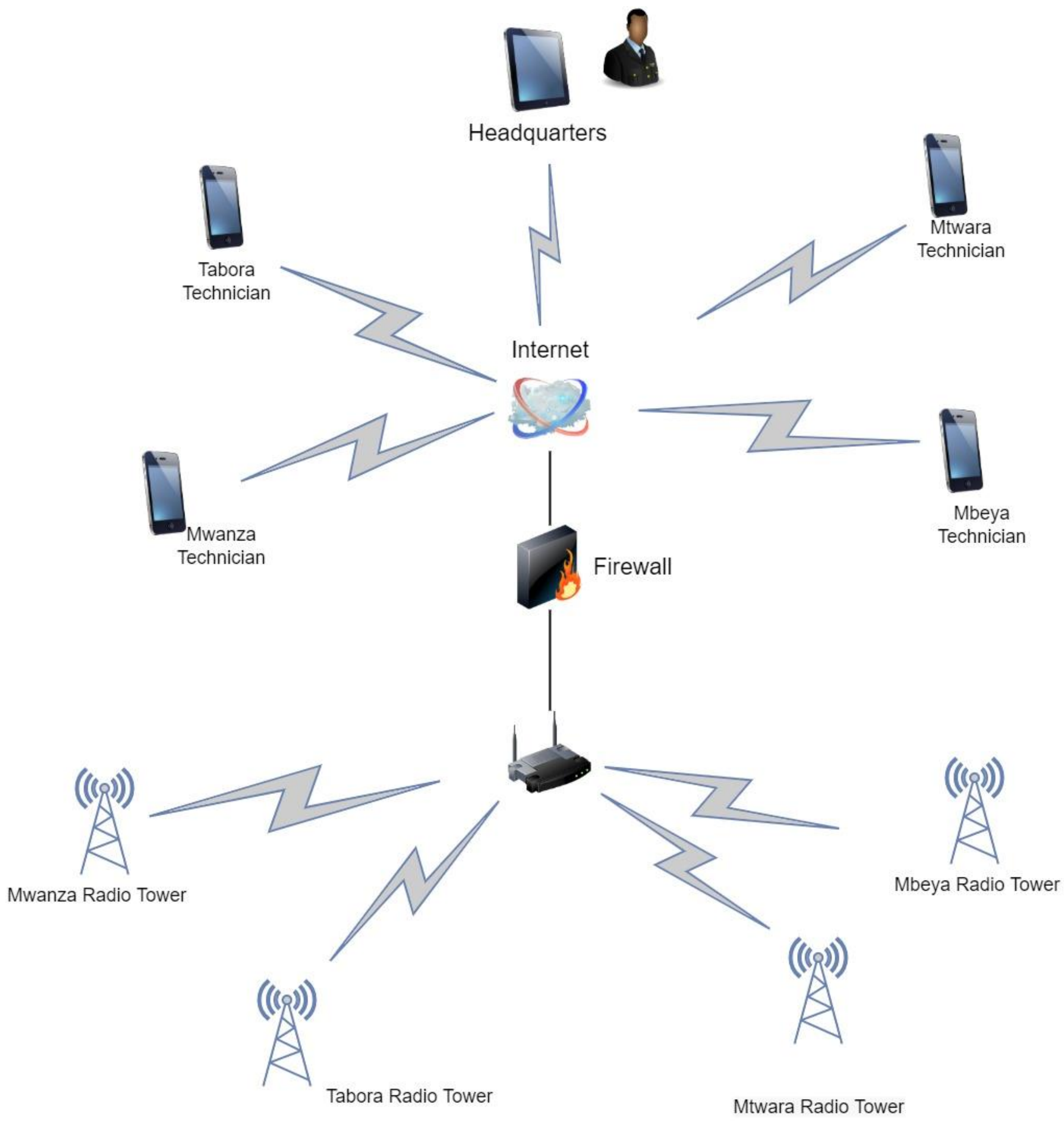

Figure 10: Conceptual framework of the proposed system

3.10 Testing and Validation

The process is performed at the end of product development to check if it satisfies the specified requirements of the technical department where the internship is performed. It indicates how the fulfillment of the system installation has contributed to solving the existing problem in the broadcasting environment. Four activities were involved and performed sequentially namely unit testing, integration testing, system testing, and user acceptance testing to analyze and approve requirement specifications, high-level and detailed designs, program specifications, and coding.

3.10.1 Unit Testing

Is the process of measuring, examining, and checking quality along with the performance of each element of system software before allowing it in user applications. As a result, the strength or capabilities of each element is identified and corrected to ensure that it is error-free; the system program executes software code as intended hence validation was approved. In the proposed system the unit testing was done for each sensor to ensure it operates properly. Four sensing units namely, Raspberry pi Camera, DHT22, MQ2, and Ultrasonic sensor are tested individually and performed their tasks correctly and as intended.

3.10.2 Integration Testing

The second stage of testing involves testing a set of software components collectively. Each software component has its code which is programmed, for that reason all components are combined in single program execution to identify defects through interaction among them. The integration test is done between Raspberry pi Camera, DHT22, MQ2, and Ultrasonic sensors in which all sensors are combined to observe their functionalities of sending input signals to the control circuit of the proposed system; the devices behaved properly as intended.

3.10.3 System Testing

Is the testing stage which approves the whole parts of the software product. It combines all modules of the system software and observes their performance and quality. In addition, it depends on a system requirement specification and/or a functional requirement specification as the last stage to approve the requirements of the product described. In the proposed system testing is done between all three sensors integrated into the control circuit, electrical energy meter, and FM transmitter prototype with the blinky mobile application. Table 4 is the observation of the data flow observed from the prototype to the mobile application.

3.10.4 User Acceptance Test

It is the stage in the software development life cycle that involves users of the system in testing and validating the software products. In the final stage of examination, priority is based on satisfying user requirements before allowing the product in the application's environment. It is performed in separate testing surroundings with a production-like data setup.

3.11 Development Hardware Tools and Technologies Used

3.11.1 Raspberry Pi 4 Model B

A single-board computer supporting any compiled language that can run on the ARMv6(ARM version 6) such as Scratch, Python, HTML5, jQuery, JavaScript, C++, C, etc. It is connected with an external keyboard mouse and monitor or TV for easy computation. It supports many applications executed by the desktop computer such as internet browsing, Streaming, and processing HD videos as well as playing the most powerful games (Upton & Halfacree, 2014) .

The major features of the Pi involve a 64-bit quad-core processor, a maximum of 4K resolution in dual-display support, dual-band 2.4/5.0 GHz wireless LAN connectivity, 4GB RAM, Bluetooth 5.0, USB 3.0, Gigabit Ethernet making it usefully for the proposed system which needs High-speed processing speed, multimedia transmission, large memory, and internet connectivity.

Figure 11: Raspberry Pi 4 Model B

3.11.2 ESP 32 Module

A total independent system or as a slave gadget incorporating MCU, which is capable of minimizing communication stack overhead on the major application processor. It is interfaced with other electronic systems through SPI/SDIO or I2C/UART interfaces to enable Wi-Fi or Bluetooth connectivity (Maier *et al.*, 2017). The modules possess in-built antenna switches, power amplifiers, filters, and power.

Figure 12: ESP 32 Module

3.11.3 Raspberry Pi 5Mp Camera Board Module

The board has a 5-megapixel camera for capturing 2592x1944 static images as well as a 720p60 and 640x480p60/90 video camera (Kulkarni *et al.*, 2016). The camera is used to capture still images of the energy meter display, after that, the balance of the electrical unit is transmitted to the mobile App via ESP 32 or GSM module.

Figure 13: Raspberry Pi 5Mp Camera Board Module

3.11.4 Arduino Uno

Arduino Uno is a module consisting of built-in ATmega328P, 14 digital input/output pins, six analog inputs, a 16 MHz ceramic resonator, a USB port, a power jack, and a reset button (Galadima, 2014). The connection between a computer and the board is done with the USB cable as well as powering the board can be done with AC.

Figure 14: Arduino Uno

3.11.5 DHT22-Temperature and Humidity Sensor

An Electronic gadget is used to sense accurate and reliable measurements of temperature and humidity concurrently after connecting it to the Arduino board or raspberry pi board. In the proposed system the DHT22 module senses the temperature and humidity of the surrounding air inside the broadcasting room. The board is powered with either 3.3V or 5V voltages in which interconnection between the sensor and only a single port of the microcontroller takes place (Mihai, 2016).

Figure 15: DHT22-Temperature and humidity sensor

3.11.6 MQ2 Gas/Smoke Sensor

It is an electronic device used for the detection of gas leakages like LPG, propane, carbon monoxide, hydrogen, alcohol, methane, propane, methane, and smoke. The device is made up of sensing elements that vary their resistance after making contact with the gas. The small deviation of resistance is used to sense the amount of gas released (Santiputri & Tio, 2018). The device operates on 5V DC mains and it can detect the gas concentration of 200 pppm up to 10000 ppm. In the proposed system the gas is used to detect the presence of fire and it releases a command signal to the microcontroller that admits the amount of liquid to extinguish the fire that emerged.

Figure 16: MQ2 Gas Sensor

3.11.7 HD44780 16X2 LCD Display Module

The module used to provide yellow backlight notification about the process or action by showing sixteen alphanumeric characters in each row rows that 16x2.one character shown in liquid crystal use 5x7 pixel matrix and powering the module needs external 5V dc (Soni *et al.*, 2012).

Figure 17: HD44780 16X2 LCD Display Module

3.11.8 ATmega 328P

A microcontroller is a RISC-based microcontroller that possesses 32KB ISP Flash memory for reading and writing functionalities with an excessive performance which makes it better operation in a voltage range of 1.8-5.5 V. Other features include 1024 EEPROM, 2 KB SRAM, 23 general-purpose I/O pins, 32 pins for operating registers, 3 adjustable and comparative modes of timers or counters. Above all, the microcontroller supports interruptions from internal and external commands, a 10-bit A/D converter is used among six channels and serial programmable USART (Etechnophiles, 2021). The chip can attain faster execution and robust commands for one clock cycle near a single MIPS/MHz, managing low power utilization and a faster speed of processing. The chip supports the automation of sequenced events of the proposed system.

Figure 18: ATmega328P

3.11.9 Real-Time Clock

Is a small device designed to be installed within a system to keep time; The device computes hours, minutes, seconds, days, months as well as years (Techopedia, 2015). In the proposed system the clock is used to ensure accurate time management all the time even if the system is powered off for any reason. The device simplifies the expenses of designing external circuits to keep the time of the circuit.

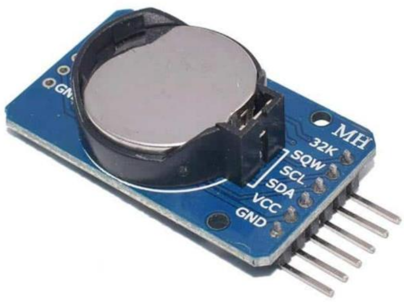

Figure 19: Real-Time Clock

3.11.10 Ultrasonic Sensor

An electronic gadget with the capability to detect the distance of an object by realizing ultrasonic sound waves direct toward it. The object reflects the sound waves to the devices which converts sound into an electrical signal (Jost, 2019). Generally speaking, the gadget has a transmitter and receiver that emit sound waves toward the object and converts them back to electrical signal respectively. The formula used to estimate the distance of the target is D=1/2T

X C (D is the distance, T is the time and C is the speed equal to 343m/s) (Zhmud *et al.*, 2018). In the proposed system the gadget is used to estimate the level of fuel in the generator, the device is located at the top of the fuel level tank facing the fuel surface. As a result, the device calculates the remaining level of fuel within the tank and sends a signal to the microcontroller for processing.

Figure 20: Ultrasonic Sensor

3.11.11 Connecting Wires

Wires are used to supply the power from the main alternating current to the individual circuits of the proposed system. The red or brown wires stand for positive voltages while the black or blue wires stand for neutral.

Figure 21: Wires

3.11.12 Solder Wire

Mostly, designing the electronic circuit using the proteus program; the circuit is printed on the empty PCB board. Later etching processing is performed followed by soldering of the electronic components on the PCB rds by using a soldering gun and soldering wire.

Figure 22: Solder Wire

3.11.13 PCB Boards

Is a circuit used to handle electronic devices connected via conductive pathways which allow current flow along its surface? The board layers are made up of fiberglass or plastic materials with copper strips on the top. The electronics devices are soldered without wires using a soldering gun and soldering wire making them simple and flexible in many applications. In the proposed system three PCB boards have been designed to support various operations.

Figure 23: Pcb Board

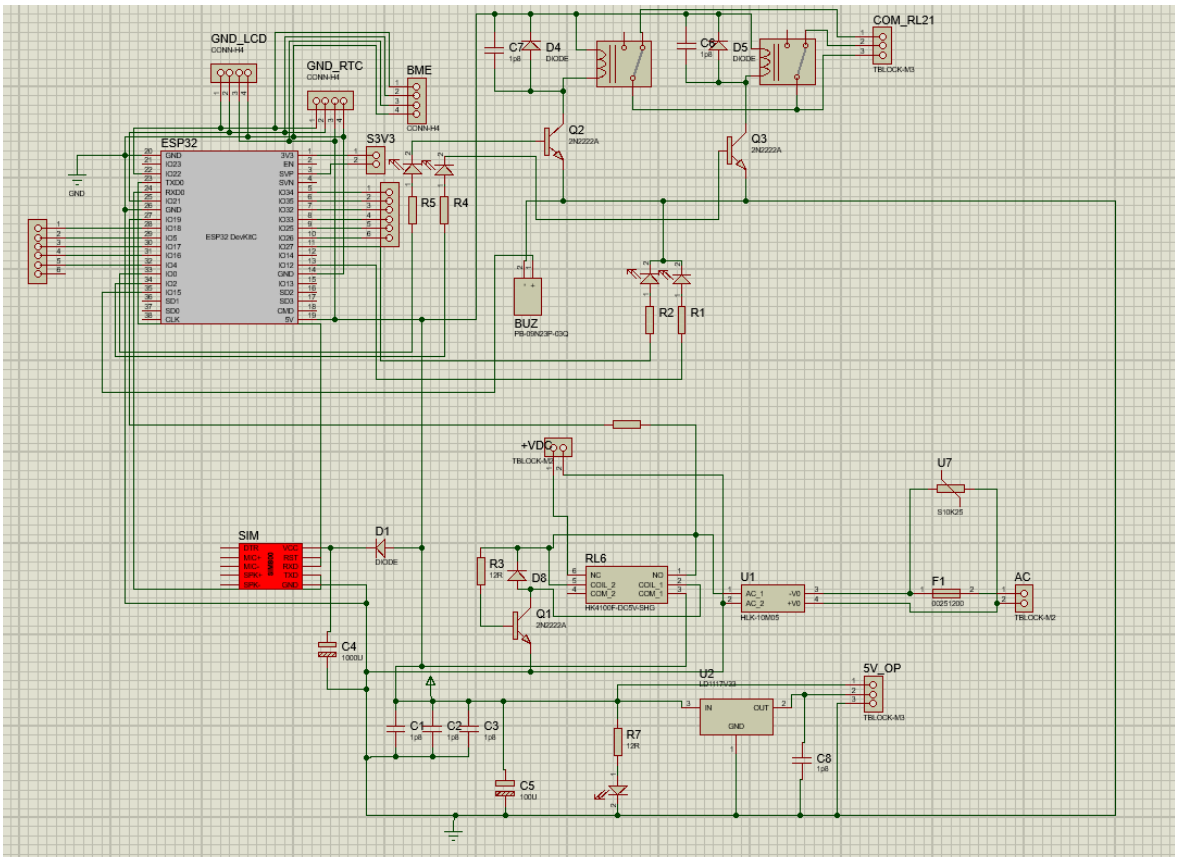

Figure 24: Circuit diagram of the main control circuit of the proposed system

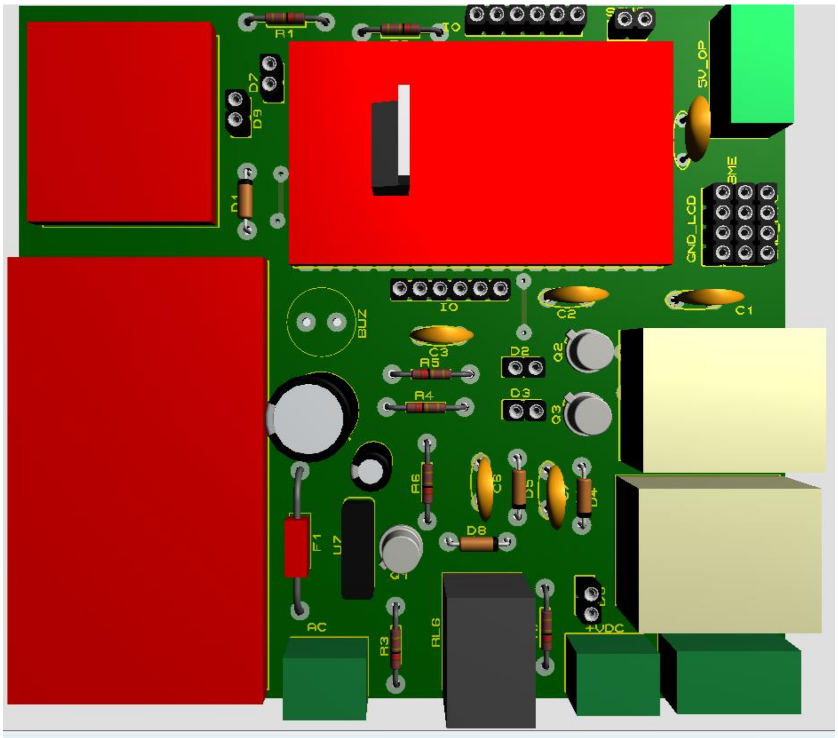

Figure 25: 3D view of the main control circuit PCB before printed

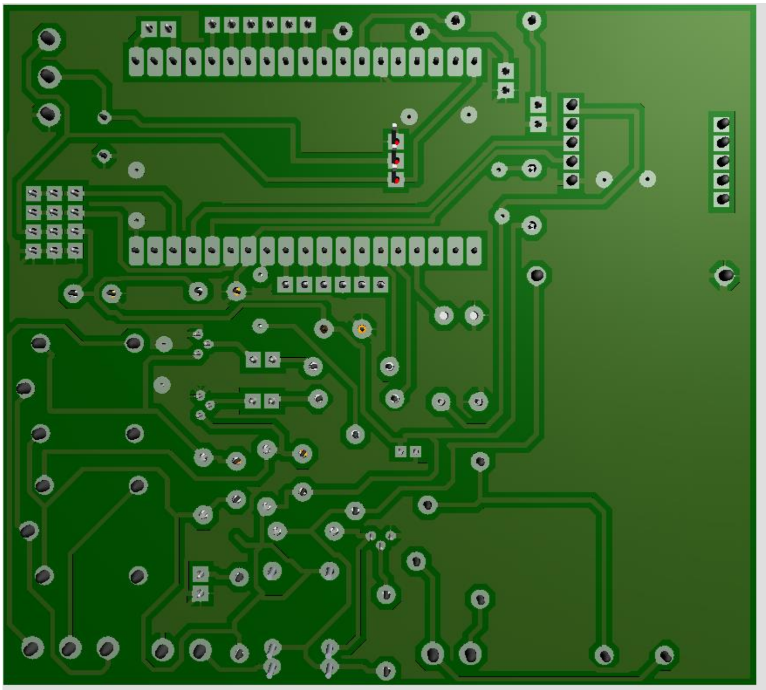

Figure 26: Pinout configuration of the electronic devices before etching process of control PCB circuit

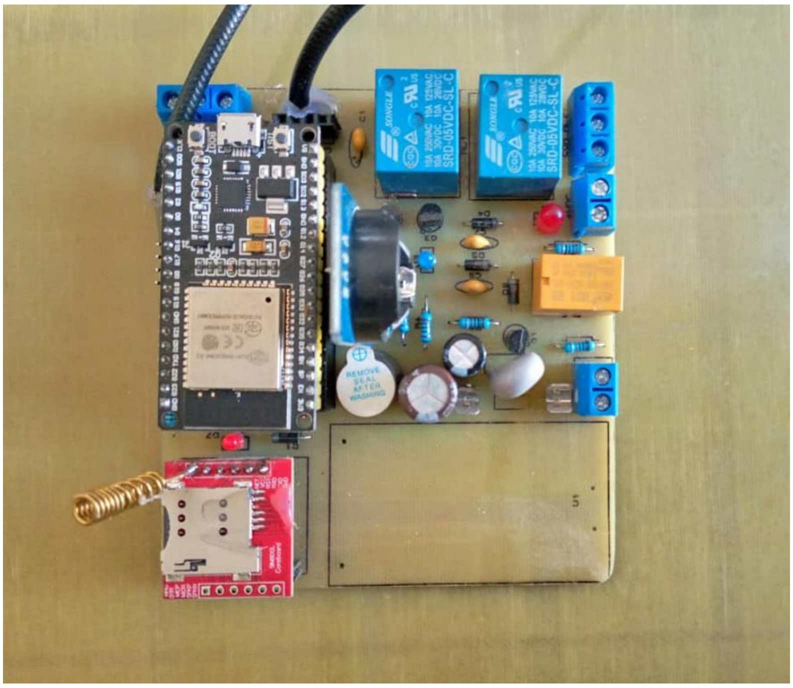

Figure 27: Assembly of the electronic devices after etching and soldering process of control PCB circuit

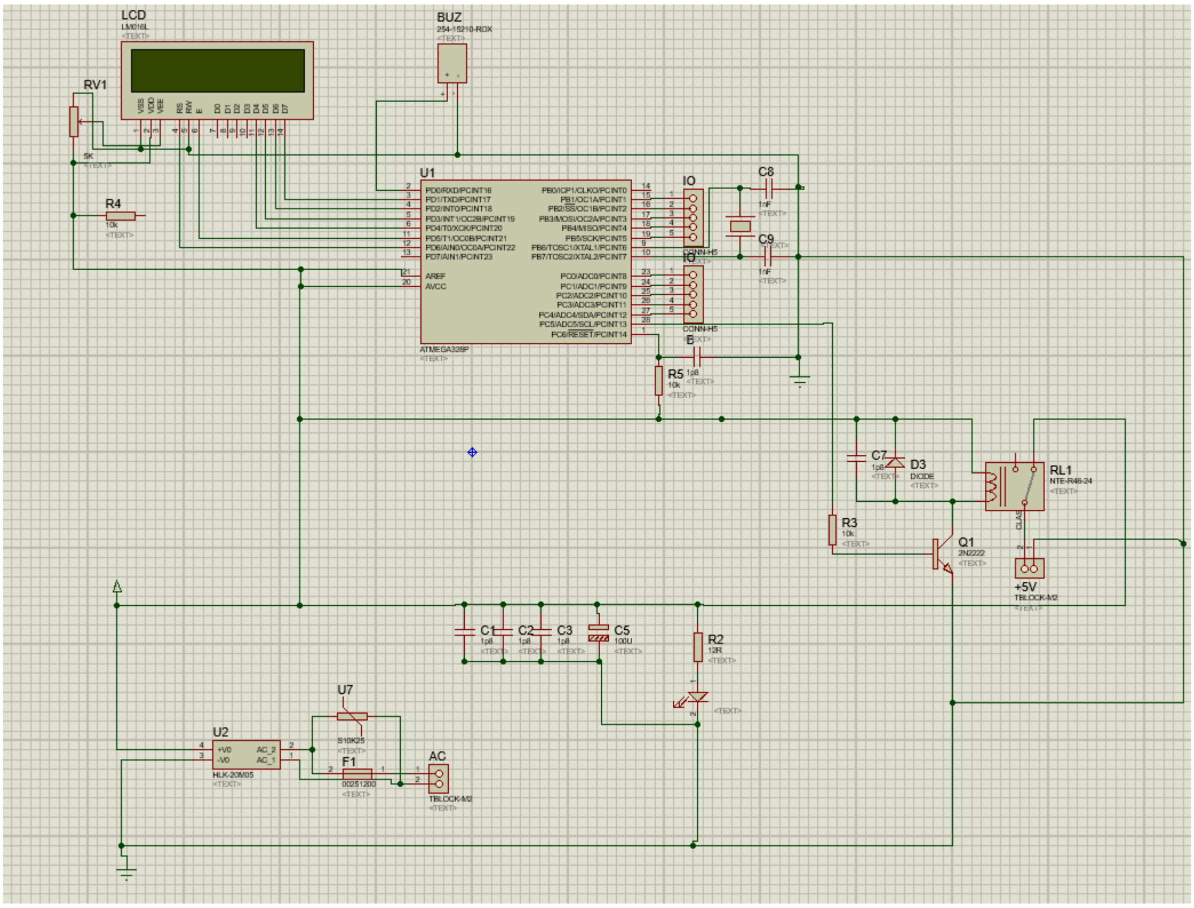

Figure 28: Circuit diagram of the energy meter of the proposed system

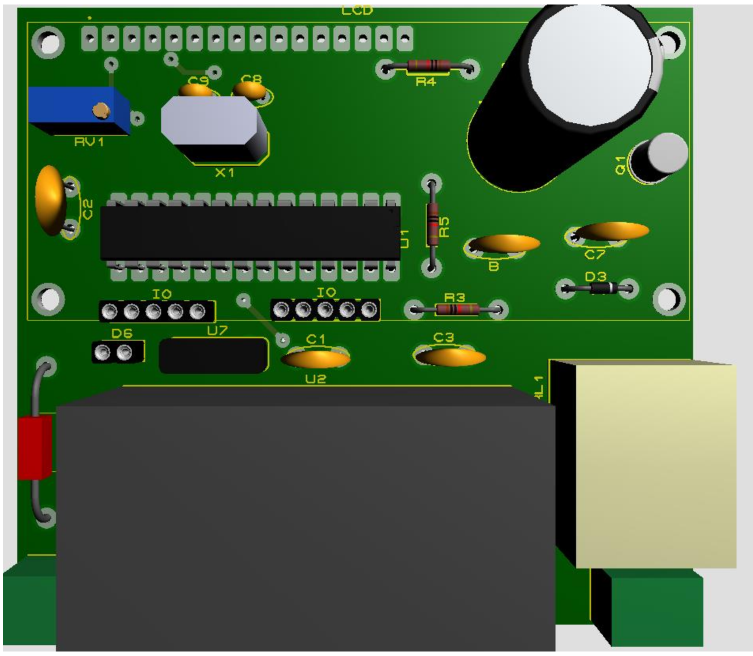

Figure 29: 3D view of the energy meter circuit PCB before printed

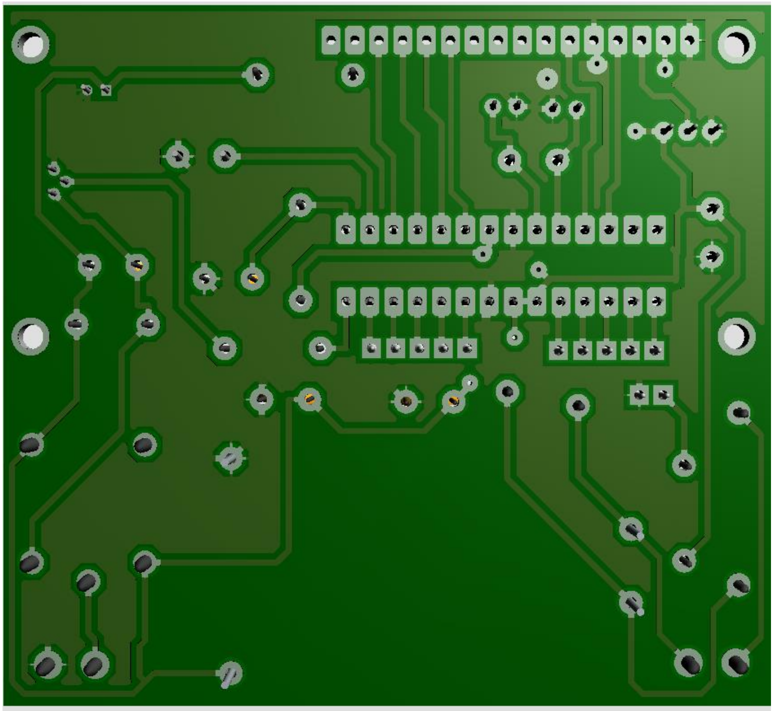

Figure 30: Pinout configuration of the electronic devices before etching process of energy meter PCB circuit

Figure 31: Assembly of the electronic devices after etching and soldering process of energy meter PCB circuit

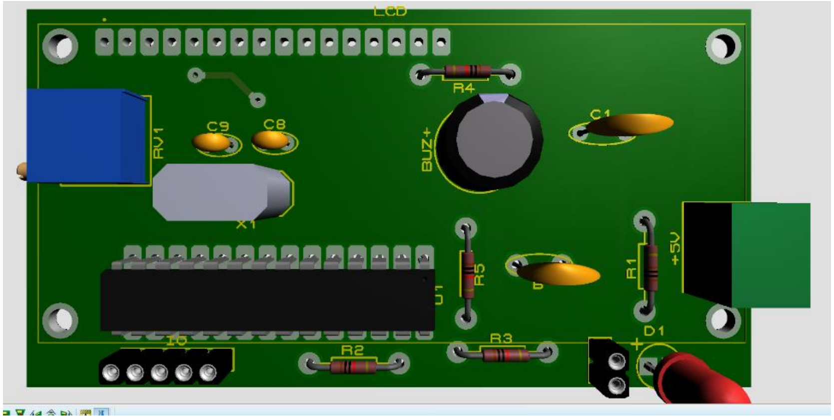

Figure 32: 3D view of the transmitter circuit PCB before printed

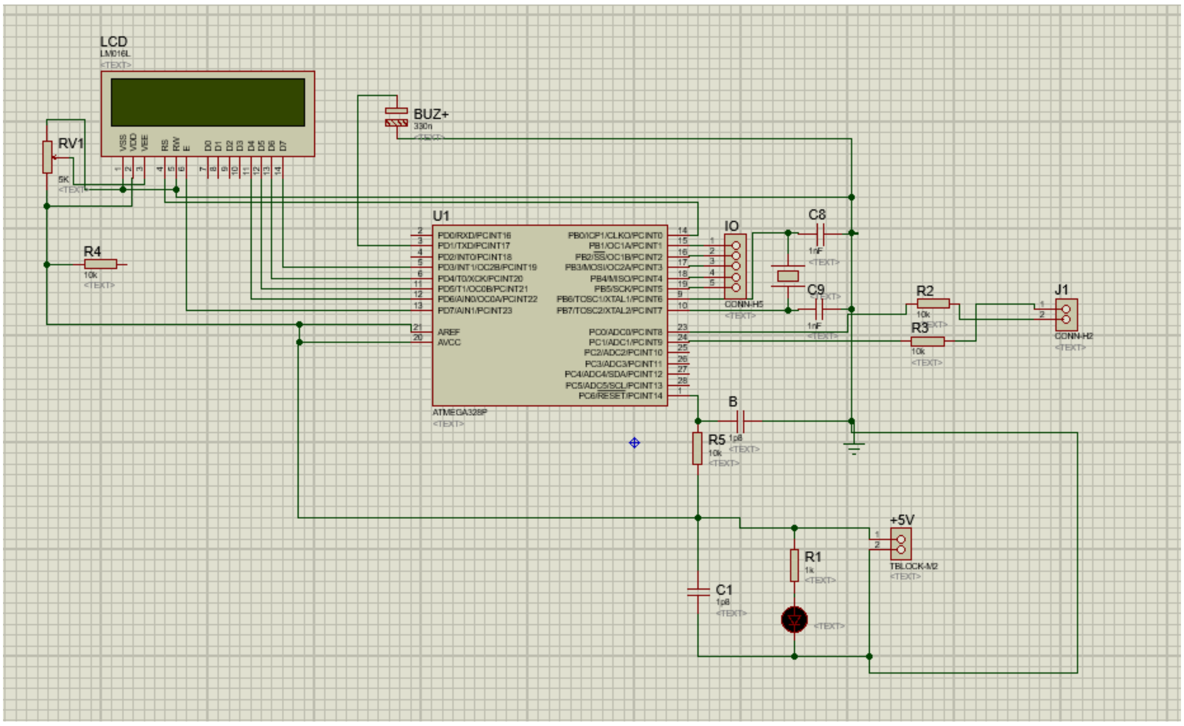

Figure 33: Circuit diagram of the transmitter prototype used in the proposed system

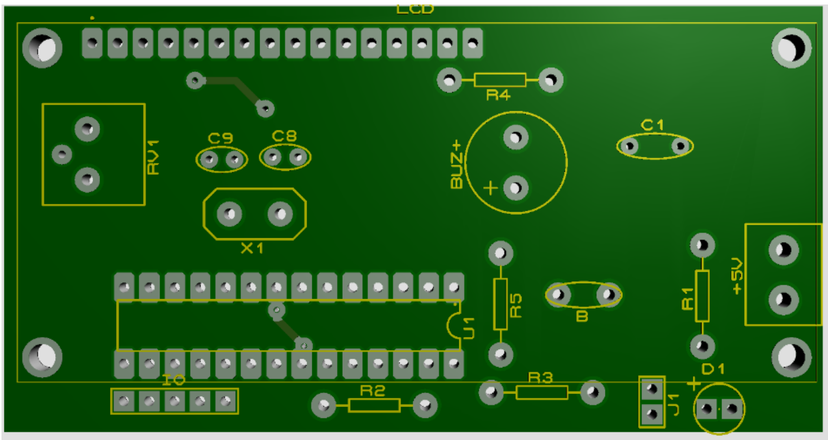

Figure 34: Pinout configuration of the electronic devices before etching process of Transmitter PCB circuit

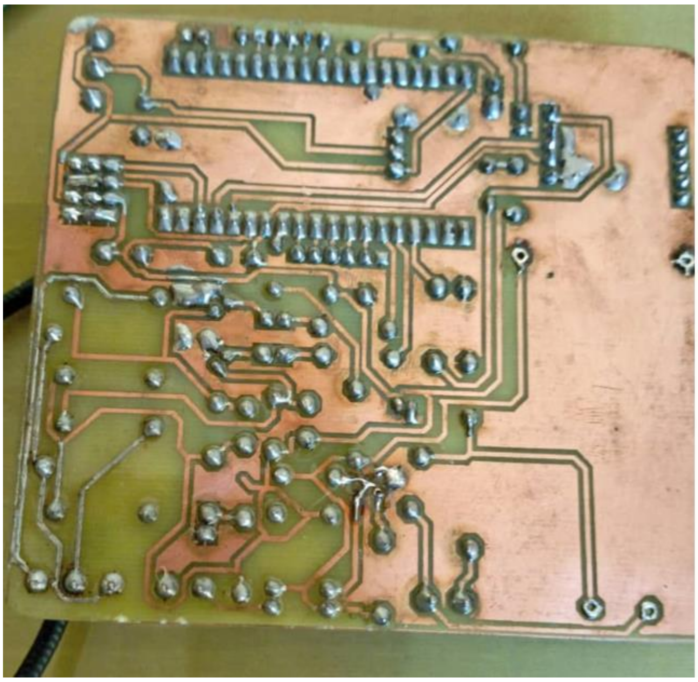
Figure 35: Rear view of the soldered main control PCB board

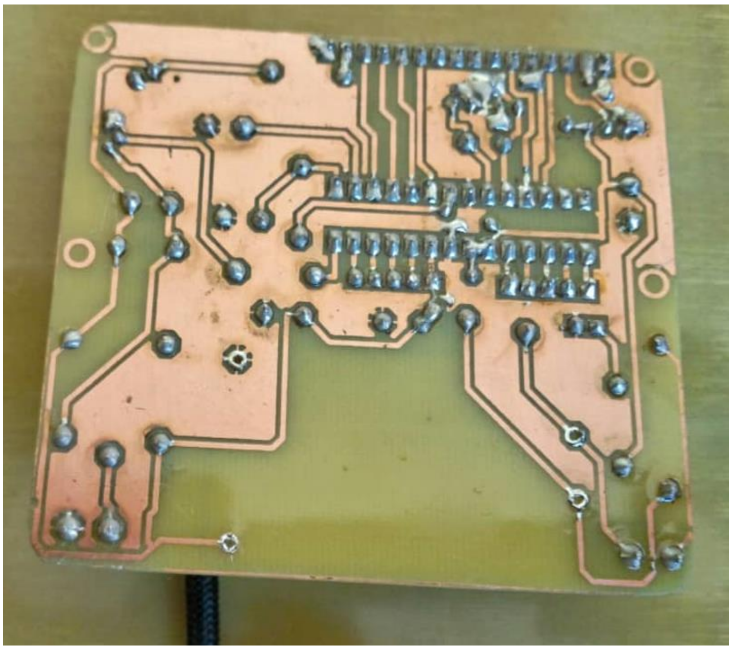
Figure 36: Rear view of the soldered energy meter PCB board

3.12 Software Tools Used

3.12.1 Blynk Mobile Application

Customization of blinky mobile App enables control and managing of the embedded systems installed in radio broadcasting equipment remotely. It is the perfect IoT platform. The major advantage of this app running on android version 4.2+ and iOS version 9+ (Durani *et al.*, 2018).

Also, it can run on many hardware modules, approximately 400 devices including ESP 8266, ESP 32, NodeMCU, any model of Arduino board, and any model of Raspberry Pi in which all of these components are used in building the proposed system. lastly, it supports internet connections of all types including Wi-Fi, ethernet, |cellular communication, Bluetooth, etc. (Sharma *et al.*, 2020). The app is available on all online stores such as google play store and apple store. In the proposed system the app is used to retrieve the information from various regional broadcasting stations to the mobile and smart devices of the technicians who are responsible for towers.

3.12.2 C ++ Programming Language

C++ is a powerful and general-purpose language used to program and develop Operating systems, browsers, games, system programs, etc. The language supports different features of programming such as object-oriented, procedural, functionality, etc. Since C++ supports fast and powerful executions as well as dynamic memory allocation which enables free and allocated memory; the language is used to program the microcontroller ATmega328P using Arduino IDE within the proposed system (Zhang & Liu, 2020).

3.13 Assumptions and Dependencies

(i) The presumptive environment considered is that all remote established broadcasting stations can access the internet service through nearby Wi-Fi from mobile network operators or via LANs installed in the office from the national fiber backbone

(ii) All regional transmitters' technicians or engineers have access to the smartphone to use the android mobile App.

(iii) Availability of access to High-speed internet to ensure real-time data transfer between embedded systems established in remote stations with mobile Apps installed on smartphones.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Case Study Area Results and Discussion

The proposed system is based on monitoring and controlling seven parameters. Six critical parameters namely forward power, reflected power, generator fuel level, temperature, humidity, and electrical unit balance are monitored. Only a single parameter namely the fire alarm is monitored and controlled. The basic parameters of the radio broadcasting station include forward power, reflected power, and temperature.

Forward power is the amount of electromagnetic energy measured in watts or kilowatts propagated from a transmitting antenna installed at the top of the broadcasting tower. The arrangement and number of the antennas determine the capacity of the radiated power from the antenna. For maximum radio coverage, the needs of maximum forward power are to be generated from transmitters and transferred to the top fixed antenna via coaxial cable. In normal circumstances, the FP can range from 500 W up to 2000 W. this variation depends on the geographical distribution of the residents who are supposed to receive the broadcasting program

Reflected power is the amount of electromagnetic energy measured in watts that bounced back from the installed antenna from the top of the tower to the transmitter inside the equipment room. Practically, it is not easy to avoid the RP in the equipment but it can be minimized, also it is recommended to ensure that RP does not exceed 10% of the forward power because it is analogous to back emf in the supply voltage. Excessive Reflected power can damage RF MOSFETs located inside the Power Amplifier.

Temperature is a physical quantity used to indicate the degree of hotness and coldness of the object. Achievement of optimal operation of the broadcasting equipment the desired range of temperature should be below 25 ^{o}C.

Other parameters such as electrical units, generator fuel level, and humidity do not affect system functionalities in loss because they have fewer impacts on equipment performance making them the secondary levels of monitoring.

The hardware section of the developed system is constituted of three parts namely the Main control circuit, the Energy meter circuit, and the transmitter prototype circuit. On the main control circuit, three sensors are connected which are DHT22, MQ2, and Ultrasonic sensors. The main control circuit use ESP32 to send the data collected to the blinky mobile app. The energy meter circuit uses a single raspberry pi camera and raspberry pi board to send electrical energy balance remotely. Lastly, the transmitter prototype also uses a single raspberry pi camera and board to send data values to the Blynk app.

Figure 37 shows the prototype of a one-meter broadcasting tower in length after the welding process. The tower provides support for the propagating antennas which are installed at the highest point. the transmitter equipment shown in Fig. 38 sends modulated signal passing through the feeder cable running towards the antenna fixed at the top. In addition, On the left-hand side of Fig. 39 shows the LCD of the real transmitter equipment and its corresponding prototype on the right-hand side. Only two parameters are monitored from the corresponding prototype namely forward power and reflected power. Other parameters like temperature, humidity, generator fuel level, and fire are monitored from the control or main circuit shown in Fig. 40.

Figure 37: The prototype of the FM broadcasting tower after the welding process

Figure 38: Broadcasting transmitter within the equipment room

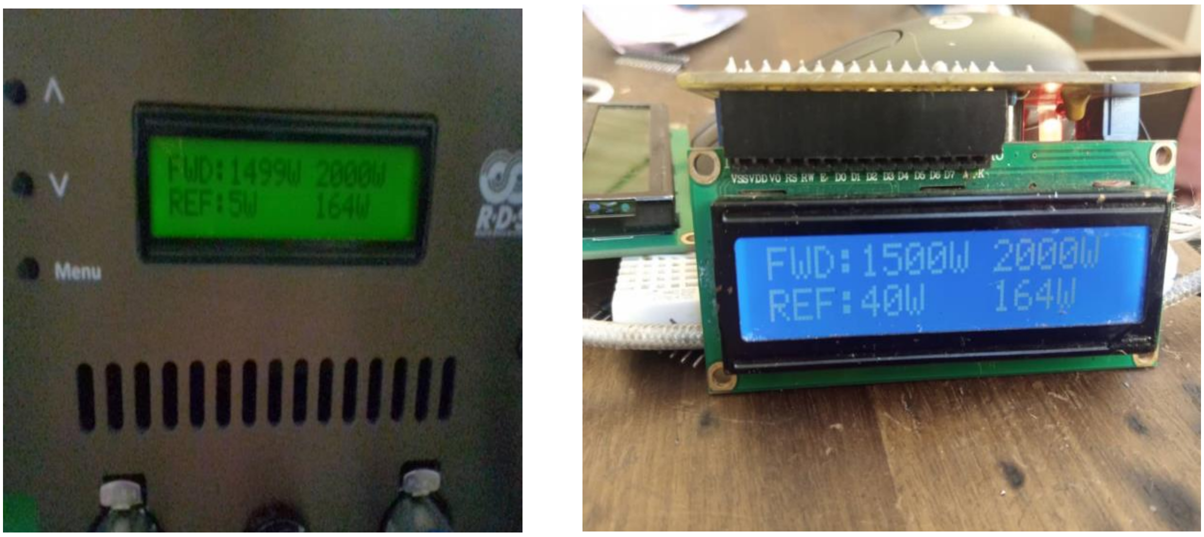

Figure 39: Appearance of the real transmitter's display and its correspondence prototype transmitter

Figure 40: Fixing of embedded systems within the broadcasting room

4.2 Results and Discussion for the Developed Systems

Within the prototype installed in the broadcasting station, the DHT22 sensor is responsible for detecting the temperature and humidity of the room. The notification is sent to the cloud via the ESP 32 in which the information is seen on the blinky application by the technician or engineer. Since the air conditioning system is responsible to ensure the optimal condition below 20^0C for the operation of the equipment. Hence if the mentioned threshold is above the range, the technician should see the alert and will take immediate action to the physical visit of the site and perform maintenance of the AC system, otherwise, it is normal operation of the system

Figure 43 shows the prototype of an FM broadcasting transmitter in which signals from DHT22, MQ-2, and ultrasonic sensors are tapped and sent information to the control circuit for processing. After processing via Atmega328P the signal is transmitted to the mobile app via ESP 32 which all the time is connected to the internet. Furthermore, the system uses a raspberry Pi-based system to recognize forward power, reflected power, and electrical unit balance automatically employing image processing. The system is fixed with two cameras interfaced to raspberry Pi boards in front of LCD circuits. The Pi boards continuously process incoming camera footage to identify the current reading of the transmitter display and energy meter display. After raspberry pi Cameras sense the image in front of the camera, the raspberry pi board processes the camera inputs and extracts the number part from the image for processing by employing OCR. Using a Wi-fi connection, the raspberry pi board takes the extracted readings which are transferred and displayed to the Blynk mobile app.

For the case of forwarding power, any range can be considered as the desire for the radio transmission because it does not affect broadcasting equipment, but for the case of the reflected power which prohibits the transmitter to broadcast on the acceptable range, notification through the blinky app can be seen and transmitter can be accessed by the technician to check up the fault which causes high reflected power on it.

Additionally, the amount of fuel within the tank can be observed remotely via a fuel level detector sensor which shows the current reading of the tank level. In Tanzania, the cut-off of the electricity supply from TANESCO is unpredictable for that reason the amount of fuel can be monitored via a mobile App which enables the station operator to understand when to refuel the generator tank to save operating costs and time. The appearance of the prototype of the broadcasting station and its corresponding tower is shown in different views in Figs. 41, 42, 43, 44 and 45.

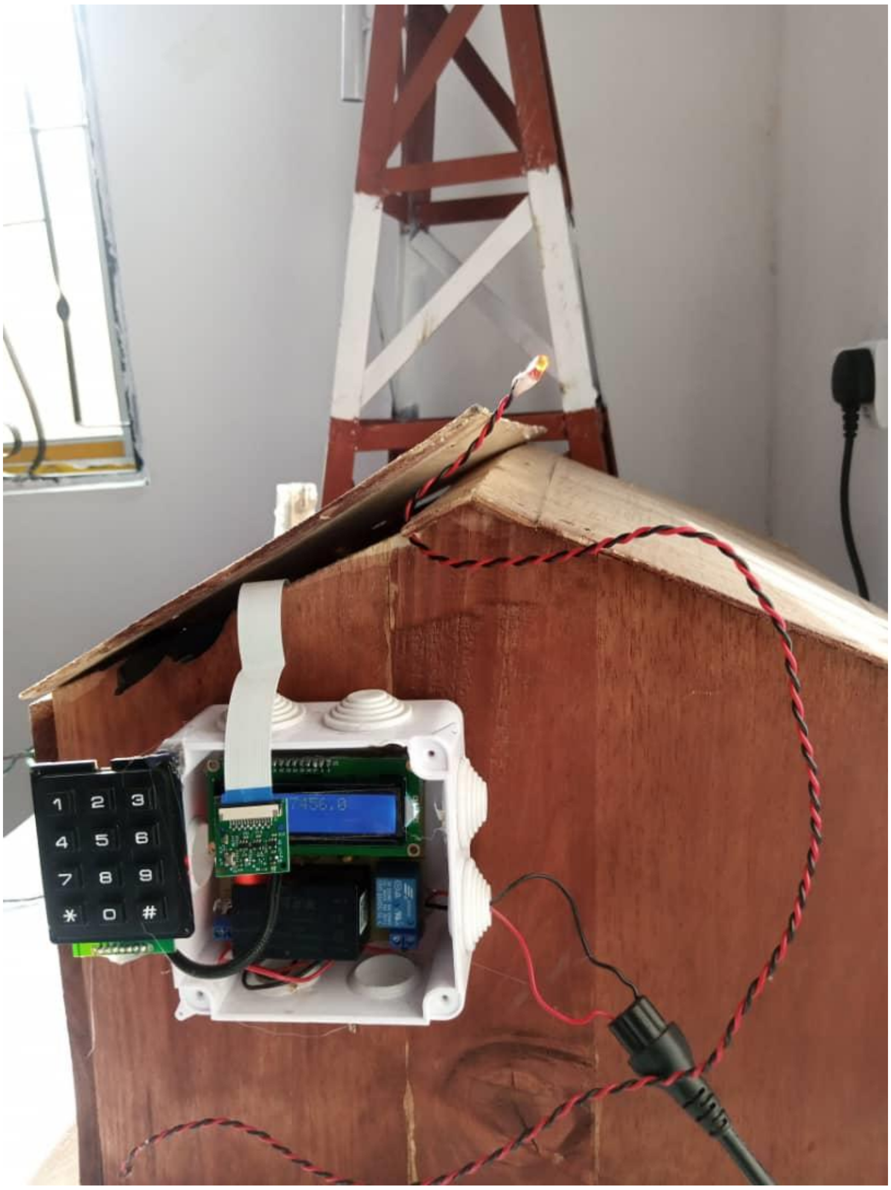

Figure 41: Monitoring of electrical units using a camera fixed in front of the energy meter (LUKU)

Figure 42: Side view of the broadcasting station

Figure 43: Front view of the broadcasting station

Figure 44: Display of operating status or parameters to be monitored

Figure 45: Camera fixed in front of FM transmitter to monitor forward and reflected powers

4.3 Mobile Application

Using the Blinky application in Fig. 45 shows the image of seven parameters that are monitored and controlled by the system. The technicians use smart and mobile devices to observe the amount of forwarding power and reflected power which are existing on the transmitter itself. Also, the degree of coldness and hotness (temperature), as well as the humidity level of the broadcasting room, is observed remotely anywhere in the world. Lastly, the alarm of the fire is observed on the mobile App together with the level of fuel present in the tank of the generator.

Figure 46: Observation of various parameters in the mobile App installed within the smart devices at different time

Table 4: System testing outcome

Device	**Parameter measured**	**Running Time(min.)**	**Circuit Readings**	**Mobile App Reading**	**Error (%)**
DHT22	Temperature Humidity	30	25.2 ^{o}C 54%	25.2 ^{o}C 54%	0
MQ22	Smoke	30	No fire	0	0
Ultrasonic Sensor	Fuel level	30	57 liters	43 liters	0
FM transmitter	Forward power Reflected Power	30	1500 W 40 W	1500 W 40 W	0
Energy meter	Electrical units	30	5444 KWH	5444 KWH	0

.

4.5 Findings and Discussion

The testing process of the system was done in the broadcasting field involving teamwork of 20 technicians from ten regions of Tanzania Mainland meaning that each region provided two technicians to participate in the study. Regions include Tanga, Tabora, Arusha, Lindi, Dodoma, Dar es salaam, Mwanza, Shinyanga, Singida and Katavi. A simple questionnaire was prepared and submitted to each technician to acquire their response to the proposed system. The system satisfied all functional requirements addressed at the beginning of the study as shown in Table 6. Furthermore, Feedback from technicians is shown in Table 5 whereby 90% of technicians accepted the performance and functionality of the proposed system in columns of agreeing and strongly agreeing. Evaluation of acceptance results of the system is shown in Fig. 47.

Table 5: User acceptance testing performed on the organization technicians

Acceptance Parameter	Strongly Disagree	Disagree	Not Sure	Agree	Strongly Agree
The system presents simple interfaces and interactions with it	0	1	1	4	14
No need for additional training and assistance when using the system	0	0	2	8	10
The system will enable technicians to access the operating parameters of equipment in the broadcasting stations	0	2	0	2	16
The system facilitates a suitable method of reporting with the Organization's headquarters	0	0	1	1	18
I have met expectations with the complete system performance	0	1	1	7	11
I can suggest other stations apply the system	0	1	2	7	10
No need for daily Climbing up and down the mountain	0	1	1	7	11

Table 6: Functional requirement of the electronic system

No.	Requirement	Results
1.	The system should have sensors to measure operating temperature, humidity, and smoke within the Transmitter room	PASS
2.	The system should have a sensor to generator fuel level outside the Transmitter room	PASS
3.	The system should transfer data from the broadcasting room to the smart devices remotely	PASS
4.	The system should have sensors to capture forward and reflected powers propagated by transmitter equipment	PASS
5.	The system should have a sensor to capture the electrical energy balance of the energy meter	PASS

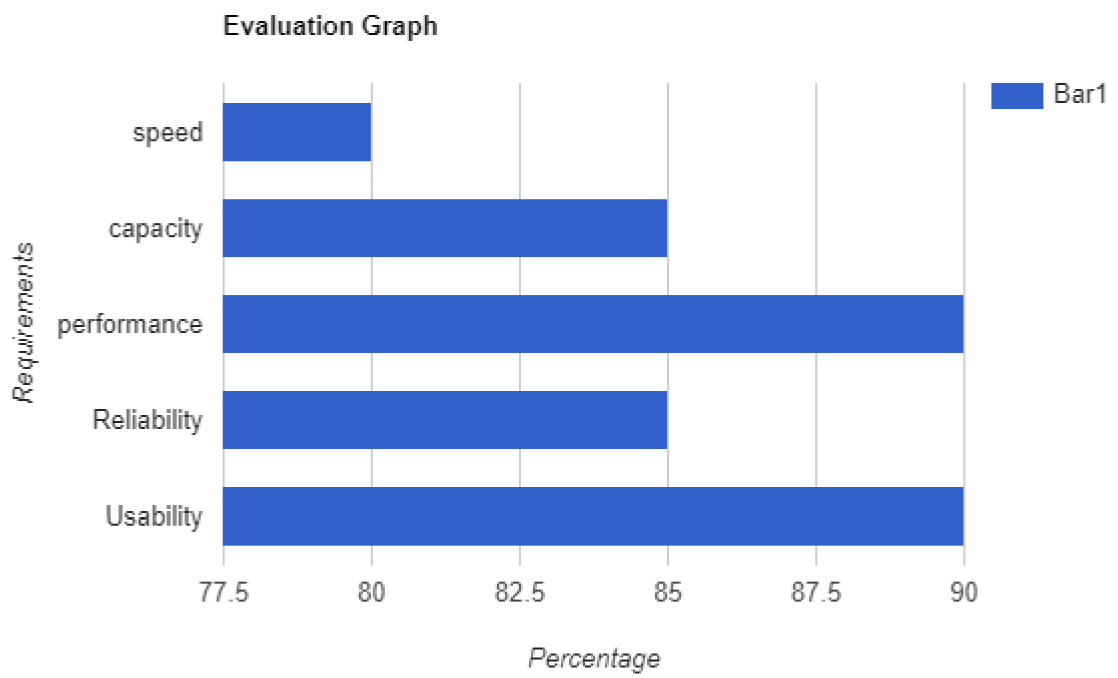

Figure 47: Evaluation of the user acceptance tests results

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Broadcasting of radio programs to the listeners is important in providing the current updated information about the world to the society. Also, it is useful for a situation of enjoyment or relaxation of listeners who need to hear the music and entertainment programs. In African countries, many areas especially rural areas are separated away from acquiring internet services. In urban areas, the internet is sometimes used as the source of news to people by accessing blogs, websites, mobile Apps, or internet radio to receive updated information. Unfortunately, in rural areas this cannot be done due to less deployment of cellular networks with high internet capability technology like 3G or 4G, the only remaining option is to listen to the radio programs. In addition, the people who cannot afford to have smartphones in urban areas depend on radio services as the primary source of information. Due to the importance of broadcasting services, used in Tanzania known as FM broadcasting, the implementation of an IIoT-based monitoring and control system is essential whereby:

(i) The functional requirements and correct methodologies for the Design and Implementation of the IIoT-based monitoring and control system for radio broadcasting networks in Tanzania were provided

(ii) Specific features were designed and implemented in the proposed solution for IIoT-based monitoring and control systems.

(iii) The developed system was validated in ten radio towers to prove its efficiency in which 90% of respondents agreed with its implementation

The contribution of the study aims to provide earlier notification on the operating status of the radio transmitters to the tower operators by eliminating strenuous and daily efforts to accomplish the data collection process. This can be attained by implementing The IoT-based monitoring and control system in a radio network. The developed solution proved that information from the radio network can be retrieved in real-time without physically climbing up to the radio towers. The process of taking readings and operating conditions of broadcasting equipment, as well as writing reports of the equipment, is performed by the developed system on duty every day. Seven parameters including forwarding power, reflected power, temperature, humidity, generator fuel level, and electrical energy balance units, have been successfully integrated and monitored in the system.

The study aimed to develop a system that will reduce the operating cost and enhance the real-time data acquisition from the towers installed in each district by remote monitoring and controlling the radio towers network in Tanzania. The solution is applicable for existing terrestrial broadcasting of Fm transmitter equipment with outdated technology which is still used in Tanzania. The aim is to assist the companies to incorporate old transmitters which do not have internet-enabled features with IoT technology instead of performing rapid installation of Lates technology at a high cost. In consequence, the broadcasting media can continue increasing their coverage and installation of new radio towers while at the same time employing the proposed system for better efficient and effective management of their towers on a fixed budget. The challenge which occurs in employing technical personnel who must physically attend the site to operate the station installed in each district has been resolved.

5.2 Recommendations

The application of the proposed system can be adopted by all 187 broadcasting radios operating in Tanzania to save operating costs and simplify schedules of technical activities. Findings from the study show that there is no direct need for human observers in radio towers or stations. For that reason, I recommend the application of the developed system to all other media. In addition, the installation of the proposed system reduces the physical attendance of human operators at the radio station while at the same time enhancing human well-being due to the reduction of exposure to electromagnetic waves which are harmful to their bodies.

Lastly, for future work, other researchers or developers should design a system mobile app rather than employing an already existing platform available on google play store and Apple store to receive the information from very far located stations to increase the security and privacy of the organization. Also, additional parameters should be monitored and controlled remotely; these parameters include VSWR, DC voltage level, Audio level, switching on/off of the transmitters, remote insertion of electrical units in energy meters and theft detectors can be introduced. Parameters knowns as EMW radiation are measured by an institution known as OSHA which oversees the security of the workplace. OSHA advises the specific media to the excessive measures after detecting that maximum radiation is emitted. Hence EMW detection was not advised to be implemented in future work.

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APPENDICES

Appendix 1: Validation questionnaire

My name is Hamisi Juma Msimbe, master's student at The Nelson Mandela Institution of Science and Technology (NM-AIST), presently engaging in a project title known as “Design and Implementation of Industrial IoT Based Monitoring and Control System for Radio Broadcasting Network in Tanzania: A Case of Tanzania Broadcasting Corporation". I have designed and developed the electronic system which monitors the overall performance of the radio broadcasting station by sensing parameters such as forward power, reflected power, temperature, Humidity, electrical units, Generator fuel level, and fire. The sensed parameters are transmitted to the mobile app installed in the technician's smart devices for observation and monitoring anywhere. This questionnaire aims to receive, analyze, and take measures to be implemented in the proposed system with consideration of your opinions. Please kindly select the best answer.

Full names ………………………………………….

Questions.

1. Broadcasting Station’s Name …………………………...
2. Can you suggest others stations to apply the system?
    a. Strong agree
    b. Agree
    c. Not sure
    d. Strongly Disagree
    e. Disagree

3. the system presents simple interfaces and interactions with it
    a. Strong agree
    b. Agree
    c. Not sure
    d. Strongly Disagree
    e. Disagree

4. can the system enable technicians to access operating parameters of equipment in the broadcasting stations?
   a. Strong agree
   b. Agree
   c. Not sure
   d. Strongly Disagree
   e. Disagree

5. Is there no need for additional training and assistance when using the system?
   a. Strong agree
   b. Agree
   c. Not sure
   d. Strongly Disagree
   e. Disagree

6. Can The system facilitates a suitable method of reporting with the Organization's headquarter?
   a. Strong agree
   b. Agree
   c. Not sure
   d. Strongly Disagree
   e. Disagree

7. Have I met expectations with the complete system performance?
   a. Strong agree
   b. Agree
   c. Not sure
   d. Strongly Disagree
   e. Disagree

8. Is there any need for daily Climbing up and down the mountain
   a. Strong agree
   b. Agree
   c. Not sure
   d. Strongly Disagree

e. Disagree

9. Do you have any other comments?

Appendix 2: Code for DHT 22, MQ2 and Ultrasonic Sensor

```
#include <LiquidCrystal_I2C.h>
#include <Wire.h>
#include "DHT.h"
#include <WiFi.h>
#include <WiFiClient.h>
#include <BlynkSimpleEsp32.h>

#define Water 0
#define Alarm 15
#define DHTPIN 33
#define MQ 32
#define Trig 25
#define Echo 26
#define vSensor 19
#define DHTTYPE DHT11
DHT dht(DHTPIN, DHTTYPE);

float Temp,Distance;
int Hum,Fire,disp[3],Level,Tm=0,nwConnect=0;
double duration;
bool Mains,FireN=false;;

const char ssid[] = {"hamisi"};
const char pasword[] = {"12341234"};
char auth[] = "N6hddK0gI3zsi2n99spENpx38ahYLJPj";
unsigned long previousMillis=0,currentMillis;

LiquidCrystal_I2C lcd(0x27, 16, 2);// LCD I2C
BlynkTimer timer;

void setup() {
//configuration
  pinMode(vSensor, INPUT);
  pinMode(Echo, INPUT);
  pinMode(MQ, INPUT);
  pinMode(Water, OUTPUT);     pinMode(Trig, OUTPUT);
  pinMode(Alarm, OUTPUT);
  lcd.begin();
  lcd.home();
  dht.begin();
  timer.setInterval(2000L, sendData);
  Wire.begin();
```

```
  delay(10);

//initial display on LCD
  connectclient();
  lcd.clear();
  lcd.setCursor(0,0);   lcd.print("**WELCOME! TBC**");
  lcd.setCursor(1,1);   lcd.print("TOWER CONTROL.");
  delay(5000);
  lcd.clear(); // clear the initial display
  Blynk.config(auth);
}

//main cycle
void loop() {
//Sensor read and quantization
  Hum = dht.readHumidity();
  Temp = dht.readTemperature();
  Fire=analogRead(MQ);
  Mains=digitalRead(vSensor);

  digitalWrite(Trig,HIGH);
  delayMicroseconds(10);
  digitalWrite(Trig,LOW);
  duration=pulseIn(Echo,HIGH);
  Distance=0.017*duration;
  if(Distance>=7)   Distance=7;
  if(Distance<=0)    Distance=0;
  duration=0;
  Level=map(int(Distance),0,7,99,0);
  disp[0]=(Level/10)%10;
  disp[1]=Level%10; //Sensor

  if(Fire>400){
    digitalWrite(Alarm,HIGH);
    digitalWrite(Water,HIGH);
    FireN=true;
  }else{
    digitalWrite(Alarm,LOW);
    digitalWrite(Water,LOW);
    FireN=false;
  }
  lcd.setCursor(0,0);
  lcd.print(Temp,1);
  lcd.print(char(223));
```

```
  lcd.print('C');
  lcd.setCursor(9,0);
  lcd.print("Hum:");
  lcd.print(Hum,0);
  lcd.print('%');

  lcd.setCursor(0,1);
  if(Fire<2000)
    lcd.print("NOFire");
  else
    lcd.print("Fire  ");
  lcd.setCursor(9,1);
  lcd.print("Gen:");
  lcd.setCursor(13,1);
  lcd.print(disp[0]);
  lcd.print(disp[1]);

  lcd.print('%');
  Blynk.run();
  timer.run();
  delay(500);
}

void Beep(){
  digitalWrite(Alarm,HIGH);
  delay(70);
  digitalWrite(Alarm,LOW);
  delay(70);
}

void sendData(){
  Blynk.virtualWrite(V1, Temp);
  Blynk.virtualWrite(V2, Hum);
  Blynk.virtualWrite(V3, Level);
  Blynk.virtualWrite(V4, FireN);
  Blynk.virtualWrite(V5, 1500);
  Blynk.virtualWrite(V6, 40);
  Blynk.virtualWrite(V7, 7456);
  if(Mains)
    Blynk.virtualWrite(V9, 1);
  else
    Blynk.virtualWrite(V9, 0);
}
```

```
void connectclient(){
//Network connect
  lcd.setCursor(0,0);
  lcd.print("CONNECTING...");
  Tm=0;
  WiFi.begin(ssid, pasword); // Attempt to connect to wifi with our password
  while(WiFi.status() != WL_CONNECTED){
    if(WiFi.status() == WL_CONNECTED)
      nwConnect=1;
    if(nwConnect==1)   break;
    delay(10);
    WiFi.begin(ssid, pasword);

    Tm++;
    if(Tm>=600)   break;
  }
  Blynk.config(auth);
  Blynk.config(auth);
  if(nwConnect==1){
    lcd.setCursor(0,1);
    lcd.print("**CONNECTED!**");
    Beep();
  }else{
    lcd.setCursor(0,1);
    lcd.print("!!UNCONNECTED!!!");
    Beep();Beep();Beep();
  }delay(2000);//ssid network connect
}
```

Appendix 3: Code for energy meter

```
#include <Keypad.h>
#include<LiquidCrystal.h>

#define Alarm 0
#define Line A5
#define LOG_PERIOD 20000

LiquidCrystal lcd(6,5,4,3,2,1);

float Units=7456;
unsigned long previousMillis=0,currentMillis;

void setup(){
  pinMode(Alarm, OUTPUT);
  pinMode(Line, OUTPUT);
  digitalWrite(Alarm, LOW);
  lcd.setCursor(0,0);
  lcd.print("Booting....");
  delay(2000);
  lcd.setCursor(3,1);
  lcd.print("SXM ONLINE");
  Beep();Beep();
  delay(2000);
  lcd.clear();
}

void loop(){
//Display
  lcd.setCursor(6,0);
  lcd.print(Units,1);
  if(Units>0)
    digitalWrite(Line,HIGH);
  else{
    digitalWrite(Line,LOW);
    Beep();
  }
}
  void Beep(){
  digitalWrite(Alarm, HIGH);
  delay(200);
  digitalWrite(Alarm, LOW);
}
```

Appendix 4: Code for FM transmitter prototype

```
#include<LiquidCrystal.h>

#define Alarm 1
#define LED A1

LiquidCrystal lcd(8,7,6,5,4,3);

int forwardPower=1500,refPower=40;

void setup(){
//Pin configuration
  pinMode(Alarm, OUTPUT);
  pinMode(LED, A1);

//Register configuration
  lcd.begin(16,2);

  lcd.setCursor(0,0);
  lcd.print("Booting....");
  delay(1000);
  for(char col=0;col<15;col++){
    lcd.setCursor(col,1);
    lcd.print('.');
    delay(500);
  }delay(5000);
  lcd.clear();

}

void loop(){
  randomSeed(A0);
  //forwardPower=random(1000,1700);
  //refPower=random(4,9);

//Display
  digitalWrite(Alarm,LOW);
  lcd.setCursor(0,0);
  lcd.print("FWD:");
  lcd.print(forwardPower);
  lcd.print("W");
  lcd.setCursor(10,0);
  lcd.print("2000");
```

```
  lcd.print("W");

  lcd.setCursor(0,1);
  lcd.print("REF:");
  lcd.print(refPower);
  lcd.print("W");
  lcd.setCursor(10,1);
  lcd.print("164");
  lcd.print("W");
  digitalWrite(LED,!digitalRead(LED));
  delay(1000);
}
```