2021-09

Remote radiation monitoring system at uranium exploration site in Mkuju river

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NM-AIST

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REMOTE RADIATION MONITORING SYSTEM AT URANIUM EXPLORATION SITE IN MKUJU RIVER

Anna M. Geofrey

A project Report Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science in Embedded and Mobile Systems of the Nelson Mandela African Institution of Science and Technology
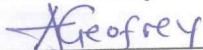
Arusha, Tanzania

September, 2021

ABSTRACT

Usage of radioactive materials in a number of countless activities has increased rapidly worldwide, thus, increasing Uranium exploration in different countries including Tanzania. As Uranium decays, it emits ionizing radiations, which has health risks associated with it. The major threats occur when ionizing radiations produced during uranium decay exceed their levels. Causing skin burns and acute radiation syndrome, though in the long-term cause cancer and cardiovascular disease, are the substantial health effects to mention a few. Thus real-time and remote monitoring of radiation at uranium mining sites is mandatory to ensure environmental and human safety. Radiation detectors are used to monitor radiation at uranium mining sites by frequently visiting however achieving real-time and remote monitoring is still the challenge. This method is time-consuming and the existing radiation detectors used in Tanzania are exported from developed countries and are expensive.

This design science study presents an effective and affordable system for remote monitoring of radiation at uranium mining sites using internet of things (IoT) technology. The system used prototype methodology and the radiation detector was programmed by using ESP32 microcontroller board. Which through its inbuilt Wi-Fi it was able to send data to the cloud data storage. The Message Queuing Telemetry Transport protocol facilitated remote visualization of radiation levels from the cloud storage dashboard and the developed mobile application. The end-users monitored radiation data and received notifications in case of excess radiation through the developed mobile application. The internet of things technology facilitated the end-users to visualize and monitor radiation levels anytime and anywhere via the internet.

DECLARATION

I, Anna M. Geofrey do hereby declare to the Senate of Nelson Mandela African Institution of Science and Technology, that this project report is my original work and that it has neither been submitted nor being concurrently submitted for degree award in any other institution.

Anna M. Geofrey   20/10/2021
_____   _____
Name and Signature of the Candidate   Date

The above declaration is confirmed by:

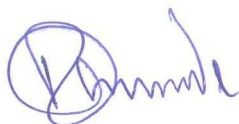Dr. Shubi Kaijage   25/10/2021
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Name and Signature of the Supervisor   1   Date

Dr. Ramadhani Sinde   25-10-2021
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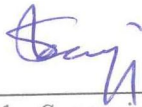Name and Signature of the Supervisor   2   Date

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CERTIFICATION

The undersigned certify that have read, and hereby recommend for acceptance by The Nelson Mandela African Institution of Science and Technology, a project entitled, "*Remote Radiation Monitoring System at Uranium Exploration Site in Mkuju River*" in partial fulfillment of the requirements for the award of the Degree of Master of Science in Embedded and Mobile Systems.

Dr. Shubi Kaijage

25-10-2021

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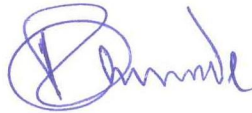
Name and Signature of the Supervisor   1

Date

Dr. Ramadhani Sinde

25-10-2021

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Name and Signature of the Supervisor   2

Date

ACKNOWLEDGEMENTS

DEDICATION

My genuine dedication for this project is to my gorgeous and sweet parents who prayed for me and believed in God. I'm grateful for their love and support through my master's studies.

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LIST OF ABBREVIATIONS AND SYMBOLS

AC	Alternating Current
CNSC	Canadian Nuclear Safety Commission
CPM	Counts per Minutes
DC	Direct Current
DNA	Deoxyribonucleic Acid
EPA	Environmental Protection Agency
ESP32	Espressif Systems 32
GM	Geiger Muller
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
ICT	Information Communication Technology
IDE	Integrated Development Environment
IoT	Internet of Things
JDK	Java Development Kit
JRE	Java Runtime Environment
LCD	Liquid Crystal Display
LED	Light-Emitting Diode
MQTT	Message Queuing Telemetry Transport
mSv	MilliSieverts
NIM	Nuclear Instrumentation Maintenance
PCB	Printed Circuit Board
SD	Secure Digital
Sv	Sieverts
TAEC	Tanzania Atomic Energy Commission
UML	Unified Modeling Language
UNEP	United Nations Environment Programme
WHO	World Health Organization
Wi-Fi	Wireless Fidelity
WNA	World Nuclear Association's
μsv/h	MicroSievert per Hour

1.1   Background of the Problem

Applications of radioactive sources in countless activities have abundant contributions to the social and economic development of diverse sectors. For example the health sector for medical diagnosis and treatment of disease, industries, mining, and agriculture (United Nations Environment Programme [UNEP], 2016). The technology has advanced in a way that is reliable and safe to use if is properly managed. As a result, human beings are exposed to radiation from various sources in their surroundings at home, hospitals, transportation, food intake, radioactive minerals, exposure to radiation in modern life cannot be escaped (Morgan, 2012). In concern, proper management of radiation sources is required especially for ionizing radiation which can be a threat to human health and the environment (Kamiya *et al.,* 2015).

Uranium being one of the radioactive sources is very potential for nuclear energy production hence its demand has increased worldwide. It decays naturally due to its unstable atoms causing ground radiation (Elaraby, 2020). The naturally occurring radioactivity has a vital role to balance the earth elements, form, and shape being naturally distributed within the environment in water, soil, and air (Cowart & Burnett, 1994; Schoene *et al.,* 2006). Whereby once more they may be geochemically organized in a way that has less impact on human health.

Though the natural decay process of Uranium sometimes is altered by human activities such as uranium mining activities disturbing the natural distribution of emitted progeny (Elaraby, 2020). The emitted ionizing radiation like Gamma rays, Alpha, and Beta particles fails to be distributed naturally resulting in presence of high-level ionizing radiation in one location which is dangerous (Cowart & Burnett, 1994; UNEP, 2016). Hence, restrictive security regulation and management of uranium mining is necessary to be strengthened. Meanwhile, in Africa, there are still inadequate radiation safety measures for radioactive sources usage, storage, and transportation (Woods *et al.,* 2015).

The interest of developed countries in uranium mining and exploration in Africa is rapidly growing (Conde & Kallis, 2012). The United States has the highest demand for nuclear energy for electrical power production followed by France (World Nuclear Power Reactors, 2012). The electricity demand is the driving force for uranium demand in today's market. It is predicted to rise at a yearly rate of 2.2% worldwide to 2035 contributed by the demand from Asian nations

like China and India (International Energy Agency [IEA], 2010; Khatib, 2011). Therefore, various companies from developed countries are investing in uranium mining in Africa such as in Namibia and Niger where there are large uranium deposits and other African countries.

Tanzania is one of the African countries in its progressive stage to commence mining the untapped uranium in various areas like Mkuju River in Namtumbo, Manyoni, Bahi, Lake Natron, and other areas (Banzi *et al.,* 2015a). The government has mandated Tanzania Atomic Energy Commission (TAEC) with the responsibility of ensuring that the legislation for uranium exploration, mining, and transportation are in place and implemented to protect both environment and human health (Tanzania Atomic Energy Commission [TAEC], 2003).

Tanzania Atomic Energy Commission is responsible for radiation safety monitoring on uranium mining sites, radioactivity analysis, and calibration of radiation survey instruments services during uranium mining. It is the impetus that TAEC has to ensure that before the commencement of uranium mining, there are should be proper means of monitoring and management of uranium sites within the country (TAEC, 2011). Real-time monitoring of radiation levels in uranium mining sites is required to ensure radiation safety (Chareyron, 2008).

1.2   Statement of the Problem

It is well recognized that radiation cannot be detected by human sensory organs. It is only through devices where it can be detected, located, and measured (Ding *et al.,* 2018). It is therefore, very important to monitor all places where radiation sources are in use to ensure radiation safety for the public and environment. Such places that need very stringent radiation monitoring are uranium mining and deposits. Uranium mining with inadequate radiation protection programs in place and improper management regulation can cause highly radiological risks to the environment and people around the mining due to excessive doses of ionizing radiation (Banzi *et al.,* 2015a).

The risks allied in uranium mining are basically from the decay of uranium emitting the gamma radiation, beta and alpha particles, the radon gas and its progeny, and the radioactive dust blown by wind known for causing lung cancer. The heavy metals which are very toxic from the uranium deposit cause the pollution of water and soil (Abdelouas, 2006; Conde & Kallis, 2012). This challenge is not supposed to be overlooked by the government and regulating authorities, the security measures to ensure safety are required.

The health effects associated with radiation exposure do not appear quickly unless a person receives quite a large dose, it can cause radiation burns and acute radiation syndrome, and long-term effects being cancer and cardiovascular disease (Canadian Nuclear Safety Commission [CNSC], 2012). However, cancer and many other effects are readily detectable after some time and happen frequently in those people who have absorbed moderate doses over time (UNEP, 2016).

Furthermore, the high cost of radiation instruments for detecting and measuring radiation at various radioactive deposits is the major hindrance factor for radiation safety and radiation protection programs. The lack of highly advanced radiation measuring tools in Tanzania is a threat limiting the performance of radiation regulating authorities for law (Banzi *et al.,* 2015a). The radiation measuring devices used in Tanzania are imported from developed countries and are very expensive thus it is a major hindrance to the proper management of radioactive sources.

However, the need for monitoring the uranium mining sites before, during mining, and after the close of mine to ensure the safety of inhabitants requires the availability of adequate radiation measuring devices (Banzi *et al.,* 2015a). Thus, it's necessary to develop an effective low-cost radiation detection system that is affordable and facilitates remote and real-time monitoring of radiation levels at uranium mining sites.

1.3   Rationale of the Study

Protective strategies are required to eliminate the health risks allied with excess absorption of ionizing radiation. For example, due to inadequate means of radiation protection by the 1950s, it was estimated that 359 early workers who worked with radiation that were mainly doctors and other scientists died from their exposure to radiation (UNEP, 2016).

The impact of excess radiation dose exposure over a short time or longer time is a serious threat to human health. As a person receives more high doses then the impact becomes more severe at higher doses for stance the damage of person central nervous system may occur (Ting, 2010). This impact is more severe for children compared to adults, the health consequences of exposure can be severe, even at lower radiation doses, the consequences can be worse such as growth retardation, abnormalities, impaired brain function, and cancer (CNSC, 2012; UNEP, 2016).

According to Canadian Nuclear Safety Commission (CNSC, 2012) and Environmental Protection Agency (EPA, 2016), the exposure of ionizing radiation to humans and environments approximately 60% comes from natural radiation such as Radon gas which is the result of the

decay of Uranium. It is estimated to be the second leading cause of lung cancer with an estimation of 20 000 annually and less than 40% comes from man-made ration sources such as medical procedures. The study conducted to determine the sources of high ionization radiation in the environment by World Health Organization (WHO) in Fig. 1, shows clearly that uranium decay is leading. Thus, there is a need for uranium mining to be monitored even after the mining is closed to ensure radiation safety.
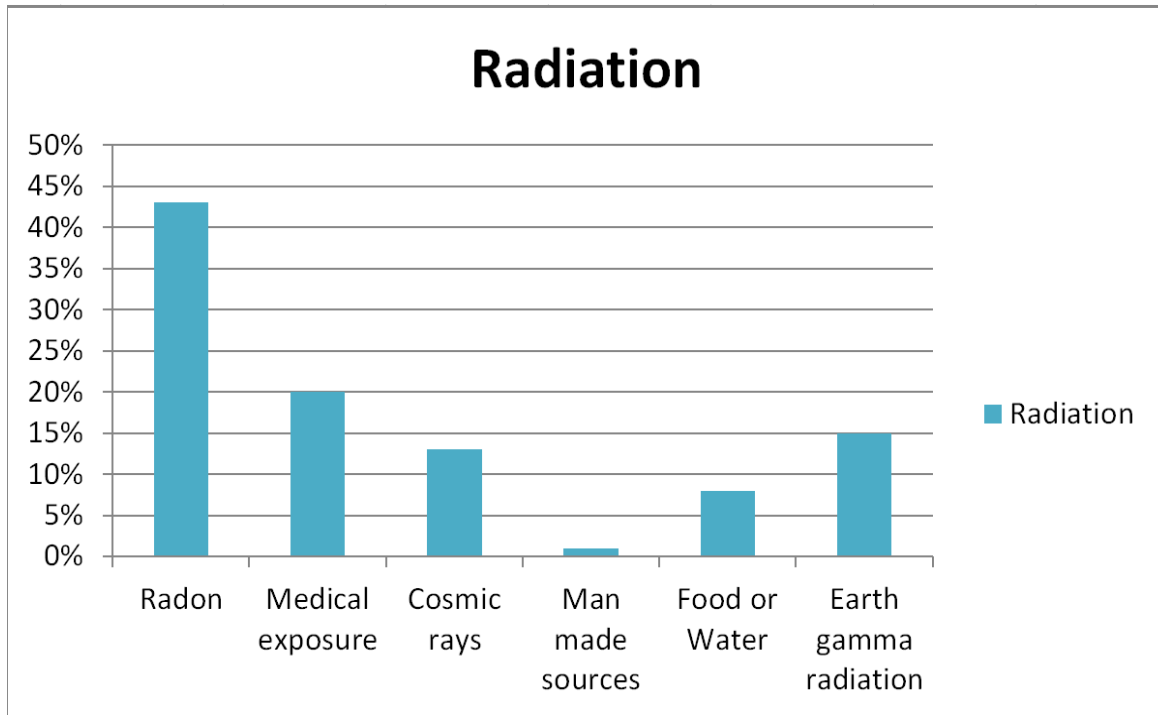
Figure 1: Radiation exposure sources and distribution to the world population

1.4   Research Objectives

1.4.1   General Objective

The main objective of this project was to develop an effective and affordable radiation detection system for remote monitoring of radiation in the uranium mining site at Mkuju River in Namtumbo, Tanzania.

1.4.2   Specific Objectives

(i)   To examine the existing radiation detection system.

(ii)   To develop an effective and affordable system for radiation detection.

(iii)   System validation.

1.5   Research Questions

(i)   What are the commonly used radiation detection systems and how do they operate?

(ii)   Why is it important to be cost-effective in the acquisition of raw materials and production techniques of radiation detection systems?

(iii)   What are the key indicators that a developed radiation detection system is right and satisfies the end-users?

1.6   Significance of Study

The developed radiation detection system was made by Geiger-Muller tube (GM) and it was used to detect the radiation levels around the radiation sources especially uranium mining sites. And through wireless technology by using Espressif Systems 32 (ESP32) microcontroller board the radiation data were sent to the cloud storage through Wireless Fidelity (Wi-Fi) and Message Queuing Telemetry Transport (MQTT) protocol. From the cloud storage, the users were able to view live and previous radiation data stored on the Cayenne dashboard.

In addition to that users were able to visualize radiation data through the developed mobile application which was possible due to the MQTT protocol. When there were excessive doses of the ionizing radiation the notification was sent to the end-users through message and alarm notification on the developed mobile application. The remote access of radiation data was possible via the internet but when there was no internet connectivity. Still, users were able to view data on Liquid Crystal Display (LCD) and view the previous data stored on the micro Secure Digital (SD) card.

This facilitates TAEC's responsibility of safeguarding the radiological state on ionizing radiation sources like uranium mining sites. The safety of mining workers and people around the uranium mining is obtained by real-time and remote monitoring of the area. Finally, precautions measures are taken on excessive exposure of ionizing radiation doses.

1.7   Delineation of the Study

The focus of the present study mainly lies on the development of an effective low-cost radiation detection system that is affordable and capable to facilitate remote and real-time monitoring of radiation levels at uranium mining site at Mkuju River in Namtumbo, Tanzania.

CHAPTER TWO

LITERATURE REVIEW

2.1   Overview

Several reviews of the literature on radiation detection systems for detecting and monitoring radiation helped to understand the merits and demerits of the existing systems. Different radiation detectors are used in measuring radiation from various radiation sources such as in hospitals, industries, mainly to prevent excess exposure of ionizing radiation to humans and the environment (Morgan, 2012; Ting, 2010).

The term radiation is omnipresent throughout the surroundings coming from both natural and artificial radiation sources. It is the energy that comes from unstable atoms or man-made, it travels in the stream or waveform of particles which involves non-ionizing radiation and ionizing radiation (EPA, 2016; UNEP, 2016). Non-ionizing radiation possesses less energy compared to ionizing radiation which has no sufficient energy to give out ions such as light, radio waves, and microwave.

While ionizing radiation has abundant energy that allows blowing electrons out of atoms, when they pass through the matter, it becomes electrically charged or ionized. The electrical ions produced by ionizing radiation can harm usual biological processes and damage Deoxyribonucleic Acid (DNA) genes (Kamiya *et al.,* 2015). During the ionization process (radioactivity) the radioactive atoms emit alpha particles, beta particles, and gamma rays which all can impact human health that is why there are many detectors for detecting ionizing radiation as explained below.

2.2   Radiation Detection Systems

Since radiation cannot be detected by using human sensing organs different detection systems such as gas detectors, semiconductor detectors, and scintillation detectors are used to detect ionization radiation. To measure the ionized radiation dose rate (level) and to find out the type of ionizing radiation emitted from the radiation source (Ding, 2018). According to Khan (2017) the accuracy of detecting and quantifying the gamma rays, alpha, and beta particles from the radiation source depends on the detector which is used as shown in Table 1.

Table 1: Types of ionized radiation detector

Attributes	Geiger-Muller (GM) Tube	Ion Chamber	Scintillation	Neutron Ball
Detects	α, β, γ	α, β, γ	α, β, γ, n	n
Medium	Gas	Gas	Solid/Liquid	Gas
Ranges	.04 mR/hr to 500 mR/hr	3 mR/hr to 10^4 mR/hr	Up to 800 000 cpm	Up to 500 000 cpm
Use	Low dose rate Frisking Area Monitor	Med to High dos Surveys Area Monitoring	Low level contamination surveys	Neutron Surveys
Advantages	Rapid response Large output Signal Moderate Sensitivity	Low Energy Dependence Simple to use Wide dose range	High sensitivity Rapid response Energy resolution	Rapid response Γ-discrimination
Disadvantages	Long Dead Time Energy dependent	Slow response Low sensitivity	Fragile Expensive	Requires Hi volt Hi maintenance

Khan (2017)

The suitability of the radiation detection system for detecting and measuring the radiation depends on the type of radiation source to be monitored and the dose rate which is emitted by the radiation source. The selection of an appropriate radiation detector for a certain application ensures the proper operation and detection of radiation (Khan, 2017).

The GM tube cannot be used to detect a very high dose rate of radiation and in very rare cases it can detect neutron particles. The Ion Chamber cannot detect a very low dose rate of radiation while Scintillation has high sensitivity and can detect a very high dose rate of radiation but is very expensive. Thus, every radiation detector has its merits and demerits depending on which area they applied (Knoll & Kraner, 1981).

For uranium mining sites monitoring GM tube is a suitable detector compared to other detectors. It is capable of detecting the low dose rate of ionizing radiation which mostly is produced in uranium mining. Also, the GM tube detects ionizing radiation like gamma rays, alpha and beta particles that are likes to be formed during uranium decay.

Furthermore, the cost of the radiation detection systems varies according to the system functionalities, the type of ionizing radiation the detector can detect, the type of tube or detector used. The volume of the tube, it's likely that the large volume of the tube the more ability to

detect ionizing radiation. Thus, in the market, the radiation detectors have different prices, for instance, the price for the radiation detectors that are used for monitoring all Alpha, Beta, and Gamma ionizing radiation. And also can be used to monitor radiation remotely in the environment are shown in Table 2.

Table 2: The cost of radiation detector at the market

S/N	Radiation detector Name	Unit price
1	Dosimeter Bereg IRI-1 Indicator SBM Radiometer Geiger Counter Radiation Detector	$5554.95
2	Veenstra VRM-202/5 area Radiation Monitoring	$1304.38
3	Veenstra (comecer) vrm-202 area Radiation Monitoring System / dose rate levels	$1808.35
4	Narda ESM-30 RadMan XT RF Field Radiation Monitor	$1350.00
5	Thermo Eberline E600 Geiger Counter / Multipurpose Survey Meter	$2200.00

www.ebay.com

2.3   Uranium Mining Radiation Monitoring Systems

Uranium mining sites have been monitored and assessed to determine the radioactivity levels for decades in different countries (International Atomic Energy Agency [IAEA], 2020). Periodic monitoring of environment and residents by using different techniques such as biomarkers for assessing the health risks to the population around the mining (Au *et al.,* 1995; Tripathi *et al.,* 2008). Through routine visitation, the regulatory bodies were able to survey the areas, measure the radiation level in soil, water, and the air around the mining sites using the various radiation detectors (Carvalho, 2014).

In case of high radiation levels, countless safety procedures were taken such as treatment of polluted water, restricting the resident from using water, food which comes from the area around the mining. Also for closed mining the remaining deposits were cleaned up and regenerated for human use (Carvalho, 2014; Hurst, 2015).

Though continuous visitation for monitoring ionized radiation levels is a very effective strategy yet it costs the regulatory bodies' frequency travel and expenses. Real-time monitoring of ionizing radiation levels cannot be achieved through this means. With the advanced wireless technology, it's now possible to have real-time monitoring of radioactivity levels in uranium waste dumps, uranium mining, and deposits (Avram *et al.,* 2017).

The wireless technology is more suitable to connect several radiation detectors in a large area (Gaware *et al.,* 2011). By using wireless communication protocols such as ZigBee protocol and MQTT protocol the radiation detectors are wirelessly connected to the data processing subsystem thus large areas can be monitored (Ding *et al.,* 2018).

The developed system has used wireless technology to allow data collected from different radiation detectors to be sent to the central data processing subsystem allowing remote data visualization and monitoring of uranium mining sites by TAEC. The added value of the developed system compared to other wireless technologies applied in this field is remote monitoring and data visualization of uranium mining sites through the mobile application.

CHAPTER THREE

MATERIALS AND METHODS

3.1   Overview

The completion of the project has involved several procedures, methods, and clear steps to obtain the project goal. The prototyping methodology was used for the system development, developing a system prototype and testing it for more corrections was a means of improving the developed system. In this project correcting errors, learning, and observing the solution was repeated several times until the goal of the project was achieved. The data for the project development were gathered from different experts in different fields like radiation, electronics. Lastly testing the developed system prototype has been essential to achieving the desired project objectives.
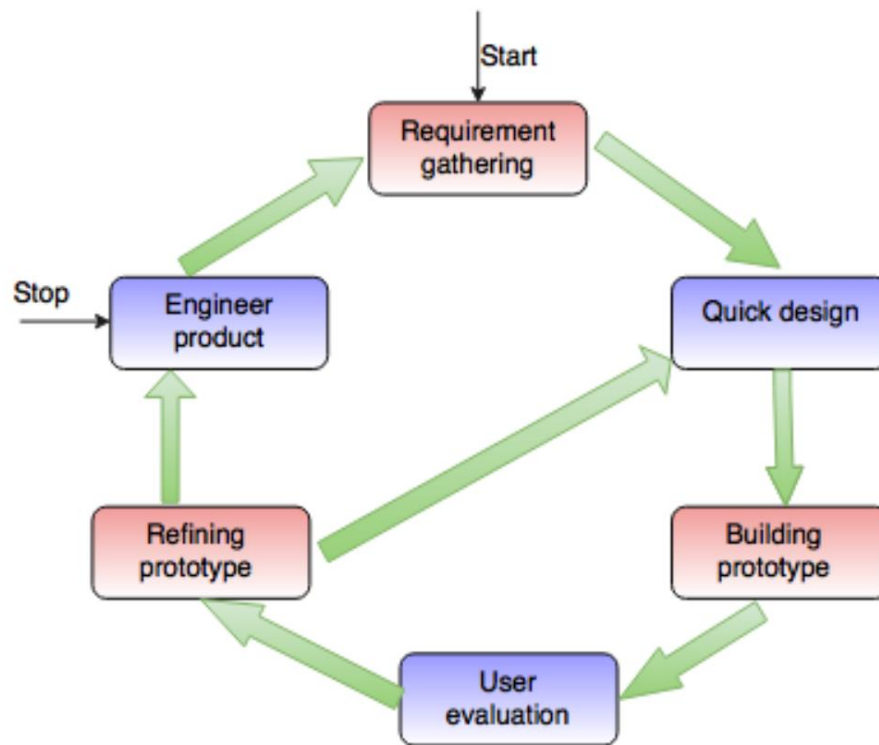
Figure 2: Prototyping Methodology

The prototyping methodology helped to develop several prototypes allowing corrections and comments from the end-users. The requirement of the system was refined several times, removing errors and bugs until the end-users were satisfied. The first and second prototypes helped in improving the power supply circuit of the working system. The challenge of an

unstable power supply which drops from 500 DC volts to 300 DC volts was solved. The overheating of some electronics components like BD 139 transistors, overheating of 7805 voltage regulator. Using the ceramic capacitors in voltage multipliers at least at has 100 volts were the data collected from the first and the second developed prototypes.

The third, fourth, and fifth developed prototyping were useful in determining how and which components can help in reducing the signal output noise. How the signal pulse overlapping can be reduced. Several components were giving not the correct results, the capacitors, comparators like LM 311 all this data were useful in obtaining the working signal counting system. Therefore, model was very useful for the project since scarce electronic components are in the Tanzania market. Changing and finding equivalent components was done frequently in reality it was a trial and error process throughout the system development.

3.2   Study Area

The study area was at Mkuju River located in Namtumbo district which is in the southern part of Tanzania in the Lindi region. This area was suitable for the project because is one of the largest uranium mining sites reserves in Tanzania and has the largest deposit of uranium estimated to be 182 million tonnes (Banzi *et al.,* 2015b; Kimaro & Mdoe, 2018). Besides, the license to allow uranium mining in this area was given by Tanzania's ministry of energy and mineral resources in 2013 (Mohammed & Mazunga, 2013).

Therefore, TAEC frequently visits the area to measure the radiation level since the residents of this area depend on the Mkuju river for their agricultural and domestic activities. The radiation safety concern by TAEC is very crucial (Banzi *et al.,* 2015a; Mohammed & Mazunga, 2013). The workers on the mine are not supposed to have above 20 mSv per year dose rate and the public is limited to a 1 mSv per year dose rate (International Commission on Radiological Protection [ICRP], 2007; Kimaro & Mdoe, 2018).

The contamination of ionizing radiation from the Uranium decay in water, air, and soil in this area needs to be monitored. Therefore, TAEC has done several surveys on the area before and after the beginning of mining to ensure radiation safety of the environment and workers in this mine (Banzi *et al.,* 2015b). Thus, the developed system is helpful to TAEC to obtain the radiation data at Mkuju river remotely and in real-time.

3.3 Data Collection

The gathered information through a qualitative approach was very useful in developing an effective and affordable system. Unstructured interviews, participatory observation, and focused group discussions with experts at TAEC were used as a means of gathering data. Likewise for understanding some basic requirements of electronic components the secondary data collection from literature review of various and manufacturers' datasheets was mandatory.

The use of unstructured interviews with different experts on radiation detectors, electronics, and radiation monitoring helped to get information for the developed system. Experienced experts were asked questions regarding the developed prototypes to obtain their comments and opinions. Not knowing the exact reasons why the developed prototype has weaknesses such as short circuits, noise in the output signal from the GM tube. It was through the challenges of the developed prototype the unstructured questions were asked to the interviewees.

On the other hand, the participatory observation was indeed useful in the process of developing the system. Watching and noticing the behaviors of the developed prototype with nuclear instrumentation maintenance (NIM) experts at TAEC. By using the devices like oscilloscope, multimeter at the NIM laboratory the behaviors of the developed prototype such as the output signal were observed. The mounting and dismounting of the electronics components on the PCB board and other behaviors. Generally noticing the errors and shortcomings of the developed prototype was a great way of improving the developed system.

Lastly, the focused group discussion approach was very suitable, the discussion was seldom done with experienced and experts in electronics, software developers, and radiation detectors. Detailed understanding of the developed prototype such as limitations and errors and the way forward to design and improve the next prototype. The discussion helped to obtain the insights, views, or thoughts on the developed prototypes. Topics like what makes the developed prototype fail, what should be added or removed from the prototype, and many other questions, ideas, theories were discussed which were used in the development of the working system.

3.4 System Requirements

The system requirement had functional and non-functional requirements without excluding both software and hardware tools. The functions, what the system should do, all key criteria that make the system give the intended output are mentioned as functional requirements. The non-functional requirements like system availability since the system is a real-time system, security,

scalability, usability, and acceptance of the system are considered. With the facilitation of relevant selection of software to be used and hardware equipment for the developed system, the project goal was achieved.

3.4.1 Functional System Requirements

(i)   The high power supply to the GM tube of 500 DC volts.

(ii)   The signal shaping and counting system.

(iii)   The radiation data sent to the cloud storage (Cayenne).

(iv)   The developed mobile application should fetch the data from the cloud storage.

(v)   Users should be able to log in on the cloud storage and mobile application.

(vi)   Users should be able to view data on the mobile application and cloud storage.

(vii)   Notification alarm and message when there is excess radiation should be sent to the developed mobile application.

(viii) The system administrator should be able to add radiation detectors on the cloud storage and set trigger level alarms for the end-users.

3.4.2 Non-Functional System Requirements

(i)   The system availability is essential, radiation data is updated after every 15 seconds.

(ii)   The system should be scalable.

(iii)   The acceptance and usability of the system are essential.

(iv)   The system should be secured allowing only authenticated users.

3.4.3 Hardware Requirements

The developed system required the development of the radiation detection system where the hardware's required were Geiger Muller tube LND 7224, high voltage supply circuit comprising of 9 volts battery, oscillator, the high-frequency transformer (step-up transformer), capacitors, diodes, resistors, jumper wires, breadboard and the ESP32 microcontroller board for programming the radiation detection system.

The wireless communication between the radiation detecting system and the data processing was achieved by using the ESP32 microcontroller board through inbuilt Wi-Fi. Finally, for the data analysis and visualization, cloud storage (Cayenne) and a smartphone were used.

3.4.4 Software Requirements

The software requirements for the developed system were Multisim and Proteus software for the designing and simulation of the designed radiation detection system, the Arduino Integrated Development Environment (IDE) for ESP32 microcontroller board programming, the MQTT broker (Cayenne) which is for data processing, and android studio IDE for developing the mobile application.

3.5 System Design
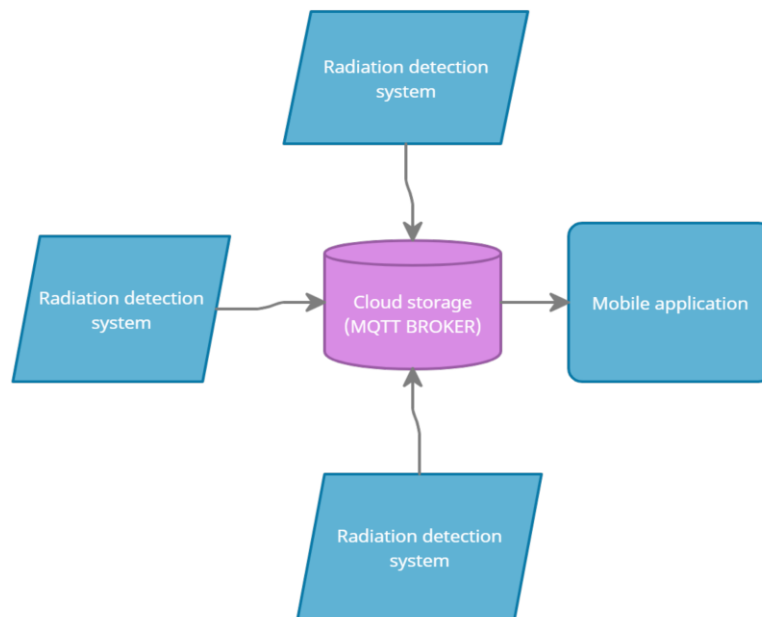
Figure 3: The design of the developed system

The design of the developed system had three parts namely radiation detection system, data processing, and data visualization as shown in Fig. 3. The first part was the radiation detection system for detecting ionizing radiation by using GM tube 7224. The electronic components were used for developing a high voltage power supply to the GM tube and signal filtering. The ESP32 microcontroller board by using C programming language was used to program the radiation detection system and through its built-in Wi-Fi, the detected data were sent to the data processing.

The second part of the system as shown in Fig. 4 was responsible for the data processing unit, where the signal output from the GM tube was counted. The radiation data in terms of CPM and dose rate were sent to the MQTT broker. The MQTT broker collected the data from different radiation detection systems before sending the data to the mobile application for remote visualization. Last part, responsible for the data visualization which was done through the cloud storage dashboard, and the mobile application which gave notifications to end users in case the radiation level is beyond normal.
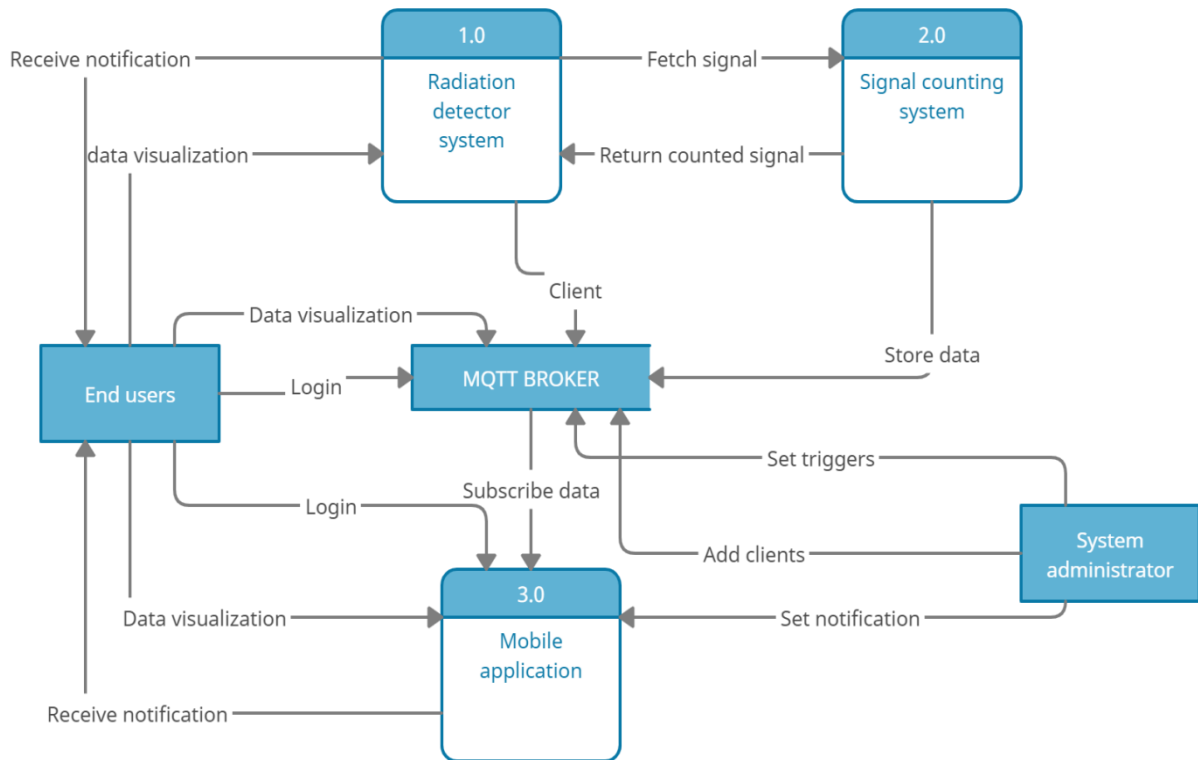
Figure 4: The Unified Modeling Language context diagram for the system design

Through MQTT protocol, different clients or internet of Things (IoT) devices can send or request information from the MQTT broker which was the cloud storage (Cayenne). This lightweight protocol allowed various radiation detection systems through ESP32 microcontroller board to send or request data to cloud storage. The in-built Wi-Fi design of the ESP32 microcontroller board makes it more appropriate for this project and other IoT solutions.

3.5.1 Radiation Detection System

The radiation detection system was developed by using the Gas detector known as Geiger-Muller tube (GM tube) which costs less compared to other radiation detectors such as semiconductors, scintillation (Khan, 2017). The GM tube is the gas detector used in the detection of ionizing

radiation such as gamma rays, beta, and alpha particles thus it's widely used in radiation detection. The developed radiation detection system required a high power supply (450V to 700V) to the GM tube 7224, pulse filtering after the detection of radiation, and ESP32 microcontroller board as shown in Fig. 5.
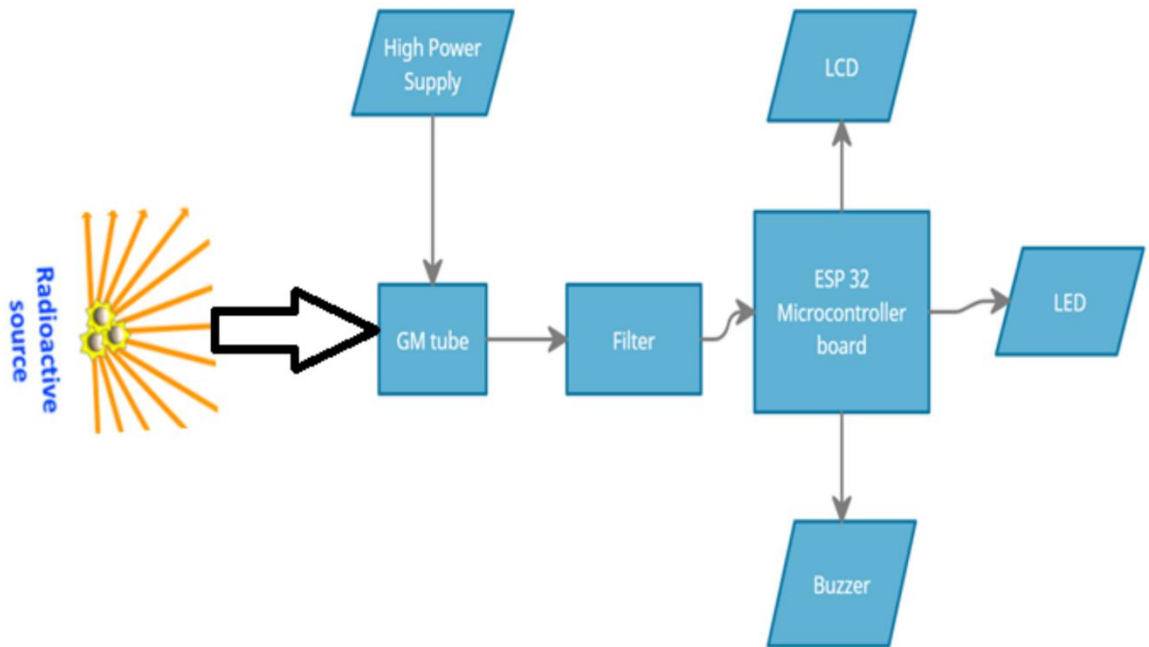
Figure 5: Radiation detection system design

The GM tube is the common radiation detector introduced in 1928 named after the inverter Hans Geiger and Walther Muller. The LND 7224 Geiger-Muller tube has two electrodes namely Anode and Cathode and its tube is filled with a gas such as Neon (Knoll & Kraner, 1981). The anode is at the center of the tube represented by a wire and on the other hand, the cathode forms the side area. The anode wire normally connects to a high positive voltage supply, for LND 7244 the recommendable voltage is 500 volts and the cathode was grounded. When ionization takes place in the tube and it detects ionizing radiation like alpha, beta, and gamma particle being incident the charge (signal output) produced is collected and measured.
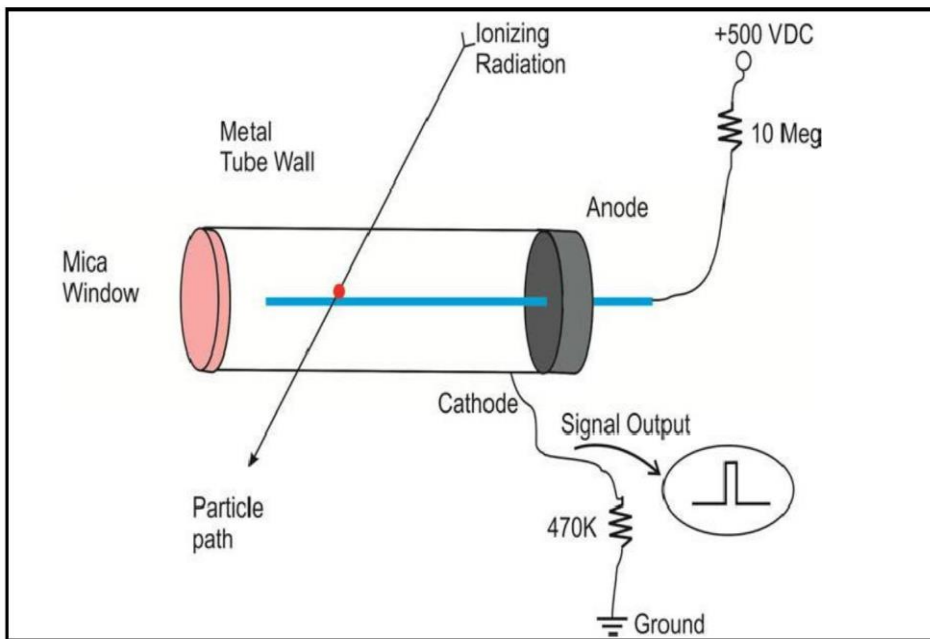
Figure 6: Geiger Muller tube diagram (Images SI, n.d.)

The high voltage supply of 450 to 700 volts was the operating voltage for the LND 7224 to be able to detect the ionizing radiation that is Gamma rays, Alpha and Beta particles. Therefore, by using the input voltage of 9 volts from the battery which through the oscillator, the high-frequency transformer (step-up transformer) and voltage multipliers, and other electronic devices such as resistors, capacitors, diodes, transistors it was easy to obtain the high voltage supply to the LND 7224 GM tube.

3.5.2   Data Processing

The radiation data detected by the radiation detection system through ESP32 microcontroller board was processed. The radiation data was calculated in dose rate microsievert per hour (μSv/h) and counts per minute (CPM) and sent to the cloud storage. The ESP32 microcontroller board is the successor of ESP8266 with a variety of new features; its low-cost and in-built wireless design such as Wi-Fi, Bluetooth its image is shown in Fig. 7. In this subsystem, the collected data was directed to the cloud storage which uses MQTT protocol, and then was shared to the mobile application for remote data visualization.

Figure 7: Espressif Systems 32 microcontroller board (Randomnerdtutorials, 2013)

The Message Queuing Telemetry Transport (MQTT) protocol is one of the network protocols which runs over TCP/IP allowing devices on the internet to send (publish) and receive (subscribe) data. It supports machine-to-machine (M2M) communication via the internet, allowing several devices to send and receive data through the MQTT broker.

The MQTT broker is the software the gathers data from all devices publish to it and distributes data to all devices which subscribe to it (Yassein *et al.,* 2018). It can manage simultaneously thousands of devices connected to it (MQTT clients), filter data, give authentication and authorization to the devices connected to it. Since the protocol is light weighted its best applied on IoT and is very well suited for remote monitoring.

The MQTT broker used was Cayenne which is one of the cloud storage platforms used for IoT. Cayenne has a friendly and attractive user interface and it uses the MQTT protocol to enable other IoT devices to share and store data to it. Users use it freely for simple services that it offers like storage of data, while the data is secured and only authenticated users can log in into the cloud storage. It offers easy triggering of messages, emails and it can schedule triggers and events that is why it was a suitable choice for this developed system.
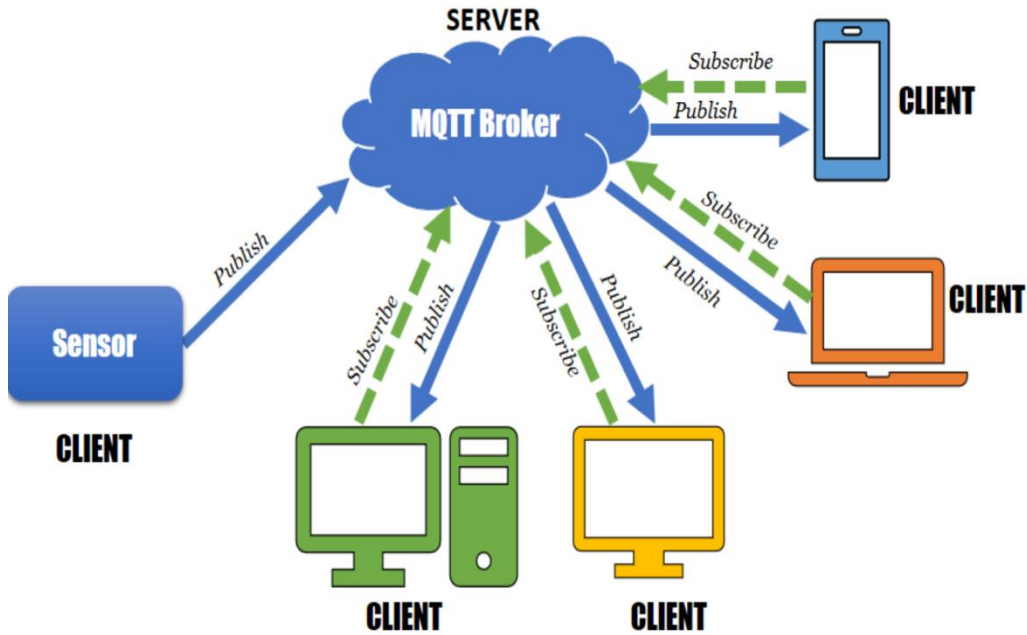
Figure 8: Message Queuing Telemetry Transport Protocol

3.5.3　Data Visualization

The radiation data from the radiation detection system was visualized on LCD in count per minute and dose rate which was microsievert per hour. Furthermore, end users can remotely visualize radiation data on a cloud storage dashboard. Likewise, a user-friendly mobile application was be developed which pulled the data from the cloud database and allowed the end-users to visualize the data in their smartphone for real-time monitoring. In addition in case of excess radiation level, the end-users received a notification through an alarm and message on the developed mobile application.

3.6　System Implementation

The implementation of the developed system was done from one subsystem to another. The first part to be implemented was the radiation detection system, followed by data collection and processing through the ESP32 microcontroller board and MQTT broker. Then finally the data visualization of radiation data on LCD, cloud storage dashboard, and mobile application.

3.6.1　Radiation Detection System

The first part to be implemented was a radiation detection system that required a high positive voltage supply (450 to 700 Volts) to the LND 7224 GM tube. By using the input voltage of 9

volts from the battery through the oscillator, high-frequency transformer (step-up transformer) and voltage multipliers and other electronic devices such as resistors, capacitors, diodes, transistors were used to obtain the high voltage supply to the LND 7224 GM tube of 500 Direct Current (DC) volts.

Figure 9: Geiger Muller tube LND 7224 (Lndinc.com:, n.d.)

The schematic diagram in Fig. 10 was drawn by using Proteus software were used as a guide in Printed Circuit Board (PCB) printing of the power supply circuit. The 9 DC voltages from the battery were sent to the regulator which gave out 5 DC volts to the oscillator transistor where the pulses were obtained as output. The output from the transistor toggles between 'low' and 'high' continuously, generating pulses. The switching functionality on the generated pulses was fed into a step-up transformer (receive 5 DC voltage to produce 220 Alternating Current (AC) voltage). Thus, around 3.8 DC voltages were entered into the secondary winding of the transformer and the output was 190 AC voltages which through the voltage multipliers the required DC voltage was obtained.
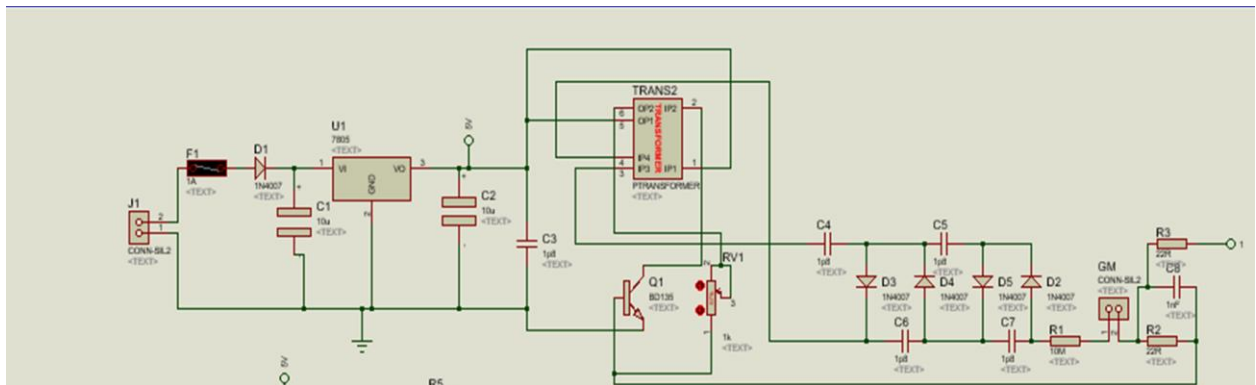
Figure 10: High power supply schematic diagram

In short, the main components in supplying the high power voltage to the GM tube are explained as follows.

(i)   Regulator

The input voltage was 9 DC volts while the transformer is limited to receiving 5 volts that is why the LM 7805 regulator of 5 DC volt was used to input 5 DC volts into the transformer.
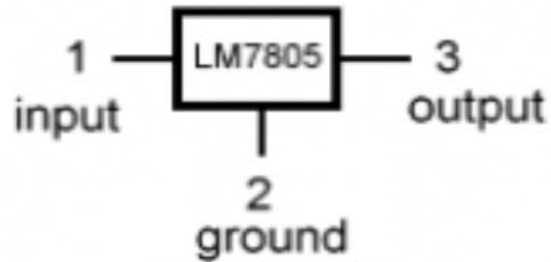
Figure 11: The 7805 regulator symbol

(ii)   Resistor

It is an electrical device that creates resistance to the current flow measured in an ohms unit. For stance, the GM tube requires high voltage and low current which is normally in microampere to operate that is why in the design of GM tube the resistor of high resistance such as 10 M Ω, 22 M Ω, 4.7 M Ω, and others are used to the limit current entering the Anode electrode.
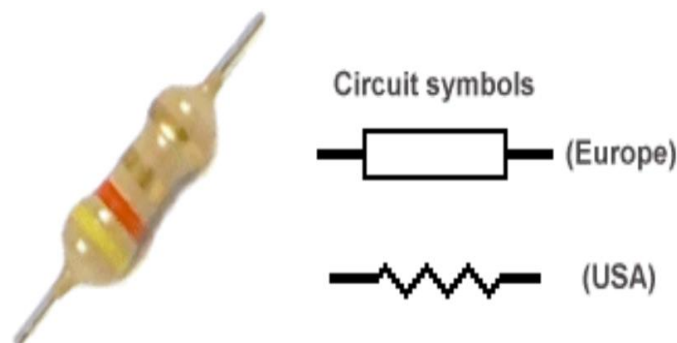
Figure 12: Resistors on the circuit developed

(iii)   Capacitor

It is an electrical component that can store electrical charge, the capacitance which the capacitor produces is measured in Farad. For example, in the voltage multiplier, the ceramic capacitor is used for smoothing the DC voltage degenerated removing DC fluctuation and make it steadier.
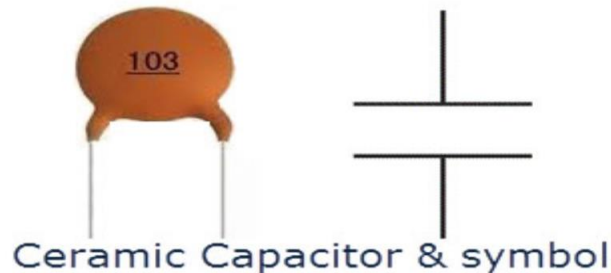
Figure 13: Capacitors on the circuit developed

(iv)   Diode

This is the electrical device having two terminals anode and cathode which allows current to flow in one direction only. For stance in the voltage multiplier, the PN junction (1N4007) diode was used as rectifiers changing the AC volts to DC voltage.
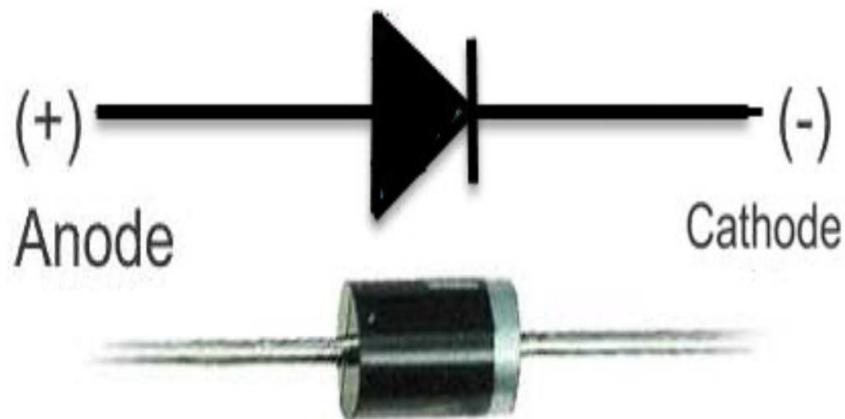
Figure 14: Diodes on the circuit developed

(v)   Transformer

A high voltage transformer namely ferrite core transformer which was a step-down transformer used in mobile phone charger (220 AC to 5 DC volts) was used in reverse whereby in the project it's used as a step-up transformer (5 DC to 220 AC volts). It's the winding of the coil in the

primary and secondary sides of the transformer which causes the transformer to be step up or step down.

Then the last stage was the voltage multipliers where diodes IN14007 and ceramic capacitors 103 were used to convert the AC voltage into DC voltage. The DC voltage was multiplied as it passes through the voltage multiplier until a suitable DC voltage for GM operation from the input of 9V DC was obtained.
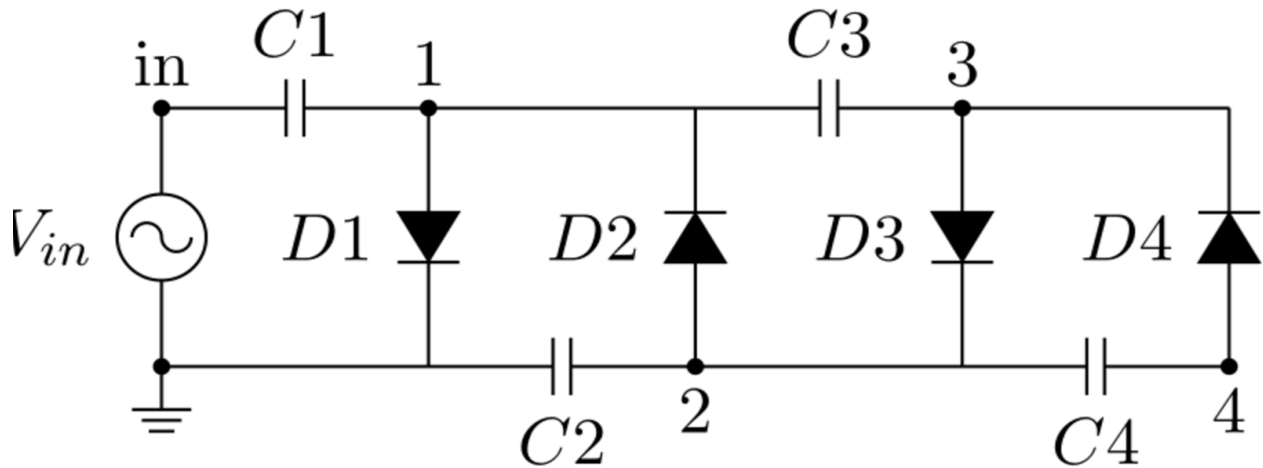
Figure 15: Voltage Multiplier

(vi)   Rectifiers

 It's the process of removing AC voltage negative and positive half cycles by using the PN junction diodes which changes the alternate form of current to direct current form which is DC with only a positive half cycle.

Figure 16: Voltage rectification

(vii) Filters

The output DC voltage from the rectifier was not continuous or pure DC voltage it had fluctuated (Fig. 17). Thus, ceramic capacitors were used in smoothing or filtering the DC voltage to remove the fluctuation. In the circuit, the capacitors were placed in parallel with the inductors. The motive of using a capacitor in parallel is to allow the AC voltage to ground and not the DC.
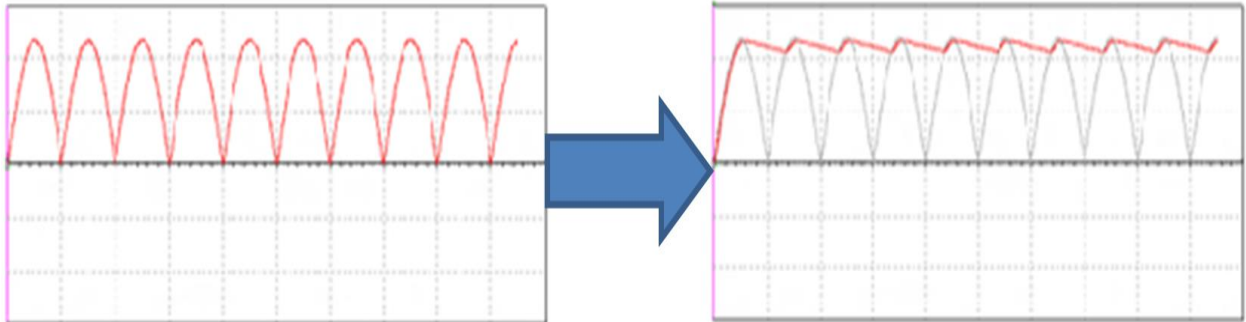
Figure 17: Filtration

Finally, the high power supply was implemented on the breadboard and applied to the GM tube allowing testing and troubleshooting of the system. Figure 18 shows the implemented prototype.
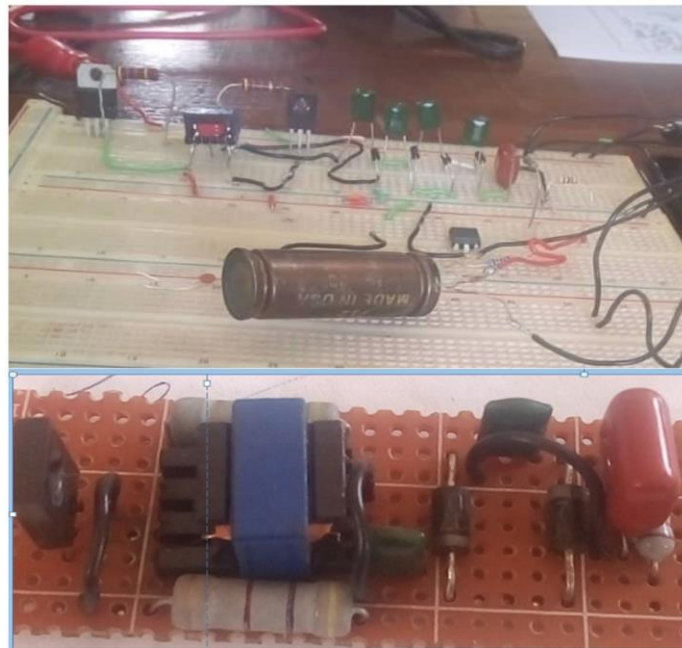
Figure 18: Power supply prototype on breadboard and Printed Circuit Board

3.6.2 Signal Counting System

When a sufficiently high power supply was applied to the GM tube, the signal output pulse was taped at the cathode electrode. The output signal pulse as shown on the oscilloscope in Fig. 19 indicated the presence of radiation detected. The number of pulses detected (counted) by the radiation detection system depends on the radiation available in the area thus, it varies from minute to minute. Once the pulse is counted, the neutralization of the charged ions takes place thus the GM tube becomes ready to count another pulse.
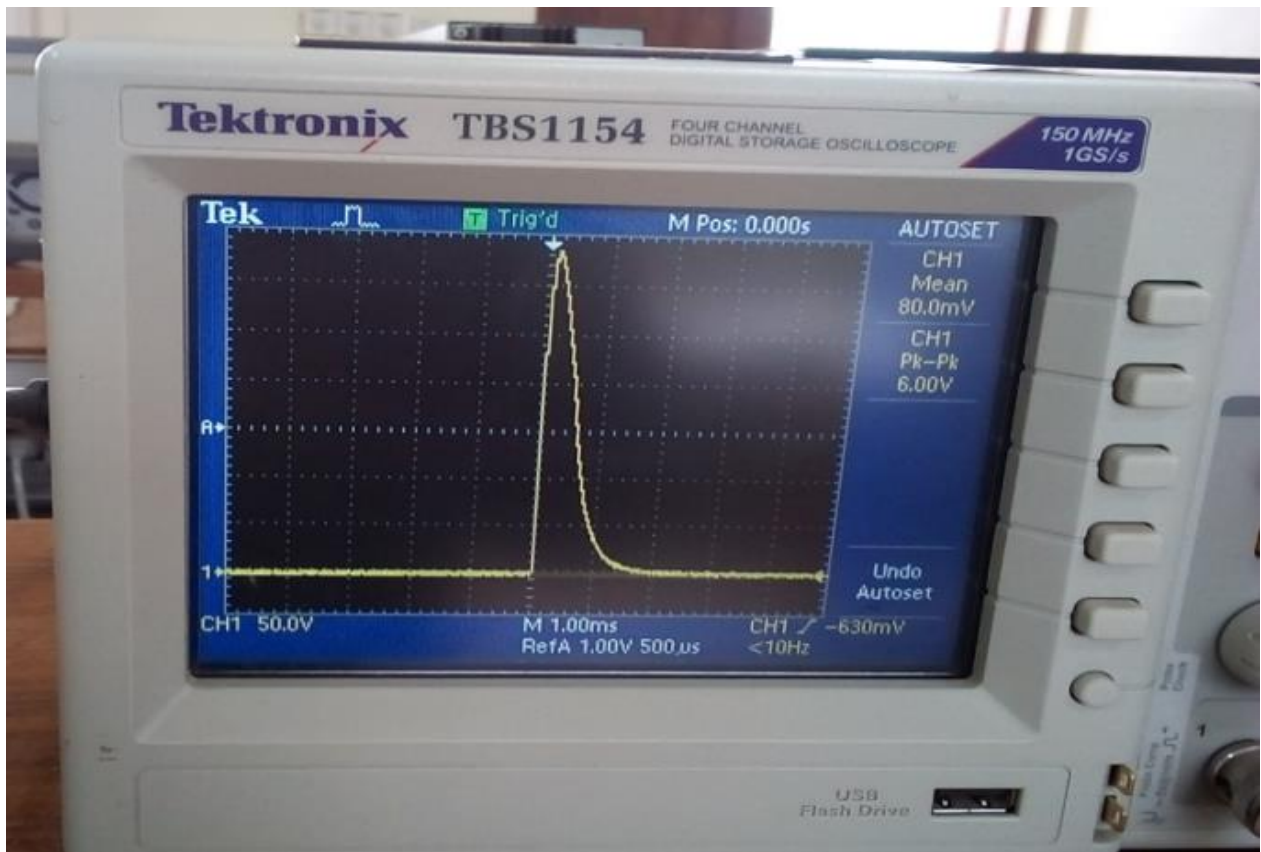
Figure 19: The output signal pulse on an oscilloscope

The produced pulse was shaped through the resistor of 6.8 k ohms and the ceramic capacitor of 47pf and the 2N3904 transistor. Lastly, by using LM 555 the signal was shaped in a way that it could be counted. The output signal was then fed to the ESP32 microcontroller board as an interrupt. The Pin 17 of the ESP32 microcontroller board received the signal and counted it by using the Service Interrupt Routine (SIR). On programming, the code line that indicates the counting of the output signal is likely as shown in Fig. 20 and for more details, it's clearly shown in Appendix B:

```
int signalpin=17;

int counts=0;

  pinMode(signalpin, INPUT);

  attachInterrupt(digitalPinToInterrupt(signalpin), impulse, HIGH );

void impulse()

{

counts++;

}
```

Figure 20: Counting system programming code line

The ESP32 microcontroller board received the signal as high if the ionizing radiation is detected and then the signal becomes low in the absence of detected ionizing radiation. Since the signal was high, an external interrupt pin on ESP32 microcontroller board was set as high interrupt mode. The other electronic components like a buzzer, LCD, LED, SD card were connected to the ESP32 microcontroller board as an output. The Pin 14 was used as the output for LED and pin 27 was used as the output of the buzzer as indicated in Appendix B. Figure 21 shows clearly how the main electronics components on the counting system were connected with the ESP32 microcontroller board.
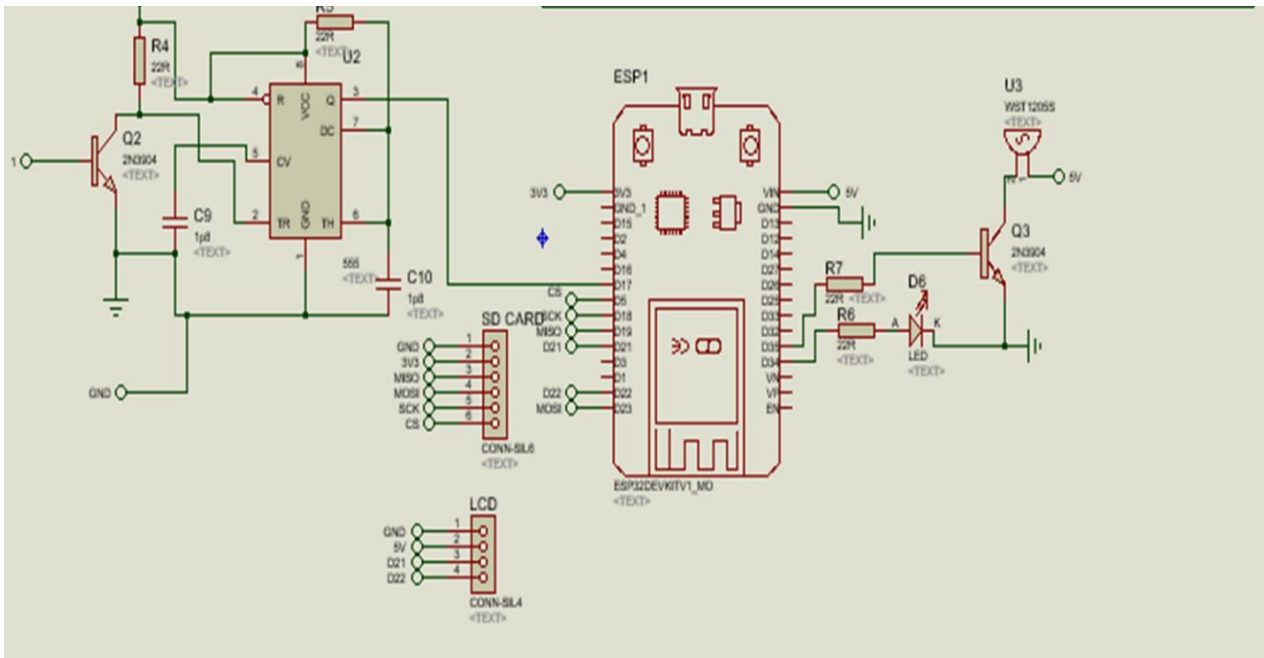
Figure 21: The schematic diagram of the counting system

The radiation detection system using ESP32 microcontroller board though the Arduino IDE software was programmed. When the detection of radiation occurred, the radiation detection system was programmed to measure the radiation level in terms of counts per minute (CPM) and dose rate which was microsieverts per hour (µSv/h). The Schematic diagram in Fig. 21 was then used as a guide to implementing the signal counting system on breadboard and PCB (Fig. 22).
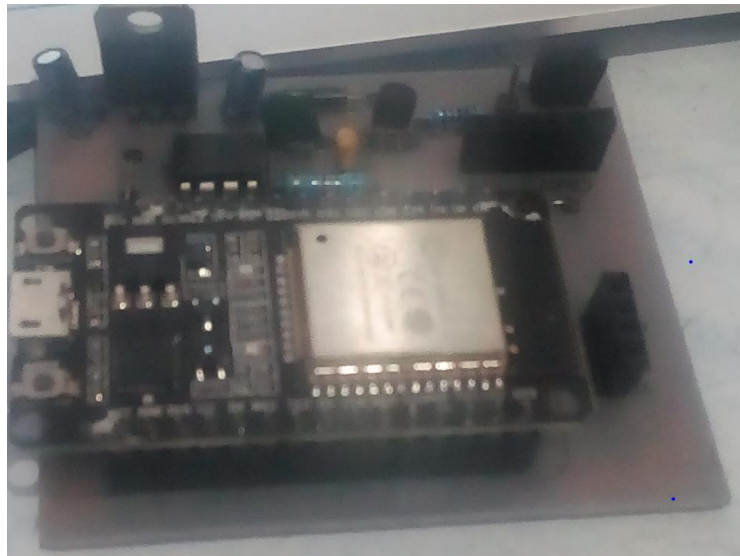
Figure 22: Printed Circuit Board for signal counting

3.6.3 Data Visualization

The measured radiation data detected by the radiation detection system was processed through the ESP32 microcontroller board to be able to display the radiation data on LCD. The LCD was connected to the ESP32 microcontroller board by using the protocol known as Inter-Integrated Circuit protocol (I2C). This protocol normally uses four wires to connect between the LCD and microcontroller board namely: Send and Receive data (SDA), Clock Signal (SCL), ground (GND), and positive power supply (VCC).

Table 3: Connecting Inter-Integrated Circuit protocol device to Espressif Systems 32

SN	12C Device	ESP32
1	SDA	SDA (default is GPIO21)
2	SCL	SCL(default is GPIO22)
3	GND	GND
4	VCC	Usually 3.3V/5V

The data on LCD was visualized even in the absence of the internet in terms of counts, counts per minute (CPM), and dose rate which was microsieverts per hour (μSv/h) as shown in Fig. 23.

Figure 23: Radiation data visualization on Liquid Crystal Display

As soon as the radiation dose rate exceeds the radiation detection system through ESP32 microcontroller board was programmed to allow buzzer to give out sound and red LED to start blinking on the radiation detection system.

Moreover, through the MQTT protocol via the internet through the inbuilt Wi-Fi on the ESP32 microcontroller board the radiation detection system was programmed to send data to the MQTT broker namely Cayenne which is the cloud storage. For example, the following cone line as shown in Appendix B were used to connect the radiation detection system data and the cloud storage.

```
#include <CayenneMQTTESP32.h>

Cayenne.begin(username, password, clientID, ssid, wifiPassword);

Cayenne.virtualWrite(1, CPM, "analog_sensor", "cpm");

Cayenne.virtualWrite(2, outputSieverts(CPM), "analog_sensor", "uSv/hr");
```

Figure 24: Connecting the radiation data to Cayenne cloud storage through programming

The MQTT broker collected and analyzed the radiation data from radiation detection systems. Thus, allowing clients to publish and subscribe data as shown in Fig. 25, Detector 1 publishes the data while the Mobile app subscribes to the data. Likewise, end-users through their computers via the internet to were able to view the radiation data remotely. On top of that, the developed mobile application was able to pull the radiation data from the MQTT broker and allow the end-users to view the radiation data on their mobile application installed on their smartphones as seen in Appendix A.
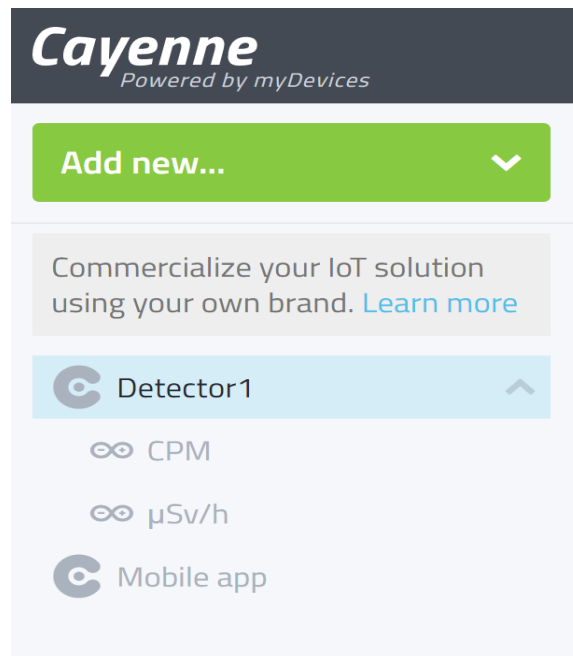
Figure 25: Clients at the Message Queuing Telemetry Transport broker

3.6.4 Notification System

Through the Paho android service as seen in Appendix A, the developed mobile application was able to fetch data from the cloud storage. Allowing the end-users to visualize the radiation data on the developed mobile application. The mobile application was designed to give message notification as shown in Fig. 26 and alarm notification in case there is excess radiation level. For ionizing radiation, the public exposure is 2 millisieverts (mSv) per year, for employees in radiation sources its 20 millisieverts (mSv) per year (ICRP, 2007). Therefore, for precaution safety measures when the radiation exceeds a certain level notification is essential.

The notification of radiation level was programmed by considering the limit of radiation exposure for employees on radiation sources per year according to International Atomic Energy Agency (IAEA) safety measures. The stage one notifications were set just at the low radiation level for example Fig. 26 shows the message notification from detector 1 to the end-users when the Counts per Minutes (CPM) is 20. Similarly, the radiation data were programmed to be measured by using the smallest microsieverts (µSv) per hour unit which is more practical compared to millisieverts (mSv) and Sieverts (Sv) which are large units.

Channel 1 has reached the threshhold value of 20. This is connected to Detector1.

Now • via VodaCom

Figure 26: Message notification

3.7   System Testing

The developed system was tested at TAEC laboratory where there are various radiation sources stored to determine if the system is working as required by the end-users. The functional and non-functional requirements of the system were tested.

3.7.1   Unit Testing

Unit testing was done by starting with the radiation detection system to determine if it's able to detect the ionizing radiation and to determine the range of detection for a very low ionizing radiation level and a high ionizing radiation level. By using one of the readymade radiation detectors known as the RIIDEYe X survey meter the radiation dose rate reading was approximately equal to the developed radiation detection system.

Then there was a testing of data transmission from the radiation detection system to the data processing unit and the radiation detection unit to determine if there is any fault. The testing of the data processing unit was done to determine if the data from the radiation detection system can be sent to the cloud. Finally, the testing of the developed mobile application was done to determine if it's working properly.

3.7.2   Integration Testing

The subsystems of the developed system were integrated and tested to determine if these subsystems can communicate and interact as required. The first stage was to test the integration of the radiation detection system and MQTT broker to analyze if the data detected by the radiation detector is the same as the data received by the MQTT broker (Cayenne). Then the integration of data processing and data visualization subsystem was tested to determine if the data in data being sent by a radiation detector matches the data visualized in the cloud dashboard

and mobile application. Lastly, the whole integrated system was tested to determine if the system operated according to the objective of the project.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1   Overview

The outcomes of the developed system are detailed explained in this chapter in correspondence to the project objectives. The objective was to develop an effective and affordable radiation detection system for remote monitoring of radiation sources such as uranium mining. The radiation detection system through the ESp32 microcontroller board was able to measure the presence of radiation. The radiation detection system, data processing, and data visualization subsystem were connected successfully as shown in Fig. 27.

The ESp32 microcontroller board facilitated the data visualization on LCD, cloud storage dashboard, and SD card. Lastly, the data was pulled from the MQTT broker to the developed mobile application allowing users to remotely visualization the data on both clouds (Cayenne) dashboard and the mobile application via the internet.

4.2   Radiation Detection System

The radiation detection system was correctly interfaced by providing a high voltage supply to the GM tube LND 7224 around 500 DC Volt, having a signal detection circuit and interfacing it to the ESP32 microcontroller board. The high power voltage of 900 DC volts as shown in Fig. 28 was obtained from the developed power supply circuit and through a 10 M ohm resistor, the 500 DC volts were applied to the GM tube.
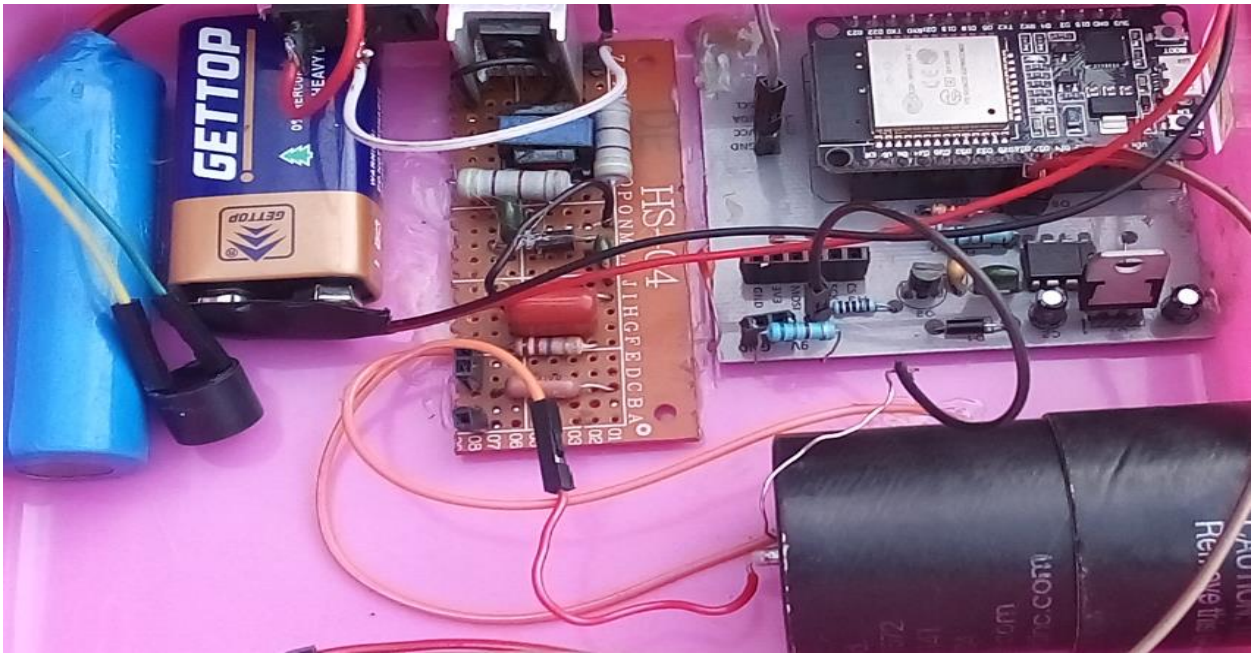
Figure 27: Printed Circuit Board of the radiation detection system
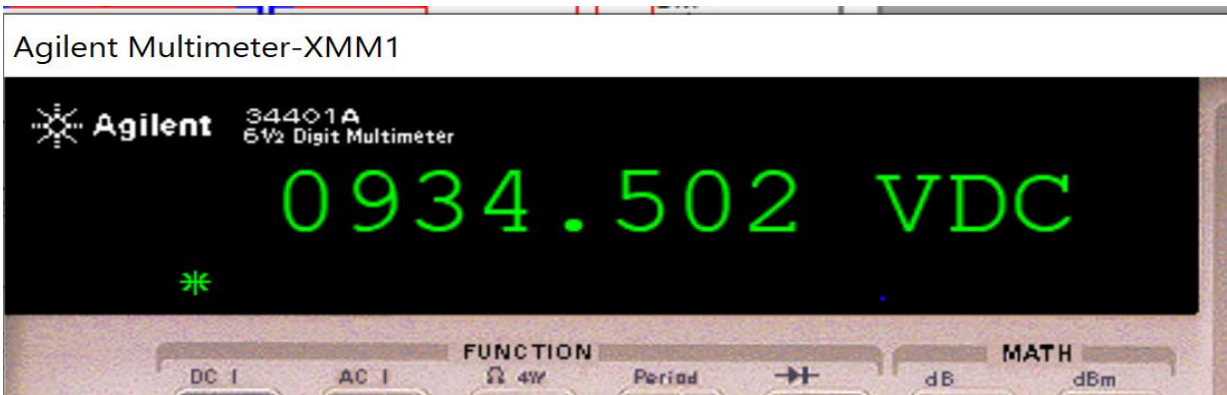
Figure 28: Simulation of the high power supply circuit

The GM tube manufacturer normally recommends the appropriate voltage to be applied to the GM tube. Once the voltage becomes excessively high, the tube experiences continuous discharge and finally, it can be destroyed. When the voltage is very low, it causes the gas atoms in the tube to obtain very low voltage to cause the movement of atoms. Therefore, the electric field in the tube becomes less strong to give out a current pulse (that is produced when the ionizing radiation is detected).
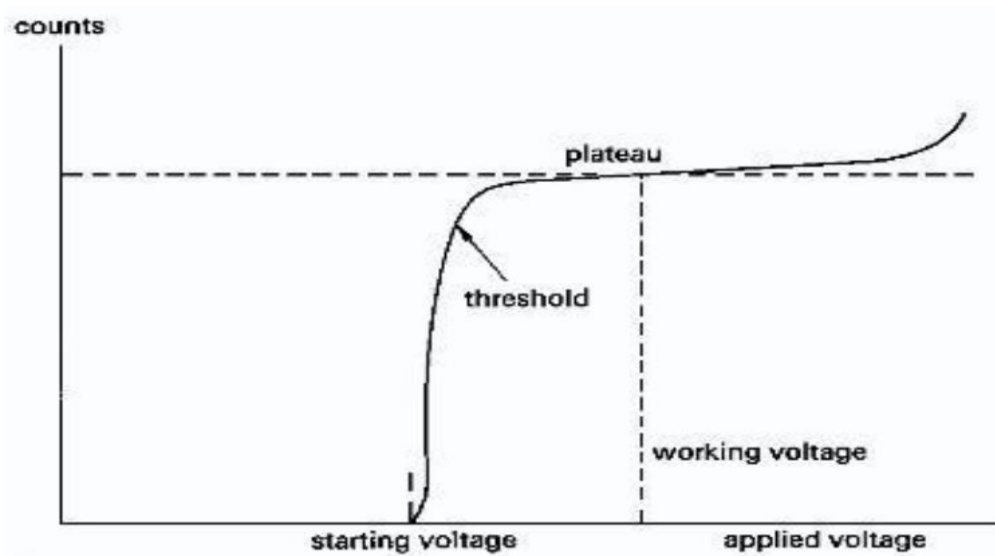
Figure 29: Geiger Muller tube operating voltage

For the GM tube LND 7224, the minimum voltage (starting voltage) for it to operate was 350 volts. The maximum voltage which could be applied to the tube was 700 volts whereby beyond this voltage the GM tube can be damaged since the gas inside the tube experience continuous discharge. Lastly, the appropriate voltage to be applied was 450 to 700 volts and the recommended voltage was 500 volts which is the working voltage (LND). When the appropriate voltage was applied to the GM tube every time it detects ionizing radiation like Gamma rays, Alpha, and Beta particles. It was able to give out a pulse of current in the wires connecting the electrodes.
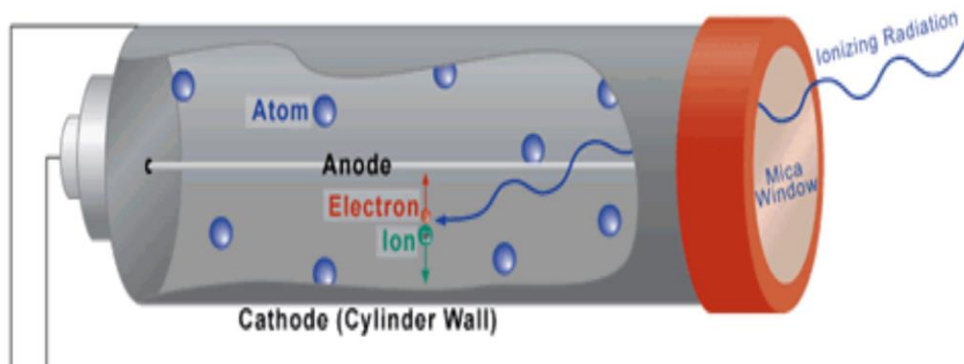
Figure 30: Ionizing radiation detected (NDEE ngineering, n.d.)

The end window of the GM tube is made up with the smallest density whereby normally Mica materials are used since it has a low mass per unit area. As shown in Fig. 30 the end window allows the low energy ionizing radiation to like Alpha and Beta particles to pass easily through

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it. Likewise, the Gamma rays with low energy can be detected by the GM tube but since most of the Gamma rays have high energy the efficiency of the GM tube to detect it is low.

When the GM tube receives appropriate voltage and it detects the ionizing radiation. The gas atom orbital electron becomes stripped away from its parental atom or molecule. This generates ion pairs that are the free electrons and atoms or molecules which are positively charged. The ion pairs through the appropriate high voltage across the electrodes accelerate the positive ions towards the cathode and the electrons towards the anode and through the use of an electric field the output current pulse is produced as shown in Fig. 31.
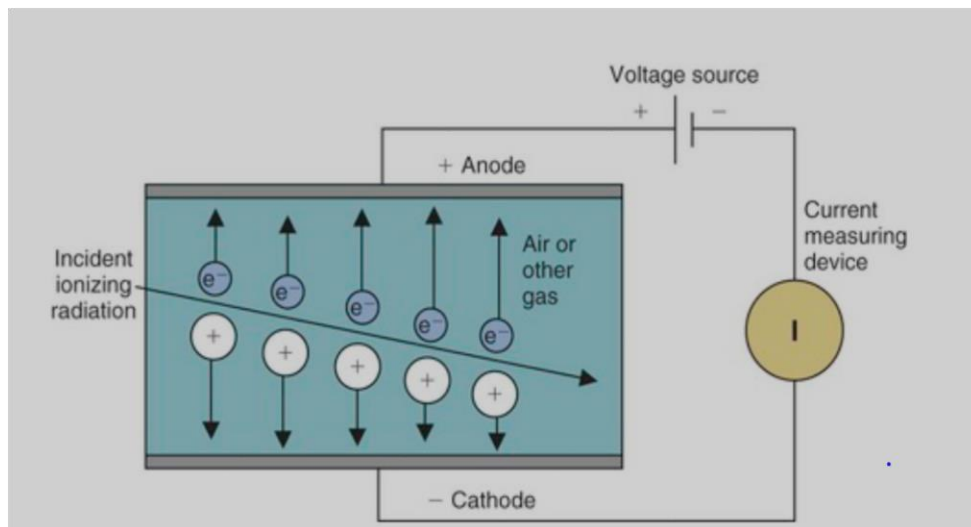
Figure 31: Ionization (Radiologykey.com, n.d.)

The produced pulse was counted, for more accurate counting of each produced pulse as an indicator of radiation presence. The signal output was shaped to remove the unwanted noise from it and programmed by using the ESP32 microcontroller board. The developed system was tested and it was able to detect the presence of radiation by blinking the LED and the buzzer on every time the system detected the ionizing radiation.

First of all the presence of background radiation was sensed by the system. And by using the different types of a radiation sources such as Cobalt-60, Americium-241, Selenium-34 the system was able to detect the presence of Gamma rays, Alpha and Beta particles as required. Figure 32 shows the type of ionizing radiation the system was able to detect their presence.
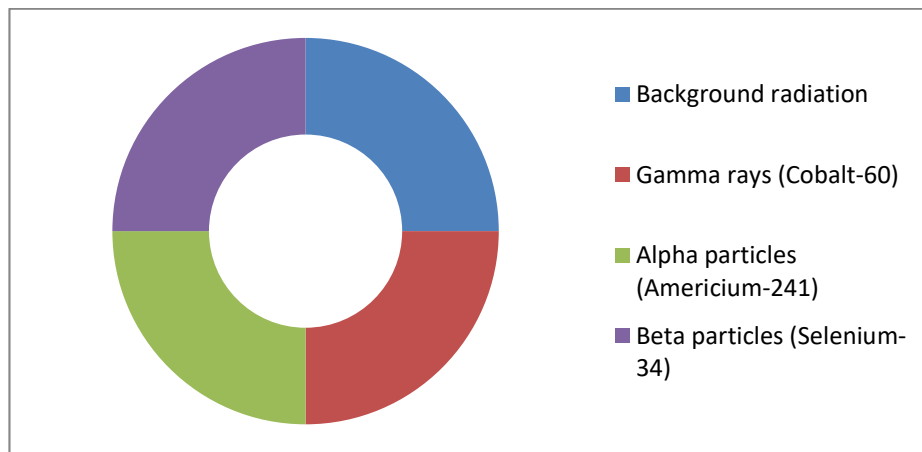
Figure 32: Ionizing radiation detected by the system

The sensitivity of GM tubes to the ionizing sources depends on the type of the GM tube used and the strength of the ionizing radiation source. Because different ionizing radiations sources produce types of ionizing radiation of different energies. Which when detected by a GM tube they produce different amounts of ionization hence different output pulse currents.

Lastly, the developed radiation detection system used few components which were cheap to obtain the project objective of developing an affordable radiation detector as shown in Table 4. The cost of the developed radiation detection system is less than 1 000 000/= Tanzanian shillings in comparison to the existing radiation detectors used by TAEC which can detect Gamma rays, Alpha, and Beta particles. The radiation detectors which have the same functionalities of monitoring radiation remotely are expensive as shown in Table 2, the cost is more than 2000 000/= Tanzanian shillings.

Table 4: The cost of the components used to develop the radiation detection system

Equipmemt	Radiation Detection System Cost		
	Amount	Unit Cost	Total
ESP32	1	25 000	25 000
Microcontroller	1	350 000	350 000
LND 7224	1	10 000	10 000
Step up transformer	4	2000	8000
Diodee	6	500	3000
Ceramic capacitors	4	2000	8000
Transitors	8	500	4000
PCB printing	1	20 000	20 000
LCD	1	20 000	20 000
Micro SD card	1	30 000	30 000
			478 000

The components that were used for developing the system cost around 500 000 Tanzanian shillings, the cost for developing and other costs included the system is less expensive compared to the list of radiation detectors in Table 2.

4.3   Data Processing and Visualization

4.3.1   Message Queuing Telemetry Transport Broker (Cayenne)

The radiation data from the radiation detection system through ESP32 microcontroller board were processed as shown in Appendix B. The counts were converted to CPM and the CPM was processed to dose rate and sent to the LCD, SD card, buzzer, and Light-Emitting Diode (LED). In addition to that, the radiation data through the MQTT protocol were sent to the MQTT broker (IoT cloud storage). The preferred MQTT broker (Cayenne) was used due to its features such as message and email notification to end-users.

On the LCD and SD card, users visualized the data without internet connectivity and user authentication. But user authentification was required for the end-user to be able to visualize the data on the cloud storage dashboard as shown in Fig. 33. Users were able to visualize the data on the dashboard remotely after they have logged in by using the email and their password.

Figure 33: User login on Cayenne

On the Cayenne dashboard, users were able to visualize real-time and previous radiation data as captured in Fig. 34. Live and the previous data like one last month, week, and day were

visualized by the users by clicking the data button on the dashboard. Even specify which data they wish to view from which date to which date.

Timestamp	Device N...▼	Channel ▼ ⬍	Sensor Name ▼	Sensor ID ▼ ⬍	Data Type ▼ ⬍	Unit ⬍	Values ⬍
2021-04-24 10:10:50	ESP32	2	Channel 2	f07bdb10-a4ca-11eb-b767-3f...			0.244
2021-04-24 10:10:49	ESP32	1	Channel 1	d25866d0-a4ca-11eb-8779-7...			30
2021-04-24 10:10:19	ESP32	2	Channel 2	f07bdb10-a4ca-11eb-b767-3f...			0.211
2021-04-24 10:10:19	ESP32	1	Channel 1	d25866d0-a4ca-11eb-8779-7...			26
2021-04-24 10:09:49	ESP32	2	Channel 2	f07bdb10-a4ca-11eb-b767-3f...			0.374
2021-04-24 10:09:49	ESP32	1	Channel 1	d25866d0-a4ca-11eb-8779-7...			46
2021-04-24 10:08:25	ESP32	1	Channel 1	d25866d0-a4ca-11eb-8779-7...			56
2021-04-24 10:08:25	ESP32	2	Channel 2	f07bdb10-a4ca-11eb-b767-3f...			0.455
2021-04-24 10:07:54	ESP32	2	Channel 2	f07bdb10-a4ca-11eb-b767-3f...			0.276
2021-04-24 10:07:48	ESP32	1	Channel 1	d25866d0-a4ca-11eb-8779-7...			34
2021-04-24 10:07:18	ESP32	2	Channel 2	f07bdb10-a4ca-11eb-b767-3f...			0.114
2021-04-24 10:07:17	ESP32	1	Channel 1	d25866d0-a4ca-11eb-8779-7...			14

Figure 34: Radiation data visualization on Cayenne

In addition to that users were able to view the radiation data in the way they wish to visualize them it can be line chart widget, value widget, Gauge widget, and so forth. Figure 35 shows the data on the value widget.
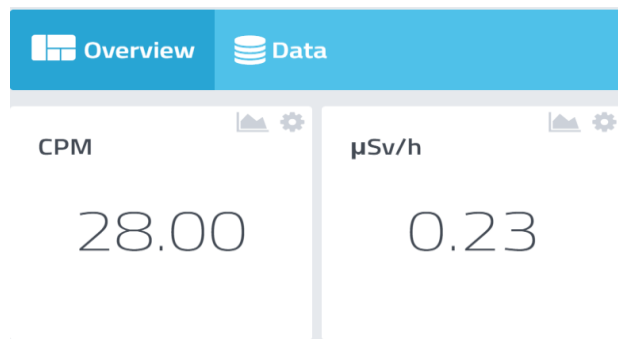
Figure 35: The Value Widget shows Counts per Minutes and dose rate of radiation

4.3.2   Mobile Application

Lastly, a user-friendly mobile application was developed through the Android studio IDE which pulled the data from the cloud database by using the Paho library. Allowing the end-users to visualize radiation data remotely. The mobile application was developed by using android IDE consisting of Java Runtime Environment (JRE), Java Development Kit (JDK), and Android

Studio and had 7 activities build by Widgets like Button, TextView, ImageView, EditText used in the design of the user interface. Last but not least it was simple for end-users to navigate from one activity to another.

The mobile application added significant value to the developed system since most end users preferred mobile applications to web-based systems. End users were able to log in on the mobile application as shown in Fig. 36 to access radiation data remotely anywhere when they want.
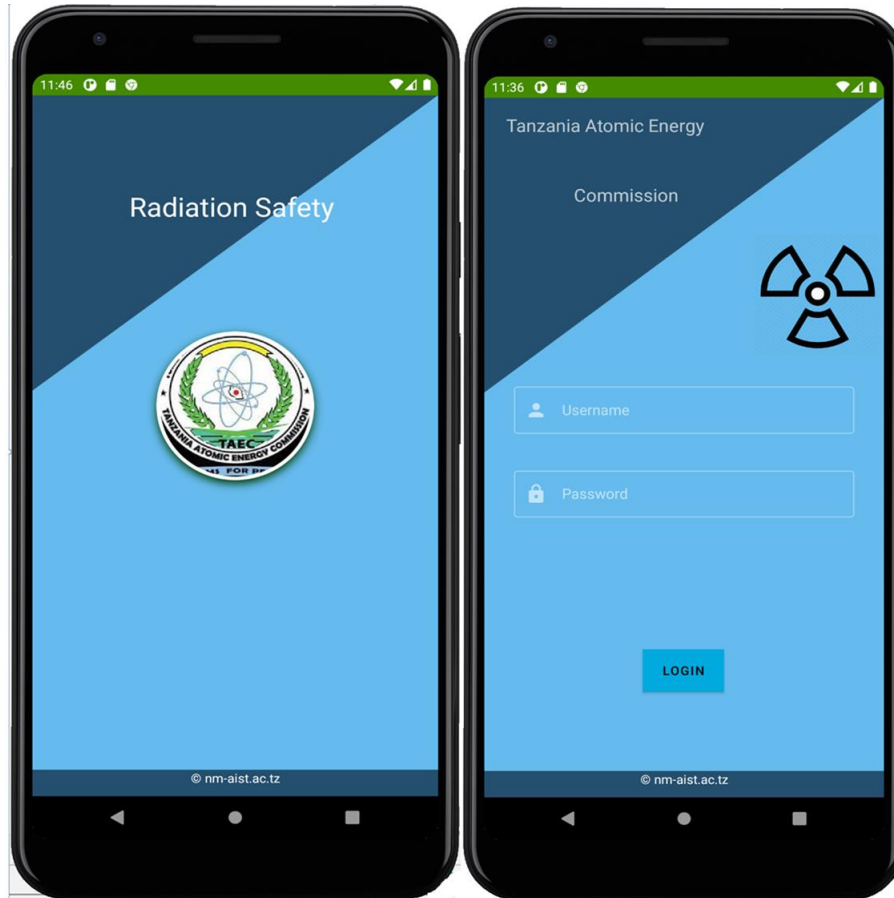
Figure 36: Mobile Application for remote visualization of radiation data

In addition to that in the end-users viewed data in terms of radiation dose rate and form of line chart graph on the developed mobile application as shown in Fig. 37. And in case of excess radiation levels in the dose rate of microsieverts per hour, the end-users received a notification through an alarm and message on their mobile application.
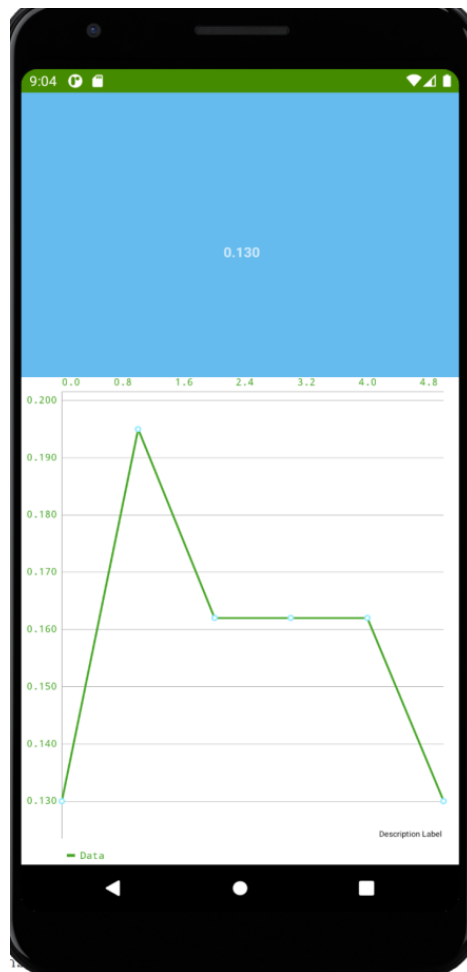
Figure 37: Line chart data visualization on mobile application

4.4   System Validation

The developed system testing assured the end-users of the reliability and effectiveness of the system. The system was tested several times by using the developed prototypes and improved repeatedly to achieve the project goal. Unit and integrated testing were done and by using the existing radiation detector RIIDEYe x survey meter and the radiation source Cesium-137 for calibration of the developed system. The radiation data were recorded after every 15 seconds as shown in Table 5. The Cesium-137 was moved at different distances toward the radiation detectors and the system gave the output data similarly to the RIIDEYe x survey meter. The slight difference in the output of radiation data measurement is because the GM tubes used are different.

Table 5: The comparison of radiation data measurements

Radiation source	RIIDEYe x survey meter radiation data measured in μSv/h	Developed system radiation data measured in μSv/h
Background radiation	0.16	0.19
	0.15	0.16
	0.18	0.21
Cs-137 far from the detectors	0.28	0.31
	0.35	0.42
	0.48	0.45
Cs-137 near to the detectors	2.54	2.69
	2. 86	3.11
	3.13	3.27

The system was developed according to the system requirements, the radiation data were measured in terms of CPM and radiation dose rate in μSv/h. The data were sent to the cloud storage, visualized on LCD, cloud storage dashboard, and mobile application. To test the non-functional requirements like usability, acceptance of the developed system the end-users gave the feedback as follows.

The developed system was given to NIM staff at TAEC for testing purposes and it was presented to the management of TAEC. The system testing influenced many TAEC staff into adaption of the system with further improvement as shown in Table 6. The developed radiation system facilitated the real-time and remote monitoring of radiation which was the added advantage of the system compared to the existing systems at TAEC. Receiving the notification in terms of message and alarm on the developed mobile application when there was excess radiation motivated the end users to accept the system.

Table 6: User system acceptance testing

Items	Strong agree	Agree	Disagree
The developed radiation system is user friendly	68	28	4
The output of the measured radiation data is reliable	70	28	2
Locally made radiation detectors can be used in monitoring radiation levels	56	41	3
The scarcity of radiation detectors can be solved by developing locally made radiation detectors	40	52	8
The remote and real-time radiation monitoring saves time and travel expenses	45	50	5
The developed radiation detection system will be of benefit to TAEC	50	48	2
The developed mobile application is user friendly	58	40	2
The maintenance of the developed radiation detection system is simple.	68	31	1
The developed radiation system is effective and affordable	45	52	3
The notification system is reliable and useful	74	24	2

With real-time and remote monitoring of radiation sources, the frequency visitation on radiation sources for the aim of measuring the radiation level can be minimized. The developed system is affordable and it functions properly thus the regulatory bodies like TAEC are willing to use the system to improve radiation safety.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1   Conclusion

Developing radiation detection system through wireless technology and Internet of Things for remote monitoring of radiation was the objective of this project. The project objective was achieved, the system for real-time and remote monitoring of radiation data was successfully developed. From the evaluation of the existing radiation detection system in Tanzania, there was a research gap on remote visualization of radiation data. As well as the high cost of radiation detectors due to shipping costs from developed countries.

Thus the project came out with the development of a locally made radiation detection system which through MQTT protocol allowed end-users to view radiation data remotely on a mobile application and cloud storage dashboard. The GM tube LND 7224 was used in the radiation detection system to detect ionizing radiation that was Gamma rays, Alpha and Beta particles which were likes to be produced during uranium decay.

The project contributes a wide range of benefits to the Regulatory bodies in Tanzania responsible for radiation safety that is TAEC. It minimizes the frequency of visitation to the radiation sources for monitoring radiation since remote monitoring is possible. This affordable locally made radiation detector can be used in several other activities of measuring ionizing radiation that is Gamma rays, Alpha and Beta particles. Without forgetting the added functionality of using a mobile application in remote monitoring and being able to view the previous radiation data stored in the SD card.

The ESP32 microcontroller board provides more additional functions of the radiation detection system, first of all, the radiation data in count per minute (CPM) and dose rate of microsieverts per hour (µSv/h) are displayed on the LCD. The LED gives a notification of the presence of radiation by blinking above the background radiation (0.16 µSv/h at TAEC). Both LED and buzzer are on at 3.00 µSv/h to give notification to the end-users. Lastly, at 10.00 µSv/h, the alarm which indicates a dangerous radiation level is sent to end-users through a mobile application.

Through the inbuilt Wi-Fi on ESP32 microcontroller and MQTT protocol. End users were able to remote visualize the radiation level in CPM and dose rate measured in µSv/h on both cloud storage dashboard and mobile application. Upon detection of the increase in the radiation data,

the notification alarm and message on the mobile application system reached the end-users. If this system will be implemented, it will make easy real-time and remote monitoring of radiation levels in various radiation sources hence facilitate radiation safety.

5.2   Recommendations

In modern society where the application of radiation is high, the strategic measure of creating awareness on the impact of excessive exposure of radiation and radiation safety is required. The low-cost radiation detectors locally made in Tanzania have to be increased to meet the demand for radiation detectors. This project recommends scholars in Tanzania to encourage the young generation to be innovative and learn to develop different instrumentation for radiation safety and other sectors in the country.

With the increase of technology such as the IoT, machine learning, artificial intelligence, embedded systems, mobile application, and other technologies they can be applied for strengthening radiation safety. This will help to increase the number of radiation and nuclear instrumentation and lower the price of importing devices from developing countries.

In addition to that based upon the project time limitation, the developed radiation detection system can only be used to detect ionizing radiation like Gamma rays, Alpha, and Beta particles but Neutron particles cannot be detected by GM tube. Thus, more radiation detectors that use other detectors like semiconductor detectors, scintillation detectors can be developed depending on their application. Lastly, this radiation detection system can be given a case for its safety and it can be reduced to more small size and very portable if surface mounting for the radiation detection system circuit can be done.

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APPENDICES

Appendix A: Mobile Application Programming

Mobile Interfaces

```xml
<?xml version="1.0" encoding="utf-8"?>
<androidx.constraintlayout.widget.ConstraintLayout
xmlns:android="http://schemas.android.com/apk/res/android"
    xmlns:app="http://schemas.android.com/apk/res-auto"
    xmlns:tools="http://schemas.android.com/tools"
    android:layout_width="match_parent"
    android:layout_height="match_parent"
    android:layout_gravity="center"
    android:background="#6be"
    tools:context=".DashboardActivity">
    <com.google.android.material.appbar.AppBarLayout
        android:id="@+id/appBarLayout"
        android:layout_width="match_parent"
        android:layout_height="wrap_content"
        app:layout_constraintEnd_toEndOf="parent"
        app:layout_constraintStart_toStartOf="parent"
        app:layout_constraintTop_toTopOf="parent" />
    <androidx.appcompat.widget.Toolbar
        android:id="@+id/toolbar_action_bar"
        android:layout_width="match_parent"
        android:layout_height="?attr/actionBarSize"
        android:background="@color/Primary"
        app:layout_constraintEnd_toEndOf="parent"
        app:layout_constraintStart_toStartOf="parent"
        app:layout_constraintTop_toTopOf="parent"
        app:titleTextColor="@color/white" />

    <View
        android:id="@+id/view3"
        android:layout_width="match_parent"
```

```
        android:layout_height="2dp"

        android:background="@drawable/darkbluecolor"

        app:layout_constraintBottom_toTopOf="@+id/textDetector3"

        app:layout_constraintEnd_toEndOf="parent"

        app:layout_constraintHorizontal_bias="0.0"

        app:layout_constraintStart_toStartOf="parent"

        app:layout_constraintTop_toBottomOf="@+id/Detector1"

        app:layout_constraintVertical_bias="1.0" />

    <TextView

        android:id="@+id/textView33"

        android:layout_width="fill_parent"

        android:layout_height="wrap_content"

        android:layout_marginTop="5dp"

        android:gravity="center_horizontal"

        android:text="Detected Radiation data"

        android:textAppearance="?attr/textAppearanceBody2"

        android:textColor="#ffd600"

        android:textSize="22dp"

        app:layout_constraintBottom_toTopOf="@+id/view3"

        app:layout_constraintEnd_toEndOf="@+id/Detector1"

        app:layout_constraintHorizontal_bias="0.0"

        app:layout_constraintStart_toStartOf="@+id/Detector1"

        app:layout_constraintTop_toBottomOf="@+id/toolbar_action_bar"

        app:layout_constraintVertical_bias="0.0" />

    <TextView

        android:id="@+id/textView3"

        android:layout_width="0dp"

        android:layout_height="wrap_content"

        android:layout_marginTop="40dp"

        android:gravity="center_horizontal"

        android:text="Detector 1"

        android:textAppearance="?attr/textAppearanceBody2"

        android:textColor="#fff"

        android:textSize="16dp"
```

```xml
        app:layout_constraintBottom_toTopOf="@+id/textDetector3"
        app:layout_constraintEnd_toEndOf="@+id/Detector1"
        app:layout_constraintHorizontal_bias="0.0"
        app:layout_constraintStart_toStartOf="@+id/Detector1"
        app:layout_constraintTop_toBottomOf="@+id/toolbar_action_bar"
        app:layout_constraintVertical_bias="0.0" />
    <TextView
        android:id="@+id/textDetector3"
        android:layout_width="180dp"
        android:layout_height="wrap_content"
        android:layout_marginTop="250dp"
        android:gravity="center_horizontal"
        android:text="Detector 3"
        android:textAppearance="?attr/textAppearanceBody2"
        android:textColor="#fff"
        android:textSize="16dp"
        app:layout_constraintBottom_toBottomOf="parent"
        app:layout_constraintEnd_toEndOf="parent"
        app:layout_constraintHorizontal_bias="0.502"
        app:layout_constraintStart_toStartOf="parent"
        app:layout_constraintTop_toBottomOf="@+id/toolbar_action_bar"
        app:layout_constraintVertical_bias="0.0"
        tools:ignore="MissingConstraints" />
    <ProgressBar
        android:id="@+id/Detector3"
        style="@style/CircularDeterminateProgressBar"
        android:layout_width="170dp"
        android:layout_height="180dp"
        android:layout_marginTop="5dp"
        app:layout_constraintBottom_toTopOf="@+id/textView8"
        app:layout_constraintEnd_toEndOf="parent"
        app:layout_constraintHorizontal_bias="0.502"
        app:layout_constraintStart_toStartOf="parent"
        app:layout_constraintTop_toBottomOf="@+id/textDetector3"
```

```
        app:layout_constraintVertical_bias="0.0"
        tools:progress="10" />
    <TextView
        android:id="@+id/Detector3_value"
        android:layout_width="41dp"
        android:layout_height="29dp"
        android:textAppearance="@style/TextAppearance.AppCompat.Large"
        android:textColor="@color/yellow"
        app:layout_constraintBottom_toBottomOf="@+id/Detector3"
        app:layout_constraintEnd_toEndOf="@+id/Detector3"
        app:layout_constraintStart_toStartOf="@+id/Detector3"
        app:layout_constraintTop_toTopOf="@+id/Detector3"
        tools:text="10%" />
    <ProgressBar
        android:id="@+id/Detector1"
        style="@style/CircularDeterminateProgressBar"
        android:layout_width="170dp"
        android:layout_height="180dp"
        android:layout_marginRight="40dp"
        app:layout_constraintBottom_toTopOf="@+id/textDetector3"
        app:layout_constraintEnd_toEndOf="parent"
        app:layout_constraintHorizontal_bias="0.0"
        app:layout_constraintStart_toStartOf="parent"
        app:layout_constraintTop_toBottomOf="@+id/toolbar_action_bar"
        app:layout_constraintVertical_bias="0.942"
        tools:progress="10" />
    <TextView
        android:id="@+id/detector1_value"
        android:layout_width="wrap_content"
        android:layout_height="wrap_content"
        android:textAppearance="@style/TextAppearance.AppCompat.Large"
        android:textColor="@color/yellow"
        app:layout_constraintBottom_toBottomOf="@+id/Detector1"
        app:layout_constraintEnd_toEndOf="@+id/Detector1"
```

```xml
        app:layout_constraintHorizontal_bias="0.539"

        app:layout_constraintStart_toStartOf="@+id/Detector1"

        app:layout_constraintTop_toTopOf="@+id/Detector1"

        app:layout_constraintVertical_bias="0.443"

        tools:text="10%" />

    <TextView

        android:id="@+id/Detector_value2"

        android:layout_width="wrap_content"

        android:layout_height="wrap_content"

        android:textAppearance="@style/TextAppearance.AppCompat.Large"

        android:textColor="@color/yellow"

        app:layout_constraintBottom_toBottomOf="@+id/Detector2"

        app:layout_constraintEnd_toEndOf="@+id/Detector2"

        app:layout_constraintStart_toStartOf="@+id/Detector2"

        app:layout_constraintTop_toTopOf="@+id/Detector2"

        tools:layout_editor_absoluteX="274dp"

        tools:layout_editor_absoluteY="314dp"

        tools:text="10%" />

    <ProgressBar

        android:id="@+id/Detector2"

        style="@style/CircularDeterminateProgressBar"

        android:layout_width="170dp"

        android:layout_height="180dp"

        app:layout_constraintBottom_toTopOf="@+id/textDetector3"

        app:layout_constraintEnd_toEndOf="parent"

        app:layout_constraintHorizontal_bias="1.0"

        app:layout_constraintStart_toStartOf="parent"

        app:layout_constraintTop_toBottomOf="@+id/textView2"

        tools:progress="10" />

    <TextView

        android:id="@+id/textView2"

        android:layout_width="180dp"

        android:layout_height="wrap_content"

        android:layout_marginTop="40dp"
```

```xml
        android:gravity="center_horizontal"
        android:text="Detector 2"
        android:textAppearance="?attr/textAppearanceBody2"
        android:textColor="#fff"
        android:textSize="16dp"
        app:layout_constraintBottom_toTopOf="@+id/view3"
        app:layout_constraintEnd_toEndOf="parent"
        app:layout_constraintHorizontal_bias="0.901"
        app:layout_constraintStart_toEndOf="@+id/textView3"
        app:layout_constraintTop_toTopOf="@+id/textView33"
        app:layout_constraintVertical_bias="0.0" />
    <TextView
        android:id="@+id/textView8"
        android:layout_width="match_parent"
        android:layout_height="30dp"
        android:background="@drawable/darkbluecolor"
        android:gravity="center_horizontal"
        android:text="© nm-aist.ac.tz"
        android:textColor="#fff"
        app:layout_constraintBottom_toBottomOf="parent"
        app:layout_constraintEnd_toEndOf="parent"
        app:layout_constraintHorizontal_bias="0.0"
        app:layout_constraintStart_toStartOf="parent"
        app:layout_constraintTop_toBottomOf="@+id/textDetector3"
        app:layout_constraintVertical_bias="1.0"
        tools:ignore="MissingConstraints" />

</androidx.constraintlayout.widget.ConstraintLayout>
```

Activity programming

```java
package com.example.radiation;
import androidx.appcompat.app.AppCompatActivity;
```

```java
import android.content.Intent;

import android.os.Bundle;

import android.view.View;

import android.widget.Button;

import android.widget.EditText;

import android.widget.TextView;

import android.widget.Toast;

public class MainActivity extends AppCompatActivity {

    /* Define the UI elements */

    private EditText eName;

    private EditText ePassword;

    private TextView eAttemptsInfo;

    private Button eLogin;

    private int counter = 3;

    String userName = "";

    String userPassword = "";

    /* Class to hold credentials */

    class Credentials {

        String name = "Admin";

        String password = "123456";

    }

    boolean isValid = false;

    @Override

    protected void onCreate(Bundle savedInstanceState) {

        super.onCreate(savedInstanceState);

        setContentView(R.layout.activity_main);

        /* Bind the XML views to Java Code Elements */

        eName = findViewById(R.id.etName);

        ePassword = findViewById(R.id.etPassword);

        eAttemptsInfo = findViewById(R.id.tvAttempts);

        eLogin = findViewById(R.id.btnLogin);

        /* Describe the logic when the login button is clicked */

        eLogin.setOnClickListener(new View.OnClickListener() {

            @Override
```

```java
        public void onClick(View view) {
            /* Obtain user inputs */
            userName = eName.getText().toString();
            userPassword = ePassword.getText().toString();


            /* Check if the user inputs are empty */
            if (userName.isEmpty() || userPassword.isEmpty()) {
                /* Display a message toast to user to enter the details */
                Toast.makeText(MainActivity.this, "Please enter name and password!",
Toast.LENGTH_LONG).show();


            } else {


                /* Validate the user inputs */
                isValid = validate(userName, userPassword);


                /* Validate the user inputs */


                /* If not valid */
                if (!isValid) {


                    /* Decrement the counter */
                    counter--;


                    /* Show the attempts remaining */
                    eAttemptsInfo.setText(" Attempts remaining:" + String.valueOf(counter));


                    /* Disable the login button if there are no attempts left */
                    if (counter == 0) {
                        eLogin.setEnabled(false);
                        Toast.makeText(MainActivity.this, "You have used all your attempts try
again later!", Toast.LENGTH_LONG).show();
                    }
                    /* Display error message */
```

```java
                else {
                    Toast.makeText(MainActivity.this, "Incorrect credentials, please try
again!", Toast.LENGTH_LONG).show();
                }
            }
            /* If valid */
            else {
                /* Allow the user in to your app by going into the next activity */
                startActivity(new Intent(MainActivity.this, DashboardActivity.class));
            }
        }
    });
}
/* Validate the credentials */
private boolean validate(String userName, String userPassword) {
    /* Get the object of Credentials class */
    Credentials credentials = new Credentials();
    /* Check the credentials */
    if (userName.equals(credentials.name) && userPassword.equals(credentials.password))
{
        return true;
    }
    return false;
}
}
/* connecting the Mobile application and the cloude storage data*/

public class MqttHelper {
    public MqttAndroidClient mqttAndroidClient;
    final String serverUri = "tcp://mqtt.mydevices.com:1883";
    final String clientId = "cb73fd50-b8e5-11eb-883c-638d8ce4c23d";
    final String subscriptionTopic = "v1/60573da0-7f30-11eb-8779-
7d56e82df461/things/3163a7b0-a422-11eb-883c-638d8ce4c23d/data/2";
    final String username = "60573da0-7f30-11eb-8779-7d56e82df461";
```

```java
    final String password = "a23255815713e35a841dd73aa24517534aad39c6";
    public MqttHelper(Context context){
        mqttAndroidClient = new MqttAndroidClient(context, serverUri, clientId);
        mqttAndroidClient.setCallback(new MqttCallbackExtended() {
            @Override
            public void connectComplete(boolean b, String s) {
                Log.w("mqtt", s);
            }
            @Override
            public void connectionLost(Throwable throwable) {
            }
            @Override
            public void messageArrived(String topic, MqttMessage mqttMessage) throws
Exception {
                Log.w("Mqtt", mqttMessage.toString());
            }
            @Override
            public void deliveryComplete(IMqttDeliveryToken iMqttDeliveryToken) {
            }
        });
        connect();
    }
    public void setCallback(MqttCallbackExtended callback) {
        mqttAndroidClient.setCallback(callback);
    }

    private void connect(){
        MqttConnectOptions mqttConnectOptions = new MqttConnectOptions();
        mqttConnectOptions.setAutomaticReconnect(true);
        mqttConnectOptions.setCleanSession(false);
        mqttConnectOptions.setUserName(username);
        mqttConnectOptions.setPassword(password.toCharArray());

        try {
```

```java
                mqttAndroidClient.connect(mqttConnectOptions, null, new IMqttActionListener() {
                    @Override
                    public void onSuccess(IMqttToken asyncActionToken) {

                        DisconnectedBufferOptions disconnectedBufferOptions = new
DisconnectedBufferOptions();
                        disconnectedBufferOptions.setBufferEnabled(true);
                        disconnectedBufferOptions.setBufferSize(100);
                        disconnectedBufferOptions.setPersistBuffer(false);
                        disconnectedBufferOptions.setDeleteOldestMessages(false);
                        mqttAndroidClient.setBufferOpts(disconnectedBufferOptions);
                        subscribeToTopic();
                    }

                    @Override
                    public void onFailure(IMqttToken asyncActionToken, Throwable exception) {
                        Log.w("Mqtt", "Failed to connect to: " + serverUri + exception.toString());
                    }
                });


        } catch (MqttException ex){
            ex.printStackTrace();
        }
    }
    private void subscribeToTopic() {
        try {
            mqttAndroidClient.subscribe(subscriptionTopic, 0, null, new IMqttActionListener()
{
                @Override
                public void onSuccess(IMqttToken asyncActionToken) {
                    Log.w("Mqtt","Subscribed!");
                }
```

```java
        @Override
        public void onFailure(IMqttToken asyncActionToken, Throwable exception) {
            Log.w("Mqtt", "Subscribed fail!");
        }
    });
    } catch (MqttException ex) {
        System.err.println("Exceptionst subscribing");
        ex.printStackTrace();
    }
  }
}
```

Appendix B: Programming the radiation detection system

```
#include <LiquidCrystal_I2C.h>

#include <Wire.h>

unsigned long counts;                    //variable for counting interrupts from dosimeter

unsigned long previousMillis;            //variable for measuring time

int  CPM;                                // variable for count per one minute measure period

#define LOG_PERIOD 15000                 // count rate interval (in milliseconds)

int ledpin=14;

 int buzzerpin=27;

 int signalpin=17;//WIFI

// Import nessesary libraries for sensding data to the  webserver

#define CAYENNE_DEBUG

#define CAYENNE_PRINT Serial

#include <CayenneMQTTESP32.h>

// Cayenne authentication info. This should be obtained from the Cayenne Dashboard.

char* username = "60573da0-7f30-11eb-8779-7d56e82df461";

char* password = "a23255815713e35a841dd73aa24517534aad39c6";

char* clientID = "3163a7b0-a422-11eb-883c-638d8ce4c23d";

// WiFi network info.

char ssid[] = "TECNO F1";

char wifiPassword[] = "anna1234";

// initialize the library with the numbers of the interface pins

LiquidCrystal_I2C lcd(0x3f, 16, 4);
```

```
//setup

void setup()

{

  Cayenne.begin(username, password, clientID, ssid, wifiPassword);

  counts = 0;                        // initialize count of interrupts as zero

  CPM = 0;                          // initialize count per one minute  as zero

  //lcd.begin(16, 4);

  lcd.begin();

  lcd.backlight();

  // initial display on LCD

  lcd.setCursor(0, 0);

  lcd.print(" TAEC ");

  lcd.setCursor(0, 1);

  lcd.print(" GM_TUBE ");

  delay(3000);

  cleanDisplay();                                // clear the initial display

  Serial.begin(115200);

  // wifi connection method

  // ThingSpeak.begin(client);                        // Initialize ThingSpeak

  pinMode(signalpin, INPUT);

  pinMode(ledpin, OUTPUT);  // LED

  pinMode(buzzerpin, OUTPUT);   //BUZZER

  attachInterrupt(digitalPinToInterrupt(signalpin), impulse, HIGH );   //define external interrupts
```

```
}

// Main loop where MQTT code is run.

void loop()

{

 Cayenne.loop();

 // display position of CPM, uSv/hr,Count on the LCD

 lcd.setCursor(0, 0);

 lcd.print("CPM:");

 lcd.setCursor(0, 1);

 lcd.print("uSv/hr:");

 lcd.setCursor(0, 2);

 lcd.print("Count: ");

 lcd.print(counts);


 // Measuring time interval between radiation detected within the time interval

 unsigned long currentMillis = millis();                //

 if (currentMillis - previousMillis > LOG_PERIOD)          //

 {

  previousMillis = currentMillis;                 //

  cleanDisplay();                      // Clear LCD

   // display the value of  CPM, uSv/hr on the LCD

  lcd.setCursor(5, 0);

  CPM = counts * 4;
```

```
  lcd.print(CPM);

  lcd.setCursor(7, 1);

  lcd.print(outputSieverts(CPM));

  //print CPM, uSv/hr on serial

  Serial.print("CPM:");

  Serial.print("\t");

  Serial.print(CPM);

  Serial.print("\t");

  Serial.print("uSv/hr:");

  Serial.print("\t");

  Serial.print(outputSieverts(CPM));

  Serial.print("\n");

  Cayenne.virtualWrite(1, CPM, "analog_sensor", "cpm");

  Cayenne.virtualWrite(2, outputSieverts(CPM), "analog_sensor", "uSv/hr")

  counts = 0;

 }

led();

buzzer();

}

// the function to count interrupts ISR

void impulse()

{

 counts++;
```

```
}

// the function to calculate the dose rate of radiation in uSv/hr

float outputSieverts(float x)

{

 float y = x / 123.14;          // CPM and the conversion factor of the tube

  return y;

}

void led()

{

 if (CPM >= 30)

  {

   digitalWrite(ledpin, HIGH);

  }else {

   digitalWrite(ledpin, LOW);

  }

  }

void buzzer()

{

 if (CPM > 100)

  {

   digitalWrite(buzzerpin, HIGH);

   delay(100);

  }else {
```

```
    digitalWrite(buzzerpin,LOW);

  }

}

// Clear LCD routine

void cleanDisplay ()

{

 lcd.clear();

 lcd.setCursor(0, 0);

 lcd.setCursor(0, 0);

}
```

POSTER PRESENTATION