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IOT BASED MONITORING AND REPORTING SYSTEM FOR DOSIMETER WEARERS IN RADIATION AREAS: A CASE STUDY OF TAEC

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IOT BASED MONITORING AND REPORTING SYSTEM FOR DOSIMETER WEARERS IN RADIATION AREAS: A CASE STUDY OF TAEC

Avith Habonimana

A Project Report Submitted in Partial Fulfillment of the Requirements of the Award of the Degree of Master of Science in Embedded and Mobile Systems of The Nelson Mandela African Institution of Science and Technology

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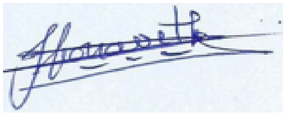
ABSTRACT

In today's modern society, the use of radiation sources in a wide range of activities has increased rapidly. As a result, occupational exposure to ionizing radiation doses that cause health effects increases. Excessive doses of 20 millisieverts (mSv) per year cause acute effects such as sterility or cancer. The health effects of ionizing radiation fall in many countries around the world, including Tanzania. Tanzania Atomic Energy Commission (TAEC) manages dosimeters in order to reduce radiation hazards to radiation workers. Nonetheless, after dispatching those dosimeters, the TAEC management room is unable to determine whether or not each supposed wearer has worn the dosimeter. This originates from an incorrect assessment of an individual occupational radiation dose. Therefore, an Internet of Things-based Monitoring and Reporting System for Dosimeter Wearers in Radiation Areas is developed. Using internet of things (IoT) technology, this project presents an effective and affordable system for real-time remote monitoring and reporting staff wearing passive dosimeters while near or in the area; radiation exposure is too high. The scrum method, which is based on agile methodology, was used for system development. The system was run by an ESP32 microcontroller board that was programmed in C using the Arduino Integrated Development Environment. The ESP 32 microcontroller could send data to the weber server via its built-in Wi-Fi. Through the mapping web application, the end-user (TAEC Managerial Officer) monitored and visualized radiation workers. IoT enabled the dosimeter to be monitored and reported on at any time via the internet.

DECLARATION

I, Avith Habonimana, do hereby declare to the Senate of The 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 a degree award in any other institution.



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Dr. Devotha Nyambo		
Name of Supervisor 1	**Signature**	**Date**

Dr. Anael Sam		
Name of Supervisor 2	**Signature**	**Date**

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CERTIFICATION

The undersigned certify that they have read and hereby recommend for acceptance by The Nelson Mandela African Institution of Science and Technology, a project report titled ***"IoT based Monitoring and Reporting System for Dosimeter Wearers in Radiation Areas: A case study of TAEC"*** 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.

Dr. Devotha Nyambo

Name of Supervisor 1	Signature	Date

Dr. Anael Sam

Name of Supervisor 2	Signature	Date

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May God's peace fill you to overflowing.

DEDICATION

This work is dedicated to my magnificent parents, Mr. Basekuwugowe Thomas and Mrs. Niyonzima Sylvane, for their unwavering support and encouragement throughout my journey of the academic career.

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LIST OF ABBREVIATIONS AND SYMBOLS

ALARA	As low as reasonably achievable
CDC	Center Disease Control
CSS	Cascading Style Sheets
DNA	Deoxyribonucleic acid
DOE	Department of Energy
FGD	Focus group discussions
GPS	Global Positioning System
HTML	Hypertext Markup Language
HTTP	Hypertext Transfer Protocol
IAEA	International Atomic Energy Agency
ICT	Information and Communication Technology
IDE	Integrated Development Environment
IoT	Internet of Things
MSv	Millisievert
MVC	Model View Controller
NEI	Nuclear Energy Institute
NM-AIST	Nelson Mandela African Institution of Science and Technology
NRC	Nuclear Regulatory Commission
OSHA	Occupation Safety and Health Administration
PPE	Personal Protective Equipment
RDBMS	Relational database management systems
RFID	Radio Frequency Identification
RWMR	Radiation Workers Monitoring and Reporting
RWMR	Radiation Workers Monitoring and Reporting System
TAEC	Tanzania Atomic Energy Commission
TLD	Thermoluminescence Dosimeter
Wi-Fi	Wireless – Fidelity

CHAPTER ONE

INTRODUCTION

1.1 Background of the Problem

The radiation source is eternally existing in all living creatures and everywhere in the environment as well. There are two categories of radiation sources: ionizing and non-ionizing radiation sources. Non-ionizing radiation sources, on the other hand, are non-destructive to human health. In contrast, ionizing radiation sources are harmful to human health when precautions to avoid contamination are not in place (OSHA, 2021; Schauer & Linton, 2009).

Indeed, individuals' average radiation dose is encountered throughout the environment, not only from natural sources. But also from artificial radiation sources such as experimental or industrial use and medical use, which results in radiation exposures to public members occupationally exposed individuals (Cole, 2012).

Thus, persons are exposed to two main primary sources of radiation, natural radiation that encompasses internal radiation, which comes from the human body, and natural environments. In addition, however, there is a secondary external radiation source, which comes from manufactured radiation.

The primary source of manufactured radiation exposure to the community in general and workers, in particular, is coming from work and as well as trial practice, mainly medical dealing, such as cancer treatment, radiation therapy, nuclear medicine, X-ray machines and industrial use (Sawyer, 2021; Shastri *et al.*, 2021).

It is well known that radiation exposure is harmful to human health because it destroys tissues that compose the human body. That damage includes fever, headaches, vomiting that might lead to severe illnesses like cancer, even to death; in the same vein, it can be extended to genetic aberrations. Overexposure to personal dose is a hazard; conversely, people do not care even for individuals working in radiation sites (Sethi *et al.*, 2019). Due to that, the imperatives for protection from radiation exposure in the workplace were established. The Culture of radiation protection is a theme in emergence along with information and awareness of radiation, personal protective equipment, radiation safety practice, education, and training as well (Rose *et al.*, 2018)

More institutions are involved in radiation safety promotion, but they all aim to achieve the common goal: to keep people informed and safe. The International Atomic Energy Agency (IAEA), the Nuclear Energy Institute (NEI), Nuclear Regulatory Commission (NRC), and Occupation Safety and Health Administration (OSHA) are among the organizations that strive and recommend that radiation safety standards must be followed (SafetyCulture, 2021; Society, 2012).

Moreover, to the local level, via the declaration which states that the use of radiation sources must be regulated to safeguard the public, employees, and the environment from the negative consequences of both ionizing and non-ionizing radiation. Here in the United Republic of Tanzania. Tanzania Atomic Energy Commission (TAEC) is an institution established by the Tanzania Government by act no. 7 of 2003 (TAEC, 2003) to ensure radiation safety via control of peaceful uses of nuclear technology and atomic energy and promoting the application of radiation source peacefully as well; This can be achieved by inspecting all centres which utilize radioactive sources to monitor the implementation of the Atomic Energy Act and its regulations.

Upon that, TAEC is responsible for tracking and keeping radiation dose perceived by occupational exposure in workplaces within the international occupational dose limits, that is 20 millisievert yearly (Nassef & Kinsara, 2017). Furthermore, TAEC realizes that via the Personal Monitoring and National Calibration section, dosimeters (TLDs) are distributed to each radiation worker to record the dose perceived at the time being at the radiation working place.

Despite the efforts, the overall performance of striving for the ionizing radiation health hazard is still needed because the workers wearing Dosimeters (passive dosimeters) in radiation sites are not abiding by safety measures ionizing-radiation. Hence, the need of being monitored and reported to enhance the strive against the hazards from radiation towards radiation workers.

As technology evolves quickly, there is an opportunity for intelligent solutions to overcome radiation hazards, from experimental scale to industrial practice, by using intelligent surveillance and real-time reports of dosimeter users.

1.2 Statement of the Problem

The carelessness of adverse effects from exposure to radioactive sources leads to various serious sicknesses such as cancer, also the cost increase of taking care of those confirmed with overdoses from the working places (Sethi *et al.,* 2019).

Here in the Republic of Tanzania, the authority in charge of radiation safety (Tanzania Atomic Energy Commission - TAEC) has tried its best to overcome hazards and the problem of radioactivity sources. Also, guidelines to radiation safety regulations and different protection mean like personal protective equipment, passive and active dosimeters while operating or being in the area with too high radiation exposure were introduced.

Despite the efforts, there is a problem in radiation practice. That is, the TAEC dosimetry department tries its best to inculcate dosimeter users the Culture of radiation protection and distribute the dosimeter to each employee. Nevertheless, after dispatching those Thermoluminescence dosimeters (TLD), the managerial officer cannot know if the supposed wearer has worn the dosimeter or not, and this is affecting the monitoring of dose recommendations accordingly to the international recommended dose limit, which is 20 millisievert (mSv) per year while monitoring the doses of occupational radiation for each radiation operative (Nassef & Kinsara, 2017).

Furthermore, according to Sethi (2019), in his survey, section "monitoring of occupational radiation exposure," found that 51.7% of respondents stated that they do not wear a dosimeter regularly and 22.1% do not know how frequently their dosimeter is tested for radiation exposure (Sethi *et al.,* 2019).

It was discovered that improper managing of a personal dosimeter might result in a poor dosimeter wearing exercise among others:

(i) A worker may put aside the dosimeter

(ii) An operator might be corrupt by radiating the dosimeter using an artificial source

(iii) An employee should move out within the estimated radiation range and then encounter an overdose outside the radiation departments.

And probably, that can source improper assessment of an individual occupational radiation dose, thereby leading to biased health risk estimation (Lee *et al.*, 2021).

1.3 Rationale of the Study

Since we live in the era of the connected world, the development of smart systems is inevitable in improving the quality of service and ensuring safety. Having the intelligent safeguard system solution for monitoring staff wearing dosimeters in radiation working places will contribute for instance: to ensuring the TAEC managerial officer to know who are wearing or not dosimeters after dispatching them, to push the radiation workers to abide by dosimeter wearing while operating or being in the area with radiation exposure, will also contribute to overcoming radiation hazards, then, reduce the cost of taking care of those confirmed with overdoses from the working places, and will allow workers to live a long life as normal, and then provide real-time employee behaviour and remote reporting. Hence, to know if the personal overdoses are received from within the occupational radiation dose.

1.4 Objectives

1.4.1 General Objective

To develop an IoT-based safeguard system capable of monitoring and reporting in real-time the non-compliance dosimeter users in radiation departments.

1.4.2 Specific Objectives

(i) To identify and analyze the requirements for an IoT based safeguard system for dosimeter users monitoring and reporting in the radiation area.

(ii) To design and build an IoT-based safeguard system for dosimeter users to monitor and report on radiation exposure.

(iii) To validate the developed system.

1.5 Research Questions

(i) What would be the requirements for an IoT-based safeguard system for dosimeter users in radiation areas?

(ii) What design rules and methods would be appropriate for developing a safeguard system for monitoring and reporting dosimeter users in radiation areas?

(iii) Would the system be valid for the context of the Tanzania Atomic Energy Commission clients?

1.6 Significance of the Study

This system will help track personal dosimeter wearing and give notifications in real-time. As a result, it will help remove the traditional close follow up of dosimeter wearing on-site and increase the accuracy in calculating an individual occupational radiation dose, finally reducing the cost related to biased health risk estimation.

1.7 Delineation of the Study

The project was done in headquarters and some of the sub quarters of TAEC, and the focus was on the remote follow-up of dosimeter wearing in radiation sites. So as to get a real-time notification for adherence and as well as non-compliance to the thermoluminescence dosimeter uses.

CHAPTER TWO

LITERATURE REVIEW

2.1 Ionizing and Non-Ionizing Radiation

Radiation refers to the energy released by radioactive material, "an unstable atom," as it changes to a more stable state. Radiation can cover different distances in space. If passing, it contains enough energy able to remove negative charge called electrons (that is, to ionize other atoms) in its pathway refers to ionizing radiation. Whereas when that energy is not enough to cause ionization refers to non-ionizing Radiation (OSHA, 2021).

Both non-ionizing and ionizing radiation can contaminate the human skin. However, non-ionizing radiations are not penetrating the human body. In contrast, ionizing radiations have the ability to penetrate the human body and destroy the tissues that compose the body. And this is the reason why ionizing radiation is said to be harmful to human health when it is not controlled correctly (OSHA, 2021). For example, when live tissues are unprotected against ionizing radiation, the atoms that comprise deoxyribonucleic acid (DNA) in cells may become ionized, which causes DNA to malfunction and can lead to cancer. Nevertheless, this does not imply that non-ionizing radiation cannot harm humans, but the harm is usually restricted to thermal damage (OSHA, 2021). Furthermore, the penetration ability of various forms of ionizing radiation to the human body induces the classification of ionizing radiation types depending on their penetration range.

2.2 Types of Ionizing Radiations

This section also introduces the types of ionizing radiation classified in nuclear Radiation and electromagnetic Radiation. In terms of atomic radiation, a type of radiation that has low penetration ability, there are:

(i) Beta particles; and

(ii) Alpha particles.

Both alpha and beta particles are able to ionize, however, at different power. Alpha particles have greater ionizing power, while beta particles have a low ionizing range.

In the electromagnetic spectrum, a type of radiation carries energy that is equivalent to or greater than the typical ionizing energy of an atom, there are:

(i) Neutron particles

(ii) Gamma rays

(iii) X-rays

These ionizing radiations in terms of electromagnetic radiation have a wide range of penetration into different parts of the human body. The penetration strength of various forms of ionizing radiation is depicted in the diagram shown in Fig. 1.

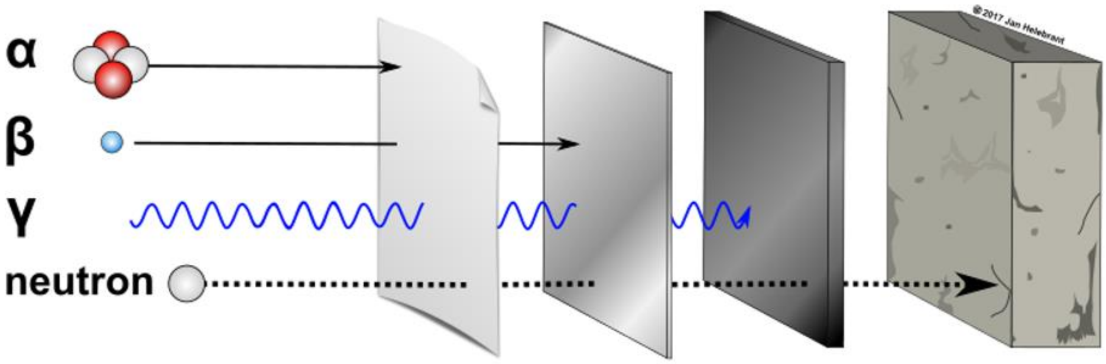


Figure 1: Penetration strength of various forms of ionizing radiation

2.3 Sources of Radiation Exposure

The ionizing radiation sources can either exist naturally, such as in radioactive materials found in the ground, vegetation, soil, water, or the human body. Or be created artificially in daily use of various nowadays technology such as trial practice, communication technology, practical and medical use (Cole, 2012; Environmental Protection Agency/US, 2021; Schauer & Linton, 2009).

Therefore, individuals are exposed to two primary sources: natural and external radiation. Natural radiation sources comprise internal radiation, which comes from inside the human body (through food and inhalation) and natural environments. On the other hand, external radiation comes from artificial radiation.

For example, Medical X-ray devices create ionizing radiation electrically and stop emitting radiation when switched off. Since the radioactive sources release ionizing radiation, devices containing radioactive materials, such as some industrial radiography equipment, cannot be switched off. To prevent or limit radiation exposure, these must be enclosed by a substance that can brock radiation. Table 1 shows the gradual evolution of sources of radiation exposures in percentage to each source. The actual value differs based on where individuals live and what they do while spending time.

Table 1: The gradual evolution of radiation sources exposures

1980	Natural Radiation	83%
	Medical	15%
	Occupational/Industrial	0.3%
	Consumer	2%
2006	Natural radiation	50%
	Medical	48%
	Occupational/Industrial	0.1%
	Consumer	2%
2009	Natural radiation	50%
	Man-made radiation	50%

Based on that trend reported in 2009, National Council on Radiation Protection (NCRP) reviewed the available data of gradual evolution of man-made radiation exposure sources. It concluded that the man-made radiation sources would continue linearly at a high level. This conclusion assumes that there is a need to enhance the safety measures to radiation and install the system for real monitoring and reporting.

2.4 Health Effects of Ionizing Radiation

Ionizing Radiation can harm cells, tissues, organs, and genetic information, i.e., DNA, when it comes into contact with them, if not properly controlled. This damage might source the cells to die or cause potentially dangerous modifications into the DNA, which can be extended to the sterility (OSHA, 2021). Health effects caused by radiation doses are classified into two forms: short-term health effects called deterministic effects and long-term health effects called stochastics effects.

Short-term health effects manifest from radiation exposures over a short time. Here are the examples of short-term health effects:

(i) Sterility.

(ii) Cataracts.

(iii) Skin reddening.

(iv) Congenital disabilities.

It is worth noting that long-term health effects may take many years to be observed after exposure. Long-term health consequences include:

(ii) Cancer.

(iii) Genetic aberration, i.e., mutation that can be transmitted to offspring.

2.5 Inspection for Radiation Safety

Radiation safety has become a more pressing concern because of the expanding use of advanced technology (Zekioğlu & Parlar, 2021). Radiation safety is a set of practices and preventive measures used to ensure worker safety when working with or near radiation. It is guided by the concept "as low as reasonably achievable (ALARA)" to prevent radiation exposure, even if it is only a little quantity.

Numerous organizations such as International Atomic Energy Agency, the Nuclear Energy Institute and, Occupation Safety and Health Administration are among the establishments that recommend that radiation safety standards must be followed (SafetyCulture, 2021). These international guidelines were established by a worldwide agreement, taking into account the current understanding of impacts and protective foundations.

According to the Center of Disease Control (CDC), along with Personal Protective Equipment, three fundamental radiation safety protocols, which are time, distance, and shielding, must be followed to reduce the hazards of radiations exposure (Centers for Disease Control and Prevention, 2015)

Then time refers to limiting the time spent near a radioactive source to only what is necessary to complete the task. By distance is to keep distance as much as possible from the radioactive source. That is, distance and dosage are inversely linked because by increasing distance, you reduce your dosage. Finally, shielding refers to protecting oneself from radiation sources by placing something between the source and the involved person.

Safety inspection and other radiation safety procedures assist to be assured that important radiation safety protections are in place to decrease the effects of overexposure since any quantity of radiation exposes the human body (cells or tissue) to the danger of harm. Even if the human body system has the capacity to repair damaged cells, prolonged exposure may result in a variety of acute illnesses, as well as long-term health effects.

2.6 Related Works

Studies have been undertaken and have come up with several solutions to overcome radiation hazards.

The University Hospital of King Abdul-Aziz University performed the tracking of the medical radiation employees to know how much their average twelve-monthly effective dosage has developed. Nevertheless, the said monitoring was done by using the thermoluminescence dosimeters (Nassef & Kinsara, 2017). Then, while performing their work, staff have to wear the TLDs at the proper place, that is, at the chest level, which is the most critical body portion where the maximum radiation is predictable. Yet, it is difficult to know if the supposed wearer has worn it. Unless the closer follow follows each operator is set up, which is also a burden to the manager.

Mohamed (2021) surveyed Egypt's awareness and implementation of ionizing radiation safety measures. The finding was that only the completion of radiation safety training was the major predictor of good adherence to radiation safety procedures (Omar *et al.,* 2021).

A study conducted in the United States about practice in use against radiation protection revealed that as a measure of personal protection, workers wearing a one-and two-piece lead apron as well as thyroid shiel (Sethi *et al.,* 2019). Still, the utilization of dosimeter was inconsistent in half of the cases. Hence personal dose monitoring is not perfectly achieved.

The international project on individual monitoring and radiation exposure levels in interventional cardiology has been conducted an assessment of staff radiation protection levels. And this was done by having an international occupational exposure database (Padovani *et al.,* 2011). When it comes to the requirement for wearing a personal dosimeter, only 57% of the regulatory bodies specify the number and location of dosimeter for staff monitoring. However, about 40% could provide only occupational dose, which induces that adherence to individual monitoring is frequently unachieved. Hence, propose the analysis incorporate monitoring compliance to achieve an accurate assessment of personal dose.

From 2011 to 2017, an evaluation of occupational radiation exposure to external ionizing radiation was performed in Tanzania. The demonstrative method compared the previous results with the fresh yearly collective dose recorded using dosimeters such as effective dose, average effective dose, individual dose distribution ratio, and collective effective dose distribution ratio (Muhogora *et al.,* 2019). Yet the need to look at the way to increase safety in the industrial application was recommended.

In South Korea, a study on the assessment of the working environment and personal dosimeter-wearing compliance of industrial radiographers was conducted. The demonstrative way to monitor individual occupationally exposed radiation dose and kept it under the internationally recommended dose limit was to wear a personal dosimeter. However, the legal personal dosimeter-wearing obedience was inspected by relationship examination between recorded dose and chromosome aberration frequency (Lee *et al.,* 2020).

For two community hospitals, a calculation of occupational radiation doses of medical radiation workers was carried out (Osei *et al.*, 2020). The TLDs put on the chest and the collar, ring dosimeters were utilized to estimate dose for the whole body, i.e., Hp (10) dosage, the lens of the eye doses, i.e., Hp (3), and dose for skin, i.e., Hp (0.07) dose respectively. However, to discover the reason for the high doses, an investigation is normally conducted to ascertain whether a personal dosimeter was accidentally left in the treatment room or not. Conversely, it was impossible to ascertain the unintentional dosimeters exposures and demonstrate compliance with applicable radiation protection measures and personal dose.

Argonne National Laboratory for the U.S, in collaboration with the Department of Energy (DOE), developed a system named ARG-US RFID System. The so-called system monitors and tracks the radioactive materials through storage, processing even packages while conveyance (Reddy, 2012). The system continually tracks the tagged items and sees their status; also, with GPS enabled, the joint RFID System is able to send data, including location, to numerous operators remotely in close real-time.

A radiation reduction strategy has been conducted, and this was done in pediatric orthopaedics patients using the development of non-radiation methods such as ultrasound (Sawyer, 2021). But workers were not taken into consideration.

Canadian Organization Medical Physicists concentrate on having the same standards for radiation safety regulations in each sector dealing with radiation exposure (Bjarnason *et al.*, 2020). However, it did not consider real monitoring and reporting workers while in Jobsite exposure to keep the personal dose within the dose limit range.

Padovani (2011) found that adherence to individual monitoring is frequently unachieved in interventional cardiology. Hence, propose the analysis to incorporate monitoring compliance to achieve an accurate assessment of personal dose. According to Mohamed (2021), training was the major predictor of good adherence to radiation safety procedures. However, the conducted study revealed that the utilization of dosimeter was inconsistent in half of the cases; still, personal dose monitoring is not perfectly achieved. Furthermore, the University Hospital of King Abdul-Aziz University performed the tracking of the medical radiation employees by wearing dosimeters (Nassef & Kinsara, 2017). Yet, this approach engages that a closer follow follows each operator to assure if the dosimeter was worn or not, which is also a burden to the manager. According to Osei (2020), an investigation approach was centered on discovering the reason for the high doses while reading dosimeters. But it was impossible to ascertain the unintentional dosimeters exposures and demonstrate dosimeter wearing compliance.

From the evaluation of the existing system for radiation and radiation workers monitoring, there was a research gap on having an intelligent strategy for monitoring and reporting remotely staff wearing dosimeter in radiation working places.

The present study proved the need to develop an IoT-based monitoring and Reporting System for Dosimeters Wearers in Radiation Areas. Therefore, a solution incorporating the Internet of Things technology, human body detect and location sensor were used. The focus was the remote follow-up of dosimeter wearing, hence witnessing individual dosimeter wearing within the radiation job site. And enabled institutions in charge of Personal monitoring dose to get a real-time report for the compliance and non-compliance to the dosimeter uses.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Area of the Study and Scope of the Research

In the present project, the study area was Tanzania Atomic Energy Commission (TAEC) under the Personnel Monitoring and National Calibration Department. TAEC was chosen because it deals with radiation matters, hence including embedded learning. But, on the other hand, it aligns with the Nelson Mandela African Institution of Science and Technology's motto. Which is "Academia for Society and Industry", and in meeting one of the criteria of completing a Master of Science in Embedded and Mobile Systems, which is to identify a challenge, then come up with a helpful solution for the society in general and company in particular.

The duration of the study was six months, from June to December 2021. The focus was the remote follow-up of dosimeter wearing in radiation sites and get a real-time notification for the non-compliance to the thermoluminescence dosimeter uses.

3.2 Research Methodology

The multimethod-based-qualitative methodology was used to achieve the project results in this project. Qualitative research is firstly opted for in this project since it is an exploratory and inductive approach in nature to get an in-depth understanding of the topic under investigation. Secondly, qualitative methods were used, which are good to fully explore the subject at hand by means of a round table discussion with open-ended questions whereby people freely express themselves in their own words, so that data collection captures feelings and persons' perceptions on having an intelligent dosimeter monitoring while at radiation workplace. It lastly became easy to gather data through methods of focus groups, group discussion, and interviews using a round table of discussion.

3.3 Target Population

This project targeted all of the radiation workers in their all entities, both closed space and opened space, hence including:

(i) All hospitals, education, and road construction companies use radioactive sources.

(ii) Businessmen and companies for the importation, ownership, transportation, and use of radioactive sources.

(iii) Engineering and telecommunication companies like those which measure the level of radiation on telephone towers and communication radars. And also, those that test environmental samples to identify radioactive contaminants in the environment.

3.4 Sample Size and Sampling Technique

The sample of this study consisted first of staff of Personal Monitoring and National Calibration Laboratory, secondly radiation workers, and lastly, the head of different departments. Then the non-probability sampling techniques based on purposive and homogenous were utilized in the study of this project.

3.5 Data Collection

Data collection, which elicited and linked information based on variables, was done (Dash, 2017). To fully comprehend and identify the key challenges to be addressed in TAEC headquarter and their sub-quarters. First, the kind of data needed was determined. Then, the sample survey participants were chosen within the TAEC population: heads of different departments, staff of Personal Monitoring and National Calibration Laboratory staff, and radiation workers. Thereby, data captured feelings, reactions, and insights on non-compliance and compliance to dosimeter wearing. The qualitative data are classified into two main categories: primary data and secondary data (Dash, 2017).

3.5.1 Primary Data

Primary data are those collected afresh and for the first time by the researcher himself, which persons do not modify, thus not published yet, and more consistent. Its advantage is that the researcher gathers data specific to the problem at hand, and there is no ambiguity about the authenticity of the collected data. The primary data were obtained through focus groups, group discussions, interview sessions of different TAEC staff and heads of different departments located at the headquarters of TAEC at Njiro-Arusha City in Tanzania. Also, observation was used.

Focus group discussions (FGD) are data gathering approach via a semi-structured interview process in which a minor homogeneous entity/a special type of group of people, typically from six to twelve people, meet to converse issues on a research plan, where participants are inspired to share underlying ideas, attitudes so as to learn the how and why of the specific study.

In the present study, the focus group was held with the different heads of departments and some of the staff. The focus group was conducted in the Information and Communication Technology room (ICT room) at TAEC headquarters, where sessions were organized for research topics' presentations. From the focus group discussion, questions were raised, answers were provided, suggestions were provided, and comments were provided. In addition, from the focus group discussion, the desired requirements were identified and recommended to be gathered to develop the proposed system.

Group discussion is a method of data elicitation in one go from several people who usually share a common experience and focus on their shared meanings, whereas an interview is a face-to-face question-answer interaction session used to gather detailed information about the responder's conceptions, views, and ideas.

In this study, the discussion session and face-to-face conversations were directed to the staff of Personnel Monitoring and National Calibration Laboratory to know how they monitor and then get the report of compliance and non-compliance about the dosimeter wearing. In addition to that, to get their point of view on what kind of information to display on a desktop computer once they have a smart dosimeter for easy monitoring and decision-making.

The observation method was utilized to acquire nonverbal data and unknown issues investigation. Thereby, the observation was used through different TAEC departments to get to know the existing systems, assess the weakness and strengths, and gaps as well.

3.5.2 Secondary Data

Secondary data are those collected from published resources. They can be considered as not much reliable. However, their reputation aids in providing information not given or cannot be accessed from the primary data. The secondary data were obtained from a review of the related works and search on the internet so as to identify what has been done by other researchers.

3.6 Data Analysis

Data analysis aids in the meaningful and symbolic content of qualitative data by explaining, comprehending, or interpreting people and circumstances.

Analyzing the contents of collected data draws a connection between data, spot patterns. It correlates information, increases the research validity, and finally makes sense of substantial data collected for a specific intention.

3.7 System Requirements

The subsequent stage after data elicitation and analysis is requirement analysis, system functional and non-functional requirements have been analyzed so as to understand what the proposed system must do and the product's expectations as well. Table 2 and Table 3 depict the functional and non-functional requirements of the proposed system.

Table 2: Functional requirements

Requirements	Descriptions
Human body detection	To be assured with the dosimeter wearing the system shall detect the presence of the human body.
Sense location and time	The TAEC managerial officer needs to ensure if the dosimeter wearing is abided with while being or not in the expected working place. Therefore, the system will sense the location and time.
View information about compliance and non-compliance to dosimeter wearing	The system shall output the real time employees 'behavior by visualizing the mapping web based on desktop computer.
General daily report generation	To have an insight on statistic view and provide a regular alert to dosimeter wearers, the system will generate a general dairy report.

Table 3: Non-functional requirement

Requirements	Descriptions
Security	The system should allow only the authenticated TAEC managerial officer to access the mapping web based so as to check the real-time employees' behavior.
Usability	The system should be user friendly to TAEC managerial officer
Performance	The system may handle numerous requests concurrently.
Reliability	The system may provide the real time notification about compliance and non-compliance to dosimeter wearing.
Scalability	The system should allow any improvement/modification to be performed.

3.8 System Development Approach

An agile methodology which is a way to manage a project by splitting it up into various phases called iterations by maintaining continuous collaboration with stakeholders, was used. In agile, the Scrum method was used. The scrum method's suitability to cope better with the change, adjust requirements and priorities and improve throughout the development process to ultimately deliver a usable end-product that meets stakeholders' needs. Additionally, development and testing are all done in parallel and synchronized.

Scrum was chosen among others due to its acknowledgement that at the beginning of a project, the development team does not know everything. Everything evolves through practice, so it encourages getting lessons/learning through achievements and losses to nonstop improvement. Further, it is based on iterations that provide feedback to the critical variables of the project, such as requirements, schedule, design, and development. It finally permits clear team communication, self-organization, turn back, and makes a quick correction in the sprint throughout the development. Hence, the control of the project schedule and state are more kept.

3.8.1 System Design

The System design was carried out to evaluate data input, processing, storage, and information output. The developed system was designed into three parts: detection and processing, software, and reporting.

(i) Detection and processing unit

The detection and processing unit consists of a human body detector, Global Positioning System receiver module (GPS receiver module), and ESP32 Microcontroller. This is to capture information about the compliance and non-compliance to dosimeter wearing and determine the real-time and location of the supposed wearer by human body detector and GPS receiver module, respectively. Finally, to treat the captured information for further processing. Figure 2 shows the flowchart of the detection and processing unit.

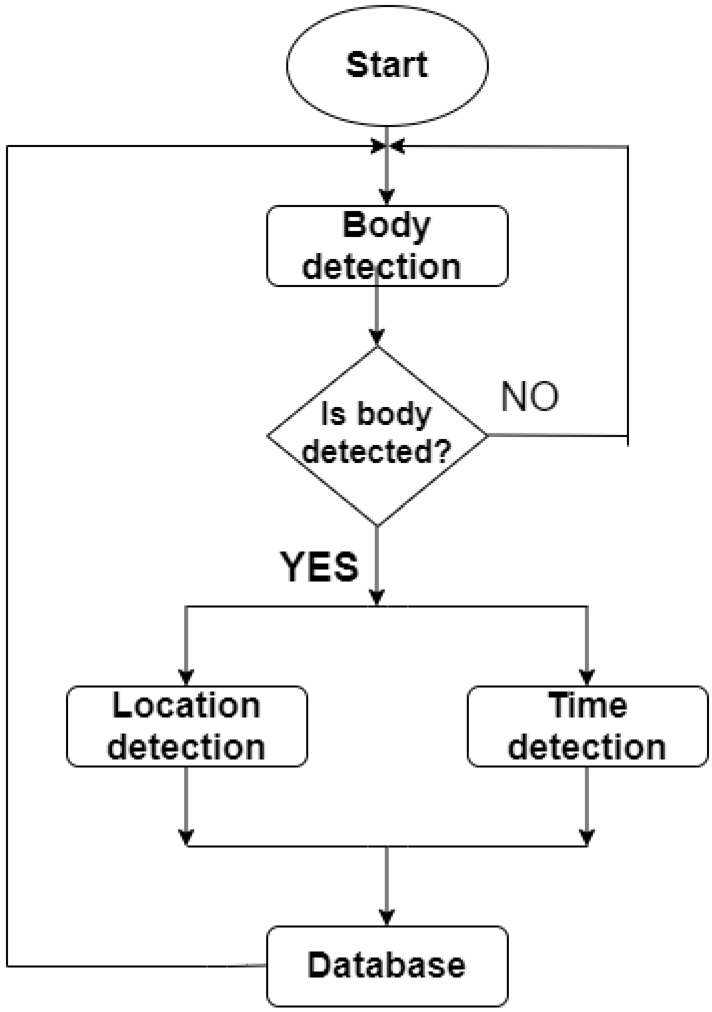


Figure 2: Flowchart of detection and processing unit

(ii) Software unit

A software unit that is a set of programs that enable the system to perform specific tasks encompasses various instructions and procedures used to generate codes for proper processing, command, and function of the proposed system. In this project, the software unit comprises storage and coding.

The software unit retrieves data of location and time recently sensed by the body detector and location sensor, respectively. It then compares that new record with the captured and stored information about the expected location. If the comparison results within the range of the predictable location, the system ensures that the person is in the expected place.

It subsequently takes that person to the mapping web-based (Fig. 4) and visualizes him/her with a green icon. On the other hand, if the new record is unmatched with the stored expected location, the system confirms that the person is out of the range of the expected location, it also takes that person to the mapping web-based (Fig. 4) and pictures him/her with a yellow icon. Lastly, if 10 minutes elapse without a new record sensed, i.e., nobody sensed, the system knows that the dosimeter is not worn. Therefore, it takes out the person from the mapping web-based and places and lists him/her in the text box. Figure 3 depicts the flowchart of the software unit.

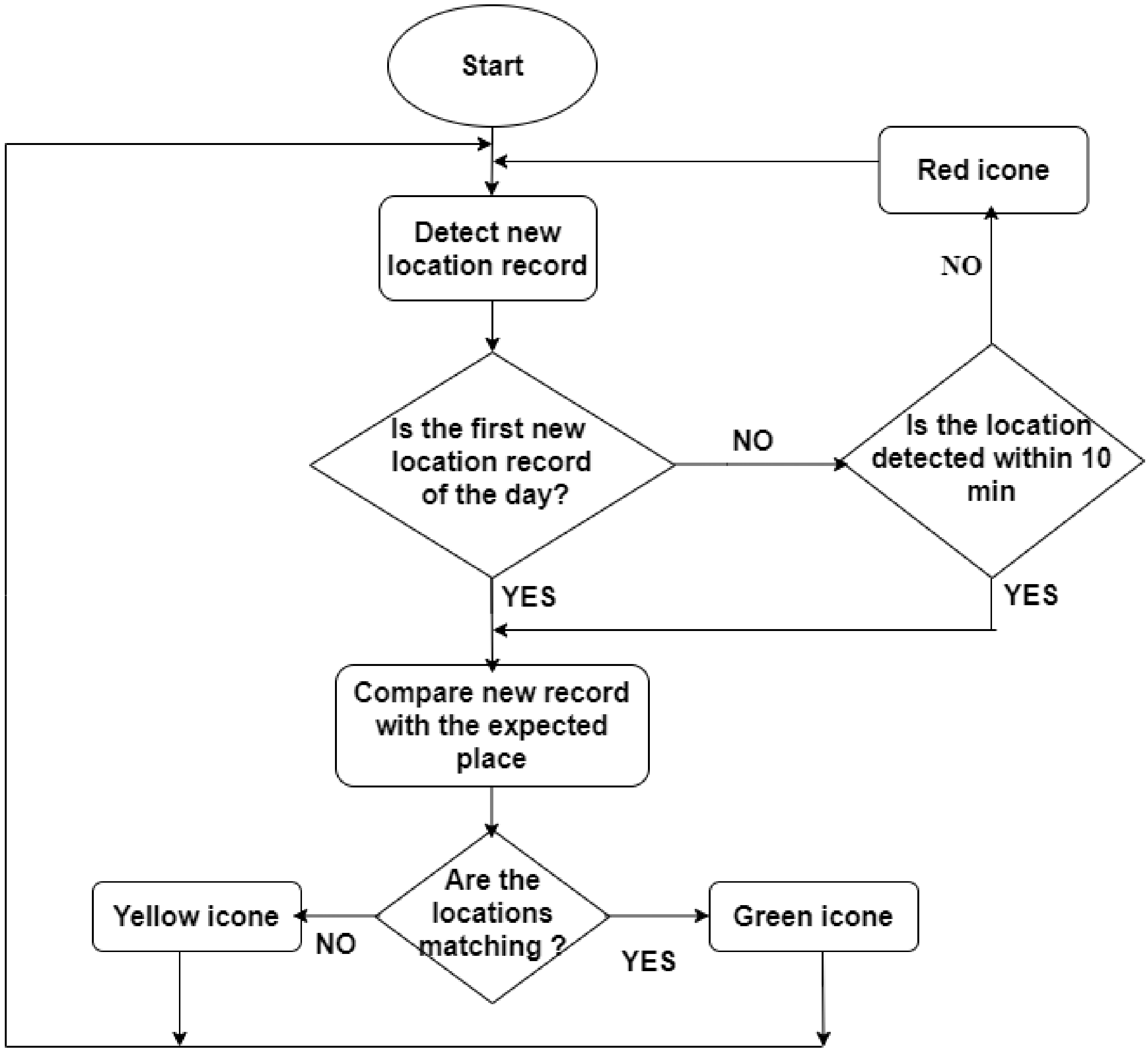


Figure 3: Flowchart of software unit

(iii) Reporting unit

The reporting unit comprises the web-based interface intended to fetch information from the cloud using HTTP protocol and then display it to the desktop computer to visualize the radiation worker's actual behaviour. First, the TAEC managerial officer views the worker's comportment by clicking the icon of the dropdown menu list of clients to display the wanted one. Then, he/she promptly grasp the Map on which location is traced and perceives three information, namely, the workers with their names:

(a) Wearing the dosimeter and being in the expected place noticeable by a green icon

(b) Wearing the dosimeter and being out of the expected place visible by the yellow icon

(c) Not wearing the dosimeter and listed in the text box.

Upon that, there is the ability to download a daily report in pdf and table format with the following data; name, location, start time, end time, total hours, and status (i.e., indicate whether the dosimeter was worn within the range or out of the range).

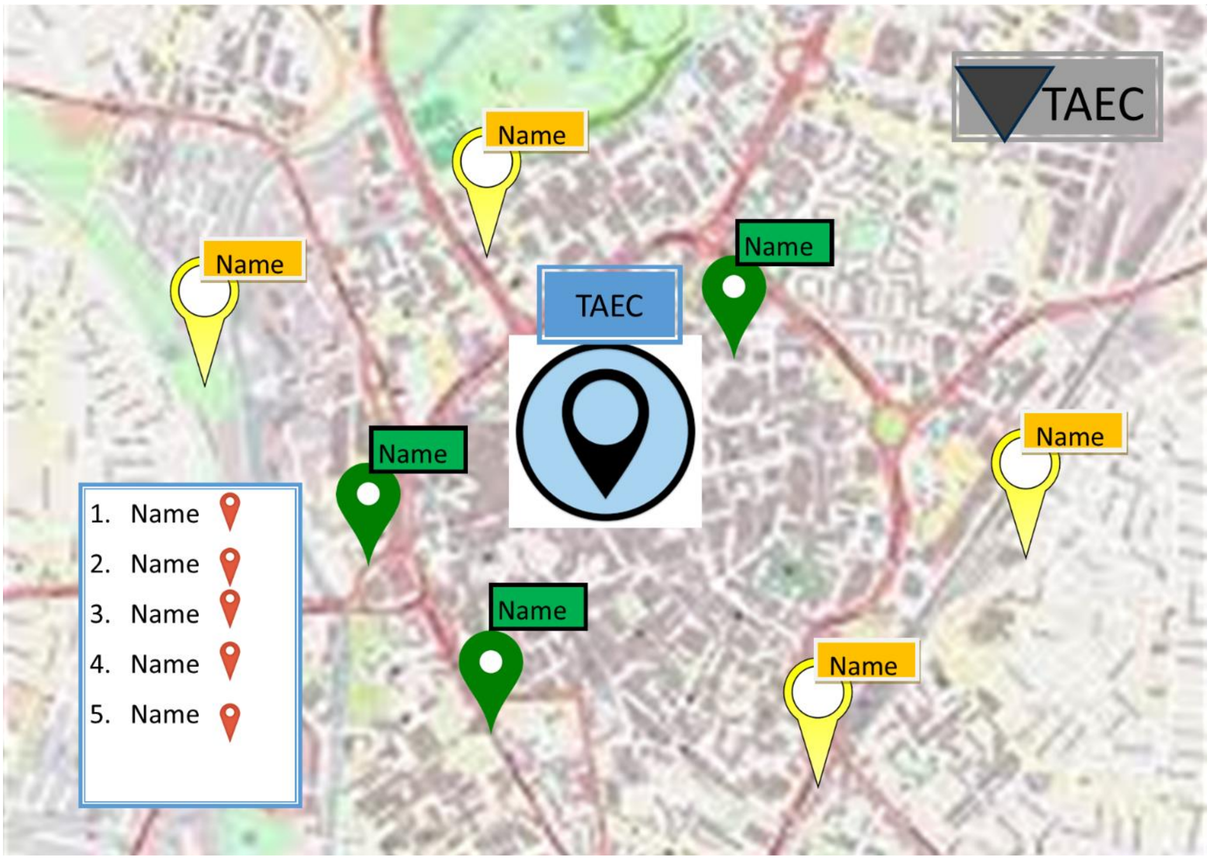


Figure 4: Visualization of the mapping functionality of the web application

3.9 System Development

The main drive of the developed system is to witness wearing individual dosimeter within the radiation job site. Principally, the system consists of the following parts: hardware, software, and Web server as well.

3.9.1 Hardware Requirements

The hardware part consists of Thermoluminescence Dosimeter (TLD), Human body detector, GPS receiver module, ESP32-Wroom-32D Microcontroller, and 9V Rechargeable battery. The main used hardware for developing an IoT-based monitoring and Reporting System for Dosimeter Wearers in Radiation Areas is summarized in Table 2.

Table 4: Components used

S/N	Components
1	Dosimeter (TLD)
2	Max30100 Oximeter sensor
3	GPS receiver module
4	ESP32 Microcontroller
5	Power supply
6	LEDs
7	Resistors
8	Jumper wires

(i) Dosimeter

A thermoluminescence dosimeter (Fig. 5) is a device that measures the dose amount of ionizing radiation that is absorbed while working in a radiation area. It is worn on a person's chest to record the radiation dose received.

Figure 5: Dosimeter

(ii) The Max30100 Oximeter sensor

The oximeter sensor (Fig. 6) helps to observe if the radiation worker has worn the dosimeter or not while performing his/her daily duties.

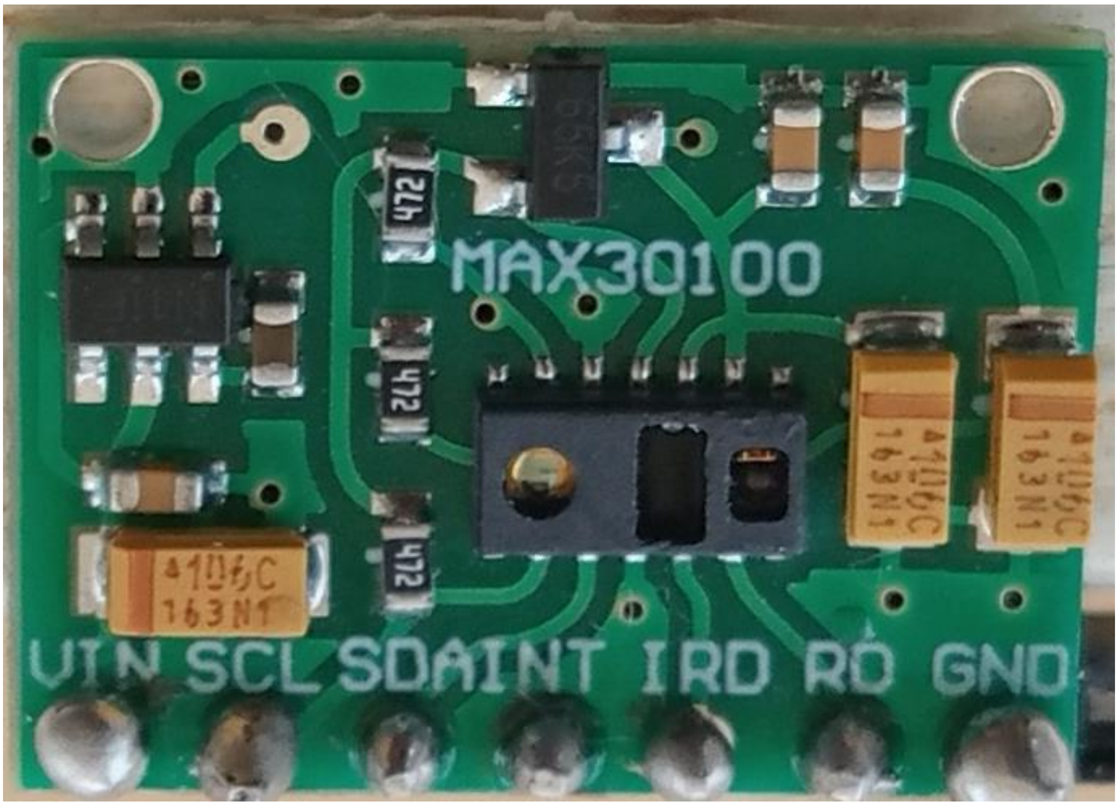


Figure 6: Max30100 Oximeter sensor

(iii) Global Position System receiver module

Global Position System receiver module is a device that tells where a person is by determining a precise location and timing information from a GPS satellite no matter where the user is on the earth. The location computation/the position determination is based on the utilization of satellites circling in the space segment that provide a signal that contains coordinates of latitude and longitude.

The NEO-6M is a GPS receiver module with an external antenna. That is, it needs to be soldered. Also, the NEO-6M GPS receiver module has a low power consumption of 3V to 5V with a default baud rate of 9600 bps. In this project, it was interfaced with the Esp32-Wroom 32 Wi-Fi microcontroller. However, the NEO-6M GPS receiver module is compatible with other microcontrollers too.

Figure 7: Global Position System receiver module

(iv) The ESP32-Wroom-32D Wi-Fi & Bluetooth Microcontroller

ESP32 Microcontroller (Fig. 8) is a system on a chip microcontroller with integrated Wi-Fi and dual-mode Bluetooth. It was the brain of the proposed system, the one to receive inputs, process them, provide a relevant command, and finally, send the data to the Webserver where the monitors for further process will retrieve them.

Figure 8: ESP32 Microcontroller

(v) The 9V Rechargeable battery

The rechargeable battery served as the source of low power supply to the entire system (Fig. 9).

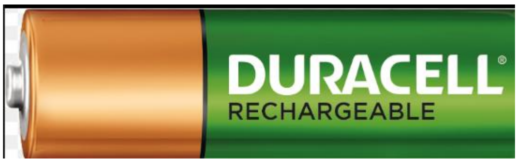


Figure 9: Rechargeable battery

Figure 10 depicts the system circuit diagram where inputs and outputs devices to and from a microcontroller are represented.

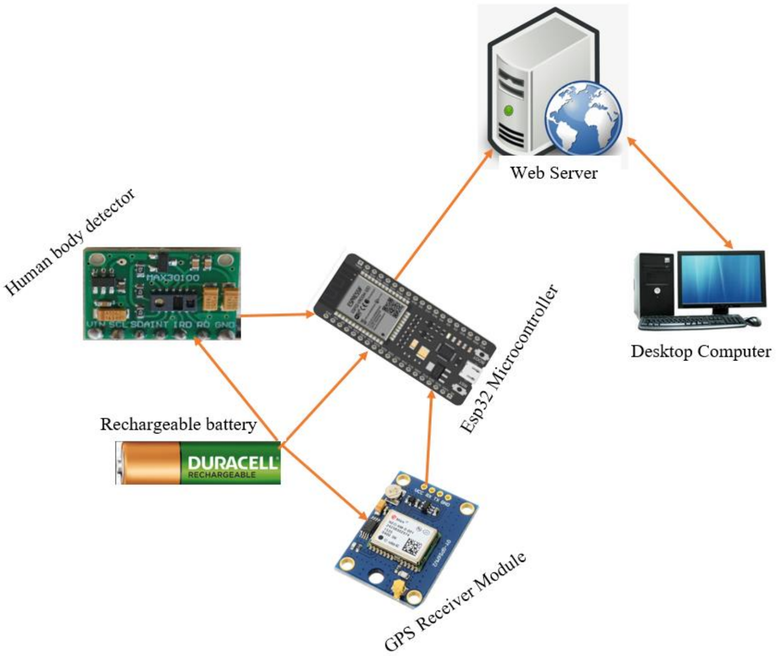


Figure 10: System circuit diagram

3.9.2 Webserver

Weber server, which is a hardware and software combination that fetches and keeps track of data, served the information to the TAEC manager room. The collection on of data through GPS and oximeter sensor after-treatment process was a source for determining the individual risk level of radiation by visualizing them through the desktop computer and ensuring if dosimeter was worn or not at exact such time and while being at the expected location. Figure 11 shows a block diagram of the system.

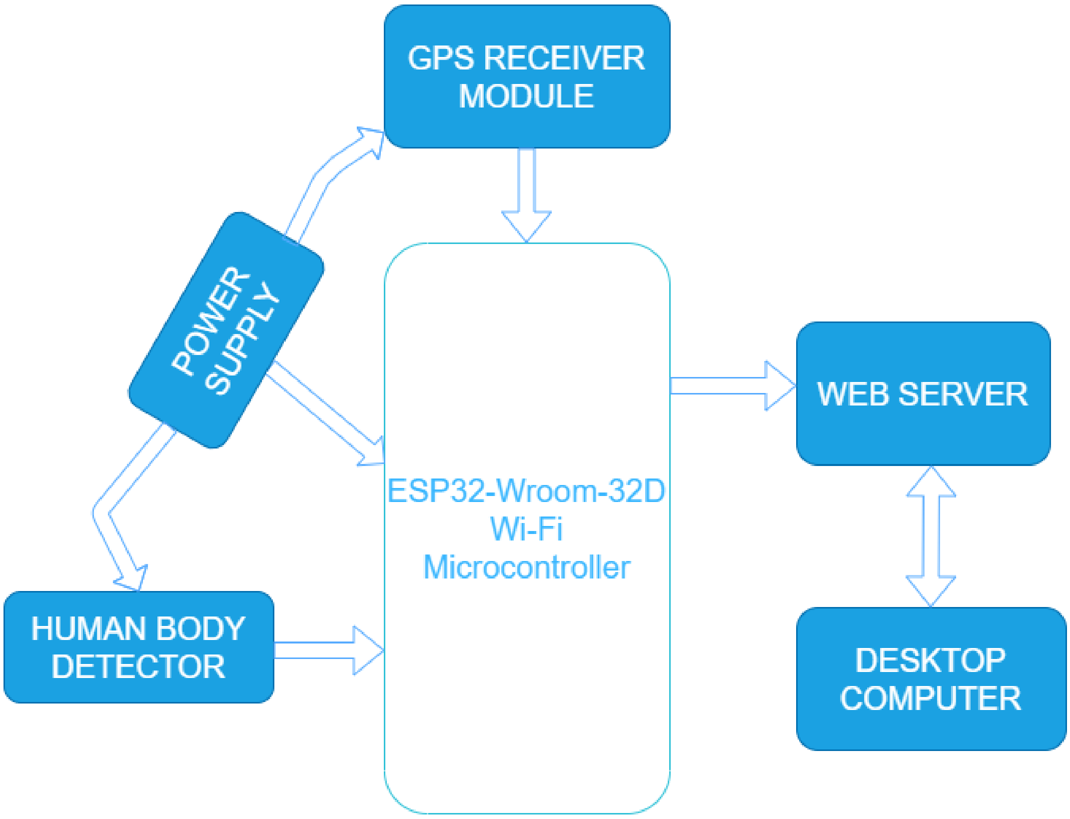


Figure 11: System block diagram

3.10 Software Requirement and Tools Used

The selection of software and tools used was based on stability since it supports more features and user-friendliness. On the other hand, devices used to develop the web-based focused on the front-end, back-end, and programming editor.

3.10.1 Front-end and Back-end programming languages

In web development, the front-end is all about the client-side (what users see on the front/screen). Simply put, it is the development of a web's graphical user interface as well as the programming that allows the interface to function so that users can view and interact with the web (*Front End vs Back End in Web Development | Engineering Education (EngEd) Program | Section*, 2022).

Conversely, Back-end web development supports the server-side (i.e., software program that users do not see). Simply put, it is the development of a program's code (inaccessible by users) that is needed to enable the user interface side of a web to exist. This includes the core application logic, databases, integration of data and applications.

(i) Bootstrap framework

Bootstrap framework is composed of Hypertext Markup Language HTML(HTML), Cascading Style Sheets(CSS), and JavaScript components (*Bootstrap (Front-End Framework) - Wikipedia*, 2022). For the front-end programming language, Bootstrap is a Cascading Style Sheets (CSS) framework aimed at responsive, mobile-first front-end development commonly used in web applications. It includes templates for typography, tables, forms, modals, and other elements that aid in the creation of web applications promptly. The following programming languages are comprised of Bootstrap.

Hypertext Markup Language (HTML) is a web page design standard (Suehring & Valade, 2013). HTML version 5 was used because of its standardized features, such as the web socket protocol, which is responsible for full-duplex communication in web technology. In addition, it agrees to take assistance from Cascading Style Sheets and JavaScript technologies.

Cascading Style Sheets (CSS) is a style sheet language used to make HTML web pages presentable. It is also a mechanism for incorporating style into a web document, such as colour, font, spacing, etc. This language was used in this project to design the appearance of the RWMR web interface.

JavaScript is a high-level client-side scripting language used in developing web pages (Suehring & Valade, 2013). It is a suitable tool for developing a dynamic form on the web page and has first-rate functions. JavaScript is a multi-paradigm programming language that can be used in object-oriented, imperative, or functional programming styles.

(ii) JavaScript libraries

JQuery and Leaflet are JavaScript libraries used to make the web interface. JQuery was used to handle queries between the front-end and back-end, while Leaflet library was used to design the web Map.

(iii) CodeIgniter framework

For the back-end programming language, CodeIgniter is an open-source PHP Model View Controller (MVC) framework for rapidly developing web applications. It includes pre-built libraries for connecting to databases and performing various operations such as sending emails, uploading files, and managing sessions.

(iv) Xampp Server

Xampp is a free and open-source web server solution stack package that is cross-platform compatible with all computer hardware and software types. Developed by Apache friend, it primarily consists of the Apache HTTP server, the Maria DB database, and interpreters for PHP and Pels scripts. It is referred to as a local webserver because it provides a suitable environment for PHP and SQL by means of its Apache and MySQL servers, respectively, and other programming languages (Suehring & Valade, 2013). The XAMPP Server is used to host MySQL and Apache Servers in this system locally.

MySQL is an open-source, reliable, and cost-effective database. MySQL is compatible with all major hosting providers. Furthermore, it is simple to use, and it has been recognized as the best tool for relational database management systems (RDBMS). Mysql is based on structured query language (Suehring & Valade, 2013). It was chosen for use in this project because it will allow users to request information from MySQL by simply typing the specific SQL statement.

3.10.2 Sublime Editor

A sublime editor is a sophisticated text editor widely used by web developers and is natively compatible with a wide range of programming languages. In addition, the sublime editor got rid of features like auto-indentation and sidebar, making it easier to work with the code base and allowing developers to track changes. Finally, the sublime editor is open source, and its current version, 4.0, which is compatible with various operating systems such as Windows, macOS, and Linux, was used for this project.

3.10.3 Hardware Programming

To program the hardware of this project, the C programming language of text editor Arduino Integrated Development Environment (Arduino IDE) was chosen due to its ease of use and compatibility with boards like ESP32 DevKit v1 ESP32 microcontroller board, NEO-M6 of GPS module, and MAX30100 of oximeter module.

3.11 System Implementation

The phase of implementation was the stage of converting the design into a working system by bringing together the hardware and software integrations to form an entire system. The hardware concentrates on integrating different sensors and components to automate tasks and processes. Moreover, the software offers various instructions for the proper function of the proposed system and features via interfaces to help users interact with that system. The complete system was implemented through the following steps:

3.11.1 Database Implementation

A database is a structured collection of information to be stored, accessed, and retrieved in a single centre to simplify the work. It was used in this radiation worker monitoring and reporting system (RWMR system) to keep all information from the Esp32 microcontroller board about wearing behaviour and the current location of each supposed dosimeter wearer. Then, it is the storage where the software looks for and retrieves information before displaying them on the web-based. The RWMR database for this system was developed and supported by MySQL database management and PHP script for users' web connectivity. Figure 12 illustrates the tables structure of the database used to develop a web-based this system.

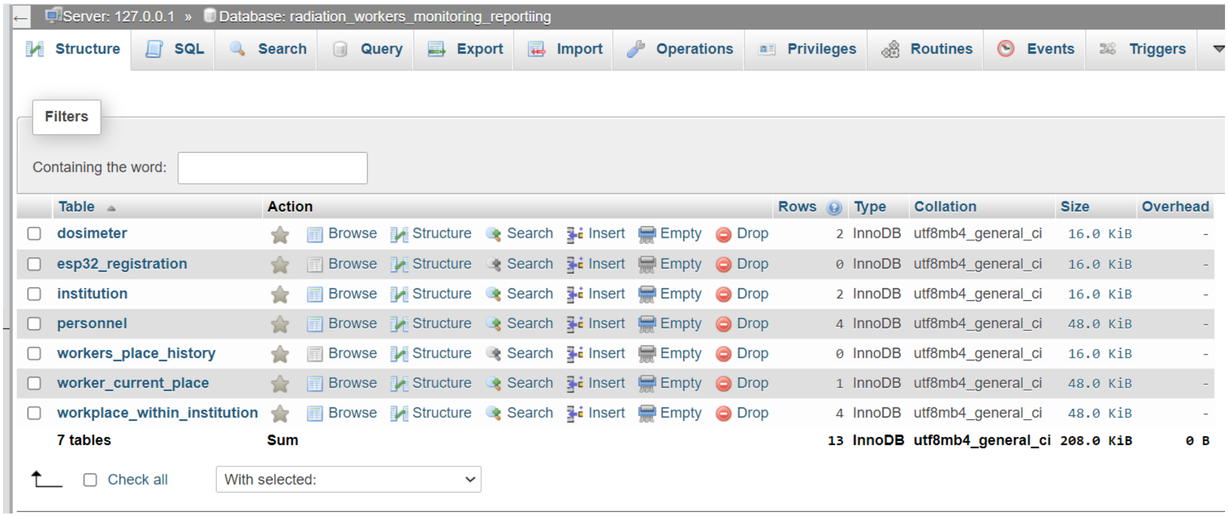


Figure 12: Radiation worker monitoring and reporting database

3.11.2 Database Tables Relationship

Figure 13 demonstrates the dependence between database tables and the rows structure of each table.

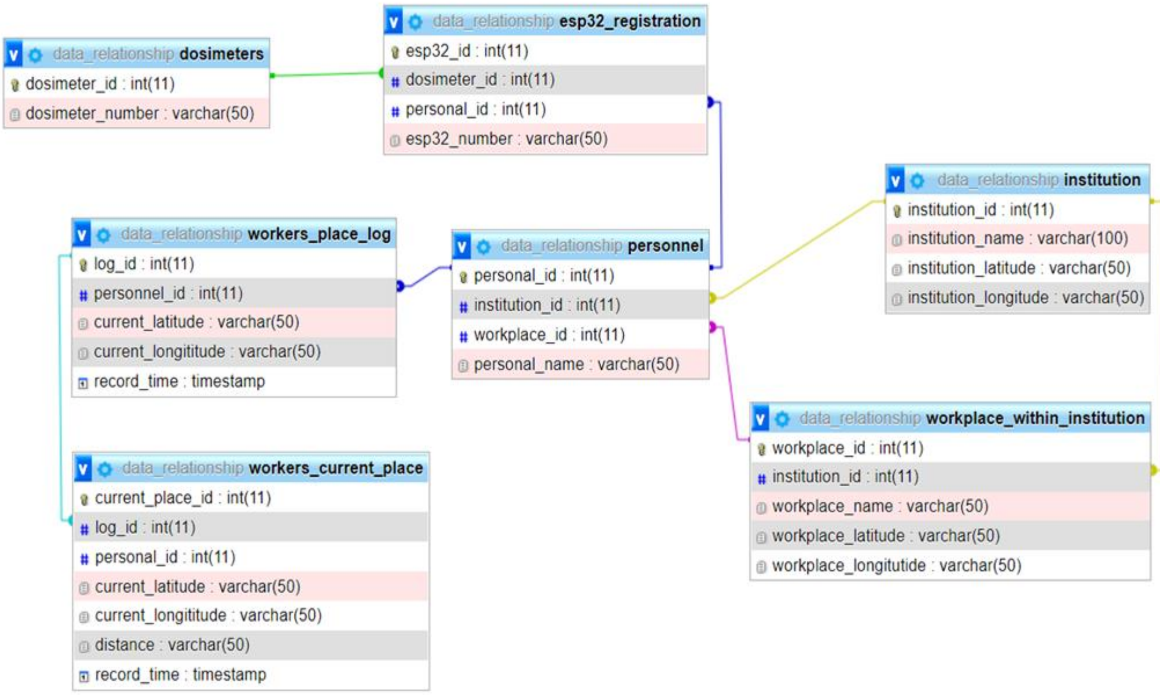


Figure 13: Radiation worker monitoring and reporting database relationship

The workerscurrent place: Table intended to store data from the workerplace log table temporarily. In Workerscurrent place table is where the software compares the expected location with the current one. And then place the workers on the Map with the corresponding information either wearing and being within or out of the expected workplace or not wearing.

The workerplace log: Table used to store all workers' events from the processing unit (ESP32 microcontroller), afterwards being detected by sensors and communicated to that microcontroller.

Esp32 registration table: Table used to store data identification of each processing unit (ESP32 microcontroller) and retrieves dosimeter identification from dosimeters table to know which dosimeter is assigned to which Esp32. In return, the one knows which ESP32 is assigned to which personnel.

Dosimeters table: Table used for storage of identification for each dosimeter.

Institution table: Table used for storing identification data of each institution and their captured location coordinates using Google Maps by capturing location latitude and longitude. Those captured coordinates are the ones that help to place on the Map the entire institution and their all-work place as well.

The personal table: Table used for storage of each staff's identification along with their institution and workplace within the institution.

Workplace within institution table: Table intended to store workplaces identification along with their location coordinates, the ones to be compared with GPS coordinates to ensure the fact of complete obedience of dosimeter wearing within or out of radiation Jobsite. For this project, the comparison is made by calculating the distance between two points of locations

3.11.3 Distance Calculation Between Two Locations Having Latitude and Longitude Points

In this project, the first location to be considered is the one determined by capturing its latitude and longitude with the help of a smartphone. The second location is the one determined by GPS coordinates.

The distance was calculated using the haversine formula. It is a special formula in spherical trigonometry, that is, to compute geographic distance on earth without regard for islands, hills, rocks, and other inconvenient factors. The haversine formula calculates the great-circle distance between two points on a sphere given their latitudes and longitudes. It has been proven to be the most accurate method of computing distances between two points on the surface of a sphere utilizing the latitude and longitude of the two points. Therefore, the first location is assimilated to the first point in spherical trigonometry and the second location to a second point. Here below is the haversine formula.

$$d = 2r\sin^{-1}(\sqrt{sin^2\left(\frac{\theta_2-\theta_1}{2}\right)+\cos(\theta_1)\cos(\theta_2)sin^2\left(\frac{\gamma_2-\gamma_1}{2}\right)})$$

Where:

d: is the distance between two points

r: is the radius of the earth which is

θ_2 and θ_1: are the latitude of the two points

γ_2 and γ_1: are the longitude of the two points

Figure 14 shows the PHP code implementation and the haversine formula used to calculate the distance for comparing the two locations.

```php
public function distance($lat1, $lon1, $lat2, $lon2) {

    $pi80 = M_PI / 180;
    $lat1 *= $pi80;
    $lon1 *= $pi80;
    $lat2 *= $pi80;
    $lon2 *= $pi80;

    $r = 6372.797; // mean radius of Earth in km
    $dlat = $lat2 - $lat1;
    $dlon = $lon2 - $lon1;
    $a = sin($dlat / 2) * sin($dlat / 2) + cos($lat1) * cos($lat2) * sin($dlon / 2) * sin($dlon / 2);
    $c = 2 * atan2(sqrt($a), sqrt(1 - $a));
    $km = $r * $c;


    return $km*1000; // return distance in m
}
```

Figure 14: Implementation of php code used to calculate distance

3.11.4 Location coordinate capturing

The location coordinates of the institution and the expected workplace for each worker have been captured and stored in the RWMR database in the table named institution table and workplace within the institution, respectively. The capturing was done using a mobile phone with the help of Google Maps. The process is simply done by first launching the google Map application, secondly, zooming in on the desired location. The subsequent stage is to press and hold on the label of that location, and then the coordinates appear at the top of the Map in the search bar. The last stage is to write down the indicated coordinate. Figure 15 shows the screenshot while capturing location coordinates at Nelson Mandela African Institution of Science and Technology (NM-AIST) using a mobile phone. The current location on an image is marked by a point labelled with blue colour with a shadow. When you press and hold on to the blue point, the location's latitude and longitude appear in the search bar.

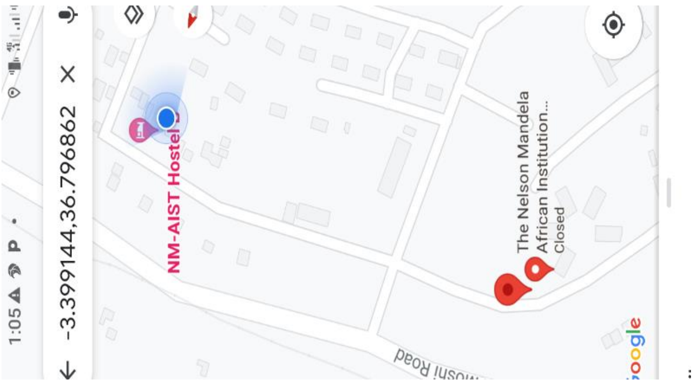


Figure 15: Location coordinates captured using mobile phone

3.11.5 Web-based implementation

A web server is a computer system that knows how to store web pages and how to serve them to multiple people at once when requested. For this system, the web-based for Radiation Workers Monitoring and Reporting System (RWMR System) receives and responds to request from the user (TAEC managerial officer) for the content containing information stored in the database about compliance and non-compliance of dosimeter wearing by visualizing workers on the mapping of the web application. The RWMR System appeals to a script and communicates with the database to produce a response through the structure client-server and database. The RWMR system web-based was implemented using PHP and Apache webserver. Figure 16 illustrates the login interface of the RWMR system. For this RWMR System, the login interface allows the TAEC managerial officer to log in, then have access to the user interface of a web application for viewing the behaviour of all workers in different workplaces within each client institution.

Figure 16: Login interface

3.11.6 Hardware Assembling

Later, the design process, sensors, and components were connected to enable them to interact, interoperate to make up the entire slight wearable device. They are afterwards configured on the ESP32 microcontroller Wi-Fi built-in, which serves as the system's brain, controls the whole monitoring cycle, and finally sends the report to the Webserver. Figure 16 illustrates how components were integrated.

The I2C SCL and I2C SDA pins of the Max30100 oximeter sensor were connected to GPIO22 (D22) GPIO21 (D21) respectively of ESP32 microcontroller. Also, the UART Tx and UART

Rx pins of the NEO-6M GPS module were connected to GPIO16(Tx2) GPIO17(Rx2) correspondingly to microcontroller ESP32.

Table 5: Max30100 oximeter and ESP board connection

Max30100 oximeter		ESP32 Board Pin
Pins	**Function**	
GND	Ground pin	GND
Vin	Voltage Input	3V3
SCL	I2C - Serial Clock	D22
SDA	I2C - Serial Data	D21

However, Vin and ground pins of both the Max301100 oximeter sensor and NEO-6M GPS module were connected to 5V designed for their proper operation since to power them from 3.3V of ESP32 causes failure of their appropriate functioning.

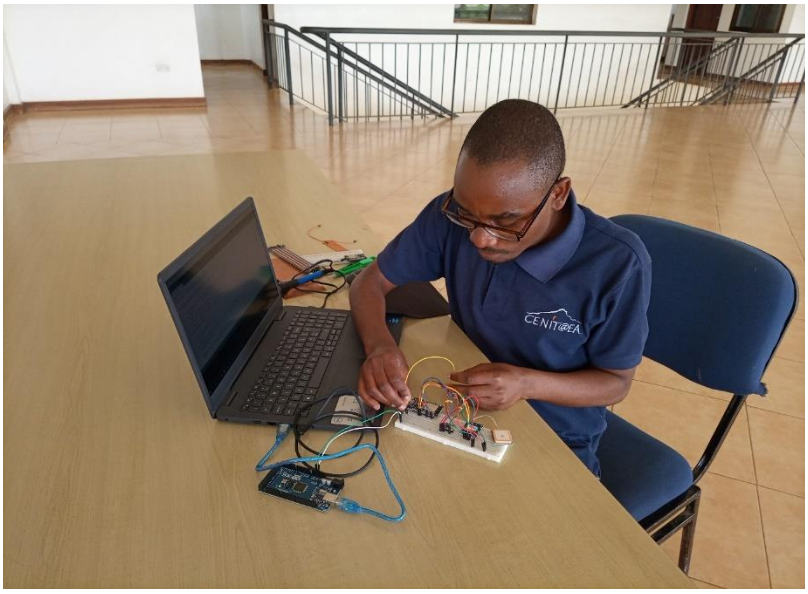


Figure 17: Breadboard test

3.11.7 System Programming

To implement this project, IoT Based Monitoring and Reporting System for Dosimeter Wearers in Radiation Areas, the ESP32 development board was programmed using Arduino Integrated Development Environment (Arduino IDE). The Arduino IDE is free software that allows manipulators to create the desired modules by writing the package code in a text editor and subsequently using them to provide instructions to the system.

To program the ESP32 development board, the first thing done was to add the ESP32 Board to Arduino IDE. Afterwards, several built-in libraries were included. On the other hand, the non-built-in were imported to and installed in Arduino IDE. Finally, the ESP32 Board is added to Arduino IDE by selecting install ESP32 by Espressif Systems, selecting the tools tab in Arduino IDE, then clicking on Board lastly Board Manager and installing it from there.

Here are some libraries used for this system:

(i) TinyGPS++.h for GPS receiver module. This TinyGPS++ library assists in dealing with conveniently getting signals from GPS modules. Among others extracting latitude, longitude, date and time, even position.

(ii) SoftwareSerial .h for serial communication. This SoftwareSerial library is built-in in Arduino IDE. It provides help to enable serial communication to take place on the other digital pins of the Board other than the serial port when simultaneous data flows are needed. In addition, the SoftwareSerial is used to replicate the functionality to ensure that any pin on the Board might be able to exchange serial data with other peripherals.

(iii) HardwareSerial.h for wiring. Hardware serial library facilitates to sending and receiving string over serial

(iv) EspSoftwareSerial.h for implementation of Arduino serial for ESP32. This ESPSoftwareSerial library is not the same as SoftwareSerial, the common library for Arduino boards; instead, it is mainly for ESP32 boards. The ESPSoftwareSerial allows users to convert a few serial ports on the Board using digital pins. This library code adds an encoder and decoder to the two digital pins, enabling them to be used for transmitter and receivers' signals in the same way that a serial port does.

(v) Arduino IDE supports languages such as C and C++; the system was made utilizing the C programming language. The program's output was displayed in the Arduino IDE's serial monitor window.

3.11.8 System Testing

This phase of system testing was done based on V-model testing, where the test is performed serially. Each step's development was straightly linked to the verification and validation stage. Then, with the aim of making sure that the system has been developed correctly, numerous tests were performed, right from program code to the working of the system, this involved unit testing, integration testing, system testing, and user acceptance testing.

(i) Unit testing

The unit test helps ensure that the minor subsystem of the system can operate properly when separated from the rest of the system. For this project, the unit test was performed to ensure the correctness of individual modules and the integration of multiple modules. This included a Max30100 oximeter sensor that sensed the human body when placed over the clothes. For this system, the code was set up so that if the human body is detected, the sensor sends the signal to the microcontroller for further process. That signal was displayed as the heart rate after the line, saying that the human body is detected via the serial monitor windows of Arduino IDE. Figure 18 and Fig. 19 depict the stand-alone hardware wiring of the oximeter sensor and visualizes the signal via serial monitor if the human body is detected.

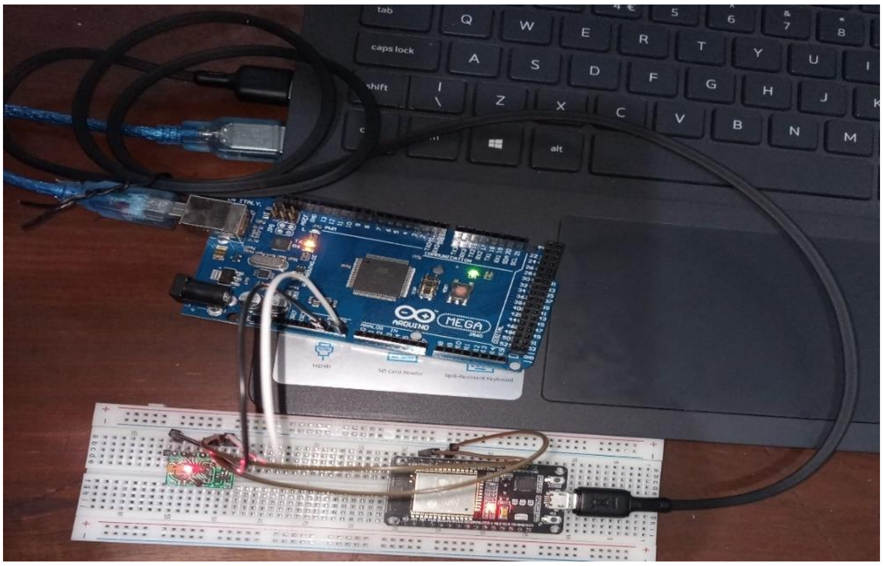


Figure 18: Oximeter sensor hardware wiring

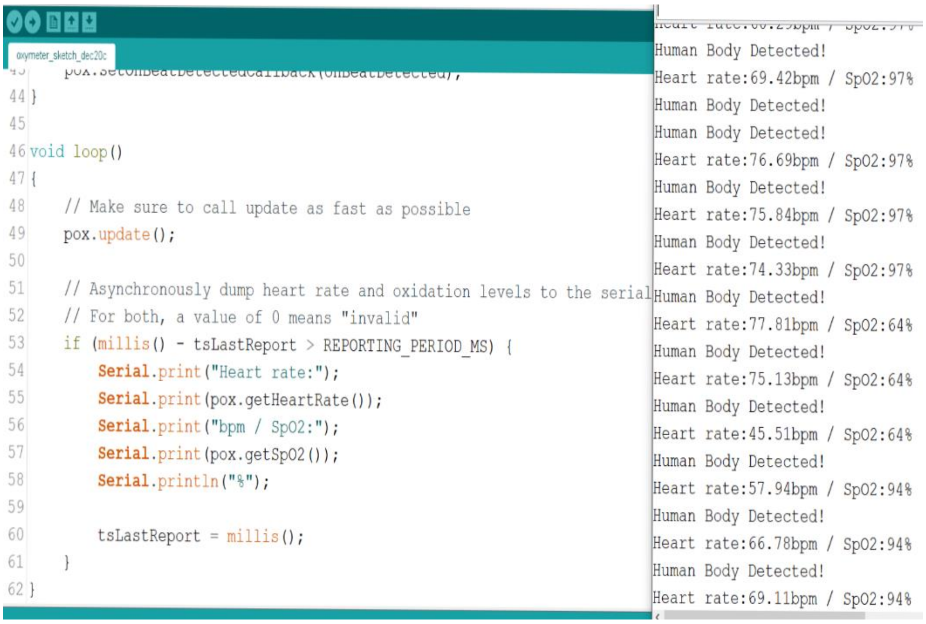


Figure 19: Signal visualization of human body detection

On the other hand, the GPS receiver module captured the signal accurately from the satellite, which carries the location's latitude and longitude. Global Positioning System (GPS) module communicates data to the processing unit. The illustration of the hardware wiring of the GPS module is shown in Fig. 20. Also, Fig. 21 depicts the visualization via the serial monitor window of latitude-longitude captured by the GPS module.

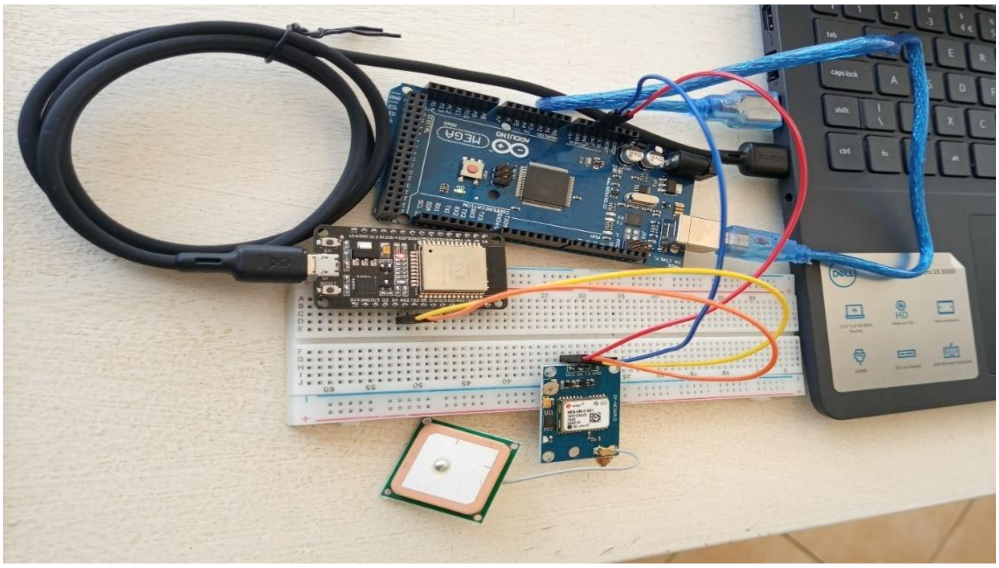


Figure 20: Global Position Service module hardware wiring

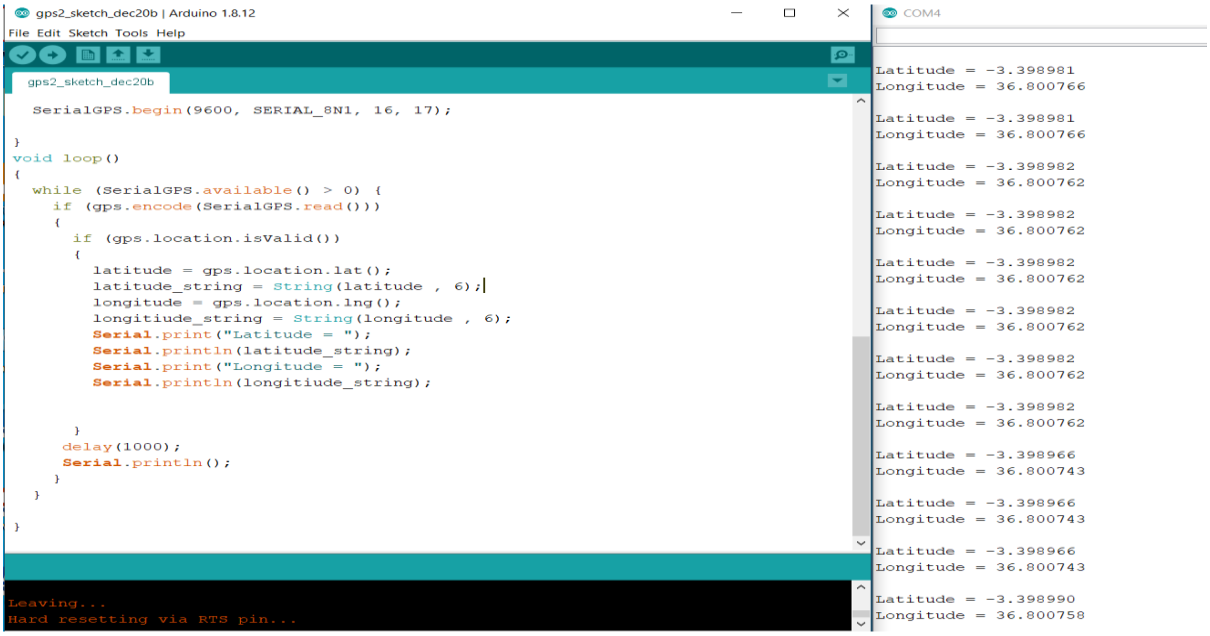


Figure 21: Visualization of latitude-longitude captured by GPS module

(ii) Integration testing

The integration testing was carried out to ensure that the created units tested independently could interact and interoperate with other parts. Testing how the Webserver radiation workers monitor and report system performance when integrated with the software that controls the hardware. The system received data from the processing unit (ESP32 microcontroller) and subsequently sent them to the database to be stored, later retrieving them for content display on the web application. Figure 22 illustrates the interaction between software that controls the system while sending data from the ESP32 microcontroller to the web server and then from a web server to the database. The assurance of interoperation was visualized in serial monitor windows with the message "GPS data sent to the database."

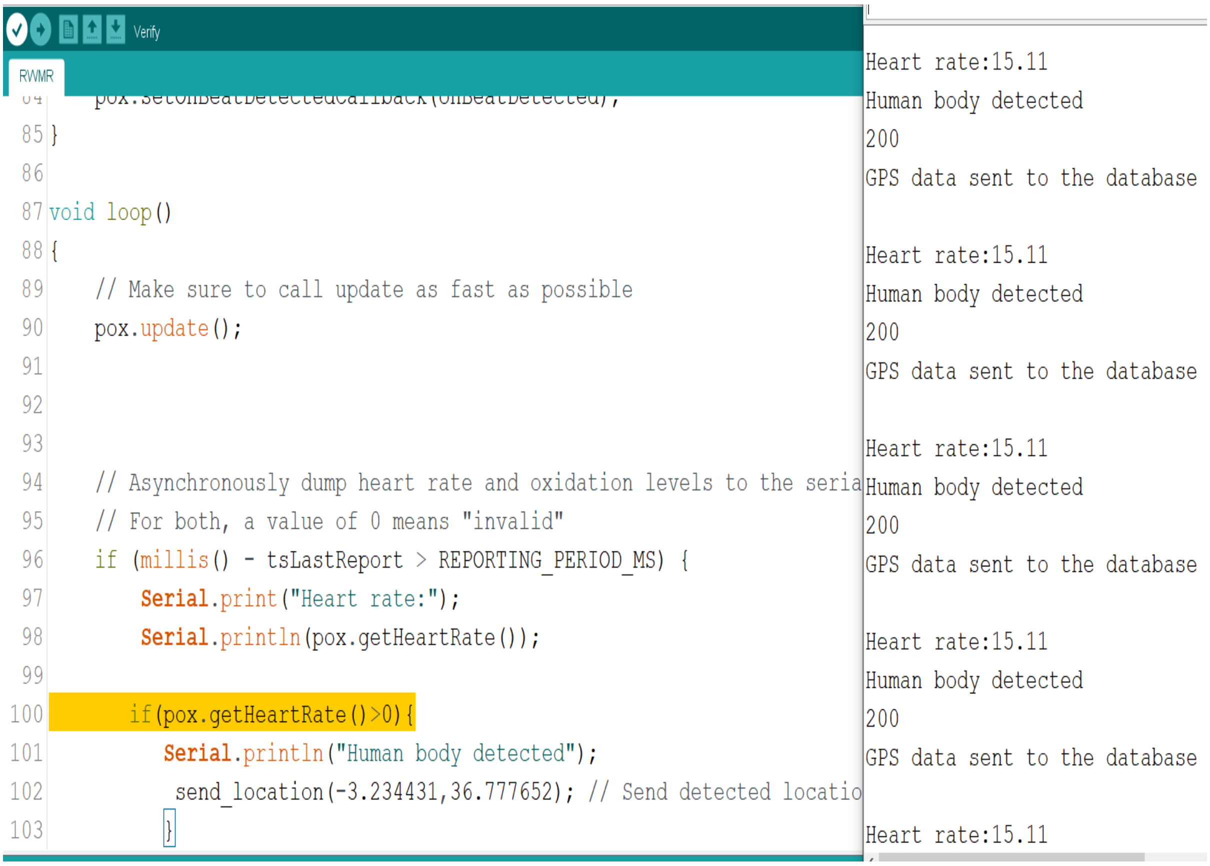
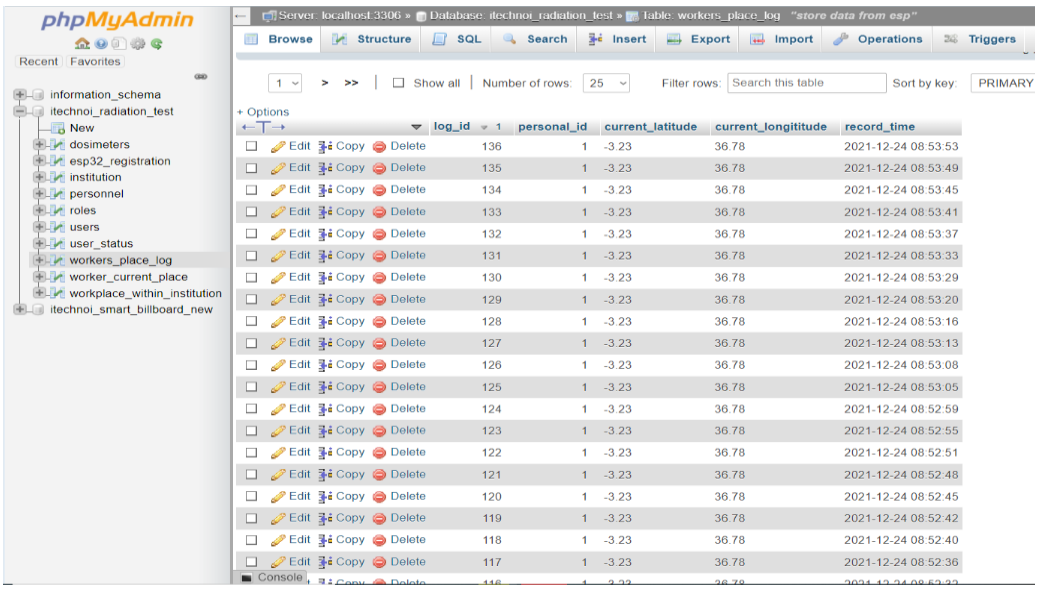


Figure 22: Visualization of interaction between microcontroller, web server, and database

Figure 23 witnesses that the workers' events processed by ESP32 are stored in the table of workersplace log while waiting to be retrieved and displayed on a web application. In Fig. 23, the events are viewed starting from the latest to the earliest one.



	log_id	personal_id	current_latitude	current_longitude	record_time
Edit Copy Delete	136	1	-3.23	36.78	2021-12-24 08:53:53
Edit Copy Delete	135	1	-3.23	36.78	2021-12-24 08:53:49
Edit Copy Delete	134	1	-3.23	36.78	2021-12-24 08:53:45
Edit Copy Delete	133	1	-3.23	36.78	2021-12-24 08:53:41
Edit Copy Delete	132	1	-3.23	36.78	2021-12-24 08:53:37
Edit Copy Delete	131	1	-3.23	36.78	2021-12-24 08:53:33
Edit Copy Delete	130	1	-3.23	36.78	2021-12-24 08:53:29
Edit Copy Delete	129	1	-3.23	36.78	2021-12-24 08:53:20
Edit Copy Delete	128	1	-3.23	36.78	2021-12-24 08:53:16
Edit Copy Delete	127	1	-3.23	36.78	2021-12-24 08:53:13
Edit Copy Delete	126	1	-3.23	36.78	2021-12-24 08:53:08
Edit Copy Delete	125	1	-3.23	36.78	2021-12-24 08:53:05
Edit Copy Delete	124	1	-3.23	36.78	2021-12-24 08:52:59
Edit Copy Delete	123	1	-3.23	36.78	2021-12-24 08:52:55
Edit Copy Delete	122	1	-3.23	36.78	2021-12-24 08:52:51
Edit Copy Delete	121	1	-3.23	36.78	2021-12-24 08:52:48
Edit Copy Delete	120	1	-3.23	36.78	2021-12-24 08:52:45
Edit Copy Delete	119	1	-3.23	36.78	2021-12-24 08:52:42
Edit Copy Delete	118	1	-3.23	36.78	2021-12-24 08:52:40
Edit Copy Delete	117	1	-3.23	36.78	2021-12-24 08:52:36

Figure 23: Visualization of data stored in the database from a web server

(iii) System testing

As opposed to the unit and integration testing, system testing is concerned with the entire system. At this stage, the overall system was tested to check whether it meets design requirements. The developed wearable prototype was worn at the chest level of the body, which is sensible for ionizing radiation while entering the human body. The oximeter sensor was positioned facing the body to continuously sense the presence of the human body, in other words, at the lower part of the device. The dosimeter and GPS module were placed at the upper part of the device to unceasingly record the amount of radiation and detect the satellite's signal to continuously capture the location's coordinates.

(iv) User acceptance testing

The user acceptability testing approach was used to evaluate the system's capability in the user environment with actual data using a prototype made from assembled sensors and components.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 System Testing Approach

The functionalities of the developed system were tested. The system functioned as expected by detecting the human body and then activating the GPS module to start sensing location, capturing the location's latitude and longitude, and then sending them to the processing unit. If there is nobody sensed, the system was able to do not trigger the location sensor to start, and there was no signal sent to the ESP32 microcontroller. Furthermore, data were stored in the RWMR database for later display accordingly to delay setting to avoid interference in data streaming. Lastly, an immediate visualization of live data about workers wearing dosimeters and being within or out of the expected working places was able to be displayed on the web application. Even the ones not wearing dosimeters were listed in the text box with their institution and workplace name. Figure 24 shows an instant visualization of a real-time report about workers' behaviour.

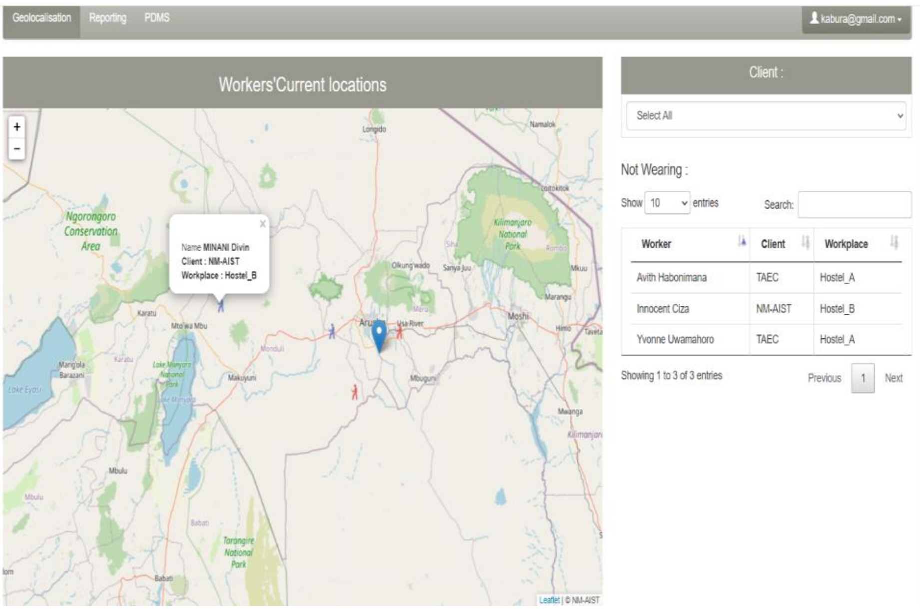


Figure 24: Visualization of real-time data about dosimeter wearing and not wearing for all institution

In the dropdown menu list of Fig. 24, when the user clicks on the select all, the system was able to output by placing the TAEC institution at the Centre surrounding client institutions. In that Fig. 24, we can see humans stick with blue and red colours and label indicating their details.

The TAEC managerial officer can directly get a general insight into ones wearing dosimeter and ones not wearing. Since the blue colour witnesses, the dosimeter wearing while being in the range of the expected working place. Conversely, the red colour witnesses wearing dosimeter being out of the expected workplace range, however, in the institution limit. The text box for non-wearing has the capability to show a maximum of ten (10) entries at once. Therefore, there is an option to click on the next button to view the rest or search for the specific worker.

On the other hand, Fig. 25 depicts the result of selecting a client- institution (for instance, NM-AIST).

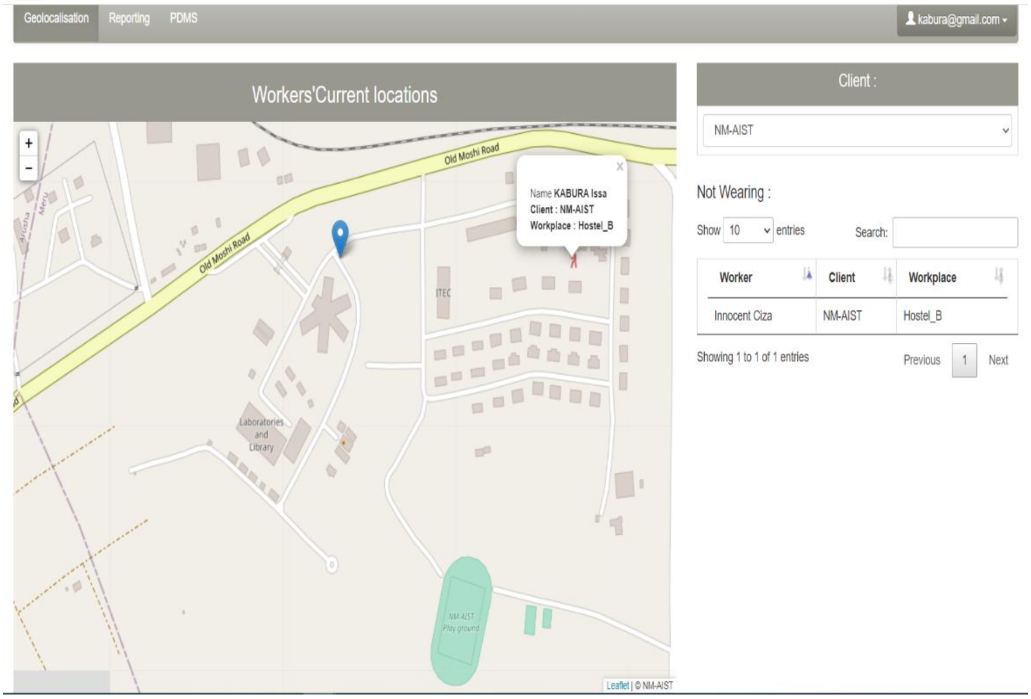


Figure 25: Visualization of the selected client-institution

In other words, the user requests the Webserver to provide information about radiation workers in the NM-AIST institution. The system responds by tracing in the centre on the Map the location with the blue icon location and all working places within. In Fig. 25, we can see a human stick in red with a label containing his/her name, client institution and workplace name. As said earlier, this means that the workers are wearing the dosimeter and are within the NM-AIST limit, but not in the expected location (their proper workplace). Lastly, the worker who did not wear the dosimeter is displayed on the right side of the Map in the text box with all the details.

4.2 User acceptance testing approach

The approach of user acceptance testing for this system was performed using the made prototype. Then, with the actual data, the prototype was tested to prove the features of the developed system. Table 3 illustrates the features of the developed system.

Table 6: Developed system features

Features	Descriptions
Smart dosimeter wearing	The system was able to distinguish the human body from other materials.
Real-time updates	The updates on dosimeter-wearing status were timely, human body and location were detected.
Real-time report	Witness of wearing individual dosimeter within radiation site was provided.
Low cost	The developed system is cost-effective and can be used in any country in the region.

4.3 System Validation

System validation of this developed system was performed using functional and non-functional requirements. Table 7 and Table 8 depict results on both functional and non-functional requirements validation.

Table 7: Functional requirements validation results

Requirements	Result descriptions
Human body detection	The presence of the human body was detected
Sense location	Location's latitude and longitude were sensed and then sent to the processing unit.
View information about compliance and non-compliance to dosimeter wearing	The witness on compliance and non-compliance to dosimeter wearing was timely visualized on the web application
General daily report generation	The general daily report was to be downloaded or printed

Table 8: Non-functional requirements validation results

Requirements	Result descriptions
Security	The login was allowed for the authenticated users and denied for the non- authenticated ones.
Usability	The system was found with ease of use when one clicks on wanted client, he/she promptly grasps the map where locations are treaced and radiation workers with their details.
Performance	The system was found able to handle multiple tasks by reporting radiation workers wearing dosimeter and being within or out of the expected place, even the ones not wearing were reported. In addition, it was able to generate a general daily report.
Reliability	The system found to be reliable by providing real-time data.
Scalability	Modification and improvement were performed without unwanted effects.

4.4 Discussion

The experiments conducted from various testing, and also from system functional and non-functional requirements validation proved that dosimeter wearing for radiation workers could be monitored and reported in real-time. Hence, reduce or eliminate the effects of non-compliance on dosimeter wearing while being at the radiation site. Figure 24 demonstrates an instant visualization of a real-time report about workers' behaviour on dosimeter-wearing. Parameters of the human body and location were monitored utilizing an oximeter sensor and GPS module, respectively. In addition, data updates from the ESP32 microcontroller were provided and stored every 10 minutes in the table of workers place log of the RWMR database. Figure 23 represents the visualization of live-stream data stored in the database.

Figure 25 shows workers wearing being out of their proper working places. Even the ones not wearing are displayed in the text box. In such a case, if those irregularities are constantly observed during working hours, a warning from TAEC can be provided to the identified ones without delay to maintain health security. Furthermore, the daily pdf document report generated by the system can be sent to radiation workers who do not abide by dosimeter wearing via email for their self-evaluation, hence saving their life.

The user acceptance testing proved that the system could effectively be utilized in a particular country in the region. Table 3 shows the features of the developed prototype. Based on the evaluations and observations carried out during system testing, the result gives assurance of the system's accuracy, effectiveness and affordability.

The system validation was carried out based on functional and non-functional requirements. Table 7 and Table 8 illustrate the system functional and on-functional requirements validation results. It is having been proved that from the development point of view, the proposed system was developed accordingly. On another hand, the developed system fulfilled the stakeholders' needs since the functions such as human body detection, location sensing, real time-employees 'behaviour visualization on map application, and daily report witnessing the dosimeter wearing were achieved.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This project aimed to develop an IoT-based monitoring and reporting system for radiation workers while they were at the radiation workplace using wireless technology and the IoT for remote monitoring and reporting the dosimeter wearing. The aim of the project was attained, the system for real-time employee behaviour and remote reporting of the dosimeter wearing was successfully developed.

From the evaluation of the existing system for radiation and radiation workers monitoring, there was a research gap on having an intelligent strategy for monitoring and reporting remotely staff wearing dosimeters in radiation working places. Therefore, this project came out with the development of a locally made radiation workers monitoring and reporting system that allows the TAEC managerial officer to visualize remotely on the mapping web application the radiation workers' behavior on dosimeter wearing then put in place adequate measures reduction or elimination of radiation hazard.

On the basis of both functional and non-functional requirements, the system validation was completed. The developed system fulfilled the stakeholders' needs. It included functions such as human body detection, location sensing, real time-employees behaviour visualization on map application, and daily report witnessing the dosimeter wearing.

Given that we live in a connected world and that the environment has an impact on human life, prevention is preferable to treatment. And it is inevitable to improve the quality of service and ensure safety in workplaces. However, many diseases may arise as a result of a lack of precautionary measures or a failure to make personal decisions against radiation, for example.

However, having a smart safeguard system solution for monitoring staff wearing dosimeters in radiation working environments is preferable, as is providing real-time employee behaviour and remote reporting, as is the goal of this proposed system. It contributes to overcoming radiation hazards, increasing families' income, and allowing workers longevity. If this system is implemented and used effectively, it will make assurance on dosimeter wearing being within or out of radiation site, hence improving radiation safety and increasing health security, also, increase the accuracy in calculation of an individual occupational radiation dose, finally a reduction of the cost related to biased health risk estimation.

5.2 Recommendations

In today's modern society, where radiation is widely used, a strategic measure to raise awareness about the dangers of excessive radiation exposure and radiation safety is to be taken into consideration and nonstop improved.

Considering the evaluation conducted by users at TAEC, the radiation workers monitoring and reporting system is recommended for implementation and used by TAEC in the dosimetry laboratory under the department of Personal Monitoring Dose and Calibration Laboratory.

The application of the developed system will significantly improve the current method of personal monitoring dose in Tanzania and the region as well. The following are the recommendations to the concerned stakeholders in radiation safety and radiation hazard reduction, also to the concerned stakeholders in education in Tanzania

(i) To implement and utilize the developed system and adopt to support in promoting early warning to ones reported not wearing the dosimeter or wearing but, being out of the expected working places.

(ii) Through the Ministry of Education, Science and Technology of Tanzania. Stakeholders in education should encourage the young generation to take radiation matter and be innovative. Emerging technologies, such as Embedded Systems, the Internet of Things, Artificial intelligence, Machine learning, the Mobile application, can be used. Finally, to develop a local system that can strengthen radiation safety and radiation hazard reduction.

In addition to that, due to the project time limitation, this project was not able to develop a mobile application so that to be able to visualize the real-time employee behaviour and remote reporting of the dosimeter wearing anywhere. Furthermore, the system can be improved to sense location using internet-enabled by the built-in Wi-Fi of ESP32 microcontroller instead of GPS module. Therefore, the improvement of the system by having a mobile application and sensing location using the ESP32 microcontroller will be an added benefit.

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APPENDICES

Appendix 1: Hypertext Preprocessor Script to Set the Map Content

Script for filtering institutions

```php
public function index()
{

    $this->update_location();// to update the temp table

    $institution_id=$this->input->post('institution_id');// get selected client

    $tab_coordonne = "";
    //$tab_itineraires = "";
    $center=8;
    $tab_Infos='';

    $criter=array();

    if(!empty($institution_id)) {

        // If you whant to display a particular client

        $sql = "SELECT * FROM `worker_current_place` WHERE `personal_id` in
        (SELECT `personnel_id` FROM `personnel` WHERE `institution_id` = ".$institution_id.");"; // Retrieve
        current locations of workers of the selected institution

        $workers_location =$this->Model->getRequete($sql);

        $sql2 = "SELECT * FROM `personnel` WHERE `institution_id`= ".$institution_id." AND `personnel_id` NOT IN
            (SELECT `personal_id` FROM `worker_current_place` WHERE 1);"; // Retrieve workers not wearing

        $workers_not_wearing =$this->Model->getRequete($sql2);

        // center points

        $institution=$this->Model->getOne('institution',array('institution_id'=>$institution_id));

        $tab_coordonne =$institution['institution_latitude'].",".$institution['institution_longitude']; // to
        center the map on the selected institution

        $data['institution_name'] = $institution['institution_name'];

    } else {
```

Script for global display

```php

    } else {

        // If there is no client selected/ display By default

        $workers_location=$this->Model->getList('worker_current_place',$criter);

        $sql1 = "SELECT * FROM `personnel` WHERE `personnel_id` NOT IN (SELECT `personal_id` FROM `
            worker_current_place` WHERE 1);"; // Retrieve current locations of all workers

        $workers_not_wearing =$this->Model->getRequete($sql1);

        // center points at TAEC

        $institution=$this->Model->getOne('institution',array('institution_name'=>'TAEC'));

        $tab_coordonne =$institution['institution_latitude'].",".$institution['institution_longitude'];  // to
        center the map on TAEC location when no instition selected


        $data['institution_name'] = $institution['institution_name'];
    }
```

Script to differentiate wearing workers

```php
        $tabledata = array();

    foreach ($workers_location as $worker_location) {


        $personnel = $this->Model->getOne('personnel',array('personnel_id'=>$worker_location['personal_id']));

        $institution = $this->Model->getOne('institution',array('institution_id'=>$personnel['institution_id']));

        $workplace = $this->Model->getOne('workplace_within_institution',array('workplace_id'=>$personnel['
            workplace_id']));

            $LIEU_GPS_LNG = $worker_location['current_latitude'];
            $LIEU_GPS_LAT = $worker_location['current_longitude'];

            $MarkerIcon = base_url().'styles/images/icon.png';

            if ($worker_location['distance']>10) {
                // set yellow icon

                $MarkerIcon = base_url().'styles/images/red.png';

            } else {
                // set green icon
                $MarkerIcon = base_url().'styles/images/blue.png';

            }


            $icon = base_url().'leaflet/icons/regroup.png';
            $MarkerFixe = true;

            $tab_Infos = $tab_Infos . $personnel['personnel_id'] . '<>' . str_replace("'", "", $personnel['
                worker_name']) . '<>' . $LIEU_GPS_LAT. '<>' . $LIEU_GPS_LNG . '<>' . $MarkerIcon . '<>' . $
                MarkerFixe . '<>'.$institution['institution_name'].'<>'. $workplace['workplace_name'] .'<>'. $
                worker_location['record_time'] .'#';

        }
```

Appendix 2: Hypertext Preprocessor Script to Update Locations

```php
		public function update_location(){

			//Set Timezone to Tanzania
			date_default_timezone_set('Africa/Dar_es_Salaam');
			$ten_minute_ago = date('Y-m-d H:i:s', strtotime('-10 minutes'));

			$sql1 = "SELECT * FROM `workers_place_log` WHERE `record_time` > '".$ten_minute_ago."' ORDER BY `log_id` DESC";
			$worker_current_place = $this->Model->getRequete($sql1);

			$sql2 = "TRUNCATE `worker_current_place`";
			$this->db->query($sql2);

			foreach ($worker_current_place as $key => $worker) {

				$sql3 = "SELECT * FROM `personnel` JOIN workplace_within_institution ON personnel.workplace_id=workplace_within_institution.workplace_id WHERE personnel_id = ".$worker['personal_id'];

				$worker_institution_place = $this->Model->getRequeteOne($sql1);

				$workplace_latitude = $worker_institution_place['workplace_latitude'];
				$workplace_longitude = $worker_institution_place['workplace_longitutide'];
				$current_latitude = $worker['current_latitude'];
				$current_longititude = $worker['current_longititude'];

				$distance = $this->distance($workplace_latitude,$workplace_longitutide,$current_latitude,$current_longititude);

				$data1 = array(
				  'log_id' =>$worker['log_id'],
				  'personal_id'=>$worker['personal_id'],
				  'current_latitude'=>$worker['current_latitude'],
				  'current_longititude'=>$worker['current_longititude'],
				  'distance'=>$distance,
				  'record_time'=>$worker['record_time']
				);

				$this->Model->create('worker_current_place',$data1);
			}
```

Appendix 3: Hypertext Preprocessor Script to Retrieve Data and Prepare Table for Non-Wearing Workers

```php
            foreach ($workers_not_wearing as $worker_not_wearing) {

            $institution =$this->Model->getOne('institution',array('institution_id'=>$worker_not_wearing['institution_id'] ));

            $workplace =$this->Model->getOne('workplace_within_institution',array('workplace_id'=>$worker_not_wearing['workplace_id'] ));


                $workers = array();

                $workers[]=$worker_not_wearing['worker_name'];
                $workers[]=$institution['institution_name'];
                $workers[]=$workplace['workplace_name'];

              // $data['result']=$workers;
              $tabledata[]=$workers;

          }

        $template = array(
            'table_open' => '<table id="d_table" class="table table-bordered table-stripped table-hover table-condensed col-sm-4">',
            'table_close' => '</table>'
        );
           $this->table->set_template($template);

           $this->table->set_heading(array('Worker','Client','Workplace'));


            $data['result']=$tabledata;

                // end table praparation

                $this->load->view('RWMR_View',$data);
            }
```

Appendix 4: HyperText Markup Language Code for Institutions Selection

```
        <div class="col-md-4">
            <div class="text-center bg-primary">

                <label class="label-control"><h4> Client :</h4></label>
            </div>

            <form name="myform" id="myform" method="post" action="<?= base_url('map/RWMR_Controller') ?>">


            <table class="table table-bordered">

                <tr>
                                <td><select name="institution_id" onchange="fx_send()" class="form-control">
                                    <option selected value="">Select All</option>

                                    <?php
                                        foreach($institution as $key){

                                            $selected = ($institution_id== $key['institution_id'])?'selected':'';

                                    ?>
                                     <option <?= $selected ?> value="<?= $key['institution_id'] ?>"><?= $key['
                                        institution_name'] ?></option>


                                        <?php
                                    }
                                    ?>

                                </select>

                                </td>
                                </tr>


                                                <\/table>
```

Appendix 5: JavaScript Code to Set Icons and Popups

```javascript
                if(currentSA[0]==1){
                        j='---';
                    }

               var IconFixe = currentSA[4];



              var BPSIcon = L.Icon.extend({
                  options: {
                      shadowUrl: '',
                      iconSize: [15,20],

                  }
              });


        var Icone = new BPSIcon({iconUrl: currentSA[4]});

              L.marker(
                      [currentSA[3], currentSA[2]],
                      {icon: Icone,
             title: "Name: "+currentSA[1]+"\nTime : "+currentSA[8]+"\nClient : "+currentSA[6]+"\nWorkplace : "+
                 currentSA[7],
                          opacity: 2.5

                      }
              ).addTo(map)

               .bindPopup("</br>Name <b>"+currentSA[1]+"</br>Client : "+currentSA[6]+"<br>Workplace : "+currentSA[7]).
                   openPopup();
           }


    }
</script>
```

Appendix 6: Hypertext Preprocessor Script for Saving Current Detected Locations

```
    public function sendGPS() {

        $ESP = $latitude = $longitude =  "";

    if($_SERVER["REQUEST_METHOD"] == "POST") {

       $latitude =$this->test_input($_POST["value1"]);

       $longitude =$this->test_input($_POST["value2"]);

       $ESP = $this->test_input($_POST["value3"]);

       $esp32 = $this->Model->getOne('esp32_registration',array('esp32_number'=>$ESP));

       //Set Timezone to Tanzania
       date_default_timezone_set('Africa/Dar_es_Salaam');

       // 2001-03-10 17:16:18 (the MySQL DATETIME format)
       $Current_time = date("Y-m-d H:i:s");


       $data_to_insert = array(

       'personal_id' => $esp32['personal_id'],
       'current_latitude' => $latitude,
       'current_longitude' => $longitude,
       'record_time'=> $Current_time

       );

        $this->Model->create('workers_place_history',$data_to_insert);


        } else {

           echo "No data posted with HTTP POST.";
        }
   }
```

)

Appendix 7: Arduino Sketch for Libraries and Valuables Declarations

```
// Global library
#include <Wire.h>
#include <WiFi.h>
#include <HardwareSerial.h>
#include <WiFiServer.h>
// HTTP client library
#include <HTTPClient.h>
//Oximiter Sensor library
#include "MAX30100_PulseOximeter.h"
//GPS Module library
#include <TinyGPSPlus.h>

// Variables declaration
#define REPORTING_PERIOD_MS     1000
float latitude , longitude;
String  latitude_string , longitiude_string;
// wifi credits
const char *ssid =  "UMUHUMURE";
const char *pass =  "avith1986";
```

Appendix 8: Arduino Sketch to Send GPS Data to the Web Server

RWMR §

```
// Function to send GPS to the server
void send_location(double latitude, double longitude){
  //Open a connection to the server
    HTTPClient http;
    http.begin("https://itechno.info/map1/Home/sendGPS");
    http.addHeader("Content-Type", "application/x-www-form-urlencoded");
  //format your POST request.
    int httpResponseCode = http.POST("value1=" + String(latitude)
    +"&value2=" + String(longitude)+"&value3=" + String("ESP101"));
    if (httpResponseCode >0){
        //check for a return code - This is more for debugging.
      String response = http.getString();
      Serial.println(httpResponseCode);
      if(httpResponseCode== 200){
        Serial.println("GPS data sent to the database");
        }
      Serial.println(response);
    }
    else{
      Serial.print("Error on sending post");
```

Appendix 9: Poster Presentation

IoT based Monitoring and Reporting System for Dosimeter Wearers in Radiation Areas

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Introduction

The radiation source eternally exists in all living creatures and everywhere in the environment as well. There are two categories of radiation sources: ionizing and non-ionizing radiation sources. Overexposure to personal dose is a hazard; conversely, people do not care, even for individuals working in radiation sites. The Tanzania Atomic Energy Commission (TAEC) is an institution established by the Tanzanian government to ensure radiation safety. Despite the efforts, the overall performance of striving for the ionizing radiation health hazard is still needed because workers wearing dosimeters are not abiding by safety measures for ionizing radiation.

Problem Statement

The carelessness of adverse effects from exposure to radioactive sources leads to various serious sicknesses such as cancer. This is affecting the monitoring of dose recommendations accordingly to the international recommended dose limit, which is 20 millisievert (mSv) per year while monitoring the doses of occupational radiation.

Tools

Figure 1: Dosimeter

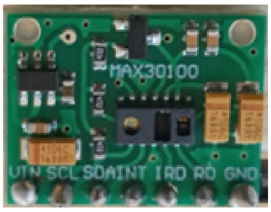

Figure 5: Max30100 Oximeter sensor

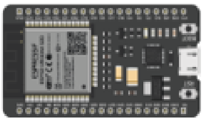

Figure 3: ESP32 Microcontroller

Figure 4: Global Position System receiver module

Figure 5: Rechargeable battery

Results

The system works by activating the GPS module to start sensing location, capturing the location's latitude and longitude, and then sending them to the processing unit. Live data about workers wearing dosimeters and being within or out of the expected working places was able to be displayed on the web application.

Conclusion

This project aimed to develop an IoT-based monitoring and reporting system for radiation workers while they were at the radiation workplace using wireless technology. It included functions such as human body detection, location sensing, real time-employees behavior visualization on map application, and daily report witnessing the dosimeter wearing.