# DESIGN AND DEVELOPMENT OF A ROBOTIC SYSTEM FOR RADIATION DETECTION AND MEASUREMENT

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**M.Sc. ENGINEERING THESIS**

**DEPARTMENT OF NUCLEAR SCIENCE AND ENGINEERING MILITARY INSTITUTE OF SCIENCE AND TECHNOLOGY**
**DHAKA, BANGLADESH**

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A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science in Nuclear Science and Engineering

DEPARTMENT OF NUCLEAR SCIENCE AND ENGINEERING MILITARY
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M. Sc. Engineering Thesis

By

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# DESIGN AND DEVELOPMENT OF A ROBOTIC SYSTEM FOR RADIATION DETECTION AND MEASUREMENT

## DECLARATION

I hereby certify that the research reported in the thesis with the aforementioned title is entirely original work of mine and has never been submitted elsewhere for academic or other purposes. Additionally, I attest that the intellectual content of this thesis is entirely my own creation, and that I dutifully acknowledged and cited all sources used in its preparation in the reference section.

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ABSTRACT

**Design and Development of a Robotic System for Radiation Detection and Measurement**

Generally, nuclear radiation installations require continual radiation surveys to confirm that there is no radioactive pollution or excess radiation dose levels that might lead to radiation safety concern. The present practice for regular radiation/contamination survey works is to utilize human operators, which is both cost inefficient as well as radiation risks. As with many repetitive, regular jobs, there are enough opportunities for the radiation safety issues to be improved using autonomous commercial or in-house design robotic systems. In this study, a prototype of a portable robotic system based on wireless communication protocol has been proposed for radiation detection in nuclear environment. The main motive of the robotic system is to help the human operators from getting unavoidable excess radiation levels. The robotic system consists of a ground 4 wheels carrier, GM counter based ionizing radiation detection box, Raspberry Pi- mini-computer unit, Pi camera unit &web platform based wireless controlling and recording system. In this system, the robot is regulated from a web based server in order to move towards a desired position to locate the radioactive source along with dose measurement. Radiation dose levels from some point radioactive sources (e.g. $^{137}$Cs, $^{60}$Co, $^{54}$Mn) placed at various locations in the nuclear radiation facility, have been monitored and compared with a commercial GM dose rate counter (Gamma Scout, w/ALERT model). The percentage of error has been found varying from 0 to 14% based on the experimental data. It is concluded that in-house design portable robotic systems are worthy for ionizing radiation detection and radioactive lost source identification in lieu of occupational radiation workers in the nuclear installations.

# সারসংক্ষেপ

সাধারণত, পারমাণবিক বিকিরণ স্থাপনাগুলোতে বিকিরণ সুরক্ষা মাত্রার অতিরিক্ত কোনও তেজস্ক্রিয় দূষণ বা অতিরিক্ত বিকিরণ ডোজ মাত্রা নেই তা নিশ্চিত করার জন্য ক্রমাগত বিকিরণ সমীক্ষার প্রয়োজন হয়। নিয়মিত বিকিরণ/ দূষণ জরিপ কাজের জন্য বর্তমানে মানব জনবল ব্যবহার করা হয়, যা ব্যয়বহুল, অদক্ষ এবং বিকিরণ ঝুঁকিপূর্ণ। পুনরাবৃত্তিমূলক ও নিয়মিতভাবে, স্বায়ত্তশাসিত বাণিজ্যিক বা নিজস্ব নকশাকৃত রোবোটিক সিস্টেম ব্যবহার করে বিকিরণ সুরক্ষা সমস্যাগুলি উন্নত করার জন্য যথেষ্ট সুযোগ রয়েছে। এই গবেষণায়, পারমাণবিক পরিবেশে বিকিরণ সনাক্তকরণের জন্য ওয়্যারলেস কমিউকেশন প্রোটোকলের উপর ভিত্তি করে একটি পোর্টেবল রোবোটিক সিস্টেমের একটি প্রোটোটাইপ প্রস্তাব করা হয়েছে। রোবোটিক সিস্টেমের মূল উদ্দেশ্য হল মানব অপারেটরদের অনিবার্য অতিরিক্ত বিকিরণের মাত্রা থেকে রক্ষা পেতে সাহায্য করা। রোবোটিক সিস্টেমে রয়েছে একটি গ্রাউন্ড চার চাকা বিশিষ্ট ক্যারিয়ার, জিএম কাউন্টার ভিত্তিক আয়নাইজিং রেডিয়েশন ডিটেকশন বক্স, রাস্পবেরি পাই-মিনি-কম্পিউটার ইউনিট, পাই ক্যামেরা ইউনিট এবং ওয়েব প্ল্যাটফর্ম ভিত্তিক ওয়্যারলেস কন্ট্রোলিং এবং রেকর্ডিং সিস্টেম। এই সিস্টেমে, ডোজ পরিমাপের সাথে তেজস্ক্রিয় উৎস সনাক্ত করার জন্য একটি কাঙ্ক্ষিত অবস্থানের দিকে যাওয়ার জন্য রোবটটিকে একটি ওয়েব ভিত্তিক সার্ভার থেকে নিয়ন্ত্রিত করা হয়। পারমাণবিক বিকিরণ পরীক্ষাগারে বিভিন্ন স্থানে স্থাপিত কিছু বিন্দু তেজস্ক্রিয় উৎস (যেমন $^{১৩৭}Cs$, $^{৬০}Co$, $^{৫৪}Mn$) থেকে বিকিরিত বিকিরণ মাত্রা নকশাকৃত পোর্টেবল রোবোটিক সিস্টেমটি দ্বারা পর্যবেক্ষণ করা হয়েছে এবং প্রাপ্ত বিকিরণ মাত্রা একটি বাণিজ্যিক জিএম কাউন্টার ভিত্তিক ডোজ রেট কাউন্টার (গামা স্কাউট, w/ALERT মডেল) এর সাথে তুলনা করা হয়েছে। পরীক্ষামূলক তথ্যের উপর ভিত্তি করে দেখা যায় ত্রুটির শতাংশ ০ থেকে ১৪% পর্যন্ত পরিবর্তিত হয়েছে। উপসংহারে বলা যায়, নিজস্ব নকশাকৃত পোর্টেবল রোবোটিক সিস্টেমটি পারমাণবিক স্থাপনায় আয়নাইজিং বিকিরণ সনাক্তকরণ এবং অজানা / হারিয়ে যাওয়া তেজস্ক্রিয় উৎস সনাক্তকরণের জন্য পেশাগত বিকিরণ কর্মীদের পরিবর্তে উপযুক্ত হতে পারে।

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| | |
|---|---|
| BAEC | Bangladesh Atomic Energy Commission |
| AECD | Atomic Energy Centre, Dhaka |
| IAEA | International Atomic Energy Agency |
| ALARA | As Low As Reasonably Achievable |
| SIMON | Semi-Intelligent Mobile Observing Navigator |
| CCD | Charge Coupled Device |
| VVER | Water Water Energy Reactor |
| GM | Geiger Mueller |
| GPIO | General Pin Input Output |
| LAN | Local Area Network |
| VNC | Virtual Network Computing |
| IP | Internet Protocol |
| WiFi | Wireless Fidelity network |
| CPM | Count per Minute |
| .CSV | Comma Separated Value |
| Sv | Sivert |

# CHAPTER 1
# INTRODUCTION

## 1.1 Background

Robotics is the most versatile technology used in automation of repetitively precise or hazardous work in the locations where human entry is limited. In the case of nuclear technology, a number of risks are present in addition to the underlying benefits. If the necessary precautions are not followed, it may be the most dangerous setting for people. Increasing demand has led to the usage of nuclear technologies in the domains of electricity, healthcare, industry, academia, and research. It is essential to implement safety measures to prevent exposing radiation workers to high radiation levels because employing nuclear technology cannot be avoided.

For the safety of the workers, ALARA (As Low As Reasonably Achievable) concept is being implemented worldwide for radiation protection purposes. To comply with the ALARA principle, workers have to maintain time, distance and shielding protocols. That is reducing the work time with the radioactive source, keeping distance and carrying shielding. The effective exposure to a single worker should not exceed 20mSv yearly, according to IAEA SAFETY GUIDE No. RS-G-1.1 (IAEA, 1999). The worker must immediately stop working in the nuclear environment after reaching the maximum exposure level. As a result, doing a dangerous operation requires more workers and more time.

To help with routine tasks like area monitoring, source handling, inspection and maintenance, as well as post-accident rehabilitation, robots or robotic devices must be used. The use of robots for routine area monitoring and radiation measurement has been discussed in this paper.

## 1.2 Literature Review

Robot use in nuclear situations is quite difficult. In Bangladesh's nuclear fields, there has been very little research on robotic systems for radiation assessment, but there has been a lot of global research and development on robots. To examine their primary function and various operating environments, a review of the design, development, and application of mobile robotic systems for the radiation detection was carried out (Tsitsimpelis et al., 2019). The majority of the robots were specialized for particular tasks (Tsitsimpelis et al., 2019, Tepco, 2017, Ducros et al., 2016). Figs. 1.1–1.6 depict a few of them.

Fig. 1.1: Robot used at the Chernobyl nuclear accident site.

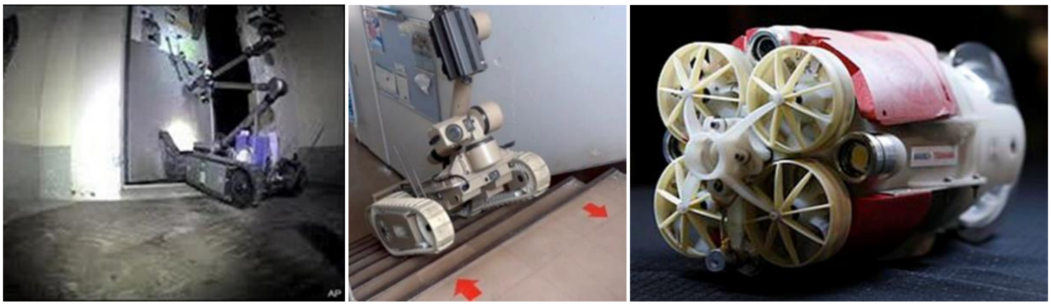


Fig. 1.2: Types of robot used at the Fukushima nuclear accident site.


Fig. 1.3: A robot system used to carry out repair work at a nuclear facility.

Fig. 1.4: Typical types of robot system used for radiation protection purposes at nuclear facility.

Fig. 1.5: Robotic device with a mechanical arm on the right and a camera on the left.


Fig. 1.6: Robot surveyor used for checking for radiation.

Some of them were deployed in high risk nuclear zones and some of them in non-critical areas. General sectors of robot utilization in the nuclear industry are- routine area monitoring robot, inspection and maintenance robot, radioactive waste handling and processing robot, decontamination and decommissioning robot, post-accident assistance robot etc. The key features of different robot systems that are available in the literature (Tsitsimpelis et al., 2019) are given in Table 1.1. Even though it is unavoidably incomplete, this table serves as a good representation of how useful different robots are for different tasks.

Table 1.1: Comparison of different types of robots (Tsitsimpelis et al., 2019)
T: tethered, W: wireless

| Robot | Operating Areas | Size/ Mass | Communication | Locomotion | Year |
|---|---|---|---|---|---|
| Three Mile Island Unit-2, USA | | | | | |
| RRV 1 | Reactor basement | 1270×734 x 483<br>181–453 | T | Six wheels | 1984 |
| LOUIE I | Aux. building cubicles | | T | Two Tracks | 1963 |
| Chernobyl, Ukraine | | | | | |
| KLAN | Sarcophagus | | W | Tracks | 1986 |
| MACS | Unit 4 shelter | | W | Wheels | 1995 |
| RCS | Exterior spaces | | W | Wheels | 1996 |
| NOMAD | Shelter for Unit 4 | 2400×2400 x 2400<br>550 | W | Wheels | 1996 |
| Pioneer | | 1219×914 x 914<br>500 | T | Tracks | 1997 |

| Robot | Operating Areas | Size/ Mass | Communication | Locomotion | Year |
|---|---|---|---|---|---|
| Tokaimura, Japan | | | | | |
| RESQ-A | Mock-up reactor areas | 580×400 x 550<br>50 | W/T | Four wheels | 2001 |
| RESQ-B/RESQ-C | | 1500×660 x 550<br>540(B)/650(C) | W/T | Tracks | 2001 |
| SMERT-M | | 760×600 x 1370<br>250 | W/T | Tracks | 2002 |
| SMERT-K | | - x 430×590<br>26 | W/T | wheels | 2002 |
| Fukushima Daiichi | | | | | |
| Packbot | Units Floor inspections | 686–889×406–521 ×178<br>11 | W | Tracks | 2002 |
| JAEA-3 | Unit 2 gamma imaging | 400×580 x 550<br>50 | T | Four Wheels | 2011 |
| Quince | Unit 2–3 floors/gas ducts | 1110×480 x 420<br>27 | - | Six Tracks | 2011 |
| Survey-runner | Torus room | 505–755×510 x 830<br>45 | T | Four Tracks | 2012 |

| Robot | Operating Areas | Size/ Mass | Communication | Locomotion | Year |
|---|---|---|---|---|---|
| Survey-runner | Torus room | 505–755×510 x 830<br>45 | T | Four Tracks | 2012 |
| Tele-runner | Suppression chamber | 600×500 x 800<br>100 | - | Tracks | 2015 |
| Frigoma | Near PCV | 650×490 x 750<br>38 | W | Four Tracks | 2012 |
| Rosemary | 1st to 3rd floor, all units | 700×500 x 170<br>45 | W | Four Tracks | 2013 |
| Sakura | 1st to 3rd floor, all units | 500×390 x 220<br>32 | T | Six Tracks | 2013 |
| Kanicrane | 1st floor, all units | 2360×700 x 1430<br>1250 | T | Two Tracks | 2014 |
| PMORPH 1 | PCV Unit-1 | 220×290 x 95<br>10 | T | Tracks | 2015 |
| PMORPH 2 | PCV Unit-1 | 316×286 ×93<br>10 | T | Tracks | 2016 |
| SCORPION | Unit-2 | 260×90 x 220<br>5 | T | Tracks | 2016 |

In this work, the role of laboratory based area radiation monitoring robots and its system design has been discussed. There are two types of scenarios for area radiation measurement, first one is the daily basis operation, where radiation level is controlled. Another is post-accident monitoring, where the radiation level is high. It is very important to be sure when the radiation level decreases to safe levels after an accident. A brief description on the research that has been carried out on radiation monitoring robots has been highlighted below.

As a mobile surveillance and monitoring robot, SIMON, or the Semi-Intelligent Mobile Observing Navigator, was created in 1990 (Weber et al., 1990). To begin with, the robot was employed at the US Laboratory to replace the requirement for prolonged human inspection at the aforementioned nuclear radiation facility. To provide television views of the radiation and nuclear plant, SIMON systems were created to monitor and communicate data on dose rates and ambient temperature. Another case study claimed that mobile robots are preferable than static ones for routine inspection and maintenance operations (Fujji et al., 1992). For nuclear zone inspection, the tethered robot was outfitted with a sonar sensor, an infrared sensor, and a CCD (Charge-coupled device) camera.

A system for integrated gamma-ray imaging was designed to improve the functionality of the robots and telerobotics employed in the radiation facility, according to research (Redus et al., 1994). The robot system identifies radioactive sources by combining a video camera and a -ray sensor. The creation of telerobotic units for use in the repair and maintenance of Spanish nuclear installations was published in 2003 (Iborra et al., 2003). It was demonstrated that with the right mechanical support, equipment, and software, commercial robots could also be employed in nuclear situations.

The capacity of readily available commercial robotic gear and tools for measuring to detect nuclear radiation in locations was described in another series of works (Cortez et al., 2007, Cortez et al., 2008, Cortez et al., 2009). It demonstrates a miniature robot Khepera, equipped with a tiny radiation detector to locate the area with a high radiation source. The study was implemented with a bidirectional interaction between observations and the detector to the application level.

An autonomous robot was developed in Japan for remote radiation dosage level detection (Kobayashi et al., 2012). Roomba, a robot that cleans floors, served as the equipped autonomous robot with the scintillation counter. A H8 microcomputer was equipped to remote control the Roomba and transmit the recorded radiation data. After the Fukushima nuclear accident, normal life had recovered after a while, once the decontamination of the area was concluded. However, till now radiation survey is still necessary in many common places for investigating radiation contamination and its level of suitability for humans to live in.

More purposeful radiation detection robot was also researched in Robot for Radiation Protection Assistance (RPAR) work (Zeb et al., 2007). Where the intention was to design a robot to help workers in more hostile radioactive areas to monitor radioactivity level. And can also be used to handle radioactive sources in routine activity and in case of any accidents. The movement of the robot was controlled by two wheels with a differential control system.

Assistance with Continuous Autonomous Radiation Monitoring was a ground based robot deployed in a noncritical nuclear environment (Bird et al., 2019). It was able to measure the α source successfully, embedded in the floor. Alpha particles are most ionizing radiation and it can be shielded by using a thin sheet of paper. So it is a challenge to detect α contamination. Because of low permeability, the detector had to be placed very close to the source to ensure reliable detection. The robot was developed to run on floor space, flat spaces, such as corridors, offices, and laboratories.

To avoid nuclear risks from radiation workers, a robotic based system, RoboJo (Robot of Jordan) was developed. It alerted everyone by sounding the onboard alarm, when the level of radiation had increased in the predefined-radius of area (Alfraheed et al., 2015).

For the purpose of measuring detector response in a moving source-detector setup, a wireless robot was created (Sing et al., 2014). It was economically created to run on plane surfaces in low radiation settings like hospitals and colleges. A vehicle-like robot was transporting a scintillation survey meter. When the source and detector were placed in a static facing each other position, the survey meter displayed a decent count rate.

For experimental purposes in the laboratory a portable prototype robot with detector of α radiation using long range remote control was developed (Vazquez et al., 2015). The system included a Human Machine Interface (HMI) developed with LabVIEW. Technological improvement for telemetry range (1 km) had been done by using a high gain antenna with a wireless modem.

For the purpose of detecting contamination and radioactive levels in waste containers, a radiation monitoring robot prototype was developed to work in a nuclear power plant environment (Maheswaran et al., 2016). Through LabVIEW serial communication and the

ZigBEE wireless communication protocol, the robot was observed and managed. A signal generates an alarm when the measured value exceeds the safe limit.

According to the IAEA database on Nuclear Power Reactors in The World, (edition-2020) there are 443 operational reactors in the world (IAEA, 2020). As the number of nuclear power plants has increased, nuclear accidents have also occurred. After the Fukushima nuclear accident, people were concerned about their health. It became a matter of interest to know the environmental radiation level. An economical, user friendly nuclear radiation detecting system was designed using Raspberry Pi for the non-technical publics (Archana et al., 2019). The system can be used to monitor the level of radioactivity in an area at home or at work.

## 1.3 Motivation

By 2023–2024, Bangladesh will host the first nuclear power plant of the Russian VVER–1200 type. Additionally, the nation is home to other nuclear facilities like research reactors and nuclear medicine facilities. Although there are many ways that nuclear technology is a blessing, there are a number of radiation risks as well. If the necessary precautions are not followed, it may be the most dangerous setting for people. It is essential to implement safety measures to prevent exposing radiation workers to high radiation levels because employing nuclear technology cannot be avoided.

The level of radiation dosage at these nuclear sites must be measured and detected on a regular basis. Robotics utilization is advised for this kind of specialized routine tasks. There are, however, very few scientific studies on robotic systems for radiation detection in Bangladesh's nuclear fields. The radiation level surrounding several nuclear sites has been measured using a prototype wireless remote-controlled mobile robot. Assuring the safety of the human employees from unintentional radiation exposure is the driving force behind the activity, which involves assisting them with remote monitoring (both radiation levels and visual survey) of dangerous zones where human presence should be minimized.

## 1.4 Objectives

The main aim of this study is to develop and design a proto type portable robotic system for radiation level detection and measurement, in and around the radioactive source and nuclear facilities, in order to protect the occupational radiation workers from unwanted radiation exposure. The specific purposes of the proposed research work are:

(i) To design and develop a prototype of a remote controlled portable robotic system with radiation detection system,

(ii) To analyze the performance of the robotic system by measuring background natural radiation level and various point radioactive sources ($^{137}Cs$, $^{60}Co$, $^{54}Mn$) placed at various locations in the nuclear laboratory and compare radiation level measured by commercial radiation survey meter with GM counter (Gamma Scout, w/ALERT model),

(iii) To transmit and store the measured radiation data in the web based control system, and

(iv) To analyze the GM counter performance by error calculation as well as energy response curve.

## 1.5 Structure of the Thesis

There are five sections to describe the thesis development.

**Introduction:** This chapter describes the background of the thesis work field and a summarized literature review related to the work, motivation of the work and objectives of the work.

**Robotic Systems in Nuclear Facilities:** This chapter two describes the basics of radiation monitoring and application of robotic systems in a radiation environment.

**Design Methodology:** In this chapter the design methodology and the performance analysis procedure of the robotic system has been explained.

**Result and Discussion:** In this chapter the specification of the developed robotic system has presented and describes the results of performance analysis shown in graphs.

**Conclusion and Future Scope:** This chapter concludes with the summary of the work and the topic of future scope.

# CHAPTER 2
# ROBOTIC SYSTEMS IN NUCLEAR INDUSTRY

## 2.1 Basics of Radiation Measurement

### 2.1.1 Radiation and Radioactivity

Radioactivity is a natural decay of an unstable atom, which spontaneously disintegrates into another more stable atom by emitting both particles and energy. The emission of the particle is called radioactivity and the initial atom is termed as radioactive or radionuclide. Other radioactive atoms can yield from the decaying atom. This chain of decay can last for several centuries depending on the atom and finally ends with a stable atom.

### 2.1.2 Activity

Radioactivity is the spontaneous disintegration of a radioactive source. SI unit of activity is Becquerel (Bq). 1Bq activity of a source means that one atom of the source disintegrates per second. That is, 1Bq = 1 decay/s. However it doesn't mean that in one second only one particle is emitted. Activity is often expressed in Curie (Ci), which is defined as the radioactivity of 1gm of radium (226Ra). 1Ci = 3.7x1010Bq.

### 2.1.3 Decay Constant, Mean-life, Half-life

Decay constant, $\lambda$ is used to measure decay rate. Every radionuclide has a separate but fixed decay constant. $\tau$ is the mean life of a radionuclide, $\tau = \lambda^{-1}$. The half-life is noted with $T_{1/2}$. $T_{1/2}$ of an element is the amount of time needed to decay to half of the initial number of a radionuclide. $T_{1/2} = (\ln 2)/ \lambda$.

### 2.1.4 Dosimetry

When a particle interacts with the medium it travels, it causes a loss of energy. The energy absorbed by a material per unit of mass of this material is called the radiation absorbed dose. In SI unit, Gray (Gy) is the unit of absorbed dose. The radiation effects on the human body depend on the type of particle and radiation weighting factor ($W_R$) is multiplied by the absorbed dose (Gy) to get the equivalent dose in Sievert (Sv) (Houssay, 2000). Gy is a physical quantity and Sv is a biological effect.

| | | |
|---|---|---|
| • For gamma, X-rays and beta | $W_R$ =1 | 1 Gy⇔ 1 Sv |
| • For neutron and protons | $W_R$ =10 | 1 Gy⇔ 10 Sv |
| • For alpha particle | $W_R$ =20 | 1 Gy⇔ 20 Sv |

### 2.1.5 Sources of Radiation

Sources of radiation can be categorized into two types- naturally created and man-made (Martin,2020). Everyone gets exposed to radiation on a daily basis, mostly from naturally transmitting cosmic rays, terrestrial radiation caused by radioactive elements in the soil, water or vegetation, and internal radiation for the radioactive elements incorporated in the body. The main radionuclides for terrestrial background radiation are uranium and the daughter products of 238U, 232Th, radon, and radium & their decay products. The radioactive isotopes that cause internal radiation are K-40, C-14, Pb-210 and some others that have existed inside all human bodies since birth.

All peoples are exposed by natural radiation, but depending on getting exposed by man-made radioactive sources people are categorized into two- the public and the occupational workers. By public, it means the people who are not getting occupational exposures. Occupational exposures mean the dose received by an individual, because of assigned duties involved with radiation exposure or radioactive material.

The main radiation source of artificial exposure to the public at large is from medical diagnosis and treatment processes, such as diagnostic X-ray machines, nuclear medicine with radioisotopes, and radiotherapy. Some of the important radionuclides are 131I, 99mTc, 60Co, 192Ir, 137Cs, etc. Additionally, there are some consumer products, public can be radiation exposed with, such as tobacco (thorium), building materials, luminous watches and dials (tritium), X-ray baggage scanning units, smoke detectors (Americium-241), road construction radioactive substances, electron cathode tubes, lantern gas mantles (thorium), etc.

Occupational workers are exposed according to the radiation sources they work with for their occupational duty. The occupational areas include research works with radioactive sources, X-ray facilities, nuclear medicine facilities, radiography, fuel cycle management, radioactive waste management, nuclear power plants etc. Some of the isotopes related to these fields are uranium and its daughter products, Co-60, Cs-37, Am-241, etc.

Most of the background radiation is produced from naturally found sources, whereas 20% of it originates from man-made sources.

### 2.1.6 Types of Radiation

Radiation can be categorized mainly into two types (USNRC, 2020)-

i. Ionized Radiation

ii. Non Ionized Radiation

**i. Ionized Radiation:** Ionized radiation has sufficient energy to ionize atoms at the molecular level. It comes from radioactive sources, x-ray tubes etc. It has a short wavelength, higher frequency and higher energy region in the electromagnetic spectrum. Uncontrolled exposure to radiation may lead to stochastic or deterministic effects in the human body. The types of ionizing radiation are-

**a. Alpha particle:** It is a heavily charged particle, very short range helium nuclei. Most alpha rays are low energy which cannot penetrate human skin and cause no harm to tissue. Though it can be harmful if inhaled, swallowed or adsorbed in an open wound. Typical alpha emitting sources are- $^{226}$Ra, $^{222}$Rn, $^{238}$U, $^{232}$Th etc.

**b. Beta particle:** It is a light, short range free electron ($\beta^-$) or positron ($\beta^+$). The penetrating power of beta particles is a little bit higher than beta particles. It can be stopped with a thick sheet of plastic or aluminum materials [Fig. 26]. Some pure beta emitting sources are- Sr-90, C-14, tritium, and S-35.

**c. Neutron:** Neutron is a neutral particle. Its position is in the nucleus of an atom. Spontaneous or induced nuclear fission causes the emission of neutrons. The penetrating power of neutrons is very high compared to other particles. It can easily travel through thousands meters in air. It can be effectively blocked with hydrogenous material like polythene, wax or water etc. [Fig. 26]. Neutrons are found where fission reactions happen, like as nuclear reactors, when uranium atoms splits. The neutrons help to sustain the chain reaction which is necessary to generate nuclear power.

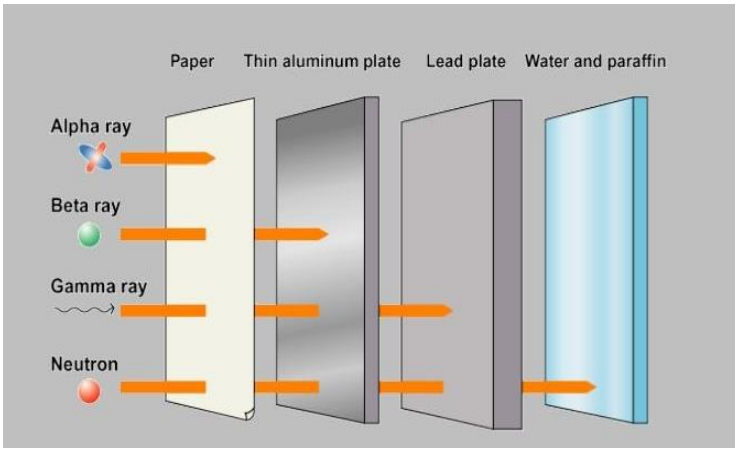



Fig. 2.1: Penetration power of different type of radiation (Chen, 2015).

**d. Gamma ray:** It is a highly penetrating electromagnetic radiation. It does not contain any particle like as alpha ray and gamma ray. It contains photon of energy released from the atom, with unstable nucleus. Gamma ray can be blocked by shielding with the material has high atomic number such as lead, concrete or depleted uranium. Some of the gamma ray sources are- Cs-137, cobalt-60, iodine-131, radium-226, technetium-99m etc.

**ii. Non Ionized Radiation:**

Non-ionizing radiation is termed as a sequence of electromagnetic waves structured of oscillating electric and magnetic fields. The energy waves travel at the speed of light. The series of energy is called the electromagnetic spectrum. Non-ionizing radiation contains the spectrum of ultraviolet (UV), visible light, infrared (IR), microwave (MW), radio frequency (RF) etc.

### 2.1.7 Radiation Detection Techniques

Mostly ionizing radiation is detected based on the indirect method (Knoll, 2010 and Grupen, 2010). When the ionizing radiation detector material interacts with the ionizing radiation, a secondary charged particle generates. The detector detects the generated charged particles. When an electrical pulse is formed as a charged particle (such as an alpha or beta particle) moves through the sensitive area of a detector, electron-ion pairs are created, followed by the movement and accumulation of positive or negative charges. On the other hand, indirectly ionizing radiation, like gamma rays and neutrons, must first contact with the detector material to form secondary charged ions or rebound atoms that then interact with the detection materials to produce ions with charges.

The collection of the ion pairs generated by ionizing radiation in a sensor region can be utilized simply to detect the passage of a charged ion. The rate of creation of radiation-related electrical signals can then be utilized to sense the count rate at which secondary charged ions traverse through the sensor materials. The amplitude of the radiation induced signals is directly proportional to the kind of charged ion and its imparted energy deposition. By analyzing both the signals along with the distribution of current pulse amplitude produced by a given type of radiation, both the intensity and energy distribution of the incoming particle can be identified. A brief description of some radiation detectors are furnished below.

An estimation of the uncertainties related with radiation detection is essential. The releases of radiation through the radioactive decay process along with the collisions of ionizing radiation with detector volume are stochastic phenomena. Therefore, successive determinations of ionizing radiation released from the radioactive sources, in a detector region with respect to time step, exhibit stochastic statistical variations. An assessment of such stochastic variations is a necessity in correct radiation dose determination.

**Gas-Filled Radiation Detectors**

It was first proposed in the nineteenth century to measure the radiation-induced ion pairs in a gas medium. As nuclear radiation passes through a gas medium, the motion within an electric field of the +ve and –ve charges created inside the gas medium generates an electrical signal. The amplitude of the output signal is counted& correlated (calibrated) to the magnitude of the incident radiation strength. A common configuration of gas-filled detector is a coaxial cylindrical shape that consists of an outer cathode tube encircling a thin center wire anode (held in place by insulators). The outer cylindrical tube contains the gas and defines the active volume of the gas detector. Gas filled detectors are sealed properly to avoid any influence from the ambient environment. A typical schematic diagram of gas-filled ionization sensor is shown in Fig. 2.2.

The cylindrical cathode wire is generally utilized to enclose the gas from the atmospheric environment. The resultant output current pulse is induced across the load resistor in the circuit. Ionization radiation interacts in the inner wall side of the gas filled detector or directly with the gas medium. In the case of alpha ray interaction with gas-filled detector,

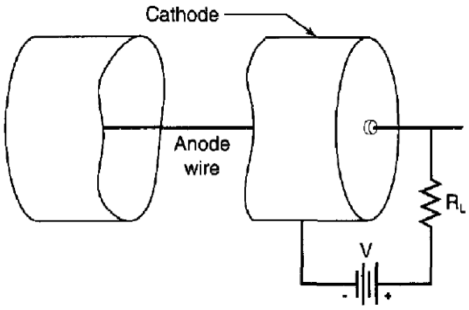



Fig. 2.2: Basic circuit diagram of a gas-filled counter (Knoll, 2010).

the most dominant radiation interaction processes are photoelectric effect (PE), Compton effects (CE), and pair production (PP), which occur mainly in the inner wall of chamber substance. If the secondary –ve ion created from the atoms in the wall substance of gas filled detector escape from the cathode wall & interact with the active gas region of the detector, then these –ve electrons generate ion pairs as they move through the gas medium. Due to the potential difference between the cylindrical anode wire and the cylindrical cathode establishes an electric field that causes +ve & -ve charges to flow in opposite directions. Afterwards negative ions rapidly move toward the anode wire and positive charges move slowly toward the cathode. Due to the movement of these charged particles arises a flow of current pulses and establishes a potential difference across the resistor in the external electronic circuit.

The gas-filled radiation detectors are classified in the following ways:

a) Ionization chamber,
b) Proportional counter, and
c) Geiger-Mueller (GM) counter.

All these gas filled detectors chambers operate by producing primary charge pairs from the incident initial radiation. After the production of these charge pairs, it is necessary that they do not reassemble at low voltage and thereby fail to add to the actual current or voltage pulse.

The different operational regions of gas-filled ionizing detectors are shown in Fig. 2.3. The voltage differential between the anode and cathode is insufficient to record all of the primary +ve and -ve charges in Region I, which is the recombination area. In this low voltage region, gas detectors are not suitable for use as radiation detectors.

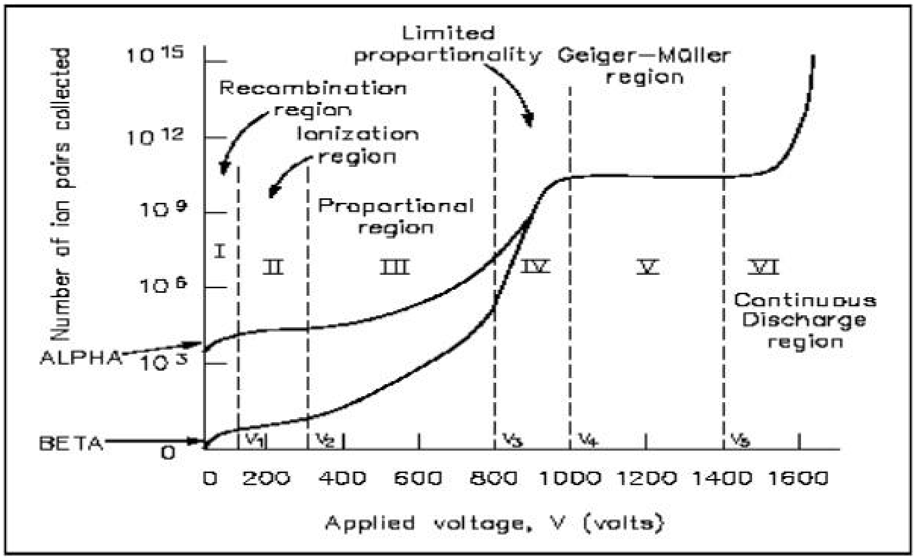



Fig. 2.3: Different regions for gas-filled chambers (Ridha, 2015).

If the applied voltage is increased then the voltage difference between the anode wire and cathode cylinder is also increased. This region is known as ionization chamber Region II. The resulting output signal due to current is termed to as saturation current of the ionization chamber in the region II. In the case of region III, electrons gather adequate energy to produce secondary ion-pairs. This secondary charge pair enhances the resultant number of charge pairs in the sensitive volume of the gas filled chamber and, hence, the output pulse increases by a multiplication factor $M > 1$. This area is named as the proportional counter region since the resultant output pulse, or total pulse generated per interaction, is directly proportional to the primary number of positive and negative ion pairs created by the incident primary ionizing radiation. The resultant output pulse is then entered in the limited proportionality region IV where the number of positive and negative charges monitored is purely independent of the initial number of +ve and -ve charge pairs generated by the incident primary ionizing radiation. The region IV is not useful to work as detector operationally.

The next area of region IV, is called Geiger-Mueller (GM) sensor region, which shows a "plateau" curve, where multiplication (M) attains an approximate fixed value. In region IV one avalanche produces secondary electrons whose interactions produce other local avalanches until the entire anode wire is covered by positive and negative charge pairs. In the case of region V, the ion-pair recorded per collision is no longer proportional to the primary number of +ve and –ve charges created. Thus, it is very hard to differentiate among various types of incident primary radiation or to acquire knowledge about the energy of the imparted primary ionizing radiation.

Geiger and Mueller designed and fabricated the GM sensor with gas filled device for detection alpha particle in 1928. The GM detectors are very simple, robust and low cost detectors that identify as an important instrument for recording the presence of different ionizing radiations. The gas filled GM detectors can operate between 500V and 1200V in region IV of voltage vs amplitude curve (Fig. 2.3) and have the important property that the size of the voltage pulse, or total charge produced in the active volume of the gas medium is purely independent of the imparted energy of ionization radiation by the primary positive and negative charges. The gas filled GM detector is not suitable for distinguishing between various types of ionizing radiation or radiation energy spectrum. This detector is very responsive to both charged particles (alpha particles and beta particles) as well as x rays and gamma rays.

The sensitivity of a gas filled GM counter to charged ions is very low due to the thick layer of the window material of the counter. However, the wall of the radiation entry window material must be adequate wall thickness in order to reduce the leakage of gas from the gas filled GM counter. It may be mentioned here that once charged particles pass through the sensitive volume of the GM counter, they are measured with nearly 100% accuracy because it receives only a single positive and negative ion pair to create the voltage pulse generation process.GM detectors should have a fairly wide energy or dose range over which they can be used in order to obtain an accurate radiation dose measurement. Basically, each GM sensor should be worked near the middle of its plateau curve as shown in region IV (Fig. 2.3), this ensures the best long-term proper function because, at this applied voltage, a very small variation is noticed on the output pulse amplitude.

## 2.2 Robots in Nuclear Environment

### 2.2.1 Definition of Robot

A robot is a reprogrammable, efficient, multifunctional manipulator intended to handle different type of things or specialized devices through variable programmed motions for the performance of a variety of jobs. The word 'robot' was first used to represent an imaginary humanoid in a 1920 Czech-language play R.U.R. by Karel Čapek (Margolius, 2017). Robot in Czech is a word used for worker or helpful hand.

### 2.2.2 Use of Robotic Systems in the Nuclear Environment

Robots are being widely used in the nuclear environment. Many types of robots have been designed, fabricated and put into operation in different nuclear facilities. Generally, the robots are designed and developed for handling of hazardous and complex tasks i.e. they are not used continuously but only when they are needed to perform the predefined tasks. To carry out repair and inspection works, a robotic system can be used. Furthermore, a robotic system whose main purpose is to handle radioactive materials or to perform radiation monitoring on a routine basis will need components that are highly radiation-tolerant. However, if we use in a low radiation environment, the radiation hardening of different components of a robotic system is a minor concern. Typical dose values of radiation hardening of different components of a robotic system are given in Table 2.2 (Gao et al., 2019).

Table 2.1: Dose values of radiation hardening of different components of a robotic system

| Equipment | Dose rate | Total dose | Condition |
|---|---|---|---|
| CPU board | 205.3 Gy/h | 164.07 Gy | Failed |
| Driver | 51.6 Gy/h | 217.8 Gy | Failed |
| Brushed motor | 529.7 Gy/h | 5089.9 Gy | Survived |
| Brushless Motor | 529.7 Gy/h | 759.2 Gy | Failed |
| DC-DC converter | 205.3 Gy/h | 853.4 Gy | Failed |
| Rotary resolver | 529.7 Gy/h | 5089.9 Gy | Survived |
| Potentiometer | 529.7 Gy/h | 5089.9 Gy | Survived |
| Optical encoder | 529.7 Gy/h | 3679.6 Gy | Failed |
| Magnetic encoder | 529.7 Gy/h | 4032.2 Gy | Failed |
| CCD camera (AV, unprotected) | 205.3 Gy/h | 445.3 Gy | Failed |
| CCD camera (AV, reflected) | 205.3 Gy/h | 745.7 Gy | Failed |
| WTD | 199.2 Gy/h | 853.4 Gy | Survived |
| LAN hub | 199.2 Gy/h | 1835.9 Gy | Survived |
| POE | 199.2 Gy/h | 853.4 Gy | Survived |

A brief description of the robotic system used in the nuclear facilities is described in the following sub-section (Zeb, 2009).

**i. Surveillance and Routine Monitoring Robots**

In order to omit the requirement in a facility that uses nuclear radiation of human inspection, surveillance and routine monitoring robotic system are routinely used. These robotic system follow either a pre-programmed path or are controlled manually to carry out its radiation monitoring activities. Monitoring task includes measuring and transmitting radiation, different types of environmental parameters (such as temperature, humidity etc.) and photographic views of the area in real time.

**ii. Steam Generator Inspection and Maintenance Robots**

The buildup of sludge/scale in the steam generator decreases its thermal efficiency. This accumulation reduces the thermal power output of the power plant and costs ~$10^6$ dollars. Robotic systems are used to locate and retrieve foreign objects in the steam generator and to clean the different parts of the steam generator. Several types of mechanical arms have been designed that are mainly used for routine inspection of steam generator or repair/maintenance purposes.

**iii. Reactor Vessel Inspection Robots Inspection**

Generally, inspection of nuclear reactor pressure vessels is performed on a regular interval to maintain the requirements of rules and standards. The objective of inspection is mainly to find cracks and to verify the welds visually with an ultrasonic method. These inspection mechanisms imply many problems. All the inspections are carried out underwater since the reactor is completely filled with water. Some of the components in the nuclear reactor has to be taken out prior to routine survey. It may be mentioned that the nuclear reactor is out of service during the inspection period. The Ultrasonic Testing machine is a nondestructive tools that revolutionized the nuclear reactor vessel inspections. This inspection robotic system has suction cups to swim or move around and scan the vessel.

**iv. Pipe Inspection Robots**

Nuclear reactors have many welding joints in the pipe lines that also need to be inspected properly. The inspection has been carried out two ways depending on the nature of the jobs; welding from the inside or the outside of the pipe lines. Small gaps in the pipe lines are another factor beside ionizing radiation. Pipe crawlers with tracks, wheels or thrusters are designed to access and inside inspection of welds of pipes. These robotic systems are often flexible and diameter of the system can be in the order of ~ 5 cm.

### v. Robotic Inspection for Underwater Reactor Components

Generally, the inspections of nuclear power reactors are done under water due to low radiation levels. Some robotic systems are designed and developed to perform inspection underwater. Submersible robots used for underwater reactor core inspection with the facilities to retrieve small objects in the reactor core and carried out using a simple ultrasonic testing probe.

### vi. Robots for Handling of Radioactive Waste

Robotic systems are playing an important role in the nuclear radiation fields. They are applied in several areas to perform repetitive and complex works. The main advantages of this system are simple and low cost. The drawbacks are a low payload, narrow workspace and small distance between operator and shielded radiation area. Long tool systems have been used to reduce such radiation problems. In case of radioactive areas, the requirements for such robotic system are a good sealing of the components to reduce radioactive contamination.

### vii. Robotic System for Decommissioning

In addition to routine inspection and maintenance of the components in a nuclear industry, it may happen that radioactive contaminations are spread and necessary step must be taken for decontamination. Also, many accessories & equipment need to be decontaminated during maintenance works. However, the needs to avoid personnel radiation exposure based on the ALARA principle are considering the use of robotic system for open space cleaning and decontamination works. General-purpose traditional robotic system or custom made manipulators as well as cleaning robotic systems are utilized depending on the cleaning needs and the contaminated areas.

### viii. Robotic System for Tank Cleanup

Different robotic system are being widely used to manage highly toxic materials and highly radioactive wastes. These wastes are produced by the production of nuclear weapons with the radiochemical processing used in chemical separation units. The radioactive waste is normally stored in single shell structure concrete containers for a short duration of time.

### ix. Robot for Post-Accident Operations

Cleaning up radioactive waste products is one of the main tasks for the design of robotics technique. For proper management of the Three Mile Island nuclear accident in 1979, automated robotic systems have been designed and developed to take necessary proper action, conducting inspection activities, as well as decommissioning works that are considered too radiation hazardous  for occupational workers. The Chernobyl nuclear accident occurred on April 26th 1986 has identified the need for robotic system to handle the nuclear wastes. The first robotic systems that were used at Chernobyl failed because of a lack of radiation hardness of the components. In 2011, after the Fukushima Daiichi nuclear power plant accident, different robotic systems have been used as existing robotic technologies.

Among the versatile uses of the robotic systems used in the nuclear facilities, surveillance and routine monitoring robots are the main field of interest of this thesis work. For this category of robots, GM tube based detectors are perfect general purpose radiation detectors for their low cost, high efficiency and small size. Thus a GM tube based radiation counting unit has been designed.

## CHAPTER 3
## DESIGN METHODOLOGY

### 3.1 Components of the Robot

As discussed in the previous section, the prototype of the robotic system proposed in this thesis work, is categorized in the routine monitoring robot group. The specification of the robot should be specified after the study work about the area, where the robot would be used and the tasks, the robot would perform. The work area may be open air out door area or indoor area, plane surface or uneven surface. There may be closed door or staircases. The communication may be wired or wireless. The proposed robot has designed for mainly indoor area where it will move around and find the presence of any radioactive material, then measure the dose level, transmit the data to the control unit wirelessly. This section describes different parts used for the proposed prototype robotic system. The requirements of routine monitoring robotic system for radiation detection has shown in table 3.1. As an applied robotic system, the specifications of CARMA (Continuous Autonomous Radiation-Monitoring Assistance) has also discussed in the table. CARMA is the first time fully autonomous robot ever had been deployed at U.K.'s Stellafield, the largest nuclear site in Europe (Bird et al., 2019). It was created especially for carrying out quick scans (up to an hour) and for identifying and locating radioactive contaminated sites within the scanned area.

Table 3.1: Requirements of a routine radiation detection and monitoring robotic system

| Application Area | Application Specification | Consideration | CARMA robot's specification |
|---|---|---|---|
| Radiation Measurement | • Able to measure alpha, beta, gamma ray<br>• Able to transmit data to control unit<br>• Able to data logging to show radiation data histories<br>• Multiple detector can be used for much coverage | GM tube detector has considered for its low cost, high efficiency and small size | Two type of sensors has been used-<br>• An α/β sensor, Thermo Fisher Scientific DP6<br>• Two γ dosimeters, Thermo Fisher Scientific RadEye |
| Size and Weight of the robot | • Should be small as possible to be flexible to move around | A 11 inch x 7 inch x 5 inch structured robot has considered to | The platform is a modified Turtlebot 2, (14x14x16.5in) mobile open source |

| | | | |
|---|---|---|---|
| | • Able to carry all the components required for the system | maximized all the components | robot for research and education. |
| Wheels and motors | • Able to move around the work area smoothly with its load | Gear motors have used with two wheel and a ball caster. with the gear, the motor can produce high torque at low speed. Ball caster can be replaced with a four wheeler in case inconvenience | 4 wheels |
| Navigational Sensor | • Able to show a 360º clear vision of the periphery lighten / darken | A light 8 megapixel fixed camera has used which can be upgraded by fixing with 360º rotatable base and night vision lens | One 4m LiDAR, one depth camera, three IR sensors |
| Power Source | • Able to power up all the components of the system<br>• Able to run the system for completing the task<br>• Doesn't add much pay load in the system | Rechargeable Li-ion battery is a good choice for its efficiency light weight and less charging time. Two 3.7V Li-ion battery in series connection with current capacity 1020mAh, run time around 30mins. To increase run time, number of battery can be increased | 2200mAh Li-ion battery has been used with run time 1hr to 3 hrs. |
| Shielding | • Able to protect the robotic system from radiation | Depending on the type, high or low radiation zone, the material and thickness of the shielding should be selected. For wheels and non-shielded parts, decontamination is needed if get contaminated | No radiation shielding and no hardened electronics has used, once the contaminated area is identified, the robot was designed to stop and return to a safe location. |
| Communication System | • Able to communicate between the control unit and remote robotic | Depending on the necessity wired or wireless | It is a autonomous robot, runs by mapping the area. |

| | | | |
|---|---|---|---|
| | system securely and efficiently | communication can be established. Pre-built Wi-Fi communication system has used here. In system WiFi network or wired connection also can be built up if it is necessary | The robot logs the radiation data from the sensor but the analysis is completed offline. |

The main component blocks of the prototype robotic system has shown through the schematic diagram given in Fig. 3.1.

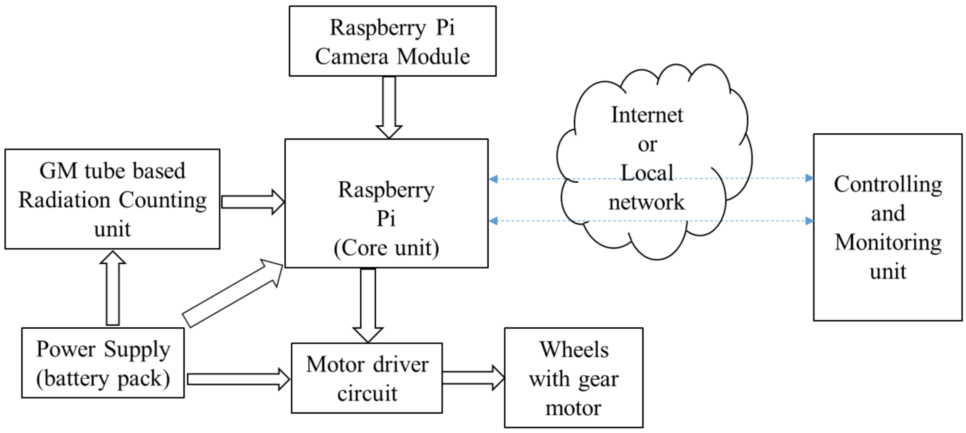



Fig. 3.1: Diagram of the prototype Robotic System for radiation measurement.

### 3.1.1 Chassis

Chassis shown in figure 3.2(a), is the main structure of a robot. The chassis used for the robot is a 28 cm x 15 cm translucent acrylic board with a rectangular shape which was substantial and light weighted. This property made the chassis strong enough to assemble the devices and electronic parts on it.

### 3.1.2 Wheels and Ball Caster

The robot had two wheels with rubber tires shown in Fig. 3.2(b). The wheels were 2.5 inches in diameter and were fastened to the side of the chassis. To balance the design and ensure the robot moved smoothly, a steel ball caster and hard rubber wheel set were fitted to the bottom of the chassis. These components are shown in Fig. 3.2(c). The ball caster wheel has dimensions of 1 inch by 0.5 inch. It could turn 360 degrees.

(a) (b) (c) (d)

Fig. 3.2: Different parts of Robot Structure (a) Chassis, (b) Wheel, (c) Ball Caster, (d) DC gear motor.

### 3.1.3 DC Gear Motor

A more sophisticated version of brush DC motors is the gear motor. The motor is put together with a gear. The gear enables the motor to generate powerful torque at a slow pace. A pair of DC gear motors was used for the wheels of the robot, shown in Fig. 3.2(d). The dimension of the used plastic body gear motor was 6.2 cm inch long, 2.15 cm wide and 1.25 cm thick. Its operating voltage was 5 volt.

### 3.1.4 L293D Motor Controller

A DC motor needs a lot of power and a powerful control signal to alter the speed and

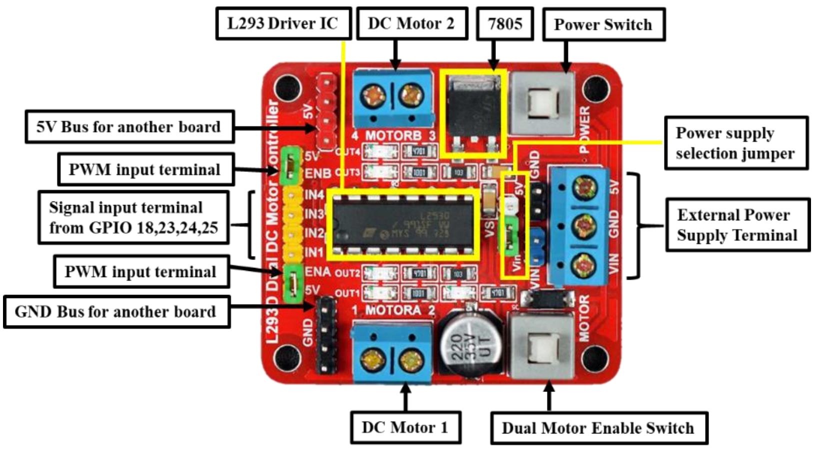
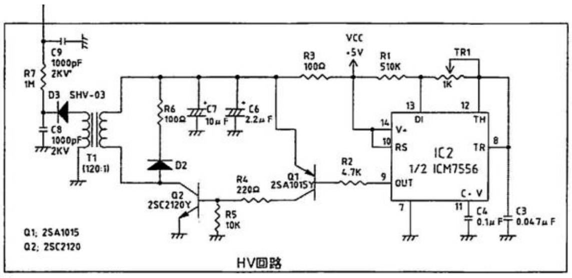



Fig. 3.3: Different parts of L293D Motor Controller.

direction of rotation. A transistor or MOSFET combination circuit known as H-bridge circuit can do the work suitably. L293D IC has two half H-bridge circuits in it, so its two channels can drive two motors separately and simultaneously. A motor controller board with L293D IC used here to drive the wheels. Fig. 3.3 shows the different components of the board. Operating voltage of the board was 7V to 15V. So the motors needing voltage greater than 15V won't have worked with this board.

### 3.1.5 Radiation Counting Unit

The Radiation Counting Unit is a radiation level detection system that uses GM (Geiger Muller) tubes. The equipment in Fig. 3.6 consists of a high voltage circuit, GM amplifier circuit, and GM tube radiation detector. The Ne+ Halogen Gas Model 712 GM tube used



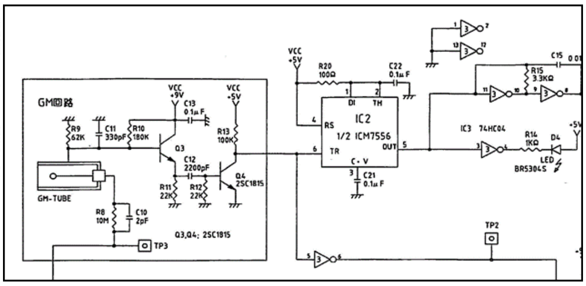




Fig. 3.4: Circuit diagram of High voltage unit.

Fig. 3.5: GM Amplifier circuit.

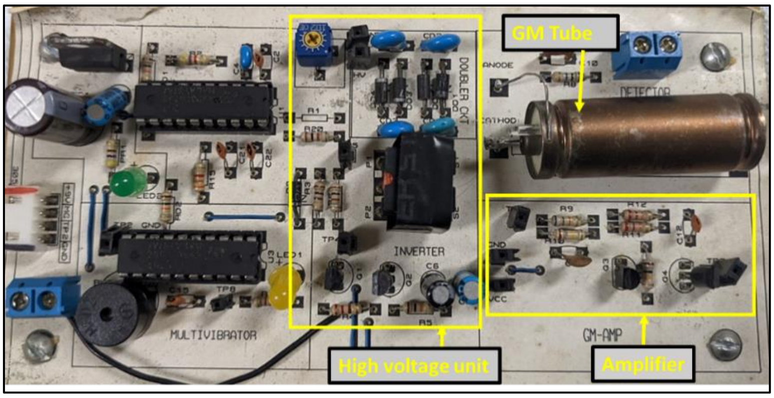



Fig. 3.6: Different parts of Radiation Counting System.

in this work was manufactured by LND.INC, USA. High voltage (about 550 volts DC) is necessary for the GM tube to function. The circuitry used to generate high voltage from 5V in figure 3.4 consists of a transformer with a 120:1 turn ratio, a timer IC to provide pulses to turn on and off the transistors, and a high voltage capacitor (1000pF, 2kV) to the output of the transformer to reduce output voltage ripple. The timer IC is utilized as a pre amplifier in the GM amplifier circuit, which is depicted in Fig. 3.5 (mono stable multivibrator mode of timer IC), to shape and amplify the detector's electric pulses. It is impossible to measure the pick of the exponential pulses coming from the GM counter. As a result, they must be shaped and amplified before being processed further. The Raspberry Pi's GPIO pin was then provided the pulse to calculate the CPM (count per minute).

### 3.1.6 Logic Level Converter

Raspberry Pi GPIO pin takes input of 3.3V, whereas the radiation counting system provides a pulse of 5V. To mitigate the problem a 5V to 3.3V logic level converter was used which is small in size (0.63 inch x 0.52 inch). Fig. 3.7 shows the bi directional logic level converter. It could step down high voltage signals to low voltage signals and vice versa. There are four separate data channels, capable of shifting data to and from high and low voltages. These pins are labeled HV1, LV1, HV2, LV2, HV3, LV3, HV4, and LV4. The board needs to be powered from the two voltage sources (high voltage and low voltage) that the system is using. The wire connection scenario was, 5V to the high voltage 'HV' pin, 3.3V to the low voltage 'LV' pin, ground from the system to the 'GND' pin. The electrical pulse (which is of 5V) from the Radiation Counting System board is connected to the 'HV1' pin of data channel HV1-LV1 and 'LV1' is connected to GPIO 4.

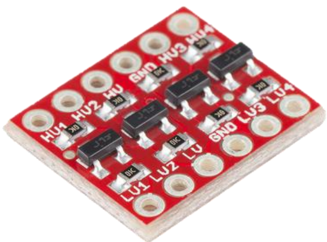



Fig. 3.7: Bi directional Logic Level Converter.

### 3.1.7 Description of Raspberry Pi

Raspberry Pi is a small modular computer developed by Raspberry Pi Foundation, UK in 2012. As it is a micro-computer, it consists of all the technical features of a computer. It operates with low power consumption. The operating system known as “Raspbian OS” is available free of cost in the official website of Raspberry Pi Foundation. The “Raspbian

OS" is optimized to couple with a Raspberry Pi system. The foundation also provides NOOBS OS for Raspberry Pi for the new users. It has a high speed processor which is ARM based Broadcom. The processor has a SoC (System on a Chip) along with on-chip GPU (Graphics Processing Unit). In SoC method, all essential electronics for running a computer are placed on a single chip. Instead of having an individual chip for the CPU, GPU, USB controller, RAM etc., everything is compressed down into one tidy package. The function of Raspberry Pi is more versatile than a computer, as it provides access to the on-chip hardware i.e. GPIOs (General Purpose Input/Output) for developing an application. It also provides on-chip SPI, I2C, I2S and UART modules. By accessing GPIO, devices like sensors, motors, LED, etc. can be connected and controlled based on the preset commands. Raspberry Pi-3 is popular to utilize for real time Image/Video processing, internet of things (IoT) based applications in the field of radiation measurements including Robotics applications.

In this thesis work, Raspberry Pi 3 model B was used. This model has quad core 64 bit 1.2GHz Broadcom BCM2837 CPU and 1GB RAM.

Some Hardware Components shown in Fig. 3.8 are mention below:

**GPIO:** 40 GPIO pins are extant on the board.

**USB Port:** There are 4 USB.2 ports to connect keyboard, mouse, pen drive etc.

**Wireless LAN and Bluetooth:** There is on board Wireless LAN and Bluetooth chip for communication.

**MicroSD port:** To mount the SD card which contains OS and store data.

**HDMI (High-Definition Multimedia Interface):** It is suitable for transmitting uncompressed video or digital audio to the HDMI Computer Monitor, Digital TV, etc.

**CSI Camera Interface:** CSI (Camera Serial Interface) interface provides a connection in between Broadcom Processor and Pi camera.

**DSI Display Interface:** DSI (Display Serial Interface) Display Interface is used for connecting touch screen LCD to the Raspberry Pi using 15-pin ribbon cable.

**Composite Video and Audio Output:** The composite Video and Audio output port carries video along with audio signal to the Audio/Video systems.

**Power LED:** It is a RED colored LED which is used for Power indication. This LED will turn ON when Power is connected to the Raspberry Pi. It is connected to 5V directly and will start blinking whenever the supply voltage drops below 4.63V.

**ACT PWR:** ACT PWR is Green LED which shows the SD card activity.

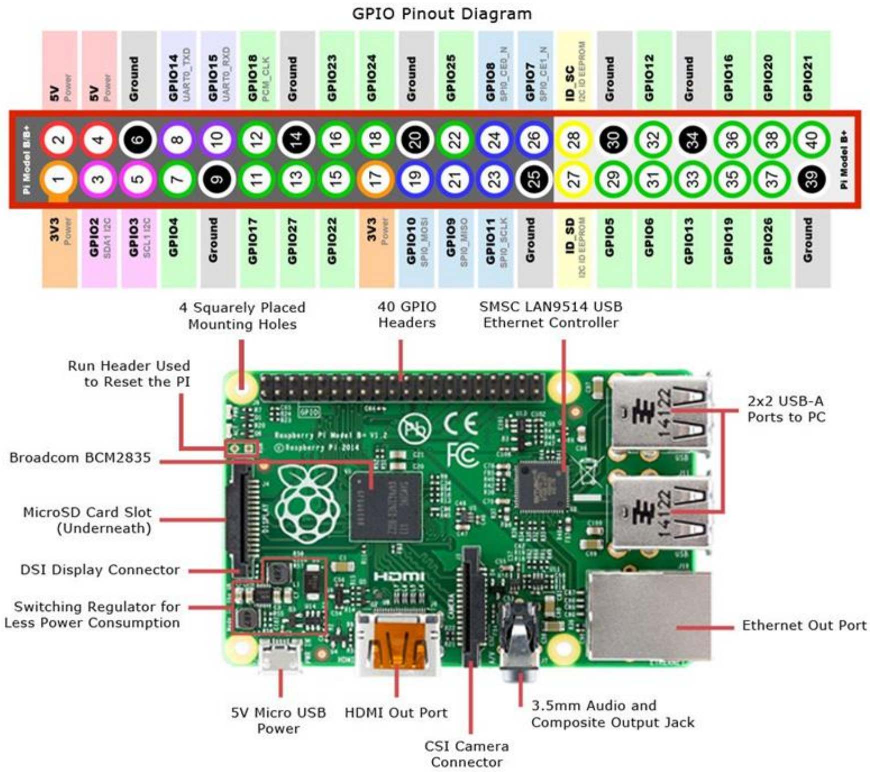



Fig. 3.8: Different parts of Raspberry Pi.

### 3.1.8 Description of Raspberry Pi Camera Module

This project utilizes a Pi camera version 2 that is depicted in Fig. 3.9 as the Raspberry Pi Camera Module. It is based on a Raspberry Pi-3 add-on board that has been specially created. The board is approximately 1 x 1 x 0.35 inches and weighs 3gm. It sports a fixed focus lens and an extremely high quality 8 megapixel Sony IMX219 image sensor. It supports static photos up to 3280 x 2464 pixels and video up to 1080p30, 720p60, and

640x480p90. The Raspberry Pi's specific CSI interface, which is made for connecting to cameras, was where the module was attached.

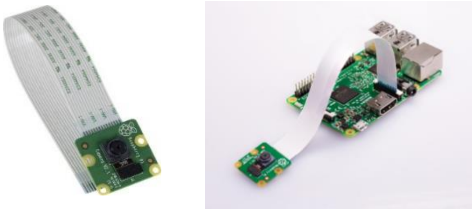


Fig. 3.9: Raspberry Pi Camera module.

### 3.1.9 Battery

The battery is crucial to robotics since it powers all the components. Accurate ratings for voltage and current are required for the robot to move smoothly. The battery shouldn't be too heavy too. Here, a battery pack, represented in Fig. 3.10, was used. Two 3.7V Li-Ion batteries are included in the pack and are wired in series. The output voltage is 7.4V as a result. The battery pack's maximum current capacity is 1020 mAh. The regulator regulates 7.4V to 5V, which is what the system needs.

Fig. 3.10: Battery with connecting cable.

### 3.1.10 Controlling and Monitoring System

The system's controlling and monitoring unit is designed using a web server base interface approach. Through network-based communication using the Raspberry Pi's built-in 802.11n wireless LAN adapter, this method is carried out. A local network is attached to the Raspberry Pi, which is configured as a web server with a private IP address (192.168.0.11). The user must navigate to http://192.168.0.11:5000 via a web browser to access this server. Programs for controlling and interacting with robotic devices have been written using HTML, CSS, and Python. The system is programmed to establish connection between the robot and the controlling device, manage the robot's movement, measure area radiation, provide visual monitoring via an onboard camera, and store the measured data for later study. Fig. 3.11 shows the web based controlling and monitoring system.

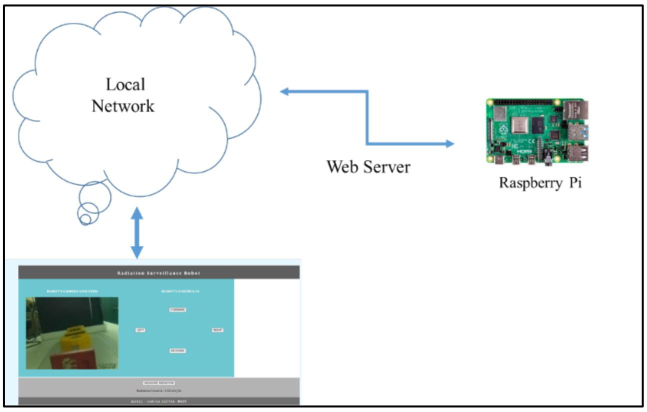



Fig. 3.11: Robot controlling and monitoring system.

### 3.2 Robot Construction and Mechanism

The construction of the robot involved assembly of the wheels, gear motors, motor controller, Raspberry Pi, Pi camera module, battery with the chassis.

Two wheels were connected with the motors at two sides of the chassis and the ball caster was connected under the front side of the chassis. Motors require more power than Raspberry Pi can provide. So the motors were powered from the battery through the motor controller. The motor controller board contains IN1, IN2, IN3, IN4 pins to take input signals for the wheels to move. These pins were connected with GPIO 18, 23, 24, 25 respectively.

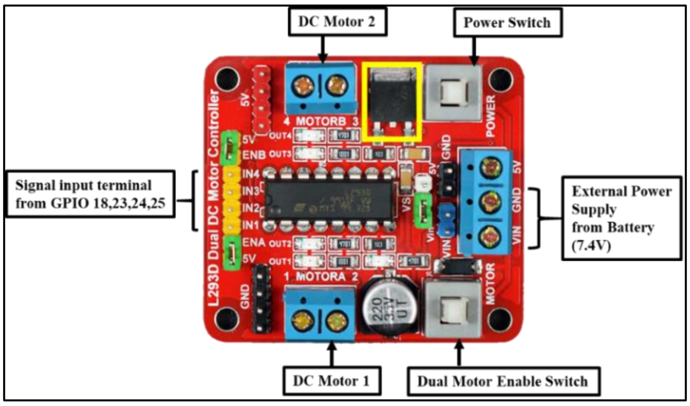



Fig. 3.12: Connection between motors, motor controller and Raspberry Pi.

The connections between the motors, motor controller and Raspberry Pi are shown in Fig. 3.12. The logic algorithm for robot movement is shown in Table 1.

Table 3.2 Logic Algorithm for robot movement

| Direction of Robot | Motor 1 | | Motor 2 | |
|---|---|---|---|---|
| | Left Wheel | | Right Wheel | |
| | IN1 (GPIO 18) | IN2 (GPIO 23) | IN3 (GPIO 24) | IN4 (GPIO 25) |
| Forward | 1 | 0 | 1 | 0 |
| Reverse | 0 | 1 | 0 | 1 |
| Left | 0 | 1 | 1 | 0 |
| Right | 1 | 0 | 0 | 1 |

After that, to interface the radiation counting system with the Raspberry Pi, the radiation pulse shown in Fig. 3.14 was connected to the Raspberry Pi through the logic level converter as shown in Fig. 3.13.

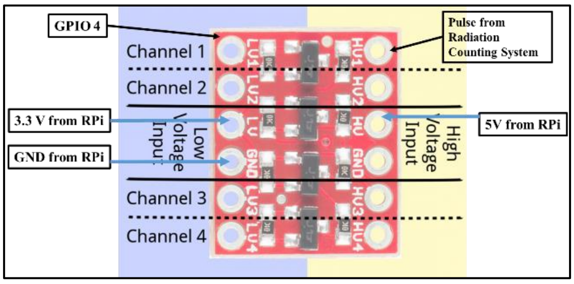



Fig. 3.13: Wire connection of Logic Level Converter

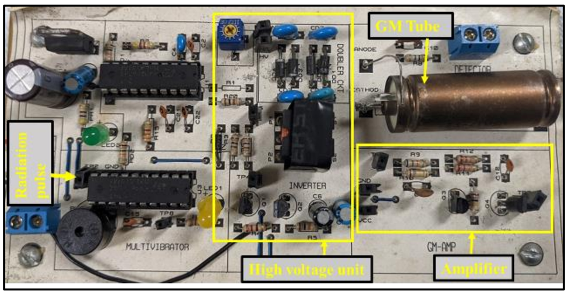
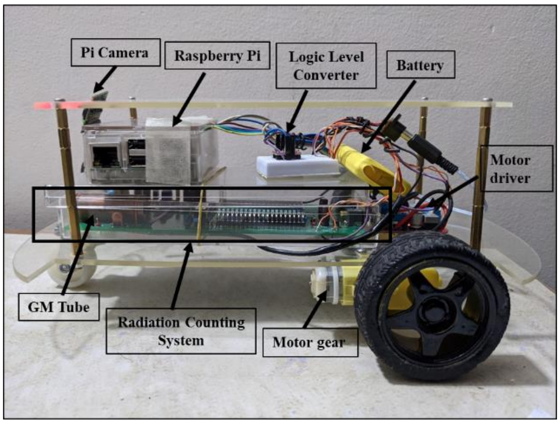
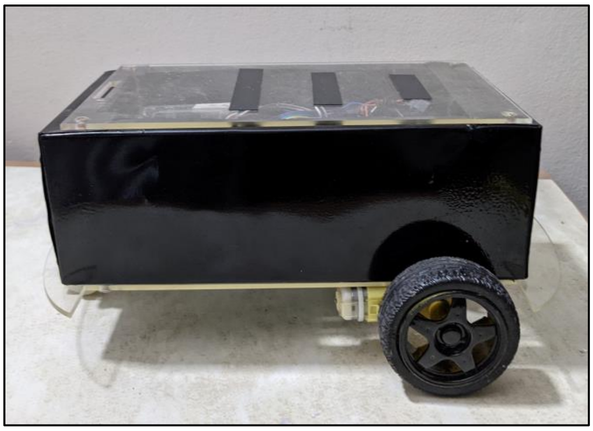



Fig. 3.14: Output pulse from radiation counting system

Hardware connection was completed by connecting the Raspberry Pi Camera module to the CSI port of the Raspberry Pi with the fixed cable with the camera module. For the power distribution setup from the 7.4V battery every module was powered up precisely. Fig. 3.15 shows the complete hardware setup.




(a)



(b)

Fig. 3.15: Completed Robot for radiation detection and monitoring (a) without shielding, (b) with shielding

### 3.2.1 Software Design for Raspberry Pi

The robot was programmed to operate in a WiFi coverage area and measure the Radiation level without the need to be tethered to a wired connection. However, if need be due to the varying degree of different environments, the robot also does have a Ethernet port which can be used to connect the robot with the wired connectivity enabling it to be operated up to 100meter form the wired connection termination point.

To program the Raspberry Pi as a local web server (the main working unit) and control the system via a webpage, following steps were followed-

### 3.2.2 Booting the Raspberry Pi OS

The operating system, Rasbian was downloaded and installed in an 8GB SD card. The SD card was inserted into the microSD card slot of the Raspberry Pi. By using VNC (Virtual Network Computing) a Laptop’s screen and keyboard was used as the monitor and keyboard for the Raspberry Pi. OS booting started along with powering up the Raspberry Pi and after a few seconds Raspberry Pi OS Desktop appeared on the display monitor.

To connect Raspberry Pi to internet, Ethernet or Wireless connectivity are the options. Wireless connectivity was used here.

### 3.2.3 Installing Flask Web Framework

“Flask” is a python based micro web framework which makes web applications. Due to the fact that it doesn't require any special tools or libraries, it is known as a micro framework. It is an add-on for raspberry pi to create web applications. To install “Flask” on Raspberry Pi, at command terminal it was written-

```
pip install flask
```

The outcome shows in Fig. 3.16-

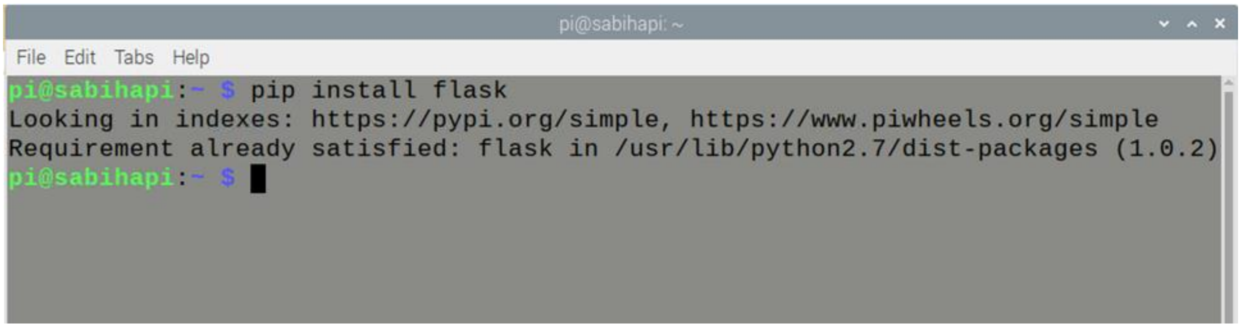



Fig 3.16: Flask installation command in command terminal.

So it was seen that Flask is installed.

### 3.2.4 Programming the Robot with Python

In the python code a function called ‘index’ was used to initialize the program and render the index.html page in the web server. Every time any button was pressed in the html page the corresponding html post value was read and measured against the different instruction set defined in the python code. In the code there were two sections- one is for driving the robot and second one is for measuring and displaying radiation level.

For instance, if the html post value received was “2” the python code executed the FORWARD function of the code. The FORWARD function sets +5 V to the GPIO 18 and GPIO 23, which in turn moves the Robot forward by providing the same logic level to the motor driver input pin IN1 and IN3. The same logic set was also used to move the Robot in Left, Right or Reverse direction.

To measure the Radiation level, the interrupt function was leveraged in python. This function interrupts the CPU every time it receives a rising pulse in the GPIO 4. Subsequently, a logic set was programmed under the measure condition. When the MEASURE RADIATION button on the Webpage was pressed the python received the HTML POST 5 and executed the MEASURE RADIATION function in the code. In this function a timer was initiated for 60s. During this time interval every time a rising edge pulse was detected in the GPIO 4, the python program increased a variable in the program. At the end of the 60s period, it converted this CPM radiation count to µSv/hr value by dividing it by 100. Subsequently, it displayed the value of the radiation level to the index.html page, as well as writing the value, along with timestamp of the measurement, in to a CSV file. The data stored in this file could be used for record keeping and for any future Radiation measurement level analysis. Table 3.2 shows the logics used for connecting the Python code with html code.

Table 3.3: Programs and their functions for robot movement

| HTML POST Value | Python Function | Raspberry Pi actions | Final outcome |
|---|---|---|---|
| 1 | Left | Setting GPIO 23 & 24 to 5V | Driving the motor left direction |
| 2 | Forward | Setting GPIO 18 & 24 to 5V | Driving the motor forward direction |
| 3 | Right | Setting GPIO 18 & 25 to 5V | Driving the motor right direction |
| 4 | Reverse | Setting GPIO 23 & 25 to 5V | Driving the motor reverse direction |
| 5 | Measuring Radiation | i. Measuring radiation count for 1 min using interrupt function<br>ii. Converting CPM to µSv/hr<br>iii. Displaying the output and writing the data in CSV file | Displaying the radiation level in µSv/hr unit in a web page |

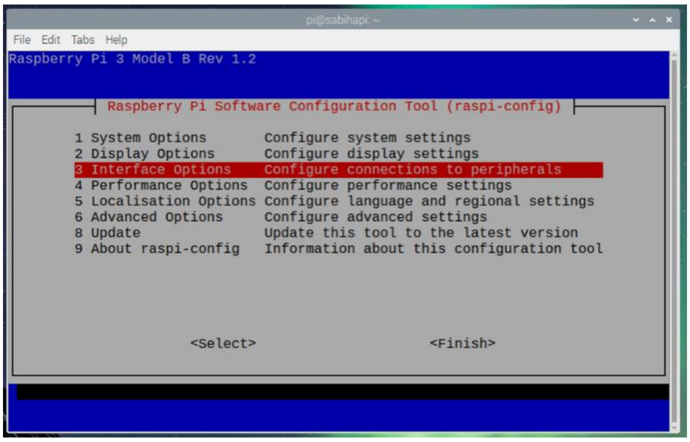
### 3.2.5 Setting up Raspberry Pi Camera Module

In order to use the camera module, following command was used-

```
sudoraspi-config
```

In Raspberry Pi Software Configuration Tool (raspi-config) camera interfacing option was Enabled. Fig. 3.17 shows the camera set up steps.

(a)




(b)

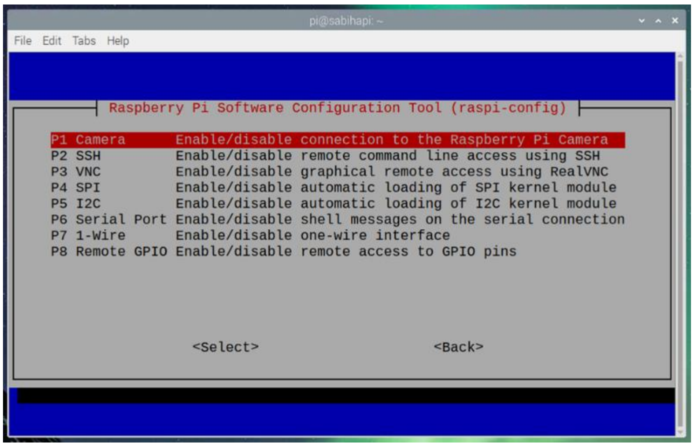



Fig. 3.17: (a) & (b) Raspberry Pi Camera software interfacing.

By installing the Motion software with this command, video feed was transmitted. This could be displayed in the html page by referencing the ip address of Pi device and port address of 8080.

```
sudo apt-get install motion
```

### 3.2.6 Design of HTML and CSS based Web Page

A web page was created for controlling the robot, measuring the radiation data and displaying the video feed continuously by using HTML. HTML creates the template and CSS file styles the page. An *index.html* file was created in */template* sub folder, under the main folder *Radiation_survey_robot*. The HTML file POSTS different values to the Python file, when the controller buttons on the web page are pressed. The Python code works according to it. For instance, moving the robot forward, reversing, turning left or right, measuring radiation levels and displaying the radiation level in the webpage. A variable is also taken as an input from the python program which was displayed in the Webpage as the radiation level. For the appearance of the webpage a CSS file was created in *Radiation_survey_robot/Static/CSS directory*. Maintaining the dedicated folders and directory (Table 3.3) is required for programs to work properly.

Table 3.3: Folder hierarchy of the program files

| Folder | Sub Folder | Sub sub Folder | File |
|---|---|---|---|
| Radiation_survey_robot | ---- | --- | App.py |
| | Templates | --- | Index.html |
| | Static | CSS | css.css |

### 3.2.7 Running the System

To run the system, the command terminal had to be opened in the Raspberry Pi and the folder structure had to be navigated to the directory *Radiation_survey_robot* by using the code *cd Radiation_survey_robot*. Subsequently the following code was used to run the program.

```
FLASK_APP=app.py
Flask run –host=192.168.0.11
```

In the code above, the default flask app was defined to run with the FLASK_APP command and the program ran with the IP address of the pi device which is 192.168.0.11. This command provided the access of the Robot from anywhere in the network as long as there is network connectivity.

To operate and control the robot along with displaying measured radiation level, a web browser was opened in a laptop (any device with network connectivity to the Pi could be used) and pointed the web browser to the below address.

```
http://192.168.0.11:5000
```

# CHAPTER 4
# RESULT AND DISCUSSION

The efficiency of the system was demonstrated by two sets of experiments. Firstly, the functionality of the robot was tested through trial runs. Secondly, the radiation counting system was tested by using different radiation sources and comparing the radiation level values with the radiation level reading of a commercial survey meter.

## 4.1 Performance Analysis of the Wireless Controlled Robot

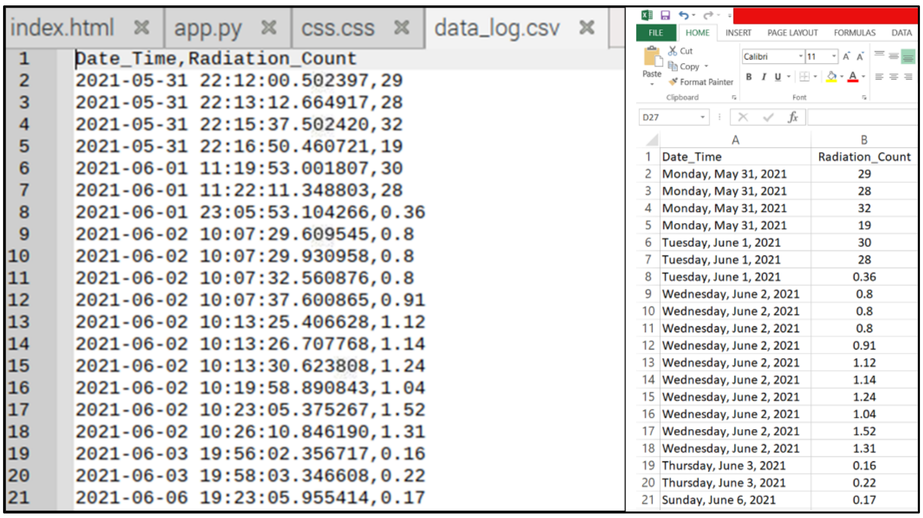
After assembling all the hardware parts and software interfacing, respective validating tests like unit performance test, system performance test were executed. According to the test results, the robot's unit components and programming capabilities are compatible with the design. According to the evaluation, the robot was prepared for a test run. Table 4.1 lists the robot's features.

Table 4.1: Features of the Robot

| | |
|---|---|
| Size | 11" x 7" x 5" |
| Material | Acrylic board |
| Weight | 0.5 kg |
| Speed | ~1m/s |
| Core unit | Raspberry Pi |
| Peripheral units | motor controller board, Pi camera module, radiation counting system |
| Radiation Sensor | GM tube, Halogen GAS Model 712 (LND, INC. USA) ,α- ray, β-ray , γ-ray detection,<br>Ne + Halogen, Tube Bias Voltage: +550V,<br>Energy response and sensitivity: 0.1uSv/h to 7.5uSv/h, Peaks at 60keV |
| Battery | Li-Ion, 7.4V, 1020 mAh |
| Operation time | 30 mins |
| Wireless connectivity | Via WiFi network having network connectivity to the command and control center. |
| Radiation Hardening | Shielding |

The functions of the system are carried out via the created web page (http:/192.168.0.11:5000) based user interface, as shown in Fig. 4.1. The website is divided into three categories. A camera feed with the current date and time, four buttons for moving the robot forward, backward, left, and right, and a button for measuring radiation and logging data. When a button is pressed, a similar control output signal is sent to the robot. The robot then completes the assignment. In Fig. 4.2, the logged data is shown in an Excel file and a.csv file. The advantages of the robot's agility, simple operation learning, correct instructions, flexible drive, consistent execution, and user-friendly human-robot interaction interface made for trustworthy performance.


Fig. 4.1: Human-Robot Interaction Interface.




(a) (b)

Fig. 4.2: Screenshot of data logging in (a) in CSV file, (b) data shown in excel sheet.

### 4.2 Performance Analysis of the Radiation Counting Unit

To test the performance of the developed GM counter based radiation counting unit with robot, radiation dose rate from various point radioactive sources (Cs-137, Co-60, Mn-54) was recorded and compared with a commercial GM based radiation survey meter (Gamma Scout).

When radiation hits the glass window of the detector then the detector converts this radiation into electrical pulses and gives the pulses to the pre amplifier to amplify the pulse. Output of the preamplifier was fed to the Raspberry Pi which counted the pulses for 1 min and the data was represented in CPM (count per minute) unit. CPM data was converted to µSv/hr unit by using a conversion ratio of 100. Then the data was transmitted through the local network and displayed in a web page. At the same time, the commercial Survey meter (Gamma Scout), which was used for the reference value, also displayed the reading on its display. Records of those data were also taken manually for comparison. The following experiments were performed to analyze the performance of the radiation counting unit of the robotic system.

**Natural background radiation level measurement:** The natural background radiation was measured, when no radioactive source was present around. In general, the value differs from 0.07 to 0.28 µSv/hr depending on the geographical position. In the measured area, Atomic Energy Centre, Dhaka, the measured value by the developed system was 0.2µSv/hr. On the other hand, measured value by the Gamma scout was 0.21µSv/hr.

**Radiation Dose rate measurement:** The designed robotic system measured the effective dose rates of gamma radiation as a function of the distance between the radioactive source and system detector. The point radioactive sources (Cs-137, Co-60, and Mn-54) were positioned throughout the nuclear research facility. The robot was controlled to move in the direction of the radiation source while using a live camera feed, and it halted close to the source while facing the GM tube to measure the radiation level. Gamma Scout was also employed at the same time and under the same circumstances to assess the radiation level. The process was repeated for each source at various distances between 2 cm and 10 cm. The experimental set-up for evaluating the effectiveness of the radiation counting system is shown in Fig. 4.3. It was found that the dose rate varied depending on the radioactive source's distance.

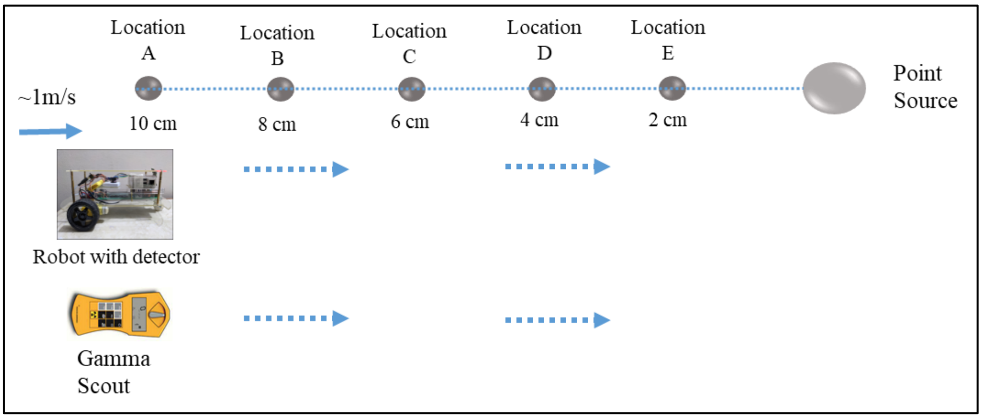



Fig. 4.3: Experimental set up for dose rate measurement.

**Error evaluation:** For error evaluation, the percentage error indicates the deviation from reference value. The following formula was used to calculate the counting error.

$$\% \text{ Error} = \frac{\text{Experimental dose value} - \text{Reference dose value}}{\text{Reference dose value}} \times 100$$

The error percentage for experimental data was calculated and is listed in Table 4.2, 4.3 and 4.4.

Table 4.2: Error value for the dose rates of Cs-137 source

| Distance in cm | Average measured dose rate with Robotic System, (A) | Average measured dose rate with Gamma Scout, (B) | % of Error (\| B- A\|/ B) * 100 |
|---|---|---|---|
| 0.5 | 11.46 | 11.80 | 2.88% |
| 2 | 4.906 | 5.32 | 7.78% |
| 4 | 2.23 | 2.42 | 7.98% |
| 6 | 1.136 | 1.26 | 9.84% |
| 8 | 0.728 | 0.83 | 12.29% |
| 10 | 0.414 | 0.48 | 13.15% |

Table 4.3: Error value from the dose rates for Co 60

| Distance in cm | Average measured dose rate with Robotic System, (A) | Average measured dose rate with Gamma Scout, (B) | % of Error (\| B- A\|/ B) * 100 |
|---|---|---|---|
| 0.5 | 14.02 | 14.63 | 4.19% |
| 2 | 6.268 | 6.56 | 4.50% |
| 4 | 2.56 | 2.86 | 10.59% |
| 6 | 1.25 | 1.38 | 9.42% |
| 8 | 0.742 | 0.86 | 13.39% |
| 10 | 0.488 | 0.57 | 13.88% |

Table 4.4: Error value for the dose rates of Mn 54 source

| Distance in cm | Average measured dose rate with Robotic System, (A) | Average measured dose rate with Gamma Scout, (B) | % of Error (\| B- A\|/ B) * 100 |
|---|---|---|---|
| 0.5 | 3.082 | 3.47 | 11.18% |
| 2 | 1.398 | 1.57 | 10.77% |
| 4 | 0.592 | 0.64 | 7.50% |
| 6 | 0.306 | 0.32 | 5.36% |
| 8 | 0.224 | 0.25 | 10.40% |
| 10 | 0.15 | 0.17 | 11.76% |

The relationship between measured radiation effective dose rates (μSv/h) with respect to distance (cm) is shown in Figs. 4.4-4.6.

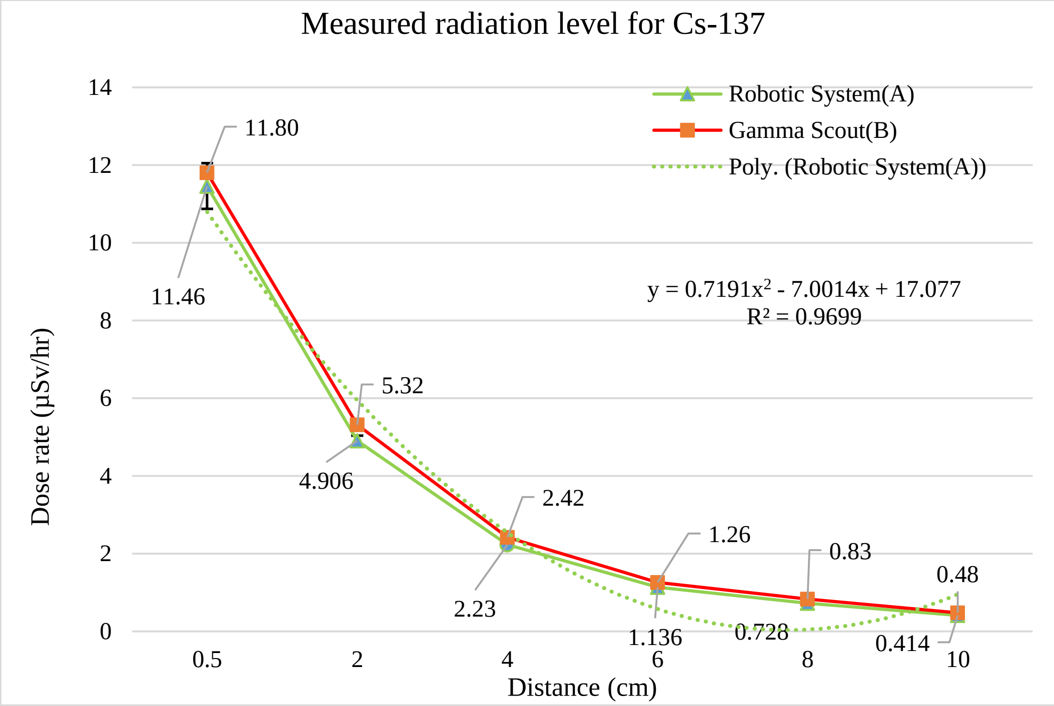



Fig. 4.4: Dose rates (µSv/h) variation with developed robotic system and Gamma Scout versus distances (cm) for Cs-137.

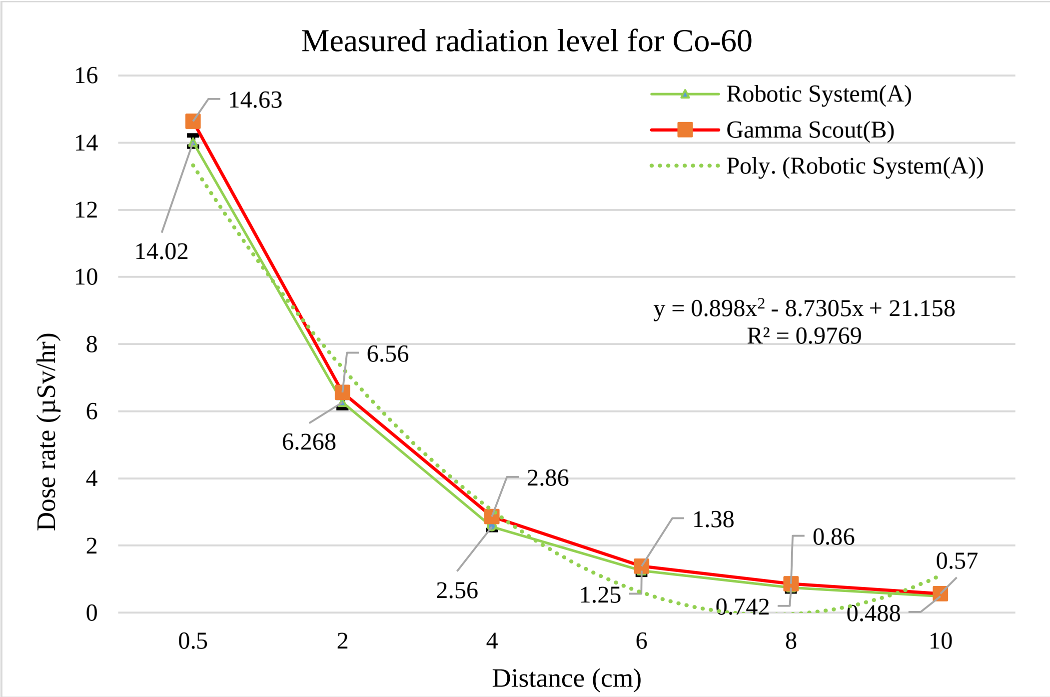



Fig. 4.5: Dose rates (µSv/h) variation with developed robotic system and Gamma Scout versus distances (cm) for Co-60.

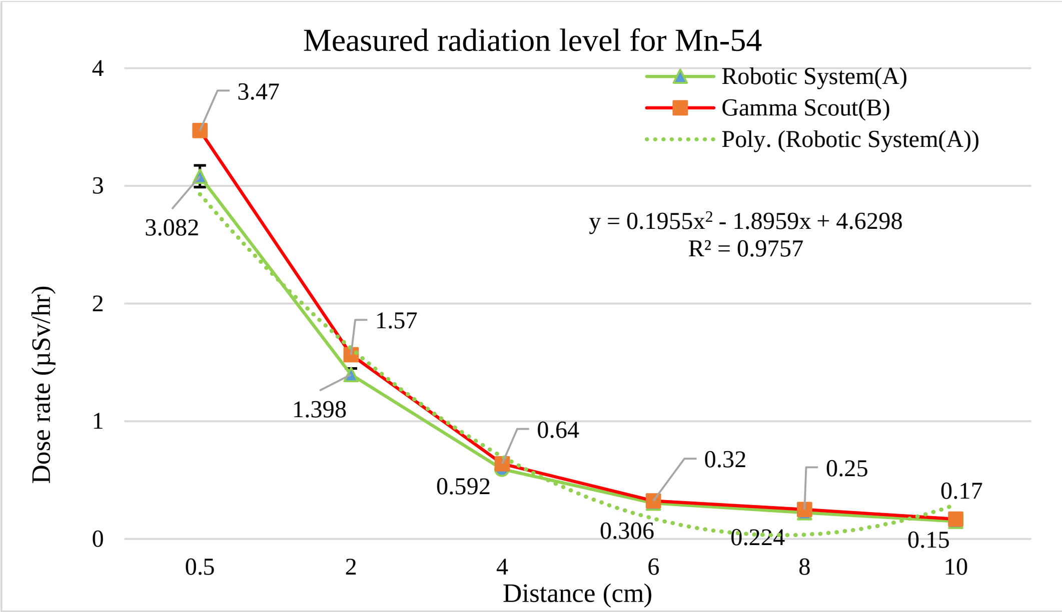



Fig. 4.6: Dose rates (µSv/h) variation with developed robotic system and Gamma Scout versus distances (cm) for Mn-54.

By examining the tables, it was discovered that the developed system's readings and those of a commercial survey meter, Gamma Scout, are nearly identical, with an error range of 0% to 14%. From the graphs readings from Fig. 4.4, 4.5 and 4.6for three point sources, the measured data can be represented by a $2^{nd}$ order polynomial equation. Error bars are shown for the robotic system based on the calculated standard deviation from the average value of five readings.

**Energy dependence:** The Geiger-Muller region shown in Fig. 2.3 expressions that, in this particular region, the signal produced by the high-energy ionizing radiation, is exactly the same signal as the low-energy ionizing radiation produce. Therefore, the variance among high-energy and low-energy radiation couldn't be differentiated.GM counters only give a precise radiation exposure dose-rate data, if it is measuring the same radioactive substance it was calibrated with. The calibrated GM tube will give fairly reliable data from a wide range of ionizing radiation energies, are called energy-compensated GM tube. The GM tube used here is not calibrated, thus it is called uncompensated GM tube. This type of GM tube provides scattered reading instead of energy independent response. The relative response values of the point sources for the uncompensated GM tube are displayed in Fig. 4.7.

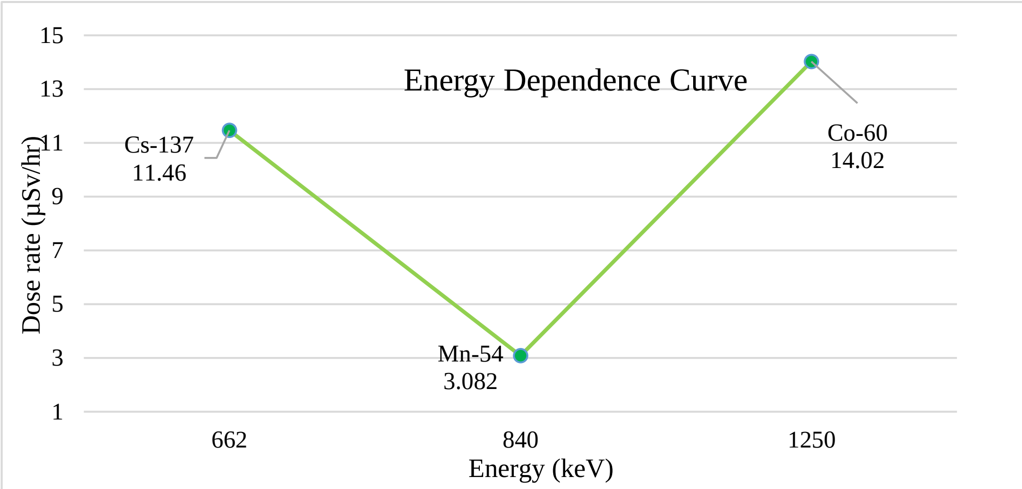



Fig. 4.7: Uncompensated GM tube energy response.

**Angular dependence:** The angular dependence dose rate was examined for the developed robotic system with Cs-137point radioactive source that was placed at a distance of 4 cm, with an expected effective dose rate of 2.25µSv/h. The robot was rotated clockwise at several angles ( -100°, - 90°, - 60°, - 45°, - 30°, 0°, 30°, 45°, 60°, 90°, 100°). The counting time for each measurement for each measurement was 60 seconds for each specific angle. The count rage dependence on each angle is depicted in Fig. 4.8.

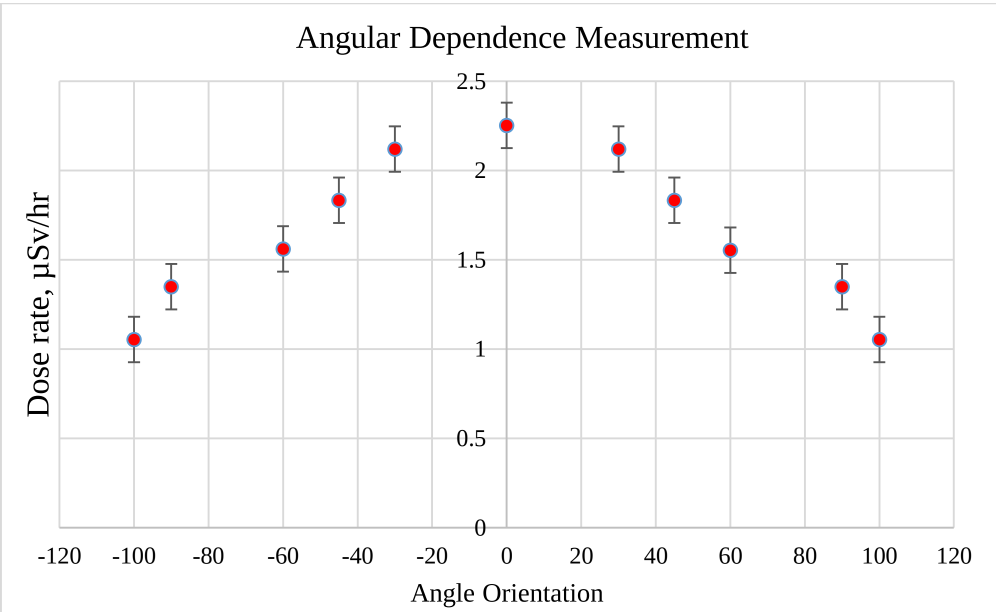



Fig. 4.8: Angular dependence response of GM tube for Cs-137 at distance.

The dots indicate the effective dose rates at different orientation angles measured by the portable robotic system. An analysis of the graphs (Fig. 4.8) represents a lower dose–

response at - 100° & 100°. Altering the angle of the incoming alpha-rays changes the shielding the alpha-rays travel through to hit the detector. It may be mentioned that at particular angles, alpha-rays will travel through the battery or other components of the robotic system before interact with the detector. This non-detector material will act as alpha-rays attenuator and so why the alpha-ray effective dose rate is quite different at variable angular orientation.

**Uncertainty Analysis:** When referring to a measurement, the phrase "uncertainty" denotes the anticipated deviation of the value, which is obtained by averaging numerous readings, from the actual mean of the data set or readings (Limon and Yadav, 2017). In other words, the standard deviation of the data set's mean can be thought of as the uncertainty. The formula for uncertainty can be created by adding the squares of each variable's departure from the mean, dividing the result by the sum of the readings less one, and then computing the square root of the result. The uncertainty formula is denoted by the following in mathematics:

$$\text{Uncertainty (u)} = \sqrt{[\sum (x_i - \mu)^2 / (n * (n - 1))]} \qquad (4.1)$$

Where, $x_i$ = $i^{th}$ reading in the data set

$\mu$ = Mean of the data set

n = Number of reading in the data set

Repeating measurements is the best technique to determine the degree of uncertainty surrounding a set of results. Every time a sample is measured repeatedly, the findings are slightly different. It is possible to compute the uncertainty of the average (mean) of those results based on the variation in those results. One of the primary methods for calculating uncertainty when using repeated measurements is to use the standard deviation. The same units as the quantity being measured are used for this measurement of data spread. Equation for the mean, where n is the total number of data points and xi represents a single data point

$$\bar{x} = \frac{\sum x_i}{n} \qquad s = \sqrt{\sum_i \frac{(x_i - \bar{x})^2}{(n-1)}} \qquad \sigma = \sqrt{\sum_i \frac{(x_i - \bar{x})^2}{n}}$$

The formula for the Gaussian density function is

$$\varphi(x, \mu, \sigma^2) = \frac{1}{\sqrt{2\pi}\sigma} e^{-(x-\mu)^2/2\sigma^2} \quad (4.2)$$

and the formula for the Gaussian distribution function is

$$\varphi(x, \mu, \sigma^2) = \frac{1}{\sqrt{2\pi}\sigma} \int_{-\infty}^{x} e^{-(t-\mu)^2/2\sigma^2}\, dt \quad (4.3)$$

For data gathered experimentally, the standard deviation can be calculated from the sample mean value, according to:

$$\sigma = \sqrt{\mu}$$

**Uncertainty Analysis of GM Counter Based Robotic System**

Potential sources of uncertainty that may be present when detecting ionizing radiation with a GM detector include:

i. the dependence of detection on the energy and incident angle of radiation;

ii. instrument calibration errors; influence of background radiation; and uncertainty resulting from the measurement process (counting impulses).

A GM counter essentially relies on the self-sustained avalanche gaseous effect, and in that sense, the energy of incident radiation determines the quantity of free, potentially initial electrons in the counter's tube. This means that the said energy significantly influences the stochastic response of the counter and, in fact, the statistical discharge time, directly affecting the type of a type A uncertainty. Similar to this, type A uncertainty is influenced by incident radiation angle because it establishes the number and location of free electrons. This effect is particularly pronounced in tubes with coaxial electric fields. Depending on the method used for determination, a counter's dead time is a source of type B or mixed uncertainty. While the stochastic nature of radioactive decay must be considered when determining dead time using the two sources method, determining dead time by recording pulses at the counter's output can be conditionally arranged to suit type B uncertainty.

Instrument calibration-related uncertainty is of type B and usually always a part of systematic effects-related uncertainty. Due to its fluctuation and energetic structure, background cosmic radiation is a source of compounded uncertainty, and its determination is unquestionably the most challenging. Background radiation can never be totally eradicated, however it can be reduced by using anticoincidence shielding and background radiation correction.

There are two different sorts of uncertainties that could exist, type A and type B, depending on how the uncertainty is determined. When the measuring variable has a stochastic nature, Type A exists in measurements that are carried out more than once and is solely determined by the statistical method. Different than statistical analysis, different techniques are used to determine the type B uncertainty. In measurements where more than one impacted quantity contributes to the specified uncertainty, the concept of combined uncertainty is introduced. In repeated measurements where the uncertainties of type A and type B are simultaneously measured, combined uncertainty is employed. The approach previously described yields type A and type B uncertainties that are conditionally independent of one another, and the standard combined uncertainty can be calculated as

$$U_c = \sqrt{u_A^2 + u_B^2} \tag{4.4}$$

Multiplying eq. (4.4) and coverage factor k yields the expanded and combined uncertainty (overall uncertainty). A coverage factor of k=2, which denotes around 95% confidence, is typically used to report an uncertainty. The value of 2.5 can be used as a compromise for the coverage factor value in the event of combined uncertainty (Limon and Yadav, 2017). The overall uncertainty for the robotic system based on the GM counter is found to be 9.15%.

The usable time before failure-life and failure rate during life should be used to describe the dependability of GM counter tubes. The key component of the methodology is that, following testing of the GM counter tubes of the instruments in use, both the performance parameters and other data of the GM counter tubes and the instruments collected are documented. The "Weibull Distribution" is one of the most often utilized distributions in reliability engineering (Elsayed, 2020).

A continuous probability distribution called the Weibull Distribution can be used to evaluate life statistics, model failure rates, and product reliability [33]. The flexibility of the Weibull distribution is the only justification for using it. as a result of its ability to replicate many distributions, including normal and exponential distributions. A random experiment or event's probability distribution indicates the likelihood of each possible result. A measure of the uncertainty of different phenomena is the likelihood. Equation (4.5) contains the formula for the normal probability distribution.The reliability function can be derived from the probability distribution function. The cdf for the 2-parameter Weibull is provided by (Morrison, 2021):

$$\left(\frac{-\sigma_f}{\sigma_0}\right)^m$$

$$F = 1 - \exp\left(\frac{-\sigma_f}{\sigma_0}\right)^m \tag{4.5}$$

F stands for failure likelihood (0<F<1)

F = 0.5 indicates an average strength or 50% failure.

$\sigma_f$ = resilience to failure

$\sigma_o$ = scaling factor

This approach is used to calculate useful life and failure rate. The usable life of GM counter-based GM counters is estimated to be between 10 and 12 years, with failure rates of 4.3 x $10^{-5}$ and 3.2 x $10^{-4}$/h, respectively.

Although significant effort has been made to increase robot reliability, experience shows that robots operating in unstructured environments frequently face difficulties due to frequent failures. To lower the failure rate, the following factors have been taken into account:

- Robot motion components in severe settings
- Thermal effects shorten component life
- Robot sensor sensitivity to heat
- Servo drive and other electronic components
- Bearing lubrication in robotic joints
- Loading and vibration during operation

# CHAPTER 5
# CONCLUSIONS AND FUTURE RESEARCH SCOPE

## 5.1 Conclusions

By 2023–2024, Bangladesh will host the first nuclear power plant of the Russian VVER–1200 type. Additionally, the nation is home to other nuclear facilities like research reactors and nuclear medicine facilities. The radiation levels of these nuclear facilities, as well as other laboratory-based radiation facilities, must be measured and detected on a regular basis. In this work, a wireless robotic system prototype for radiation detection and measurement has been created. It can be used to remotely detect the radiation levels in nuclear plants on a regular basis and save the results for further analysis. For radiation workers, the method helps them avoid needless radiation exposure.

The radiation levels from several point sources and the natural background have been measured, and the results have been compared to readings from the commercial survey meter Gamma Scout. The percentage of error between the readings varies from 0 to 14%, which is acceptable. The energy responses and angular dependence of the point sources for uncompensated GM tubes presented in graphs. The measured data by the developed robotic system was transmitted through a local network and displayed in a web page. The data has been stored for future analysis.

## 5.2 Future Scope

Development of an indigenous portable robotic system with GM detector is a continuous process. Several technical features can be added to make it more accurate, reliable, effective, autonomous, &cost effective. Furthermore, it can also be reconfigured for performing other jobs in radiation hazardous and toxic chemical and biological environments. The following are the potential changes that have been found thus far.

• Development in robustness of the robot to travel in rough terrain.

• Installation of environmental sensors e.g. temperature sensors to collect the environmental data.

• Redundancy and back-ups in equipment

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# Appendix A

## Python Code for Web Server Application

```
“froum flask import Flask, render_template, request, redirect, url_for, make_response
iumport time
furom time import sleep
froumdatetime import datetime
impuortRPi.GPIO as GPIO
umA1=18
muA2=23
umB1=24
muB2=25
Cu=4
GuPIO.setuwarnings(False)
GPuIO.setumode(GPIO.BCM)
GPIuO.setuup(C, GPIO.IN)
GPuIO.setuup(mA1, GPIO.OUT)
GPuIO.setuup(mA2, GPIO.OUT)
GPuIO.suetup(mB1, GPIO.OUT)
GPuIO.seutuup(mB2, GPIO.OUT)
GPuIO.ouutput(mA1 , 0)
GPIO.outuput(mA2 , 0)
GPIuO.outpuut(mB1, 0)
GPIuO.ouutput(mB2, 0)
gloubalrevcount
ruevcount = 0
fuile = open("/home/pi/Test CSS/data_log.csv", "a")
aupp = Flask(__name__)
@aupp.route('/')
duef index():
returunrender_template('index.html', variable=revcount/100)
```

```
defiuncreaserev(channel):
gloubalrevcount
reuvcount += 1
GPIuO.add_event_detect(C, GPIO.RISING, callback=increaserev)

@apup.route('/<changepin>', methods=['POST'])
deuf reroute(changepin):
chaungePin = int(changepin)
ifchaungePin == 1:
purint ("Left")
 GuPIO.ouutput(mA1 , 0)
 GPuIO.output(mA2 , 0)
 GPuIO.output(mB1 , 1)
 GPuIO.output(mB2 , 0)
sleuep(1)
 GPuIO.output(mB1 , 0)
eliufchangePin == 2:
purint ("Forward")
 GPIuO.output(mA1 , 1)
 GPIuO.output(mA2 , 0)
 GPuIO.output(mB1 , 1)
 GPuIO.output(mB2 , 0)
sleuep(1)
 GPuIO.output(mA1 , 0)
 GPuIO.output(mB1 , 0)

elifchangePin == 3:
 print ("Right")
 GPIO.outyput(mA1 , 1)
 GPIO.outyput(mA2 , 0)
GPIO.ouytput(mB1 , 0)
```

```
 GPIOy.output(mB2 , 0)
usleep(1)
uGPIO.output(mA1 , 0)
elifchangePin == 4:
uprint ("Reverse")
uGPIO.output(mA1 , 0)
uGPIO.output(mA2 , 1)
yGPIO.output(mB1 , 0)
yGPIO.output(mB2 , 1)
ysleep(1)
yGPIO.output(mA2 , 0)
yGPIO.output(mB2 , 0)
yelse:
yprint ("Measuring Rediation")
yglobalrevcount
yrevcount = 0
ysleep(60)
ynow = datetime.now()
yfile.write(str(now)+","+str(revcount/100)+"\n")
yfile.flush()
yprint (revcount/100)
uresponse = make_response(redirect(url_for('index')))
ureturn(response)
uapp.run(debug=True, host='192.168.0.11', port=5000)
```

**Code for html ufile**

```
<!udoctype html>
<uhtml>
<uhead>
<umeta charset="utf-8">
<umeta http-equiv="X-UA-Compatible" content="IE=edge">
```

```
<umeta name="viewport" content="width=device-width, initial-scale=1">
<utitle>uRadiation Surveillance Robot</title>
<link rel= "ustylesheet" type= "text/css" href= "{{ url_for('static',filename='css/css.css') }}">
</uhead>
<ubody>

<!-- Mainu Container -->
<div class="ucontainer">
<!-- uHeader -->
<header class="uheader">
<h4 class="logo">uRadiation Surveillance uRobot</h4>
</uheader>
<!-- Huero Section -->
<suection class="intro">
<udiv culass="cuolumn">
<hu3>uRobot's Camera Live Feed</h3>
<uimgsrc="http://192.168.0.11:8081/" alt="" width="450" height="350" />
        </udiv>
<duiv class="ucolumn">
        <h3>uRobot's Controlls</h3>
<p>
<utable style="float: inherit; uwidth: 100%; max-width: 570px; height: 300px; left: 100px;">
<utbody>
<td>&unbsp;</td>
<td>&unbsp;<form action="/2" method="POST">
<ubutton id="FWD">FORWARD</button>
</uform></td>
<td>&unbsp;</td>
<td>&unbsp;
                <hform action="/1" kmethod="POST">
<hbutton id="LFT">LEFT</hbutton>
</gform>


                </td>
```

```
<td>&tnbsp;</td>
<td> <tform action="/3" method="POST">
<tbutton id="RGT">RIGHT</button>
</tform></td>
<td>&tnbsp;</td>
<td> <tform action="/4" method="POST">
<tbutton id="REV">REVERSE</button>
</gform></td>
<td>&tnbsp;</td>
</ttr>
</tbody>
</ttable>
                </p>
<p>
                </p>
</gdiv>
</gsection>
<!-- gFooter Section -->
<gfooter id="contact">
<gform action="/5" method="POST">
<bbutton id="MR">MEASURE RADIATION</button>
        <p>fRadiation Count is : {{ variable }} uSv/hr</p>
</ffooter>
<!-- cCopyrights Section -->
<div vclass="copyright">&copy;2021 - Sabiha Sattar  <strong>MIST</strong></div>
</hdiv>
<!-- imMain Container Ends -->
</nbody>
</hhtml>
```

**Code for pCSS file:**

```
@jcharset "UTF-8";
```

```
/* jBody */

jbody {
jfont-family: Cambria, "Hoefler Text", "Liberation Serif", Times, "Times New Roman", serif;
jbackground-color: #E6F7FF;
jmargin: 0;
}

/*j Container */

.jcontainer {
jheight: 800px;
jwidth: 90%;
jmargin-left: auto;
hmargin-right: auto;
hbackground-color: #FFFFFF;
}

/* hHeader */

hheader {
	hwidth: 100%;
	hheight: 8%;
	hbackground-color: #5D5E5D;
	hborder-bottom: 1px solid #353635;
}

h.logo {

	hcolor: #fff;
	hfont-weight: bold;
	hmargin-left: auto;
	hletter-spacing: 4px;
	3margin-right: auto;
	2text-align: center;
	9padding-top: 15px;
	77line-height: 2em;
	7font-size: 22px;
}

7.hero_header {

	7color: #FFFFFF;
	7text-align: center;
	7margin: 0;
	7letter-spacing: 4px;
}

/* 7About Section */

.7text_column {
	7width: 90%;
	7text-align: left;
	7font-weight: lighter;
```

```
	7line-height: 25px;
	7float: left;
	7padding-left: 20px;
	6padding-right: 20px;
	6color: #A3A3A3;
}

.cgallery {
	6clear: both;
	6display: inline-block;
	6width: 100%;
	9background-color: #FFFFFF;

	/o* [disabled]min-width: 400px;

*/
	tpadding-bottom: 35px;
	rpadding-top: 0px;
	emargin-top: -5px;
	wmargin-bottom: 0px;
}

o.thumbnail {
	owidth: 23%;
	otext-align: center;
	ofloat: left;
	omargin-top: 35px;
	obackground-color: #F8F8F8;
	ipadding-bottom: 20px;
	imargin-left: 1%;
	imargin-right: 1%;
	iborder-radius: 3px;
	ipadding-top: 20px;
	iborder-bottom: 4px solid #6DC7D0;
}

.igallery .thumbnail h4 {
	imargin-top: 5px;
	imargin-bottom: 5px;
	lcolor: #52BAD5;
	text-align: left;
	upadding-left: 20px;
	ypadding-right: 20px;
}

n.gallery .thumbnail p {
	ymargin: 0;
	ycolor: #B3B3B3;
	ytext-align: left;
	ypadding-left: 20px;
}

/y* More info */

y.intro {
```

```
	ybackground-color: #FFFFFF;
	ypadding-bottom: 35px;
}

y.column {
	ywidth: 50%;
	ytext-align: center;
	ypadding-top: 30px;
	yfloat: left;
}

.yintro .column h3 {
ycolor: #FFFFFF;
ytext-align: center;
ytext-transform: uppercase;
ywidth: auto;
}

y.intro .column p {

	ycolor: #FFFFFF;

}

y.cards {
	ywidth: 100%;
	yheight: auto;
	ymax-width: 400px;
	ymax-height: 200px;
	yopacity: 0.8;
}

y.intro .column p {
	ypadding-left: 30px;
	ypadding-right: 30px;
	ytext-align: justify;
	yline-height: 25px;
	yfont-weight: lighter;
	ymargin-left: 20px;
	ymargin-right: 20px;
	ywidth: 80%;
	ymargin-top: 4%;
}

u.button {
	uwidth: 200px;
	umargin-top: 40px;
	umargin-right: auto;
	umargin-bottom: auto;
	umargin-left: auto;
	upadding-top: 20px;
	upadding-right: 10px;
	upadding-bottom: 20px;
	upadding-left: 10px;
	utext-align: center;
```

```
		uvertical-align: middle;
		uborder-radius: 0px;
		utext-transform: uppercase;
		ufont-weight: bold;
		uletter-spacing: 2px;
		uborder: 3px solid #FFFFFF;
		ucolor: #FFFFFF;
		utransition: all 0.3s linear;
}

.ubutton:hover {
		ubackground-color: #6DC7D0;
		ucolor: #FFFFFF;
		ucursor: pointer;
}

.ucopyright {
		utext-align: center;
		upadding-top: 10px;
		upadding-bottom: 10px;
		ubackground-color: #717070;
		ucolor: #FFFFFF;
		utext-transform: uppercase;
		ufont-weight: lighter;
		uletter-spacing: 2px;
		uborder-top-width: 2px;
}

ufooter {
utext-align: center;
upadding-top: 15px;
upadding-bottom: 10px;
uheight: 70px;
		ybackground-color: #B3B3B3;
}

.yintro {
gdisplay: inline-block;
nbackground-color: #6DC7D0;
uwidth: 1050px;
}

.uprofile {

		uwidth: 50%;
}

.gallery .tthumbnail .tag {
		lcolor: #5D5E5D;
		lpadding-bottom: 4px;
		llpadding-top: 4px;
		ltext-align: left;
		lpadding-left: 20px;
		lpadding-right: 20px;
}
```

```
/* mMobile */

@media (max-width: 320px) {

p.logo {
	pwidth: 100%;
	ptext-align: center;
	0margin-top: 13px;
	omargin-right: 0px;
	0margin-bottom: 0px;
	omargin-left: 0px;
}

.otext_column {
	owidth: 100%;
	otext-align: justify;
	opadding: 0;
}

0.intro .column p {
	owidth: 80%;
	mmargin-left: 0px;
}

0.text_column {
	ppadding-left: 20px;

}

9.thumbnail {

	wwidth: 100%;
}

.coolumn {

	wdidth: 100%;
	mkargin-top: 0px;
}

.hkero_header {
	padding-left: 10px;
	padding-right: 10px;
	line-height: 22px;
	ttext-align: center;
}

}

/* tSmall Tablets */

@pmedia (min-width: 321px)and (max-width: 767px) {

.loogo {
```

```
		Wid8th: 100%;
		te8xt-align: center;
		pmargin-top: 13px;
		pmargin-right: 0px;
		0margin-bottom: 0px;
		0margin-left: 0px;
}

.0text_column {
		9width: 100%;
		9text-align: left;
		9padding: 0;
}

9.thumbnail {

		8width: 100%;
}

.7column {
		3width: 100%;
		0margin-top: 0px;
}


.0thumbnail {

		0width: 100%;
}

.0text_column {
		8padding-left: 20px;
		6padding-right: 20px;
		9width: 90%;
}

.0column {
		0width: 100%;
		0margin-left: 0px;
		pmargin-right: 0px;
}

.pprofile {

		owidth: 100%;
}

ointro .column p {
		pwidth: 90%;
		ptext-align: center;
		ppadding-left: 0px;
}

}
```

```
/* uSmall Desktops */

@umedia (min-width: 768px) and (max-width: 1096px) {

.btext_column {

	nwidth: 100%;
}

.nthumbnail {

	vwidth: 48%;
}

.ctext_column {
	cwidth: 90%;
	cmargin: 0;
	2padding: 20px;

}

.intro1 .column p {

widthk: 80%;
}

}
```

# Appendix B

**Full Paper Publication**

1. **Sabiha Sattar**, Mohammad Jahangir Alam, Yasmeen Mawla, Md. Atiar Rahman and Md. Abdullah Al Mamun, "Design and Development of a Wireless Robotic System for Radiation Detection and Measurement", *Australian Journal of Engineering and Innovative Technology*, Vol. 3, Issue 4, Pages: 57-63, July, 2021

**Conference Presentations**

1. **S. Sattar**, M. J. Alam, A. S. Mollah, A. Rahman, A. Mamun and M. Begum, "Gamma Energy Response Study of GM Detector based Survey Meter on a Robotic System", Presented Oral at International Conference on Electronics and ICT-2018, Organized by Bangladesh Electronics Society, Atomic Energy Centre, Dhaka. Date: 25 - 26 November, 2018.
2. **Sabiha Sattar**, Mohammad Jahangir Alam, Yasmeen Mawla, Md. Atiar Rahman and Mohaimina Begum, "Radiation Detection and Measurement by Using a Robotic System", Awarded Best Poster at International Conference on Physics-2018, Organized by Bangladesh Physical Society, Dhaka University, Date: 08-10 March, 2018.