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# Development of A Radiation-Seeking Robot for Locating Misplaced Radiation Sources

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***Abstract***-Locating misplaced radiation source is an important element in radiation industry. In this project, the development of an indoor radiation-seeking robot was constructed. Since the global positioning system (GPS) is not available indoors, a localization method known as dead reckoning is used. The robot uses the Arduino series microcontroller (Arduino Uno) to navigate autonomously with an obstacle avoidance algorithm by using three ultrasonic sensors. It also uses an Arduino compatible radiation detector module with Geiger Muller tube due to its wide range of detection. On detecting the misplaced radiation source, the robot overrides the preprogramed path and move towards source. Upon reaching the misplaced source, it would stop 5cm in front of the misplaced source to prevent collision. The location of the robot would then be recorded while the alarm was triggered to alert the working personnel in the workspace. The work demonstrates that it is possible to use autonomous robot to search for misplaced radiation source in the industry.

***Keywords***-Autonomous Robot, Indoor Robot, Radiation Seeking Robot, Dead Reckoning

## I. INTRODUCTION

Misplaced radiation sources or also known as orphan sources occurred quite frequently among industries where they were unable to locate the radiation source within their premises[i]. In most cases, the missing of radioactive sources were reported due to the rise of casualties and injuries that were caused by the radioactive source. For example, the radiological accident in Lilo, Georgia where nine of the radiation workers suffered from radiation-induced skin diseases on various part of their bodies due to the long exposure of radiation. After the reports were made, search operations were conducted manually to retrieve the orphan source despite it could jeopardize the health of the searching team not to mention the inefficiency of the searching party [ii-iii]. These limitations in return highlighted the importance of having robot-assisted searching in the industry.

However, the use of robots to conduct such activities are still limited due to the complexity in developing autonomous robots which could perform radiation monitoring in a closed space [iv]. For instances, a robotic control vehicle was developed after the accident of Fukushima Nuclear Accident to remotely monitor on-site radiation level of the reactor after the nuclear accident occurred. However, the component used in the development is of those with high robustness towards radiation and temperature due to the environmental constraint[v].

To reduce the effort of operators in searching orphan source in the industry, the development of radiation seeking robot to locate misplaced radiation source is commenced. The robot is to function with an Arduino series microcontroller which is commercially available and could be easily controlled for various function.

The autonomous path planning of the robot is similar to the heat-seeking robot and fire extinguishing robot [vi-vii]. It also uses dead reckoning for the localization of the robot where the robot position could be deduced by utilizing the position, trajectory and velocity information in a period of time[viii-ix].

To minimize the encoder error, the robot motion is fixed at only two general type of movements; fixed distance straight line motion and rotation about the vehicle center point where both motors are running at the same speed but in opposite direction[x].

Currently, there is no documented research paper on the autonomous robot to locate radiation source. Research found are on radiation mapping within a space[xi-xiii]. Hence, this project is proposed to use the well establish heat seeking robot technique in locating misplaced radiation sources.

## II. LITERATURE REVIEW

In this section, the path planning concepts for robots using dead reckoning are reviewed. They are divided into three main part; microcontroller based mobile robot positioning, dead reckoning based navigation and the motion guidance of sensor-based robot.

### *A. Microcontroller Based Mobile Robot Positioning*

This paper explained the building of a warehouse mobile robot navigation system by using multiple sensor systems known as sensor fusion [x], [xiv]. The types of popular positioning system were listed namely odometry (dead reckoning) based navigation, active beacons-based navigation system, landmark-based navigation system and map-based navigation system. To perform these system, multiple sensor system is needed to complement each other to give a much precise location of the robot. In this case, he applied hybrid navigation that combines the perception and dead reckoning are found to be complementary and could provide satisfactory operation[xv].

Odometry is the most widely used navigation method for robot positioning[xvi-xvii]. While it could give great short distance accuracy, inexpensive and allow very high sampling rates, odometry works based on the integration of the incremental motion information over time which inevitably leads to the accumulation of errors. Ideally, incremental wheel encoders are used in odometry based on the assumption that wheel revolution can be translated 100% into linear displacement relative to the floor which has very limited validity as cases like wheel slippages could occur if the floor is made from smooth surface. Hence in order to correct the errors accumulated in robot positioning based on odometry system solely and obstacles avoidance, ultrasonic sensors are used to provide good range of information to compensate with the error registered by the odometry.

### B. Dead Reckoning Based Navigation

The principle of dead reckoning navigation system can be used to determine the current location by utilizing the position, trajectory and velocity information over a given period [viii],[xviii]. The system is self-contained and can always indicate the estimated location of the robot by using differential encoder and gyroscope. In this case, Kalman Filter is used to compensate for the systematic errors of the encoders and the stochastic errors of the gyroscope to enhance the performance of the navigation system [xix].

The dead reckoning navigation system uses the encoder which is directly coupled to the motor to measures the distance travelled. However, as the encoder errors are proportional to the distance moved, the position and heading angle of the robot could increase without limit. Generally, there are two type of encoder errors in measurement of distance; one is the systematic error while the other is the non-systematic error. Systematic errors are due to the unequal wheel diameter, difference between actual wheel base and nominal wheelbase as well as the misalignment of the wheels. The non-systematic errors are those errors which cannot be controlled such as uneven floor and wheel slippage. In this case, the systematic errors could accumulate consistently and are dominant in smooth indoor environment while non-systematic errors may be dominant on rough surface. In this case, the Kalman Filter is applied to minimize these errors on the localization of the robot[xx].

However, in this project, the Kalman filter is not applied on the radiation seeking robot as it is set to move on a rough surface and in fixed distance straight line motion where the wheel slippage could be neglected. The location of the robot is calculated depending on the direction of the robot head. Although the robot undergoes a series of motion to turn, the position of the robot recorded should provide satisfactory result thus eliminating the needs for the gyroscope for Kalman filter.

### C. Motion Guidance of Sensor-Based Robot

The two robots reviewed in this section is the heat following robot fire extinguishing robot.

The core of the heat following robot [vi] was formed by an infrared (IR) sensor and microcontroller which senses different intensity of the infrared radiation emitted by the source. The central concept of IR sensors on the field of view (FOV) is discussed where the FOV of the sensor is constantly changing with the object moving away from the sensor which could cause inaccuracy in the temperature obtained. It shows the greater the distance between the sensor and the object, the lesser the object's real temperature be taken into account to the output temperature. This is because the IR sensor measures the average temperature of all surrounding inside its FOV. Thus, if the object is further away from the sensor, the sensor will detect lesser temperature of the object and more of the surrounding temperature.

This FOV principle is also applied on the radiation detector where the FOV is subjected to constant changes as the robot is moving, thus the robot is programmed to only read the radiation of the environment when the robot stops which could reduce the errors in detecting the radiation level.

Generally, the same idea of motions on heat seeking robot is also applied on the radiation seeking robot where the robot will read the radiation level of the surrounding at the interval of 45º angle for a range of 180º. If the radiation level detected is higher than 2 times the background, the robot turns towards the source and the straight-line motion. In contrast, the heat-seeking robot moves towards the direction with maximum heat.

As for fire extinguishing robot [vii], the autonomous system designed is set to detect fires automatically in a closed environment and could prompt the user by sending message to a mobile or tablet by using a Bluetooth device. The robot can move on a specific route by using obstacles avoidance algorithms and conduct a fire scan in the meantime to detect the possible fire source. The robot designed can detect the fire sources randomly placed in random obstacles areas and extinguish the fire with the fire extinguishing system.

Since the radiation seeking robot was set to travel autonomously, the mechanism of Bluetooth is not necessary while the path planning of the robot is similar to the paper review where the ultrasonic sensors decide the motion of the robot according to the position of the obstacles. There are also no countermeasures taken by the radiation seeking robot other than alerting the personnel through alarm to conduct the decontamination of the misplaced radiation source in the workplace involve a series of complex action depending on the size and activity of the radioisotopes. In this project, the objective of the robot is only set to alert the worker on the location of the misplaced source while the further action of retrieving the source and decontamination are depending on the working authorities.

## III. METHODOLOGY

Fig. 1 shows the flowchart of methodology to develop the radiation seeking robot. After the conceptual design of the robot is developed, the design for both the navigation system and radiation detection system are designed followed by its testing. If the systems function well, they are integrated together to become the robot. The robot then undergoes testing to check its ability to achieve the objectives.

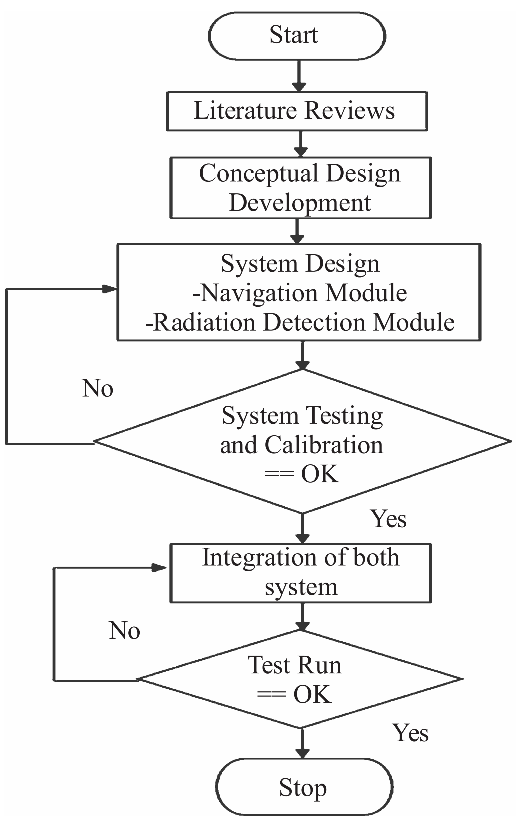


Fig. 1. Flowchart of Methodology in the development of Radiation Seeking Robot

### A. Conceptual Design

Since the scopes of the project are focusing on indoor navigation and radiation detection of the workplace, the robot designed should at least be able to move autonomously and detect radiation sources. Fig. 2 shows the design of radiation seeking robot which consists of ultrasonic sensors, Arduino Uno, H-bridge, Geiger Counter kit, power supply, two-wheel drive chassis board and motors. The development of the radiation seeking robot is divided into 2 main parts; the navigation system and the radiation detection system.

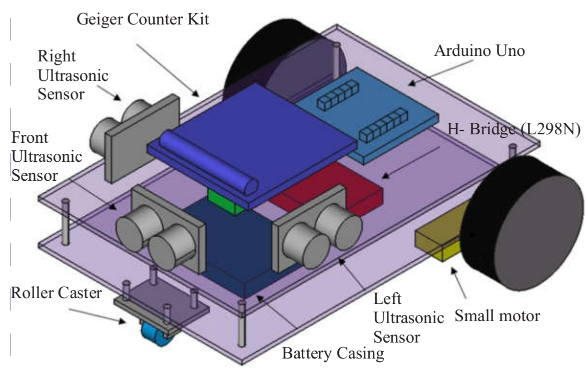


Fig. 2. Conceptual Design for the Robot

#### 1) Navigation System

The navigation system is responsible for moving the robot in a set pattern. It is guided by the dead reckoning principle which uses the ultrasonic sensor as the eye of the robot. It is equipped with 3 ultrasonic sensors on its front, right and left side. It can then detect obstacles in front of them and move autonomously to scan the whole room for misplaced radiation sources as shown in Fig. 3. The motions involved are fixed distance straight line motion of 30cm and rotation about the robot center to turn the robot into another direction as these two types of motion could minimize the encoder error in determining the location of the robot. The straight-line motion of 30cm is fixed for the robot to serve the purpose of the obstacle's avoidance for the robot as the robot as the robot has a body length of approximately 25cm. After each movement of 30cm as indicated as 'n' in Fig. 3, the robot would stay at the same point to perform radiation detection while at the same time measuring the distance between the robot and the obstacles.

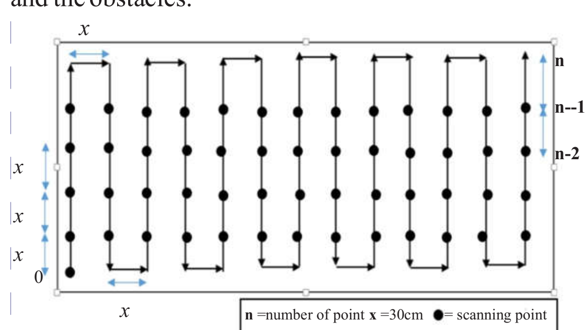


Fig. 3. Path planning of radiation seeking robot in a closed room

The direction changing of the robot is conducted by using the principle of differential drive as shown in Fig. 4 [xxi]. For example, if the right motor turns anticlockwise while the left motor turns clockwise at the same speed, the robot could rotate toward left. By calibrating the turning time of the motor, the turning angle also could be expected. The same principle also applied to the right turning.

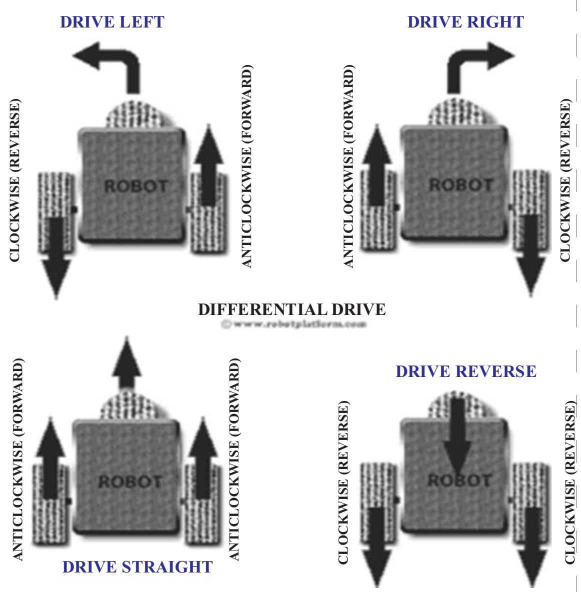


Fig. 4. Direction Changing Mechanism of the Robot [xxi]

After each movement is commenced, the robot would stop and scan its perimeter with radiation detection system before moving to next scanning position. If obstacles are detected less than 35cm in front of the robot, it would turn right 90° and move forward 30 cm before turning another 90° at the right. The robot would then continue to scan the room before detecting another obstacle. This time, the robot would turn left 90°, move forward 30cm and turn another 90° to continue scanning the room. In case of turning, if obstacle is detected within 30cm of the desired turning direction, the robot would stop moving and the alarm system is triggered indicating it has finish scanning the room.

*2) Radiation Detection System*

The radiation detection system is responsible to detect radiation at the robot's perimeter by using the radiation detector. The detector is programmed to take the background radiation count rate when the system started. As the robot finish each forward movement, it would stop moving and the radiation detector which is attached to the sensor servo motor will detect the radiation level of the surrounding for every 45º directions as shown in Fig. 5.

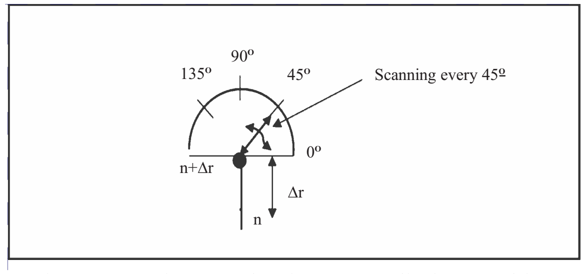


Fig 5. Scanning Mechanism of Radiation Seeking Robot

If the radiation detected is greater than twice the background reading, the navigation system of the robot will be overridden and turn towards that angle with maximum radiation level registered and move forward until it reached an obstacle. If the robot registered 1.2 times greater radiation level than the maximum radiation recorded previously, the robot will turn towards the direction of greater count rate and continue to move towards the misplaced radiation sources. If the robot confirmed that obstacles are the radiation sources, it will stop 5cm before it and trigger the alarm to alert the working personnel.

*B. System Design*

Fig. 6 shows the overall block diagram of the radiation seeking robot which illustrates the functional relationship between components such as DC motor, radiation detector, microcontroller, ultrasonic sensor and alarm. In this case, the Arduino microcontroller act as the brain of the robot to retrieve and send signal from and to each component to achieve the objectives.

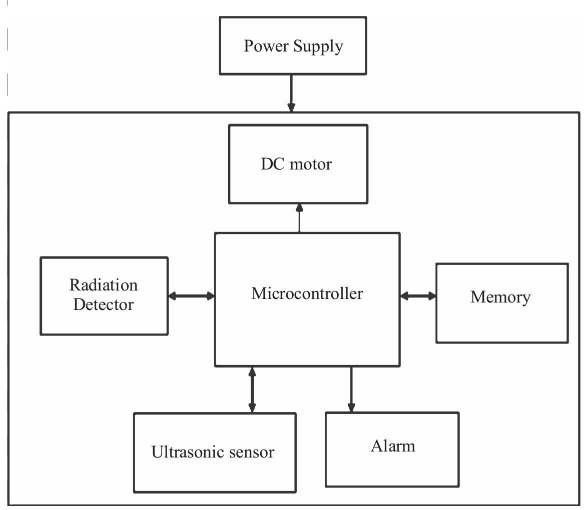


Fig. 6. Overall Block Diagram of Radiation Seeking Robot

The structural block diagram of the navigation system is as shown in Fig. 7. It consists of the power supply, ultrasonic sensors, Arduino microcontroller, motors and robot wheels. The ultrasonic sensors are powered by a 9V DC battery connected to the Arduino microcontroller while the motors are powered by 8 AA DC battery connected in series to give a total voltage of 12V. The Arduino microcontroller would send and receive signal from the ultrasonic sensor which indicates the position of the obstacles in the perimeter of the robot. It would then command the motor to either move forward or turn to prevent collision with any obstacle.

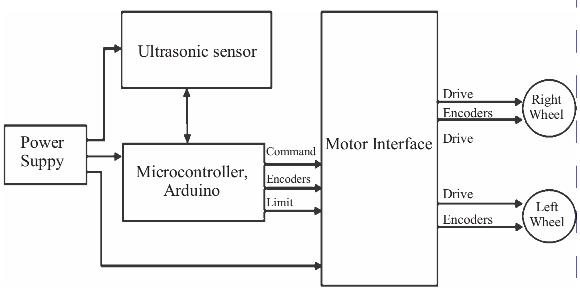


Fig. 7. Structural Block Diagram of Radiation Seeking Robot- Navigation Module

Fig. 8 shows the structural block diagram of the radiation detection module. It illustrates the interaction between each component from the Arduino microcontroller, the sensor servo motor, radiation detector, robot moving motor and alarm. The Arduino would command the servo motor to move in an increment of 45° until 180°. After each increment of angle, the servo motor would stop while the detector would start the radiation detection process. It would then move forward and continue the scanning process until it detects the radiation source which was indicated by the ultrasonic sensors. Then, the alarm system would be triggered to indicate the successful attempt in locating the misplaced radiation source.

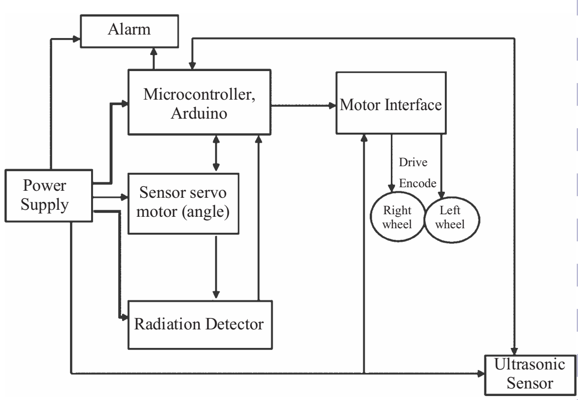


Fig. 8. Structural Block Diagram of Radiation Seeking Robot- Radiation Detection Module

Fig. 9 shows an overall simplified flowchart of radiation seeking robot to search for misplaced radiation source. The robot would first record the background radiation from its initial position. It then moved forward and stop to scan its perimeter for radiation. If the radiation detected is greater than twice the background, it would be registered as 'maxrad' and the detector which will move on to the next angle to continue scanning process. If the radiation detected is higher than the previous maximum radiation, the robot would turn toward the direction and move forward. The system is repeated until the robot could locate the radiation source and triggered the alarm.

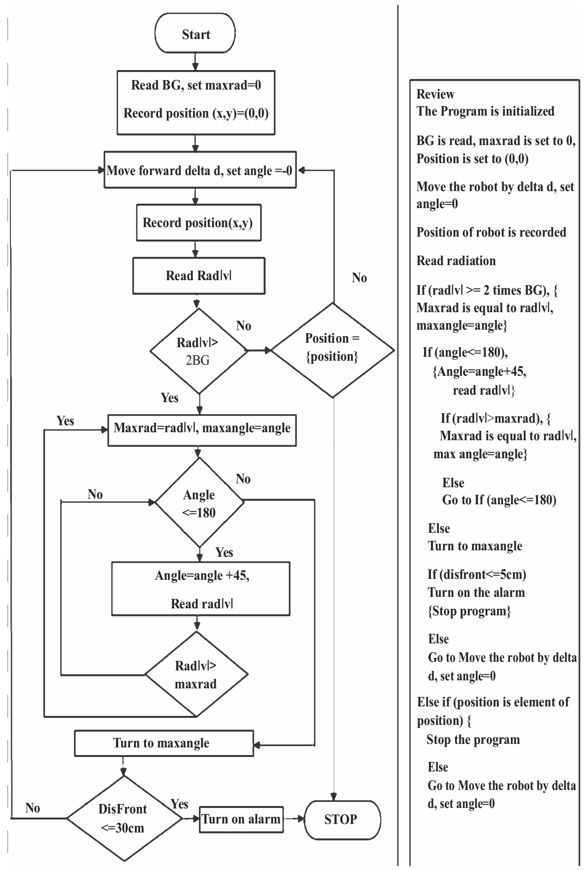


Fig. 9. Operational Flowchart of Radiation Seeking Robot

## *C. Components*

The components used in this robot is Arduino Uno, 2-wheel motor chassis kits, DC motors, dual H-bridge motor driver, sensor servo motor, ultrasonic sensors, Arduino compatible radiation detector, alarm and power supply.

The chassis kit selected is composed of a readily made 22cm x 15cm Plexiglas, high-quality tires with the radius of 3.3cm, biaxial gear DC motors along with the speed encoders and a caster with the aluminium metal fastener. The selection of Plexiglas chassis board on the radiation seeking robot is due to its high durability and is much cheaper in cost as compared to other metal chassis [xxii].

The GM detector is also readily made and acquired after comparing multiple detectors available. The selection of detectors is conducted based on the sensitivity and efficiency of the detector to achieve the objectives of the project.

The apparatus needed is the soldering set of electronics as there are plenty of electrical components involved in the development of the robot.

*D. Navigation System Design and Testing*

The navigation system of the robot is comprised of basic components for the robot to move around and scan the workplace as shown in Fig. 10.

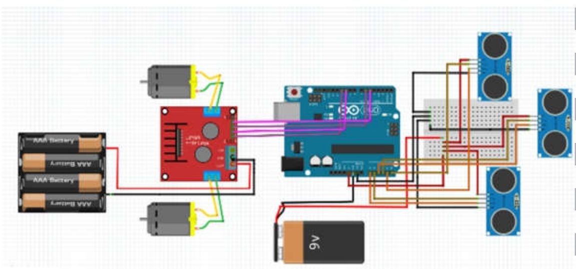

Fig 10. Arduino Circuit Diagram for the Navigation System

The system is tested with the moving command such as forward movement and turning of left or right. Each straight-line distance is calibrated and set at 30cm to ensure that the location of the robot could be identified after each movement.

The navigation system is also tested on the robot whether it can move according to the expected trajectory as shown in Fig. 3.

*E. Radiation Detection System Design and Testing*

The selected Geiger tube for this project is SBM-20 which is compatible with the Geiger counter kit. It has an effective tube length of 91mm and an effective diameter of 10mm which allow it to detect both beta and gamma radiation effectively. The Geiger counter kit as shown in Fig. 11 is integrated into the radiation detection system.


Fig. 11. Geiger Counter Kit for the Radiation Detection System

Calibration and test are conducted on the system by measuring the background radiation count rate and the count rate of specific source obtained in Nuclear Physics Laboratory in UTM. The turning motion of the servo motor was also calibrated to ensure the robot can achieve the mechanism shown in Fig. 4 when detecting the radioactive source.

The source-detector distance is set according to the radioactive sources used within the laboratory. It is assumed that the range of the detector is the distance where the count rate detected by the detector is two times bigger than the background count rate. In this project, the minimum range of 60cm is needed for the robot in ensuring the radiation detection and collision avoidance of the robot.

However, the count rate of the detector is subjected to the efficiency of the detector itself. Thus, the radioactive source needs to have high radioactivity to make sure the detector can at least detect two times the background radiation from a range of 60cm. Hence, the radioactive source suitable for robot testing is determined in the radiation detection testing.

The detector count rate is also compared with the result obtained from the RDS-31 Modular Radiation Survey Meter to ensure the validity of the result obtained from the SBM-20. The RDS-31 is a compact GM tube-based gamma radiation detector with a calibration accuracy of ±5%. It also has a large dose rate measurement range from 0.01μSv/h to 0.1Sv/h [xxiii]. From the datasheet obtained for the SBM-20, the conversion factor of the tube also allows the count rate to be converted into dose rate and the result could then be verified by comparing it with the result from the RDS-31 survey meter.

*F. System Integration*

After systems are tested and calibrated, they are integrated into a complete robot. The Geiger counter kit is located above the servo motor to make sure that the detectors could detect the origin of the radiation and move towards it by controlling the motor of the robot.

*G. Robot Testing*

Field testing is conducted by placing a radioactive source at a location with a known position within the laboratory. The workplace is then taped with some cloth tape which could indicate the position of the robot and the radiation source. The robot is then placed at the origin position of (0,0) and initiated as per explained by the mechanism mentioned. The origin (0,0) is at the location in room as shown in Fig. 12.

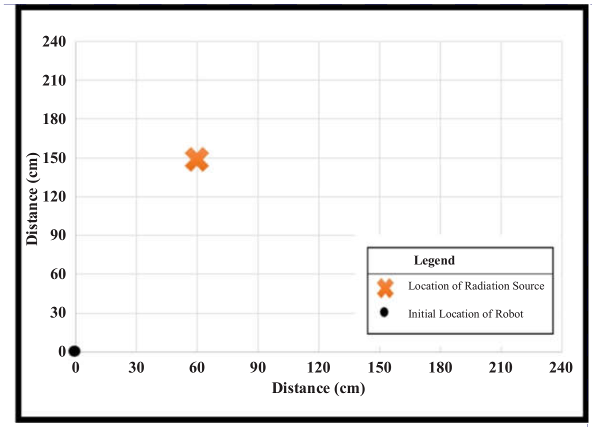


Fig. 12. Workplace setup of field testing

## IV. Result and Discussion

The result and discussion of the robot are divided into sub-system testing and robot testing.

### A. *Sub- system Testing Result and Discussion*

There are 2 sub-systems testing conducted in this project. One of them is the navigation system while the other is the radiation detection system.

*1) Navigation System*

From the testing conducted, the robot could move in a straight line by turning both motors at the same speed. However, the movement of the robot in turning into both right and left are not consistent. This is because the type of third wheel used in the robot is a roller caster type wheel where additional energy is needed to change the direction of the roller before it is used to turn the direction of the robot.

For an autonomous robot, the essence of the robot movements needs to be accurate and precise. Since the time spend for the robot to turn either right or left is fixed, this direction could undergo dramatic changes if some of the time is spent to change the direction of the roller or much turning is applied in the movement of the robot.

One of the possible solutions for the problem detected could be the usage of ball caster wheel which would not spend the allocated time to turn the direction of the roller caster [xxiv]. The wheels in front of the motors were changed to ball caster wheel as shown in Fig. 13(b) which allow omnidirectional movements without any additional effort to change the direction of the caster itself.

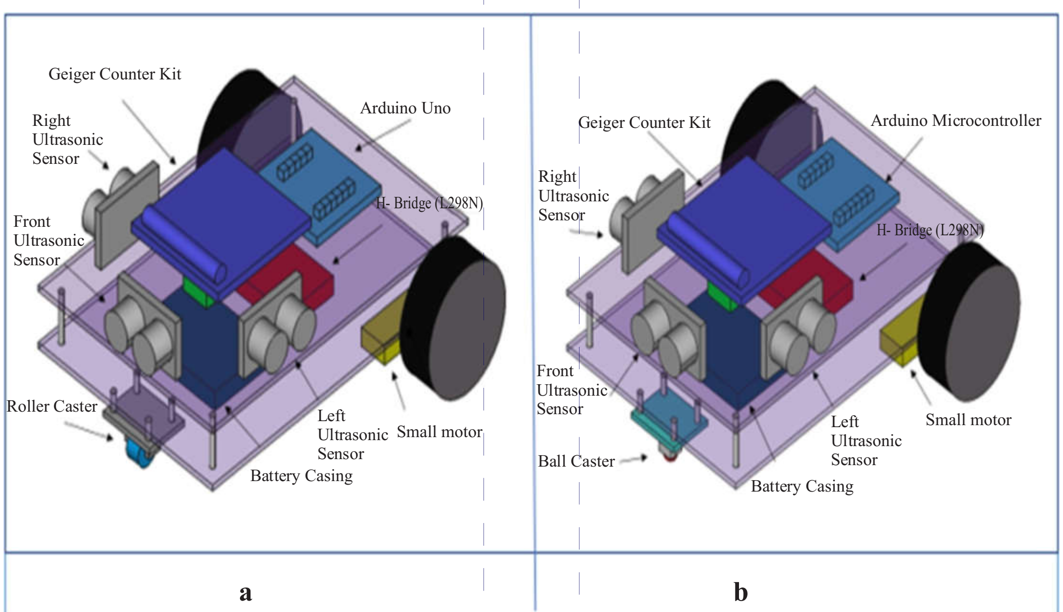


Fig. 13. Robot Design
(a) with roller caster (b) with ball caster

*2) Radiation Detection System*

Table I shows the count rate of the detector at different source to detector distance when tested with Cobalt-60. It is noticed that the point where the count rate detected is 2 times greater than the background radiation lies between the source to detector distance of 15cm to 30cm. While the count rate detected at the distance of 30cm is 48cpm which is almost similar to the background count rate. It indicates that if the same source is used for test run of the robot, the detector could not recognize the radiation source if the distance between the detector is more than 30cm.

To increase the range of the detector, the strength of the radioactive source needs to be increased. Hence, the radioactive seal source is changed to Eu-152 which has an activity of 6110kBq. The same testing is also conducted on Eu-152 to check the distance where the count rate is twice the background count rate. It is conducted with an increment of 15cm distance up until 105cm. The result of radiation testing on Eu-152 is as listed in Table II. From the result, the source to detector distance which has 2 times the background count rate lies between 60cm to 75cm which fulfil the scope of the project in term of the minimum range of the detector. Hence, the radioactive source used for the robot testing is set as Eu-152.

TABLE I
TESTING OF RADIATION DETECTION SYSTEM WITH Co-60
Background Count Rate: 40 cpm

| Source to Detector Distance (cm) | Count Rate (cpm) | | | Average Count Rate (cpm) |
|---|---|---|---|---|
| | C1 | C2 | C3 | |
| 0.1 | 2736 | 2660 | 2732 | 2709 |
| 7.5 | 240 | 260 | 256 | 252 |
| 15.0 | 128 | 112 | 152 | 131 |
| 30.0 | 44 | 44 | 56 | 48 |

TABLE II
TESTING OF RADIATION DETECTION SYSTEM WITH Eu-152
Background Count Rate: 43 cpm

| Source to Detector Distance (cm) | Count Rate (cpm) | | | Average Count Rate (cpm) | Survey Meter (μSv/hr) |
|---|---|---|---|---|---|
| | C1 | C2 | C3 | | |
| 15.0 | 720 | 600 | 604 | 641 | 1.70 |
| 30.0 | 272 | 260 | 244 | 258 | 0.97 |
| 45.0 | 168 | 132 | 120 | 140 | 0.54 |
| 60.0 | 88 | 116 | 108 | 104 | 0.42 |
| 75.0 | 92 | 52 | 80 | 74 | 0.32 |
| 90.0 | 84 | 60 | 56 | 66 | 0.29 |
| 105.0 | 64 | 60 | 60 | 61 | 0.27 |

Despite the difference in unit measurement, there is also a relationship between the dose rate and count rate of the detector. It is the conversion factor of the detector which is 0.0057 according to the Geiger tube datasheet[xxv]. In this case, by determining the count rate of the detector in the robot testing, the operator could prevent this amount of exposure while locating the misplaced radiation source. Hence, the application of radiation seeking robot could aid the operator in reducing the radiation exposure while locating the misplaced radiation source.

Table III shows the comparison of dose rate obtained from the detector and the survey meter. At a greater distance, it is seen that the error between the detectors and the survey meter decreases. It indicates the verification of the data obtained for the detector as the exposure increases while distance reduces.

TABLE III
COMPARISON OF DATA OBTAINED FROM SURVEY METER AND COUNT RATE

| Source to Detector Distance (cm) | Average Count Rate (cpm) | Dose Rate (μSv/hr) | | Error (%) |
|---|---|---|---|---|
| | | SBM-20 | RDS-31 Survey Meter | |
| 15.0 | 641 | 3.6537 | 1.70 | 114.92 |
| 30.0 | 258 | 1.4706 | 0.97 | 51.61 |
| 45.0 | 140 | 0.798 | 0.54 | 47.48 |
| 60.0 | 104 | 0.5928 | 0.42 | 41.14 |
| 75.0 | 74 | 0.4218 | 0.32 | 31.81 |
| 90.0 | 66 | 0.3762 | 0.29 | 29.72 |
| 105.0 | 61 | 0.3477 | 0.27 | 28.78 |

The big difference in the percentage error obtained for the exposure rate for the SBM-20 compared with the survey meter may be due to the dead time of the SBM-20 detector and the survey meter. As the activity of the source increases, their dead time also might increase which lead to the inaccuracy of the result obtained. In addition, the readings obtained from the survey meter also might not be accurate as the experiment is conducted consecutively in a short amount of time. While the calculation of dose rate from the survey meter is based on the total dose received divided by the amount of time, the result obtained from the survey meter may yet to be stable and affect the accuracy of the readings. The comparison also would be more accurate and useful if the result obtained from the survey meter could be displayed in the unit of cpm.

### *B. Robot Testing and Discussion*

Fig. 14 shows the movement of robot during the testing. The robot was able to move forward 30cm for 5 times before turning towards the direction of the radioactive source when it is within robot detection range. The location detected was (60, 150) while the robot is able to stop in front of the sources and initiate the alarm system. It indicates that the robot can locate the radiation source and move towards it while avoiding collision with any obstacles.

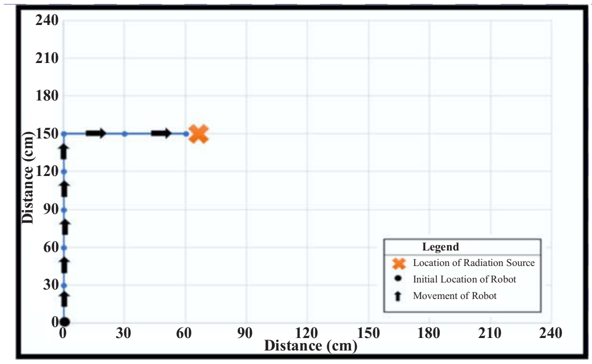


Fig. 14. Robot Movement during Testing

According to the result obtained, the objectives of the project is achieved as the radiation seeking robot can locate the radiation source in a room based on the path planning developed while moving towards the direction of the radiation source and preventing collision with any obstacles. Next, the location of the robot also could be identified based on the gridline developed which aid in determining the position of the robot. The alarming system was also triggered when the robot discovers the radiation source which could alert the personnel.

Despite there are some errors in the forward motion of the robot, which lead to the inconsistent distance travelled on both wheels due to wheel slippage [xxvi], the errors are well within the acceptable range of 5cm. Next, the change in direction of the robot towards the radiation source also do not align with the gridline. This is due to the accumulation of wheel slippage errors for the few previous movements which changes the initial direction of the robot from 0° to roughly 20°. From these errors, the robot would turn 110° instead of 90° as the errors are cumulative and could affect the next movement and location of the robot. However, the robot was able to recognize the direction of the source and turn towards it by taking a 45° left before triggering the alarming system. It indicates that the robot is able to recognize the direction of radioactive sources and move towards it.

## V. CONCLUSION

In a nutshell, the development of radiation seeking robot considered successful as all the objectives proposed are achieved where the radiation seeking robot is able to locate the radiation source in a closed room.

It is recommended that a blockage or obstacle could be included in front of the robot before reaching the source to test the obstacle avoidance of the robot. However, this can be done only with higher source activity which is not currently available in UTM. It is also proposed that the robot specification could be improved by involving a 3-dimensional workspace which allows the robot to navigate through air and not limited on flat and rough surface only [xxvii]. The localization of the robot could also involve other type sensors such as camera for visual image processing as an indirect Kalman filter to improve the accuracy of the position recorded [xxviii]. The path planning of the robot could also be improved by involving the map generation of the workspace for the calibration purpose. Then, the map generated could be displayed on the screen which allows the operator to detect the position of the robot easily as well as the radiation level detected in the robot. Last but not least, the radiation mapping could be conducted by using the same path planning to shows the radiation distribution within the room [xxix]. It can also be used to estimate the location of the misplaced radiation source from the radiation mapping conducted.

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