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Arduino programming of an educational robotic platform applied in radiological accident simulation

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Astract: This work aims to develop a robotic platform coupled to radiation detectors for application in radiological accident simulation experiments. To this end, a robot was assembled on a platform on six wheels with Arduino programming, seeking movement in different degrees of freedom. The robot was controlled by remote control and viewed by a camera so the operator could follow the path taken by the robotic platform. The radiation values were seen instantly from the display of the radiation monitor/detector (RadEye). This platform model used non-destructive tests with radioactive sources in the laboratory for an environmental radiometric survey simulating a radiological accident. The results showed the command synchronization between the controller and the platform in an environment with only the presence of the background and the visualization of the instantaneous dose rate in Sv/h. However, when faced with the radiation field, there was interference in the signals and communication controlling the robot's movements. However, due to the short exposure time to gamma rays, the electronic components did not show any damage. It can be concluded from this experience that the prototype should be improved by adding shielding to the electronic boards, which are sensitive to radioactivity. The relevance of this investigation lies in developing robotic platforms for exposure in environments that pose health risks and for the radiological protection of emergency teams in actions during radiological and nuclear accidents.

Keywords: Programming, Arduino, Radiometric Survey, Accident.

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Programação em Arduino de uma plataforma robótica educacional aplicada em simulação de acidentes radiológicos

Resumo: Este trabalho tem como objetivo desenvolver uma plataforma robótica acoplada a detectores de radiação para aplicação em experimentos de simulação de acidentes radiológicos. Para tanto, foi montado um robô sobre uma plataforma sobre seis rodas com programação em Arduino, buscando movimentação em diferentes graus de liberdade. O robô foi controlado por controle remoto e visualizado por uma câmera para que o operador pudesse acompanhar o caminho percorrido pela plataforma robótica. Os valores de radiação foram vistos instantaneamente no display do monitor/detector de radiação (RadEye). Este modelo de plataforma utilizou ensaios não destrutivos com fontes radioativas em laboratório para um levantamento radiométrico ambiental simulando um acidente radiológico. Os resultados mostraram a sincronização de comandos entre o controlador e a plataforma em um ambiente apenas com a presença do background e a visualização da taxa de dose instantânea em Sv/h. Porém, ao se deparar com o campo de radiação, houve interferência nos sinais e na comunicação que controlavam os movimentos do robô. Porém, devido ao curto tempo de exposição aos raios gama, os componentes eletrônicos não apresentaram danos. Pode-se concluir desta experiência que o protótipo deveria ser melhorado adicionando blindagem às placas eletrônicas, que são sensíveis à radioatividade. A relevância desta investigação reside no desenvolvimento de plataformas robóticas para exposição em ambientes que oferecem riscos à saúde e para proteção radiológica de equipes de emergência em ações durante acidentes radiológicos e nucleares.

Palavras-chave: Programação, Arduino, Levantamento Radiométrico, Acidente.

1. INTRODUCTION

Accidents with sources or in radioactive installations can happen due to human error or natural phenomena. In these circumstances, robots prevent emergency teams from being potentially exposed to a radiation field, providing radiological protection while a precise radiometric survey of the environment is carried out. Events of this nature were seen on March 11, 2011, when a strong earthquake followed by a tsunami hit the east coast of Japan, affecting the Fukushima Daiichi nuclear plant [1, 18]. The release of radioactive material into the environment became a global disaster, and the first disaster response mission of this type was the use of robotic technologies for environmental damage assessment and local radioactive dosimetry [2, 3, 18]. Improvements in the robot system used in internal surveillance missions at the Fukushima Daiichi nuclear plant are objects of study and implementation [4, 18].

In accident situations, environments composed of radioactive materials pose incalculable risks to emergency teams, especially in areas where radiation exposure exceeds permissible limits. In this adverse scenario, using teleoperated robots with the ability to operate in hostile environments is the most suitable option to preserve workers' health [5]. Several studies have shown the need for a teleoperated robot [6-10, 18]. These studies showed remotely controlled robots as a viable solution for accident situations.

The influence of radiation on materials is a worrying factor for the study prototype in robotics used in radioactive environments. Gamma radiation is the most concerning damage caused to electronic systems [11]. Exposure to this radiation does not cause sudden failure of the components, but over time, the material is damaged, and its properties change [12].

Although the use of robots that identify chemical, biological, radiological, and nuclear agents (CBRN) is the most suitable in situations of severe accidents, this product could be an option for inclusion and improvement in the defense industry, with its primary customers the country's Armed Forces, especially the departments focused on radiological and nuclear defense [13].

The purpose of this work was to develop in detail a project for a low-cost educational robotic platform with 6 wheels and 6 degrees of freedom, with open-source programming on an Arduino board, coupling a RadEye gamma radiation detector/monitor to employment in a controlled environment with radioactive sources, in the Nuclear Instrumentation and Detection Laboratory of the Military Institute of Engineering (LDIN/IME/SE-7) of the Nuclear Engineering Section (SE/7). This experiment aimed to evaluate the platform's performance in a radiation field where there are inherent risks to people, depending on the radioactive activity of the source. The mission consisted of moving the robotic platform from a safe laboratory environment, where a background predominates - BG (pre-existing natural background radiation), towards a place where there is a radioactive source (radiation field), and informing, in a safe distance, remotely, the dose rate values on site. The main objectives of the experiment were the following:

a) Evaluate the performance of electronic circuits in the presence of a radioactive field with a gamma source;
b) Check whether the robot would fulfill the mission of moving from an environment with BG to an environment with radioactive sources;
c) Verify that the robot can send, in real-time, the measured instantaneous dose rates to avoid unwanted exposure of emergency team members;
d) Evaluate whether, under simulated conditions, the radiological protection criteria would be met, and
e) Evaluate whether the electronic components and parts of the Arduino would be preserved and whether the test would be non-destructive.

2. MATERIALS AND METHODS

The robot, or robotic platform for radioactive and nuclear monitoring and detection, used in a radiological emergency, comprises a robust mobile platform, nuclear detection instruments, onboard electronics, and a smartphone with a camera attached to a mobile support. The choice of these materials was based on the fact that this educational project met the criteria of low cost and wide availability on the market.

Two Arduino C language libraries were used for the control and navigation system, which had assured compatibility and previous use in similar radio frequency communication activities [14, 18]. This concern stands out, as frequent updates carried out in libraries for this type of project can be the reason for later incompatibilities in the control and navigation system [15].

2.1. Mobile platform

The 6-wheel, 6-degree-of-freedom chassis model Dagu Electronics was used (Figure 1). This platform is designed to travel over rough terrain and steep inclines, taking advantage of its significant suspensions. The platform can reach a speed of 7 km/h and carry up to 5 kg. The platform has small holes for the versatile coupling of components and onboard electronic boards. This platform's availability allows the researcher to adopt different configurations in the project, adapting the model to different scenarios and study cases.

Figure 1: Mobile Platforms with 6 wheels

2.2. Electronic components

2.2.1. Microcontroller

The Arduino R3 board was used in this prototype because it is low-cost, and its programs have simple language in an integrated development environment (IDE), typical of Arduino. The Arduino Uno R3 board has an ATmega328 microcontroller with a clock speed of 16 Mhz; regarding the I/O inputs, the platform has 20 inputs, 6 of which are built to support PWM connection, and the maximum current for the I/O pins has a maximum current of 40 mA. The dimensions of the Uno board are 53.4 x 86.6 mm, which, in turn, fits appropriately for the project in question. The Arduino board allows users to send programs through the USB port, which energizes the platform with 5 V. In cases where there is a need for more energy, the board has an extra 7-12 V connection. Furthermore, several public and free libraries allow users to perform tasks with complex commands more quickly. The Arduino platform also has a wide variety of sensors and shields developed by the community. Shields are modular circuit boards plugged into the Arduino board base to extend functionality [16]. With this, the user can customize their hardware to meet their needs, making the Arduino ideal for this project, both for the remote control and the robot.

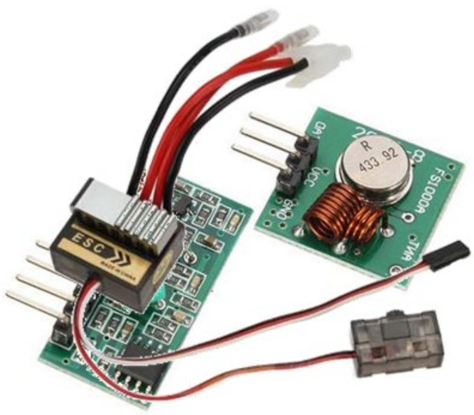
2.2.2. Communication

A 315Mhz AM radio frequency (RF) transmitter and receiver module was used, with operating band 1 and a 5 V power supply. Given its characteristics as an off-the-shelf component, it has a low cost, easy implementation, and a satisfactory range of approximately 150 meters.

2.2.3. Electronic Speed Controller

The ESC (Figure 2) electronic speed controller interprets control information. When inserted into a control system, this component regulates the speed of the motors through the variable feed rate in a network of field effect transistors, or FETs. This allows a much smoother and more precise variation of engine speed in a very efficient way, accepting a much higher amperage than most H-bridges available on the market. ESCs are controlled by PWM (Pulse Width Modulation) and generally get a nominal 50 Hz PWM servo input signal whose pulse width varies from 1 to 2 ms.

Figure 2: Electronic Speed Controller



2.2.4. Joystick Module

The operating principle of the Joystick module consists of reading 2 potentiometers and a button. Two potentiometer inputs refer to the X and Y axes, and the button, when pressed, refers to the Z-axis. This model with fewer pins becomes an excellent option for Arduino projects, as they avoid many connections.

2.2.5. SD Card Module

This module allows reading and writing to an SD card, easily connecting to Arduino and other microcontrollers. Ideal for setting up a data recorder, recording them in a text file on the SD card.

2.2.6. Brightness Sensor

The LDR (Light Dependent Resistor) is a component whose resistance varies according to the intensity of the light. The more light falling on the element, the lower the resistance. This brightness sensor can be easily used in project prototyping.

2.2.7. Temperature Sensor

The DHT11 is a temperature and humidity sensor that allows temperatures between 0 and 50 Celsius readings and humidity between 20 and 90 %. This sensor was used because it presents a specific library for Arduino that directly provides the temperature value in Celsius (ºC) and the percentage humidity.

2.2.8. Distance Sensor

The HC-SR04 ultrasonic sensor has a ready circuit with an emitter and receiver coupled to it. For measurement, the sensor emits a sound wave that returns to the module when encountering an obstacle. The distance calculation method relies on the time it takes for a sound wave to travel from a sensor to an object and back again. This allows for accurate measurement of distances ranging from 2 to 4 cm and is a cost-effective option for the project.

2.3. Instrumentation for radiological and nuclear detection / monitoring

The RadEye model PRD was the radiological measurement detector [17]. It is a highly sensitive gamma radiation detector for measuring the absorbed dose rate given in Sv/h [17]. The detector has an audible device that alerts when dose limits are reached. It can also accumulate doses over time and measure dose rates instantly, making it suitable for laboratory practice. This pocket meter has versatile features: small size, mass of 0.9 kg, ease and flexibility of operation, and low energy consumption. Because it is light, it was chosen to be attached to the robotic platform assembly. It also has an intuitively driven menu, a large display, audible and vibrating alarms, and a removable rubber sleeve for extra protection [17]. The detector is calibrated in the manufacturer's metrology laboratory using a cesium-137 source.

2.4. Camera Support

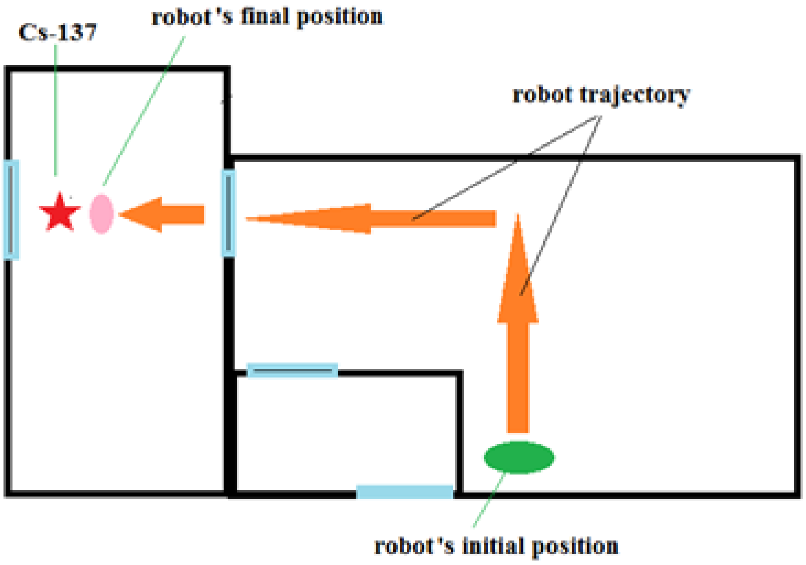
A camera support similar to the one depicted in Figure 3 was utilized, which provided the camera with two degrees of freedom. The support is manipulated by two servo motors that possess high torque in relation to their weight and size. Servo motors are devices that can rotate angularly between 0 and 180 degrees through the control of a PWM signal.

Figure 3: Camera Support

2.5. Application of robotic platform for radiometric survey experiment

Using a robotic platform, an experiment was conducted at the Nuclear Instrumentation and Detection Laboratory of the Military Institute of Engineering (LDIN/IME) of the Nuclear Engineering Section (SE/7). The experiment aimed to simulate a radiological accident scenario where radioactivity exposure occurs and test the robot's ability to perform tasks in a hazardous environment rather than putting human emergency teams at risk. The robot's mission was to move from a safe point (initial position) with natural background radioactivity (BG) to a radiation field (final position) along a predetermined path, providing real-time environmental dose rate information. The remote control operator was stationed at the robot's initial position. Figure 4 shows the layout of the LDIN/IME/SE-7, indicating the positions of the simulated scenario. The experiment used Cesium-137 as the radioactive source with an activity of 5 μCi, and the distance between the robot operator and the radioactive source was 9 meters in a straight line, with a 30 cm masonry wall separating the two internal LDIN/IME/SE-7 rooms.

Figure 4: LDIN/IME/SE-7 layout for the experiment.



3. RESULTS AND DISCUSSION

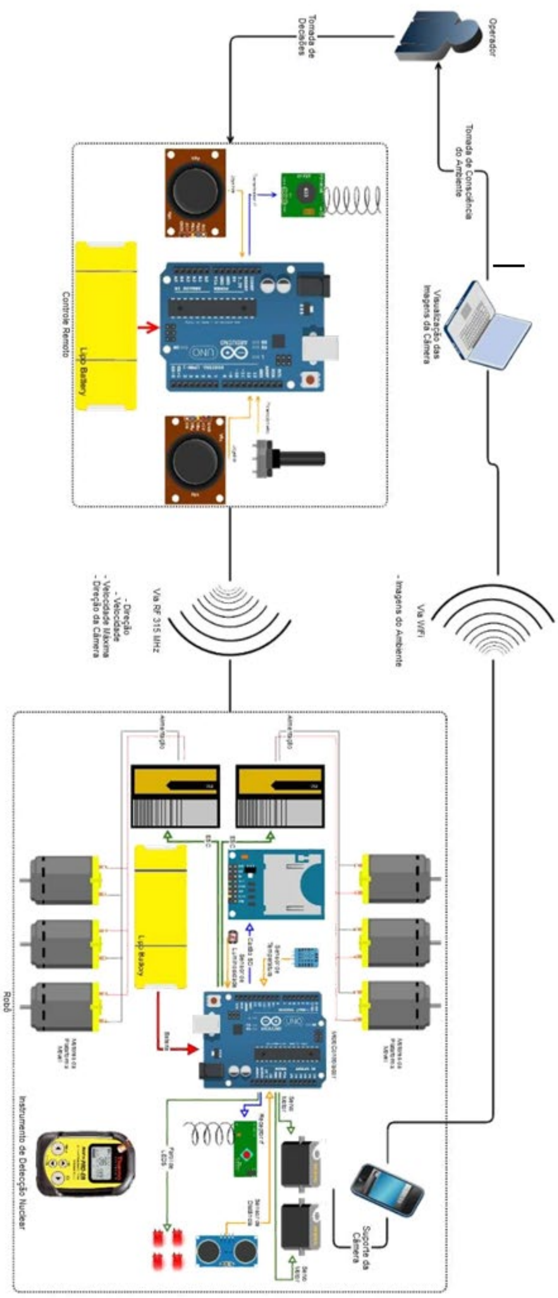
3.1. Control system

Figure 5 presents the result of the flowchart of the entire control system and the assembly of the robotic platform, showing how the teleoperated robot control system works. In this designed system, the operator is the "brain" of the robot, the one who makes the decisions, and the robot is the "body" of the one who executes the actions.

The operator uses the joystick shown in Figure 5 to move the robot. The same movement controls apply when the robot is moving in reverse. On the left side of Figure 5, the joystick can also control the camera's direction of view. The mobile platform boasts powerful and efficient motors that require precise regulation. This is achieved through a potentiometer, which allows for speed control. The resulting data is then transmitted to the robot via an RF transmitter, ensuring a reliable and stable speed control system for the platform.

The RF receiver on the robot captures the data, and the firmware embedded in the Arduino microcontroller processes it. This defines the speeds of the moving platform motors and the angles of the servo motors on the camera support. The ESCs and servos receive PWM signals to achieve the robot's mobility by changing the camera's viewing angle.

Figure 5: Teleoperated Control System

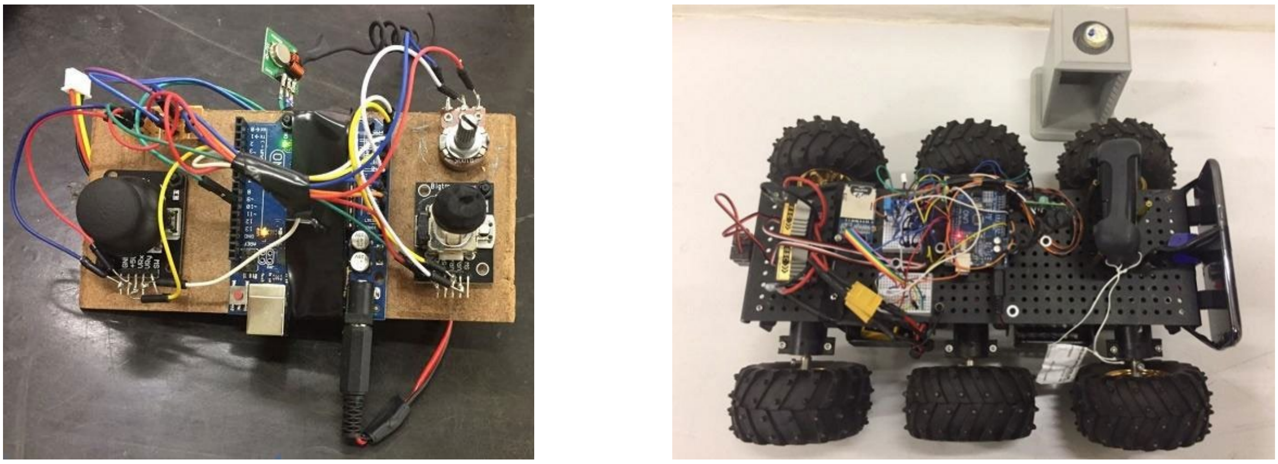


Placing the distance sensor in front of the robot with a particular inclination made it possible to identify the existence of an insurmountable obstacle ahead. If, for example, there is a wall in front of the robot, the microcontroller prevents the robot from moving forward. This situation was verified, and the robot responded to this command.

The temperature and humidity of the environment were recorded on an SD card for later analysis. For the effect of the interaction of radiation with matter, temperature and humidity parameters were not applied and considered in this study. The brightness sensor was used to turn on the robot's headlights automatically.

Visual support was necessary to carry out the operation with the capacity to provide information for interpreting the environment around the robot. Due to its ease, a smartphone with a [Rage pixel/resolution] camera was used in this prototype. The images were transmitted through wifi. Furthermore, the images could be viewed using a notebook and a second smartphone device, which was in the operator's possession, making it possible to view the location around the robot.

Figure 6: (a) Joystick control used. (b) Robotic platform in its final version. Besides, support is provided by the radioactive source of Cesium-137.



(a) (b)

Figures 6 (a) and 6 (b) show, respectively, the final assembly of the joystick control system and the final version of the assembled platform that was used in the experiment. With the robot assembled, the radiometric survey experiment simulated a radiological accident situation. Table 1 presents the results of the experiment's verifications and evaluations.

Table 1: Tasks established in the experiment.

ADDITIONAL OBJECTIVES OF THE EXPERIMENT	INDICATOR		OBSERVATION
	Yes	No	
(a) Did the robot present any changes in its functioning in terms of the performance of the electronic circuits in the presence of a radioactive field with a gamma source?	X		Upon arriving close to the radioactive source, the robot stopped and did not respond to commands.
(b) Did the robot fulfill its mission of moving from an environment with BG to a radioactive source, representing a location with a radiological accident?	X		It moved without any difficulty; the signal was fully functional.
(c) Was the robot able to send, in real-time, the measured instantaneous dose rates, preventing people (emergency personnel) from heading to the location of the accident and being exposed to radiation?	X		Although stationary and not moving, the sensors responsible for transmitting data worked perfectly.
(d) The radiological protection criteria would be met under the simulated conditions.	X		The team did not need to travel to the simulated accident area.
(e) Have the electronic components and parts of the Arduino been preserved? Was the test non-destructive (ndt)?	X		Although stopped before the radioactive source, no robot part was damaged.

In the first evaluation item (robot performance), the robot's movements were paralyzed when faced with the radiation field. As there was no destructive damage to any sensor or electronic component, the result of this question suggests that gamma radiation interfered with the robotic platform's onboard electronics. The radiation field interfered with the communication signals from the motion sensors.

The Cesium 137-point source emits gamma rays, energetic electromagnetic particles caused by nuclear processes. When these particles come into contact with materials, they can ionize atoms and create an electrical charge. This ionizing effect of radiation on matter can interfere with electronic boards, like those on Arduino, and alter the states of electronic components. As a result, unwanted electrical currents can be generated, leading to failures in transistors and other semiconductor devices in the circuit. The interference of gamma rays on electronic boards is primarily caused by the ionization of materials, resulting in disruptions in electronic components and ultimately causing device malfunctions.

In the second question (displacement), the robot followed the plane according to the trajectory shown in Figure 4. After measuring the BG of the LDIN/IME/SE-7, the robot moved easily without presenting signal problems. The systems halted at 40 cm from the radiation source emitting 5μCi. The radiation caused interference between the operator and the platform, affecting the Electronic Speed Control Device, Joystick Module, and RF Transmitter and Receiver Module communication.

In terms of sending dose rate information, the robot could send it to the operator in real-time. The RF communication module was affected by gamma radiation from the Cesium 137 source. At this point, the measured dose was 10-16 Sv/h. This result suggests that tasks like this show that robots can carry out missions by using a camera with higher resolution in order to transmit data of interest to emergency teams, aiming for radiological protection and mitigating risks to the health of individuals. Instead of people being exposed to radiation, robotic means can perform this task.

Finally, after the experiment, all components of the robotic platform were evaluated to check for damage caused by exposure to radioactivity. There was no severe damage to the electronic components, which characterizes a non-destructive test (ndt). This result suggests that the damage generated was caused by the interference of gamma particles from the Cesium-137 source only in the electronic signals of the platform's onboard boards. It was observed that placing the robotic platform 40 cm away from the source on the bench led to the replication of the experiment. During this process, faults and interference were noticed in the robot's control, causing it to stop working. The results indicate that electronic devices are highly sensitive to gamma radiation and the spurious generation of undesirable electrical charges in the circuits.

4. CONCLUSIONS

The objective proposed in this study was achieved by developing the educational robotic platform and programming on Arduino coupled with a gamma radiation detector. The robot could move from a background environment to another location with a radioactive Cesium-137 source, simulating a radiological accident. Instead of people (emergency staff) being subject to radioactive exposure, the robot fulfilled the mission of exposing itself to a radioactive environment. It was able to send the data of interest remotely and safely.

The main findings of this work suggest that robotic platforms equipped with shielding and physical protection against radiation in embedded electronic components using Arduino technology can withstand exposure to radiation fields and avoid interference with signals. This data represents a research and technology option for development and applications in real scenarios in radiation fields hundreds of times larger using appropriate materials.

5. FUTURE PERSPECTIVES

As opportunities for improvements so that this experiment can be successful in the situations tested, evaluated, and discussed in this paper, new research can be carried out, such as:

a) Implement a routine so that when the robot loses the radiofrequency signal, it returns to the starting point, avoiding the disposal of the robot at the site of the radiological accident;

b) Use a lighting system to view the radiation monitor in dark environments;

c) Use a better-quality radio frequency module with greater range with an obstacle (thicker walls);

d) Add identifiers for chemical and biological agents, as well as alpha and beta radiation, to the platform;

e) Use radioactive sources with more significant activity through appropriate shielding of on-board electronic components;

f) Use a camera with a higher resolution for the task;

g) Provide encapsulation (protection) of the electronic components so that they operate in adverse situations.

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