

Radioactive Emissions Mapping Robot

REMBot

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Abstract—The Radioactive Emissions Mapping Robot (REMBot) is an autonomous robot capable of scanning a rectangular room for radiation with the purpose of creating a spatial radiation map. It is primarily intended for service in nuclear power plants to save personnel time and prevent overexposure. The REMBot scans the room in a serpentine pattern and returns to its starting point. The user then downloads the collected data via a USB thumb drive onto a personal computer. This file is loaded by the user into a MATLAB routine, which generates a spatial color map, with various levels of radiation represented as different colors.

Index Terms—Geiger counters, microcontrollers, navigation, nuclear measurements, pulse width modulation, radiation detection, radiation monitoring, robots.

I. NOMENCLATURE

- a) **UART (Universal Asynchronous Receiver Transmitter)**- device that sends collected data from the microcontroller to the PC for mapping.
- b) **Geiger counter**- Device used to measure radiation.
- c) **TTL- Transistor-transistor logic**.

II. INTRODUCTION

THE Radioactive Emissions Mapping Robot (REMBot) was designed to perform a potentially dangerous task in nuclear power plants. The nuclear industry prides itself on limiting the exposure of its personnel to hazardous environments including high heat and radiation by means of the acronym As Low As Reasonably Achievable (ALARA) [1]. Currently, personnel working in the nuclear industry are regularly tasked with making spatial radiation maps of rooms

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in the plant that contain radioactive materials or rooms that may have become contaminated. These maps require time and could expose personnel to dangerously high levels of radiation. A more accurate and safe solution is an autonomous, battery-operated robot capable of generating radiation maps and limiting personnel exposure.

The Geiger counter employed has a digital output, which is accumulated in a temporary counter and loaded into the memory of the robot at regularly-spaced intervals in a room. These data are stored sequentially, and mapped on a grid by a routine developed in MATLAB. The result is a mosaic map whose elements represent six-inch by six-inch squares of the floor of the room. No radiation results in a blue square and maximum radiation results in a red square. There are 256 colors between zero and maximum available. Fig. 1 shows the general block diagram for the REMBot.

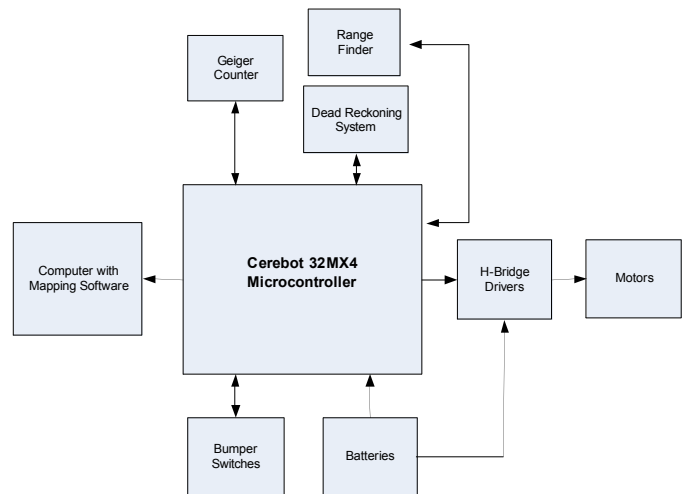


Fig 1. REMBot block diagram.

The dead-reckoning system is an encoder used to measure wheel rotations. The Geiger counter sends pulses to the microcontroller, which stores the counts in a temporary register until prompted by the software to store the total counts in a memory block. This event is triggered when the dead-reckoning system measures a distance of six inches traveled by the REMBot. The bumper switches are contact switches on the front bumper of the REMBot to signal that it has encountered a wall. This event triggers a turning algorithm, which creates the serpentine scan pattern. The H-bridge drivers allow logic signals to turn the motors at variable frequencies and speeds, based on pulse-width modulation

from the microcontroller. The mapping computer is external to the REMbot and contains software developed by the team. The REMbot is connected to a USB thumb drive after a room has been scanned, to download the data to a PC, which creates the radiation map.

The remainder of the paper is divided into the following sections. Section III describes the details of the REMbot control system. Section IV describes the software and map generator user interface. Section V discusses the conclusion.

III. REMBOT CONTROL SYSTEM

The following sections outline the components, controls, and operation of the REMbot. Fig. 2 shows the serpentine pattern followed by the REMbot as it scans a rectangular room.

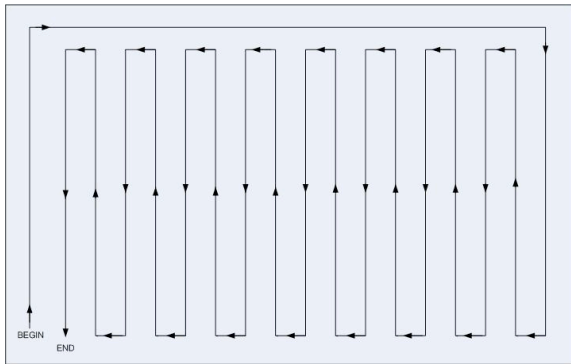


Fig 2. REMbot scanning pattern

The following description of the control system explains how the REMbot follows this pattern and collects radiation data.

A. Chassis

The REMbot employs a differential drive scheme, using two tank-style treads to drive and turn the robot. All sensors, batteries, and controller are contained within the chassis enclosure, shown in Fig.3. The top of the chassis opens to change the batteries and replace damaged parts. The power switch and USB port are exposed on the back of the chassis.

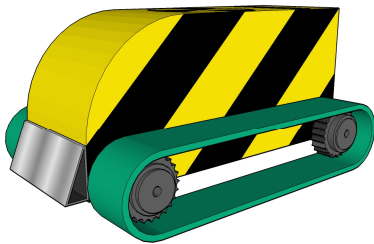


Fig 3. REMbot chassis.

B. Cerebot 32MX4 Microcontroller

The control unit for the REMbot is the Cerebot 32MX4, which contains a PIC32MX460 microcontroller, 9 I/O ports, 512KB internal program flash memory, 32KB internal SRAM memory, and two UART serial interfaces [2].

C. Digital Geiger Counter

The device used to measure radiation is a GCK-05 Geiger counter, made by Scientific Images. It is a standard Geiger tube integrated onto a digital circuit card, which converts the analog current pulse from the tube to a TTL pulse. This pulse is read by the microcontroller and stored as data to be downloaded after the scanning process. The Geiger counter has a maximum input of 1100 millirems per hour, after which it is saturated and the output levels off.

D. H-Bridge Drivers

H-bridge drivers use transistors to allow logic signals to control the flow of current to motors. The microcontroller uses variable pulse width modulation to control the speed of each motor independently. One motor is set at a constant speed by assigning a 25% duty cycle to the H-bridge driver. The duty cycle to the second motor is a program variable that is constantly updated based on the path of the REMbot. The path must be kept parallel to the sidewalls to assure the final radiation map is not skewed. To achieve this, the duty cycle of the variable motor is modulated to adjust the trajectory. The H-bridge drivers also allow the direction of the motors to be controlled by the microcontroller, since logic signals are not powerful enough to drive motors. The drivers provide a maximum of 2 amps, well above the 0.5 amps starting current of the motors [3].

E. Ultra-Sonic Rangefinder

To maintain a path parallel to the sidewalls, as shown in Fig.2, the distance to the walls must be constantly monitored. Also, each column must be spaced six inches apart to maintain the horizontal quantization of the room. To enable this precision without the use of a grid printed on the floor, or expensive triangulation devices in each surveyed room, an ultra-sonic rangefinder was used. The rangefinder, facing out the side of the chassis, allows the REMbot to determine the distance to the wall and maintain it. Each successive pass, the distance to the wall changes in the algorithm, keeping the robot on the correct path.

F. Dead-Reckoning System

To quantize the floor of the scanned room into squares, the vertical dimensions must be measured also. To measure the distance traveled, the rotation of the gears that drive the treads are counted. An infrared LED, an infrared phototransistor, and two resistors make an encoder circuit shown in Fig.4.

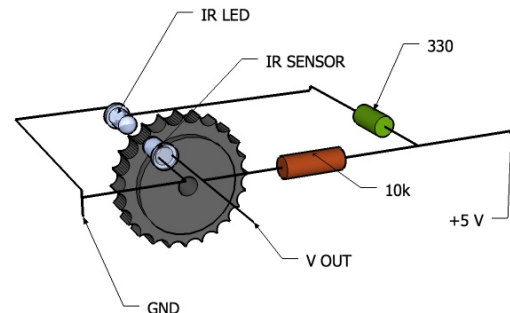


Fig. 4 Dead reckoning model.

The pin labeled “V OUT” is monitored by the microcontroller. As the gear teeth break the light beam from the LED, the phototransistor switches states, allowing current to flow through the 10kΩ resistor. As this happens, the voltage at V OUT changes from 5V to 0V. As the REMbot moves in any direction, these pulses are read by the microcontroller and used to calculate distance traveled. Experimentation showed that sixteen pulses correlated to a linear distance of approximately six inches traveled by the REMbot. At each interval, data is being accumulated in a register in the microcontroller. At the end of each pass that data is added to the memory block reserved for that column of data. The process is repeated at each interval.

G. Bumper Switch

The front of the REMbot is equipped with a bumper switch that is energized with 5 volts from the microcontroller. When the vehicle encounters a wall the switch is depressed, closing the circuit shown in Fig. 5. This changes the output voltage, signaling the microcontroller to enter the turning algorithm.

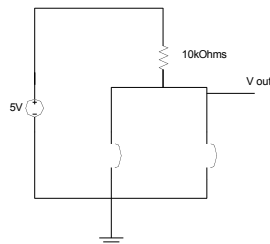


Fig. 5 Bumper switch circuit

H. Motors and Treads

The motors used in the REMbot are Interactive Servo Motors from LEGO®. They were chosen because the rotor design was easily integrated into the tread system. They have a through-hole rotor which allowed the square shaft of the VEX Robotics® treads to be rotated without slipping or requiring additional mechanical coupling. The treads are high-density plastic, low weight, and do not easily slip on most surfaces. Also the treads allow the REMbot to drive over rough terrain as well as the radioactive sources used in testing.

I. Batteries

The batteries used are a rechargeable 9.6V, 1800mAh Nickel-Cadmium pack for the motors and 4 standard AA batteries for the microcontroller, which delivers power to the peripheral devices. The REMbot can be used for over an hour without recharging.

IV. SOFTWARE

The following section outlines the software required for the REMbot to operate autonomously.

The requirements for the REMbot are to traverse a rectangular room no greater than 8ft x 8ft and obtain radiation count samples at a resolution of 6in X 6in. The REMbot is autonomous and provides the capability to download the

radiation count data to a PC. The PC generates a plot of the radiation count in millirems per hour.

The software design encompasses two areas: hardware integration and system functionality. By separating the hardware and state design, the coding process for each could proceed in parallel and the code for each hardware component could be written and tested independently of the whole. The state flow diagram, shown in Fig. 6 could also be designed independent of the implementation details.

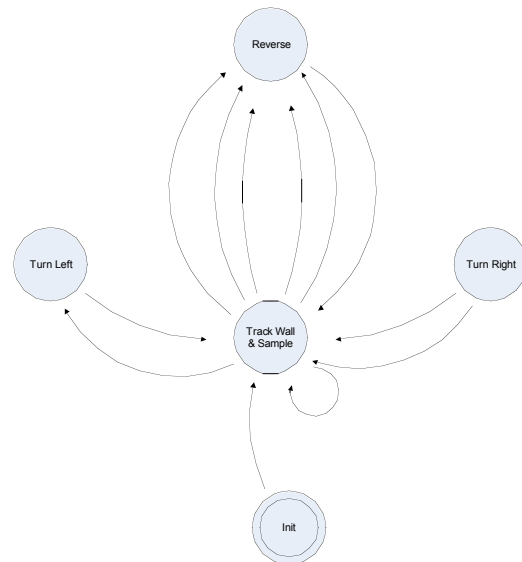


Fig. 6 REMbot state machine diagram

Data transfer is handled by a USB flash drive. This method, shown in Fig. 7 was chosen for simplicity and convenience.

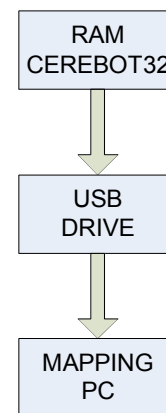


Fig. 7 Data flow diagram

At the beginning of the scanning process, the REMbot measures the width and length of the room. These lengths are stored at the beginning of the data block that will be populated with radiation measurements. The width and length are determined by the uppermost and rightmost traces in Fig. 2. These numbers are used to set the dimensions of the map. As the room is surveyed, the data are stored in a temporary register. Even-numbered passes across the room must be flipped before they are stored to the data block. This is necessary because the mapping software breaks the data string

into segments, which are used to build a two-dimensional array. Referring to Fig. 2, the data is collected from top to bottom on odd passes and bottom to top on even passes. Flipping even columns of data allows them to be concatenated in matrix form as column vectors in MATLAB[®].

The data collected in a scan is stored serially in a reserved memory block of the PIC32MX460 microcontroller. Upon completion of the scan the REMbot is in its place of origin to be collected by the user. A USB port on the back of the robot allows the user to access this memory with a USB thumb drive, using the PIC32 USB On-The-Go application [4]. Insertion of the thumb drive prompts the REMbot to automatically download the data to a file named with a time and date stamp. A MATLAB[®] routine developed by the team is used to open this file and make the radiation map. The user loads MATLAB[®] and enters the command “rembot”, and is prompted by the program to browse the computer for the map file. The file on the thumb drive is selected and the program creates a two-by-two array of the sequential data. A map generated from test data is shown in Fig. 8. After the map is generated, the matrix of actual numbers is also displayed for a more quantitative output.

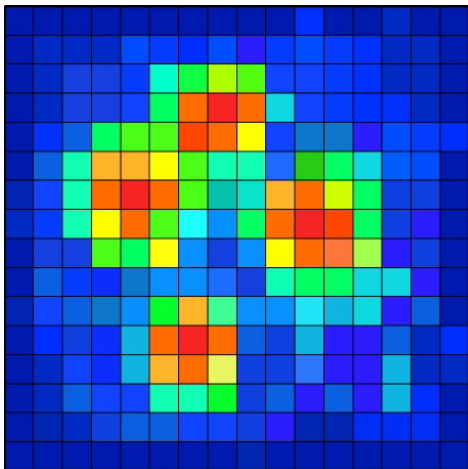


Fig. 8 Sample radiation map of a square room.

V. CONCLUSION

The REMbot is an autonomous robot capable of scanning a rectangular room for radiation, and storing this data in an allocated memory block of a microcontroller. The data is transferred to a USB thumb drive by inserting it into the chassis of the robot after a scan is complete. The data is then automatically saved to the drive, which is loaded to a PC by the user. The map is generated in MATLAB[®] with a program created by the design team.

VI. ACKNOWLEDGMENT

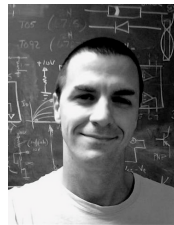
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VII. REFERENCES

- [1] *DOE Standards*, Vol. 1 Standard 10 CFR Part 834 and DOE 5400.5 ALARA Program Requirements, Apr. 1997.
- [2] Microchip PIC32 documentation Available: www.microchip.com/stellent/idcplg?IdcService=SS_GET_PAGE&nodeId=2612.
- [3] Digilent Inc. *Digilent PmodHB3 2A H Bridge Reference Manual* 200, pg. 2.
- [4] John Loomis' PIC32 Documentation Available: www.johnloomis.org/microchip/.../32-bitPeripheral-Library-Guide.pdf.

VIII. BIOGRAPHIES



Brian Egenriether was born in Alpena Michigan on July 21, 1977 and raised in Charleston, SC. He graduated summa cum laude from The Citadel in May 2010 with a Bachelor of Science in Electrical Engineering. He is currently employed as an electrical maintenance technician at Nucor Steel Berkeley – Cold Mill. He is a member of Tau Beta Pi Engineering Honor Society, IEEE, and a Bernard Gordon Scholar.



Nick Rhodes was born in Oklahoma City, Oklahoma on April 20, 1977 and moved to Charleston, SC in 1992. He graduated from The Citadel in May 2010 with a Bachelor of Science in Electrical Engineering. He is currently seeking employment as an electrical engineer. He is a member of Tau Beta Pi Engineering Honor Society.



Jeremy Evans was born in Enterprise Alabama on November 1 1978 and raised in Charleston, SC. He graduated from The Citadel in May 2010 with a Bachelor of Science in Electrical Engineering. He is currently employed as an electrical maintenance technician at Nucor Steel Berkeley – Beam Mill. He is a member of Tau Beta Pi Engineering Honor Society.



Michael Schmick was born in Woodbury, NJ, on June 2, 1986, and raised in Swedesboro, NJ. He graduated from The Citadel in May 2010 with a Bachelor of Science in Electrical Engineering. He has worked summer internships in the nuclear power industry since 2007 and will be working for PSEG Nuclear in New Jersey as an Electrical/I&C Engineer.



Erick Muniz was born in Inglewood, California and raised in Myrtle Beach, South Carolina. He graduated from The Citadel in May 2010 with a Bachelor of Science in Electrical Engineering. After graduation he plans on working for Santee Cooper in Conway, SC or Moncks Corner, SC while attending The Citadel Graduate College to receive an MBA.