Sensing and Collecting Radioactive Materials as a Project to Teach Engineering Design

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Summary

The remote detection and isolation of radioactive materials is both a challenging engineering design project and a relevant issue given modern nuclear circumstances. This project is used in the undergraduate capstone class of the Engineering Physics Department at McMaster University to teach students engineering design. This paper discusses the course outline and learning outcomes of the students who took the course over the 2014-2015 academic year.

1. Introduction

In January 1978, a Russian nuclear powered satellite called Kosmos 954 depressurized and began an uncontrolled reentry into Earth's atmosphere [1]. The remnants of the satellite were disbursed over more than 300000 m^2 of Canada's arctic [1]. Such an accident has demonstrated, among other things, the need to access remote areas to collect and identify contaminated objects.

One method of performing this task would be to deploy autonomous robots capable of sensing and collecting contaminated debris. The design of such a robot requires an extensive knowledge of physical sciences to understand material detection, autonomous control and electrical design. It also requires soft skills such as teamwork, budgeting and scheduling to ensure the device is affordable and made in a timely manner. This type of project makes an ideal task to teach engineering design to undergraduate students and was chosen by the Engineering Physics Department at McMaster University to be implemented as the final year Capstone project. This paper discusses the course structure and the learning outcomes of the project.

This paper is unique because the first draft of each section was written by groups of undergraduate students who were taking the course. David Drake led the other teaching assistants (TAs) Tara Majdi and James Strack in assembling the text. The final abstract was reviewed by all parties, including the instructor, Dr. Buijs.

2. Course Structure

The Capstone project is a full-year course that follows a hands-on approach. The majority of classroom resources are devoted to project-based learning instead of conventional lectures. Students formed groups that were evaluated on their ability to demonstrate professional skills and develop a device that performs to the assigned specifications. Students were aided by TAs, laboratory technicians and professors who provided them with a safe working environment and access to a variety of facilities and equipment.

2.1 Project Requirements

To ensure fair evaluation and a project that can be tested on campus, several design constraints were established. The student's had to build a robot capable of distinguishing between randomly located samples of size 1.4 to 2 cm^3 with one of three compositions: inactive, vitrified uranium (U) and monazite crystalline thorium (Th) (see Fig. 1). The device had to be able to search in simulated outdoor conditions consisting of a 120 cm^2, square sandbox with a roughened surface. All robots were required to fit inside of a $30 \times 25 \times 37.5$ cm^3 box. The device had to be capable of completing the search within 7.5 minutes, which is enough time to collect counting statistics through use of a device like a Geiger counter. Student's had to consider a budget as devices over $200 were penalized. Commercial robot kits were not allowed.

Figure 1: Image of samples FLTR: The Monazite crystal, a regular marble, a U-glass marble. Note the fluorescence in the U-marble caused by the blue light.

2.2 Evaluation

During the initial phase of the course, students had to participate in safety training and learn about the engineering design process. These initial components accounted for 10% of the course grade and were evaluated through the students' individual written work. Within the first month of the project, students submitted a written proposal on their plan to design and build a device that would operate according to specifications. This proposal represents 10% of the course grade and had to be updated throughout the year to reflect any major design changes. Throughout the year, students received 25% of their mark for demonstrating communication skills, teamwork and progress through weekly updates to TAs and six progress presentations to a panel of professors.

Students took part in an interim demonstration worth 10% half way through the year and a "race day" evaluation worth 30% at the end of the year. Each group was given the opportunity to present their project in a format where the completion of the assigned task is timed. Timing the demonstrations was primarily done for grading purposes but also creates a friendly, quasi-competitive environment where groups vied to demonstrate the most efficient device. The interim demonstration serves as a milestone where a robot can search the sandbox for samples and a separate device can distinguish between active samples (U and Th) and inactive detritus. There were two final race days separated by a week in March. On each day, teams were given two opportunities to show that their robot could navigate the search region, detect active samples, pick them up and return them to a designated area. Students could choose to perform additional challenges of varying complexity for extra credit. At the end of the course, a final report detailing their design had to be submitted for the last 15% of their grade.

2.3 Facilities and Safety

For the project, students were given exclusive use of a lab facility outfitted with oscilloscopes, power sources, multimeters, and other common electronics equipment. U and Th samples were provided to students for testing purposes. Students also had access to a variety of other facilities such as a machine shop for custom metal-working, a laser cutter for high precision material cuts, and multiple 3-D printers for rapid prototyping.

The open nature of this course allowed groups to choose how they design their robot, and to independently construct this robot without constant supervision. The safety concerns that pertain to each group depend greatly on their specific design and were addressed individually. Before any potentially dangerous activities were undertaken, students submitted safety reports to their TAs during their weekly meetings. These reports had to demonstrate an understanding of the relevant hazards, the recommended safety precautions, and appropriate response in the event of an accident. The common safety concern of all groups was work with the U and Th samples. These are Naturally Occurring Radiative Materials (NORMs, purchased on EBay), and as such, they are not subject to regulations of radioactive sources and pose no risk [2] [3].

3. Acquired Skills

The design process was integral in effectively prototyping design solutions subject to the project requirements and constraints. In its most primitive form, the Engineering Design Process is an iterative process consisting of: defining the problem, researching the need, designing possible solutions, choosing the best solution, prototyping, testing and evaluating, and repeating the process. The process is essential to refine a working solution into an optimal solution. Through this iterative approach students developed a variety of skills ranging from teamwork to microcontroller programming.

3.1 Theoretical Physics

The most direct application of physical knowledge was the sample identification itself. The two active samples, U and Th are both radioactive and emit a wide spectrum of alpha, beta and gamma radiation. Ostensibly, all Th and U samples could be located by the robot in the sand and classified by their relative activities before even being collected. However, both the Th and U energy spectra are primarily low energy (<250keV), meaning that even a small amount of sand between the detector and sample would result in severe attenuation. Furthermore, although the Th sample was sufficiently active (with nominally 100 Bq), the U sample was found to be of very low activity, with a count rate only nominally 50% above background. Given time limitations, assaying the U sample long enough to provide acceptable counting statistics to differentiate it from detritus was not feasible for any group. All groups independently chose to use a second test to identify U. It was discovered that U fluoresces green when illuminated by UV light and can therefore be identified with optoelectronics. Most groups built Geiger-Muller type detector (mainly from kits) to identify the Th sample. Students directly applied their theoretical, engineering knowledge while designing their solution to this challenge.

3.2 3D Printing

A 3-D printer takes a computer model of an object and uses a layered plastic filament to create a solid object. Designs can be quickly, easily and cheaply fabricated to evaluate their feasibility. These objects can incorporate complex geometries that are difficult to fabricate through conventional means. However, despite having advantages, students also assessed the shortcomings of the technology. The small nozzle width of 0.5 mm, affects the fabrication of the component by limiting the thickness of each layer and sharpness of the component edges. Alternately, the layering technique for fabrication means freestanding arches are not feasible. The centre of the arch would not have supporting material below and would collapse while being printed [4]. In addition to printing limitations, students had to assess the physical limitations of the printed components in their overall design.

3.3 Microcontroller Unit and Printed Circuit Board Design

A robot that can search the specified area, operate sensors and isolate a sample, needs a microcontroller unit (MCU). All groups independently chose to use some form of Arduino board due to its simplicity, low price and ease of transitioning to a printed circuit board (PCB) [5]. Students approached the MCU programming challenge by using block diagrams to plan out function interaction and writing pseudo code to organize their programs. Once students had a high level process flow, sensors, motors and other components could be quickly and easily implemented using vendor provided Arduino libraries. Students would improve these libraries where necessary. A critical aspect of successful programming was to apply engineering principles like modular design.

PCBs are a tool used in industry to quickly, cheaply and reliably reproduce a circuit. It was expected that students combine all their electronics onto a PCB. Students were provided with learning materials for EAGLE, a CAD program built for the implementation of PCBs [5]. Most students designed single layer PCBs which were fabricated at the local IEEE branch. A few others found alternative fabrication services who offer more professional quality with additional features. While learning new software and fabrication techniques, students learned to be careful with their designs to ensure they didn't order faulty boards.

3.4 Vehicle Assembly

All teams elected to develop a mobile robot which moved through the sandbox to find and identify samples. Combining all the parts into a single mobile chassis proved quite a challenge considering the presence of sand. Most groups elected to use tank tracks for their design. These tracks spread the weight of the robot over a wider area; improving traction. Most groups used pre-made robot track kits, although one group attempted to build their own tracks while another group designed custom wheels. Robots were steered using differential steering provided by independent motors. A strong material capable of holding all sensors and motors was necessary to form the body of the robot. Many groups approached this issue differently, using different materials like: acrylic, wood, or steel plate, among others. A picture of one such robot is included in Figure 2. The mechanical design of this project really highlights the interdisciplinary nature of engineering and was a valuable experience for the students.

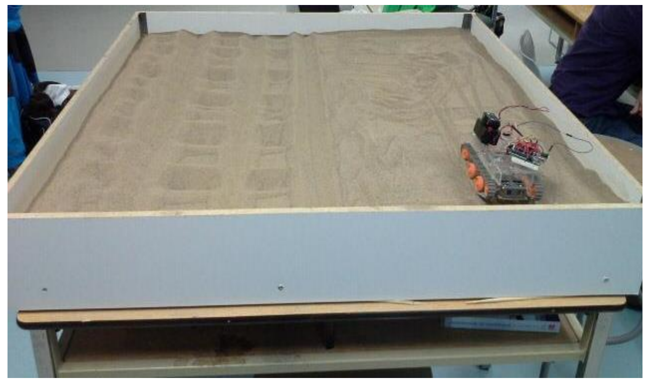

Figure 2: A partially completed robot being tested in the sand box test area; note the rough sand surface on the left.

4. Conclusion

This course provided a unique and valuable learning experience to the students. Through the design and construction of these robots, students gained many transferable skills. From brainstorming to design, students applied many of the skills of the engineering design process. Students developed communication and time management skills through the use of Gantt charts, and weekly progress letters. Students left the course with varied technical skills as and make for bright future employees in a variety of fields including Canada’s nuclear industry.

5. References

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