Overview of the Carnegie Mellon University Robotics Institute DOE Traineeship in Environmental Management – 17493

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ABSTRACT

The Robotics Institute of Carnegie Mellon University (CMU), through support from the Department of Energy (DOE), is offering an Environmental Management (EM) Traineeship program that is shaped by the inherent challenges in EM-related missions and seeks to cultivate the technical foundation and practical skills required to address these challenges. The traineeship program includes multiple new fellows per year of support (MS and/or PhD students) and builds on the existing core robotics curricula while introducing specialized topics that ensure a thorough understanding of EM-relevant concerns. The traineeship incorporates supervised research opportunities with CMU faculty advisors and through collaborations with DOE national labs (Pacific Northwest National Laboratory and Savannah River National Laboratory). These research opportunities aim to produce specialists who have the skills required to envision, develop, and deploy autonomous and semi-autonomous systems that directly address DOE-EM needs. Specifically, the Robotics Institute identifies two specializations in addition to the three core areas that students must master in order to develop these kinds of systems: (1) a theory perspective of how to develop autonomous systems for applications in constrained environments, and (2) a practicum that challenges students to build systems that can operate in constrained EM-relevant environments. The DOE Traineeship in Robotics is formulated to provide a course of study that balances theory and practice with opportunities for field evaluation in collaboration with domain partners toward addressing relevant DOE-EM challenges through robotics.

INTRODUCTION

Recent events highlight the need for robotic solutions to many fundamental and distinct challenges in environmental management. Robots can be deployed for preventative measures, including persistent, autonomous inspection of critical EM infrastructure and facilities, and are particularly advantageous for components that are not readily accessible to human inspectors. Such systems would help prevent scenarios such as the pipe failure at the THORP facility in 2005 that resulted in approximately 83,000 liters of highly radioactive dissolver solution being leaked and yet went undetected for months before being discovered and prompting a two-year plant shutdown [1].

When a 55-gallon drum of nuclear waste ruptured at the Waste Isolation Pilot Plant (WIPP) in February 2015, the primary challenge was to locate the source of the leak that was slowly discharging plutonium into the plant ventilation system. The response was to send a crew to search the facility. However, the protective suits required for humans to work in this hazardous environment lacked sufficient battery power, and the search was terminated before finding the source due to safety concerns.

This problem could be avoided by deploying an autonomous system to search for the leak. For example, CMU has developed and demonstrated Micro Aerial Vehicles (MAVs) equipped with radiation-hardened sensors to inspect damaged reactor buildings, such as those in the aftermath of the 2011 Fukushima-Daiichi nuclear disaster (Fig. 1, left). By leveraging advanced autonomy and health-management algorithms, such a system could be deployed remotely, thereby dramatically reducing the risk to emergency responders. Moreover, future accidents could release highly irradiated materials that would make it impossible for humans to access the plant to search for and fix a leak, but through careful design, robots can readily overcome these limitations.

However, the Fukushima-Daiichi disaster also demonstrated that current state-of-art robots lack the capabilities required to inspect nuclear facilities, assess damage, and fix problems effectively [2]. The 2015 DARPA Robotics Challenge also illustrated many of the technical challenges that remain to be addressed before robots can be deployed for these types of response scenarios (Fig. 1, right). Therefore, it is imperative that we prepare a next generation of STEM workforce capable of developing robots and robot technologies that can autonomously inspect, investigate, repair, and clean up EM facilities both as part of routine maintenance and in the event of an emergency, accident, or catastrophe.

Figure 1: (left) CMU’s autonomous MAVs enable mapping and exploration of hazardous indoor environments. (right) CMU’s CHIMP turns a valve while operating semi-autonomously at the DARPA Robotics Challenge.

Environmental Management Traineeship in Robotics

To enable the development and deployment of these next generation EM-focused robot systems, new training programs are required that cover core robotics concepts as well as key ideas specific to EM. State-of-the-art robots integrate ideas from three core areas: perception, cognition, and action, and together, they enable the *sense, think, and act* paradigm that is fundamental to the development of robots for any application. Therefore, we propose that any effective robotics program should first establish this foundation to ensure the autonomous systems being developed employ state-of-the-art techniques for maximum efficiency and performance.

However, each of these core areas must also be considered in the context of EM scenarios. In order to create robots capable of tasks such as inspecting, investigating, repairing, and cleaning up nuclear waste facilities, it is necessary for the student, engineer, and researcher to have a specialized understanding of the unique challenges and constraints of the particular application. This may entail, for example, being able to translate information regarding gamma radiation levels in an environment into a set of design constraints on motion planning or mapping algorithms to ensure viability given the limited computational resources on sufficiently radiation-hardened microprocessors [3]. These types of considerations may be mentioned briefly in traditional STEM/robotics programs but are crucial to the development of robot systems that can operate in hazardous environments and execute the types of missions required for EM-relevant applications. Therefore, an EM traineeship program of this kind is essential for training robotics engineers with a strong foundation augmented with the necessary domain knowledge to enable the design, manufacturing, and deployment of advanced radiation robotics.

Specialized Environmental Management Domain-Driven Curriculum

In order to develop a STEM workforce equipped with the core competencies needed to address DOE-relevant applications, we propose that an effective traineeship should tightly integrate domain-specific concepts, applications, and experience throughout the duration of the program. For example, case studies, such as the accidents at THORP, WIPP, Fukushima-Daiichi, and Three Mile Island, are often used to motivate the development of autonomous systems. However, in the context of the traineeship, these events can also illustrate the need for a systems-level analysis of nuclear site safety and health monitoring when developing systems to maintain and inspect these facilities effectively.

The traineeship curriculum must also integrate practical, hands-on experience by developing systems that accomplish EM-relevant tasks. This can be achieved through a set of courses designed around domain-specific challenges that reinforce and enhance the theoretical foundation. CMU’s Model Robot Design and Advanced Mobile Robot Development courses currently implement this model in the context of space navigation and planetary landing (Fig. 3). Students investigate a broad spectrum of topics including robot mobility, energetics, sensing, computing, software, payload, and operating environment, while developing and integrating lunar robot prototypes. To further the skills developed through hands-on coursework, we pursue a curriculum that emphasizes directed research and provides opportunities for students to gain real-world experience applying the concepts they have studied to practical EM applications.

By the conclusion of a focused curriculum highlighted by this domain-driven practicum, trainees should be cognizant of the general challenges in robotics as well as the practical limitations imposed by domain-specific factors. A domain-driven curriculum provides the essential skills for a robotics engineer to assess key EM-related considerations, such as the cost and performance limitations of radiation hardened sensors and microprocessors, the requirements for ensuring safety and reliability via semi-autonomous remote operation, or the logistical requirements for deploying such systems in a variety of EM-application scenarios. The remainder of this paper details the formulation of the EM Traineeship offered by the Robotics Institute (RI) of Carnegie Mellon University, through support from the Department of Energy, in order to achieve these desired outcomes.

Figure 3: Students in CMU's Mobile Robot Design course gain domain-relevant experience developing a prototype lunar rover.

TRAINEESHIP PROGRAM

The DOE Traineeship in Robotics is a specialized curriculum that trains students to solve high-impact, DOE-relevant problems by leveraging the existing Robotics MS and PhD curricula and introducing specialized DOE-relevant coursework, supervised research, and partner mentoring. The program is outlined in the following sections.

Course Requirements

DOE trainees complete four core courses (one in each of the areas of Perception, Cognition, Action and Mathematical Foundations), two special topics courses that give students the knowledge to solve DOE-relevant problems, and one elective for a total of seven courses. The special topics courses highlight systems development and instruct students on developing complete systems for remote access into nuclear waste facilities including both domain challenges and the implications of radiation hardening on system capabilities and performance.

Supervised Research

Students are paired with an advisor and engage in supervised research designed to impart the necessary skills to develop robotic solutions to critical, unsolved environmental management problems. For example, significant state estimation challenges arise in indoor or underground environments due to reliance on noisy sensor data and the need for real-time operation. DOE-relevant environments impose additional requirements due to the need for radiation tolerant operation. The supervised research component enables trainees to develop the necessary skills to understand the state of the art, identify the gap in the state of the art that limits operation in relevant domains, and find solutions that enable robots to operate autonomously using radiation-tolerant sensors.

Partner Collaboration and Mentoring

Students and advisors work with the partner labs to identify and define specific DOE-relevant problems. Engagement with the laboratories consists of individual meetings and bimonthly seminars where students present ongoing work and receive feedback from partners.

ROBOTICS CORE CURRICULUM

Perception

The perception core course instructs students on computer vision techniques, image sensors, range data interpretation, tactile and force sensors, inertial guidance and other sensors. Fundamental concepts are presented that are essential to enabling robotic inspection in cluttered and irradiated environments given sensor failures and changes in sensor performance caused by dynamic environmental conditions (such as lighting and radiation).

Cognition

The cognition core course instructs students in artificial intelligence for robotics, including knowledge representation, planning, and task scheduling. Students learn how to develop robots that can plan paths in unknown environments or plan optimal paths if the environment is already known. Optimal path planning enables robots to quickly and efficiently explore an environment to enable radiation leak detection and regular inspection of infrastructure.

Action

The action core course instructs students in kinematics, dynamics, control, manipulation, and locomotion. Students investigate the mobility of autonomous systems in constrained and cluttered environments to enable ingress and egress of remote access environments given potentially challenging operating conditions.

Math Foundations

Math foundations are developed through a core course that instructs students in signal processing, optimal estimation, differential geometry, and operations research.

SPECIALIZED DOMAIN-RELEVANT COURSES

Introduction to Remote Access Mobile Systems

The purpose of this course is to convey method and experiences relating to formulation, development, and evaluation of remote access mobile systems. Remote access mobile systems provide remote entry into areas and spaces that are otherwise inaccessible or prohibit direct access by workers.

The goals of this course are to evolve navigation, electronics, software, and representation for remote access by mobile systems. Technology development must be adapted to meet the mechanical, computing, and electrical constraints imposed by the environment. This course covers component-level development, system integration, and operational testing to build robots that will operate in constrained environments. The challenges require complementary skill, collaborative teaming, and mentoring from DOE lab partners to build a system to solve a specific DOE-relevant problem.

Advanced Remote Access Mobile Systems in Constrained Environments

This course serves as a follow-on course to *Special Topic: Introduction to Remote Access Mobile Systems*. Students refine the system developed through prior courses to operate in a disaster scenario in a nuclear waste facility. The course teaches advanced robotics concepts about the coupling of individual components of autonomous systems. The coupling of perception and planning with belief uncertainty, perception and cognition, and control and cognition are explored from a theoretical perspective and incorporated into the existing robotic system while taking into account the environmental constraints. The course covers autonomous system integration and introduces perceptual adaptation, adaptation of planning strategies, adaptive control, and how to leverage prior system experience toward informed future actions.

TRAINEESHIP ADMINISTRATION AND OVERSIGHT

An advisory board reviews the success of the program and provides feedback to program administrators. The review board consists of both vested faculty and partners. The ARB meeting reviews each trainee’s progress in the program, assesses the quality of the trainee program based on the trainees’ results, and determines the overall impact of the trainee program on the workforce-training goal of the sponsoring DOE Program Office. An internal review committee consisting of RI faculty involved in the program conduct a similar review once every semester.

CONCLUSION

The Environmental Management Traineeship sponsored by the Department of Energy offered by the Robotics Institute of Carnegie Mellon University provides the next generation of roboticists and engineers the technical foundations and practical skills required to develop robots and robotic technologies that can address the EM-relevant applications of autonomous inspection, investigation, repair, and clean up of EM facilities both as part of routine maintenance and in the event of an emergency, accident, or catastrophe.

Students undertake a specialized robotics curriculum with topics that ensure a thorough understanding of EM-relevant concerns. The program also incorporates supervised research opportunities with CMU faculty advisors and through collaborations with DOE national labs (Pacific Northwest National Laboratory and Savannah River National Laboratory). These research opportunities aim to produce specialists with the skills required to envision, develop, and deploy autonomous and semi-autonomous systems that directly address DOE-EM needs. Specifically, the Robotics Institute identifies two specializations in addition to the three core areas that students must master in order to develop these kinds of systems: (1) a theoretic perspective of how to develop autonomous systems for applications in constrained environments, and (2) a practicum that challenges students to build systems that can operate in constrained EM-relevant environments. The DOE Traineeship in Robotics is formulated to provide a course of study that balances theory and practice with opportunities for field evaluation in collaboration with domain partners toward addressing relevant DOE-EM challenges through robotics.

REFERENCE

1. K. Skonieczny. *Lightweight Robotic Excavation*. PhD thesis, Robotics Institute, Carnegie Mellon University, Pittsburgh, PA, April 2013.
2. DARPA Robotics Challenge Finals 2015. http://www.theroboticschallenge.org/. Accessed: 2015-09-30.
3. L. P. Houssay. *Robotics and Radiation Hardening in the Nuclear Industry*. PhD thesis, The University of Florida, Gainesville, FL, 2000.
4. Pacific Northwest National Laboratory. http://www.pnnl.gov. Accessed: 2016-11-04.
5. Savannah River National Laboratory. http://srnl.doe.gov. Accessed: 2016-11-04.