A Multidisciplinary Approach to Learning Human-Robot Interaction (HRI) Through Real-World Problem Solving—The "BUSA Dig"

Rob Blain, Alex Ferworn, Jean Li, Jimmy Tran, & Michael Carter
Ryerson University

This article examines a cross-disciplinary approach to learning human-robot interaction (HRI) through real-world problem solving. The problem originated from the need of archaeologists at the University of California, Berkeley, and Ryerson University to safely explore archaeologically significant areas disturbed by heavy looting activities at the ancient site of el-Hibeh, Egypt. The learning objectives were developed through interdisciplinary collaboration of three departments at Ryerson University. The deliverable was an HRI final examination—known as the "BUSA Dig"—in which students teleoperated a robot of their own design and manufacture that explored and mapped a simulated archaeological site. The students participated in the examination through their membership in one of six mixed groups composed of undergraduate computer science and graduate digital media students. At the end of the exam, students were expected to understand and explain HRI principles, paradigms, and metrics, construct appropriate robots that could survive and function in a defined environment, and employ mobile and teleoperated robots that solved problems.

Keywords: human-robot interaction, teleoperation, HRI education, archaeology robotics

Introduction

The field of human–robot interaction (HRI) examines the role of physical robotic systems in the realm of human activity (Goodrich & Schultz 2007; Murphy, Nomura, Billard, & Burke, 2010). This field involves designing, understanding, and evaluating robotic systems in which a human communicates directly with a robot (Murphy et al, 2010). HRI influences almost all modern robotics, including numerous application areas such as manufacturing, space exploration, aviation, undersea vehicles, surgery, rehabilitation, agriculture, education, package fetch and delivery, policing, and military (Sheridan, 2016). This paper explores HRI as it relates to education and archaeology.

HRI pedagogy is problematic, as the field continually changes and expands. Thus, the majority of courses are offered in technical disciplines: computer science, mechanical engineering, and electrical engineering (Alimisis, 2013; Berry, 2015; Kokosy, Micea, & Saey, 2014; Riek, 2013; Sheridan, 2016). One objective of HRI education is the creation of a workforce that is able to translate HRI theory into practice (Murphy et al, 2010). This paper examines an interdisciplinary HRI education project that combined technical and artistic disciplines. This highly engaging project has implications for applications beyond the classroom, offering insight into real-world problem solving.

The Problem

The project was developed to explore potential solutions to the real-world problem of archaeological destruction as a result of looting activities. Since 2001, the University of California, Berkeley, under the directorship of Professor Carol Redmount, has conducted archaeological research at the site of el-Hibeh, Egypt. In 2011, the "Arab Spring" spread throughout countries in the Arab League. The political shift in Egypt's government resulted in diminished

Journal of Human-Robot Interaction, Vol. 6, No. 2, 2017, Pages 70-91, DOI 10.5898/JHRI.6.2.Blain

protection of archeological sites across the country. El-Hibeh, in a rather isolated region of Egypt, was badly affected. In 2015, with the appointment of Professor Jean Li as an Associate Director of the el-Hibeh project, Ryerson University entered into collaboration with UC Berkeley. The immediate goals of the collaboration were then focused on the safe retrieval of archaeological information in the aftermath of extensive looting at el-Hibeh.

The increased looting activity involved uncontrolled and extensive tunneling by looters. The photographic documentation (Fig. 1) of the looting reveals a site that is now "pockmarked with looting pits, areas of the site resemble Swiss cheese." (Redmount, 2014, p. 13). Confronted with news of the irreversible destruction of humanity's past through looting, the devastation of el-Hibeh was both disturbing and a call to action to find new approaches for dealing with the aftermath. The teams are scheduled to return to the site, however, before excavation can resume, an examination of the damage caused by the illicit excavation and looting is required (Ryerson University, 2016).

Jean Li and Carol Redmount posed the challenges of the safe exploration of looted tunnels and pits to Michael Carter, Director of Industry Relations, Master of Digital Media program at Ryerson University. Carter, a Virtual Archaeology specialist, suggested that robots could be used to explore and map the shafts that were potentially too dangerous for humans to enter (M. Carter, personal communication, November 5, 2015). In the course of discussions with Alex Ferworn, a professor specializing in robotics in the Department of Computer Science, Ryerson University, an opportunity arose in Ferworn's HRI class for students to build robots that addressed the needs of the archaeological site (M. Carter, personal communication, November 12, 2015; Ryerson University, 2016).

Figure 1. Photos from 2009 (upper) show the site before looting.
Photos from 2011 (lower) show the extent of looting activities in the same locations.

The Significance of El Hibeh

With over 3,000 years of history involving numerous cultures, the ancient settlement of el-Hibeh is an important site for understanding ancient Egypt. Located about three hours south of Cairo, el-Hibeh was a fine example of a well-preserved provincial town with many structures.

Founded at the beginning of the Third Intermediate Period (c. 1069-664 BCE), the geographical location of the town facilitated its importance. During this period, el-Hibeh marked the northern political boundary of the High

Priests of Amen, who controlled the southern area of the country (Wenke, 1984). After the unification of Egypt under the Saite Dynasty 26 (664-525 BCE), el-Hibeh became an administrative center and may have produced a number of important papyri documents, including *The Rylands Papyri* (Redmount, 2014).

In addition to its political importance and long history of occupation, until recently, the town of el-Hibeh was arguably among the most well-preserved provincial town mounds in Egypt (Redmount, 2014). The urban and provincial nature of the site offers unparalleled opportunities for archaeological investigation of ancient Egypt—a culture that has been characterized as a "civilization without cities" (Wilson, 1958).

El-Hibeh offers a wealth of information for the understanding of various aspects of Egyptian history and culture. The preserved archaeological evidence, including religious, domestic, and the mortuary, has the potential to increase and clarify our knowledge of urbanism, provincial life, and quotidian practices of ancient Egyptians. It is therefore vital to retrieve archaeological information in light of the site's continued deterioration.

Teaching HRI

HRI is a multidisciplinary field. Students need to understand a variety of disciplines to grasp the materials of an HRI course. The following topics might all apply to an HRI course: robotics, artificial intelligence, communications, computer science, cognitive science, cybernetics, engineering, human factors, natural language, interaction design, psychology, sociology and human-computer interaction (Alimisis, 2013; Berry, 2015; Kokosy et al, 2014; Murphy et al, 2010; Riek, 2013). As such, it is difficult to create any HRI course that does not require students to have taken a large number of prerequisite courses or have prior knowledge of programming languages (Berry, 2015; Murphy et al, 2010). Bridging the large gap between engineering, science, and the humanities is difficult, and a project-based learning methodology focused on collaborating with industry has shown to be effective (Kokosy et al., 2014). Due to the broad range of potential content in HRI and the lack of textbooks and standardized curriculum, it has been a challenge to create an 'introduction to HRI' course (Murphy et al, 2010; Sheridan, 2016).

The literature alludes to the difficulty in creating a course where technology and people are involved. Technology advances at a rapid rate, and formal education has difficulties keeping pace (Alimisis, 2013). Technological evolution is not an isolated challenge for HRI, as other disciplines must also accommodate such changes. It is recommended that any course development in HRI should involve industry. Doing so has shown a development of communication and teamwork skills needed after graduation (Tur & Pfeiffer, 2006).

It has been suggested that an HRI course should include a definition of HRI, modes of interaction, key issues in HRI, current applications, and social robotics (Berry, 2015; Murphy et al., 2010). Research also suggests an experiential approach to learning where a series of small assignments, involving robots and users, increase in complexity and culminate in a final project chosen by the students (Berry, 2015; Murphy et al, 2010; Riek, 2013).

CPS813/DG8010 Human Robot Interaction – Ryerson University

The introductory HRI course offered through Ryerson University's Department of Computer Science (Appendix A) was created by Dr. Ferworn and used a multidisciplinary approach. The course consisted of undergraduate computer science students and graduate digital media students. All computer science students had a prerequisite course where they built basic autonomous robots. The digital media students had a varied knowledge base; some had programming experience while others had no knowledge of programming. The goal of the mixed classroom was to create a learning environment similar to industry, where individuals of varied backgrounds and skill levels work together to solve problems.

With the exception of the midterm exam or literature review, all work was completed in groups. Groups represented a mixture of computer science and digital media students—there were no exceptions. The requirement to form groups was to foster knowledge dissemination between individuals with very different backgrounds, compel interaction, and provide opportunities to collaborate in solving "many humans with one robot" problems. Group work was also a more accurate reflection of the overall industry work environment that students would face upon graduation.

Learning outcomes for the course were for students to have the following abilities:

- Explain HRI principles, paradigms, and metrics.
- Construct appropriate robots that could survive and function in a defined environment.
- Employ mobile and teleoperated robots that solved problems.

Unlike many robotics courses (Ruzzenente, Koo, Nielsen, Grespan, & Fiorini, 2012), a standardized robot kit was not provided or even suggested. Students were encouraged to creatively design and build robots made from inexpensive parts—often repurposed from items in daily life. While the purchase of microcontrollers, motors, chips, and other electronic parts was required, ping-pong balls, plastic spoons, coffee cups, flooring samples, and broccoli elastics were also utilized to build effective robots. This required students to prepare unique solutions. For example, determining which sensors were required and understanding the construction of a robot helped students understand the relationship between the robot's parts, the code used to control it, and how a human interacted with it. Through the prototyping of their robots, groups proposed and tested multiple solutions to a single problem. The iterative process of designing the robots gave students a better understanding of the HRI challenges from each project.

The course was delivered through weekly lectures that reinforced practical lessons presented in labs. Most of the assignments were informed and assessed through the successful completion of lab exercises. Additional evaluation occurred through a differentiated midterm assessment consisting of a midterm exam for computer science students and an extensive literature review for digital media students. The iteration of the course presented in this paper involved a final examination, which took the form of an exercise and was intended to combine skills practiced in the labs informed by concepts explored in the lectures. Lectures were used as a means to introduce students to key HRI concepts tied directly to lab assignments. The following topics were explored: teleoperation, telepresence, presence, agency, situational awareness, sensors and sensing, mapping, collision avoidance, tether management, dealing with ambiguous and incomplete information, and robot-human teamwork.

As both undergraduate and graduate students took the course, the evaluation of each type of student was differentiated but complementary. Undergraduate students received a week-long, take-home midterm exam (Appendix B), which placed emphasis on analyzing a problem and devising a succinct explanation for its potential solution. Students were asked to propose a hypothetical solution using computational thinking to devise algorithms that might lead to an end state that would significantly fulfill the requirements of the problem statement. They were not required to build their solutions but were evaluated based on a rubric emphasising practicality, efficiency, and completeness.

Graduate students completed an extensive literature review (Appendix C), where they conducted extensive research in an individual HRI application area, consulted peer-reviewed literature concerning the topic, and assessed the possibilities for the future.

Labs allowed for the practice of students' abilities to synthesize knowledge from lectures and apply it to robots. Students were required to work collaboratively to solve problems, propose solutions, create robots, test, and test again. Test environments were provided for all labs, meaning students were able to rapidly prototype solutions, test their robots in the environment, and make revisions. Labs were assessed through timed completion of assigned tasks. Tasks always required the coordinated, cooperative efforts of every human in each group interacting with their robot.

The first lab (Appendix D) was an introduction to robotics, sensors, and building a basic intelligence that would respond to stimuli. All groups used the same tutebot circuit (Jones & Flynn, 1999) and were required to build and design their robot to autonomously drive on a rough, irregularly shaped table. The robot had to detect if it was about to fall off the table and react accordingly. Students were required to spend less than $15 on the robot. The objective was to have students use readily available parts to design, test, and iterate as they observed their robot creations. Iterations gave students insights into the relationship between sensor placements and functions of the robot's intelligence.

The second lab (Appendix E) built on the learning from the first and introduced teleoperation, situational awareness, and communication between humans and robots. Each group was tasked with driving their robot from one end of a maze to the other without colliding with walls. Groups were required to traverse the maze under different circumstances:

- The maze was visible by another member through a video feed. Instructions were sent through a two-way radio to a driver who could not see the maze.
- The maze was visible to a driver through a video feed provided by an unmanned aerial vehicle (UAV/drone) hovering over the maze. Another member of the group controlled the UAV.
- The maze surface was seen in mirror view by the driver and the group.

Figure 2. Apparatus with BUSA tunnel entry/exit shown.

The challenge of the assignment was that the driver of the robot could not see where they were driving. They had to rely on team members and sensor data from the robot to warn them of an impending crash. Students learned effective communication methods when working in a team and how the robot can be used to assist human challenges.

The third lab (Appendix F) introduced telepresence, manipulation, interaction, and time pressure. Students had three minutes to remotely drive a robot on a "soccer pitch," use a mechanical device to pick up five balls, drive toward a goal, and try and score into the net. The driver could only see the pitch through cameras mounted to their robot. Students had to design a solution where they could not only see to drive their robot, but also see the mechanical device used to pick up the balls. The lab required students to understand the challenges of manipulation and interacting with an environment through a camera feed. Unlike the first two labs, students were given a finite amount of time to complete the task. Handling the balance between task completion and time management created a situation where the driver—and team—had to decide, prioritize, and communicate while trying to complete the task.

The final exam (Appendix G) was a culmination of all topics covered in the course put into practice. Students continued to work in their groups. The same methodology employed for the labs was used for the final exam. Although students had limited access to the testing environment, they were given extensive information of the intent of the exam and the nature of the environment. This was created as a means to provide students with a more accurate representation of a lifelike experience. Namely, inferences could be made as to what to expect, but many unknown elements existed that would not be understood until the robot was in the actual environment.

The BUSA Dig

In this iteration of CPS813/DG8010 Human Robot Interaction, two course components were used to develop potential solutions to the el-Hibeh looter tunnel exploration problem.

The first was the written midterm test for the computer science students. The students were required to propose a solution to an analog to the el-Hibeh problem using hypothetical robots. They were asked to consider a site where an abstract robot with unspecified sensors was lowered into an unknown shaft using a tether. The robot would be required to explore the site and provide information to create a dimensionally accurate floor plan and dimensions of all chambers, complete with depictions of their contents. A bonus mark was awarded if students could suggest a plausible method for extracting their robot unharmed. The students were to consider how relevant and actionable information could be relayed to a human operator. Students were not required to build a prototype, and each student's work was to be their own, but they could reference the literature and discuss relevant concepts with their classmates. The assignment was used to assess the potential of students in the class to conceptualize and address the el-Hibeh problem. Students were encouraged to provide simple, realistic systems for their solution. Based on the submissions of the midterm exam, it was determined that there was sufficient knowledge, ingenuity, and competence to proceed with the construction of an actual mock site and to authorize the building of prototype robots.

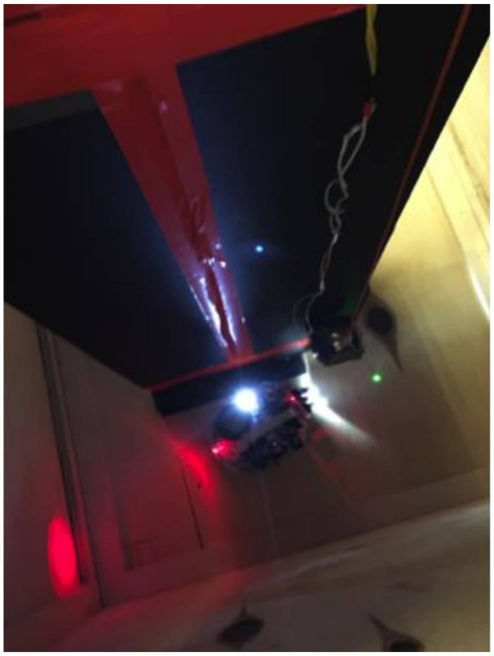


Figure 3. Scene moments after detaching from its tether, running a diagnostic and turning on all sensors a robot prepares to explore the BUSA Dig. © 2016 Alex Ferworn. Used with permission.

The second evaluation tool was the final exam for the course. The exam was a simulation of exploring and mapping of a tunnel that might be found at the el-Hibeh site. As envisioned in the midterm assignment, a robot was lowered into a large chamber using a tether (Fig. 2). Once lowered into the chamber, the robot was required to detach from the tether (Fig. 3) to explore, map, and identify significant objects in the area (Fig. 4). After exploration, the robot had to re-attach to the tether to be extracted. The exam was nicknamed the "BUSA Dig," named after the bright green and pink children's play tunnel that formed an entry/exit point to the exploration site.

The objective of the final exam was to create six prototype robots demonstrating the potential to explore the tunnels of el-Hibeh. The expectation was that, while the prototypes would not be field ready, significant learning would develop through the process of creating the robots, and the challenges faced by the groups would inform the eventual construction of the field robot(s) that would be deployed. In addition to the design and construction of the robots, learning from the interaction among the computer science and digital media students was important, as a similar interaction experience between archeologists and roboticists could be expected.

While many of the digital media students lacked the technical abilities of the computer sciences students to program a robot, they provided insight into communications, driving strategy, and mapping that were complementary to the computer science students. For example, the digital media students often devised the communication protocols used to control the mixed human-robot team during exploration. As it turned out, the effective driving of a robot is a skill bestowed by no discipline and desired by all.

A Non-Traditional Final Exam

The final exercise transformed into a non-traditional university examination, open to the public, with cheering onlookers and covered by the media. Through various industry contacts at Ryerson University, the "Daily Planet," a program of The Discovery Channel, Canada, covered the event, with local TV coverage provided by CTV News, Toronto. The el-Hibeh problem was explained to the audience through a large-screen view, and the exam was posted for all to see (Fig. 5). To accommodate the camera crews, the final examination was held in the foyer of Ryerson University's Student Learning Centre

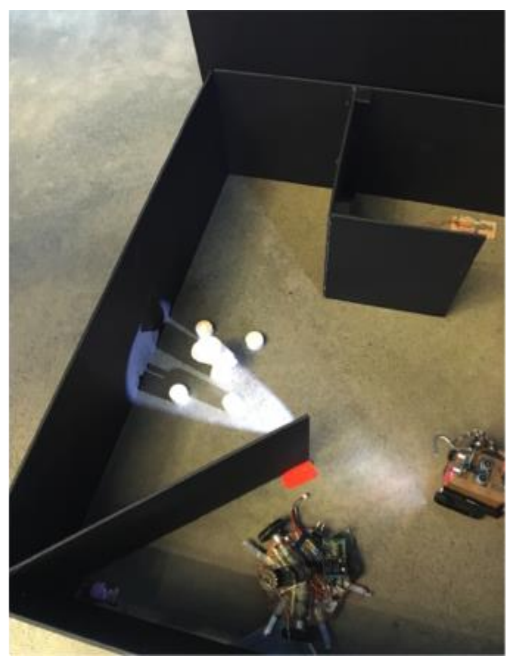


Figure 4. Robot discovering Nefertiti's temple. Note the device to left of the robot. Called "the squid", this was a form of IED with counter-rotating flails armed with fish hooks designed to rip out wires and sensors. © 2016 Alex Ferworn. Used with permission.

Figure 5. View from the foyer of the SLC at Ryerson University showing the final exam. © 2016 Jean Li. Used with permission.

(SLC), a space with ample room for members of the public to observe the exam. Examinees interacted with the public and film crews during the entire exam, discussing their robots and broadcasting screens from their laptops or other control and display devices. Doing so enabled students to disseminate knowledge of the HRI process. Each group had fifteen minutes to complete the examination but could repeat the process as many times as they liked. However, only one group could explore the BUSA site at a time. The BUSA chambers were stocked with points of interest, or "artefacts," such as toys and dolls. One of the chambers was fashioned into a temple featuring a 3D printed miniature of Nefertiti. Groups lost marks for touching any artifact but, perhaps more effectively, various improvised explosive devices (IEDs) made of mouse traps armed with fishing hooks were deployed to challenge students' ability to use sensors and a camera to detect and avoid objects within the chambers. Chambers were reorganized after each group completed an exam run to prevent students from copying results.

The publicity and public nature of the final exam challenged groups to prepare for uncertainty. The task was open ended, and as such, students had to hypothesize about the potential threats and dangers to their robot. The exam was different from the closed setting of the labs. Labs were informal and students could show up with unfinished work. The final exam was a formal and public event. Students had to be prepared with their robots to perform. This public nature of the exam was consciously created to reflect industry, as being prepared and ready is a pivotal skill for students to learn. Another skill required by industry is for students to be able to critically analyze a problem and troubleshoot. The first group to take the exam experienced this challenge. In a closed environment, their robot operated flawlessly. However, in the open environment a problem occurred. The equipment from the camera crews caused radio interference with the signal of the group's robot. They experienced a latency of 8–10 seconds between the video feed and the controls of their robot. Such a delay meant that they would not be able to complete the exam in the 15 minutes allotted. The students were able to quickly troubleshoot and reduce their latency to 1–2 seconds by significantly reducing the data transmission on their video feed. It was not an ideal solution, but it enabled the group to successfully take the exam. Other groups experienced similar challenges as they partook in the exam. They would all have to think critically and adapt new solutions to unexpected challenges. This methodology contrasted with a typical exam, in which if students prepared and studied, they should be guaranteed success. This was not the case of the BUSA Dig, as preparation did not guarantee success.

Construction of the Maze

The components of the maze were constructed as challenges that would assess the learning of the students throughout the semester. Each component (Fig. 6) required students to think critically about the relationship of sensors to hardware and then design a solution. The maze was constructed to represent a looter tunnel, and each component was designed to challenge how students critically analyzed the problem. The following components were created:

- **Winch**. Students were required to create a system that enabled their robot to attach and detach from a winch that lowered and raised the robot into the maze. The connection between the robot and winch had to be secure, as students applied sufficient force to pull their robot out of the maze.

Figure 6. View showing the components used to construct the maze. © 2016 Jean Li. Used with permission.

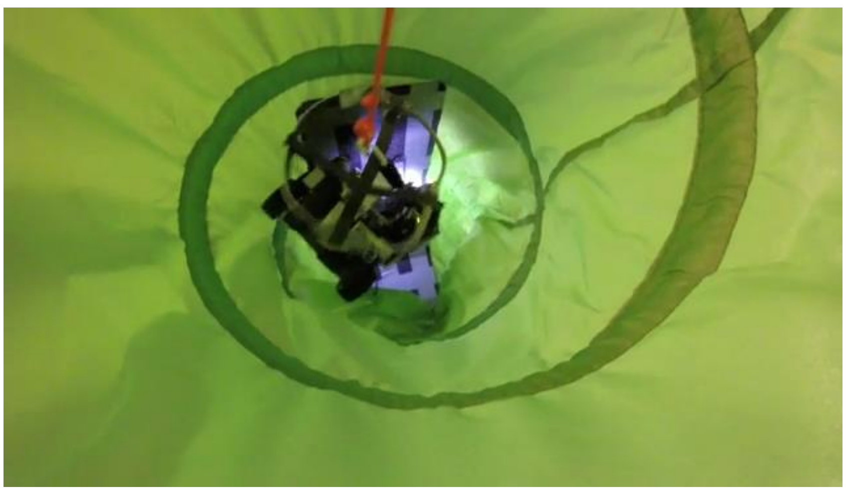


Figure 7. View showing a robot being lowed on the winch inside the entry tunnel. © 2016 Alex Ferworn. Used with permission.

- **Entry Tunnel**. After attaching their robot to the winch, students had to lower their robot into the entry tunnel. The tunnel was a small cylindrical enclosure, made from flexible polyester material. The enclosure (Fig. 7) made it difficult for groups to orient their robot, as the general appearance through a camera showed the green walls of the tunnel.
- **Entry Drop**. After traversing the entry tunnel, the robots had to navigate a 90° drop. The drop challenged a group's ability to raise and lower their robot without damaging the components.
- **Antechamber**. At the bottom of the entry drop, robots entered the antechamber. The antechamber challenged a group's ability to navigate a small, enclosed space. Students were required to take measurements of the antechamber, including the height of the ceiling.
- **Treasury Room**. After mapping the antechamber, students were required to drive their robot to the treasury room. The room was at a height much lower than the rest of the maze and had little to no light. Students had to build their robots to be under a predetermined height and add sensors to measure distance, provide visual feedback, and illuminate the room.
- **Ramp Between Antechamber and Treasury Room**. To navigate between the antechamber and treasury room, students needed to drive their robot over a low incline ramp. The ramp was at such an angle that robots designed with two wheels and a castor could get stuck on the ramp.
- **The Squid**. Within the Treasury Room was a robot with fish hooks that spun in circles. The robot was designed to catch any extraneous wires emanating from the bodies of the student-designed robots.

Each component in the maze challenged how students critically analyzed a problem and required their knowledge from the course to create a solution. Students were able to test their robots on the winch, entry tunnel, entry drop, and a sample ramp before the final exam. Prior to the exam, the challenges of these components were the least familiar to students.

A Collaborative Approach to Problem Solving

There were several significant challenges in the BUSA Dig, most notably, the short time frame of two weeks from conception to completion. The time frame dictated the pace and schedule of the HRI project each group undertook. A list of key milestones, deliverables, and drop-dead dates was developed—almost organically by each group—to ensure all individuals involved in the project could work efficiently and remotely. By its nature, the short time frame drove cooperation within each group and compelled cooperation across groups. If a component of the groups' solution could not be successfully tested by the drop-dead date, alternate methods were proposed and carried out. Components were also categorized as being either a 'must have' or 'nice to have'.

At the onset of the project, it was important to examine the HRI and determine how much control the driver required and how much "intelligence" the robot needed. If the robot was in plain sight, the driver would have spatial awareness and could make adjustments to control the robot. However, line of sight was not always available, and sensors were needed to collect data to inform the driver or robot how to react. Complexity was added as the BUSA chambers were mostly dark. Interpreting the data to relay information to the driver and filtering out unnecessary data was a critical component of the designs (Norman, 2013). Since data needed to be transmitted in real-time, any delays would affect the performance of the robot and frustrate the driver.

User expectation, as it relates to the concept of real-time feedback and control, was challenging. The necessity to have a low-latency video/data feed on the robot was essential but problematic. Being able to experience presence through the robot would provide valuable visual information. The camera feed needed to be as efficient as the navigation of the robot. When the two were not synchronized, it resulted in costly collisions (with the result of deducted points).

Student Accommodations

Students were amenable to the non-traditional exam and were highly motivated and engaged in both its preparation and execution. In addition, the university's administration was highly engaged and supportive—especially the library. Librarians participated in the exam, often seen adjusting parts of the apparatus that formed the BUSA Dig. Even the video crews became involved in repositioning and repairing BUSA components as students driving the robots inadvertently damaged them.

While there were accommodations for students due to their many and varied commitments, there were certain rules that could not be broken: 1) All teams are mixed between computer science and digital media students, and 2) Every student must be clearly involved in their own examination.

Remote Teleoperation of a Robot

A challenge arose for a student who was unable to attend the final exam. The student was attending a conference in Montreal: 500 km of distance from the examination site in Toronto. She proposed a solution to her problem—could she participate in the final exam by driving her robot from Montreal? Being able to remotely operate a robot in real time was beneficial to the el-Hibeh problem. If a network infrastructure was designed to communicate between the robot and driver at a distance, this model could be used in Egypt to broadcast information to groups located at Berkeley and Ryerson University simultaneously. The concept proved to work with the student driving from the offices of the Computer Science Department at McGill University.

The advantages of a collaborative classroom were critical for the execution of real-time, remote teleoperation of the robot. The student who wished to drive her robot from Montreal, and her group members, had no experience building a robot that could be remotely controlled in real time at a distance. The multidisciplinary background of the students in the course was advantageous, as a digital media student in the HRI class had experience building real-time, screen-to-screen web applications. He had investigated and earlier presented a seminar using web technologies to control a robot in real time. The seminar used an HTML website to control a robot over a local network. Using the same technology, he hypothesized that it was possible to use a cloud-based network to control a robot. Since his group in Toronto was also participating in the final exam, it was determined that the Toronto group and the group driving from Montreal would utilize the same technology to pass information between the human and the robot. The

Toronto group would use a local network while the Montreal group would use a cloud-based network. This gave the two groups the ability to test the differences between the two scenarios and assess the benefits for the el-Hibeh problem.

For all students engaged in the remote operation of the robot, work over and above what was needed to participate in the final exam was required. One student's problem of not being able to attend the final exam required six students in two disciplines and educational levels to work with one another and collaborate to find a solution.

The HRI Challenge – The End User

Students were instructed to focus on the end user when creating their robots. For the BUSA Dig, the end user was considered as an archaeologist who does not necessarily have much experience with technology. The robot's interface would need to synthesize the data from the robot and present it to the user in a meaningful way. The interface would need to be informative, clean, and easy to use. The overall goal of the robot's design was to provide a high degree of situational awareness while reducing cognitive overload.

Situational awareness refers to how the operator perceives the environment through the robot. Using a robot to explore and map the tunnels requires the operator have a high situational awareness, and the robot will need to relay a large amount of data to the user. As such, it is important to beware of cognitive overload (Labonte, Boissy & Michaud 2010). Cognitive load is total amount of mental effort being used by the driver (Matheson et al., 2013). The longer a user operated the robot and the greater the amount of information provided to the user, the greater the cognitive load. An ideal solution is to provide a high level of situational awareness with a low cognitive load.

Factors That Affect a Novice User's Ability to Teleoperate a Robot

The end user needs to be able to use the robot to explore dark tunnels that are not accessible or safe for humans. Ideally, the robot needs to give archaeologists the ability to map looter tunnels and enable them to assess whether a tunnel is safe and/or worth future exploration. As students operated their robots in the final exam, they were able to appreciate the HRI challenges faced by the end user. The challenges they experienced were limited field of view (FOV), robot orientation, camera viewpoint, depth perception, degraded video image, and time delay (Chen, Haas, & Barnes, 2007).

Limited FOV

As soon as a robot is out of the line of sight of its operator, the most common solution is to use a camera to provide a visual feed. However, a camera does not accurately provide a 1:1 simulation of the human's first-hand perspective. Only a portion of the environment can be captured and presented to the operator. A robot needs to have a mechanism to manipulate a camera to provide additional views to increase situational awareness (Chen et al., 2007).

A restricted FOV affects remote perception in numerous ways. Ground robots are affected by something known as "cognitive tunneling" (Chen et al., 2007; Thomas & Wickens, 2000), where your brain fixates on what is in front of you, and you do not see the rest of the environment. Drivers have more difficulty judging the speed of the vehicle, time to collision, perception of objects, locations of obstacles, and the start of a sharp curve (Chen et al., 2007; Thomas & Wickens, 2000).

A potential solution is to use a camera with a wider FOV, which is especially useful where the driver has to navigate in unfamiliar terrain (Johnson, Rae, Mutlu, & Takayama, 2015). However, with increasing FOV, especially when using wide-angle cameras, the speed of travel tends to be perceived as increased because of the scene compression, and drivers need to travel more slowly to compensate (Chen et al., 2007). The result is an increased cognitive load.

Robot Orientation

To successfully navigate a remote environment, a robot operator needs to have an understanding of orientation. Globally, they need to be aware of areas of interest in relation to their robot's location. Locally, they need to navigate and avoid obstacles to reach a desired location. Navigation with a traditional (north-up) map can be challenging at times because of the need for mental rotation and increased cognitive load. Studies comparing human performance consistently show that track-up maps are better for local guidance (i.e., navigation) and north-up maps are better for global awareness. User interface design guidelines recommend making both north-up and track-up maps available (Chen et al., 2007, Tversky et al., 2006).

To successfully navigate locally, the operator also needs to be aware of the robot's attitude (pitch and roll) in order to avoid a roll-over. Attitude may be easy to determine when the operator has a clear understanding of the remote environment. However, studies of novice operators have shown their inability to determine the correct attitude of a robot (Kanduri, Thomas, Cabrol, Grin, & Anderson, 2005).

Camera Viewpoint (Context)

Multiple camera viewpoints are usually employed to enhance the driver's perception and identify objects. Keyes, Casey, Yanco, Maxwell, and Georgiev (2006) observed that an overhead view that includes the robot chassis significantly increases the operator's situation awareness. In addition, using two cameras, one forward-facing and one rear-facing, also resulted in improved situation awareness. However, research has shown that integrating information across views can be challenging for the operator as they inadvertently create a bias for one view over the other (Thomas & Wickens, 2000).

Degraded Depth Perception

The use of monocular cameras and the effects on a teleoperator's depth perception have been investigated in various contexts. Using a monocular camera results in compressed or "foreshortened" depth perception (Fig. 8). The compression is worse with a ground robot because of their low viewpoint (Chen et al., 2007). In unfamiliar or difficult terrain, depth perception is extremely challenging due to lack of apparent size cues.

Stereoscopic displays provide advantages over monocular displays, such as faster and more accurate perception of the remote scene, enhanced detection of slopes and depressions, enhanced object recognition and detection, visual noise filtering, faster learning, and faster task performance with fewer errors (Chen et al., 2007). Empirical studies examining the utility of stereoscopic displays, however, generally report that they are useful in only certain circumstances. Generally, participants in studies quickly learned how to use monocular cues with monocular displays to accomplish the same tasks as when using a stereoscopic view.

Degraded Video Image

Degradation of video feed to the teleoperator can affect spatial awareness. Common forms of video degradation include: reduced frame rate, reduced resolution of the display, and a lower grayscale. Due to bandwidth limitations, a video signal is often reduced in one or more of the three areas. Much research has been conducted to determine the lowest frame rate that does not affect spatial awareness. It has been shown that frame rates can be reduced as low as 8 fps before any noticeable effect is seen on the operator (Chen et al., 2007).

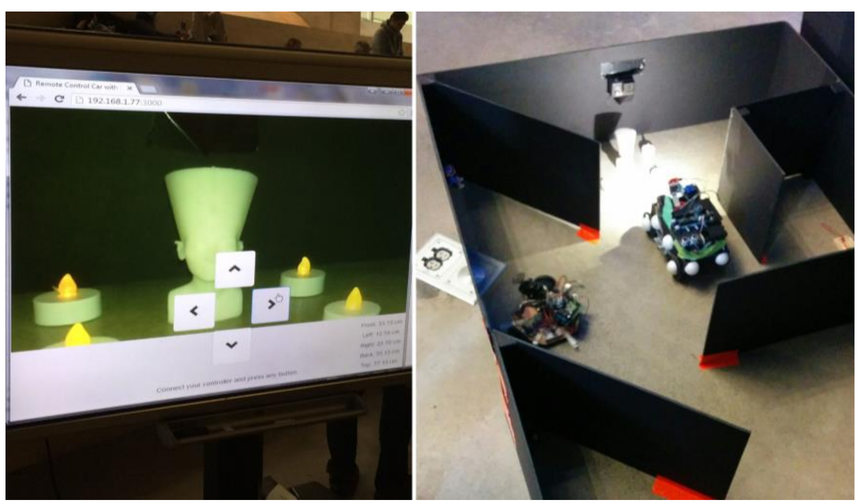


Figure 8. View from a robot's camera (left) and the position of the robot in the treasury room (right). Objects are "foreshortened" as a result of the compressed depth perception. © 2016 Jean Li. Used with permission.

Time Delay

Time delay, or latency, is the delay between an input action and an output response. Latency is usually caused by the transmission of information across a network. When a system latency is over 1 s, the operators begin to switch their control strategy to “move and wait,” instead of continuously commanding and trying to compensate for the delay (Chen et al., 2007). It has been suggested that any high-latency teleoperation robot use predictive displays to assist with driving (Matheson et al., 2013). A predictive display gives the user immediate response to input by simulating how an image would show in a simulated response (Berntsen, 2012).

Results

The results of the BUSA Dig were impressive. All groups that participated in the exam were able to successfully lower, detach, explore, map, reattach, and raise their robots from the site. Each group’s robot appeared significantly different from the others’. The differences extended to the programming languages used to control and interface with the robot, the design of the robot, and the mechanisms used to attach and detach from the tether. The robots were the result of students learning how to problem solve and create robots that responded to a specific challenge. Each group strategically used the expertise of their group members to program their robot. This was evident from the differing communications protocols and programming languages used in the designs. Within the six groups, there was a wide spectrum of solutions used. In many cases, the parts used to construct a solution were similar—however, how the parts were used differed greatly. For example, the majority of groups used a servomotor to control a grapple hook to attach and detach from the tether. Each of these solutions was entirely different with respect to the materials used for the grapple hook and how it would attach and detach from the tether. Some groups fashioned a hook from used coat hangers, where others used a rock climbing carabiner. In all cases, whatever the material, groups used found objects from everyday life and transformed them into useable parts for their robots. Having students build their own robots required them to not only design and understand HRI, but to also understand the mechanical application of the sensor within the functionality of the robot.

Using a real world problem for an academic final exam was a success. The multidisciplinary groups of students were able to work together and create potential solutions for archaeologists to use at the el-Hibeh site. The level of engagement from students was high, such that students were willing to assist one another with more complex programming to help their peers.

The six robots created for the final exam (Fig. 9) were unique proto-solutions to the el-Hibeh problem. Knowledge gained from using these robots may be applied to any future work on the el-Hibeh problem. Table 1 lists the robots and the various parts used to construct them.

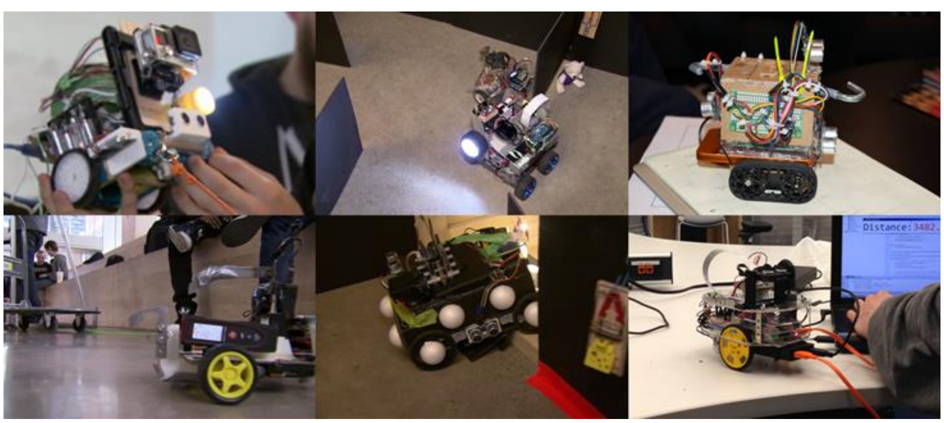


Figure 9. The robots created by students for the BUSA Dig. Talos (top left), Tesla Model M (top middle), Thor (top right), Zippy 4.0 (bottom right), Osiris (bottom middle), and Hathor (left bottom). © 2016 Rob Blain and Alex Ferworn. Used with permission.

Table 1. Robots created for the BUSA Dig

	Osiris	Talos	Tesla Mini M	Zippy 4.0	Thor	Hathor
Platform	Raspberry Pi 2 Model B	Raspberry Pi 2 Model B	Arduino with Motor Shield	Raspberry Pi 3	Raspberry Pi 3	Arduino with Motor Shield
Programming Language	Nodejs	Nodejs	C/C++	Python	Python	C/C++
Communications Protocol	Wi-Fi	Wi-Fi	Wi-Fi + Zigbee Radio	Wi-Fi	Wi-Fi	Bluetooth & Wi-Fi
Robot Interface	HTML Webpage	HTML Webpage	Processing	Remote SSH Connection	Remote SSH Connection	Wiimote
Video Feed	Pi Cam via http with 180-degree tilt	iPhone 5s cam streamed via facetime and GoPro stream via App	Xiaomi Yi Webcam stream on App with 180-degree tilt	Pi Cam streamed via http with 180-degree tilt	Pi Cam streamed via http with 180-degree tilt	GoPro stream via App
Chassis/Body	Foamcore	Metal	Metal	Aluminum	Acrylic	MDF board
Wheels / Tread	4 Wheels / 4 Motors	2 Wheels with castor	4 Wheels / 4 Motors	2 wheels with castor	Two tank treads / 2 Motors	2 Wheels with castor
Distance Measurement	5 Ultrasonic Sensors – Front, back, left, right & top	3 Ultrasonic Sensors – Front, right & top	3 Ultrasonic Sensors – Front, back, & top	1 Ultrasonic Sensor mounted on a swivel	3 Ultrasonic Sensors – Front, back, & top	Laser distance measurer
Attach / Detach Mechanism	Servo Controlled Grappling Hook with electromagnet	Servo Controlled Grappling Hook	Servo Controlled Grappling Hook	Electro-Magnetic Coupling	Servo Controlled Grappling Hook	Servo Controlled Grappling Hook
Light	LED light integrated within robot; ability to turn off and on through web interface	Flashlight attached to robot; permanently on.	LED light attached to robot; permanently on.	LED light integrated within robot; ability to turn off and on through ssh interface	LED light integrated within robot; ability to turn off and on through ssh interface	LED light attached to robot; permanently on.
Interface	Integrated user interface. All sensors / components viewed through web interface	Robot controls and distance viewed through web interface. Camera feed separate.	Robot controls and distance viewed through processing interface. Camera feed separate.	Robot controls and distance viewed through ssh connection.	Robot controls and distance viewed through ssh connection.	Robots controls through Wiimote. Camera feed separate.
Additional Notes	Robot body had small Styrofoam balls used to protect the body from damage	Robot was driven remotely from Montreal		Used a very strong electromagnet: the most successful attach / detach mechanism	Group had latency issues of up to 8-10 seconds when they first tested; had to reduce the data transmission	

Having students work in interdisciplinary groups was a highly effective strategy. This methodology unexpectedly resulted in the creation of a web-based network to relay data between a robot and human in real time. A web-based interface makes access to data from the robot easy to achieve for multiple users and is a practical application of HRI knowledge.

All students that took Dr. Ferworn's CPS813/DG8010 Human Robot Interaction course were able to meet the learning outcomes for the course. Assessing knowledge through increasingly complex labs and a final exam, all involving robots and users, was a successful model to disseminate knowledge. The hands-on and iterative design-based approach used to create robots was also a favorable method. Students were able to understand how simply changing the position or angle of a sensor could affect the overall operation of the robot. A robot kit with pre-fabricated parts and sensors in fixed positions would not have given the students the same opportunity or freedom to explore and understand the relationship between sensors, code, and the relationship between the robot and human.

Discussion

The significance of the BUSA Dig is that it shows that a multidisciplinary group of HRI students can provide solutions to a real-world problem using principles learned in a course. The solutions can be seen as a first step for archaeologists and roboticists to address the el-Hibeh problem.

The next stage in solving the el-Hibeh problem is to create a test site that accurately depicts disturbed archaeological contexts and build more robust robots. Most notably, creating a tunnel or pit involving sand and debris will present the robot-human teams with a new challenge when trying to traverse the site (Georgia Institute of Technology, 2009). In addition, it will be important to incorporate a team of archaeologists to determine the level of detail and quality of measurements needed to map and explore the tunnels.

A further challenge is sustainability; that is, how to continue to solve the el-Hibeh problem with future students. The HRI course at Ryerson does not have any subsequent courses. Without proper documentation, the majority of the work created by current students will not be readily accessible or available. The knowledge level of students entering the HRI course is not sufficient to begin work without the knowledge from previous students. To mitigate this problem somewhat, each group provided extensive video documentation of their lab work and some of the examination.

Lastly, budget may be the determining factor for any future work. To build a suitable test site and a robust robot would require time and effort from all parties involved to secure funding. This could be potentially linked to a grant or institutional funding availability.

The BUSA Dig illustrates the value of applying HRI methodology to a non-HRI problem. Engaging students to apply HRI to non-traditional disciplines is encouraging for the future of teaching HRI. The mixed classroom forced students to work together, and as a result, six unique solutions to the problem were created. The CPS813/DG8010 model has shown that HRI can address problems where robotics would not traditionally be considered as a solution. For members of the HRI community, a key takeaway is to discover the problems and challenges of their peers and see how HRI could lead to a potential solution.

References

Alimisis, D. (2013). Educational robotics: Open questions and new challenges. *Themes in Science and Technology Education*, *6*(1), 63-71.

Berntsen, E. (2012). Development of a predictive display interface to assist control of a robot arm in a telepresence system. (Master's thesis, Norwegian University of Science and Technology, Trondheim, Norway). Retrieved from http://hdl.handle.net/11250/260620

Berry, C. A. (2015). Teaching a first course in human-robot interaction. In *Proceedings of the 2015 ASEE Annual Conference and Exposition, Seattle, Washington, 2015, June*. Retrieved from https://peer.asee.org/24799

Chen, J. Y. C., Haas, E. C., & Barnes, M. J. (2007). Human performance issues and user interface design for teleoperated robots. *IEEE Transactions on Systems, Man, and Cybernetics, Part C: Applications and Reviews, 37(6),* 1231-1245. doi:10.1109/TSMCC.2007.905819

Georgia Institute of Technology. (2009). "Why robots get stuck in the sand—And how to keep them going." *ScienceDaily, 10*. Retrieved from http://www.sciencedaily.com/releases/2009/02/090209205058.htm

Goodrich, M. A., & Schultz, A. C. (2007). Human-robot interaction: A survey. *Foundations and Trends in Human-Computer Interaction*, *1*(3), 203-275.

Johnson, S., Rae, I., Mutlu, B., & Takayama, L. (2015, April). Can you see me now?: How field of view affects collaboration in robotic telepresence. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (pp. 2397-2406). ACM. doi:10.1145/2702123.2702526

Jones, J. L., & Flynn, A. M. (1999). 2. TuteBot. In *Mobile robots: Inspiration to implementation*. (2nd ed., pp. 13-42). Natick, MA: AK Peters, Ltd.

Kanduri, A. K., Thomas, G., Cabrol, N., Grin, E., & Anderson, R. C. (2005). The (in)accuracy of novice rover operators' perception of obstacle height from monoscopic images. *IEEE Transactions on Systems, Man, and Cybernetics-Part A: Systems and Humans*, *35*(4), 505-512.

Keyes, B., Casey, R., Yanco, H. A., Maxwell, B. A., & Georgiev, Y. (2006, August). Camera placement and multi-camera fusion for remote robot operation. In *Proceedings of the IEEE International Workshop on Safety, Security and Rescue Robotics* (pp. 22-24). Gaithersburg, MD: National Institute of Standards and Technology.

Kokosy, A., Micea, M. V., & Saey, P. (2014, October). A professional project-based learning method in mobile robotics. In *Proceedings of the Frontiers in Education Conference (FIE), 2014 IEEE* (pp. 1-7). IEEE. doi:10.1109/FIE.2014.7044409

Labonte, D., Boissy, P., & Michaud, F. (2010). Comparative analysis of 3-D robot teleoperation interfaces with novice users. *IEEE Transactions on Systems, Man, and Cybernetics, Part B (Cybernetics)*, *40*(5), 1331-1342.

Matheson, A., Donmez, B., Rehmatullah, F., Jasiobedzki, P., Ng, H. K., Panwar, V., & Li, M. (2013, September). The effects of predictive displays on performance in driving tasks with multi-second latency aiding tele-operation of lunar rovers. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* (Vol. 57, No. 1, pp. 21-25). Sage CA: Los Angeles, CA: SAGE Publications.

Murphy, R. R., Nomura, T., Billard, A., & Burke, J. L. (2010). Human–robot interaction. *Robotics & Automation Magazine, IEEE*, *17*(2), 85-89.

Norman, D. A. (2013). *The design of everyday things: Revised and expanded edition*. New York: Basic books.

Redmount, C. (2014). El-Hibeh: a plundered site. *Egyptian Archaeology 45(Autumn 2014), 13-17.*

Riek, L. D. (2013). Embodied computation: An active-learning approach to mobile robotics education. *IEEE Transactions on Education*, *56*(1), 67-72.

Ruzzenente, M., Koo, M., Nielsen, K., Grespan, L., & Fiorini, P. (2012, April). A review of robotics kits for tertiary education. In *Proceedings of the International Workshop Teaching Robotics Teaching with Robotics: Integrating Robotics in School Curriculum* (pp. 153-162). Riva del Garda, Italy.

Ryerson University. (2016, May). Cross-disciplinary project could advance archeology research. *Office of the Vice-President Research & Innovation*, 16 May 2016. Retrieved from http://www.ryerson.ca/research/media/archive/2016/0516.html?platform=hootsuite

Sheridan, T. B. (2016). Human-robot interaction status and challenges. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *58*(4), 525-532.

Thomas, L. C., & Wickens, C. D. (2000). *Effects of display frames of reference on spatial judgments and change detection* (No. ARL-00-14/FED-LAB-00-4). Illinois University at Urbana-Champaign, Savoy IL: Aviation Research Lab.

Tur, J. M. M., & Pfeiffer, C. F. (2006). Mobile robot design in education. *Robotics & Automation Magazine, IEEE*, *13*(1), 69-75.

Tversky, B., Agrawala, M., Heiser, J., Lee, P., Hanrahan, P., Phan, D., & Daniel, M. P. (2006). Cognitive design principles for automated generation of visualizations. In *Allen G, editor. Applied Spatial Cognition: From Research to Cognitive Technology*, 53-75. Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Wenke, R. (1984). *Archaeological Investigations at el-Hibeh 1980: Preliminary Report.* Malibu, Undena: American Research Center in Egypt Reports 9.

Rob Blain, Master of Digital Media, Ryerson University, Toronto, Canada. Email: rblain@ryerson.ca; Alex Ferworn, Department of Computer Science, Ryerson University, Toronto, Canada. Email: aferworn@ryerson.ca; Jean Li, Department of History, Ryerson University, Toronto, Canada. Email: jeanli@history.ryerson.ca; Jimmy Tran, Department of Computer Science, Ryerson University, Toronto, Canada. Email: q2tran@scs.ryerson.ca; Michael Carter, Master of Digital Media, Ryerson University, Toronto, Canada. Email: wmcarter@ryerson.ca.

Appendices

Appendix A – CPS813/DG8010–Human Robot Interaction (HRI) Syllabus

Instructor: Dr. Alex Ferworn
Professor, Department of Computer Science, Ryerson University
[Original syllabus includes address, telephone number, and e-mail address]

Graduate Teaching Assistant: Jimmy Tran
PhD Candidate, Department of Computer Science, Ryerson University
[Original syllabus includes address, telephone number, and e-mail address]

Course materials:

Lecture: 1 hour/week
Labs: 2 hours/week
Course Website: http://www.scs.ryerson.ca/~aferworn/courses/CPS813/INDEX.HTML
Course Media: Readings and other media will be provided

General Course Information

Pre- or Co-requisites: None (Graduate), CPS607 (undergraduate) or permission of the instructor
Credit Hours Earned: 1 credit

Learning Outcomes:

After successfully completing this course, students will be able to: explain HRI principles, paradigms, and metrics; construct appropriate robots that can survive and function in a defined environment; and employ mobile and tele-operated robots to solve problems.

Evaluation Outcomes:

Item:	Value	Due Date
Midterm Test (Take Home, 1 Week to Complete) *To be completed by undergraduate students*	30%	March 8
Literature Review (10 pages minimum with proper citations) *To be completed by graduate students*	30%	April 15
Lab 1 – Autonomous Surface Exploration	10%	February 11
Lab 2 – Teleoperation of Robot Through Labyrinth	15%	March 3
Lab 3 – Wireless Robot Soccer	15%	March 24
Final Exercise – The BUSA Dig	30%	Exam Week

Assignments and Labs:

Late assignments, tests, and labs will not be accepted for marking. Labs and assignments must be submitted in the format detailed on the course website. If they are submitted in any other fashion, they will not be marked. Labs will be marked by a TA. All labs and the final exercise must be completed in teams of three. All teams will include at least one graduate student. You will not be allowed to work alone. A team will share marks for each of the labs. You may form your own teams. If you wish to change teams, you must receive instructor permission. All labs are performance based. This means that the team will be expected to present a robot and demonstrate that does what is required when the lab is due.
YOU WILL HAVE TO WORK OUTSIDE OF THE LAB TO CREATE A ROBOT IN ORDER TO COMPLETE THE ASSIGNED TASK IN THE LAB PERIOD USING THE ROBOT.

Selected Topics:

- Human Robot Interaction Introduction, Taxonomy, Agency, Delegation. A discussion of different models of robot interaction and control with humans and with each other.
- Introduction to Mobile Robotic Systems.
- Implementation 1: Building. A review of building techniques and introduction to rapid prototyping.
- Implementation 2: Computing and networking for robots. The fundamentals of getting a camera-equipped, networked, interaction-enabled computing device ready to use.
- Basic Robotic Interfaces. Standard interface components, video, audio, telemetry, and control metaphors.
- Alternative Robotic Interfaces.
- Presence and Telepresence. We will examine the notion of being "present" through the feed from a robot.
- Projecting Persona. Making your presence felt at a distance and how you influence what is at a distance through a robot.
- Sensing and manipulating the robot's environment.

Tentative Course Calendar

Date	Topic
Week 1	Introduction to Human Robot Interaction (HRI)
Week 2	A Taxonomy for Human-Robot Interaction
Week 3	Robotics Interfaces
Week 4	Telepresence, Presence, and Situational Awareness
Week 5	Archaeology and HRI (Prof. Jean Li)
Week 6	Space Robotics on the International Space Station (Prof. Elliot Coleshill)
Week 7	Spring Break (No Class)
Week 8	Urban Search and Rescue Robotics
Week 9	Assistive Robotics
Week 10	Mobility
Week 11	Data Transfer
Week 12	HRI Special Topic: Medical Robots
Week 13	Robotic Augmentation of Biology
Week 14	Review

Appendix B – CPS813 (Undergraduate) Take-Home Test

Instructions:

- This is a take-home test and is due at the start of class on the 8th of March.
- The work must be accomplished individually.
- You may not write any more than 2 pages, including diagram(s).
- You must hand in (physically) this test paper as a cover sheet that has the information above filled in.
- Your work should be typed (no incomprehensible handwriting), checked for spelling and grammar, and written in a 12 pt font.
- Cite any sources of information you use using in APA formatting style.
- The test will be marked out of 10 (+1 bonus). Simpler realistic systems are preferred.

There exists a hole at the top of a rock hill. The dimensions of the hole are such that the hole is large enough for a human to crawl through, but this cannot be done because the hole is considered unsafe. It has been determined that

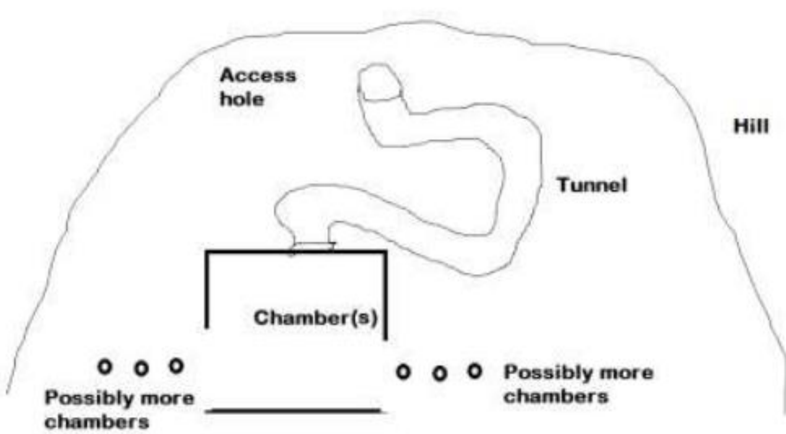
the hole leads into a tunnel that goes into an archaeological site consisting of at least one chamber. Several attempts have been made to lower cameras into the hole, but it became apparent that the underlying tunnel is too curved to make progress.
Attempts to use wireless cameras failed due to signal loss.

You are asked to describe a robotic system in sufficient detail, so that you can build it to be used for the following:

1. Move through the hole and tunnel until the chamber can be entered.
2. Determine the number of chambers.
3. Provide enough information to create a dimensionally accurate floor plan.
4. Provide information concerning the contents of the chamber(s).
5. Determine ceiling heights.

Discuss your proposed system in terms of what it would look like, its parts, how it would be controlled and behave, what it can sense, and how that data can be provided to human operator(s). It is not considered necessary to retrieve the robot, but a bonus of 1 mark will be provided if a plausible means of retrieval can be described.

Example: http://motherboard.vice.com/read/indiana-robot



Appendix C – DG8010 (Graduate) Literature Review

Instructions:

- This work is due no later than noon on April 15th, 2016.
- This work will be marked out of 10.
- The work must be accomplished individually.
- The literature review consists of at least 8 pages but no more than ten 8.5” x 11” pages of edited, double-spaced text in 12 point Times-Roman font.
- The review shall be conducted on peer-reviewed material from the literature using clear and consistent citations (see librarian for this or look it up).
- Resource for writing literature reviews in this course:
    - Randolph, Justus (2009). A guide to writing the dissertation literature review. *Practical Assessment, Research & Evaluation, 14*(13).
- Resources can be obtained from the course website and various locations around web.

What is the history, current state, and future prospects for human-robot interaction in the selected application area?

Application Areas (choose 1)

- Explosive disposal unit (EDU)/Chemical, biological, radiological, nuclear explosive (CBRN)
- Space robotics
- Archaeology robotics
- Urban search and rescue (USAR) robotics
- Social interaction robotics
- Health care robotics
- Exploratory robotics
- Entertainment robotics
- Assistive robotic
- Augmentation of biological systems through robotic technology
- Other (permission required from Prof. Ferworn)

Appendix D – CPS813/DG8010 Lab 1 – Autonomous Survival in a Hostile Environment

The Environment:

There exists a lethal environment consisting of a flat but irregularly shaped surface. The surface exists surrounded by an infinite void of certain destruction for anything that falls into it. The surface is devoid of obstacles except for the sheer precipices leading to the void. Additionally, the environment is governed by a single rule: Anything on the surface must be in significant motion at all times.

Requirements:

Each group is required to collaborate to create an autonomous robot that can survive in the environment for not less than 2 minutes. The robot cannot employ any form of digital electronics or prefabricated controller boards. Using analog electronics is fine (parts and instructions available from the computer science office for a nominal fee). The robots other components are not to exceed $15 in value. The robot may have as many "found" parts as necessary.

Scoring:

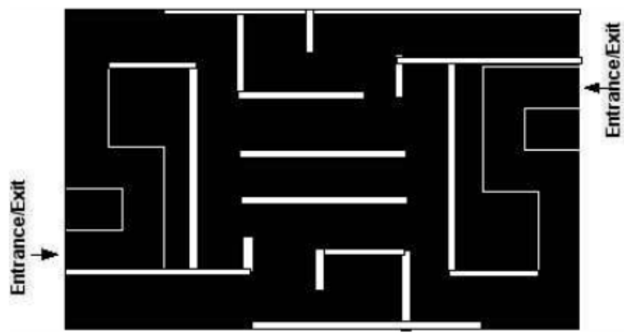
The lab will be marked out of 10. Marks will be allocated as follows:

- 1mark: 8.5 in x 11 in printed sheet with the title "CPS813/DG8010 Lab 1"; the sheet will indicate the name and student numbers of each member of the group and the name of your robot.
- 1 mark: Submit a video no longer than 30 seconds sent to the course TA with file name "`CPS818DG8010Lab1P1<robotname>.mov`", where `<robotname>` is the name of your robot. The video will clearly show each member of your group and your robot. Each member of the group will state their name, and someone will state the name of your robot. You must indicate at least 1 feature of the robot that you find interesting.
- 1 mark: Submit a video file named "`CPS818DG8010Lab1P2<robotname>.mov`" no longer than 2 minutes showing the performance of your robot in the environment.
- 7 marks: the robot will successfully exist for the requisite amount of time in the environment.

Appendix E – CPS813/DG8010 Lab 2 – Labyrinth Situational Awareness

The Environment:

A labyrinth is an intricate structure of interconnecting passages through which it is difficult to find one's way.



Requirements:

Each group is to build a teleoperated mobile robot capable of driving between lines and negotiating fixed hallways in a labyrinth similar to the one depicted in the diagram above. In the diagram, thin lines represent white tape on a black surface. Thick lines represent walls. Exits/entrances are shown.
Robots must traverse the labyrinth three times under different circumstances:

1. Labyrinth visible by another group member through a video feed. Instructions sent through a two-way radio to a driver who cannot see the labyrinth.
2. Labyrinth visible to a driver through a video feed provided by an unmanned aerial vehicle (UAV/drone) hovering over the labyrinth. UAV is controlled by another group member,
3. Surface seen in mirror view by driver and group.

Scoring:

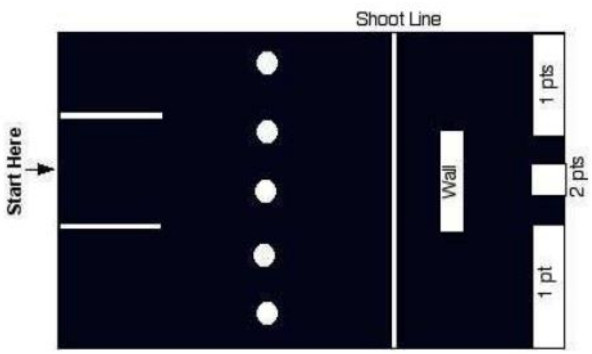
The lab will be marked out of 10. Marks will be allocated as follows:

- 1mark: 8.5 in x 11 in printed sheet with the title "CPS813/DG8010 Lab 2"; the sheet will indicate the name and student numbers of each group member and the name of your robot.
- 1 mark: Submit a video no longer than 30 seconds sent to the course TA with file name, "`CPS818DG8010Lab2P1<robotname>.mov`", where `<robotname>` is the name of your robot. The video will clearly show each member of your group and your robot. Each member of the group will state their name, and someone will state the name of your robot. You must indicate at least 1 feature of the robot that you find interesting.
- 1 mark: Submit a video file named "`CPS818DG8010Lab2P2<robotname>.mov`" no longer than 2 minutes showing the performance of your robot in the environment.
- 7 marks: 2 marks per task with 1 mark awarded at the discretion of the TA.

Appendix F – CPS813/DG8010 Lab 3 – Learning About Manipulation, Interaction and Time

The Environment and Concepts:

There exists a "pitch" facilitating "rounds" of soccer between two wirelessly controlled robots. One robot is the "kicker," the other is the "goalie." Each robot must have a human operator.



Pitch
The soccer "pitch" or field is shown to the right. There are 5 round dots that represent balls that are temporarily affixed to the surface until they are retrieved by a kicker.

Rounds
Points can be scored when a round has started. Each round is 3 minutes long.

Kicker
Points are scored by a kicker when a ball is caused to move into a scoring area (points awarded as shown). The kicker must stay on the left of the pitch and cannot cross the "shoot line."

Goalie
A goalie starts out with 10 points. Points are deducted based on the amount of points earned by the kicker for a shot (-1 or -2). However, if the goalie is successful in stopping all balls, 2 additional points will be awarded. If the goalie fails to stop all balls, a penalty of -2 points will be applied.
The goalie must stay on the right side of the pitch and cannot cross the shoot line.

Operator
The operator operates a robot using its human interface. The operator cannot see the pitch directly.

Required:

Each robot must complete each of the three rounds described below (in any order).

1. Kicker round—A kicker robot is alone on the pitch and must score as many points as possible (max 10 points).
2. Kicker Meet Goalie round--A kicker robot is on the pitch with a goalie robot facing it. (max 10 points).
3. Goalie Meet Kicker round--A goalie robot is on the pitch with a kicker robot facing it (max 10 + 2 points).

Scoring:

The lab will be marked out of 10. Marks will be allocated as follows:

- 0.5 marks: 8.5 in x 11 in printed sheet with the title "CPS813/DG8010 Lab 3"; the sheet will indicate the name and student numbers of each member of the group and the name of your robot.
- 0.5 marks: Submit a video no longer than 2 minutes showing the performance of your robot performing in the 3 rounds.
- 9 marks: Performance with scaling points to fit available marks.

Appendix G – CPS813/DG8010 Final Exercise – The BUSA Dig

Mission:

CPS813/DG8010 teams will provide robotic archaeological exploration services within the BUSA Dig to determine the general layout of the chamber system, the locations of significant artefacts, and booby traps.

Execution:

Operations will be conducted in the Atrium of Ryerson University's Student Learning Centre (SLC, 341 Yonge Street, Toronto, Canada) on April 26, 2016 starting at 1500 and shall be complete no later than 1800 (all times local). (The chamber is currently in the Digital Media Experience space of the SLC undergoing preparations).

Teams will deploy robots equipped with appropriate sensors, controls, and actuators. Campus planning has provided a block and tackle system that will enable teams to lower and raise their robots into and out of the access tunnel via a rope.

Human members of the team will control individual robots that will make their way through the tunnel into a chamber and move through the chamber(s) providing data, so that human members of the team can produce an accurate map detailing the salient data required by the mission.

Robots will be extracted not less than 15 minutes after insertion begins. Robots need not be functional on extraction.

Scoring:

At the end of the session, each team must submit a structural map indicating the configurations and approximate dimensions of the chamber(s) with indications of objects of interest. (You must find as many as you can and avoid the dangerous ones.) The lab will be marked out of 30 to be allocated as follows:

- Robot insertion (5 marks)
- Robot extraction (5 marks)
- Structural map (10 marks)
- Point of interests (10 marks)
- If the robot requires manual extraction at any point either due to malfunction or is dealt with harshly by a "booby trap," the timer does will not pause (-5 marks/extraction)
- Damages to the environment (-2 to 20 marks at marker's discretion)
- Overtime penalty (-2 marks/minute -max 5 minutes)