TEACHING A FIRST COURSE IN HUMAN-ROBOT INTERACTION

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Abstract

This paper will present the details of the design and implementation of an introductory course in human-robot interaction (HRI) for graduate and undergraduate students from various disciplines. Human-Robot Interaction is a multidisciplinary field that focuses on identifying methods for robots to successfully interact with humans. This field of study involves the understanding, design, and evaluation of robotics systems to be used by or with humans [1].

The author will summarize the key elements of a first course in Human-Robot Interaction with a survey of the most relevant areas in the field. The first step involved determining what topics to emphasize as well as how to meet the learning objectives. This course was created to have a special emphasis on HRI design as it applies to mobile robotics. The presentation will provide the learning objectives as well as the details of the assignments necessary to meet those objectives. These assignments included weekly readings, quizzes, labs and projects. A big part of this course involved the implementation of the HRI concepts on an actual robot platform. The labs included creating a robot dancer, music machine, touch free robot racer, robot conga line, robot remote control, and Braitenberg vehicles. The first phase of the final project involved the creation of an urban search and rescue scenario. The second phase of the final project involved the students implementing one of the HRI concepts presented during the semester on their robot. One interesting note about this course is that it was taught to undergraduate students from non-technical fields. Therefore, it was necessary to teach them about the technical aspects of robotics and programming while they also learned HRI.

Introduction

Human-Robot Interaction (HRI) is a relatively new branch of robotics research and application. It involves the understanding, design and evaluation of robotics systems that will interact with humans [1]. It has been an established multidisciplinary research field since the early 2000s. One key benefit of this field is the multidisciplinary nature which includes concepts from robotics, artificial intelligence, engineering, computer science, cognitive science, cybernetics, human factors, natural language, psychology, sociology, interaction design, and human-computer interaction. There are several attributes of HRI including level of autonomy, nature of information exchange, team structure, learning, and type of task [1]. Some of the key problem domains are search and rescue, assistive robotics, educational robotics, entertainment, military, and space exploration. Due to the broad spectrum of application for HRI, it is necessary for students introduced to HRI to understand it in this broader context[1].

One primary goal of HRI is to develop principles to allow for natural and effective communication between humans and robots. HRI is a relatively new field established around 2001 as a natural offshoot of hybrid control. Since HRI is a multidisciplinary field it involves elements of robotics, artificial intelligence, psychology, human-computer interaction, human factors, interaction design, education, cognitive science, computer science, engineering, psychology, sociology and several others. There are several branches of HRI including interfaces, interaction design, metrics, autonomy, perception, urban search and rescue, museum, situation awareness, emotional intelligence, dialog, embodiment, supervisory control, assistive, social robotics, telepresence and teamwork. Due to the broad range of content in this field as well as the dearth of textbooks and standardized curricula, it is sometimes difficult to design a course appropriate for a diverse audience [2].

Murphy et al. states that the course objectives in an HRI course should include a definition of HRI, modes of interaction, key issues in HRI, current applications, and social robotics. In addition, projects such as search and rescue would be engaging to students because they also represent a benefit to society. This course should include a high level of interaction between the students, faculty as well as the robots. This would require team assignments as well as hands on labs, projects, and discussions. Some topics in the course would include humanoids, emotion, teaming, ethics, machine learning, natural language processing, robot control, safety, user interfaces, user-centered design, social behaviors, the Uncanny Valley, and HRI metrics. Murphy et al. states that one challenge in creating such a course is identifying a cost-effective robot and case studies to illustrate these key principles of HRI [2].

The HRI Young Researcher Workshop was part of the inaugural ACM/IEEE Conference on Human-Robot Interaction (HRI'06) [3]. This workshop provided a means for young HRI researchers to present their current research and provide students with the opportunity to present what they feel are challenges to a career in HRI. This allowed for the formation of collaborative relationships across disciplines and geographic boundaries [3]. The most important and relevant topics were breakout sessions and included application, users, education, and future research directions. Part of the education breakout sessions addressed the appropriate academic background or experiences and also how to structure HRI education in the future. There was a consensus that a variety of academic backgrounds or disciplines are necessary for a successful team in HRI research. It was also integral that there was a common language so that these various disciplines could communicate and collaborate. One of the challenges to education is the ability of technical and non-technical students to take coursework in other disciplines to educate themselves on other relevant aspects of HRI. The course designed by the author attempts to address some of these challenges. The lectures and labs focused more on the concepts than the technical aspects of the field and were related to the topics of robot entertainment, interaction design, teaming, supervisory or shared control, urban search and rescue, animal-like behavior, interface design and obstacle avoidance.

This paper will present the details of the design, implementation, and results of an introductory course in HRI for graduate and undergraduate students from various disciplines. Since the field is so new, there are no standard textbooks, objectives, or assignments but there will be a review of some of the course offerings at other universities that were used as a reference in the design of this one. There will also be details about the format, learning objectives, and assignments for this course. Finally, the results of the first offering of this course will be presented as well as conclusions drawn based upon it.

Reference Courses

In order to identify any HRI reference courses to aid in the design, an internet search was performed and the most relevant results are presented here. This section will summarize the audience, objectives, format, assignments, and hardware platform, if any. There was an HRI course in the School of Informatics and Computing at Indiana University that was for senior undergraduate and graduate level students [4]. It is a survey course that covers the basic topics and methods in HRI with a focus on application in real-world contexts such as health, rehabilitation, domestic service, urban search and rescue, entertainment and companionship. The objectives were that the student will learn about the theoretical perspectives on interaction, design and application for robots. The students also became familiar with human-centered methods for designing and evaluating human-robot systems. Finally, the students gained practical skills to create a human-robot interaction project and present it to an interdisciplinary audience. The assignments included course reading responses, film review, class participation, and a final project. All assignments were part of a learning community with individual and team projects. There was no standard hardware platform although students may use a microcontroller for the projects.

At Georgia Tech, there was a graduate course in computer science on Human-Robot Interaction [5]. The course focused on students interested in HRI research and students must have a background in AI, robotics, or HCI. This course covered topics related to social intelligence including human intelligence, and building computational systems with social ability. The assignments included reading responses, lab assignments, and a final project. The lecture topics included social learning, measuring HRI, social robots, intention, human-compatible perception, emotion and empathy, and collaboration and teamwork. The hardware platform for the final project varied.

At the University of Massachusetts – Lowell, there was a HRI course that focused on interaction based upon the robot's shape, location, and capabilities [6]. The course focused on design principles from HCI, design studies, collecting and analyzing data. The course used case studies and readings on HRI. The assignments included reading discussions, labs, and projects. The lecture topics included robot morphologies, situation awareness, autonomy and trust, interaction types, metrics, human subject protocol and IRB, teams, and social robotics. The final project involved designing an interface for a real robot.

In the graduate school for engineering and applied sciences at Johns Hopkins University, there was a Human-Robot Interaction course for graduate students with pre-requisite skills in linear algebra, MATLAB, Simulink, and Digital Signal Processing [7]. This course focused on an investigation on human-robot interaction and prosthetic control. There was a specific focus on advanced man-machine interface including neural signal processing, electromyography, and motion tracking interfaces for controlling and receiving feedback from robotic devices. There was an exploration of human physiology and anatomy, signal processing, intent determination, communications between the human and the device. The labs were completed by using the Virtual Integration Environment (VIE) and with robotic devices. All of the programming was completed in MATLAB and Simulink. The goal was to master fundamental mathematical techniques for modeling and control of robots based upon human control signals. The objectives included writing robot control algorithms, measuring control signals based upon physiological variables such as EMG, ECG, joint angle, and programming the virtual integration environment to simulate robot actions. The assignments included homework, exams, projects, labs, and participation. The lectures included robot introduction and anatomy, system integration, physiology, human actuation, robot actuation, EMG processing and classification, haptics and VIE.

The final course reviewed was at Carnegie Mellon University, Principles of Human-Robot Interaction, for graduate students conducting HRI research [8]. The course is part of The Robotics Institute and taught by a computer science professor. The pre-requisites were a mastery of computer programming languages, as well as an understanding of research methodologies. The lab assignments were team-based, and there were also reading assignments and semester-long projects. The focus of the course was on integrating the concepts from multiple fields to have more natural and rewarding interactions with humans through multiple functionalities. The course included reading, discussions, team exercises, problem-solving sessions and a team project. The lectures covered topics such as social robotics, multi-modal human-robot communication, HRI architectures, sensors and perception, museum robots, educational robots, urban search and rescue, and quality of life technologies.

The most evident conclusion from the course research is that the courses including the objectives, assignments, and hardware were as varied as the field itself. Based upon the content and prerequisites, most of the courses were for graduate students with some type of technical background. One prevailing question would be, is there a way to standardize the curriculum, format, and assignments in an introductory HRI course? In particular, how should the course be offered for students with diverse skill sets and backgrounds?

Methods/Course Design

This course was created to have a special emphasis on HRI design as it applies to mobile robotics. This presentation will summarize the course format, learning objectives as well as the details of the assignments necessary to meet those objectives. These assignments included weekly readings, discussions, quizzes, labs and projects. A big part of this course involved the implementation of the HRI concepts on an actual robot platform. The Arduino robot was selected due to the large online community and access to sample code to help students get started on assignments [9]. The labs included creating a robot dancer, music machine, touch free robot racer, robot conga line, Braitenberg vehicles, and robot remote control. The first phase of the final project involved the creation of an urban search and rescue scenario. The second phase of the final project involved the students implementing one of the HRI concepts presented during the semester on their robot. One interesting note about this course was that it was taught to undergraduate students from non-technical fields. Therefore, it was necessary to teach them about the technical aspects of robotics and programming while they also learned HRI. Some resources that enabled the author to achieve this goal was the use of online content as well as videos [10,11].

Course Format

The Human-Robot Interaction Design course was 3 credits and included a lecture and a lab. It was taught in the Indiana University Purdue University Indianapolis School of Informatics and Computing to undergraduates in Computer Science and Media Arts and Sciences. The course was taught by the author while on sabbatical from Rose-Hulman Institute of Technology. IUPUI is a large state school in an urban setting with a diverse student population. Rose-Hulman is a small primarily undergraduate engineering school. The original intent was to teach the course to graduate students in Human Computer Interaction but due to the enrollment demographics this had to be modified. Therefore the author's goals were modified in order to design this course such that it could be taught to various populations with few changes.

The prerequisites for the HRI course were proficiency in an object-oriented programming language such as C and some familiarity with AI, HCI, or other relevant fields. The course met once per week for 2 ½ hours for 15 weeks. The class format was approximately an hour for lecture and the remaining time to work on the lab projects. There was no single textbook but weekly readings on the state of the art as well as written discussion and quizzes on the readings. The literature review quizzes and discussion were due each week before the related lecture. The course grade was based upon the criteria shown in Table 1.

Table 1: HRI Course Grading Criteria.

Participation	10%
Discussion	15%
Quizzes	15%
Labs	30%
Final Project	30%

Upon completion of the course, the students should be able to

- Explain and discuss basic HRI theory, terms, and principles,
- Apply HRI principles to design a robotic system, and
- Use practical knowledge of HRI to complete a research project and present it to an interdisciplinary audience.

Readings

Each student reviewed the weekly reading and submitted a typewritten discussion of the content. It should be a ½ page summary of the paper with discussion of the pros and cons of the reading as well as a list of three issues or questions. Each student also completed a weekly quiz that covered the reading material as well as relevant content from the prior week's lecture. The quizzes were online and typically included multiple choice and true-false questions. There were typically 2 to 3 papers to read per week for a total of 24 in the course.

Lectures

The weekly overview for the lectures are provided in Table 2.

Table 2: Lectures and Activities.

Week	Lecture/Activity
1	Introduction to Robotics and HRI
2	Classifying HRI
3	Evaluating HRI
4	Shared Control
5	Human-Robot Interfaces
6	Evaluating Human-Robot Interfaces
7	Robot Teams
8	HRI Applications – Museum Robots, Urban Search & Rescue
9	Final Project
10	Final Project
11	Final Project
12	Final Project
13	Final Project
14	Final Project
15	Final Project Presentation

Labs

The students were typically given one week to complete the laboratory assignments using the Arduino Robot. Each lab had a recitation, video demonstration, as well as skeleton code to help them get started. There were also Arduino Robot tutorial videos available on YouTube to reference [12]. A summary of the laboratory assignments is given in Table 3.

Table 3: HRI Laboratory Assignments.

Labs	Assignment
1	Get to know your robot – Robot Dancer
2	Touch-Free Robot Race
3	Robot Conga Line
4	Braitenberg Vehicles
5	Robot Music Machine
6	Robot Remote Control

Each lab was worth 30 points where 10 points was assigned to the demonstration, code, and memo. The demonstration involved showing all of the robot required actions based upon the assignment deliverables. The student was required to submit a memo for each of the laboratory assignments. The memo included a statement of purpose, strategy or pseudocode for robot behavior, tests, methods, results, and conclusions. The code grade was based upon properly commenting the code with in line and header descriptions. In addition, it was graded on organization and modularity by using functions and a clear structure.

In the first lab, the students followed the Arduino robot video tutorials to move the robot and calibrate the motors. This lab demonstrated the HRI concept of robot entertainment. The robot was required to play one of the songs on the robot's SD card and the student wrote the choreography for the robot to dance to it. The robot was programmed by using Sketch which is similar to C and they started with skeleton code from the Arduino website. Figure 1 provides a stock image of the robot.

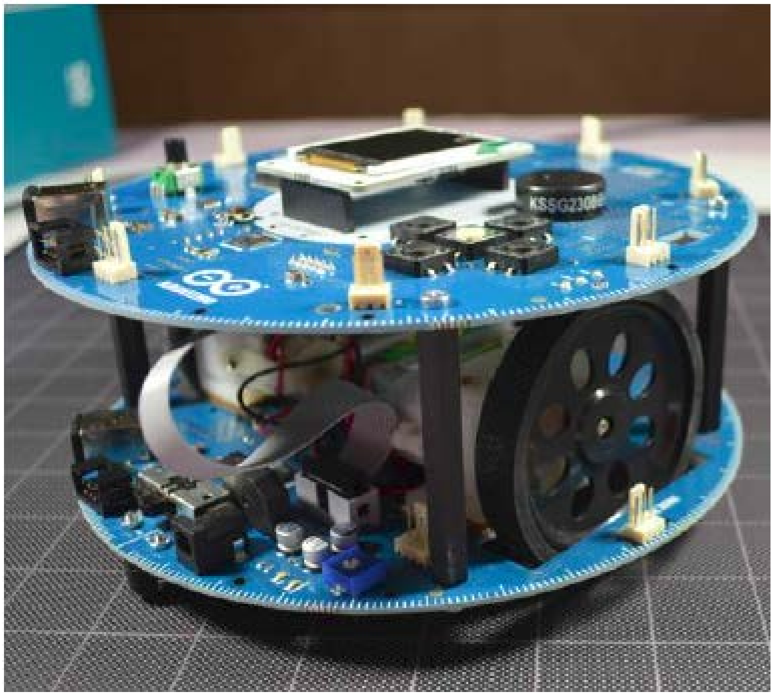

Figure 1: Arduino Robot.

In the second lab, the students were introduced to sensors. They learned about the functionality of infrared and ultrasonic sensors and learned how to attach them to the robot. The students were given the pinout for the sensors and terminals on the robot but after several mishaps with crossed wires and destroyed sensors, everything was color coded to eliminate mistakes. This was one of the byproducts of them not having any technical background. For the touch-free robot race, the students were required to use the distance sensors to move the robot down a hallway. This was similar to using a potential fields approach for robot obstacle avoidance. The students could use their hand or another object to move the robot forward, backward, left or right. This lab demonstrated the HRI concept of interaction design. Figure 2 provides some images from the wiring diagram and lab demonstration.

In the third lab, the students were introduced to LEDs and light-dependent resistors (LDR). This lab demonstrated the concept of robot teaming. They were required to mount these sensors to the robot by using Tinkerkit cables. Since the Tinkerkit connections had a polarity and could only be connected in one direction, it eliminated the wiring issues from the previous lab. The robot would use the LDR to move forward and beep when a bright white light was detected. The light was generated by either the bright white LEDs or a flash light. The robot's speed should be adjusted proportional to the distance from the light source or light intensity in order to maintain a certain distance. The range sensors were also used to detect the distance to the light. If the light was lost, the robot should scan the environment to locate it and continue attempting to follow it. Finally, the bright white LED was mounted on the back of a classmate's robot and the program was used to create a robot conga line. Figure 3a provides some images from the lab demonstration.

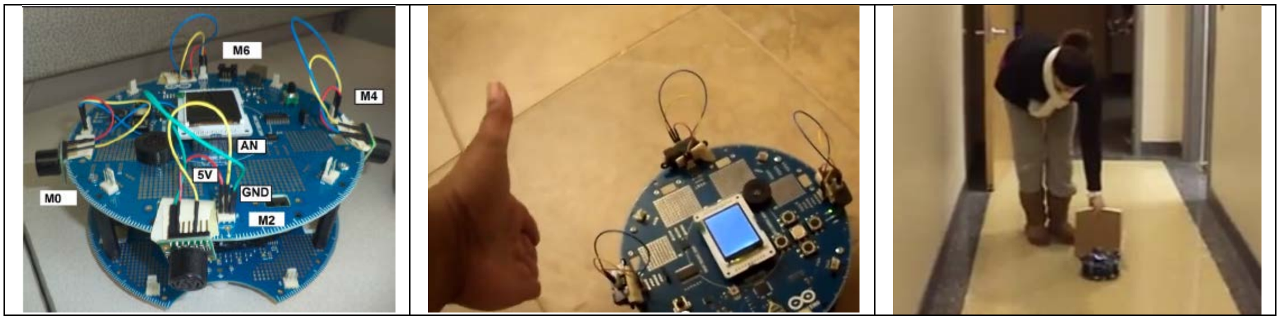

Figure 2: Touch-Free Robot Race.

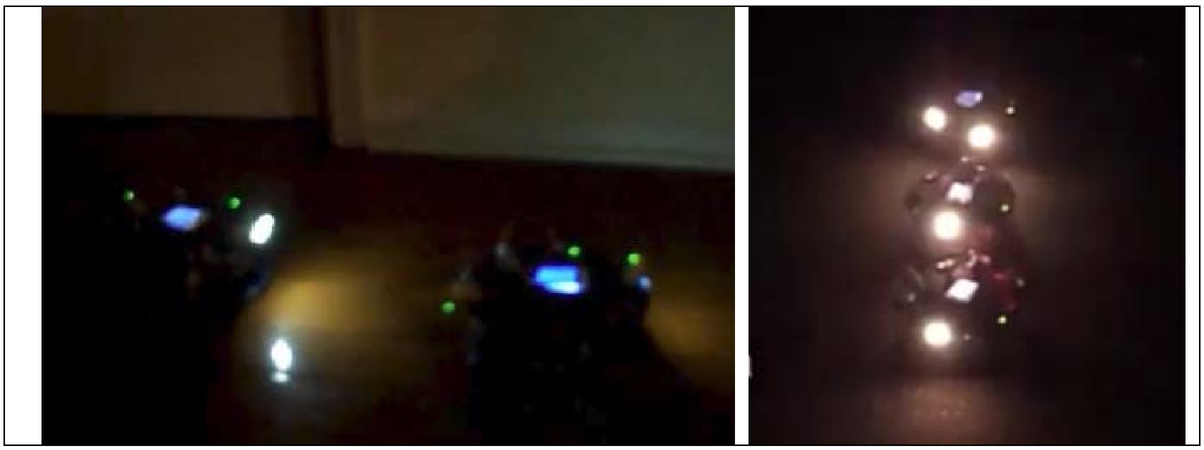

Figure 3a: Robot Conga Line.

The fourth lab was also based upon light sensing and required the students to implement Braitenberg vehicles. This was a demonstration of reactive control and creating photophobic and photophilic animal-like behaviors based upon excitatory and inhibitory connections between the sensors and motors. Based upon the wiring connections, the robots would demonstrate love, aggression, fear, and explorer behaviors. The wiring and the lab demonstration images are shown in Figures 3b and 4.

In the fifth lab, the students were required to create a robot music machine. They were to use the IR sensors, potentiometer, pushbuttons, LEDs, and LCD to make the robot play music. They were introduced to the new peripherals as well as the concept of entertainment robotics. This lab was based upon the HRI concept of interface design. Figure 5 shows some screenshots from the robot music machine demonstration.

In the final lab, the students were introduced to the infrared transmitter and receiver and Sony protocol for remote controls. The students were required to write a program to assign robot behavior to the buttons such as movement, lights, or sound. This lab was based upon the robotics concept of supervisory or shared control. Figure 6 provides images from the robot remote control lab.

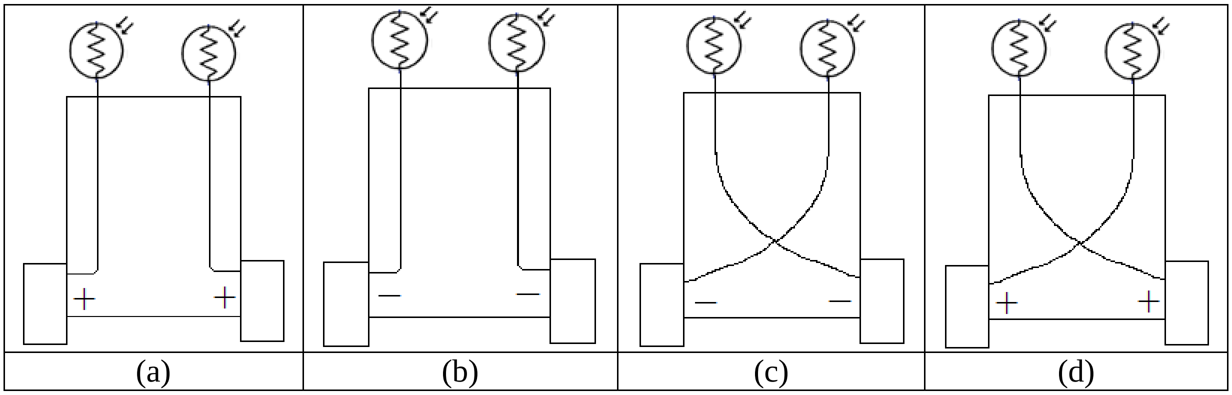

Figure 3b: Valentino Braitenberg Vehicles.

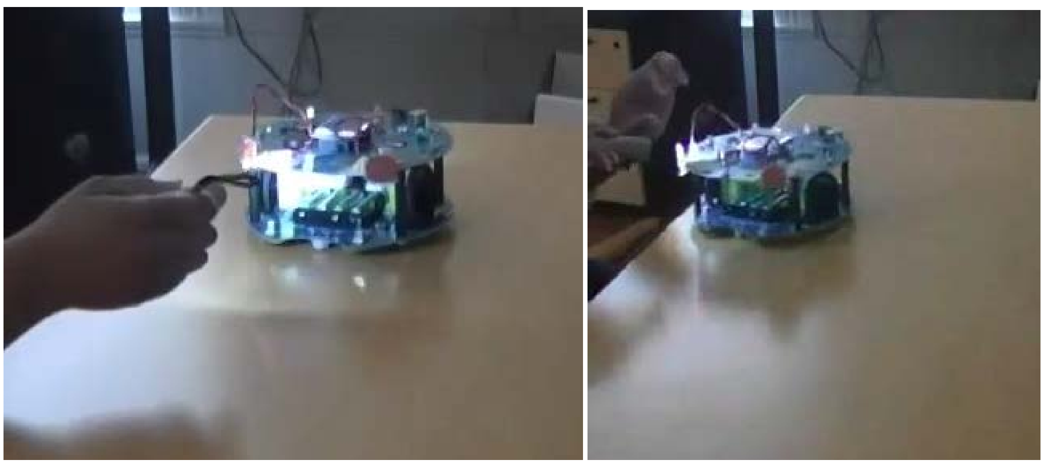

Figure 4: Braitenberg Vehicles Lab.

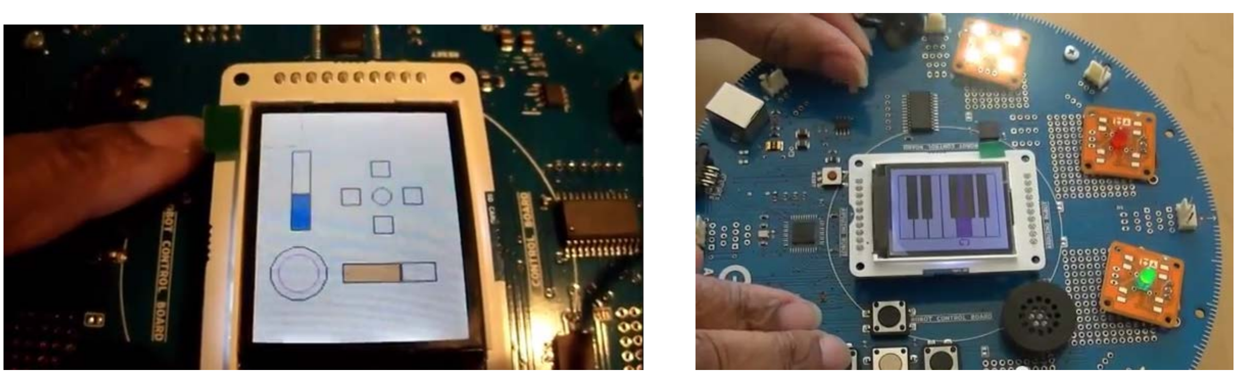

Figure 5: Robot Music Machine Lab.

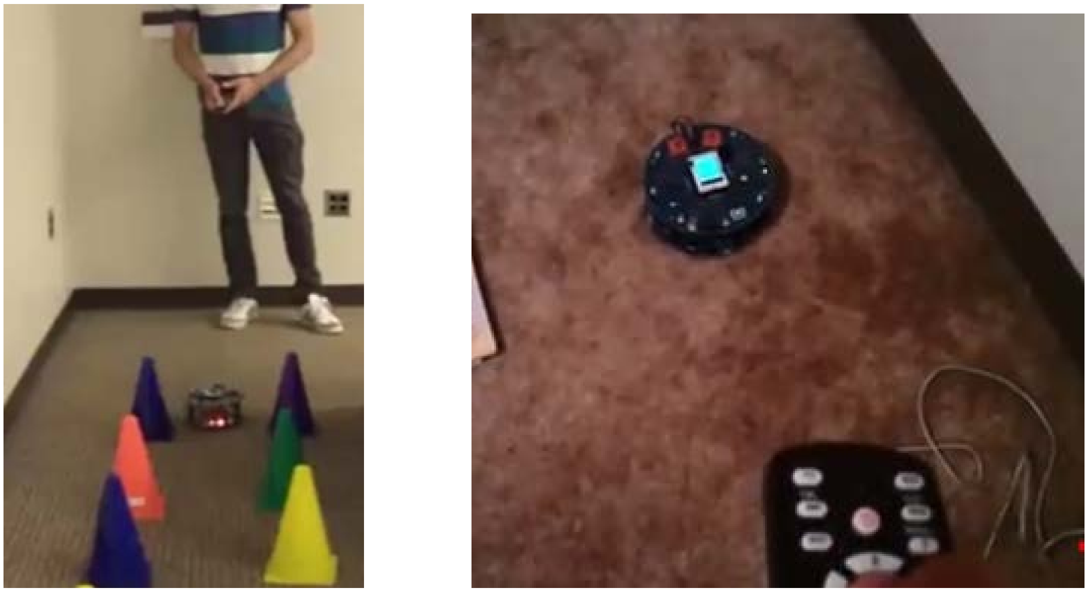

Figure 6: Robot Remote Control Lab.

Project

The final project included 4 distinct parts. It was based upon the HRI application of urban search and rescue. The first task involved tuning the IR sensor array to follow a line. Next, the robot was to use the range sensor to identify survivors on the line track and move them to safety before returning to the line to continue searching for survivors. The robot was then to use the IR transmitters and receivers to communicate signals between the robot rescuers. Figure 7 shows screenshots from the first three phases of the final project.

Finally, the last part was the robot surprise where each student was required to design some robot interaction based upon what they had learned about HRI during the semester. Examples of the demonstrations included designing robot communication based upon music, safe robot remote control using obstacle avoidance, and a robot picture viewer on the SD card. The robot picture viewer advanced images on the LCD screen by using the pushbuttons or internal tilt sensor or digital compass. The robot communication project changed the music playing on the receiver robot to match the song on the transmitter robot. The students were required to submit a technical report for the final project. The components of the report were the abstract, objective, theory, methods, results, conclusions and recommendations. The students were also required to submit the properly commented code and the demonstration. Figure 8 provides images of the student robot surprise projects.

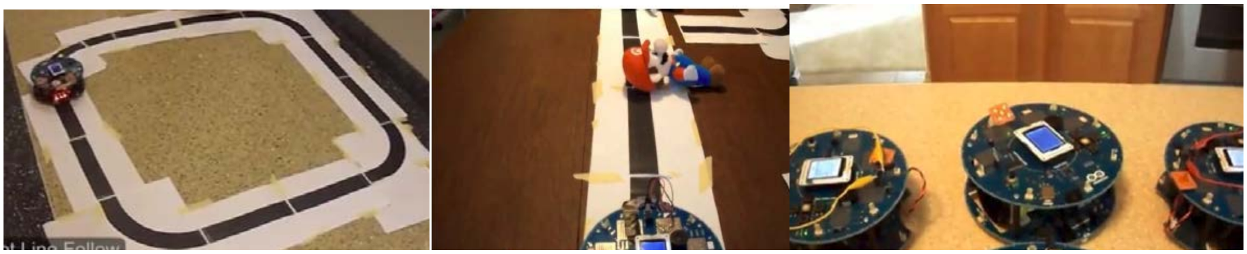

Figure 7: Robot Line Follow, Urban Search and Rescue, Marco Polo Final Project.

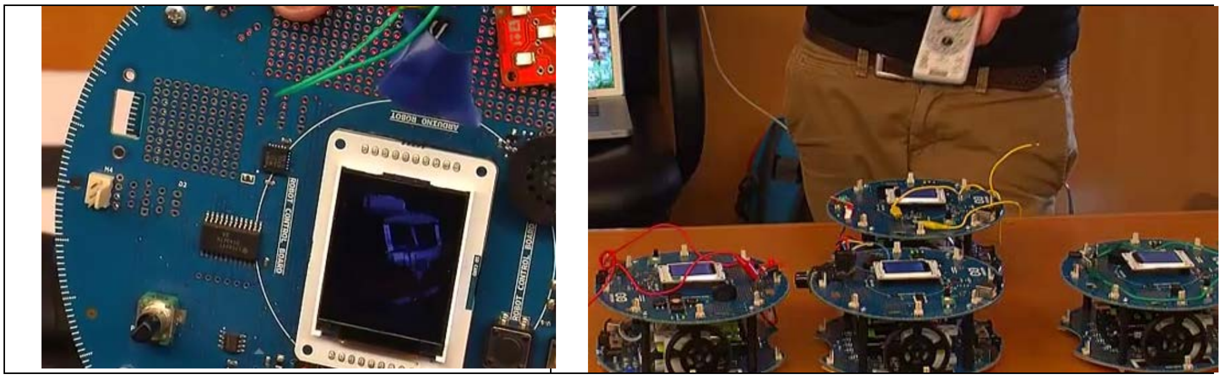

Figure 8: Robot Surprise Final Project.

Results

In general, most of the students were able to complete all of the labs but some were not able to get all parts of the final project completed. The easiest labs for the students were the robot dancer, Braitenberg vehicles, and robot remote control. The labs with range sensors were the most challenging because they did not have a complete understanding of odometry and sensor error. For example, specular reflection for sonar or lighting conditions for infrared. This sometimes made getting the line following, robot following, and obstacle detection to work correctly a bit frustrating. There were also some challenges with the robot marco polo and robot communication for similar reasons. One solution we found to make the robot communication more accurate was the addition of electrical tape on the sensor to narrow the field of view.

Although many of the students had never written a technical memo/report before, reviewed technical literature, or written a discussion or annotated bibliography, with some guidance they were able to achieve it by the end of the semester. The overall average on the reading quizzes was 84%. The labs had an overall average of 91%. The reading discussion was an average of 88%. The project average was 91% and the overall course average was 89.47%.

The end of course evaluation was completed by 75% of the students. The quantitative results from the end of course evaluation indicated that students rated the course as a 3.33 or higher on a 4 point scale on most of the qualitative questions. The questions related to the course goals, objectives, syllabus, description, materials, assignments, critical thinking, learning, and knowledge/skills. The qualitative feedback indicated that the students enjoyed the course because of the hands-on learning component. This was because they learned about software development, robot hardware, sensors, and technical writing in the form of the lab reports and how they integrate to produce a complete system.

Conclusions and Recommendations

Although the author is an engineering professor at a small technical primarily undergraduate school in the Midwest, the first offering of the course was while she was on sabbatical at a large state university. This course would eventually be taught at the author's home institution to undergraduate engineering and computer science students so it was vital that it was appropriate for diverse audiences. Even though, the students at the sabbatical institution were to be graduate students in human-computer interaction (HCI), the students who enrolled in the first HRI course were undergraduates in computer science and media arts and sciences. One of the original goals was to examine parallels and differences between HCI and HRI. However, this was no longer possible based upon the enrollment in the course. This presented some interesting challenges since the majority of the students did not have any technical background or familiarity with hardware such as a mobile robot platform. This required modification of the laboratory assignments in order to be more achievable.

One key lesson learned for doing this was to frame the lab assignments in terms of the expected robot behavior without the use of technical terms. For example, color coding the wiring on the sensors instead of explaining signal, power, and ground connections. This also meant explaining sensors without providing overwhelming detail about digital, analog or I2C concepts. Another example with respect to the algorithms was to provide skeleton code as well as organization guidance with respect to functions and structure. Some of the students understood conditionals and loops but some had only used video creation software. One additional great benefit was the Arduino video tutorials as well as the lab demonstration videos created by the author.

In conclusion, it was possible to teach a multidisciplinary course in Human-Robot Interaction for students with various backgrounds and levels of technical skill. In order to make the objectives achievable, it was necessary to frame the lab assignments in non-technical terms. This required a focus on the robot behavior outcomes as opposed to the algorithm and structure for the programs. Lessons learned included making the course a survey of key topics in HRI but focusing on some of the most relevant based upon the student's experience. In the next offering, there will be more rigorous labs and projects due to the hopes that there will be more graduate students as well as students with technical backgrounds. There will also be more of a focus on interaction and interface design as well as evaluation techniques.

All of the students who enrolled in this course took it as a free elective not necessarily required for their major. However, how could they use this work or take an advanced course that is applicable to computer science or media arts and science? I think that the answer is embedded in the STEM to STEAM initiative. This will allow the integration of art and design with science, technology, engineering, and mathematics. It will use the artistic and design principles to encourage creative solutions. These students will use their backgrounds in media arts and science or computer science along with the concepts learned in HRI to create more innovative projects in their field. For example, one student from the course decided to continue integrating robotics and Arduino microcontrollers in her projects for some of her follow on courses. Other students in the arts could now use the concepts of user studies, interaction, and interface design when creating media for customers. Therefore, I believe that an appropriate follow on course in advanced HRI would more tightly integrate the student's background foundation in their field into the labs and projects in order to exploit this STEAM concept.

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