AC 2009-162: INTRODUCING ROBOTS

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Ryan Meuth received his Bachelors and Masters degrees in Computer Engineering from the University of Missouri –Rolla in 2005 and 2007 respectively. He is currently a Computer Engineering PhD student at Missouri University of Science and Technology (formerly the University of Missouri – Rolla). He works as a research assistant in the Applied Computational Intelligence Laboratory, contributing to research projects on optimizing the behavior of robot swarms, large scale optimization problems such as computer Go, and high performance computing methods utilizing video game consoles and graphics processing units. His research interests include robotics, computational intelligence, machine learning, and cognitive science. Ryan is also heavily involved in the university Robotics Competition Team, where he manages the development and interfacing of sensors for the team's robotic entries into the annual Intelligent Ground Vehicle Competition.

Paul Robinette, Missouri University of Science and Technology

Paul is currently a master's student at the Missouri University of Science and Technology.

Paul has been involved in robotics since he joined the UMR Robotics Competition Team the second semester of his freshmen year. The team competes annually in the Intelligent Ground Vehicle Competition (IGVC). This competition requires the team to design and build a medium-sized robot to autonomously traverse an outdoor obstacle course. Obstacles normally consist of colored barrels, construction netting, white lines and trees. The team uses stereovision cameras as the primary obstacle detection sensor. The team is currently exploring several algorithms for path planning.

Paul recently become a member of the UMR Applied Computational Intelligence Lab. He recently spent the summer developing adaptive user-interfaces as part of a research partnership with Boeing.

Donald Wunsch, Missouri University of Science and Technology

Donald C. Wunsch II (S'87–M'92–SM'94–F'05) received the B.S. degree in applied mathematics from the University of New Mexico, Albuquerque, and the M.S. degree in applied mathematics and the Ph.D. degree in electrical engineering from the University of Washington, Seattle. Heis the Mary K. Finley Missouri Distinguished Professor of Computer Engineering, University of Missouri-Rolla, where he has been since 1999. His prior positions were Associate Professor and Director of the Applied Computational Intelligence Laboratory, Texas Tech University, Lubbock; Senior Principal Scientist, Boeing; Consultant, Rockwell International; and Technician, International Laser Systems. He has well over 200 publications, and has attracted over $5 million in research funding. He has produced eight Ph.D. recipients—four in electrical engineering, three in computer engineering, and one in computer science. Dr. Wunsch has received the Halliburton Award for Excellence in Teaching and Research, and the National Science Foundation CAREERAward. He served as a Voting Member of the IEEE Neural Networks Council, Technical Program Co-Chair for IJCNN'02, General Chair for IJCNN'03, International Neural Networks Society Board of Governors Member, and is now President of the International Neural Networks Society.

"Introducing Robots"

Abstract

This paper presents the Missouri S&T Introduction to Robotics course which exposes undergraduate and graduate students to technologies behind robotics projects ranging from the historical to the state of the art, as well as fundamentals on robotics architectures, sensing, navigation, and control. Topics covered included basic sensor and image processing, sensor fusion, world modeling, planning, kinematics, control, software agents, machine learning and simulation. Instruction utilized example problems presented by real-world competitions such as the Intelligent Ground Vehicle Competition (IGVC), AHS First Responder, and the Association for Unmanned Vehicle Systems International (AUVSI) Unmanned Aerial Vehicle (UAV) and Unmanned Underwater Vehicle (UUV) competitions.

Introduction

Robotics is an inherently interdisciplinary engineering field, encompassing electrical, computer and mechanical engineering, as well as computer science, mathematics, physics, systems engineering, and, in some instances, psychology, cognitive neuroscience, and even philosophy. The breadth of the problems presented by robotics development encourages the integration of knowledge and problem-solving methods from a wide range of fields. With the advent of autonomous vehicles in the military and consumer robotics products, such as the iRobot Roomba, the robotics industry is growing rapidly and is expected to continue to do so as consumer spending on robotics increases. Study of the discipline of robotics can give engineers a valuable perspective on systems integration, as well as experience in a wide range of fields and real-world problem solving, increasing the flexibility of the engineer in a rapidly changing world.

The course was designed around a philosophy of openness; lectures utilized freely available, non-copyrighted material from the WikiMedia project, as well as public and freely available online videos, exercises, programming environments and code examples. The course itself was designed using free, collaborative tools, primarily Google services. The course website was maintained using Google Pages, lectures were presented using Google Presentations, assignments and class notes were created using Google Documents, and grades and feedback were maintained using Google Spreadsheets and Forms.

Also of great importance is hands-on learning. Assignments were project-based, requiring students to rapidly learn programming interfaces and the semantics and capabilities of several languages, including LOGO, the open-source Player-Stage Framework, MatLab and embedded C programming. In lieu of a textbook, students constructed and programmed a small mobile robot from a kit designed by the instructors. This robot gave the students real-world programming experience with motion control, sensor acquisition, path planning algorithms and multi-vehicle interaction capabilities.

Semester research projects culminated in updating WikiBooks pages to share the students' new-found knowledge in a particular robotics topic. Students were encouraged to apply their semester practical projects to various Missouri S&T robotics competition entries such as the IEEE Robotics Competition and the Intelligent Ground Vehicle Competition. Continuing in this open-source philosophy, all course documents, including lecture slides, reading material, source references and robot kit hardware and software were posted online. This enables the educational and hobby community to contribute and develop the course-ware beyond the duration of class sessions, creating a 'living course' that continues to evolve and improve, increasing its value and inherently promoting the course and the university.

The course was targeted to engineering juniors with programming, math and statistics experience, with no strict prerequisites. Twenty students registered for the class (the maximum allowed by the registrar) primarily composed of computer science, computer engineering, and electrical engineering majors, with a handful of math and mechanical engineering majors.

Background

Recently, engineering educators have started integrating robotics into their classes. The 2005 Computing Curricula recommendations by the Association for Computing Machinery (ACM), Association for Information Systems (AIS), and the IEEE Computing Society (IEEE-CS) specifically mentions robotics in its recommendation to Computer Science educators: "Now CS researchers are working with scientists from other fields to make robots become practical and intelligent aides"[1]. Robotics can apply to lessons across several different disciplines in engineering, science, math and business.[2,3] Whole institutions are being created to educate students in the robotics field.[4]

While some educators are discussing the inclusion of robotics into existing curricula, others are writing about the changes required to teach robotics as a major[5]. Dr. McKee describes three basic divisions robotics education should have: designing and building robots, programming robots for practical situations, and making robots act more human. He also believes that education in robotics should start with practice and work its way to theory instead of the other way around, as most engineering is taught.

Robotics competitions have been a big factor in interesting students of all ages in robotics specifically and engineering in general.[6] In 2000, the Society of Manufacturing Engineers offered 14 different robotics competitions, from pick and place machines to remote control vehicles to maze-solvers. The Association for Unmanned Vehicle Systems International organized six collegiate level competitions in 2008.[7] These competitions have driven students to learn more about robots through experience. Some schools are developing their own robotics competitions for freshman introductory courses to expose new students to engineering immediately.[8]

Several instructors have found it necessary to create their own electronics packages to give their students adequate experiential learning in electrical and computer engineering. One such package used two Atmel AVRs, four H-bridges to control motors, an LCD screen and several general purpose input and output pins to give students a platform for their senior capstone course.[9] Several kits are also commercially available, such as Lego Mindstorms, iRobot Create and

Parallax Scribbler.[10] Each of these kits has a niche that it favors in terms of student age, programming proficiency and expense.

Lecture Format

Most classrooms at the Missouri University of Science and Technology are outfitted with now-standard digital projectors and computers to aid in instruction. The instructors took it upon themselves to utilize these capabilities while attempting to avoid their associated pitfalls, such as monotonous lectures, "teaching to slides" and other behaviors that decrease the quality of instruction.

The class format was two lectures per week, an hour and a half per lecture, starting at 8am. This early start time presented unique challenges to instruction. Each lecture began with a 15-minute video segment demonstrating some application or development in the field of robotics, followed by a short class discussion of how the video related to topics of instruction. Video segments often included news items covering current developments in robotics, but historical footage was also utilized. The instructors found that starting each class in this manner helped to engage students and provided a useful context for instruction.

The introductory video segment was followed by more traditional instruction, typically in the form of a set of presentation slides relating to the topic of the day. In order to maintain student interest in the class, slides were used to enhance instruction, not to focus instruction. Most instruction, such as concepts and relationships, were explained verbally, only using the computer visual aid for illustration, so that the instructor was never "just reading from a slide." For example, during the exploration of holonomic kinematics, the general concept was presented primarily verbally, equations were displayed using the computer, examples were worked using the traditional chalkboard, and at the end of instruction, a short video of holonomic devices in application was presented to give students an intuitive understanding about the functionality of holonomic systems. The last 10 or 15 minutes of each class were typically allocated to taking questions from the class on the material covered and explaining assignments.

Topics

As robotics is a highly interdisciplinary field, the topics covered by the course spanned a very large range. The instructors believe that as an introductory course, the field as a whole should be investigated, emphasizing only a few fundamental skills to the point that students gain proficiency. As a result, lecture topics tended to vary greatly, while assignments exercised project development, group interaction, knowledge sharing, unconventional programming paradigms, and real-world results. Below is a syllabus outlining each lecture and a brief overview of the information contained within. Full lecture materials can be found in the Course Materials section at the end of this paper.

History / Philosophy of Robotics

"Robots Through the Ages" - A light introductory lecture on the history of robots from ancient times (~ 400 B.C. with Archytas of Tarentum's Mechanical Pigeon) to modern developments of walking robots, DARPA projects, and unmanned systems. This was presented in the context of the history of computing, as there are significant parallel developments.

Simple Sensing - Bump-bot

An overview of simple sensors, such as tactile bumpers, short-range infrared, capacitive proximity, and ultrasonic ranging. Maze navigation and avoidance behaviors were also included.

Model-Based Planning

This topic included methods for storing and representing sensory information. Lectures included coverage of tree-based search methods, optimization, ray-casting navigation, wall-hugging, and potential-field planning.

Behavior Based Planning

A description of model-free planning was provided, with details on the functionality of Finite State Machines and Brook's Subsumption Architecture.

Coordinate Transformation

Procedures for transforming points between coordinate frames were described. Examples focused on two-dimensional rotation and translation.

Micro-controller Programming

The basics of micro-controllers were presented in this short series of lectures, including an overview of the differences between C++ and C programming languages, as well as I/O interfaces, math limitations, interrupts and timer functionality. Students were prepared for their first hardware-based assignment.

Motor Control

The motor control series provided an overview of motor types and their design guidelines as well as the operational details of transistors and H-Bridges. Particular emphasis was placed on the concepts and implementation of Pulse-Width Modulation and Proportional-Integral-Derivative control, as these two elements would be used in a later assignment.

Unmanned Aerial Vehicles

This lecture included the modeling of flight dynamics as well as flight control and danger situations, such as stalling. Helicopters and quaternion representation were also covered.

Ground Vehicle Kinematics

The modeling of different kinds of ground vehicles was covered. Differential drive, car kinematics, car-trailer kinematics and holonomic drives were investigated.

Manipulator Kinematics

The modeling and control of manipulator kinematics was explored. Forward kinematics was detailed, and methods for solving the inverse kinematics problem were reviewed.

Swarm Intelligence

The swarm intelligence lectures introduced some concepts of biologically-inspired social robot systems, emphasizing swarm intelligence characteristics, swarm behaviors, and robot-to-robot communication schemes. Some common swarm behaviors were demonstrated using StarLogo.

Machine Vision

These lectures introduced image processing techniques for the purpose of machine interpretation. Color spaces, filtering, edge-finding, blob-finding and other techniques were discussed. Image processing filters were demonstrated using sample images and Matlab.

Machine Learning

This series of lectures provided an overview of the methods and capabilities of machine learning, including a discussion of supervised, unsupervised, and reinforcement learning paradigms. Methods investigated included artificial neural networks, clustering methods, and Markov decision processes. Also discussed was machine learning in the context of psychology, and the No Free Lunch theorem as applied in search and optimization.

Contextual Awareness

The difficulty and importance of teaching robots to recognize common human situations were discussed. The concept of ontology was introduced as a way to unite semantic and pragmatic definitions.

Expert Systems

Software systems to replace expert technicians were introduced to give students experience with methods to give robotics and intelligent systems information about how to act when given clues about their surroundings.

Knowledge Bases

Several knowledge bases were discussed, including Cyc and Open Mind. This gave the students an idea of how difficult it is to enumerate all of the "common sense" information humans use every day.

Software Agents

Software agents represent a way to apply autonomous robotics algorithms in pure software. Several agents were discussed, including web crawlers, product recommendation systems and daemons.

LabRat

LabRat is a small, mobile robot kit designed by Rolla Engineered Solutions, LLC for use in education, scientific research and hobby robotics.

Figure 1. A swarm of 20 LabRats, constructed by students enrolled in the Introduction to Robotics Course at the Missouri University of Science and Technology.

LabRat is a completely autonomous, self-contained mobile robot kit with batteries, motors, two bumper whisker sensors, and three infrared proximity sensors that also double as channels for "Rat-to-Rat" communication. What distinguishes LabRat from other small robot kits is an optical mouse sensor on the bottom of the robot, providing high-rate, high-accuracy position information, as well as the ability for instructors to incorporate machine vision into their courses, as the optical sensor is effectively a small CCD camera.

High School and college educators can use LabRat to teach programming, electronics, and introductory robotics, while researchers can upgrade LabRat with a serial radio and a very small Linux computer to provide an unprecedented level of capability in a small package at very low cost. Hobbyists can change any aspect of the design through the use of freely available open source tools and documentation.

In the Missouri S&T Introduction to Robotics course, students constructed their LabRat kits outside of class, learning traditional and surface-mount soldering methods and electronics debugging.

Through their assignments with the LabRat, students helped construct a library of code and functionality that is available to future LabRat developers. This crowd-sourced development paradigm not only increases the value of an individual's LabRat, but of every other LabRat and similar products that are available.

Assignments

Maze-bot

The first programming assignment in the class required students to create a control system that would allow a simulated LabRat to find its way through a maze. According to student feedback, the most challenging portion of the assignment was installing and working in the Player/Stage simulation environment.

Waypoint Navigation

Utilizing the Player/Stage simulation environment, students were tasked with developing a way-point navigation program for a differential drive robot equipped with a simulated LIDAR unit. This robot was modeled after an actual robot built by the Missouri S&T Robotics Competition Team. Students were required to develop methods that balanced avoidance with navigating toward a goal position.

Image Processing in MatLab

This assignment required students to utilize the image processing toolbox in MatLab to find all of the orange construction barrels in a given image. The input image was taken from a picture of the Intelligent Ground Vehicle Competition to give the students a real problem to solve.

Star-Logo Swarm Programming

This open-ended assignment was to create a swarm of turtles in the Star-Logo swarm programming environment (http://education.mit.edu/starlogo/) that uses simple rules to achieve complex behavior. The swarm algorithm used could be original or a new implementation of an existing algorithm.

LabRat

As with most first-generation electronics projects, production of LabRats was delayed. Final delivery to the students could not take place until near the end of the semester. Originally, the instructors planned to have the students complete several LabRat assignments, including an implementation of the maze-bot on the LabRat and a swarm robotics assignment involving three or more LabRats. Due to the delay, students were only able to complete a simple speed controller program. This still gave students the opportunity to learn about the differences between simulating robots and implementing them in the real world.

Mid-Term WikiBooks Article and Class Presentations

Basic robotics education available online is very lacking. WikiBooks is an online community for creating a free library of textbooks that anyone can edit.

A Robotics WikiBook (http://en.wikibooks.org/wiki/Robotics) has been started, but work on it seems to have stalled; several basic sections are still unwritten. Each student picked one unwritten section and wrote a comprehensive study on the topic. Each student joined a group of 3-4 other students to form a peer editing group. Students also presented their topic to the class and then submitted their work to the instructors after revisions. Students were expected to follow WikiBooks' policies while contributing their work to the WikiBook.

This project generated over 20 new pages on the Robotics WikiBook, significantly increasing the quantity and quality of information available.

Semester Projects

Students formed groups of 3-4 people to accomplish a project related to robotics. The student groups were free to submit whatever project they thought was sufficient for a semester project, pending instructor approval. The result of the project was a 20-minute group presentation, a 10-page final report, and a demonstration of developed projects.

Students chose projects ranging from machine vision to inertial measurement to telerobotics. Several projects were completed in partnership with the Missouri S&T Robotics Competition Team.

In less than a semester, many students completed projects that rival those produced by S&T's year-long engineering capstone course, both in terms of quality and depth.

Class Reviews

At the end of the course, a short, 4-question survey was administered, with the following selected responses.

Question 1. Did you like the general way lectures were taught? Why?

"videos at the beginning of class were nice to get a good overview of robotic achievments."

"The general lectures where okay. They didn't teach a whole lot per day though. They were more a general glimpse into various fields of robotics. They were interesting enough, but they probably aern't good enough on their own for practical application."

"Yes. The lectures were laid back but still presented important information. They weren't forcible because they were actually pertinent and the value of the information was obvious."

"Overall, I thought the lectures were handled pretty well (the ones I saw). The slide shows seemed well prepared, and you've obviously got some knowledge that's worth sharing. You also managed to scare up quite a bit of Youtube content that I haven't seen."

"I liked the topics covered. I wish there had been a little more application. I didn't feel that we were always taught how to implement things as much as the general theory. I realize that the scope of the class was very large and that this was somewhat a necessary evil, but I think a better medium could be found."

"Yes. I liked starting out watching cool videos of applications of robotics, it was a good way to ease into the lecture. Also learning about all different sections and topics of robotics we went over was very interesting. A very good introductory course."

"Yes. The videos to start were a nice way to get going considering the early time of the class. The lectures were great overviews and introductions to a number of topics without going so in depth that they would be over my head."

"Sure. The videos were a fun way to start the class. Plus if somebody was 5 minutes late, they didn't miss anything REALLY important. Just fun stuff.

Not having written exams/homework was WONDERFUL!!! It made the class more of a "fun" class, like for an elective - than a "normal" class. I couldn't have taken the class otherwise. I am taking 19 hours, and I got married in the middle of the semester - but I really wanted to take this class."

"Yes - this was an over-view survey course - you covered a lot of material to just about the right depth. I enjoyed the topical videos, and for the most part, they related to the course. You provided an excellent explanation of the state of the art in robotics - where advances are being made, and where they're stalled out, and why.

You both were very available and approachable for extra help - I appreciated that very much. I've had other instructors who took the view..... - "that was covered in pre-requisite courses" - never heard that from either of you. "

"Yes. The videos at the beginning of class were a nice touch. Brought me back to the good ole days of physics 23. I like how the lectures were kind of an overview of what is out there as far as robotics goes, and then there were homeworks that went into the detail."

"In general.
It was an early class, so I liked that it started out with videos that were both informal and entertaining. The instructors did a good job tracking down things that were pertinent to the class. Lectures could have had more meat to them; sometimes concepts were glazed over without what I felt were adequate examples of their purposes or uses. But in general, yeah they went well."

"Yes, most lectures were able to keep me interested throughout. Powerpoint presentations were generally rich enough to be interesting. I like how open the class is to student questions, opinions, and even allowing students to lecture if they have knowledge to share."

"Sometimes you guys were a little bit less than fully prepared, but that got better as the class went on. If you can manage to get out the TTh ghetto I think you'll do just great, but if they keep giving you the same time slot just do a bit of revising now that you know what you want to cover and how it works out in the long run."

"Yes, they were great. I liked the presentations, especially that they were posted online for review. The presentations also weren't the standard word doc in slides I'm used to at this school. I like how they were used as springboards for lecture, not as the lecture itself."

Question 2. Did you like the topics covered by the class? Were there any topics you would like to see covered in greater detail? Are there any topics we did not mention that you would like to see and what should we replace with said topic?

"I think the addition of some basic mechanism design would be helpful. There are some simple methods that can get fairly good solutions to many mechanism design problems."

"I think the class covered all of the topics it should have and in proper detail. It would have been nice to do more work in some of the larger areas, but I'm not sure that it would really be possible as some of the subtopics have entire classes about them. The way that topics were introduced served as a good jumping off point for some of the more complex areas."

"There were a couple of topics I could have done without, but I understand why they were included.

I thought the variety of topics was good, and I feel as though I have been thoroughly introduced to robotics. I also feel like I learned quite a bit about the current state of robotics, and what kind of work people are doing."

"I thought there was a good range of topics covered. It was sometimes a little computing heavy (a lot of dynamics stuff left out) but I guess it is listed as a CompE/EE course."

"Not really, I liked the way y'all did things in class. I think if there seemed to be a lot of questions on any one subject in class there were many questions on of there was a lot of interest shown, then obviously go into greater detail on those specific subjects, but I felt y'all did very well."

"Yes, though I wouldn't mind seeing a little bit more time spent on some of the programming techniques for certain areas, especially path finding."

"Most of them were good, some we never used, but from just having a general interest in robotics I liked it alot and learned I want to keep learning more."

"Good coverage of the field - especially enjoyed the controls and kinematics topics. Would have liked to see an assignment in this area to deepen the exposure.

Labrat was an excellent into to microcontrollers - I got a lot out of the fabrication and debugging as well. Next time, you'll be able to start with the real thing a little earlier, instead of relying so much on player-stage, although it would be good to include at least exercise in that environment."

"I would have liked to seen more hardware stuff instead of software, but I'm also going to be switching to EE next semester, so that's just me. I think I got the most out of assembling the labrat. It was nice to have someone actually tell you how to solder, which suprisingly isn't something that is taught at umr. Also, I think being the guinea pigs for the labrats was a good experience, because the kinds of unexpected problems we ran into are the kind of problems we'll run into in the workplace."

"I think I would like to have seen more of the mechatronic side of things, if I'm using the word correctly. There was a lot about various means of processing data, but I don't recall there being a lot about the actual design of the mechanics of robotics. I still don't know how servos are actually controlled; things like that. We mentioned many things but I don't recall discussing them in detail."

"See I'm a software guy by name, but a hardware guy by background. My people are mechanical people rather than computation people, so I have an interest in the machine side more than the high-end software side."

"I enjoyed learning about most of the topics covered in the class. I think there is a good balance between software and hardware concepts. I had some trouble following some of the kinematics lectures mostly because I couldn't see how the equations were applied to an actual robot or what sensors would give me the information needed."

"You're not sociologists and I may be the only one who cares, but some exploration into the social impact of robots could be really interesting and might get people thinking about things they hadn't before."

"The topics were wide and varied. They provided a good overview, but the field of robotics is so large you could spend an entire course going over what we went over in a few days."

Question 3. How were the assignments (too hard, too easy, too boring)? Would you like to have done any other assignments (assuming you had the time)?

"The assignment level of difficulty was OK, but it seemed like much of the time on each assignment was spent in learning new systems and working out bugs in installation, so the assignments ended up taking much more time than it seemed like it was worth for the level of the assignment. It might be helpful if the assignments could be done with software pre-installed on campus computers so that if any difficulties in installation came up there would be another alternative. I think the class would benefit from more exposure to hardware rather than just simulations."

"The assignments ranged from easy to fairly difficult, but they were graded accordingly and required an equal amount of time to get an equal grade. It would have been cool to do more work with the labrat, but that was understandably constrained by the design and construction."

"The only thing really difficult about the assignments, for me, was just sitting down and doing them. I would've liked to have seen more development on the LabRat itself.

I'm sure there are people in the world who have had wonderful experiences with Player/Stage, but I am not one of them. Still, I can understand that a student taking the class who might potentially enter the field of robotics should be familiarized with the tools of the trade. Similarly, StarLogo is an interesting piece of software that seems to have been made for children and repurposed by engineers. While I like the concept of a virtual environment for studying swarm behavior, I found the programming language absolutely infuriating. My kids will learn C..."

"I would've liked to have had better explanation on some of the homework assignments. It seemed most of the time y'all hadn't done the assignment or understood all the angles of the assignment to provide adequate tutoring on it, especially in lecture. More tutoring on the LabRat and more assignments with that. It seems now with one assignment with the LabRat and that one didn't even work half way as was expected, the LabRat was kind of a waste of my money, I don't really see myself using it much, especially with all the bugs and such to work out of them still."

"Of course I'd prefer if we had the labrats earlier and got more assignments, but I like using player stage, they were good assignments and used stuff taught in class."

"Difficulty = Good. Fair. Well balanced. Grading = Nice. :) You were understanding of time constraints and problems. Willing to work with students out of class. They were good assignments overall. The player/stage assignments applied directly to what I felt as "newbies" to the robotics field that we needed to learn. The "bump bot" or "wall follow" (hw1) was great for the first hw. And the one with the lidar, and finding the simulated GPS points was good too. The image one was ok, too. It would have been nice to use the lab rat BEFORE the last couple weeks of school. - maybe in more than 1 assignment. I understand they took longer to develop than you thought."

"For future classes, I would dive into the assignments quicker. I remember getting nervous that the first homework assignments were delayed for a few weeks, and this caused a certain amount of compression towards the end of the class. However, you were also fairly forgiving and very accessible for help. Many of the assignments (at least for me) required a steep learning curve for development environments that others may have had from prerequisite courses, but getting a crash course in Linux, C++, and OpenCV was what I was looking for, so I felt good about the challenge of the assignments.

Overall, the assignments were just about right, but get into them sooner. Front-load the course a little more to relieve the pressure and rush at the back-end. People can handle being lost, if it's at the beginning of the course."

"I felt the assignments were challenging at times but always interesting enough to be worthwhile. If possible, an assignment covering robot vision and how software would actually interpret an image would be interesting. I also think more assignment with the LabRat would be very interesting and will probably be more possible next now that Rev. 1 is done."

"Overall they seemed alright. The first couple player-stage projects were kindof a pain just in dealing with player-stage and its lack of documentation.

The turtle assignment was a bit tough to figure out something to code that hadn't already been done. I liked the computer vision assignment, except for using matlab. I think it would have been a bit more interesting to use opencv. HW5 was a bit tough, especially for people that haven't programmed microcontrollers since cpe213. I think people would have had more success with this one if it wasn't thrown in so close to the end of semester."

"The assignments were (for the most part) incredibly easy. They were this way because of their loose requirements. Now don't get me wrong, I like easy assignments as much as the next person, it just was not very challenging.

As a side note, I think there's something wrong when someone can sit down on the last day of class, finish every assignment and turn it in for full credit. It doesn't encourage people who actually get work done on time to do the work in any sort of timely manner (although I'm sure you already know this)."

"I liked how varied the assignments were. Also, I liked the simulation assignments, they were pretty neat.

The other assignments were pretty tough though. The worst that I could imagine, would be someone having to learn C, Matlab, and Logo. For me it was just Matlab and re-learning Logo, but because the homeworks were so varied, it took a lot of work before I could really start doing anything useful. Also, having the due dates be the end of the semester was very nice, especially for the assignments that involve new languages."

Question 4. What was your overall impression of the class? Do you have any other recommendations for us?

"The class was good. It seemed like in some ways the class was stuck in the middle ground between a beginners class and an advanced class. (i.e. some of the assignments were a bit complicated for a complete beginner, but an advanced student should not need to be taught about basic sensors.)"

"I enjoyed the class quite a bit and would recommend it to anybody who's interested in robotics."

"I like the class very much, it seems time will help smooth out the kinks overall. If y'all use the LabRats again, try to get them out earlier and better customer support.

I enjoyed the class and I hope its a success!"

"I really enjoyed it - I was looking for a way to quickly get me introduced to C++, Linux, OpenCV, and applied machine vision, and between the class and club activities, that goal was fully met. The Labrat project was an ambitious undertaking, given it's state of readiness at the beginning of the semester, but I'm glad you guys pressed on and made these a critical part of the course. Player Stage is good to know, but dealing with real world problems like we had with Labrat was a positive learning experience."

"Keep up the good work on the labrats. I would have like to seen a more powerful uC on the labrat, but for all I know that gumstick deal might do the trick (i have no idea what a gumstick does). I really liked the idea of having a labrat instead of a textbook. Overall, I would say you guys did a great job on the class."

"It was a good course. I'm glad I took it. I saw fliers (flyers? What is the correct term?) on bulletin boards which sparked my interest, but I talked with Chris and he was interested also so I ended up taking it. Glad I did too. It's the first class I've had in three years where I knew more than one other person. So it made for good times."

"This was my favorite class so far at this school (which is why I was able to deal with 8am). I would like to have a career in robotics of some kind and I think this class prepared me for it more than any I will take for a long time."

"Your class is one of the most enjoyable ones I've taken at Rolla. You knew what you were talking about and actually care about the subject matter which goes a long way to making a course worthwhile."

"If there were a major in robotics, this would be [the introductory computer engineering class].

Teach it again?"

The instructors analyzed each comment and developed a numeric response from each student for each question. The scale used is listed below:

1 - Horrible

2 - Poor

3 - Ok

4 - Good

5 - Great

	Question 1	Question 2	Question 3	Question 4
Mean	4.1	4.0	3.0	4.4
Std Dev.	0.99	0.91	1.22	0.61

Table 1. Feedback Analysis

Discussion

Question 1

The students overwhelmingly supported the decision to show videos at the beginning of class. The feedback indicates that this dramatically helped wake everyone up for the early morning class. The videos also showed practical demonstrations of the lecture at hand and of robotics in general.

The overall structure of the presentations received good reviews, receiving an average rating of 4.1. Several students mentioned that the instructors used the slides for reference, as intended, rather than reading from them or teaching to them. Students also welcomed the open nature of the course as questions and discussion were encouraged at any point.

Some students mentioned that lectures earlier in the semester were worse than later ones. This was due to the instructors' inexperience lecturing at the beginning of the course. The students mentioned that lectures were better as the course progressed. Some students wrote that the lectures should have contained more practical material relevant to the assignments. This will be included in the next iteration of the course.

Question 2

In general, students seemed to enjoy the topics covered in the course since they gave an average rating of 4.1. There were some strong recommendations to cover more mechatronics and robot design. Most of the recommendations were to cover more material relevant to the assignments. To this end, the instructors plan to use more Player/Stage and LabRat examples in the next iteration of the course. The instructors also plan to present more concrete examples in lectures and, whenever possible, work through complete problems from beginning to end.

Question 3

This question received an average rating with the largest standard deviation of any of the questions. One student said that the assignments were too easy and another said they were too hard, but most of the students agreed that there were a wide variety of assignments that could be accomplished in the time allotted. Most students were thankful that the instructors were lenient on deadlines. Many students appreciated the variety from an interest standpoint but did not like that they had to learn four different environments (Player/Stage, Matlab, StarLogo and AVR C programming) to complete the course. The instructors will work to unify the development environment to make this easier on future classes. It would be possible to write a Player/Stage replacement in something like Matlab or Python to ease student programming; however, this is a large project and would not answer all of the students' comments about lack of realism in simulation. It would be easiest on the instructors to require that the image processing and swarm intelligence assignments were all done in C or C++, possibly using open source libraries like Open Computer Vision (OpenCV). This would make programming somewhat more difficult, but with some good examples from the instructors it should be easier than learning new systems and would only require the students to know C and C++, as these languages are taught to undergraduates early in the computer science/engineering curriculum at Missouri S&T. Instructors will also assign some non-programming homework in the next offering of the course, particularly in the kinematics section.

Almost every student wished that the LabRats were completed earlier so that more work could be done with them. Most liked that the robot replaced a textbook but one in particular felt that he probably would not use his again and would rather have not purchased it. Each student was given a choice to purchase a LabRat; the instructors loaned three to students who did not wish to purchase one.

Question 4

Several students said that this was one of the best classes or the best class they had taken at Missouri S&T. Some students even indicated they would not have woken up for an 8:00 AM time slot for any other class. The average rating for this question was 4.5 with the lowest standard deviation, so the class was a success and most students seemed happy with the results. Most students said they would recommend the course to a friend, and some have already done so.

Conclusion

Based on student reviews, student time investment, and the quality of student work, the instructors consider the first offering of the Introduction to Robotics class at Missouri University of Science and Technology to be a great success. It has been shown here that modern teaching methods, open technologies, and hands-on, project-based assignments can create an exceptional learning experience for all involved. Continuing in a philosophy of openness, all course materials are made publicly available at the links below, and all future instructors and students are invited to copy and contribute to this living course.

Course Materials:

http://introrobotics.googlepages.com/home

http://en.wikibooks.org/wiki/Robotics

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