Designing an Online, Distributed, Project-Based Course in Mobile Autonomous Robotics

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Abstract

We are currently developing an online, distributed course in mobile autonomous robotics for high school students. The goal of the project is to greatly increase access to a version of the project-based Robotic Autonomy Course, which has been successfully taught during the last two summers at Carnegie Mellon's West Coast campus. We're attempting to make enough structure, help and motivational energy online, so that students can work with relatively light onsite coaching and supervision, with expert mentoring and evaluation of the students' work done from a distance.

Making High Quality Robotics Education Widely Available: Valuable but Challenging

A high-quality, project-based course in mobile autonomous robotics has the potential to be an extremely valuable addition to the high-school curriculum. Aside from the opportunities that the future is likely to hold within the field itself, robotics – especially when it involves autonomous mobile robots with advanced sensing (such as vision) can provide a concrete and motivating means to situate projects that integrate a broad range of important subject areas, including math, computer science and programming, electronics and electrical engineering concepts, and mechanics and mechanical engineering and other areas a host of other topics such as human visual processing the study of visual processing. Robotics is also an exciting way to introduce students to the challenge of innovative problem-solving, as it represents an area where relative novices can work on problems that are not far removed from the state of the art [1].

On the other hand, some of the very things that would make robotics a valuable addition to the high school curriculum make it very challenging to offer such a course. First of all, the fact that a single robotics challenge typically brings together multiple disciplines makes it difficult for many schools to provide highly-expert instruction in all the requisite areas. Add to this the fact that since robotics is not currently part of the core curriculum in a typical school, enrollments can be limited in a way that makes it difficult for many schools to justify hiring the specialized staff needed to teach such courses. Furthermore, the excitement of robotics is its hands-on nature, implying that good robotics courses are project-based courses. These are extremely demanding to design well and to deliver. Finally, there's the hardware costs involved; however, the trend in that area continues to be favorable, and we have found that it is now becoming possible to provide students with relatively robust and affordable robotics platform that is sufficiently capable to support a very adequate range of projects.

Addressing Challenges to the Delivery of High Quality Robotics Education

We are attempting to overcome the challenges (outlined above) to unlocking the potential of widely available high-school level courses in autonomous mobile robotics.

Because those challenges outlined above are themselves rather multi-faceted, their solution also brings together a number of strands of work, three of which we'll briefly discuss in this paper.

We make use of a robotics platform, called the Trikebot, which has been explicitly designed to affordably facilitate the exploration of the core issues in mobile autonomous robotics. This platform was originally designed by (Hsiu et al. [2]). The Trikebot is a simple 3-wheeled robot, designed specifically for use in this course, equipped with a CMOS vision sensor (the CMUCam) mounted on a head that can pan and tilt, along with an infra-red rangefinder and back-emf speed control.

First, we build on key lessons that we have learned teaching an onsite summer course for high-school students during the summers of 2002 and 2003. The curriculum for this course (first developed and taught by Prof. Illah Nourbakhsh and later adapted during the second summer Prof. Mel Siegel, Prof. Khalid Al-Ali and ourselves) takes the students through a carefully-crafted sequences of challenges; beginning with the process of building the robot from a kit and progressing through an increasingly complex series of programming challenges, through during which students learn to employ sensors, control actuators, and execute navigation strategies. The online course curriculum represents an attempt to preserve the most successful aspects of the onsite curriculum, while filling gaps we've discovered while delivering the course, and also adding the extra support necessary to translate the onsite success into a distributed course.

Second, we make use of a robotics platform that has been designed explicitly to affordably facilitate the exploration of the core issues in mobile autonomous robotics.

And third, we leverage a relatively rich advanced model of project-centered, Web-based, project-centered curriculum delivery that we've already had experience deploying with Master's students at Carnegie Mellon University and in a few pilot projects at the high-school level in areas other than robotics. The "Story-Centered Curriculum" approach provides coherence and motivation by weaving assignments into an appealing story in which the student plays a central. For the robotics course, we use the story of a startup company seeking to develop emergency services robots and put the student in the role of a newly-hired robotics engineer.

The Platform

The Trikebot was designed with the primary objective of providing a low-cost, robust and versatile robot programming platform for the students. The Java API provided with the kit allows abstraction of the underlying electro-mechanical system, so that students are free to focus on programming at the algorithmic level. The inexpensive CMUCam vision sensor allows novice roboticists to explore the interesting issues involved in visual processing. The mechanical design is simple enough that any student can take it apart and put it together easily. The platform contributes to a feeling of competency, allowing students to feel confident that they can easily repair broken parts or replace them with off-the-shelf components.

The Trikebot is thus well-suited to a course in which the student's job is to understand the basic embedded electronics and the mechanics involved in mobile autonomous robotics, and then to focus primarily exploiting this hardware to program complex sensing and navigation behaviors. It is not as well suited for having students redesign the hardware platform. It was designed to be simple and easy to program, not to be easily extensible or modifiable. This is reflected in the curriculum used in the onsite summer camps. The same emphases are being stressed in our online course.

One surprising lesson that we learned about working with the Trikebot during the onsite course is that the ease with which one can assemble and wire up the components of the Trikebot can actually be an educational detriment if the curriculum is not carefully designed; it is possible to rush through the assembly process without fully understanding what one is doing, which some of our students, in fact, did. This represents missed opportunities to learn and also makes diagnosis (and debugging) of hardware problems that crop up later much more difficult. In the online curriculum, we are addressing this problem by putting a much greater emphasis on the initial assembly of the robot's "neuro-muscular system"; having students work through an extensive series of challenges that require them to wire components up and work with them on the laboratory bench before they even begin to build the robot skeleton.

Building on Our Experience with The Robotic Autonomy Summer Camp Carnegie Mellon University (CMU) has held two annual, 7-week, full-time high-school robotics camps at the NASA Ames Research Center, during the summers of 2002 and 2003[3].

The camps assumed rudimentary Java programming skills. The main goal was to provide selected high school students with an immersive exploration of mobile robotics using leading-edge technologies. The curriculum designers sought to present the complexity of mobile robotics incrementally and in a step-by-step fashion through a series of Challenges and Contests. Challenge projects encourage students to learn theoretical ideas in the context of augmenting their robots' capabilities. Contests are playful competitions between different teams that push the student to perfect the skills acquired in the previous set of challenges, thinking beyond the basic algorithm, and making improvements to their code and/or mechanical design so that their robot outperforms the others.

A significant portion of the teaching during the on-site course is given 'on the fly', as individual students and/or groups confront challenging problems that raise interesting questions. Therefore it is not possible to simply make the formal presentations given on-site and call that an online course. To be effective at supporting more independent work, an online course must make much more material explicit than is formally presented to students. For instance, detailed project requirements; a discussion of what makes a really good (as opposed to merely passable) solution; and hints and pitfalls to be encountered during the task, all must be made explicitly available whenever students need it.

The integrative and cross-disciplinary nature of robotics is part of what makes it intellectually exciting. However, this can also make it especially challenging for novice students to sort out what's happening when things go wrong.

One lesson we learned when teaching the onsite course is that debugging, which is difficult for high school students to do in pure software systems, can become overwhelming when the hardware and software are both involved in the debugging processes. We have found that students find it challenging and sometimes frustrating to think about where in the system the problem is originating –whether in the code, or because of real-time issues or because they are pushing the underlying electronics beyond their designed capabilities. Students need explicit help learning how to break a complex system down into pieces that can be analyzed, implemented and tested, and debugged independently. This involves guiding students to doing at least three things:

1. Considering what sub-tasks the assignment should be broken down into. This involves a systems-level perspective of the problem at hand.
2. Determining the most straightforward way to test each of these modules before adding them to the overall solution.
3. Identifying possible sources of error (either in the individual sub-systems or in the final design).

Leveraging the Web

A key part of our long-term strategy for making a rich and engaging robotics learning experience widely available is to leverage the World Wide Web to provide engaging assignments, high-quality multimedia explanations, and the means to communicate with distant mentors.

The instructional design methodology employed in the Web-based robotics course which we currently have under development calls for providing all instruction in the context of projects. Our intention is to provide the student with a motivating series of assignments, and to support them very richly with various forms help and instruction, all provided on an as-needed basis: either in response to student requests for help, or in response to the review of the student's initial attempts to perform one of the assignments. The assignments all fit into a coherent story, and each assignments results in the implementation and demonstration of some enhanced robot functionality. There are no examinations separate from these assignments. In the remaining space available to us, we attempt to illustrate how both the assignments and the associated help and advice are presented.

Assignments situated in a story

The Web-based course involves the student in the story of a fictional startup company, "Robots to the Rescue" (RttR), which intends to take the world by storm through the introduction of a new, low-cost emergency-services robot, based on the Trikebot design. The student is inside this story, playing the role of a Robotics Engineer, responsible for carrying out a multi-phase technology prototyping plan as the company has promised its investors.

Before the new "robotics engineers" are allowed to work with the robotics hardware, they are told that they must complete a robot-programming training sequence. This is a series Java-based programming assignments in which students control a simple on-screen simulated robot. The "Simbot" has a simple simulated sensor, and can turn and move over an on-screen playing field that can be set up with obstacles and targets. The training assignments assume no programming background and are designed to develop basic programming skills in the context of a task that resembles (albeit in simplified form) the programming of a real robot. The API provided to control Simbot is a simplified version of the API that students will then go on to use to control the real Trikebot.

After students complete the programming assignments with the Simbot, they are introduced to the robotics hardware gradually, through a series of assignments that require them to build up the "neuro-muscular" system of the robot step by step, on a breadboard, rather than on the robot chassis, so that they can more easily understand what each component does, and how the components are connected. They are asked to do some simple programming of each component as they wire it up, to demonstrate the functionality of the components to their company's nervous investors. The idea is ensure that students really understand the wiring and functioning of the components as they go. At the end of this phase, they have wired up all the electro-mechanical components, and learned the basics of how one operates each under program control. The next steps are to build the chassis (which is a fairly simple process with the Trikebot), and to install the electro-mechanical components on the assembled chassis.

The remaining phases of work involve programming navigation behaviors that allow the Trikebot to carry out various emergency-services assignments autonomously. The work progresses from tele-operation, through the use of simple sensors, to the use of complex combinations of sensors, including vision. It is explained to the student that the investors in this company are very nervous about their investment, so they will need frequent demonstrations to convince them that everything is on plan and that robots really can do what the company's management claims. For instance, building the robot, the students are asked to demonstrate tele-operating the robot in a timed attempt to defuse bombs in a simulated hostage situation.

All the student's assignments in the course come in the form of video/text emails from various bosses at RttR, as illustrated in Figure 1. This sequence of video email assignments forms the backbone of the student's learning experience. The story, and the way it is delivered to the student by the 'characters' in it are meant to add a human touch and to keep motivation up.

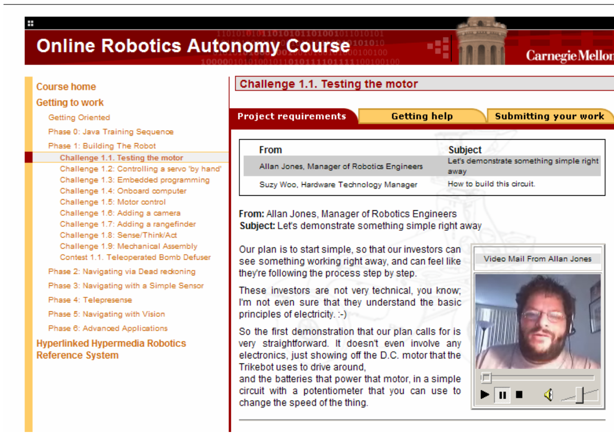

Figure 1: Simulated Email Message from boss presenting student assignment

Help and instruction are provided in several different forms:

The first major category of help is provided from within the online course. These include several sub-categories of help:

- Specific pointers about how the hardware and software work are included in simulated emails from RttR's technical experts.
- A Plan of Attack for each assignment, with explicit tips and warnings, are included on the 'Help' tab associated with each assignment. (see Figure 1 again). These plans of attack will include detailed advice about the projects, especially including some of the skills that we learned needed more attention in the onsite course, such as subdividing the problem, and testing and debugging plans.
- Extensive theoretical and conceptual help is provided in the online "Robotics Knowledge Center", (depicted in Figure 2) which is essentially a multi-media robotics help and reference system. This includes many videos (currently about 150 clips, ranging in length from 30-seconds to several minutes) of robotics experts answering anticipated student questions and making key visual demonstrations.

The second source of help will include an onsite coach (often a high school teacher). This person is likely to lack in-depth robotics expertise but will be able to answer basic questions, ensure that students are keeping up with assignments and keep students from doing any accidental damage.

The final source of help and feedback will come from the expert mentors who may not be onsite. The Web site mediates communication with these mentors (via the third "Submitting your Work" tab, shown in Figure 1).

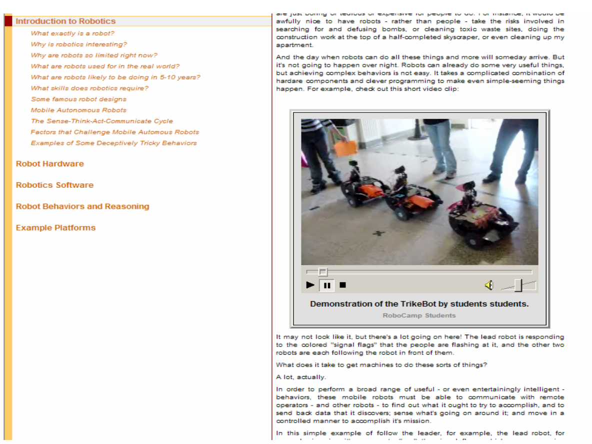

Figure 2: A typical screen for the simulated multimedia reference system

In order to address the issues mentioned in the previous section and improve the students' understanding of the operation of the electro-mechanical components (as well as the underlying theory) the online curriculum takes a much more step-by-baby-step approach to the building of the robot than we took in the onsite course. As Figure 1 illustrates, this phase has been broken into 10 distinct tasks, culminating in a contest in which they show off how well they can tele-operate the robot. After each task is complete, the student submits the results, including code, written explanations and perhaps drawings or video, to their mentor(s) using the interface provided by the site.

Conclusion

Versions of this online distributed course in mobile, autonomous robotics are expected to be piloted in various forms during 2004. The course will be refined in accordance with lessons learned during those interactions with students. A number of interesting questions remain relatively unexplored, such as what the best way is to train and support local mentors, and how best to facilitate interaction between students at distant sites. But none of these seem like show-stoppers. We believe, based on our experience using this Web-based paradigm in other areas, as well as our experience teaching robotics to the intended audience in the onsite camp, that we are on a very exciting track toward creating just the set of materials needed to open up the world of the project-based robotics course to a broad distributed audience, without requiring very specialized expertise in any local teachers.

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