Using Autonomous Robots to Improve University and Two-Year College Courses and Attract Secondary School Students to Science and Engineering

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Abstract

Two undergraduate laboratory courses using small autonomous robots have been developed to demonstrate control theory and learning, and as a vehicle for teaching mathematical concepts. One course is taught in the Bioengineering Department at Binghamton University. The other is taught in Mathematics at Broome Community College. The bioengineering lab consists of several modules that demonstrate concepts in classical control theory, fuzzy logic, neural network control, and genetic algorithms. The mathematics lab consists of using the robots to teach vector concepts.

The autonomous agents are easy-to-build, inexpensive kit robots. Each robot functions independently in a real-world environment. Students program and retrieve data wirelessly using handheld computers. The hands-on nature of the lab modules engages students in ways that lectures, readings and software simulations cannot. By interacting with these robots, students directly experience the effects of unexpected environmental factors on designs and deviations from software simulations.

The robots are easily adapted for use in many different aspects of K-12 STEM education. Data from computer programming classes in two local secondary schools are presented as examples. Students are motivated to understand engineering, math and science principles in order to control the robots.

Time and again we have seen students unable to integrate knowledge and skills from one course or section to another. All too often our educational system does not require students to apply their knowledge and theory to real-life situations, to solve unstructured problems, or to go beyond clear-cut textbook examples. Engineering students have a disturbing tendency to compartmentalize their knowledge by the courses they have taken. The Society of Manufacturing

Engineers summarizes the results of a 1999 survey concerning competency gaps in newly hired engineering undergraduates:

> The greatest single gap is their ability to structure problems from real messes. They're great if somebody else gives them the problem – they'll find a solution. But it isn't the solving, it's the structuring, it's getting the right problem definition …"; "One of the things we see as an issue is the lack of hands-on skills and the application of the theory that's learned in the schools.[1]

To address this issue, we developed an autonomous robots laboratory course with six self-contained lab modules that can be used to incorporate active learning into engineering and mathematics programs. Being able to see, touch and interact with entities that demonstrate complex and autonomous behavior is exciting and appealing for students, and it encourages them to integrate their knowledge and skills in a hands-on environment in order to control and manipulate the robot behaviors.

It is important to emphasize that we are not using the lab to teach students about *robots, per se*, but rather to develop lab modules that will use the excitement and interaction with the robots to reinforce other concepts, especially key concepts in bioengineering, such as, the importance of interaction with the environment, feedback control in the face of inherent instability, and, the effect of variation of control algorithm on patterns of behavior. We believe that these key concepts can be well understood through working with and experiencing the behavior of autonomous robots. Furthermore, as in most labs, students work in teams, providing the opportunity for *cooperative learning*, which has been shown to greatly increase the effectiveness of learning.

There is a great deal of research showing the value of using techniques such as Active Learning (Learning by Doing), Affective Learning, Goal-Based Learning, and Role-Playing. A few general sources on the benefits of this kind of learning are included in the bibliography. Silberman, for example, describes studies showing that students in lecture-based classrooms are not attentive about 40 percent of the time.[2] The most effective kind of learning comes when students are involved in immediate, direct, concrete experiences. Felder and Brent point out that after ten minutes the attention of most students begins to drift and by the end of the lecture they are taking in very little and retaining less.[3] Similarly, Roger Shank, Director of the Institute of the Learning Sciences at Northwestern University, argues that the reason Learning by Doing works is that it strikes at the heart of the basic memory processes upon which humans rely.[4] Students taught with cooperative learning tend to exhibit better grades on standard tests than students taught conventionally, as well as showing better analytical, creative and critical thinking skills. They also demonstrate deeper understanding of the material and greater intrinsic motivation to learn and achieve.[5]

The objectives of this project are:

1. Develop an active and affective learning tool using autonomous robots to apply to STEM education.
2. Ensure the robots are sufficiently inexpensive and robust enough for community outreach. (Each robot will be able to be purchased or constructed as a kit for a cost of less than $500.)
3. Develop lab modules for teaching the role of the environment and real world interactions in undergraduate bioengineering and reinforce understanding of complex and emergent behaviors.

In this paper we will describe the bioengineering course at Binghamton University in which the autonomous robots were used. Next we will describe the robots themselves. This will be followed by a brief introduction to the software written for the robots and the GUI's used on the Pocket PCs. The implementation of the course is discussed. The paper will end with a preliminary evaluation of the effectiveness of the robots in the course.

The Course in the Curriculum

The major motivation for developing this lab is for use in an innovative new bioengineering undergraduate program.[6] Binghamton University has recently created a Department of Bioengineering within the Watson School of Engineering and Applied Science. Robotic autonomous agents provide an unusual and fascinating tool for interactive, cooperative active learning. Robots are fun and captivating to students. Working with robots involves hands-on interaction where the students predict behavior, are often surprised by the actual behavior, and then revise and try again. These are the kinds of experiences that research shows will lead to learning. In addition, the robots give us a unique opportunity to demonstrate real-world aspects of systems that are not possible using pure simulation.

The robot modules were developed for a junior-level elective course, BE 380B, *Autonomous Agents with Lab.* The course will become a required senior course during the 2006-2007 academic year. In *Autonomous Agents with Lab*, students will have the chance to see the various concepts of autonomous systems that they have been learning about via simulation taken to another level as actualized in the real world. Much of biology is modeled in computer simulations, this lab will give the students a rare opportunity to take these concepts out of the world of computer simulation and see them physically instantiated in a real environment with real randomness. One of the objectives of the autonomous agents course is to give the students experience and a deep appreciation for the role of the environment in real-world systems.

The Autonomous Robots

Over the past decade research in robotics engineering and applications has seen remarkable advances. Numerous academic, commercial, and governmental programs have been developed to attract and train individuals to fulfill the needs of this growing field.[7] However, despite the multitude of robotic programs, the majority of the undergraduate educational initiatives in robotics have been directed toward robot design, construction, and implementation, while strategies of machine learning and intelligence and group dynamics are left to graduate studies and research programs.[8] Thus, our use of autonomous robots in an undergraduate curriculum as an educational tool to explore characteristics of autonomous agent systems is genuinely unique. It is especially distinctive in that we are using the robot lab to demonstrate many of the characteristic features of intelligent biological systems.

Several commercial robotics platforms are available for educational purposes. For example, LEGO *Mindstorms* have been used for educational purposes from grade school to graduate study.[9] But, while these platforms offer a great degree of flexibility in robot design and programmability, effective communication is not easily achieved. Commercial platforms such as *Khepera* from K-team[10] and *Garcia* from Acroname[11] have sophisticated communication that facilitates complex collective behaviors. However, with these additional features there is a substantial cost and an increase in robot fragility.

As an alternative to these platforms we developed a new robot design that maximizes effective exploration of complex adaptive behaviors of autonomous agents while minimizing the technical expertise of students, remaining cost effective and mechanically robust. We refer to the basic design as a "BIObot." The BIObot design is based on the Autonomous roBot controllEr, A.B.E., board developed by Abe Howell's Robotics.[12] The A.B.E. board provides the "brains" for BIObot and allows students to control it wirelessly using a Bluetooth™ equipped handheld computer, cell phone, laptop, or desktop PC. A total of five infrared obstacle sensors (three in front and two in the rear) supply BIObot with the ability to sense its environment and perform such tasks as obstacle avoidance and wall following. BIObot can sense the amount of light in its environment with two frontward facing light sensors. Students are able to control the motion of BIObot using three different methodologies: closed loop position, closed loop velocity and open loop velocity. When using closed loop position the number of encoder ticks for each wheel must be supplied and BIObot will utilize Proportional-Integral-Derivative (PID) position and velocity controllers to achieve the desired position. For closed loop velocity, both wheel velocities must be specified and a PID velocity controller will ensure that the wheel speeds are maintained. These two motion controls are made possible through the use of off-the-shelf low cost quadrature wheel encoders, which have only recently become available to the robotics community. Open loop velocity control requires a power level and direction for each wheel. One final feature of BIObot that is entirely unique has to do with its ability to read and write to passive Radio Frequency Identification (RFID) tags. A suitable antenna resides on the base of BIObot and is mounted parallel to the ground surface. Tags that have been embedded in the environment floor can be read or written to when BIObot drives over top. This ability opens up the world of experiments and allows students to perform "Survival of the Fittest" experiments, where virtual food is placed randomly on embedded tags and robots are empowered with varying levels of intelligence in an attempt to see which algorithm(s) perform best.

The Software

One of the goals of this work was to not only develop suitable lab modules, but also transfer the student's focus from programming over to the concepts or theories covered in lecture. (See Table I.) To achieve this we created software specifically designed for each of the lab modules. This software was created for handheld computers (Pocket PCs) to make the labs highly portable. Students are able to execute an entire laboratory by using the appropriate software, Pocket PC (PPC), and a BIObot. For example, during the Simple Behaviors lab students utilize a program named "BIObot Behaviors (BB)" and are able to create simple rule based behaviors and finally execute them using the robot.

The program logs all data with regard to inputs and outputs while a behavior is executed. This affords students the opportunity to focus on observing the robot and afterwards they can review the logged data to see how or where they can fine-tune their system. This becomes a necessity during the Fuzzy Logic lab where there are multiple variables that need tuning.

The use of BIObot makes it possible for software creation in all programming languages that support simple asynchronous serial communication. Users can remain focused on the high level programming aspects instead of getting bogged down with the low level portion. Programs can be created for numerous platforms, for example, Windows®, Linux, UNIX, Mac, etc. While we have created our programs using Visual Studio® it must be noted that the following languages can also be used: Java, Python, C, C++, etc. Furthermore, we have discovered that math programs such as Mathematica and MatLab can also be used to write software for BIObot. Students in the Autonomous Agents with Lab course are required to write a Mathematica program to solve their final project. However, we provide them with a Mathematica template that pulls in all the robot's commands from a dynamic library link (DLL) and creates the equivalent Mathematica function.

The Laboratory Course

The first class of undergraduate students in Bioengineering took this course in the spring of 2006. For this first offering, this course was presented as an elective course, BE 380B. (It will be offered as the required course, BE 470, in the fall of 2006.) Twenty students were enrolled. Course material for the program builds on topics and examples covered in previous courses. For example, in BE 302, *Intelligent and Learning Systems*, students learn to incorporate intelligent behavior into agents through fuzzification of rule sets. In the autonomous agents course, fuzzy logic, neural networks, and classical controls are covered. The lab modules are completely self-contained labs that can be used in other contexts as well as in the course. The course is structured as a two-hour lecture and a two-hour lab each week. There are two lab sections of ten students each and labs are performed in teams of two students working with one robot.

There are seven modules in this laboratory course. The modules are shown in Table I.

Table I. Lecture and Laboratory Structure

Lab	Description	Lecture	Weeks
1	Introduction to the robot & software	Autonomous agents introduction	1
2	Simple Rule-based Behaviors	Built-in learning, simple rules	1
3	Robot Control Methodologies	Reinforcement learning	2
4	Fuzzy Logic	Fuzzy set theory	2
5	Intro. to Neural Networks	Neural networks	2
6	Neuro-Fuzzy Systems	Neural networks	1
7	Genetic Algorithms	Genetic Algorithms	2

The Autonomous Robots Teaching Lab facility is a highly flexible yet moveable lab, which is located in the Innovative Technologies Center at Binghamton University. The lab is approximately 1,000 square feet, with a painted concrete floor, and with moveable tables, benches and storage cupboards along the back wall. The essential part of the lab is the robots themselves, the software modules that will be developed to use them and the relocatable "environments" in which the robots operate. The on-board hardware provides Bluetooth™ communication capability, which allows BIObot to be controlled by virtually all Bluetooth™ enabled devices.

The robots have also been employed at Broome Community College (BCC) where they were used to reinforce concepts in mathematics. Several of the topics covered using the robots are as follows: curve fitting & interpolation, linear functions, geometric relationships, and vectors. For example, using the infrared obstacle sensors and recording the sensor's output for varying distances of obstacle blockage allows students to correlate the sensor output to a distance measurement in inches or centimeters. First, students learn how to interpolate their sensor data so that they can obtain information for data points that are not listed in the chart. Finally, students are required to find a best-fit curve equation for the highly nonlinear sensor data, so that they can easily enter a sensor output value and immediately calculate the obstacle distance. Topics in vectors are covered using a dry erase marker, 22 in. x 28 in. dry erase pad, simple marker attachment, and closed loop position control. Students are supplied with a set of vectors and must command the BIObot to trace out the vectors on a dry erase pad.

Evaluation

Summative evaluation data will be collected regarding:

- Student perceptions of appeal and effectiveness of the autonomous robots (experimental group) and of lectures (control group) as a learning tool.
- Faculty perceptions of the effectiveness of the autonomous robots (experimental group) and of lectures (control group) as a teaching tool.
- Performance measures that assess degree of knowledge acquisition, level of integration of knowledge and depth of understanding of learned material for students in both groups.

Results of the evaluation effort will determine the best means of modifying the program for future implementation.

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