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Abstract

As the practicality of using robotics continues to rise, so do students' (and educators') aspirations to learn and apply them in a variety of ways. This paper outlines a successful approach to marry the interests of a commercial client and undergraduate education in robotics as well as how to establish a vision and supporting curriculum for a robotics program that engages students in meaningful challenges that sustain enthusiasm and helps meet expectations of all sides.

Introduction: Reinvigorate Robotics

Robotic science and systems is a very fast growing area of research and it has significant potential for various applications to include military, security, commercial, scientific (space exploration), academic, social, humanitarian, medical, etc. The primary focus of this paper is on military, security, and academic applications, with an emphasis on using robotics as a teaching tool and to develop pedagogical methodology.

Congress has set a goal for the Armed Forces to achieve the fielding of unmanned, remotely controlled technology such that: One, by 2010, one-third of the operational deep strike aircraft of the Armed Forces are unmanned; and Two, by 2015, one-third of the operational ground combat vehicles of the Armed Forces are unmanned [1]. In support of this, the vision of the United States Military Academy (USMA) is studying and developing *cooperative* robotics systems that work together *autonomously* to carry, employ, deploy or retrieve sensor for a variety of purposes. Examples include improvised explosive device (IED) detection and eradication as well as the emplacement and retrieval of surveillance sensors and networks.

The main tactical advantages of using unmanned systems to find carry, employ, deploy, or retrieve sensors are that robotic systems can take point during convoys, travel in hazardous environments, maneuver in relatively small areas, be utilized in hostile situations, be used as a decoy or be sent to draw out opponent fires or explosives without risking the life of the operator.

There are various research and development interests in academia and industry that focus on the capabilities and potential of robotic systems. However, single unmanned systems provide no redundancy for a single point of failure if only one unmanned system is deployed to perform a mission. Concentrating all payloads or sensors into one system also provides no flexibility. Hence, we are conducting research of cooperative robotic platforms where payloads, sensors and tasks are divided into various specialized modular platforms. These platforms then can be assembled as a team, custom tailored for the various mission requirements.

As the practicality of using robotics in this manner and many others continues to rise, so do students' (and educators') aspirations to learn and apply them in a variety of ways. This paper outlines a successful approach to readily marry the interests of a commercial client and undergraduate education in robotics as well as how to establish a vision and supporting curriculum for a robotics program that engages students in innovative and meaningful challenges that sustains enthusiasm and helps meet expectations of all sides. This paper outlines the partnership agreement, the project creation and the positive impacts of this endeavor on course curriculum as well as relevant proposals derived for future work in cooperative platforms.

Background: Find Partnerships

Our approach begins with a scoped summer internship with a robotics designer and manufacturer, iRobot in Burlington, MA. We chose iRobot because of the mission needs of the US Army they are currently meeting in designing and building robots to destroy IEDs. We requested iRobot to challenge two students to design and build something meaningful for the company that they could also continue to work on back in USMA in hope that the endeavor would meet course requirements to fulfill a two semester capstone multi-disciplinary senior design project. The main goal of this negotiation was to set the stage for a continued relationship, one that would benefit the client's business, the students' education and our evolving robotics program in terms of relevant focus. Within days, iRobot responded with a challenge to do the following:

> We believe that a need exists for a "Cheapbot" - a very low cost robot which can be used to check around the corner or inside a building without risking a soldier. It needs small size, light weight, good speed, the ability to climb obstacles and have video & 2-way audio.
>
> We will task the cadets with creating a proof-of-concept vehicle using technology currently in iRobot's inventory. iRobot engineers will advise and critique the cadets as well as train them up on the design and operation of our in-theatre military robot; the PackBot.
>
> The cadets will be exposed to all of the issues common to robot design: ruggedization, power management, thermal management, electronic integration and user interface design. By the end of the project they will have a good understanding of what it takes to make a truly useful robot and what the design tradeoff issues are. And we will have a proof-of-concept system that we can use to evaluate the idea.

Collectively, we agreed to design and build a robot for a particular purpose, one that met the marketing interests of the client and the learning objectives of the academy. Given that there is a growing number of robotics designer and manufacturers, we believe other universities should be able to achieve similar offers and agreements. Perhaps the most critical aspect in carrying this type of arrangement through is a show of good faith in providing feedback and results of efforts. One possible sticky area may be an agreement ahead of time on how and to what extent the exchange and ownership of intellectual property should be handled. This is an issue most appropriately handled by the university's legal office.

Approach: Project Relevance

Robotic science and systems is a truly multidisciplinary field of study. Within this field, our robotics-related research deliberately addresses fundamental issues in the areas of cooperative robotic systems. As such, proposed activities include faculty and undergraduate basic research, academic classes to develop and support the baseline knowledge, and industry/military training. These experiences give our students a well rounded education and better prepare them to manage technology in the military.

At USMA there are various departments, such as Electrical Engineering and Computer Science, Mechanical Engineering and Systems Engineering that are already working with some aspect of robotic science and systems. Each of these departments provides a broad base and challenging education to students. During their junior and senior year, students take various specialized courses in their respective disciplines. For concentrations in robotics, electrical engineering majors will take various courses in Power, Microprocessors, Controls, and Mechatronics.

One of the most difficult and rewarding undertaking in the teaching profession is to motivate and inspire students to learn. There are numerous examples to motivate students [2]. Various strategies abound to institutionalize this behavior, such as modifying the course structure, de-emphasizing grades, soliciting useful feedback, providing incentives, etc. Lang [3] provides some potentially very effective ideas to try out. We believe that lecturing or a single teaching technique should never constitute the sole teaching technique in a course or even the dominant one; effective teachers use multiple approaches because every teaching method carries with it inherent problems. The most insightful observation from the Lang article is the conclusion that "comprehension lies outside of the classroom." Thus he practices and advocates students reading course homework materials in advance, lecturing highlights for 20 minutes in class and then forming students into groups to work on assigned homework problems.

Given the increasing role of robotics in both commercial and military sectors, our program advocates a similar approach to the study of robotics to even non-engineering majors. For example, non-engineering majors take a three course sequence with the first two courses covering fundamentals and the last course focusing on robotics and microcontrollers. We structure the last course primarily on laboratory time: the first third of the course is 90% lecture and the last two thirds of the course are based on 90% laboratory time. During the last two thirds of the course, we provide students with the necessary references, lecture for the first 10 minutes, and direct their learning using experimentation. We are currently using the *Board of Education Basic Stamp* platform to teach majors and non-majors how to control and integrate various input and output components (such as sensors, speakers, lights, motors, etc.) using microcontrollers. Despite this being the first year robotics were introduced to non-majors as the last of their three course sequence, over 75% of 36 students surveyed indicated that they would recommended their peers to take the class because they believe that using robotics as a teaching tool fits their learning style; robotics not only assisted learning, applied properly it inspires students to learn.

Nevertheless, there are various learning styles, they vary from person to person, and most people have many of them. McKeachie reflected that too many teachers think of students as a featureless mass; too many rarely vary their teaching methods, thinking that the method by which they were taught is best for everyone [4]. However learning styles are preferences and habits of learning that have been learned and everyone is capable of going beyond the particular style preferred. Although learning styles are learnable, they do not impact a student's prior knowledge, intelligence, and motivation Thus, it is important for both teachers and students to realize that learners always encounter many situations that are not adapted to their own learning preference. Consequently, educators need to help students develop the skills and strategies needed for learning effectively even when a teacher does not match student's preferred learning style. Good teaching involves more than communicating the content of one's discipline; a good teacher also needs both to motivate students to continue learning and to teach them the skills and strategies needed for continued learning. Robotics lends itself nicely to this as students are usually eager for the challenge to both design and build a logically functioning machine, particularly when these devices compete against each other. Or, in our case, must cooperate with each other in order to accomplish specific tasks to standard within a specified time.

There are various types of learning styles and strategies described by Felder and Soloman [5] to include how each style of learners could help themselves and how the specific learners could break their habits. Their studies link the Myers Briggs Type Indicator (MBTI) to map a certain type of personality to a particular type of learning style. An interesting anecdote from this is that many institutions tend to push team leaning styles that are very much suited for extroverts, not introverts. This may have to do with the type of students Admission Offices accept into our institutions or that over 83% of the college student leaders are extroverts [6]. In any case, we have found that working in teams for cooperative related tasks in robotics is a comfort zone for extroverts and introverts alike. The students want to succeed but they do so only as teams and only if their robotic platforms cooperate with each other. Effectively, no student is singled out as a winner or a loser; they are measured by how well their robots work together to accomplish a task.

To provide our students opportunity to learn from various learning styles and infuse that back into their course work, students are selected after their junior year to go on an Academic Individual Advanced Development (AIAD) internship for three to five weeks with an industry partner or military installation. Students are expected to see the development of technology research first hand as well as an engineering design, build and analysis process to better prepare them for their senior capstone projects. This is why two of our students (CDT Gavin McMahon and CDT William Lee) were selected to perform their AIADs at iRobot.

When they arrived iRobot advisors presented the students with the task to develop a "cheapbot" (previously mentioned) with the following constraints: low cost, commercial off the shelf components and user friendly. In addition, the students had to conduct a business and market analysis to determine if there is a market for such a robot. Within five weeks the students designed and built their "COTSbot" (commercial off the shelf robot) prototype derived from available kits and a plausible market analysis. The students' COTSbot performed so well and their return on investment (ROI) for the use of these robots proved so convincing that the shareholders of iRobot have since insisted that similar ideas and prototypes be presented. For example, the students proved that an effective and versatile version of a COTSbot can be built for approximately $1000. They made the case further that if one out of eight police cars (local, county and state) carried such a device, then the ROI would be in the tens of millions. Their estimate did not include other similar state and government agencies or the armed forces who would benefit from the same technology. iRobot has since requested to host more students from USMA on an AIAD and further involvement with cadet design projects.

Figure 1
Cadet "COTSBot" Prototype

The bigger success story is the fact that students learned and enjoyed their AIAD so much that they decided to continue pursuing the robotics area of study during their senior year. The cadets approached faculty on their interest and the faculty conducted an independent study course on Microcontrollers and Microprocessors for the students. This development supported the students' interest as well as improved their knowledge of robotics to assist in the design and construction of cooperative robots for their capstone project. During their senior year at USMA the engineering majors have to take a two semester course on capstone design [7]. Presently most engineering projects are interdisciplinary, and we encourage interdisciplinary capstone design projects in our department. Robotics lends itself very well to the pursuit of interdisciplinary design in that it is very important to have the mechanical, electrical and systems engineering as well as computer science students work together towards the same goal. These teams learn to appreciate the complexity of their project and all the disciplines required to make it successful.

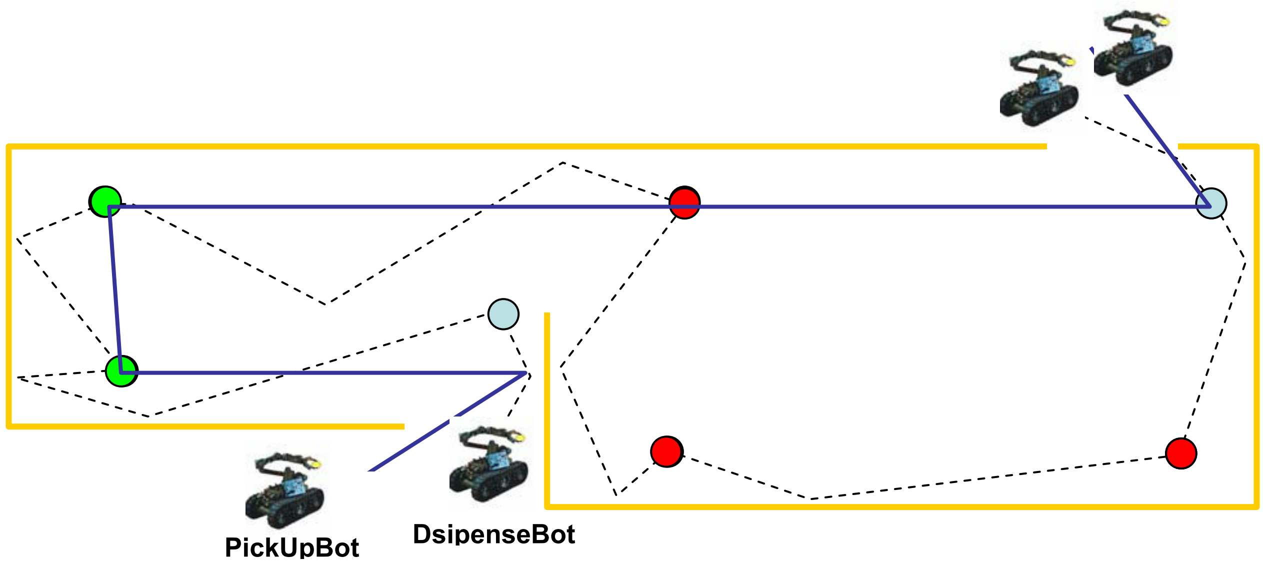

Figure 2
Cooperative Robotics Challenge

Since there was so much enthusiasm generated from the AIAD at iRobot, students persuaded faculty to offer an interdisciplinary capstone design project in robotics. The notion of cooperative robotics comes from the US Army's vision for Future Combat Systems to provide the same services soldiers do using unmanned vehicles and a variety of specialized robotics platforms. The current project is named HAGAR (Hordes of Autonomous Ground and Ariel Robots.) The project goal is to build two robots that cooperatively perform a task autonomously. Figure 2 provides an illustration of the challenge faced by HAGAR. The team must build and program one robot to logically and autonomously dispense several sensors within a room of unknown size and configuration and have it transmit sensor location information back to another robot that will retrieve a subset of the sensors distributed, all within a given period of time. An example of HAGAR's requirements model is provided in Figure 3 to show the interplay between electrical engineering and computer science. If Team HAGAR succeeds, the students plan to compete in the MIT Soldier Design Competition and submit their undergraduate research to NCUR as well as a graduate level conference.

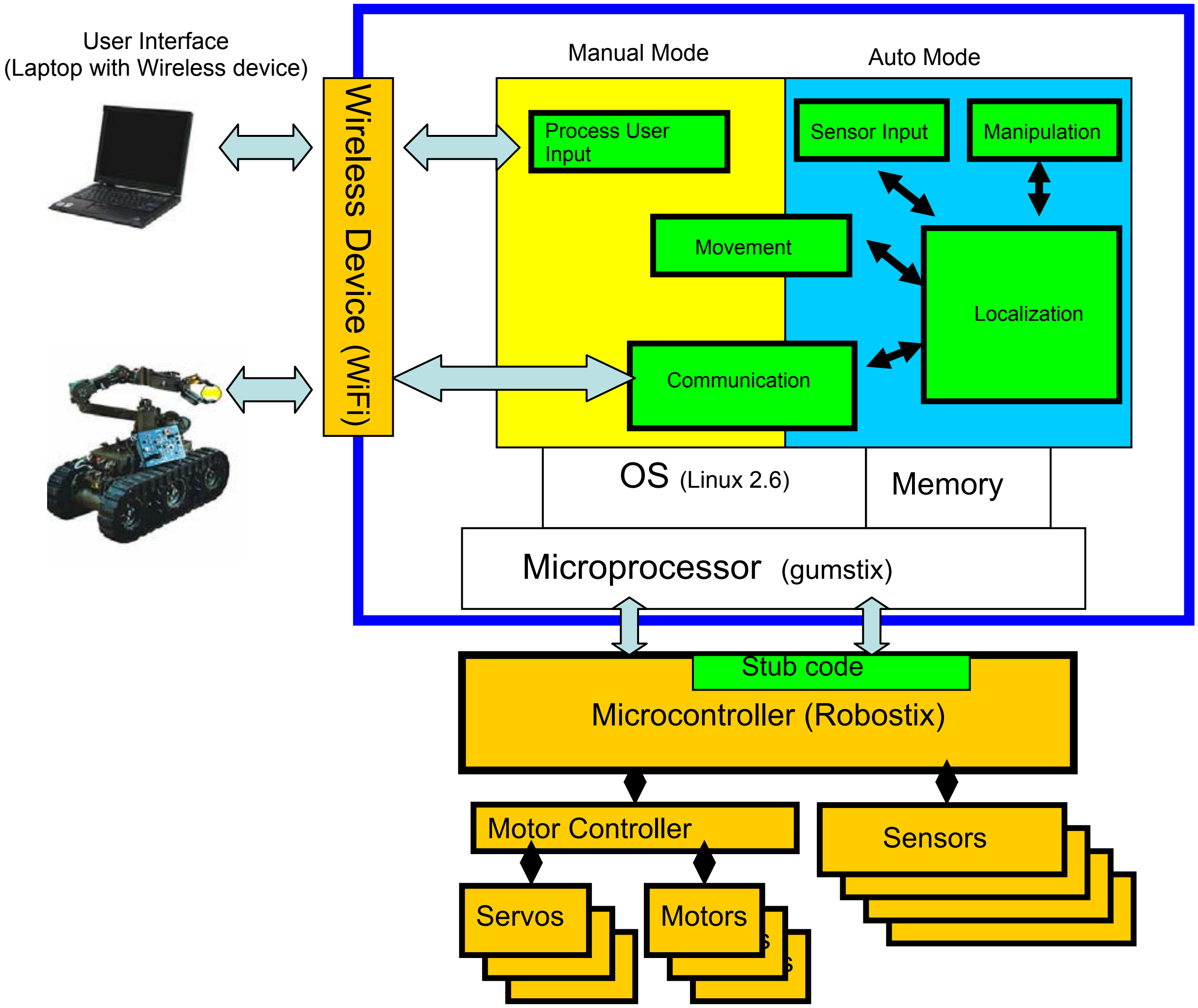

Figure 3
Typical Robotics Requirements Model

Partly as a result of the enthusiasm surrounding the videos taken during the iRobot AIAD, emphases and examples provided by faculty on the increased role of robotics in walks of life and the increased use of robotics during the electrical engineering and computer science department recruiting demonstration, electrical engineering majors doubled. Moreover, the majority of these majors enrolled in the Robotics Track (one of five EE tracks offered to EE majors). These students most often cited that the idea of seeing immediate results of their work in building robots to perform a variety of missions was very alluring and conceivably more rewarding than other endeavors. Afterwards the program has again revaluated on how best to accommodate this growing interest and its potential impact upon graduates, the robotics program itself and its relevance in new military applications. Consequently, our program is working with various companies, other universities, and other government organizations to conduct joint research, develop future platforms/algorithms, and design courses to meet the rising demand. Presently, we are attempting to redesign several courses to use one robotics platform. This will assist in coupling the courses and students can conceptualize how the course could be applied to one system. This approach also provides ownership of the system and empowers the students to experiment and be creative with the system outside of the classroom. Figure 4 depicts how these different players as well as the program itself are aligned to support our robotics effort.

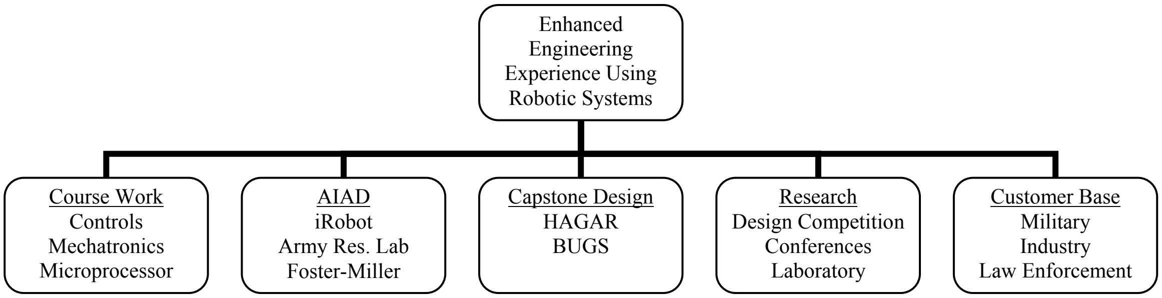

Figure 4
Emerging Facets of the Robotics Program

Contributions: Program Development

In addition to teaching non-technical/ non-engineering majors about electronics and systems by utilizing robotics and microcontrollers, describing the advantages and limitations of this research initiative and capstone endeavor provides guidelines to develop and implement other academic courses. The following table highlights the advantages that have been derived from robotics-related partnerships and emphasis on cooperative robotics:

Event	Advantage	Limitation
1. Internship and partnership with robotics enterprise	• Outreach, exposure and exchange of ideas	• Intellectual property rights
2. Solicitation and creation of multi-disciplinary capstone team in cooperative robotics	• Allows students to share knowledge and experiences from diverse backgrounds • Place for extroverts and introverts	• Not all interested students may be able to participate
3. Creation of a related/complementary independent study	• Complements capstone, capitalize on work	• More time from faculty
4. Capstone course with mandatory project completion	• Develop familiarity with the design, build, and test methodology, preparing students to use this process in future work	• Resources are limited
5. Building prototypes	• Gives students experience and helps them prepare for graduate school and the marketplace by converting theory into practical application • Building a working prototype of this level requires a much deeper understanding of the work at hand	• Resources are limited

6. Market analysis	• Students learn about return on investment (ROI): If their product won't quickly provide a profit margin, a commercial enterprise might not support its development	• Social benefits, while desirable, usually give way to economics • Finding the right economies of scale for a technology to be profitable is an area most undergraduate CS and EE majors have never considered before
7. Engineering Design Competitions	• Incentive and it distinguish them from other undergraduates when applying to graduate school or for a job	• Not ready in time
8. Submitting a paper to a graduate level conference	• Few undergraduates conduct real-world research and fewer still publish before they graduate. • Acceptance provides the authors with an accolade to distinguish themselves in their graduate school applications, and they understand more of what most graduate programs will require from them.	• Mid to lower-tier conferences are the probably the best an undergraduate paper can achieve
9. Renewal and expansion of a robotics program in cooperative robotics	• Provides vision and informs future courses, keeping them relevant as well as meeting the university's goals, as well as some of those of the robotics partner	• Lack of funding

Table 1
Cooperative Robotics Program Advantages and Limitations

Given that this area of research is growing very fast elsewhere, the most prominent limitations at this point have been the number of research personnel and funding to put towards this program in order to keep it relevant and of desirable quality.

Our short term goals are to evaluate existing technology that could make an immediate impact to the operational setting. Our long term goals are to continue doing research and educate our students on the development of coordinated robotic systems to be used in future combat systems. We intend to use this knowledge to stimulate additional interest in other departments, faculty, and students to further study cooperative robotic systems as a combat multiplier and future weapon system.

Future Work: Supporting Activities

As a result of the renewed emphasis in robotics for real missions and the recent successes of collaborative efforts with industry and the subsequent positive impacts on robotics courses and enthusiasm for same, we are in the process of proposing a renovation of our facility to support a robotics lab to 1) test and evaluate existing robotics systems and platforms; 2) conduct research and development of future systems in cooperative robotics; and 3) educate future leaders on employment and deployment of these systems.

The ability to lead and facilitate the research and development of unmanned, autonomous, coordinated and other systems offers potentially significant advantages in important applications for national security. Thus, we are proposing to develop a flexible indoor testbed to facilitate streamlined experimentation with inter-networked agents and sensors for decentralized and networked control in a dynamically rich setting. This testbed would be a multivehicle testbed that focus on testing control algorithms based approach and vehicle coordination schemes. The testbed would consist of multiple autonomous agent platforms that are wirelessly networked and can be commanded remotely. Our proposed research plan is to initially look at performing a coordinated task by cooperation among similar robotic platforms and then move to various different platforms, sensors, and team integration.

Presently we have started to evaluate various small robotic platforms and research algorithms of deploying and retrieving sensors. We intend to implement a small scale proof of concept in the robotics test facility proposed above and then the concepts, software, and algorithms developed could be applied to a larger scale application or operational setting. Carnegie Mellon University has already looked at dynamically formed heterogeneous robot teams accomplishing a treasure hunt task [8]. Thus, we aim to research algorithms for decision making, task allocation, synchronized task execution, allocation of roles amongst agent platforms for the cooperative robots to coordinate and deploy/retrieve sensor networks for IED detection and the cooperative robots could also be utilized as forward detection/warning systems in convoys, decoy or sent to draw out opponent fires or explosives, and explore hazardous environments, hostile situations, or constrained areas.

Conclusion: Lasting Benefits

The preparations before, during and after an internship between USMA and iRobot was leveraged to inform and prepare a capstone multi-disciplinary two semester senior design project that exceeded undergraduate research objectives of both electrical engineering and computer science programs. The benefits of sharing applied engineering and math, designing, analyzing, researching, marketing, learning through hands on and interacting with different disciplines provide not only enthusiasm among students and faculty, they sustain capstone goals sought by the different disciplines as well as the vision of the robotics program itself. The steps profiled in this report can be mirrored elsewhere to facilitate real world research collaboration between equipment manufacturers and academia. Provided robotic projects address real world application needs, more relevant focus in robotics curricula is provided and more undergraduate interest in science and engineering is attained.

Acknowledgement
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Bibliography

1. National Defense Authorization Act for FY2001 H.R. 4205 Section 217, http://www.fas.org/man/congress/2000/hr4205eas.htm, November 15, 2006

2. Davis, Barbara G. "Tools for Teaching" Jossey-Bass, San Francisco, 1993.

3. Lang, James M., "Beyond Lecturing" The Chronicle of Higher Learning, September 29, 2006.

4. McKeachie, W. J., "Learning Styles Can Become Learning Strategies", The national Teaching and Learning Forum, 4(6), 1-2, November 1995.

5. Felder, Richard M. and Soloman, Barbara A., "Learning and Teaching Styles in Engineering Education" Engineering Education, 78(7), 674-681, 1988.

6. Myers, Isabel Briggs and McCaulley, Mary, "A Guide to the Development and Use of the Myers-Briggs Type Indicator", Consulting Psychologist Press, 1985.

7. Jacoby, Grant and Blair, Jean, "An Undergraduate Success Story: A Computer Science and Electrical Engineering Integrative Experience," IEEE Pervasive Computing, August 2006.

8. Jones, E. Browning, B., Dias, M., Argall, B., Veloso, M., and Stentz, A., "Dynamically Formed Heterogeneous Robot Teams Performing Tightly-Coordinated Tasks", International Conference on Robotics and Automation, May, 2006.