AC 2007-2675: DESIGN-ORIENTED COURSE IN MICROPROCESSOR-BASED CONTROLS

Lifford McLauchlan, Texas A&M University-Kingsville

Dr. Lifford McLauchlan completed his Ph.D. at Texas A&M University, College Station. After spending time in industry, he has returned to academia. He is an assistant professor at Texas A&M University - Kingsville in the Electrical Engineering and Computer Science Department. His main research interests include controls, robotics, education, adaptive systems, intelligent systems, signal and image processing, and watermarking.

Design Oriented Course in Microprocessor Based Controls

Abstract

Previously, the microprocessor based control class at Texas A&M University - Kingsville has been taught using lecture based class material and microprocessor simulators to illustrate microprocessor operations and control system issues to students. "However, students learn more and get more engaged in a project oriented learning environment."[16] For this reason the course has been completely restructured to include a practical design project as opposed to only simulations that will enable the students to directly apply the knowledge that they have gained from the course. This experience "will enable the students to gain a greater understanding of the material given a project that will engage them in the design activity."[16] The course has been designated a Quality Enhancement Plan (QEP) course by Texas A&M University – Kingsville due to its restructured format including more student engagement.

In this restructured course, the sensors and controls were developed by four design teams for a small six-legged robot. The student teams assessed the problem and developed one or more solutions. The class used an industry approach to the design. Each team was lead by a team leader. These lead personnel, students, in turn, were responsible to the overall project manager, another student in the class. The students together chose the best design alternative under the constraints, such as scheduling, power, space, costs, and available resources. Each team designed and tested one or more subsystems. These systems were next integrated into the full system. The design teams, thus, gained a better understanding of practical design considerations and integration as well as project management. The students tested the functional ability of the robot in the laboratory after subsystem integration.

The success of the hands-on practical design approach in the microprocessor based control class is clearly demonstrated by student satisfaction, presentations, reports, and overall achievement in the course. The new redesigned course allowed more realistic practical industry based design concepts to be adopted together with more active student engagement.

Introduction

Until recently the microprocessor based control class at Texas A&M University – Kingsville has been taught using lecture based class material and microprocessor simulators to demonstrate as well as to allow refinement of microprocessor operations and control system issues to students. This inherently leads to problems for the students relating the material to real systems and applications. To alleviate this issue, the course was completely restructured to incorporate a more cooperative and collaborative active problem based learning environment. New robotic vehicles and arms were purchased so that students could collaboratively and cooperatively develop, test, and document real systems and issues.

Much research has been done regarding active and problem based learning (PBL).[1-6] Prince states that "active learning is generally defined as any instructional method that engages students in the learning process."[1] Prince further defines three other learning methods which are collaborative, cooperative, and PBL. In addition, Prince states that active learning can be more effective as students generally have a short attention span. Using active learning involves the students more often in the class increasing their attention. Teamwork can be used for cooperative as well as collaborative learning leading to increased communication and interpersonal skills. Prince relates that PBL can lead to "more positive student attitudes" [1] as a result of increased interest in the subject due to the particular problem or problems being utilized to relate the course material. [1,2] Waters and McCracken look at different assessment methods in PBL. [3] One of the problems they note is that PBL is not necessarily repeatable, due to the open ended problems generally used in PBL, which would be highly desirable for assessment and evaluation purposes. Roy *et. al.* instead look at developing a repository of PBL or as they refer to it, "experience based learning (EBL)," material.[6] Their goal is to develop a PBL teaching aid, consisting of notes, lectures, exam questions, to name a few items, that teachers could use to further develop and enhance PBL assignments.[6]

Smith *et. al.* also discuss PBL as well as cooperative learning.[4] They state that in PBL teachers are there to aid, as a guide, students in the learning process. They further relate that positive interdependence is important to cooperative learning. In positive interdependence students must rely on each other to succeed at the given task(s). [4]

Pucher *et. al.* describe two student motivations for learning.[2] These include intrinsic and extrinsic motivations. Student intrinsic motivation means that the students are of their own will interested in the material and problems while extrinsic means that the students receive outside driven rewards such as money, grades, etc. Thus student intrinsic motivation is the one of choice. For this reason PBL should use problems that are of interest to the students or that students choose themselves which should lead to increased student attention and interest in the material.[2]

Hadim and Esche applied project based learning to two engineering courses at their university. [5] They acknowledge that in engineering there is an increased interest in PBL due to ABET. In the ABET EC 2000, ABET has mandated that engineering programs must integrate more design into the engineering courses. In addition ABET EC 2000 also looks at such skills as communication and teamwork both of which can be developed using PBL.[5]

Carroll and Hirtz discussed the use of a solar car design for a multidisciplinary project. [7] They broke the course into three main areas. These are modeling, design, and management. The solar car design project gives the students a practical example to illustrate the principles behind multidisciplinary design.[7]

Robots have been used in many microcontroller courses to enhance student learning and illustrate design problems. [8-12] Manseur's paper discusses the details of an undergraduate course in robotics. [8] The class content included kinematics, path planning, sensors, and concluded with a robot competition. On the other hand, Bishop *et. al.* discuss a robotics course for senior students in which they develop using Lego Mindstorms[13] their own open ended mobile robot project.[10] In addition, Weis discusses a course in which the students design the controls for the Lynxmotion Carpet Rover[14] in order to navigate a closed course.[11] Lastly, Barger relates industry design methods and how to adapt these methods to the academic setting.[12]

In this paper a collaborative and cooperative active PBL project is utilized in the microprocessor based control class. Previously, the microprocessor based controls course utilized simulators such as TexasS, PSpice, and MATLAB to implement simulations of embedded control systems and microcontroller programs. However, as previously discussed, Prince states that active learning can be more effective as students generally have a short attention span. Using active learning involves the students more often in the class increasing their attention.[1] The students will thus gain a greater understanding of the material given a project that engages their attention.

For this reason, the course was completely modified, restructured, and enhanced with a more engaging and realistically constrained robot design project. In this case an Extreme Hexapod 3-R[14] which is a six-legged omnidirectional robot from Lynxmotion is used as the base robot platform. The students were allowed to choose from some of the different processors available in the lab. The students decided to use the Servopod, from New Micros, Inc, which is a DSP microcontroller.[15]

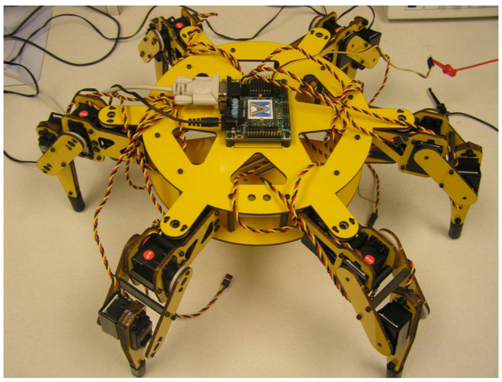

Figure 1 – Extremer Hexapod 3-R Under Initial Testing by Microprocessor Based Control Course Spring Semester 2006

The rest of the paper is organized as follows: project description, course topics, design process, professional and research engagement activities, learner outcomes and assessment measures, assessment, conclusions, future work, and bibliography.

Project Description

As in Weis[11] and Bisop *et. al.,*[10] a base robot system is utilized to allow students to concentrate on the design and choice of sensors for embedded control of robotic systems. In this case, a small mobile legged vehicle based on the Extreme Hexapod 3-R[14] robot was designed by four teams. Before the class tested and developed the control for the legged hexapod robot, they first experimented with different processors in different applications such as robotic arm control. The class then decided that the Servopod was the best processor available to the class for the Extreme Hexapod 3-R control due to the complexity of the robot.

The class developed a management structure with an overall project manager and four teams with team leaders. Each team developed different systems for the same robot. This provided the students with research and management experience as it relates to a more practical design. Each team also tested different robot locomotion techniques.

Next, the class defined the problem and specifications required to perform the task, that the robot would be able to navigate on its own and collect environmental data. The design teams next developed the sensor systems and motion control that they decided would be required to perform the application. After testing, the four teams decided that they would use the best walking routine developed by one of the four teams.

They gained a better understanding of practical design considerations and integration as well as project management. The students next tested and documented the functional capabilities of their robot system in a controlled environment setting. Finally, the class presented their findings. Thus, the class also gained a better understanding of robotics.

The sensors available to the students include temperature, humidity, infrared, and ultrasonic, to name a few. In addition, sensor stands, rechargeable battery packs, cameras, and wireless transceivers are also available for students to use in their mobile robot designs and control systems. The students in the course each spring semester are evaluated using the following: [16]

1. two progress reports and a final report,
2. report presentations, including a final presentation/demo,
3. performance of the product of their project (working robot and sub-systems), and
4. their homework and exams.

Course Topics

The lecture in the course consisted of more general information concerning microprocessor and embedded control system design. This gave the students a basic framework to aid in the analysis and design for the particular application. The following topics were covered in the class.

1. Transfer Functions
2. Laplace Transforms
3. Physical System Modelling
4. Filters/Signal Conditioning
5. System Response
6. Programming RTI, A/D, PWM
7. PID Control and Implentation
8. Input/Output Interfacing
9. Noise Considerations
10. Embedded Systems
11. RTOS
12. Case Studies

Design Process

With the course topics discussed above, the students are better prepared to define the problem and specifications, develop design alternatives, test and analyze the system components, integrate the subsystems, and document the design. Figures 2 and 3 show the students' testing of the Extreme Hexapod motion control in the laboratory. The robot in these tests shown does not have any sensors attached. This was a walking test from the microprocessor based controls course offered spring semester 2006. The approximate timeline for the student project can be found in Figure 4.

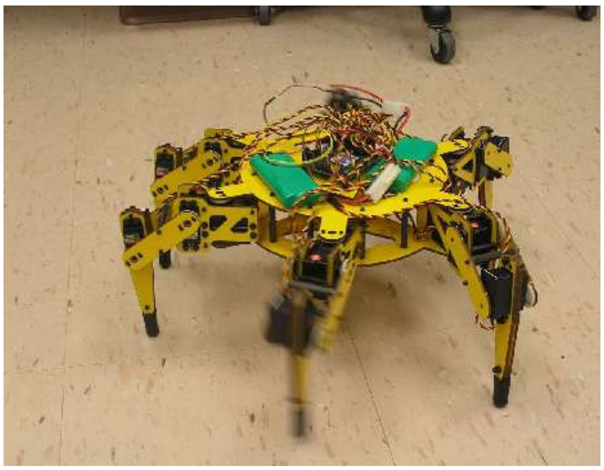

Figure 2 – Initial Walking Test Spring Semester 2006

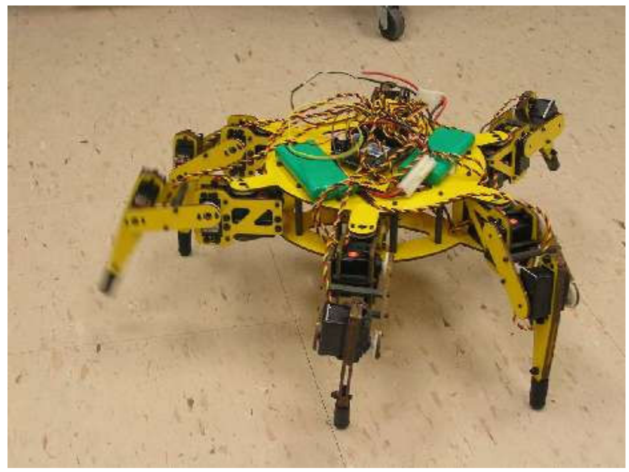

Figure 3 – Another Picture from the Walking Test Spring Semester 2006

Professional and Research Engagement Activities

The following list of activities, which can also be found in the class syllabus and the quality enhancement proposal "enhance the students' education by looking at a practical design project from an industry viewpoint."[16] The course is offered each spring semester and will be offered this semester, spring 2007.

1. "The students will assess the problem and develop one or more solutions. The students will then break into design teams. The students will have to consider the operational environment and how this affects their design. This will also involve assessing different sensors as well as power systems for use on the robot. The students then will have to choose the best designs while considering constraints such as costs, resources, scheduling, etc.
2. Each design team will be responsible for at least one sub-system design and documentation.
3. The students after completion of each sub-system will verify and test the sub-system. They will design a test procedure and document the results.
4. The students will then fully integrate the sub-systems into the embedded control system. At this point the fully integrated system will be tested and verified in the laboratory. They will design a test procedure and document the results." [16]

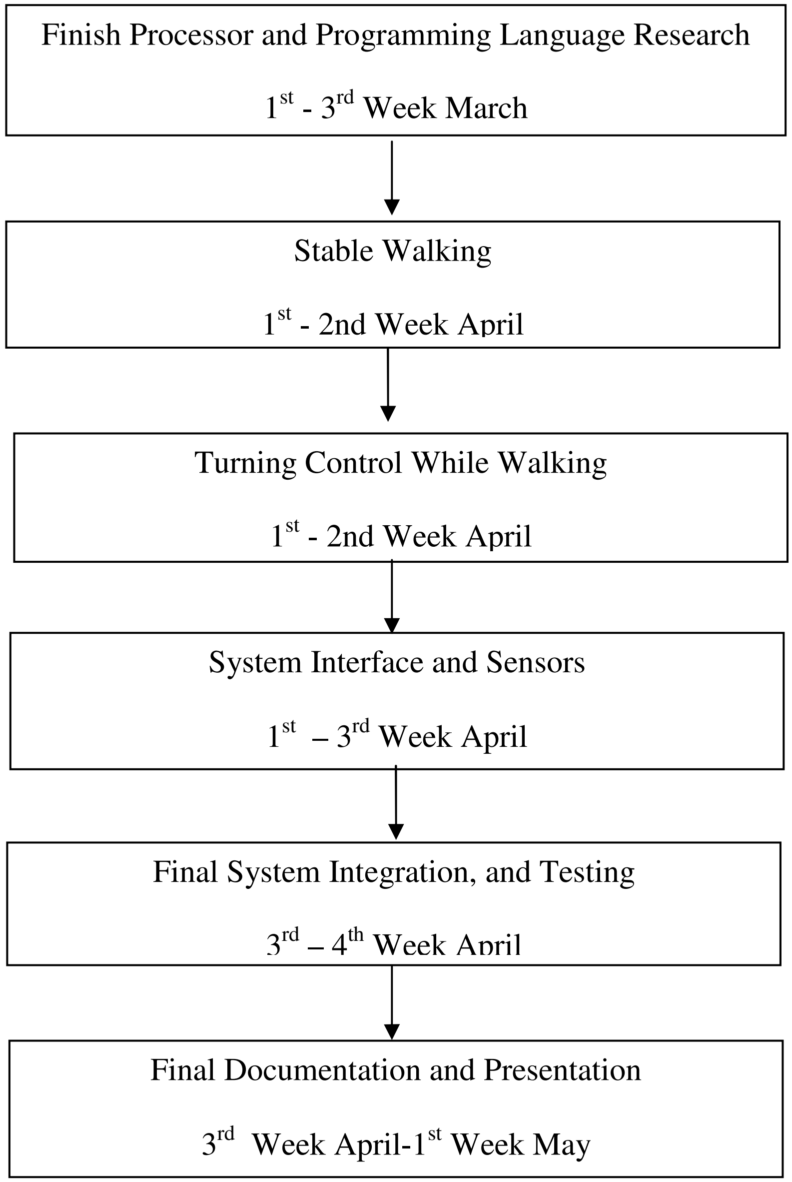

Figure 4 – Mobile Robot Design and Implementation Timeline

5. "The students each semester will next take the robot into a controlled environment setting to test its capabilities.
6. The students will then present the design and analysis of data in a seminar setting (presentation and written report).
7. In addition, the students will have to develop a project management team. Each design team will then be responsible to the management team. This team should develop the project schedule.
8. The project design will also promote teamwork as well as communication between different design teams." [16]

These activities engage the students in an active learning environment; this will improve the student learning as well as prepare the students for more open-ended designs.

Learner Outcomes and Assessment Measures

The students during the time frame of 2nd week January – 2nd week April learned about embedded systems, issues such as noise and signal conditioning, rechargeable battery types, RTOS, PID/fuzzy logic control, federal and international industry standards, to name a few class lecture topics. After the 2nd week of April, specific examples of student design projects were examined.

Students in this course gained a better understanding of the following using the present course format, a PBL environment, as compared to the previous course format which utilized simulations to demonstrate the embedded system design and related issues: [16]

1. embedded control systems and sensors by practical design,
2. practical design problems, such as scheduling, costs, documentation, and testing,
3. sub-system design integration,
4. practical design experience for use in their professional career, and
5. practical implementation experience (Hands-on experience).

The student learning outcomes listed above were evaluated using the following: [16]

1. two progress reports and a final report,
2. report presentations, including a final presentation/demo,
3. performance of the product of their project (working robot and sub-systems), and
4. their homework and exams.

The reports were assessed according to how well the following content was addressed as described below in the class project handout:

1. Progress report #1 addresses the timeline, milestones, critical design components, project breakdown by groups, different possible designs for systems and why (justify) your design choice is best, understanding of practical design considerations and integration, assessment of design problems, and documentation of preliminary results.
2. Progress report #2 again addresses the following as well as any modifications to the timeline, milestones, critical design components, understanding of practical design considerations and integration, assessment of design problems, software coding and documentation, sustainability, testing plan and documentation of preliminary results.
2. Final Oral and Written Reports must address the timeline, milestones, critical design components, understanding of practical design considerations and integration, assessment of design problems, software coding and documentation, testing plan and documentation of results, future improvements, lessons learned, and contemporary issues related to the implementation of the project.

The performance of the project systems was assessed based upon whether the subsystems and overall system worked for the desired application. Each team was graded on the project as a group except on the oral presentations on which each student was graded individually. The students were also evaluated individually on homework and exams.

Assessment

In addition to the learner outcomes listed in the previous section, the understanding of the following criteria was also assessed:

1. contemporary issues that arose,
2. procedures for testing, and
3. system software.

These three outcomes and how they related to the design project were to be addressed by the students in the reports.

The spring semester 2005 (old course format) and 2006 (new restructured course format) assessment results are found in the tables below. In 2005, before the course was redesigned, the desired assessment goal was that 70 % of the students achieved a minimum of 70 % on the assessment criteria. In 2006, after the course was designated a quality enhancement plan (QEP) course and had been restructured, the goal was raised to 80 %. Thus the 2005 data has been reevaluated with the 80 % assessment goal to allow a better comparison. The 2005 class which consisted of 7 students met the original assessment criteria but not the 80 % criteria for comparison purposes. The 2005 offering of the course utilized as the project, the simulation of the design of the interface circuitry and the software to control a magnetic levitation system .

Table I. – Outcome Assessment Spring Semester 2005

Outcomes	Test Questions*	Final Project Report *	Test Questions†	Final Project Report†
Practical Design	67.87 % / 77.14	100 % / 92.14	35.71 % / 77.14	100 % / 92.14
Practical Design Issues				
System Integration				
Hands-On Implementation				
Testing				
Systems Software		100 % / 92.14		
Contemporary Issues		100 % / 92.14		100 % / 92.14

* , † – Percentage/ Score is the percentage of students who scored at least 70 %*, 80 %† on problems or assignments used for assessment under the criterion/average actual score by students on the problems or assignments used for assessment under the criterion.

Table II. – Outcome Assessment Spring Semester 2006

Outcomes	Test Questions	Progress Reports	Overall Project Score	Final Project Reports
Practical Design	82.4 % / 89.5		100 % / 88.9	
Practical Design Issues			100 % / 88.9	
System Integration			100 % / 88.9	
Hands-On Implementation				100 % / 91.0
Testing		100 % / 88.0		
Systems Software		100 % / 88.0		
Contemporary Issues				100 % / 91.0

Note –Percentage/ Score is the percentage of students who scored at least 80 % on problems or assignments used for assessment under the criterion/average actual score by students on the problems or assignments used for assessment under the criterion.

From Table II., one can see that the spring semester 2006 class which consisted of 12 students met the assessment criteria. One reason is that the students were interested in the material and spent extra time in the lab running tests and refining the walking motion control and the sensor systems.

The project and course outcomes were assessed as in Tables I-II. Practical design considerations were included in the project design and also were incorporated into test questions. In 2006, in the newly restructured course, the system functionality and system integration were evaluated using the progress reports, final report, final testing, and final presentation. In addition, during the spring semester 2006, the instructor also observed the class interaction and progress throughout the semester. The testing and systems software were detailed in the two progress reports. Finally, any issues and overall system implementation were discussed in the final oral and written reports.

As can be seen in the new course format results (Table II.), the assessment shows that the students have met the criteria for evaluation. This is an improvement over the previous course offering and also allowed more practical design issues and considerations to be considered in the project. However, it was noted that students and instructor all agreed that the project begin date needed to be moved back into early February to allow the students more time to work on the project and any issues that might arise.

During previous offerings of the course students had commented that the course needed a laboratory component. This restructured course is a preliminary attempt to address this need. In the spring 2006 course evaluations, one student commented that “this course provided great experience with many things needed for the real world. Group work, project management and reports were required and improved on.” This reiterates the objectives of the course.

Conclusions

As the assessment results demonstrate the initial offering of the restructured course met the assessment objectives. However, much work still remains to be done. The next time the course is offered, the class will look at enhancing the previous class's work. This will allow the class to integrate more sensors, cameras, or wireless communication and develop control algorithms for cooperative control of two or more robots.

The success of the hands-on practical design approach in the microprocessor based control class is clearly demonstrated by student satisfaction, presentations, reports, and overall achievement in the course. The newly redesigned course allowed more realistic practical industry based design concepts to be adopted together with more active student engagement.

Future Work

A survey will be given to the class to study the impact of the course material and objectives on student understanding of design, testing, and practical applications. In addition, more robots will be controlled by the class simultaneously allowing for more complex behavior and control to be studied.

Acknowledgements

The author would like to acknowledge the funding support in the form of a Quality Enhancement Plan (QEP) grant from Texas A&M University – Kingsville as well as HEAF funding from the Texas A&M University – Kingsville College of Engineering. The author would also like to thank Dr. Duane Gardiner and Dr. Gail Dantzker for their help and discussions about this course. Finally, the author also acknowledges the students and their feedback during the teaching of this course.

Bibliography

1. M. Prince, "Does Active Learning Work? A Review of the Research," *Journal of Engineering Education,* pp. 223-231, July 2004.
2. R. Pucher, A. Mense, and H. Wahl, "How to Motivate Students in Project Based Learning," *6th IEEE Africon Conference in Africa*, vol. 1, pp. 443-446, Oct. 2-4, 2002.
3. R. Waters, M. McCracken, "Assessment and Evaluation in Problem-Based Learning," *27th ASEE/IEEE Annual Conference Frontiers in Education Conference,* Pittsburgh, PA, pp. 689-693, 1997.
4. K. Snith, S. Sheppard, D. Johnson, and R. Johnson, "Pedagogies of Engagement: Classroom-Based Practices," *Journal of Engineering Education,* pp. 87-101, Jan. 2005.
5. H. Hadim and S. Esche, "Enhancing the Engineering Curriculum Through Project-Based Learning," *32nd ASEE/IEEE Frontiers in Education Conference,* Boston, MA, pp. F3F-1 – F3F-5, Nov. 6-9, 2002.
6. J. Roy, D. Richards, and Y. Pisan, "Helping Teachers Implement Experience Based Learning," *Proc. of the Int. Conference on Computers in Education,* vol. 2, pp. 1396-7, Dec. 3-6, 2002.
7. D. Carroll and P. Hirtz, "Teaching Multi-Disciplinary Design: Solar Car Design," *Journal of Engineering Education,* pp. 245-8, April 2002.
8. R. Manseur, "Development of an Undergraduate Robotics Course," *27th ASEE/IEEE Annual Conference Frontiers in Education Conference,* Pittsburgh, PA, vol. 2, pp. 689-693, Nov. 5-8, 1997.

9. D. Mehrl, M. Parten, and D. Vines, "Robots Enhance Engineering Education," *27th ASEE/IEEE Annual Conference Frontiers in Education Conference,* Pittsburgh, PA, vol. 2, pp. 613-618, Nov. 5-8, 1997.
10. B. Bishop, C. Wick, and G. Piper, "Teaching Robot Design: Student-Driven, Open-Ended Design Projects," *Proc. of the ASEE 2006 Annual Conference,* Chicago, IL, 2006-1905, 2006.
11. R. Weis, "A Hands-on Microcontroller Project Using Mobile Robots," *Proc. of the 1999 ASEE Gulf Southwest Annual Conference,* Dallas, TX, March 7-9, 1999.
12. A. Barger, "On Teaching Engineering Design: Lessons Learned from Industry," *Proc. of the 1999 ASEE Gulf Southwest Annual Conference,* Dallas, TX, March 7-9, 1999.
13. Lego Mindstorms, http://mindstorms.lego.com/Overview/ accessed January 15, 2006.
14. Lynxmotion, Inc., P.O. Box 818, Pekin, IL 61555-0818, www.lynxmotion.com accessed January 16, 2006.
15. New Micros, Inc., 1601 Chalk Hill Road, Dallas, TX 75212, www.servopod.com accessed January 16, 2006.
16. L. McLauchlan, Quality Enhancement Plan Course Proposal for EEEN 4343 Microprocessor Based Control, Texas A&M University – Kingsville, 2005.