2006-1713: THE DANCING MARIONETTE - AN INTERDISCIPLINARY CAPSTONE DESIGN EXPERIENCE FOR ENGINEERING TECHNOLOGY AND COMPUTER SCIENCE STUDENTS

Jyhwen Wang, Texas A&M University

Jyhwen Wang joined the Department of Engineering Technology and Industrial Distribution at Texas A&M University in 2001 after working 10 years as a researcher and R&D manager in industry. He teaches mechanical design applications and his research interest is in the areas of mechanical design and material processing technology. He received his Ph. D. degree in mechanical engineering (1991) from Northwestern University.

Steve Liu, Texas A&M University

Steve Liu is an Associate Professor in the Computer Science Department at Texas A&M University. He received his Ph. D. degree in Electrical & Computer Engineering (1989) from University of Michigan. His research interest is in real-time distributed computing systems, network performance and security, medical informatics, and Intelligent Transportation Systems (ITS). Dr. Liu teaches Microcomputer Systems (CPCS 462) course.

Angie Price, Texas A&M University

Angie Hill Price, Ph.D. is an Associate Professor in the Manufacturing and Mechanical Engineering Technology program at Texas A&M University, where she has been on the faculty for 14 years. She has taught the Mechanical / Manufacturing Technology Projects course for the last 5 years.

The Dancing Marionette - An Interdisciplinary Capstone Design Experience for Engineering Technology and Computer Science Students

Abstract

With the advances in microelectronics devices, often computers, sensors, and actuators are integrated into mechanical systems. Modern engineering design thus requires efforts from a multidisciplinary team. Traditional capstone design projects offer few opportunities for inter-departmental collaborations. This paper presents an experimental capstone project organized to allow computer science students and manufacturing and mechanical engineering technology (MMET) students to work together on a "dancing marionette". The project involved three major components: 1) mechanical/kinematics design, 2) computer motion control, and 3) manufacturing. The MMET students took on the tasks of the mechanical design and fabrication of an electro-mechanical movement system. The computer science students developed motion control hardware and software to prescribe life-like movements of the puppet. While the highly successful prototype demonstrated the value of interdisciplinary collaboration, feedback from faculty and students also suggested that better communication can further improve the learning experience of future students.

1. Introduction

In most of the Engineering Technology (ET) programs, capstone projects are requirements in the senior year for students to utilize their technical knowledge, problem solving skills, and project management skills to develop a product or a system related to their disciplines. While the format and the implementation of the capstone projects may vary from institution to institution and from program to program, the courses, however, share similar characteristics. In a typical senior project, students are challenged to integrate the knowledge they accumulated in the previous years to design and develop a solution for a practical problem. The projects are normally selected from a list of problems provided by faculty members or industry advisors. In addition to the instructor of the capstone course, a faculty member or an industry advisor will be a "sponsor" of the project. Student teams are organized to match students' background (work experience and technical electives taken) and interests with the proposed problems. The course generally involves proposal writing to define problems and identify solution approaches. Progress reports, mid-term presentations, a final report, and a final presentation are commonly required. An objective of the capstone design course is to allow the students to demonstrate the knowledge and skill they acquired by the time of graduation; thus, the course can be an outcome assessment tool for continuous improvement of the program. Another key objective of the capstone course is to provide the opportunities for students to obtain some close-to-real-world project experience.

Traditional capstone design projects are administrated within a program and offer few opportunities for inter-departmental collaborations. With the advances in microelectronics devices, often computers, sensors, and actuators are integrated into mechanical systems. Modern engineering design requires efforts from a multidisciplinary team. Therefore, involving ET students in a specific discipline to collaborate with students in other disciplines in the capstone course could greatly enhance the students' learning experience. This paper presents an experimental capstone project organized to allow manufacturing and mechanical engineering technology (MMET) students and computer science (CS) students to work together on a "dancing marionette." The paper focuses on the learning experience of MMET students. In Section 2, the course objective, description, and the rationale for collaboration are presented. Section 3 describes the electromechanical system that was accomplished. Section 4 is the assessment of the developed system (product) and the collaboration process. A concluding remark is presented in Section 5.

2. The Collaborative Project

Engineering Technology Capstone Projects

The Manufacturing and Mechanical Engineering Technology (MMET) program in the Department of Engineering Technology and Industrial Distribution at Texas A&M University uses a typical model for senior capstone design course. The published course description and prerequisite for the course are:

ENTC 422 Mechanical/Manufacturing Technology Projects
Course Description: A capstone projects course utilizing a team approach to an analysis and solutions of mechanical/manufacturing problems. Prerequisite: ENTC 429 Managing People and Projects in a Technological Society; completion of junior-level courses; must be taken semester of graduation; approval of instructor; admitted to major degree sequence (upper-level) in engineering technology.

With the prerequisite, the students enrolled into the course all have the required technical competency and the background in fundamentals of project and people management such as proposal writing, project planning, scheduling, basic financial management, and team building. Upon the assignment of the problems, the student teams, consisting of four to five students per team, make their own decisions on work hours and job assignments. If a project involves implementing the students' design, a budget normally is available from the project sponsor, and the student team is given the responsibility to manage the budget. To strengthen students' communication skill, the project teams are required to submit written proposals and progress and final reports. The entire class meets once a week in the scheduled lecture hours so that the teams can give a short presentation of their progress. In this way, the students can learn the factors leading to the success or failure of each of the projects conducted in a 15-week time frame.

In the past, the MMET capstone projects have been carried out within the program. The students lacked the opportunities to engage in external collaboration to tackle interdisciplinary projects that are commonly seen in industry. To help the MMET students to gain a perspective on the practical, real world project, it was believed that interdisciplinary collaboration should be encouraged. The students needed to learn to interact with people who have a different "work vocabulary" and whose assumptions and knowledge bases vary from their own.

Computer Science Course Projects

An integral part of the interdisciplinary capstone project experience presented in this paper is the course project in CPCS 462 Microcomputer Systems offered by the Department of Computer Science at Texas A&M University. The course description and prerequisite are:

CPSC 462 Microcomputer Systems
Course Description: Microcomputer as components of systems; VLSI processor and coprocessor architectures, addressing and instruction sets; I/O interfaces and supervisory control; VLSI architecture for signal processing; integrating special purpose processors into a system.
Prerequisite: CPCS 410 Operating Systems

The objective of this course is design of embedded computing systems, based on high performance hardware and software technologies with limited hardware resources. In addition to technical knowledge on basic system architectures and system building blocks, students are also expected to explore new ideas independently, and transform the ideas into working prototypes by the end of the semester. Students taking the course are generally assigned an open team project. Through the project, the students are expected to demonstrate their hardware and software knowledge and programming skills.

One of the CPCS 462 class projects proposed and completed by a student team that achieved significant success, in terms of the course requirements, was the robotic manipulation of a marionette (Figure 1). The motion of the puppet was successfully prescribed and controlled by a program running on a PC. As the computer science students generally have limited experience in mechanical system design and fabrication, it was believed that the marionette system could be improved with the involvement of MMET students.

(a) Front view (b) Side view

Figure 1 The marionette prototype developed by CPCS 462 students

Interdisciplinary Collaboration

Recognizing the students from different programs can have complementary skills, the interdisciplinary collaboration was organized to develop a marionette system from scratch. The project consisted of three major components: 1) mechanical/kinematics design, 2) computer motion control, and 3) manufacturing. If successful, the marionette system could be brought to a nursing home for entertainment or to a K-12 school to spark students' interests in science and engineering.

Following the capstone design course schedule, the problem definition was given to the MMET team by the project sponsors, faculty from CS and ET departments, in the beginning of the semester. The CPCS 462 team started later as learning several weeks of lecture materials was needed for them to start their assignment. The MMET students took on the tasks of the mechanical design and fabrication of an electro-mechanical movement system. The computer science students developed motion control hardware and software to prescribe life-like movements of the puppet. Informal communication between the teams was maintained to exchange the ideas and update the progress.

3. Design, Manufacturing and Programming of a Dancing Marionette

The marionette is a popular art form that exists in many cultures. In addition to the theatrical content, people are attracted to marionette performances due to the interesting human like motion demonstrated by the puppet. Putting aside the artistic performance of the puppeteer, manipulating a marionette to achieve lifelike bodily movement is a challenging task that involves physical laws and engineering principles.

The objective of the project was to design, develop, and fabricate an electromechanical system to prescribe and control a marionette to perform a dance routine. A marionette could be designed to exhibit different level of complexity in terms of kinematics and dynamics behavior. The MMET team was given the instruction to deliver the highest complexity they could achieve with a budget of $500, excluding computer hardware and free resources. Another requirement was that the system had to be assembled and disassembled easily such that it could be shipped or taken to various places for demonstration. Five MMET students signed up to work on the project. Collectively, the students had the following technical background and job experience that was critical to the success of the project:

- Manufacturing and Assembly Processes I & II (including metal working and welding)
- Metallic and Nonmetallic Materials
- Mechanics
- Strength of Materials
- Solid Modeling and Analysis
- Computer Aided Manufacturing (including CNC machining)
- Mechanical Design Applications I & II (including design for manufacturing and assembly and machine elements)
- Managing People and Projects in a Technological Society

<u>Step One: Design Review of Prior Efforts in CPSC462 Project</u>

Although the team was given great freedom to design and fabricate the system, a design review of the prototype built by the previous CPSC462 team was implemented in order to prevent the new project teams from repeating the same design and construction methods. The computer science students who constructed the original prototype were more concerned with their field of study and were also bound by a short project time frame. Consequently, the prototype was lacking the quality in structure integrity and mechanical capability. As shown in Figure 2, the stage frame was constructed using $1'' \times 1''$ wood segments assembled with simple nails, screws, and thin metal strips without cross-bracing (see Figures 1 and 2).

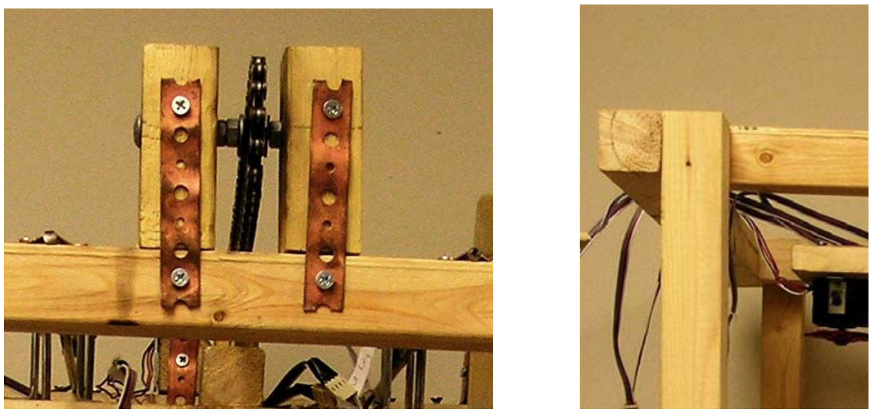


Figure 2 Construction of the original prototype

The basic movement of the system was provided by a chain drive (Figure 3) that could move the marionette across the stage. The arms and legs of the puppet were attached to strings that were connected to pulleys functioning as winches. Four stepper motors were used to control pulley rotation (Figure 4). The stepper motors were mounted to a thrust bearing (a Lazy Susan), and the end plate of the bearing was connected to a vertical shaft that allowed the marionette to rotate about its center line (Figure 5). The shaft was driven by the fifth stepper motor.

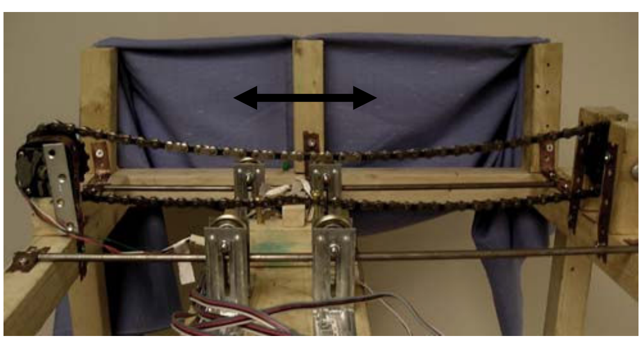


Figure 3 Chain drive

Figure 4 Pulley and stepper motor assembly

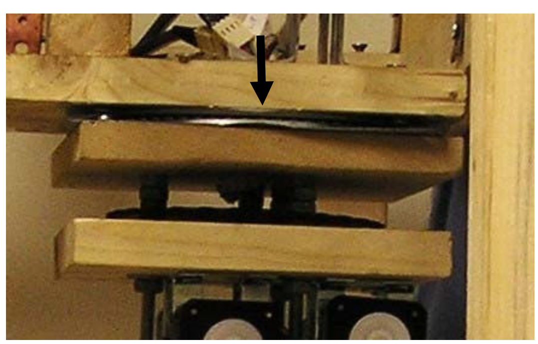


Figure 5 Bearing assembly for rotating motion

From the design review, the MMET team identified several issues that could be addressed to improve the original prototype from the mechanical design and manufacturing perspective. A sturdy stage frame could be built to accommodate curtain, backdrop, and possibly stage lights. The repertoire of the marionette could be expanded by increasing the complexity or degree of freedom in translation and rotation of the mechanical movement system. The movement of the puppet could be refined by reducing the slack in the chain, minimizing the friction on the thrust bearing, noting that the Lazy Susan is mounted in tension, and eliminating the jerky motion due to stepper motor. It was believed that with the integration of new mechanical design, fabrication methods, and computer control, the capability and quality of the marionette system would be greatly enhanced.

Step Two: Mechanical System Design and Manufacturing

The mechanical system consisted of two major subsystems. The first subsystem was a collection of actuators and mechanical components that create the puppet's motion. The second subsystem was the stage and frame that housed the first subsystem.

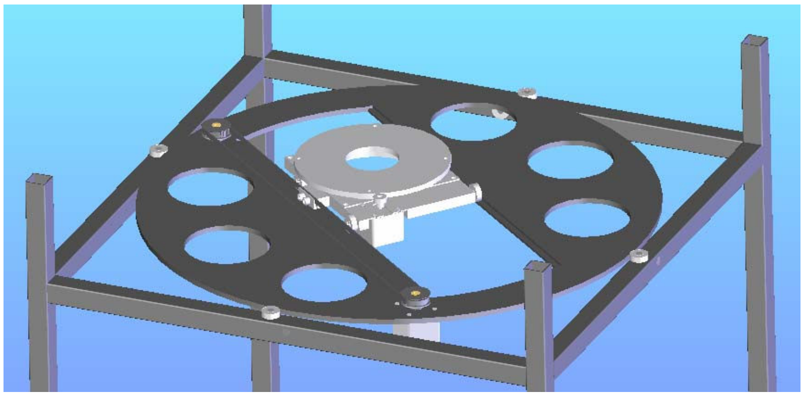
Stage and frame design and construction
The MMET capstone design team tackled the stage and frame design problem first. The objective was to develop the stage and frame that was easy to assemble and disassemble and also was structurally sound. Square aluminum tubing was used to construct a $26'' \times 26'' \times 36''$ (width, depth, height) frame. To address the portability requirement, the structure comprised a welded square top and bottom and four posts that could be assembled or disassembled easily (Figure 6a). A high degree of dimensional accuracy on the welded corner joints was achieved (Figure 6b). Four wheels also were installed in the bottom frame to add the mobility to the system.

(a) The top frame and posts (b) A welded joint

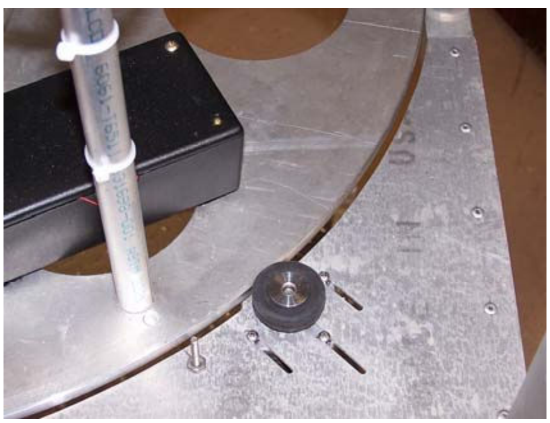
Figure 6 Design and construction of the frame

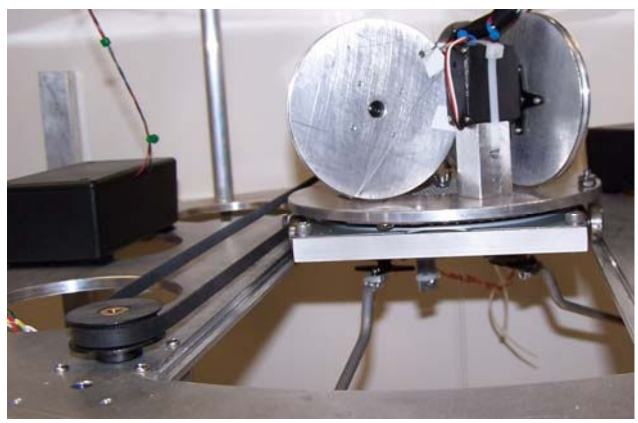
Motion system design and fabrication
Instead of a conventional two-axis gantry system, the backbone of the motion system was a rotating disc and a small moving cart. The disc rotated about the vertical center line of the stage, and the cart ran on a slot along the diameter of the disc (Figure 7a). With strings connecting to a subassembly on the cart, the marionette was suspended in the air. Motion of the disc and the cart

determined the crude motion of the marionette. For example, by positioning the cart at the center of the disc with the disc rotating, the marionette would spin. With the cart on the edge of the disc and the disc rotating, the marionette would be moving in a circle. The disc was driven by friction contact with a rubber wheel. The shaft of the wheel was connected to a stepper motor and mounted on the top frame (Figure 7b). The cart was fastened on a timing belt driven by another stepper motor mounted on top of the disc (Figure 7c).



(a) Design of crude motion control





(b) Friction contact to control large disc rotation (c) Timing belt to control cart movement

Figure 7 Crude motion control system

The fine motion of the marionette was controlled by the mechanical system on the cart. A small rotating disc driven by the third stepper motor allowed the marionette to spin. Two servo motors mounted beneath the cart were used to enable the arms to swing. Four more servo motors mounted on top of the small disc and cart were used to drive pulleys and strings to control the wrists and legs of the puppet. A hole was machined in the small disk and cart in order to permit the pass through of four strings on which were hung the arms and legs of the marionette (Figure 8).

At this stage, the MMET and CS teams had to work closely together to determine the arrangement of the strings, pulleys, and motors. The directions (clockwise vs. counter clockwise) and limits (degrees) of rotation of the motor shafts were carefully defined to prevent the strings from tangling. These constraints were to be observed while programming the dance routines.

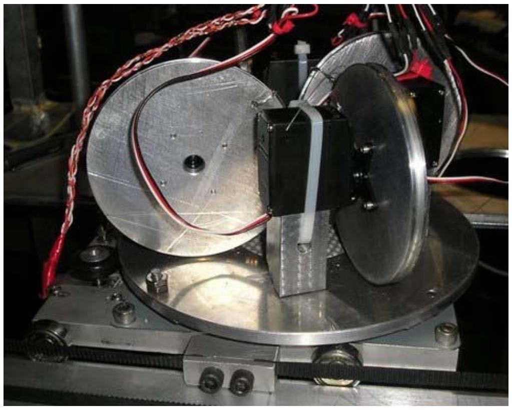
 

Figure 8 Fine motion control system

<u>Step Three: Computer Hardware and Motion Control Programming</u>

Control of the single puppet in the marionette system was implemented by a single board microcontroller, based on the Atmel eb63 evaluation board, a Xilinx Spartan 3 field programmable gate array (FPGA) evaluation board, power supplies, and the interface electronic circuits between FGPA board and the stepper/servo motors. The FPGA board received motion commands from the eb63 board, so that it could repeat or shuffle prescribed motions based on the commands. The eb63 board was responsible for higher level operations, including dancing routines, communications to and from the workstation.

Two types of control software were needed for the microcontroller and FPGA boards, respectively. C programs were written and compiled for the microcontroller board, and Verilog routines were written, compiled into FPGA configuration bitmap files. The C application codes ran under the Microsoft *Invisible Computing*, which is a research operating system for embedded applications that has been adopted by the CPSC462 class for three years.

<u>Step Four: Connecting the Electronic/Computer System and the Mechanical System</u>

To complete the marionette system, the electronic system and mechanical system had to be connected by electric wires and power cords. Toward the end of the semester, the need for shelving space for electronic components was identified. The shelf was a square plate of plexiglass supported by four aluminum columns on top of the large rotating disc (Figure 9). All of the control components were on the shelf, and the wires ran through a hole down to the motors. Having the shelf fixed to the large disc reduced the problem with tangling electric wires while the large disc rotated. A minor problem still existed as the power cord running to the shelf had to twist when the large disc made complete revolutions.

4. Evaluations

The student teams working in the collaborative project have generated impressive results. At the end of the 15-week semester, the marionette system was fully functional. Several of the MMET team members had practical job shop experience and also had free access to machine shops. As the results, all of the cost of the project ($195.24) was related to material purchase. The capability and the build quality of the mechanical movement system were significantly improved over the original system. The project allowed MMET students to demonstrate their knowledge and skills in mechanical design and manufacturing. It also provided the CS students an opportunity to visualize the movement of the marionette controlled by the microcontroller hardware and software they put together.

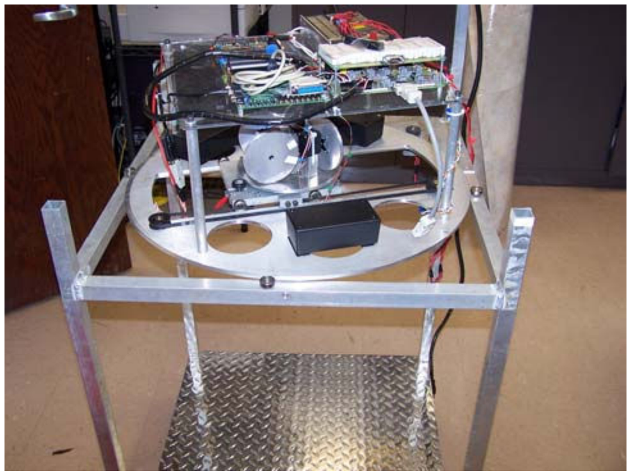


Figure 9 The integrated electromechanical marionette system

In the final report, the MMET capstone team identified several aspects of the system that could be improve upon. For example, the large disc, the cart, and the electronic components add up to significant weight for the motor to drive the mechanical system. Reducing the weight could lead to a faster response time and make the marionette more nimble. Another improvement which could be made was to the wiring and shelving of the microcontroller. To prevent the wires and power cords from tangling, a redesign of the mechanism or the use of battery powered actuators and microcontroller could be investigated. Due to time limitation, the overall aesthetics of the marionette was not a priority. It was suggested to powder coat the frame and install a stage curtain, a backdrop scene, and stage lights in the future.

Lessons Learned

As a part of this collaborative effort was to determine if this type of interdisciplinary project can bring significant value to student learning, feedback from the students was sought. It is observed that the student appreciated the experience to work with peers in another discipline to achieve a common goal. In fact, the students pointed out that it would be beneficial for the two teams to have a longer time frame to work together. (CS team could start the project in the beginning of the semester.) They believe this would allow the two teams to spend more time creating solutions for the wire tangling problem. In addition, meetings between the teams could be held on a regular basis to improve communication.

5. Conclusions

A senior capstone course is an excellent means for students to integrate their knowledge and skills to solve technical problems. Like other courses in engineering and technology programs, the course content and teaching method of the capstone course should evolve over time. As design and manufacturing of modern engineering systems require multidisciplinary efforts, involving students in an interdisciplinary project can better prepare students to make contributions in a real world project. This paper presents an experimental capstone project for MMET students to work with CS students in the design and manufacturing of a marionette system. The results of their effort were impressive. The student teams designed and manufactured an electromechanical system that controls the movement of a marionette. Through a computer program, the microcontroller instructed the actuators to drive the mechanical system and directed the puppet to dance with music. The feedback from students supported the belief that such a project can enhance students' learning in communication and team building. Although extra efforts will be required from the faculty in project selection and course coordination, such interdisciplinary collaboration should be encouraged as it can bring significant impact to students' learning experience.

Bibliography

1. Bachnak, R., Verma, S., and Coppinger, T., "Restructuring the Capstone Course Leads to Successful Projects," Proceedings of the 2005 ASEE Annual Conference and Exposition, Section 1647, June 2005.

2. Burbank, K., Holcomb, J., Cooper-Duffy, K., and Prohn, JK., "A Wheelchair Navigation System as a Collaborative Senior Project," Proceedings of the 2005 ASEE Annual Conference and Exposition, Section 1347, June 2005.

3. Chen, I.-M., Xing, S., Tay, R., and Yeo S. H., "Many String Attached, From Conventional to Robotic Marionette Manipulation," IEEE Robotics & Automation Magazine, pp. 59-73, March 2005.

4. Dobson, R., Kowalski, K., Ostermann, S., Pittenger, J., and Tiller, W., Marionette Prototype Design Final Report, Department of Engineering Technology and Industrial Distribution, Texas A&M University, May 2005.

5. Mirman, C. R., "An Engineering Technology Capstone Course Which Integrates Theory, Design, and Construction in an Open-Ended Project," Proceedings of the 2005 ASEE Annual Conference and Exposition, Section 1648, June 2005.

6. Morgan, J. A., Wright, G., and Porter, J. R., "Managing Senior Design Projects to Maximize Success: The TAT Team," Proceedings of the 2005 ASEE Annual Conference and Exposition, Section 1347, June 2005.

7. Mott, R., Machine Elements in Mechanical Design, 4^{th} Ed., Prentice Hall, 2004.