Session: 3447

Open-Ended Robotic Design for Enhanced Capstone Experience

Arif Sirinterlikci

Ohio Northern University

Background

This paper elaborates on the capstone experiences in the Technology Program of the Technological Studies Department at Ohio Northern University. Students from different levels participate in RI/SME (Robotics International Association of the Society of Mechanical Engineers) Student Robotic Technology and Engineering Challenge, work for two consecutive quarters and earn TECH 435 – Advanced Robotics/Automation and TECH 495 – Senior Project credit. The successful student projects have well represented the program with at least one first place finish since 1993. While most of the projects completed at Ohio Northern University focused on fixed goal problem solving, such as stair climbing or sumo wrestling, the rest were open-ended designs intended for the Robot Construction segment of the competition. Robot Construction is an important segment of the competition leading to design and construction of robots with minimal restraints like safety. ONU robot construction projects included industrially applicable robots, like a gantry (Cartesian) robot and entertainment robots, such as a PLC (Programmable Logic Controller) controlled baseball batter. A new initiative has been launched to improve the robotics program at the Technological Studies Department and to add fun and creativity components to bring more student excitement and higher learning [1]. It will also complement a pure teaching department with a research component through the involvement of state-of-the-art technologies. Animatronics was chosen as the main area of focus. Animatronics is the art of bringing inanimate objects to life through computer, cable, remote, radio controls and puppetry [2] as defined by Jim Henson. From a technical point of view, an animatronic is a figure that is animated by means of electromechanical or mechatronic devices. Its goal is to emulate an actual living being or a fictitious character to entertain. Animatronics will transform the capstone projects from an inter-disciplinary mechatronic design experience to a cross-disciplinary experience with the addition of topics such as biomechanics and artistic design for creativity. Another new addition is the use of microcontrollers in a PLC dominant program. As an initial attempt, an animatronic polar bear, the mascot of Ohio Northern University was created for the 2003 RI/SME competition.

This paper briefly covers the scope of the Robot Construction contest, and TECH 435 – Advanced Robotics/Automation course and is concluded with a summary of the capstone experience encountered by the students and faculty during the design, fabrication and programming stage of the animatronic bear. The conclusion will also include the future of the program and possible improvements [3] [4].

Robot Construction Contest

Students select a task for a robot perform and consequently design, build and demonstrate that the robot can fulfill its mission. The rules of the contest can be listed as [5]:

1. The actual robot must be built from the scratch, and cannot be a modification of a commercial robot.
2. Commercial or specially constructed parts are acceptable for building the robot. The parts that are designed and fabricated by the students must be clearly marked with red dots.
3. The demonstration of the robot and its capabilities cannot exceed 10 minutes. An additional 10 minutes are designated for questioning by the judges.
4. Scoring is based on the uniqueness and quality of the design, functionality of the task, performance of the robot, quality of the workmanship, safety design and issues, and a final descriptive report. Final descriptive report should include:
   a. The purpose or function of the robot
   b. The design process
   c. A schematic of the design
   d. Safety considerations
   e. Listings of the purchased and manufactured items
5. As a technical point, SME provides a 110 VAC standard outlet, 20 amp single phase 60-Hz quad box and access to one compressed air line at 100 PSI with ¼ inch male quick disconnect requested on the registration form.

TECH 435 – Advanced Robotics/Automation

Students take TECH 435 for two consecutive quarters. With the successful completion of their project and grades no less than B they become eligible to earn TECH 495 – Senior Capstone Project credit towards graduation. TECH 435 is a 2 credit hour course with meeting times, now once a week on Monday evening 6:30 – 10:00 PM for the whole class to work within their team environments. Each team is also required to meet at an arranged time spot with their advisor. The course description focuses on advanced investigation of robotics and automated equipment. Topics of investigation include robot construction and programming, PLC's (Programmable Logic Controllers), CAD/CAM (Computer Aided-Design and Manufacturing), CIM (Computer Integrated Manufacturing), FMS (Flexible Manufacturing Systems), and work-cell construction. The course is mainly based on problem solving in manufacturing scenarios in team environments through project management practices. The official prerequisites of the course are: TECH 120 – Introduction to CAD or GE 102 – Engineering Problem Solving and CAD, TECH 140 Microcomputer Applications in Technology, and TECH 332 – PLC's and Industrial Robotics. There have been many occasions that some of the prerequisites are waived for exceptional lower classmen. At the beginning of the term students respond to a survey asking about their backgrounds and comfort levels in Electricity and Electronics (TECH 261), Digital Electronics (TECH 362), CAD/CAM and Automation Systems (TECH 335) fields. Some necessary background in materials, processes, hydraulics/pneumatics and mechanical design are in question as well. Efforts are made to create teams that are balanced and will be successful. The make-up of the teams is based on past experiences, performances, and knowledge base of the students. Each team is matched with a faculty member who has the background in the specific field to serve as the primary advisor to the team. The other faculty members involved in the process are also available as resources to all teams as needed. Once formed, all teams are expected to compete in the competition [6].

The objectives of the course will give the student the opportunity to [6]:

1. Learn safe operation, application and maintenance of robotic and automation related equipment.
2. Develop creativity and resourcefulness in solving technical problems.
3. Develop an understanding of work-cell construction and operation.
4. Develop an understanding of robot construction an operation.
5. Develop problem solving skills.
6. Demonstrate leadership and team membership skills.
7. Take part in departmental and SME professional experiences.
8. Develop documentation for fulfillment of the requirements for a senior capstone.

Course requirements include attendance to class and team meetings, individual journal recording for each and professional meeting including sketches, names of contact and resource persons including vendors, problems encountered, tasks to be completed, time spent on each activities, and plans for future activities driven by the Gantt chart for the entire project. Three team progress reports per quarter are expected to be delivered through PowerPoint presentation before the advisors and the class. First report will include the following [6]:

1. Problem definition
2. Review of the contest rules
3. Alternative designs
4. Proposed solution and reason for the decision
5. Timeline (Gantt Chart)
6. Preliminary BOM (Bill of Materials) and list of vendors.

The other reports will focus on [6]:

1. Problems encountered
2. Solutions to problems
3. Resources utilized
4. Detailed sketches and engineering drawings
5. Progress related to timeline

Student grading is also affected by the peer review and advisor feedback regarding each individual team member [6].

Open-Ended Robotic Design

Following section describes the open-ended design experience for the 2003 RI/SME competition. The open-ended design is an ideal path for reaching an original and non-restrained design practice that may involve in various fields and possibilities.
After studying Robot Construction competition rules, it was decided that animatronics would be the area of focus. Brainstorming was then done to expose many possible design ideas. After narrowing the ideas down, considering many factors of feasibility, the final decision was to construct an animatronic polar bear [7].

The objective of this project was to design and build an animatronic polar bear that will interact with the outside world through the use of sensors. The robot will be controlled by a preprogrammed embedded microcontroller and will present life-like motions for entertainment purposes [7].

Design Process

A literature review was conducted on animatronics and polar bears. The design team focused on the physiological features of the polar bear (as shown in Figure 1) and their kinematics, possible mechanical components, sensors, and controllers. Since the objective of the robot was to emulate life-like motions and to interact with the outside world, the next step was to identify all types of movements that could be accomplished and possible sensor locations. It was then realized that all of these possibilities, including use of sensors, were probably not feasible within the time constraints. However, the team chose to brainstorm freely and keep our options as extensive as possible for a better learning experience and potential future projects.

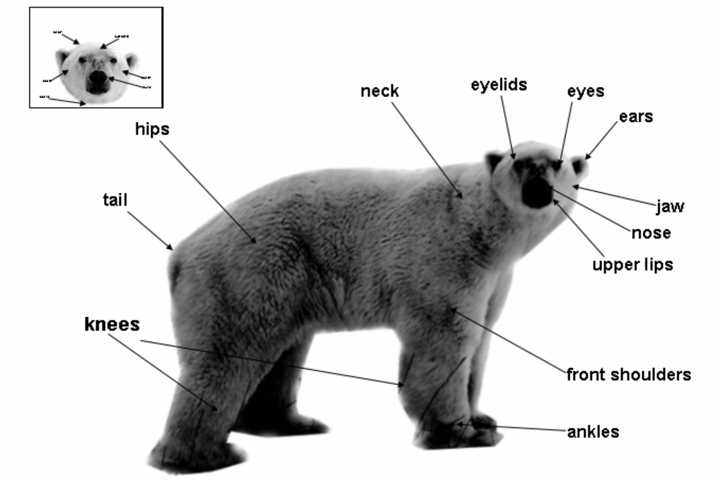

Figure 1. Areas of movements

After the completion of initial steps mentioned above, a Gantt chart was prepared for planning of the project activities. Possible components for mechanism design were studied. Several models of the polar bear, showing different angles and positions for which the robot's limbs will move to were sketched and are shown in Figure 2. From these models an accurate scale, also shown in Figure 2, for which the robot will be based, was developed.

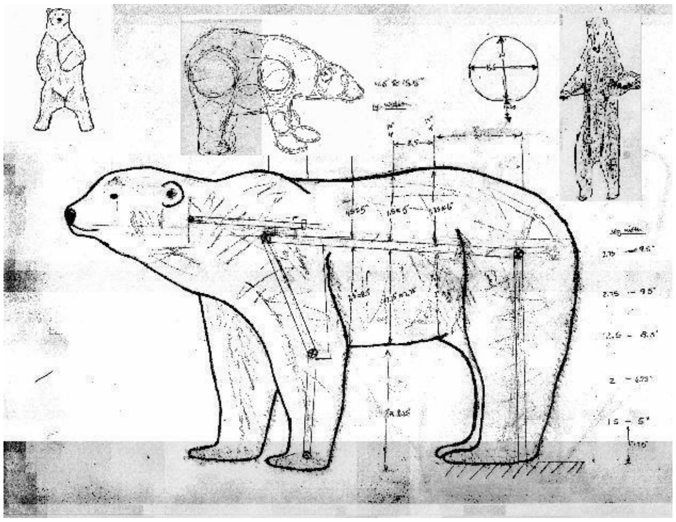

Figure 2. Models and movements of bear

The individual components for the main joints and skeletal structure were designed first. As the design progressed, parts were improved with continuous brainstorming and sketching, as seen in Figure 3. When the final designs were compete with their appropriate dimensions, they were then modeled through Pro/ENGINEER software. These engineering drawings can be seen in Figures 4 and 5. After the completion, engineering models were used in the fabrication and assembly of limbs/armatures as shown in Figure 6.

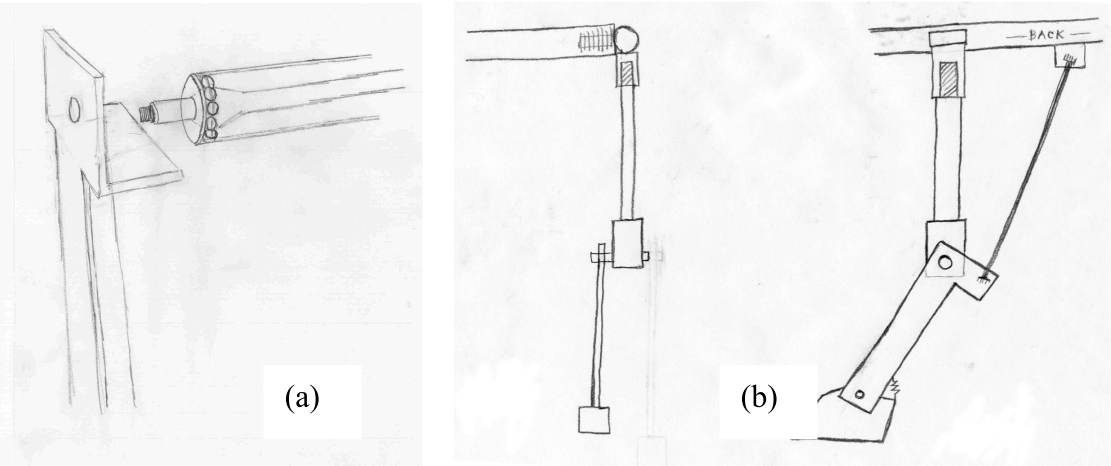

Figure 3. Sketches of (a) hind leg/hip joint and (b) front leg/shoulder/knee and ankle joints

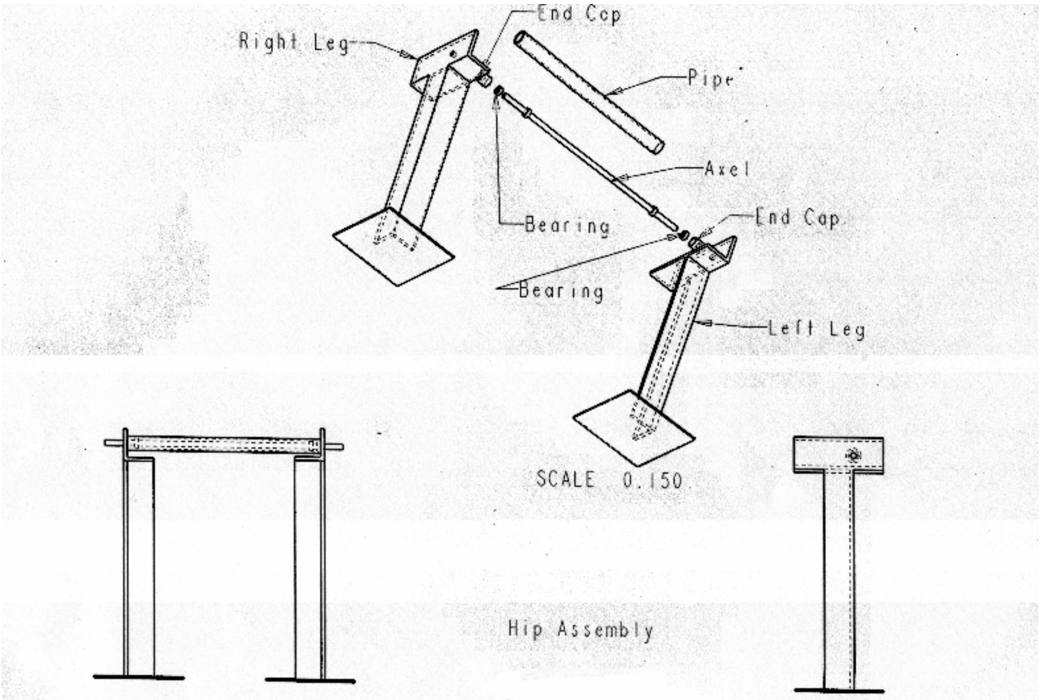

Figure 4. Pro/ENGINEER model of the hip subassembly

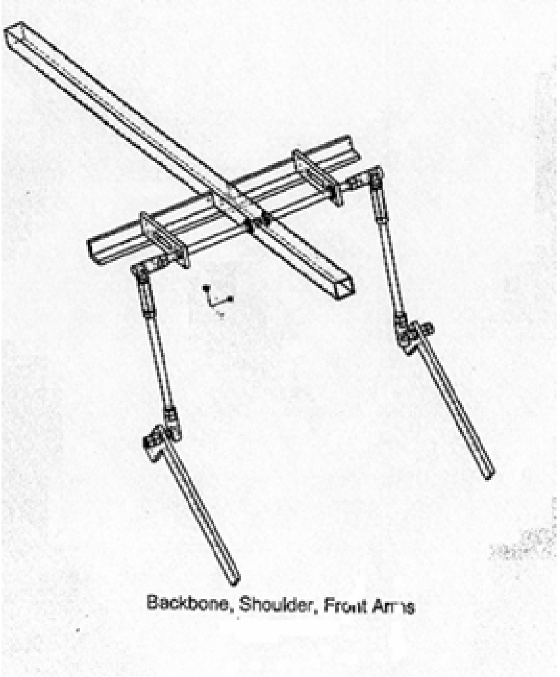

Figure 5. Pro/ENGINEER model of the backbone, shoulder and front legs (arms)

Figure 6. The front leg subassembly

A wooden base was designed and built to mount the robot on. Hind legs were constructed out of angle iron and the back bone was made out of steel tubing. Each hind leg was connected to the base through a set of four bolts, while the backbone is welded to a long, rotating cylinder (pipe) as shown in Figure 4. The cylinder, with the use of bearings, was attached to fixed screws that were held at the hip joint. The next major step was to developing the front legs (arms). Shoulders, made out of weldment of an angle iron and two slotted steel plates, were welded to the front half of the backbone. A subassembly of two steel rods connected through two-ball jointed rod ends constituted the moving portion of the shoulder and the upper leg, or the shoulder and knee joints. An L-shaped aluminum part was attached at the knee joint to function as the lower leg.

The neck joint was developed next. Self-aligning bearings were mounted on the top of the front-most half of the backbone. A steel rod was inserted through the bearings and was hooked into a universal joint. A square, steel face plate was then attached to the end of the universal joint by way of a bolt through its center. Head of the bolt was welded onto the faceplate to strengthen the joint between the plate and the bolt.

Next, two smaller items were established. Both can be seen in Figure 3 (b). The aluminum linkage arms connected the knee of the front leg and the edge of shoulder angle iron to achieve forced motion at the knee joint. Also, the free-rotating front paws, made out of polyurethane pieces, were attached to each front leg at the ankle joints.

At this point, a head needed to be developed for the polar bear. It was decided to use a lightweight material to help reduce the torque required to lift the front half of the bear at the hips. The design team determined to make the head out of a synthetic material known as "plasti-paste". The polar bear head had to be first sculpted out of clay. From this clay model, a five piece plaster mold was made. The plaster mold was used to create a hollow, yet durable and functional head, with a separate bottom jaw. The head was then machined to reduce its weight and create eye sockets, and attached to the front faceplate. The next challenge was the creation of the drive train.

The greatest challenge in drive train design was creating a smooth action at the hip. For this, a steel chord wound around a metal shaft was used, each end of the chord being attached to opposite sides of the backbone of the bear. This was done so that when the shaft rotates forward, the bear will rise, and when it rotates in reverse direction, the bear will be lowered. A sprocket and chain mechanism driven by a DC motor is used to drive shaft as seen Figure 7, and a vary heavy counter weight was attached to the rear to help offset the force created by the long and heavy front half of the bear, also reducing current requirements for the motor.

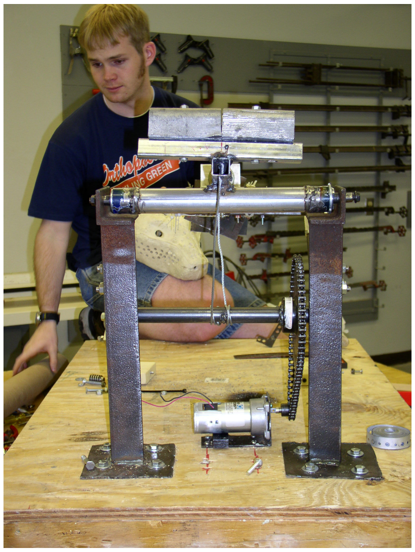

Figure 7. Driving the hip joint

Each of the front shoulders is controlled by separate DC motors to move independent of each other. The mechanism used to drive the shoulders is a simple worm gear setup mounted on the fixed portion of the shoulder, which comes off of the backbone as shown in Figure 8.

The neck uses one DC motor for its rotation, the roll motion. Although room is provided for additional motors to be utilized for the yaw and pitch motions, instead of driving with motors, several springs were mounted between the face plate and the motor mount on the neck. This greatly increases the degrees of freedom that the head has, mimicking a “bobble head” design, and allows for a much more realistic look in the overall movement. A string was attached between the bottom of the head and a fixed position on a hind leg. This simple addition ensures that when the bear rises up on its hind legs, the head will be pulled down so that the head is facing forward as opposed to staring unrealistically straight up into space.

The jaw joint was the next to be completed. A worm gear mechanism was utilized to rotate a shaft. Attached directly to the shaft, by a piece of steel, is the jaw piece made out of plasti-paste. This whole piece was accurately positioned inside of the hollow head, and fixed into location.

With the completion of the jaw, all of the motors were mounted, and the main, functional structure was done. The next task that needed to be done was electrical wiring. Before starting on wiring, all of the batteries, relays, fuses, and connectors were set-up on a board that was placed underneath the hollow base of the polar bear. Circuit drawings were created at Automation Studio software. The control circuits were simplified by using 12 VDC motor outputs of the controller with magnetic relays with 12 VDC coil rating. Solid state relays with low input voltage limit of 3.5 VDC were used with 5 VDC digital outputs of the controller. 1 ½ - 3 amp fuses were used in overload protection depending upon the need of each DC motor.

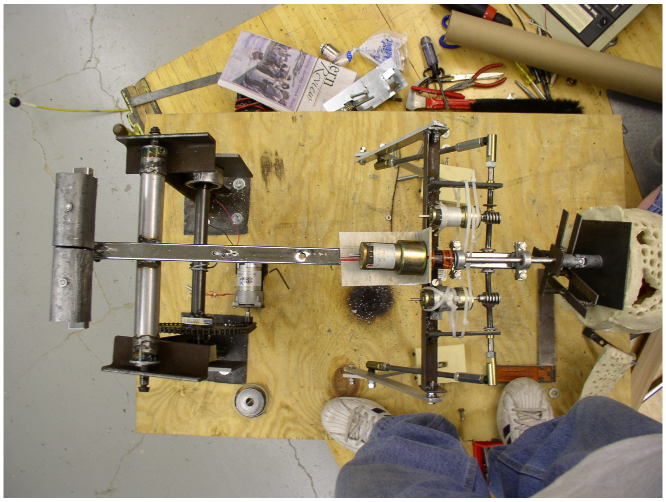

Figure 8. Top view of the robot including DC motors

The two shoulders operated independent of the microcontroller. This was mainly due to a lack of relay for use because of the financial constraints. A set-up of four SPDT (single pole double throw) toggle switches and two DPDT (double pole double throw) magnetic relays were utilized to control the shoulder manually, two of them were used in turning motors on and off, and two of them were used to control the direction of rotation of the each motor. Electrical schematic of the shoulder control circuit is given below in Figure 9. Magnetic relays constructed an H-bridge for direction controls. 12 VDC was used in the shoulder motors and proven to be supplying enough power to drive the shoulder and the legs.

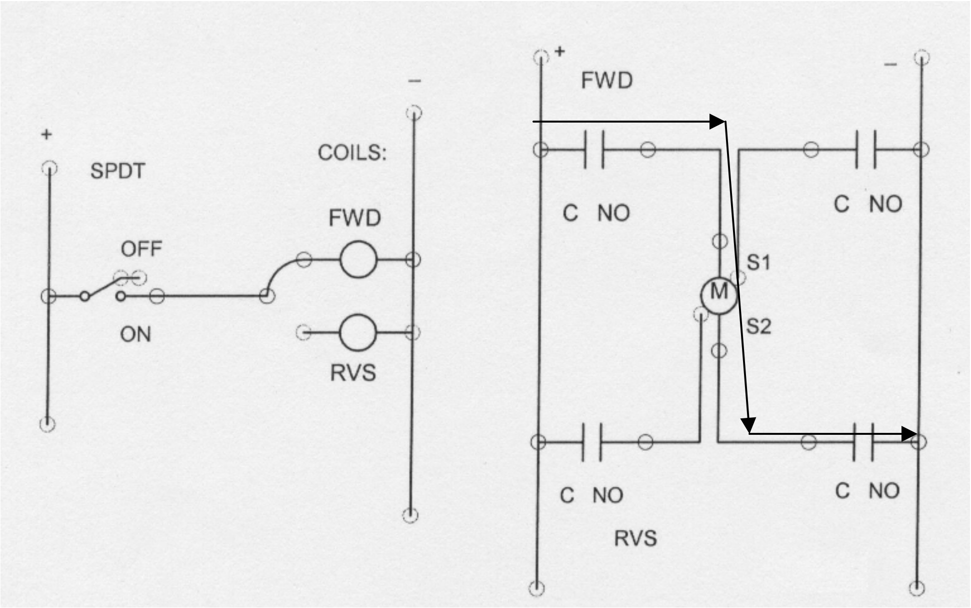

Figure 9. Electrical schematic for the shoulder drives (arrow indicating direction of the conventional current when motor is running in the forward direction)

An H-bridge made up from four SPST (single pole single throw) solid state relays were used for the jaw joint, driving the motor with 6 VDC. The jaw was wired to two digital outputs of the microcontroller, where the digital outputs D0 and D2 controlled the forward and reverse actions of the jaw respectively. The schematic for the jaw drive is below in Figure 10.

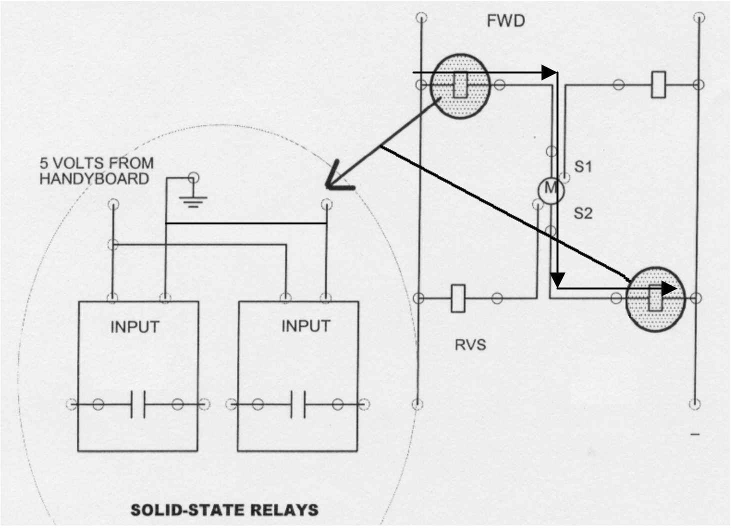

Figure 10. Electrical schematic for the jaw drive (small arrow indicating direction of the conventional current when motor is running in the forward direction)

For the hip and neck joints, the design team used two DPDT (double pole double throw) magnetic relays for each, driving them with 18 volts and 6 volts DC respectively. The neck and hip were wired to the DC motor outputs of the microcontroller. DC motor outputs were used as discrete (ON/OFF) signals. Their forward and reverse outputs for the each joint were: for the hip, 0 and 1; for the neck, 2 and 3. Schematics for the neck and hip drives are shown below in Figure 11.

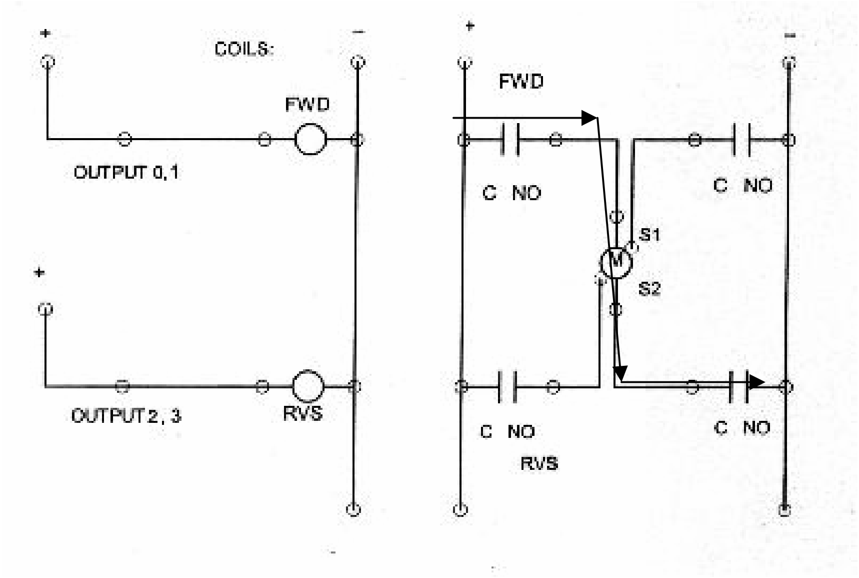

Figure 11. Electrical schematic for the (a) neck and (b) hip drives drive (arrow indicating direction of the conventional current when motor is running in the forward direction)

Having everything wired, the microcontroller was needed to be prepared and programmed. The microcontroller, M.I.T's "Handy Board", a LEGO controller, had already been assembled with its expansion board and tested. It had also been initiated by downloading the pseudo code. The Handy Board is a Motorola 68HC11A processor based controller and was designed for M.I.T. 6.270 Robot Design Competition. The design team had learned a comfortable amount of the programming language, Interactive C. Interactive C, is a multi-tasking application of the C programming language that is intended to run on small, 8-bit microprocessor [8]. A variety of motion sequences were studied, and then a few programs, corresponding to the separate combinations of movements, were created. A partial sample of one of the programs, "multi3.c"can be observed in Figure 12.

```
void main () {
        move_neck();
        raise_hip_and_move_neck_twice();
        open_mouth();
        lower_hip();
        move_neck2();
        neck_mouth();
        pounce();
}
void move_neck () {
                /* rotate right */
                        bk(1); msleep(2000L);
                        off(1);
                /* rotate straight */
                        fd(0); msleep(2000L);
                        off(0);
                        msleep(2000L);
}
void raise_hip_and_move_neck_twice () {
                start_process(raise_hip());
                start_process(move_neck_twice());
}
void raise_hip () {
        /* raise hip */
                fd(2); msleep(4000L);
                off(2);
}
void move_neck_twice () {
        /* rotate left */
                fd(0); msleep(2000L);
                off(0);
        /* rotate right */
                bk(1); msleep(4000L);
                off(1);
        /* rotate straight */
                fd(0); msleep(2000L);
                off(0);
}
void open_mouth () {
        /* open mouth */
                set_digital_out(0); msleep(1000L);
                clear_digital_out(0);
                msleep(2000L);
        /* shut mouth */
                set_digital_out(2); msleep(1000L);
```

Figure 12. Microcontroller program

Once everything had been installed, some costuming was done to the animatronic polar bear. It was accomplished by first creating a wire-frame shell about the whole exterior using proper dimensions scaled from drawings. The wire used was a mix of coat hangers, welding wire and thin black electric wire. On the shell, a white fur recycled from a stuffed polar bear doll was attached shaping the robot to a polar bear's exterior with the closest fit shown in Figure 13. Two black marbles were used for the eyes, also shown in Figure 13. Proper placement of the fur with proper material allowance permitted desired motions with ease, and sewing was completed. The fur was only applied to one half of the robot. It was partly done this way to allow for an accurate observation of the inside of the robot, and also due to a lack of fur material. Only half of the base of the robot was painted black, an Ohio Northern color, to aid in the overall theme and visual effects.

Figure 13. Costumed robot

Conclusions

It was a good learning experience that covered various fields of mechanical, electrical, industrial, and manufacturing engineering, biomechanics and artistic design concepts. Both the faculty and the students involved in the project enjoyed the multi and cross disciplinary learning experience. Hands-on experience was supported with theory. A new type of controller, a microcontroller, and Interactive C, a C-based programming language were used in a traditionally PLC dominant program. Problems encountered were solved with simple but effective solutions by avoiding complications in the design process. Solutions such as eliminating complex electrical interfacing between the LEGO controller and large industrial electrical motors with use of DC motor outputs as discrete outputs or absorbing the impact energy of the falling bear through rubber padding placed at the hips were achieved. Due to time and financial limitations, some of the initial intentions such as use of sensors or cameras were not realized. However, this was initial attempt to start the preparations for the enhancements of the Ohio Northern University Robotics program before HONR 218 is offered for the first time.

Near future open-ended robotic projects will include but not be limited to design of articulated and walking robots, use of ultrasonic and infrared sensors, sophisticated vision systems, muscle wires, and air muscles.

References

[1] Sirinterlikci, A., Rouch, D., Robotics Design Initiative through an Honors Program, NAIT (North American Industrial Technology Association) Annual Convention, Nashville, TN, 2003.

[2] Braga, N.C., *Mechatronics Source Book*, Thomson/Delmar Learning, Clifton Park, NJ, 2003.

[3] http://biorobotics.cwru.edu

[4] http://www.creatureshop.com/

[5] Participant Manual and Rules for 17th RI/SME Robotic Technology and Engineering Challenge, 2003.

[6] Syllabus for TECH 435 – Advanced Robotics/Automation, Ohio Northern University, Ada, OH, 2003.

[7] Toukonen, K., Mason, S., Robot Construction: Animatronic Polar Bear, Senior Capstone Project Final Descriptive Report, Ohio Northern University, Ada, OH, 2003.

[8] Martin, F., *Robotic Explorations: A Hands-On Introduction to Engineering*, Prentice-Hall, Upper Saddle River, NJ, 2001.

Biography

ARIF SIRINTERLIKCI is currently serving as a faculty member at Ohio Northern University Technological Studies and Honors Programs. He holds a Ph.D. degree from Industrial & Systems Engineering Program of the Ohio State University and M.S. and B.S., both in Mechanical Engineering from Istanbul Technical University, Turkey. His previous work experiences include various engineering, teaching and research appointments and projects in Mechanical and Manufacturing Engineering fields.