A Multi- and Cross-Disciplinary Capstone Experience in Engineering Art: Animatronic Polar Bear

Arif Sirinterlikci, Kayne Toukonen, Steve Mason, Russel Madison
Ohio Northern University

Abstract

An animatronic robot was designed and constructed for the 2003 Annual Student Robotic Technology and Engineering Challenge organized by the Robotics International (RI) association of the Society of Manufacturing Engineers (SME). It was also the senior capstone design project for two of the design team members. After a thorough study of body and biomechanics of polar bears, the skeleton and limbs of a polar bear robot were designed to scale. The design was complemented with the drive train and DC electric motors as actuators. A microcontroller, a LEGO controller, was utilized to control the motions of the bear. Design experience included artistic design of the bear and its shell for placement of fur, mechanism design for the body and its limbs, the design of power train, selection of the electric actuators and control circuit design, and programming of the microcontroller. Most mechanical and electrical components were obtained through recycling of old robots and equipment from laboratories.

Introduction

Automation and Robotics are the major strengths of the Technological Studies program curriculum at Ohio Northern University. Traditionally Ohio Northern University has been well represented at the RI/SME's Student Robotic Technology and Engineering Challenge since 1993. It has been a great learning experience for Technology students in terms of working towards problem solving in team environments and through project management practices. The involvement of faculty has assured faculty growth as well. Most projects were involved in reaching a fixed goal such as climbing stairs, some were open-ended design projects such as robot design and construction of choice. As an initial step of enhancing the Robotics Program at the Technological Studies Department, an Honor's Seminar on Animatronics will be offered with the goals of:

- attracting quality students with interest in Robotics and Mechatronics,
- involving interested Technology students in open-ended design projects enforcing creativity and articulate robotic system design,
- utilizing state-of-the-art and current sensing, actuation and control technologies including micro or nano-controllers, shape memory alloys or air muscles.

The 2003 RI/SME Student Robotic Technology and Engineering Challenge was the starting point of the Robotics Design Initiative [1]. An animatronic polar bear, the mascot of Ohio Northern University, was chosen as the challenge for the Robot Construction category.

An animatronic puppet is a figure that is animated by means of electromechanical devices. In today's terms, it can be described as a mechatronic puppet emulating an actual living being or a fictitious character. Animatronics was a popular way of entertainment that had proven itself in the theme parks and cinematography industry [2]. In the last two decades, animatronic puppets and robots have been replaced by computer animations. However, with the emergence of toys such as Furby and Fur Real Cat, animatronics is having a comeback in the toy industry. There are many examples of Mechatronics related educational activities through small robots and LEGOs at secondary and higher educational levels with the common goal of introducing and experiencing Multi-disciplinary Engineering, which is the today and future of Engineering [3] [4]. However, Utilization of Animatronics in Education has been rare. These included Adrian Woolard's Ph.D. thesis entitled "Animatronics: The Development of a Facial Action Sensing System to Enhance Performance Control" [5] and a M.S. Thesis entitled "Design and Development of an Expressive Animatronic Face" by Christopher Vincent Nowakowski [6]. Involvement of artistic concepts such as costume design and realistic animation elevated the multi-disciplinary experience to a cross-disciplinary one.

Problem Statement

The objective of this study 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 create life-like motions for entertainment purposes [2].

Design Process

After studying the description and the rules of the Robot Construction category of the RI/SME competition, it was decided that animatronics would be our area of focus. Brainstorming was then done to expose many possible design ideas. After narrowing the ideas down, considering many factors of feasibility, our final decision was to construct an animatronic polar bear.

Research was the next step in the design process. A literature review was conducted on both animatronics and polar bears. Using the Internet, literature, and faculty resources, the design team focused on the physical features of the polar bear and their kinematics, possible mechanical components, sensors, and controllers (Figure 1.). Although a concentrated amount of our research was completed at the initial phase, research continued throughout the design process for design improvements. Since the objectives of our robot were to emulate life-like motions and to interact with the outside world, the next step was to identify all possible sensor locations and areas of movements that could be accomplished. 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 its options as extensive as possible for a better learning experience and for future projects.

Once the initial steps mentioned above were completed, a Gantt chart shown in Figure 2 was developed. Possible components for mechanism design were studied. Several models of the polar bear, showing different angles and range of motion for the robot's limbs were developed and are shown in Figure 3. From these models, an accurate scale for which all components of the robot will be based, was developed.

The individual components, creating the main joints and skeletal structure were designed first. As various design issues were examined, parts were improved with continuous brainstorming and sketching, as seen in Figure 4 and 5. When our

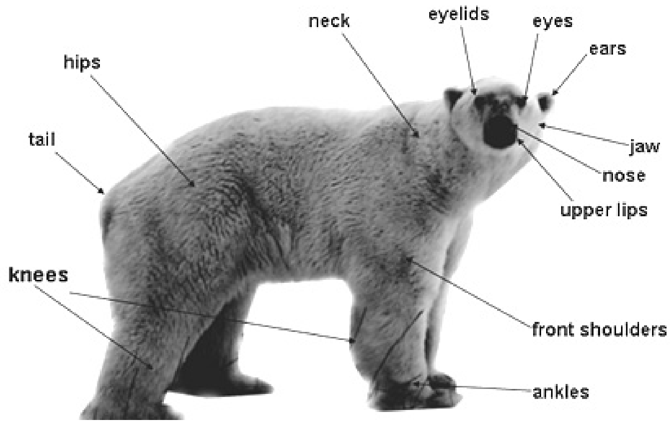


Figure 1. Areas of Movement [2]

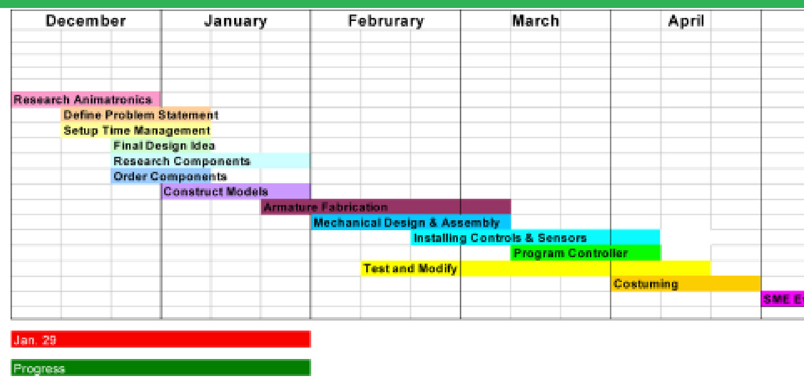


Figure 2. Gantt chart [2]

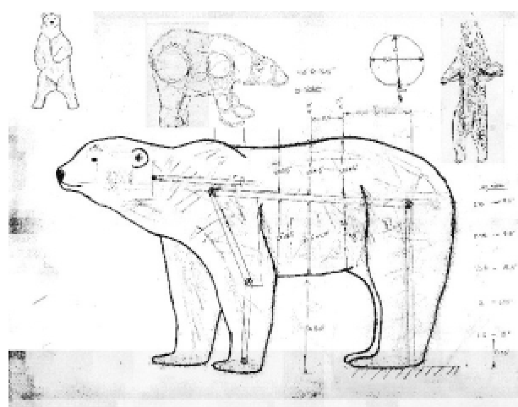


Figure 3. Models and Movements of Bear [2]

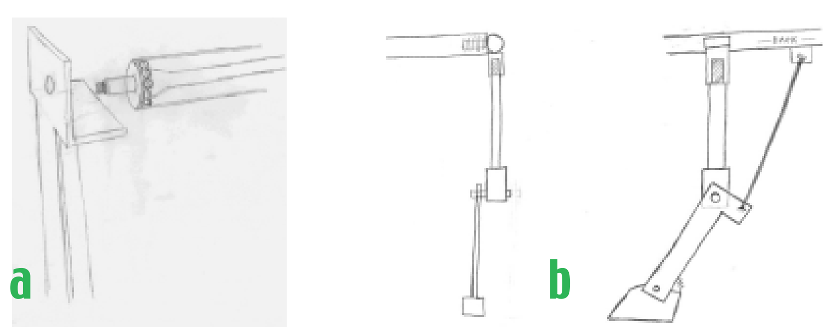


Figure 4. Sketches of (a) hind leg/hip joint and (b) front leg/shoulder/knee and ankle joints [2]

final designs were complete with their appropriate dimensions, they were then modeled using Pro/ENGINEER software. These engineering drawings can be seen in Figures 6, 7, and 9. After the completion of engineering models, engineering drawings were used in the fabrication of limbs/armatures as shown in Figure 8.

A wooden base was designed and built for mounting the robot. Hind legs were constructed out of angle iron and the back bone was made out of steel tubing. The hind legs were connected to the base through a set of four bolts per leg, while the backbone was welded to a long, rotating cylinder (pipe) as shown in Figure 7. The cylinder, with the use of (3/8") brass bearings, was attached to fixed screws that were held at the hip joint.

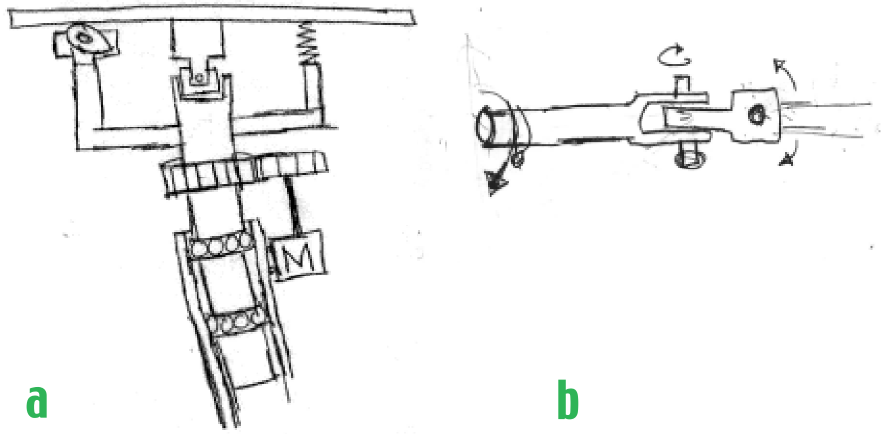


Figure 5. Sketches of (a) preliminary neck design and (b) neck joints (universal joint) [2]

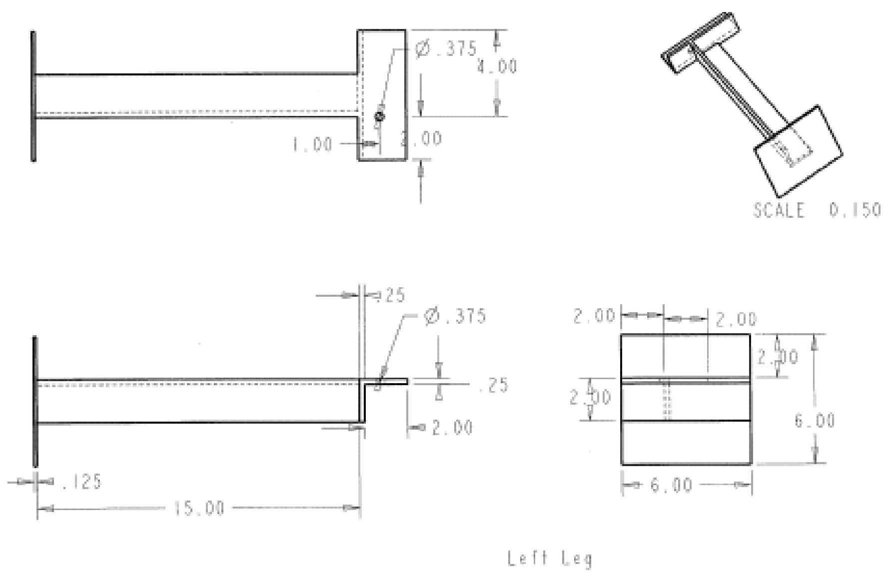


Figure 6. Pro/ENGINEER model of the left hind leg [2]

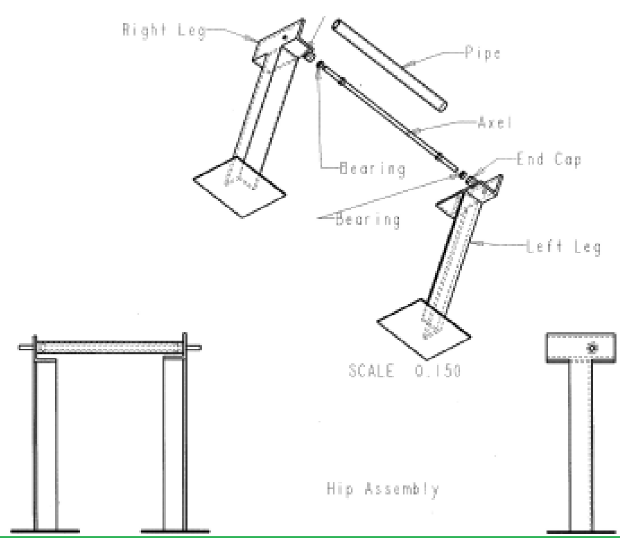


Figure 7. Pro/ENGINEER model of the hip subassembly [2]

The next major step was developing the front legs (arms). Shoulders, made out of weldment of an angle iron and two slotted steel plates, were welded to the upper half of the backbone. A sub-assembly of two steel rods connected through two automotive ball-jointed tie-rod ends constituted the moving potion 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 completed shoulder-leg assembly can be seen in Figures 8 and 9.

The neck joint was developed next. Self-aligning (3/8") bearings in pillow blocks 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. The head of the bolt was welded onto the faceplate to strengthen the joint between the plate and the bolt. The neck assembly was now complete as seen in Figure 10.

Next, knee and ankle joints were established. Both can be seen in Figure 4 (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 the ends of each front leg at the ankle joints.

Figure 8. Photograph of the front leg subassembly [2]

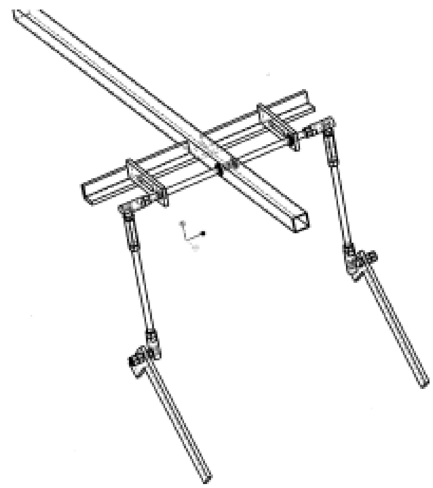


Figure 9. Pro/ENGINEER model of the backbone, shoulder and front legs (arms) [2]

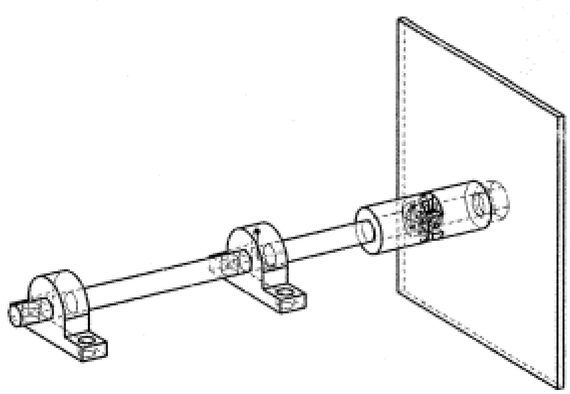


Figure 10. Pro/ENGINEER model of the neck joint [2]

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 decided to make the head out of a synthetic material known as "plasti-paste". The polar bear head had to first be 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 piece as shown in Figure 11. The head was then machined to reduce its weight and attached to the front faceplate. The next challenge was the creation of the drive train.

Our greatest challenge in drive train design was creating a smooth action at the hip. For this reason, a steel cord wound around a metal shaft was used, each end of the cord 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 (Martin 35BS60/35BS9) and chain mechanism driven by a DC motor (Matsushita GMX-6MP013A) is used to drive the shaft as seen in Figure 12, and a counter weight was attached to the rear to help offset the force created by the long and heavy front half of the bear.

Each of the front shoulders is controlled by separate DC motors (Pittman GM8712E465 with 96:1 gear ratio) so as 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 13.

Figure 11. Head and jaw [2]

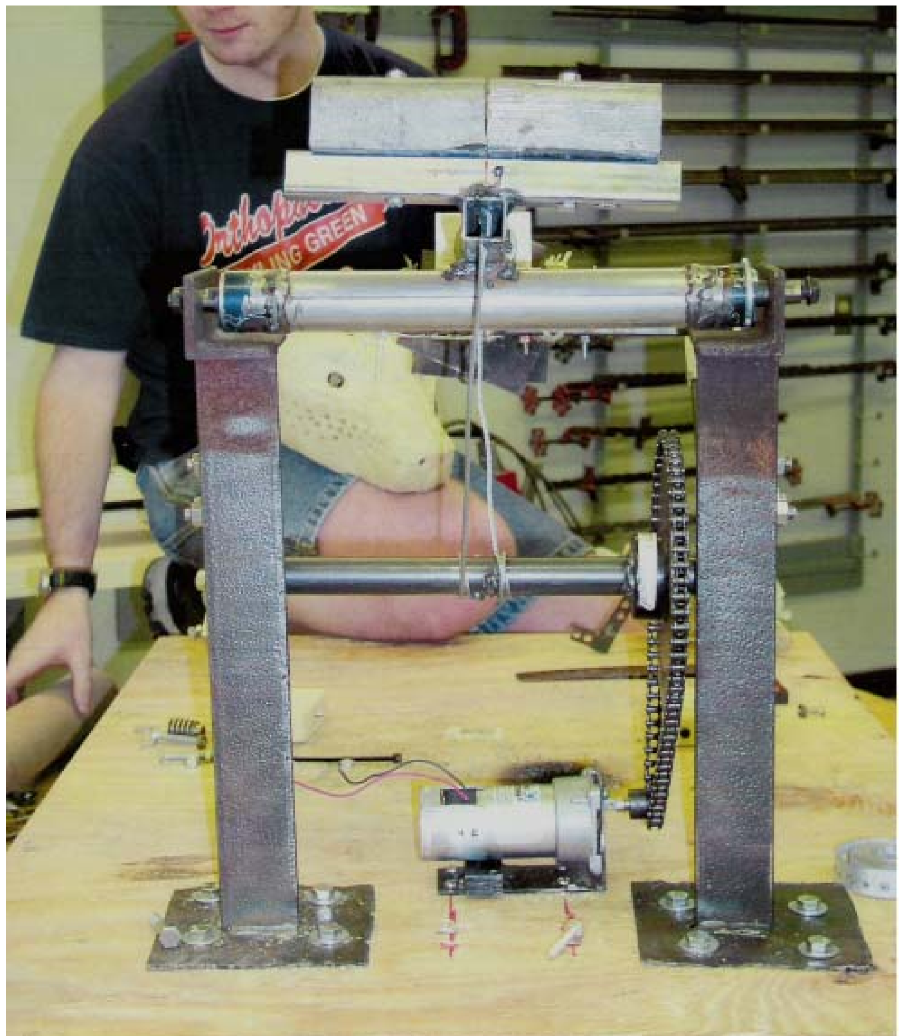


Figure 12. Driving the hip joint [2]

The neck uses one DC motor (Pittman GM9413F759 with 65.5:1 gear ratio) for its rotation, the roll motion through a flexible coupling (Lovejoy L-050: 3/8" bore no keyway jaw coupling). 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. Also, a string was attached between the bottom of the head and a fixed position on a hind leg. This simple mechanism 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. A Pittman GM9413F154 DC motor was employed to actuate the jaw without its gearhead. Attached directly to the shaft, by means of a piece of steel, is the jaw piece which is made out of plasti-paste. This whole piece was correctly positioned inside of the hollow head, and fixed into location accordingly.

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 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 using Automation Studio Software [7]. The control circuits were simplified with the use of 12 VDC motor outputs of the controller with magnetic relays of 12 VDC coil rating. Solid state relays (CRYDOM D1D40 with input voltage limits of 3.5 - 32 VDC and output rating of 100 V and 40 A) were used with 5VDC digital outputs of the controller. Fuses were used in overload protection depending upon the need of each DC motor.

The two shoulders operated independent of the microcontroller. This was mainly due to a lack of available relays because of financial constraints. A set-up of four SPDT (single pole double throw) toggle switches and two DPDT (double pole double throw) magnetic relays (Schrack TM010012 12 VDC coil with 10 A contact rating) were utilized to control the shoulders manually; two of them were used in turning the motors on and off, and two of them were used to control the forward and reverse action of the each motor. Electrical schematic of the shoulder control circuit is given in Figure 14. Magnetic relays constructed an H-bridge for direction control. A 12 Volt battery was used in the shoulder motors and proved to supply enough power to

Figure 13. Top view of the robot including DC motors [2]

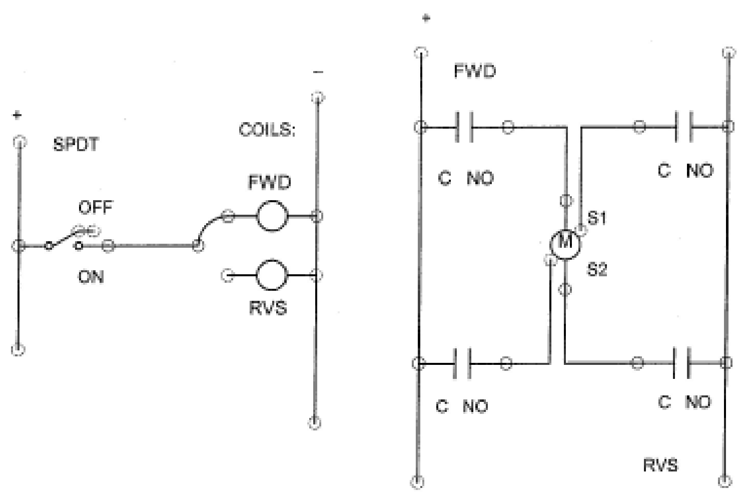


Figure 14. Electrical schematic for the shoulder drives [2]

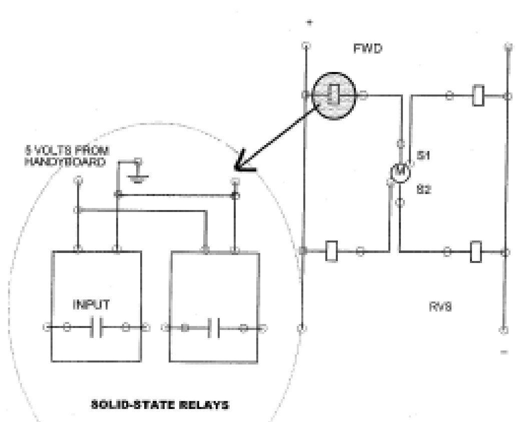


Figure 15. Electrical schematic for the jaw drive [2]

drive the shoulders and the legs.

An H-bridge made up of four SPST solid-state relays were used for the jaw joint as shown in Figure 15, driving the motor with 6 volts DC. 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.

For the hip and neck joints, the design team used two DPDT magnetic relays for each joint, 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) output signals. Their forward and reverse outputs for the each joint were: for the hip, 0 and 1; for the neck, 2 and 3. An H-bridge of relays was constructed to wire the motors as shown in Figures 16.

With everything wired, the microcontroller had to be prepared and programmed. The microcontroller, M.I.T.'s "Handy Board", a LEGO controller, had already been assembled with its expansion board for servo-control ability and tested [8]. It had also been initiated by downloading the pseudo code. The Handy Board is a Motorola (52-pin) 68HC11A processor-based controller and was designed for M.I.T.'s 6.270 Robot Design Competition. The controller has the following basic features:

- 256 byte RAM
- 32 Kbytes of battery-backed static RAM
- 16x2 LCD display
- 4 bidirectional motor outputs
- 16 sensor inputs (9 digital/7 analog)
- infrared subsystem
- potentiometer
- ultrasonic ranging capability under 9.6 V rechargeable battery pack.

The design team had learned a comfortable amount of the programming language of the microcontroller - Interactive C. Interactive C is a multitasking application of the C programming language that is intended to run on a small, 8-bit microprocessor [9]. Interactive C consists of an interactive compiler/debugger and a run-time machine language module. It implements a subset of C with control structures, variables, arrays, pointers, integers, and floating point numbers. It also has a support of built-in libraries for sensors and actuators for easy use in controls applications [10]. A variety of motion sequences were studied, and then a few programs, corresponding to the separate combinations of movements, were created. A sample of one of the programs written, "multi3.c" can be observed in Figure 17.

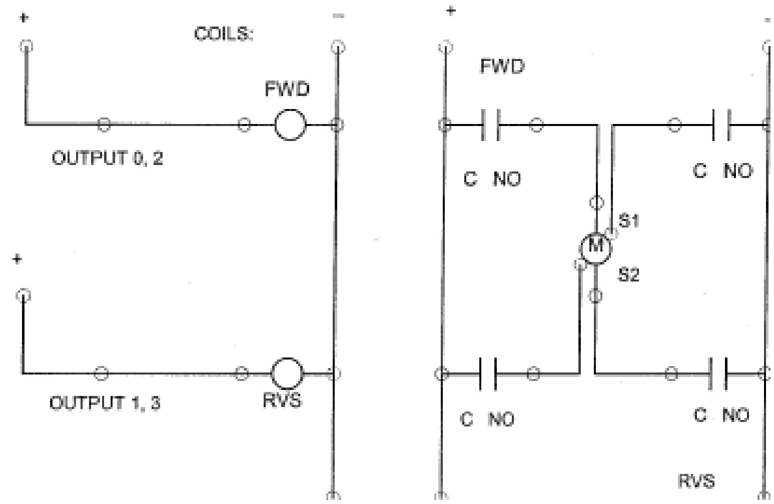


Figure 16. Electrical schematic for the (a) neck and (b) hip drives [2]

```
void move_neck2 () {
        /* move neck right */
                fd(0); msleep(1000L);
                off(0);
        /* move neck left */
                bk(1); msleep(1000L);
                off(1);
        /* move neck right */
                fd(0); msleep(1000L);
                off(0);
                msleep(4000L);
}
void neck_mouth () {
        start_process(b_f());
        start_process(open());
}
void b_f () {
        /* rotate left */
                bk(1); msleep(2000L);
                off(1);
        /* rotate right */
                fd(0); msleep(4000L);
                off(0);
        /* rotate left */
                bk(1); msleep(2000L);
                off(1);
}
void open () {
        /* open mouth */
                set_digital_out(2); msleep(250L)
                clear_digital_out(2);
                msleep(4000L);
        /* close mouth */
                set_digital_out(0); msleep(250L)
                clear_digital_out(0);
}

void pounce () {
        /* pounce */
                msleep(8000L);
                fd(2); msleep(1000L);
                off(2);
                msleep(1500L);
                fd(2); msleep(1000L);
                off(2);
                msleep(500L);
                fd(2); msleep(2600L);
                off(2);
                set_digital_out(2); msleep(250L)
                clear_digital_out(2);
                msleep(3000L);
        /* fall back down */
                bk(3); msleep(1000L);
                off(3);
                set_digital_out(0); msleep(250L)
                clear_digital_out(0);
```

Figure 17. Microcontroller program [2]

Once everything had been installed, some costuming was done to our animatronic polar bear. Costuming was accomplished by first creating a wire-frame shell about the whole exterior using proper dimensions scaled from our drawings. The wire used was a mix of coat hangers, welding wire and thin black electric wire as shown in Figure 18 (a). On the shell, a white fur recycled from a stuffed polar bear was attached, shaping the robot to a polar bear's exterior with the closest fit as shown in Figure 18. Two black marbles were used for the eyes, also shown in Figure 18 (b). 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 18. (a) Robot wire shell and (b) costumed robot [2]

Conclusions for the Project and Future Work

This was a good learning experience that involved various fields of mechanical, electrical, industrial, 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 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 electrical interfacing between a LEGO controller and large industrial electric motors with the 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 were not realized. However, this was an initial point to start the enhancement of the Ohio Northern University Robotics program. Major problems encountered were the instability of the bear during sudden acceleration, accessibility to the control circuits, and the jamming of the gears driving the mouth. Students spent some time fine tuning the robot motion to prevent vibration problems and additional springs with high stiffness were added to keep the head stable. Although a large hole at the base was opened to allow access to the control circuits, accessibility remained an issue. The jamming of the gears was an intermittent issue and was not dealt with.

Near-future improvements will include, but will not be limited to the design of articulate and walking robots, use of ultrasonic and infrared sensors, sophisticated vision systems, muscle wires, and air muscles.

The Design Team and Learning Experience: A Note from the Advisor

Assigned by the faculty committee, the project team was initially composed of 4 technology students, 3 of whom were in the Design Analysis track. Even though 3 of the team members were from the same track, a pre-project survey indicated varying past coursework, experiences, interests, and learning styles [11]. Design Analysis is basically a General Engineering Technology program base with Industrial Technology focus. In this track, students take additional physics and mathematics courses as well as various general engineering courses including Fundamentals of Engineering, Engineering Problem Solving and CAD, Statics, Dynamics, and Strength of Materials. The fourth student was enrolled in the Advanced Manufacturing Option. Advanced Manufacturing is an Industrial Technology track enhanced by additional content of Automation/Robotics and Virtual Manufacturing with Virtual Design and Simulation of Manufacturing Systems, Ergonomic Design, and OFF-LINE Robotic Programming. The fourth student had to leave the project due to high course load which in turn put extra pressure on the other team members. This was the major problem that the team faced, and it was handled by scaling down the project by eliminating the development of a virtual model of the polar bear and by some extra work distribution to the members.

With the initiation of the project, one of the members assumed an active role and was appointed by the faculty advisor as the team leader. Distribution of the work and execution of the tasks were handled very smoothly and in harmony. During the early execution stage, each of the three students had shown strengths in different areas. One student handled the mechanical design portion of the project due to his stronger theoretical background in engineering as a previous student and his past practical experiences in a car service. He was also comfortable with electrical and electronics concepts. The second student, who was an art minor, was in charge of concept and artistic design stage converting biomechanical information into animatronic design constraints, costuming including design of the body shell, and programming of the microcontroller. The third student served as the manufacturing process technician, since he had extensive hands-on experience in processes. Most of the technology students carry traits of sensory, visual, inductive and active learners. However, the project leader had also a strong intuition and deduction ability with global focus. The student with the art minor had a strong deductive and reflective learning ability as well as the traits mentioned above for technology students. The result was a programmable animatronic polar bear.

The team met once a week. However, they were in constant dialogue. Everyone was alert on what was going on at all times since they assisted each other. It was a small team with an ambitious project to be completed with very limited resources and in a short time span (two 10-week quarters). Students were required to make four presentations to the faculty committee and their peers. They also kept a record of their progress including design ideas and sketches, issues faced and their solutions in their individual journals. Peer review and a review of the project course as an exit review were also conducted.

This was a student-led project and problem based learning experience under the supervision of the advisor. Proper project management practices were followed. The open-ended design enhanced each team member's view of the various fields involved. Every technical problem encountered was solved by simple, but effective solutions mostly produced by the team members as mentioned throughout this paper. Team members also sought assistance by researching and accessing expert opinions.

References

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

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

[3] Sahin F., Walter, W., Multi-disciplinary Microrobotics Teaching Activities in Engineering Education, Proceedings of the 2003 American Society for Engineering Education Conference & Exposition, Nashville, TN.

[4] King, L. S. et al., Building a Process for Establishing an Interdisciplinary Design and Manufacturing Freshman Course, Proceedings of the 2003 American Society for Engineering Education Conference & Exposition, Nashville, TN.

[5] Woolard, A., Animatronics: The Development of a Facial Action Sensing System to Enhance Performance Control, Ph.D. Thesis, the University of Newcastle upon Tyne, 1994.

[6] Nowakowski, C. V., Design and Development of an Expressive Animatronic Face, M.S. Thesis, Bucknell University, 2002.

[7] http://www.automationstudio.com

[8] http://lcs.www.media.mit.edu/groups/el/projects/handy-board

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

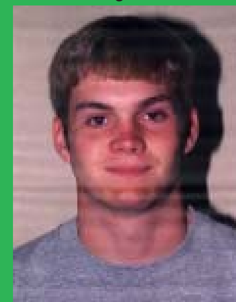
[10] http://www.kipr.org/ic

[11] Felder, R.M., Masters of Style, ASEE Prism, pp. 18-23, 1996.

Arif Sirinterlikci is an Assistant Professor 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. He is the current editor of ASEE (American Society for Engineering Education) Manufacturing Division and is serving as one of the leaders of the Industrial Technology Interest Group in ASEE Engineering Technology Division. He is a member of National Association of Industrial Technology (NAIT), American Society of Mechanical Engineers (ASME), Alpha Pi Mu Industrial Engineering Honorary, Epsilon Pi Tau Technology Honorary, and Sigma Xi Scientific Research Honorary. He is a Certified Senior Industrial Technologist (CSIT).

Kayne Toukonen attended Ohio Northern University where he was a two-time NCAA Academic All-American in wrestling. He graduated with summa cum laude from Ohio Northern University in 2003 with a Bachelor of Science in Technology, a Design Analysis option, and a minor in Art. He is currently pursuing graduate work at Kent State University in the Visual Communication Design curriculum and works part time at the engineering firm of Bair, Goodie and Associates, Inc. in New Philadelphia, Ohio. He is a member of Society of Manufacturing Engineers (SME) and Epsilon Pi Tau Technology Honorary.

Steve Mason graduated from Ohio Northern University Technology Department in August 2003 with a Bachelor of Science in Technology as a member of the Design Analysis option. He is currently employed at Cooper-Standard Automotive as a SPC (Statistical Process Control) Coordinator at their Seal Plant in Bowling Green, Ohio. He is a member of Society of Manufacturing Engineers (SME) and a Certified Manufacturing Technologist (CMfgT).



Russel Madison is currently enrolled as a senior at Ohio Northern University Technology Program. He specializes in the Design and Analysis option. He is a member of the Society of Manufacturing Engineers (SME) and Epsilon Pi Tau Technology Honorary.