A Hands-on Paradigm for EAP Education: Undergraduates, Pre-college Students, and Beyond

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ABSTRACT

Electroactive polymers (EAPs) are receiving increasing interest from researchers due to their unique capabilities and numerous potential applications in biomimetic robots, smart structures, biomedical devices, and micro/nanomanipulation. Since these materials are relatively new, it is imperative to educate students and the general public to raise their awareness of EAP potentials and produce the talent pool needed for continuing, rapid advances in the field of EAPs. In this paper we describe our concerted effort in teaching EAP to undergraduates, grade school students, and the general public, through hands-on research and learning on EAP-based biomimetic robots. Two integrated activities are highlighted: A senior Capstone design program on EAP robots, and the subsequent programs that use these developed robots to reach out to pre-college students. A robotic fish and a sociable robot enabled by ionic polymer-metal composite materials are used as examples throughout the paper.

Keywords: Electroactive polymers (EAPs), ionic polymer-metal composite, EAP education, robotic fish, sociable robot

1. INTRODUCTION

Electroactive polymers (EAPs), also known as artificial muscles, are emerging actuation and sensing materials with numerous potential applications in biomimetic robotics, bio- and micromanipulation, biomedical systems, and smart structures.[1–12] Their unique properties and long list of applications have attracted interests from researchers all over the world. However, since these materials are relatively new, it is imperative to educate students and the general public to raise their awareness of EAP potentials and produce the talent pool needed for continuing, rapid advances in the field of EAPs. In this paper we describe our concerted effort in promoting the EAP education among undergraduates, grade school students, and the general public through an innovative, hands-on paradigm. Due to the appealing nature of biologically-inspired robots,[13] the educational activities are centered around EAP-enabled biomimetic robots.

Two integrated activities are highlighted. The first is a senior Capstone design program focused on EAP-enabled robots. Two examples will be presented, a robotic fish-based mobile sensing platform[9] and a sociable robot. Both robots are driven by ionic polymer-metal composite (IPMC) actuators. For the development of each robot, a team of five senior students was assembled. These interdisciplinary projects provided unique learning opportunities for the students directly involved, but the impact went far beyond the team. Through lectures

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and project presentations, the teams educated their peers and the general public on EAP materials and their applications.

As the second component of our EAP-related educational program, the developed EAP robots are used extensively in outreach and recruitment activities. The close collaboration between EAP researchers and the Recruitment and Outreach Office has proven successful and mutually beneficial. Steady progress is being made to further streamline and enhance the educational programs by developing a formal curriculum.

The remainder of this paper is organized as follows. In Section 2 the development of an EAP-propelled robotic fish is described. The sociable robot project is discussed in Section 3. The educational impact beyond the senior design teams is introduced in Section 4. In Section 5 the outreach activities involving EAP-based robots are presented. Section 6 provides concluding remarks.

2. AN EAP-ENABLED AUTONOMOUS ROBOTIC FISH FOR MOBILE SENSING

Sponsored by an educational grant from SPIE, a special program on EAPs was developed under the umbrella of the Electrical and Computer Engineering senior design curriculum at Michigan State University. Every semester the senior design class has approximately sixty students in total, organized into about twelve teams. Each team is assigned a project, typically supported by some company or some funding agency, and takes the semester to complete the project while receiving training on professional ethics and other skills. During Fall'05 and Spring'06 semesters, two teams were specifically involved in the development of EAP-driven robots. To motivate the interests of the students, the projects were formulated to be intellectually challenging with appealing potential applications.

In the first project, the team was required to develop a mobile sensing platform propelled by an IPMC actuator. IPMC-driven robotic fish were previously reported by several research groups (see, e.g.,[14–18]). The team was challenged to go beyond the state of the art by integrating power, navigation, control, communication, and sensing units all inside the robotic fish and thus creating an autonomous platform for sensing applications. The stepping stone for this project was a first-generation prototype developed by an undergraduate research team sponsored by the Diversity Programs Office (DPO) at Michigan State University, where a radio receiver from a Zip Zaps^{TM} toy car was used to remotely control the robot.[9]

The senior design team named their fish NEMO (**N**avigating **E**AP-Controlled **M**odule with **O**nboard Resources). The overall design of NEMO is illustrated in Fig. 1. The robot is equipped with a GPS and a digital compass for navigation. It can communicate wirelessly with a PC through the ZigBee protocol (`www.zigbee.org`) to receive instructions and send sensor data. The mesh-networking capability of ZigBee allows collaboration of multiple robot fish in the future. As an example application, a temperature sensor is used. An IPMC actuator serves as a caudal fin and propels the robot. A microcontroller performs all essential coordination and control functions of the robot, including interfacing with the navigation, sensing, and communication modules and controlling the output to the IPMC actuator.

A printed circuit board (PCB) was designed to accommodate all the electronic components. A toy fish (Rainbow Reef Fish, Swimways Corporation) was utilized for housing the PCB and for providing a fish-like looking. For waterproof packaging, silicone adhesive was applied to cover the PCB board except for the power wires and the interface for reprogramming of the microcontroller. A special clamp was manufactured to provide secure and flexible mounting for the IPMC actuator. Two rechargeable lithium batteries (3.6 V, 750 mAh) enabled the robot to run continually for at least one hour without recharging. The batteries were safely housed in the battery compartment of the original fish body. A user-friendly GUI was developed to allow convenient remote monitoring and control of the robotic fish through a PC . Basic functions of the GUI included display of sensor data, GPS/compass readings, and XBee signal strength, and motion control of the robot. The developed robot is shown in Fig. 2. Research is also underway to implement a compact indoor RF/acoustic localization system on the robot, so that the robot can navigate in the absence of GPS signals.

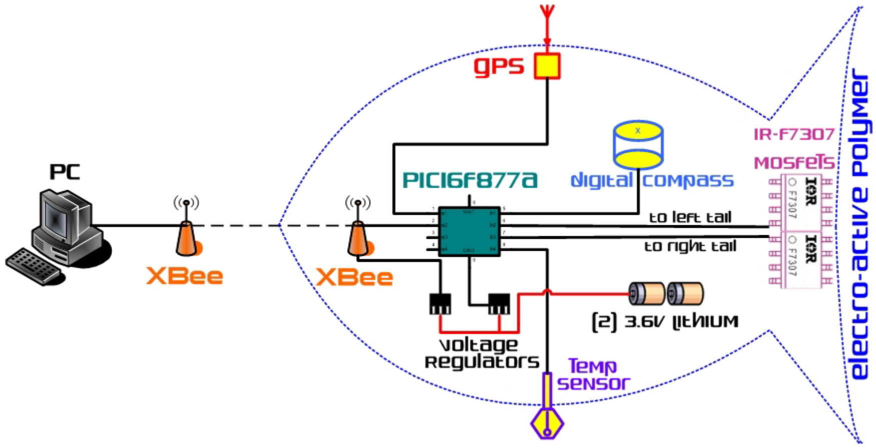


Figure 1. Schematic of the robotic fish-based mobile sensing platform.[9]

(a) (b)

Figure 2. The autonomous, biomimetic robotic fish propelled by an IPMC actuator. (a) Bending of the IPMC caudal fin; (b) swimming in water.

3. AN EAP-BASED SOCIABLE ROBOT

The potential application of sociable robots to entertainment, psychological therapy, and patient care has been well recognized. Flexible, life-like movement of EAPs makes these materials suitable for actuating sociable robots.[19,20] A senior design team was tasked to develop a simple yet aesthetically pleasing robot that can express emotions when interacting with humans. One specific requirement is that EAPs should play a significant role in creating the facial expressions. To make it feasible for a one-semester project, the robot-human interactions were limited to that the robot listens to a voice command (such as "happy", "angry") issued by a human and then responds accordingly. In future design projects, visual and other more complicated interactions can be incorporated.

Fig. 3 shows the team's design schematic for the sociable robot. Three IPMC pieces, two representing the eyebrows and one representing the mouth, are mounted on the robot face. A voice processing circuit is used to interpret the human voice command. Based on the command, a microcontroller coordinates the bending movements of different IPMC samples to express the requested emotion. Each "eyebrow" can also be rotated by a servo motor (Hitec HS-55) to enhance the expressions. In addition, light-emitting diodes (LEDs) of different colors are used to accentuate various emotional states.

The engineering students also demonstrated their artistic talent in creating the face mask.[21] Mesh wire was first molded onto a human face, and clay was molded over the mesh wire and sculpted. Plaster cloth was then

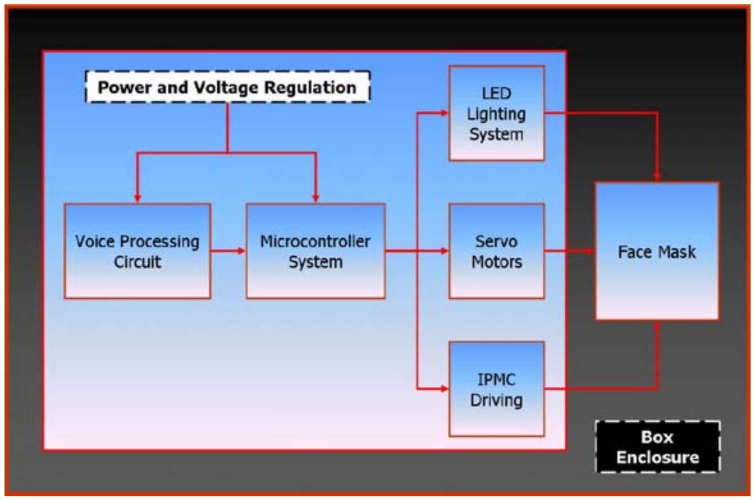


Figure 3. Design schematic for the sociable robot.[21]

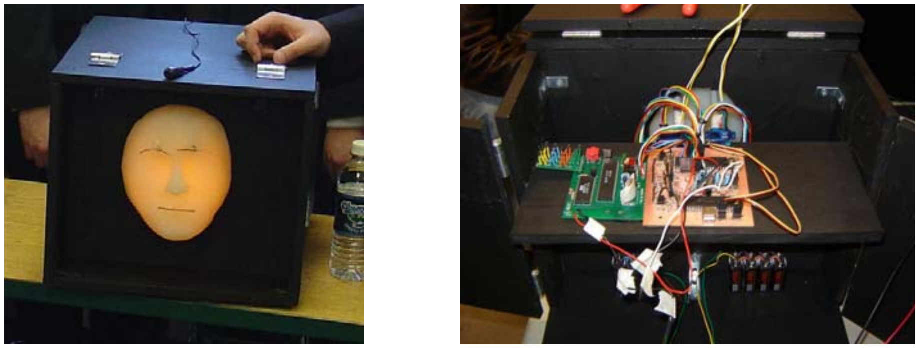
used to cover the mold. After drying, the plaster cloth mask was removed and served as the final mold for the face. Glue sticks were melted and poured into the plaster cloth mold, and then allowed to cool down. The simple yet revealing face mask is translucent, allowing LED lights to go through. Three holes were made on the mask for mounting the IPMC samples. Fig. 4 shows the fabricated face mask.

(a) (b) (c)

Figure 4. The face mask for the sociable robot. (a) The detailed clay mold; (b) the final glue mask; (c) the mask under blue LED illumination.

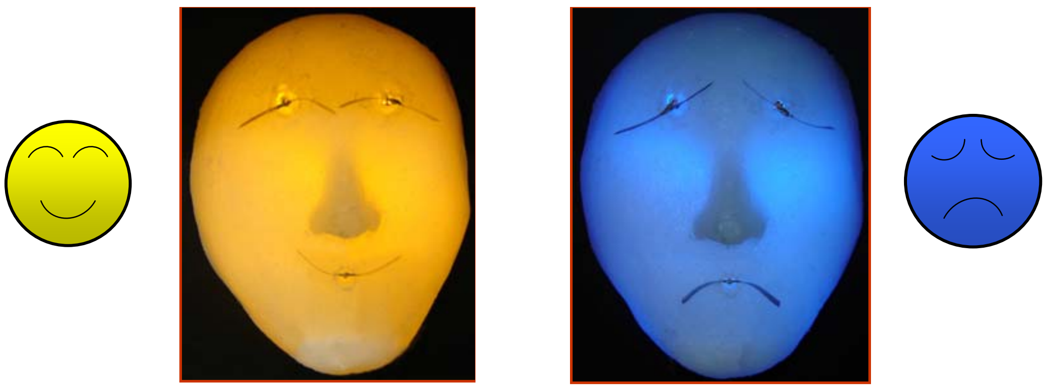
The design team had in mind the portability requirement for the sociable robot, which facilitated later uses of the robot for outreach purposes. The robot is operated on 9V batteries. The students built an enclosure, as seen in Fig. 5. The robot face is mounted at the front side of the enclosure, while all electronic components for voice processing and robot control are housed in the back.

As an example, Fig. 6 shows two emotions of the robot under the voice commands, "happy" and "sad", respectively.



(a) (b)

Figure 5. The enclosure for the sociable robot. (a) The face mounted in the front; (b) The circuitry in the back.



(a) (b)

Figure 6. Emotions of the robot in response to voice commands. (a) “Happy”; (b) “sad”.

4. OTHER EAP EDUCATIONAL OPPORTUNITIES IN SENIOR DESIGN

The senior Capstone design program on EAP robots provided excellent opportunities for the students directly involved to learn and appreciate EAP materials while serving regular purposes of Capstone projects. In the mean time, various interaction activities in the senior design class and on the “show-off” day - ECE Design Day enabled EAPs to be exposed to a much broader audience. For instance, one requirement of the ECE senior design program is that each team shall give a lecture on some technical aspect related to their project. The sociable robot team prepared and delivered a lecture, entitled “Electroactive Polymers and Ionic Polymer-Metal Composites”, to the whole class. Daily interactions of the EAP teams with their peers further enhanced such exposure.

The ECE Design Day, usually the last day of the semester, is the show time for all senior design teams including the EAP teams. This is a whole-day event, where faculty, staff, graduate and undergraduate students, pre-college students from local schools, parents, and teachers gather on campus to check out the senior design projects. Each design team displays their project product, and makes an oral presentation to a panel of judges in a room full of audience. Fig. 7(a) shows a picture, where Beniamin Sabadus was explaining the EAP-based robotic fish project to a visitor. Fig. 7(b) shows the sociable robot team answering questions from the floor at the end of their oral presentation. Hundreds of people learned the EAP materials through these events.

(a) (b)

Figure 7. (a) Sabadus (right), an EAP-robotic fish team member, explaining the project to an interested visitor on the Design Day; (b) the sociable robot team addressing questions from the audience.

5. OUTREACH PROGRAMS INVOLVING EAP ROBOTS

The attractive features of EAP materials make them ideal for various outreach activities. The EAP robots developed in the senior design projects have proven popular in a number of programs held for pre-college students at Michigan State University in the summer of 2006. A few examples included the Detroit Area Pre-College Engineering Program (DAPCEP), the WIMS for Teens Program, and the Women in Engineering Program. In these programs, accessible lectures on EAP materials and biomimetic robots were delivered to middle school and high school students (Fig. 8(a)) and the students had opportunities to check out the robots by themselves (Fig. 8(b)). In Summer 2007 the sessions on EAP robots will be further introduced into some new programs, one exciting example being the Grandparents University Program (`http://grandparents.msu.edu`). In this program, grandparents and their grandchildren (ages 8-12) will come together to Michigan State University for a three-day learning experience. The EAP-based robots have been received well by pre-college students, teachers, and parents, and played positive roles in inspiring young students' curiosity and their interest in studying science and engineering. Of course, a byproduct of this is that more and more students and members of the general public have learned about and developed appreciation for EAP materials.

Researchers of the Smart Microsystems Laboratory at MSU are currently working with the Recruitment and K-12 Outreach Office of the College of Engineering to develop a two-week long curriculum focused on the EAP robotic fish. The curriculum will cover both step-by-step instructions to build the robot and appropriate fundamentals on physics, robotics, circuits, and EAPs, the latter in the form of lectures. In this program, the students will be able to replicate and even improve the robot fish while learning relevant interdisciplinary knowledge and skills. The curriculum will carry variants to accommodate the grade levels of pre-college students, and to reflect the different constraints between summer camps and in-school programs.

6. CONCLUSIONS

In this paper a hands-on paradigm for teaching and learning EAPs has been presented. The unique properties of "artificial muscles" and the biomimetic robots make them accessible and attractive to wide audience outside the immediate research community of EAP materials and their applications. Two integral and representative EAP-educational activities were discussed, one at the undergraduate level, and the other targeting pre-college students and their teachers and parents. These efforts have impacts on several fronts. They provide an effective venue for educators to convey the importance of science, engineering, and technology in general, in addition to promoting the awareness of EAP materials and related technologies among students and the general public.

(a)

(b)

Figure 8. (a)The students in the WIMS for Teens Program listening to the lecture on EAPs; (b) A student (middle) of the Women in Engineering Program interacting with the sociable robot in Spanish, with the help of Stephan Shatara (left), a graduate student at Michigan State University and a member of the Smart Microsystems Laboratory.

It should also be noted that the close synergy between research faculty and educational staff has proven mutually beneficial. For instance, the robotic fish initially developed for educational purposes is currently used as a testbed for several research activities in the Smart Microsystems Laboratory, including modeling and control of IPMC actuators, control and maneuverability of EAP-based swimming robots, and collaborative control of multi-agent systems.

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