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## **AC 2012-3426: TEACHING MICRO-ROBOTS IN BIOMEDICAL APPLICATIONS: A MODIFIED CHALLENGE-BASED PEDAGOGY AND EVALUATIONS**

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# Teaching Micro-robots in Biomedical Applications

## Abstract

Supported by an NSF CCLI award, we have developed teaching materials based on a case study on a pill-sized robot in gastro-intestinal (GI) tract to teach undergraduate micro-robotics and also principles of robot programming and navigation. The case study consists of a lecture unit and a laboratory module. The lecture unit introduces commercial capsule endoscopes and proposes a conceptual design of a vitamin pill size robot vehicle that can operate within human's GI tract. The objective of the laboratory modules is to teach students how to program robots to navigate in an uncertain environment and how to control the robot. In this paper, we present our experiences in pilot-testing of the developed case study in a course at Stevens Institute of Technology. We used a modified challenge-based pedagogy, and obtained evaluation results using anonymous student surveys. We also learned a few things through interacting with students on this emerging application. This paper discusses the pedagogy, evaluation results, and lessons learned.

## Introduction

Micro/nano-robots for biomedical applications are an emerging area that has received advancement during the last decade. Though books/textbooks exist in nanotechnology, there are a growing number of articles appearing in journals and conference proceedings in biomedical micro/nano-robotics. Medical robotics has been an active research area since the 80s and an enormous amount of teaching materials is available, particularly in medical instrumentation and medical imaging. Contrary to the large amount of teaching and learning materials on large-scale medical robots, instructional materials on micro/nano-robotics for bio-medical applications are very limited. There is a general lack of learning materials on micro/nano-robotics in engineering education.

Supported by an NSF CCLI award, we have developed teaching materials based on a case study on a pill-sized robot in gastro-intestinal (GI) tract to teach undergraduate micro-robotics and also principles of robot programming and navigation. The case study consists of a lecture unit and a laboratory module. The lecture unit introduces commercial capsule endoscopes and proposes a conceptual design of a vitamin pill size robot vehicle that can operate within human's GI tract. The objective of the laboratory modules is to teach students how to program robots to navigate in an uncertain environment and how to control the robot<sup>1</sup>. We also pilot-tested the developed case study in a graduate-level course in Electrical and Computer Engineering.

In this paper, we first review the design example and laboratory module we have developed. We then describe the pedagogy used in delivering the materials developed. Evaluation results will be presented, which is followed by discussions on the experiences and lessons learned.

## Design Example of Pill-Sized Robot

Our conceptual design of the capsule robot is inspired from the earthworm-like locomotive mechanisms proposed by Kim *et al.*<sup>2</sup>. In order to realize a 2-dimensional locomotive mechanism, four spring-type SMA actuators are required to have long stroke and a strong enough force to overcome resistance force due to deformation of small intestine. The developed actuator is integrated with claspers mimicking claws of insects and an earthworm-

like locomotive mechanism is proposed. The SMA actuators can be controlled to contract and stretch by passing current through the wire. When all four SMA are actuated in the same rhythm, the capsule robot moves forward or backward. Turning capability can be achieved by actuating the left and right SMAs in the opposite rhythm. Based on the design of actuators, the capsule robot has the ability to move in 2-dimensional, moving forward and turning, which enables it to implement tracking and navigation in the GI tract.

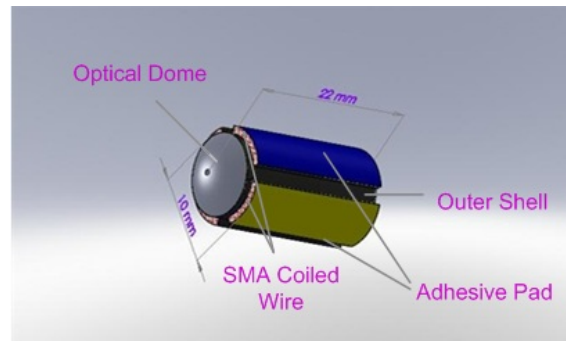


Figure 1. The endoscope capsule robot.

The capsule robot measures about 10 mm in diameter and 22 mm in length, see Figure 1. The outer shell of the device is biocompatible material. The SMA coiled wire is attached to an adhesive pad. An optical dome is embedded in the front of the capsule. An inner shell contains five modules: vision module, sensors module, communication module, CPU module and battery.

*Vision Module:* Unlike PillCam, which uses CMOS (complementary metal-oxide semiconductor) image sensors, this device uses a CCD (charge-coupled device) image sensor. This results in superior image quality but with much greater power consumption due to the intense digital signal processing involved. The CCD image sensor is compassed by four illumination light emitting diodes (LEDs) with different wavelengths.

*Sensors Module:* Sensors convert physical properties such as light, pressure, or temperature into electrical signals. The capsule robot embeds sensors, including temperature, pressure and pH data.

*Communication Module:* The communication module can then both transmit and receive the signal to communicate with outside the console. The RF antenna is utilized to receive external operation signal, such as activation, motion commands and switch operation modes. Transmitter block sends the data, which is gathered from the sensors module, to the outside console.

*CPU Module:* The system's brain, the CPU, on one hand, digitizes the signals which are provided by the sensors and vision modules. On the other hand, the CPU performs additional processing of execution commands, which operates the SMA actuators in control principle.

*Power Supply:* The capsule robot is powered by silver oxide batteries, which can provide over 5 hours of continuous video recording. In battery-powered devices, the battery itself is likely the largest system component. Therefore, designers must minimize both supply voltage

and current consumption while using high-efficiency topologies to achieve the required system performance.

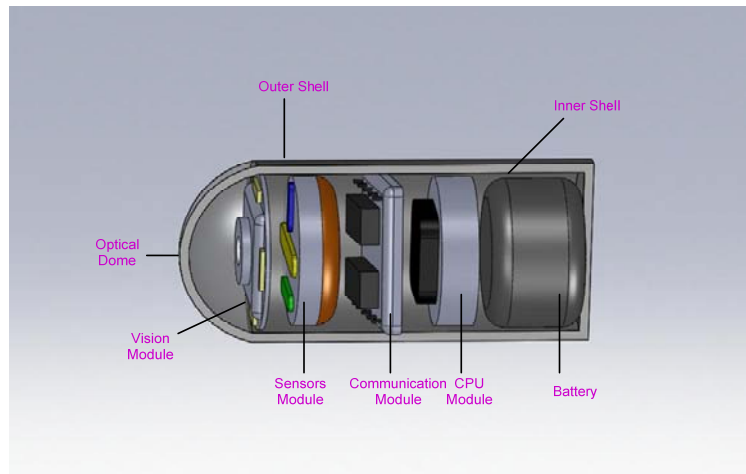


Figure 2. Inside of the endoscope capsule robot.

As a conceptual design, one-third of the capsule will house the power supply and propulsion system, one third will house the electronics including guidance, data transmission and control, and one third will house the hardware associated with sensing capabilities such as imaging, see Figure 2.

### **Laboratory Module to Simulate Pill-Sized Robot in GI Tract**

We have built a biomedical environment in Webots<sup>3</sup> simulator to imitate the GI tract. The tracking and navigation operation modes are simulated. For the tracking mode, we simulate a scenario of the capsule passing through the GI tract and getting a map of the whole GI tract, as shown in Figure 3.

The capsule is activated when it reaches the esophagus. The vision module starts to work and gets real-time video sequences, as shown in Figure 3 a. Figure 3 b shows the capsule is approaching the stomach. Figure 3 c and Figure 3 d show the capsule is tracking in the stomach and small intestines, respectively.

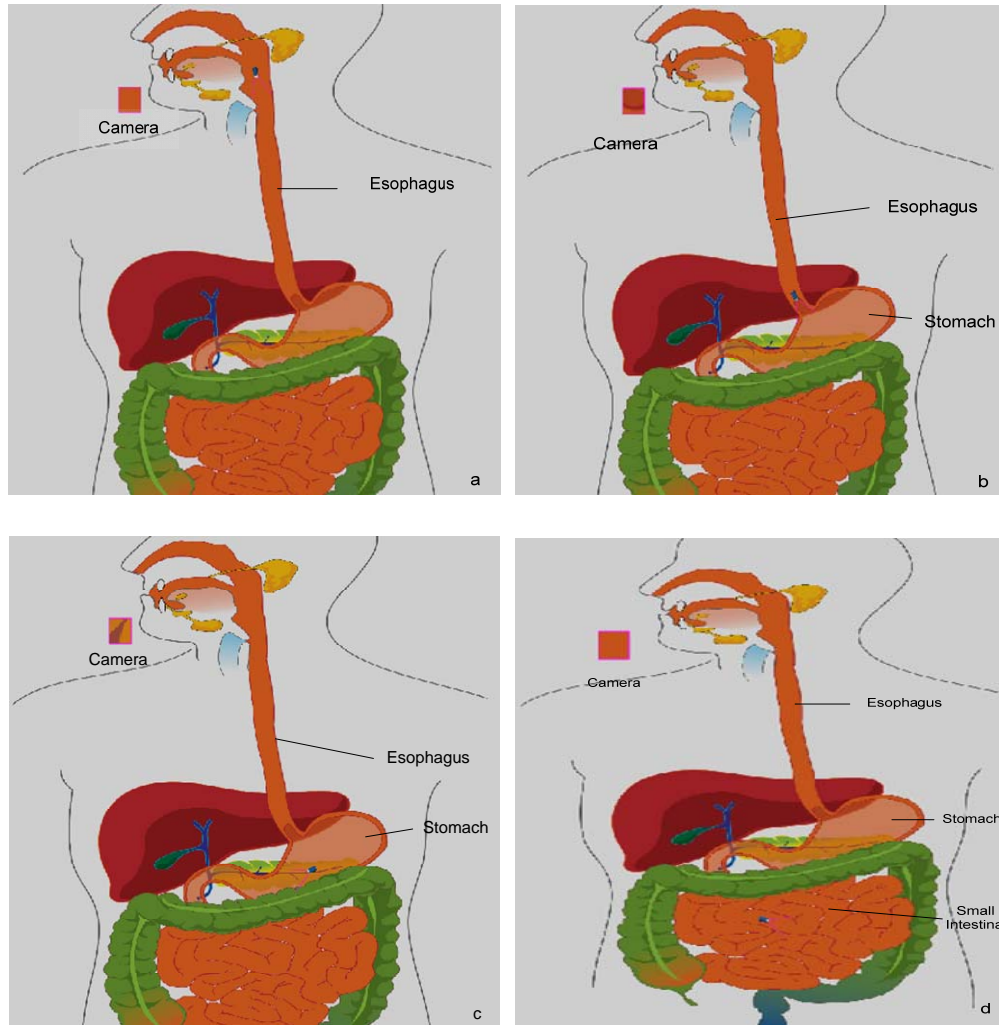


Figure 3. Webots simulation of a capsule robot operating in the human's GI tract.

### **Classroom Instruction and Pedagogical Consideration**

We have delivered the developed design example and laboratory module in the course *EE/CpE 631 Cooperating Autonomous Mobile Robots* at Stevens Institute of Technology in Spring 2011. The course is a graduate ECE course, and can also be chosen by undergraduate students as a technical elective. In Spring 2011, we have 15 enrolment, of which there are 3 undergraduate students. The course discusses advanced topics in autonomous and intelligent mobile robots, and we introduced the micro-robots as a special topic during the second half of the semester. We used a modified challenge-based pedagogy.

In a typical challenge-based implementation, a complex problem (the challenge) is presented to the students. Students then generate ideas based on what they already know and what they will need to know to solve the problem. This step can be materialized using the case studies developed under the project. In the second step, students discover different ideas on important aspects of the problem and key components of the knowledge taxonomy. This is supported by the developed lecture materials at various subject and modular levels. Next, students conduct research and revise their ideas, which is complemented by the design

examples created by the project. Students then “test your mettle”, where laboratory modules can be used to test students’ design. Finally, students publicly present their solutions to the challenge and receive feedback. The sequential implementation cycle helps insure that the challenge-based principles are incorporated into learning materials to improve both knowledge and innovation. The research and revise, multiple perspectives and test your mettle components primarily develop the knowledge component, while the generate ideas phase primarily develops innovative skills. The approach also develops skills in team building. Students share ideas and get multiple perspectives. These approaches increase motivation and awareness of the connections between their in class experiences and their future work, lead to positive attitudes about learning for both students and teachers, and, when structured well, lead to significant increases in knowledge and innovation<sup>4</sup>.

The challenge-based teaching provides an efficient pedagogy to educate students on multi-disciplinary subjects. However, it’s usually implemented through one complete course through a whole semester, or a series of courses through a few semesters. In our practice, we only have a few classes in one course for the special topic. We therefore modified the challenge-based pedagogy to fit our needs. At the beginning of the case study, we showed an episode on the capsule endoscope technology in the PBS series “Making Stuff Smaller”. We then followed to present the “Grand Challenge” as to create a semi-autonomous robot that can navigate in the human body to detect abnormality or to destroy inimical tissues. We then provide a lecture to motivate the problem and to introduce the design example and the laboratory module we developed above. The lecture unit is complemented by a paper presentation session where each student is asked to present a published paper on the topic, and grades are given to evaluate the quality of the presentation. After that, the students are asked to do their own research, and complete a report to summarize their research results. We have collected students’ report and survey results by the end of the class. In the next section, we present the evaluation results.

## **Evaluation Results**

In the anonymous survey, we asked students to rate their learning experience in eight questions. Question 1 asks whether the case study motivates students on the subject of micro/nano-robotics in biomedical applications. Questions 2 and 3 ask students’ understanding before and after the class, respectively. Question 4 asks if the paper presentation section helps to understand the topic. Question 5 asks if the case study helps to learn science and engineering principles. Question 6 asks if the case study helps to enhance interdisciplinary skills. Question 7 asks if the case study helps to enhance critical thinking. Question 8 asks about the overall learning experience. Question 2 and 3 use a number, 1 to 5, to indicate the level of understanding, with 5 the highest level. All other questions have five choices, Strongly Agree, Agree, Somewhat Agree, Disagree, and Strongly Disagree. Representing the choices from Strong Agree to Strongly Disagree using number 5 to 1, we summarize the evaluation results in Figure 4. We can see from the figure that students’ understand before and after the case study increases from 1.93 to 3.87. The paper presentation is considered positive as it receives 4.13 out of 5. Students’ capability enhancement in Science and Engineering Principles, interdisciplinary skills, and Critical Thinking is also rated 3.73 and above out of 5. The overall learning experience is an average 4.2 out of 5.

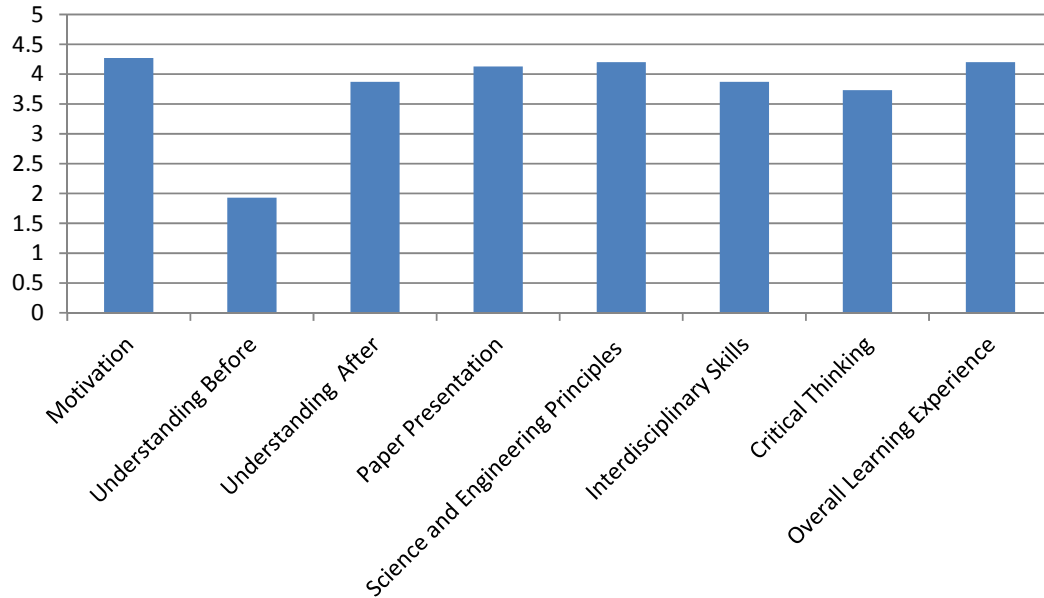


Figure 4. Survey results.

### Discussions on Evaluation Results

As the first time classroom delivery, we are overall satisfied with the evaluation results. Particularly, we feel that the video played at the beginning from a PBS education program is very useful in motivating students' interest in this topic. As the students in the class have some background in robotics from the first half semester of lecturing, some discussion time was given for students to discuss the given "Grand Challenge". We observed active discussions in classroom.

We also learned a few lessons during the process. The robot simulator Webots is a commercial software, where a 30-day trial version with limited functionality can be free downloaded from the web. This limits what the students can do with the software and the time frame using the software. Also, in the paper presentation section, the student gets familiar with the topic in the paper he/she presented only, but loses connections with other topic or the global picture. We'll need to add some discussions to connect the papers and to summarize the main ideas and technologies during and at the end of paper presentation. Another lesson we learned is that depending on students' background, they may be grouped to work collaboratively on the final report.

### Conclusion

Wireless capsule endoscopy represents a significant technical breakthrough for the investigation of the GI tract, especially in the light of disadvantages of other conventional techniques. Capsule endoscopy has the potential for use in a wide range of patients with a variety of illnesses. In this paper, we present instructional materials to teach students on the design and control of a capsule robot navigating in a human's GI tract, and its classroom delivery and teaching pedagogy. Evaluation results show positive learning experiences. Future work includes more pilot-testing in biomedical engineering courses.

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