Computer Applications in Bioengineering: An Active-Learning Laboratory Course for Undergraduates

Daryl R. Kipke
Arizona State University

Introduction

Bioengineering is a diverse field that bridges several traditional engineering disciplines to medicine and biology. In competing for bioengineering-related jobs with peers from traditional engineering disciplines, the B.S.-level bioengineer should have particular knowledge and experience about making measurements from or analyzing physiological and biological systems. It is challenging to devise an undergraduate bioengineering curriculum that provides an appropriate broad coverage of the field and that also provides sufficient in-depth, practical coverage of at least one bioengineering sub-specialty, such as bioinstrumentation or biomechanics. Lecture-based courses typically provide the theoretical basis of the technical subjects, while laboratory courses provide the opportunity for experiential learning. In bioengineering, laboratory courses are especially important because of the complexities of investigating living systems, e.g. the selection and operation of electrodes, and understanding and implementing techniques for reducing biological noise.

In the undergraduate bioengineering program at Arizona State University, laboratory courses in physiological systems and medical instrumentation have been offered for many years. These courses emphasize making measurements from and analyzing properties of physiological systems using clinical instruments or special-purpose computer hardware and software. The laboratory projects are generally highly structured and closed-ended to ensure ample coverage of the selected subjects. While these courses are an important part of the curriculum, they do not provide students with the experience of developing solutions to open-ended, systems-level bioengineering projects. In order to fill this gap, over the last three years we have developed and offered a laboratory course that provides senior-level bioengineering students with intensive experience in developing and using bioinstrumentation systems to solve scientific and clinical problems. This course, "Computer Applications in Bioengineering," requires the students to integrate their previous coursework to find workable engineering solutions to complex problems.

The main objective of the course is to provide an experience in which the students gain knowledge, expertise, and confidence in biomedical signal recording and analysis. This knowledge base involves understanding the basic structure of bioengineering instrumentation systems and, more importantly, being able to design, build, test, and use instrumentation systems for a variety of bioengineering applications. This course involves both formal and informal active-learning as the students work in teams on each project.

Course structure and content

The course is offered for four credit hours and it has both a laboratory section (six hours per week) and a lecture section (three hours per week). The primary emphasis is on the laboratory projects, with lecture sessions intended to present and discuss technical topics that arise during work on the projects. The lecture sessions also provide a forum for discussing difficulties that teams may be experiencing, solutions developed by other teams, and the results of data analyses. In the lecture sessions, the instructor serves more as a manager and technical adviser to the teams rather than as an expert whom provides the "right" answers. The lecture classroom is conducive for interactive discussions with large work tables rather than individual desks, a computer with a projection display device, and ample whiteboards.

Project teams consist of three or four students and are fixed for the duration of the course. For each project, each team member is given primary responsibility for one of three jobs:

- *Systems engineer*: Ensure that the objectives of the project are met. Design hardware and software interface. Conduct system-level testing. Design experiments. Be the lead person in preparing the project report.
- *Hardware engineer*: Design, construct, and test the electronic circuits. Develop data acquisition program.
- *Software engineers*: Design, write, and test the signal processing programs.

These job assignments rotate for each project so that by the end of the semester, each team member serves in every job at least once. Completing each job is sufficiently complex that communication and cooperation among team members is essential.

Each team is assigned a laboratory workstation that is equipped with a personal computer containing a National Instruments data acquisition board (LabPC+), LabView software, and a spreadsheet program (Microsoft Excel). The workstations also have an oscilloscope, an electrical circuit breadboard, a function generator, and related equipment and ICs for circuit development and testing. An electronic circuit simulation program (Electronics Workbench) is available in the laboratory for easily prototyping amplifier and filter designs. Appropriate electrodes and sensors are provided for each project.

The students are assessed primarily by scores on project reports and individual exams. In addition, a pass/fail laboratory practical exam *must* be successfully passed in order to pass the course. This exam tests students ability to make measurements using the oscilloscope, make circuits from schematic diagrams, and write elementary signal processing programs, which are all stated learning objectives of the course.

Project Descriptions

The laboratory projects are intentionally open-ended. In a two-page handout for each project, the students are given each project's principal objectives or set of hypotheses along with a partial list of job-related tasks. From this partial information, each project team devises a strategy for building and testing the required computer-based instrumentation system (hardware and software), designing the appropriate experiments, and collecting and analyzing the data. The project teams must identify and decide the many engineering tradeoffs that are required in order to complete the project within the two or three weeks that are allotted. Their solutions may not be optimal, but they are generally sufficient for acquiring some data that allows the hypotheses to be evaluated or the objectives to be met. All of the projects end with laboratory and lecture demonstrations by each team. Shortly after the completion of each project, each team submits a seven page lab report describing their work in the lab and the experimental results. Two of the projects are briefly described below.

EMG Project. The objective of this project is to investigate the relationship between the force generated by a muscle and the muscle's surface-recorded electromyogram (EMG). Each team develops an instrumentation system to record and analyze the EMG following broad guidelines that are provided. The system is used to investigate four specific aims which involve estimating muscle force from the EMG and evaluating the consistency of the EMG. Each group designs experiments and collects data (using class members as subjects) to reach some type of conclusion for each specific aim. The specific aims are to:

1. Develop a reasonable measure for muscle activation from the surface EMG
2. Determine if muscle activation varies linearly with force.

3. Determine if muscle activation varies with muscle fatigue.
4. Evaluate the consistency of the EMG for estimating muscle force.

ECG Project. The objectives of this project are to develop an electrocardiogram (ECG) recording system for investigating the effects of exercise on heart rate and the cardiac cycle. The specific aims are to:

1. Develop signal processing algorithms for measuring heart rate and the cardiac cycle using a single lead ECG.
2. Investigate resting heart rates and the increase and decrease in heart rate as a function of exercise, fitness, and age.
3. Investigate the heart contraction rate as a function of heart rate.

Outcomes and Discussion

This course has been well received by a majority of the students as evidenced by consistently high rankings in the standardized course evaluations and unsolicited, informal comments from graduating students. While it requires a substantial time commitment, the students typically feel that it is worthwhile because they gain practical experience developing and troubleshooting electrical circuits, data acquisition programs, and signal processing programs. The resulting skills and confidence in their technical abilities help to propel the students out of school and into the job market or graduate school.

DARYL R. KIPKE received a Ph.D. in Bioengineering from the University of Michigan in 1991. He completed a post-doctoral fellowship at Syracuse University in 1992 and then joined the faculty at Arizona State University as an Assistant Professor in the Department of Chemical, Biological, and Materials Engineering. Dr. Kipke's primary research interests are computational neuroscience, auditory neurophysiology, and neural prostheses.