A New Biomedical Engineering Course Based on Aerospace Applications

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Abstract

Engineering students at the United States Air Force Academy (USAFA) have an extremely full course load. Because of this, creating a new course that can fulfill an elective option and be relevant to their future Air Force careers is quite challenging. In order to accomplish this, a mechanics professor and electrical engineering professor teamed to create a new Introduction to Biomedical Engineering course, open to all senior level engineering students. The first block of the course focused primarily on physiology, the second on electrical engineering topics, and the third on mechanics issues. At the end of the course, teams of students completed a final project which focused on some type of control system within an aerospace cockpit. The teams had to create working hardware that collected some type of physiologic signal that would indicate pilot stressors, then determine some action based on these signals. Examples of projects include collecting electro-oculography to determine if a pilot is spatially disoriented, using electromyography and heart rate to predict G-induced loss of consciousness, and using thermal sensors to help control pilot stress and over heating. The course content attempted to provide the students with necessary tools to complete the project throughout the semester. After each lesson, each student completed the following survey answering the following questions: (1) The topic was interesting, (2) Today's lesson motivated me to learn more about the material, (3) The topic is useful to add to my "engineering toolbox", (4) The topic will be useful to me in my Air Force career, (5)The topic should be covered in next year's Intro to Biomed class. Results from the survey and open ended comments will be presented.

Introduction

Biomedical engineering is relevant in a large variety of applications, most of which are well established. The relevance to the US Air Force may not be obvious, but are numerous. Air Force pilots experience extreme environments during flight, including thermal stress, high altitude flying, sustained acceleration, spatial disorientation, and pilot ejections. High mechanical forces can occur during accidents and ejections, while the cardiovascular system is stressed while pulling G's. These types of biomedical applications were used to help frame a new course at the United States Air Force Academy (USAFA).

Before discussing the development of any course, it is necessary to describe the unique challenges faced at the Academy. USAFA has a significantly different population of

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undergraduate student as compared to the typical university or college. The differences do not come so much from aptitude or motivation but from the constraints of a Military Academy. The student's time at the USAFA is in high demand, as they are required to graduate from challenging academic programs with extensive core course requirement in addition to their engineering curriculum. All students must graduate in no longer than four years. They are also loaded with military, leadership, and athletic requirements. It is not unusual for students to have less than an hour free every other day that they can use to take advantage of "extra instruction" (office hours), making it difficult for them to become critical thinkers. Finally, all engineering majors are required to take a course in each of the following engineering disciplines (civil, mechanics, aerospace, aeronautical, and electrical).

Since all engineers have a basic knowledge of the different disciplines, the course was offered as an elective for all engineering majors. Because many of the assignments were performed in teams, it was hoped that each group would have at least one electrical engineer and one mechanical engineer. Unfortunately only three electrical engineers signed up for the course; the rest of the class was comprised of two in astronautical engineering, two in engineering mechanics, and six in mechanical engineering. The class was team taught by one instructor from the Department of Engineering Mechanics (EM) and one from Electrical Engineering (EE).

Course Objectives and Syllabus

The course objectives for Introduction to Biomedical Engineering were:

1. Obtain an understanding of basic physiologic systems, including cardiovascular, musculoskeletal, respiratory, neural, and sensory systems.
2. Develop an appreciation of various biomedical measurement methods and sensory feedback systems.
3. Apply mechanical principles to biological material properties and basic human movement.
4. Apply signal processing techniques to bioelectric signals
5. Apply engineering and design principles to solve physiologic problems related to aerospace applications.

The course syllabus is shown in Table 1. As can be seen, the first major block provided background information in basic physiology including nervous potentials, action potentials, and biosensors. Then the course moved into electrical engineering issues and instrumentation. Laboratories on electrocardiograms (ECG), signal processing, and electromyography (EMG) were utilized to reinforce the learned principles.

The third block involved mechanics, including gait analysis, injury mechanisms, and biomaterials. The final portion was primarily pilot stressors, namely spatial disorientation and sustained acceleration (pulling G's). The material was arranged to help feed into their final project, where students were instructed to:

(1) Measure at least one actual input parameters (physiologic and/or aircraft),
(2) Simulate the remaining input parameters

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(3) Using these parameters, make a decision about the state of your system
(4) Provide feedback to the control system enhancing pilot performance and/or safety.

The project was intended to incorporate a number of different skills, including defining a problem, creating actual hardware to address the issue, taking biomedical measurements, and taking some type of action based on those measurements. It was hoped that the interdisciplinary team members would be able to make contributions based on their backgrounds: the EE majors would take responsibility for any circuitry or electrical issues, the MEs would be in charge of the construction of hardware and any structural analysis, and the Asto majors would contribute their knowledge of control systems.

The course objectives were focused to support several of the US Air Force Academy's educational outcomes, including: breadth of integrated, fundamental knowledge in the basic sciences, engineering, the humanities, and social sciences, and depth of knowledge in an area of concentration of their choice; ability to frame and resolve ill-defined problems; ability to work effectively with others; and being able to apply their knowledge and skills to the unique tasks of the military profession.

Table 1 - ENGR 495 Course Syllabus

Introduction to Biomedical Engineering			
	SPRING 2004		
Lesson	**Topic**		
1	Intro	**22**	Ejection biomechanics
2	Ethics, IRB issues	**23**	Ejection biomechanics
3	Circulation/Tissue/Resp	**24**	Introduction to Controls
4	Nervous system Membrane potentials	**25**	Controls Applications
5	Musculoskeletal	**26**	Biocompatibility
6	Action potentials	**27**	GR 2
7	Sensors	**28**	FDA Regulations
8	Basic Instrumentation	**29**	Aerospace Physiology
9	Amps, A/D, Nyquist	**30**	Vestibular system
10	ECG lab	**31**	Modeling the vestib system
11	Bio Signals	**32**	Demo (Gen Aviation Trainer)
12	Signal Processing	**33**	Sustained Acceleration
13	LAB - Signal Conditioning	**34**	Sustained Acceleration
14	GR 1	**35**	Project Introduction
15	Physiologic modeling	**36**	SD Presentations
16	Basic mech	**37**	GR 3
17	Viscoelasticity, Biomaterials	**38**	Project Time
18	Muscle mechanics, kinematics	**39**	Project Time
19	Biomechanics, Gait Analysis	**40**	Project Time
20	Gait Lab	**41**	Project Time
21	Injury mechanics (impact)	**42**	Final Presentation/Demos

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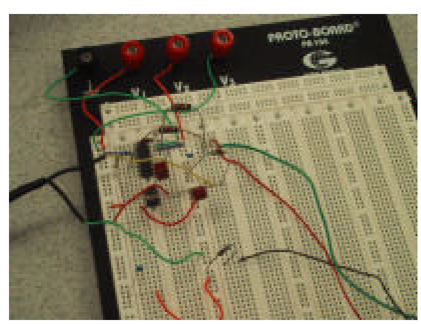
Laboratories

Several different laboratories were planned to provide the students with hands on experience with biomedical engineering. Most classes were held in an electrical engineering classroom, so basic circuitry and oscilloscopes were readily available for smaller projects. Labs were completed in teams, which were assigned to maximize group diversity (e.g., one EE or Astro major per group). It was hoped that these labs would provide the students with appropriate background to assist with their final projects.

ECG Laboratory

The first lab accomplished in the course was measuring and analyzing the ECG signal from the heart. A physiology laboratory in the Biology Department was available for our testing. An iWorx 214 Physiology Recorder (Dover, NH), Dr Lee Model 120-B Electrocardiograph, and an American Diagnostic digital blood pressure monitor were used to collect data. Objectives of the lab were: (1) Learn proper placement and preparation of electrodes, (2) Understand the sources of noise that may be present when measuring bioelectric signals, and (3) Interpret data from an ECG and blood pressure reading. Students were required to construct an Einthoven's Triangle to determine the cardiac vector and to estimate cardiac output at rest and after exercise. Students also had to answer the following questions: (1) How do the amplitudes of the R waves compare between the iWorx and the Dr Lee systems? How about the heart rates? Why might they be different? (2) What happened when you changed the filter settings? What cut off frequency do you recommend? Do a web/lit search to find what cutoff frequency is typically used. (3) Attach the calculations of the cardiac vector (Einthoven triangle) to the lab. Do the calculations make sense?

EMG Laboratory



In order to help students understand the intricacies of biosignals, the students were required to build their own circuitry to measure EMG signals. Students had to consider electrical isolation, amplification, noise reduction, and filtering and design their own circuitry to collect data. In addition to these specific electrical considerations, this lab was also used to help the students learn to solve ill-defined problems, build their design skills, and use commercially available design tools for signal processing.

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Gait Laboratory
During the biomechanics block, students completed a two-dimensional gait analysis. Subjects were told to walk, skip, or hop across the field of view and land on an AMTI force plate (Watertown, MA). Raw displacement data for the hip, knee, ankle, and toe were collected at 60 Hz using Peak Motus (Peak Performance, Inc, Englewood CO). Velocity and acceleration for each point were calculated by the instructor and provided to the students after the lab. They had to manually synchronize the force and kinematic data, calculate joint angles, and determine the internal knee moment for two different trials. Calculations were done by using Excel, and intermediate turn-ins were required to make sure that students were performing the calculation steps correctly.

Other Graded Events
Homework sets were assigned to the students during the semester. These were again completed in teams; it was hoped that the electrical engineering students could help teach the mechanical engineers the instrumentation and biosignal material. In return, the MEs helped their EE counterparts with the mechanics sections. Since all of the material was individually tested on the exams, the students were motivated to do this.

During the Control System Lectures, each student team was required to create a feedback system that would help enhance pilot performance and/or safety (which is step four of the Final Project description). This forced the students to begin thinking of their final project's midway through the semester. Half of the students used this control diagram for their final project – in future offerings this will be a requirement. There was a required literature search and background paper written by each team on their chosen final project area prior to the start of hardware design.

Final Project
The final project was the culmination of the course. Students were provided the following information.

Goal: (1) Measure input parameters (physiologic and/or aircraft)
(2) Using these parameters, make a decision about the state of your system
(3) Provide feedback to the system to enhance pilot performance and/or safety

Possible Project Topics

1. G induced Loss of Consciousness (GLOC): Develop the required pilot sensors to detect the onset of GLOC and supply the necessary outputs to the aircraft.
2. Ejection
3. Eye Tracking
4. Spatial Disorientation
5. Pilot Stress & Work Load
6. EEG determination of mental performance
7. Thermal stress
8. Centrifuge subject monitoring

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Minimum Project Requirements

1. Input to system: at least one physiologic signal (e.g., EMG, heart rate, temperature); could also include aircraft performance parameters. May also include other parameters in your overall algorithm that you aren't measuring.
2. Design of interface/data acquisition system: may include signal conditioning, filters, A/D.
3. Control system to that provides feedback to the pilot and/or the aircraft.

Final Project Descriptions
The projects chosen by the students were interesting and creative. The five teams accomplished the following projects.

1- The Anti-g Straining Maneuver (ASGM) Training System. During sustained acceleration, pilots must contract their legs, abdomen, and buttocks to create an effective strain to prevent GLOC. This group attempted to measure EMG output for each muscle group to determine if the pilot had an effective AGSM.
2- Pilot Stress and Workload Effects on Performance: the project measured heart rate, skin temperature, and galvanic skin response to determine if a pilot was over stressed. The students developed an algorithm to determine the pilot stress level and provided a warning light and/or tone to the pilot.
3- Bailout, Bailout, Bailout: Investigation of Pre-Ejection Body Position Training Module for the Aces-II Ejection System: The students constructed a small chair with mock ejection handles. Because body positioning is important when ejecting, they developed a training system using switches and potentiometers to provide feedback to the pilot. The trainer ensured that the head was back, legs down, and the ejection handle pulled at the appropriate time.
4- G-Induced Loss of Consciousness: A study on the use of electrocardiography and pulse oximetry as a means of detecting and warning the pilot if GLOC is imminent. This system was simulating environment of a high performance aircraft.
5- Eye Tracking and Detection. An ME and EE attempted to use eye tracking and EOG to predict the presence of spatial disorientation and engage an autopilot to prevent aircraft loss.

Assessment

After each class period, students were asked to fill out the following survey:

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TOPIC: ________________________________

Rate on a scale of 1 (strongly disagree) to 7 (strongly agree)

___ The topic was interesting
___ Today's lesson motivated me to learn more about the material
___ The topic is useful to add to my "engineering toolbox"
___ The topic will be useful to me in my Air Force career
___ The topic should be covered in next year's Intro to Biomed class

Comments:

Results from the survey are shown in Figure 1-6.

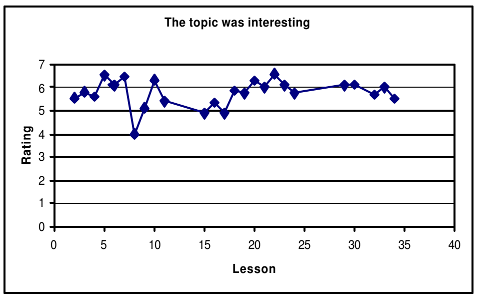

Figure 1 - Question #1

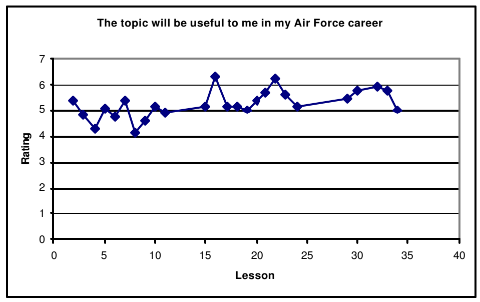

Figure 2 - Question #2

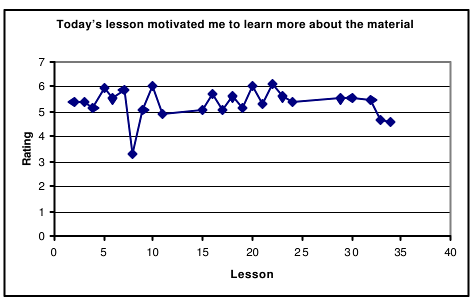

Figure 3 - Question #3

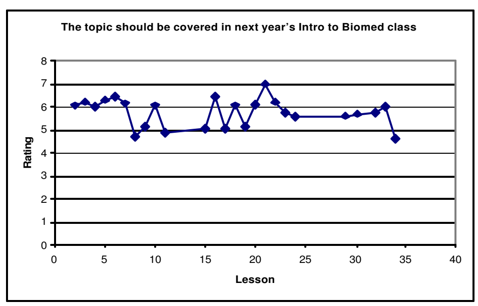

Figure 4 - Question #4

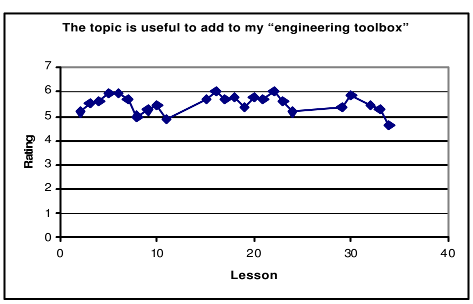

Figure 5 - Question #5

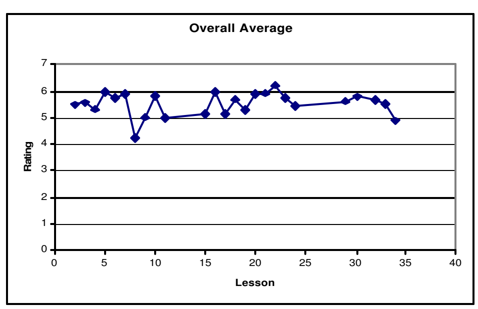

Figure 6 - Lesson Average

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Some subjective comments from the students were:
(Ethics lesson) It was nice to take the time to consider whether we should do something with engineering, rather than just whether we could… Too fuzzy--teach it in ethics class, not engineering!
(EMG Lab) -- Went too fast through the lab, make it too hard to follow.
(EE block) Too much EE.
(ECG lab) Using instrumentation devices was interesting and applicable to what I expect from an engineering course
(Modeling) Finally, something useful that has to do with engineering and not super-technical.
(Muscle mechanics) It's as if class notes has no relation to homework problems. The concepts in homework seem to be fairly simple--but require reference to books on subjects that have not been visited in a long time. The course obviously requires a great number of previous knowledge of courses.
(Gait analysis lab) I think knowing the concept is enough. Not really necessary to do full data analysis.
(Sustained acceleration) Useful because I want to fly. Should talk more about combat edge.

Overall comments:
- I enjoyed the class and think it has a lot of potential to be a great class in future years. Thank you!
- I think I speak for our group when I say that we really enjoyed the class and definitely recommend keeping it around for following years...Maybe even offer it fall semester and have a spring semester final project class where we further develop our prototypes...
Again, thanks...I learned a lot about a field I have a growing interest in...
- Poorly defined homework/test prep/objectives lead to a lot of frustration…

Lessons Learned

In general, the course went well considering it was the first offering at the US Air Force Academy. The syllabus ended up fluctuating considerably, and this frustrated some of the students. Some of the lab exercises also need to be refined – instead of having everyone try to design and build their own circuit, we will have them do a paper design and then provide them with a circuit to actually build and use. We will also stress the final project more from the beginning, trying to tie everything in more closely (e.g., their control diagram will be their final project topic).

It was difficult to have the students work as well in teams as we were hoping. Instead of incorporating peer instruction, the cadets often used "divide and conquer" due to time constraints. We may need to provide some tutorial information before the different blocks of material – a quick mechanics refresher for the EE students and a circuits tutorial for the mechanical engineers. Luckily, the MEs all have an experimental mechanics class the semester before our offering; measurement techniques are reinforced in this class before they get to our biomedical course.

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Conclusions

Overall the course met its desired learning outcomes. The students enjoyed the final project and being able to take what they learned and put it into practice. The course was constructed around aerospace applications, which is the first time this has been done to our knowledge. Working in teams with students from other engineering disciplines helped them understand the environment they will be required to work in when they graduate and perform research in the US Air Force.

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Biographical Information

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