BENG 304: Modeling and Control of Physiological Systems

Fall 2016

Credits 3
MW 10:30 am -11:45 am
Nguyen Engineering Building, Room 2608

Instructor:
Siddhartha Sikdar, PhD
Associate Professor
Department of Bioengineering
Office: Krasnow Institute Room 141
Email: ssikdar@gmu.edu
Phone: 703-993-1539
Office hours: Monday/Wednesdays 12:00-1:00 pm and by appointment

Co-Instructor:
Sahar Jafari Chamkavi, PhD
Adjunct Professor
Department of Bioengineering

Prerequisite(s): Grade C or better in
1. Calculus including Differential Equations (MATH 214 or equivalent)
2. Elementary Physics (PHYS 260 or equivalent)
3. Signals and Systems (BENG/ECE 320 or equivalent)
4. Human Physiology (BENG 313 or equivalent)

Textbook (Required):
Physiological Control Systems: Analysis, Simulation and Estimation
By: Michael C. K. Khoo
Publisher: Wiley IEEE Press, 1999

Course Description: The complexity of human physiology and the interrelationships between molecules, cells, tissues, organs and organ systems has been a daunting challenge in our quest to understand life and disease. One aspect of bioengineering aims to utilize quantitative mathematical descriptions of physiological processes in the form of computer models to understand complex relationships that cannot readily be experimentally observed. These techniques have the potential to provide a more in-depth understanding of the function of the human body, both for basic science research as well as for diagnosis and treatment of disease. This course will introduce the basic concepts and tools for modeling physiological systems using engineering principles and analogies, and discuss several practical applications. The course will involve extensive hands-on modeling using MATLAB and SIMULINK.

Learning Objectives
a) At the end of the course:
• Students will be able to explain the need for modeling in biomedical science and medicine.
• Students will be able to describe the considerations for developing predictive models at multiple scales to answer specific physiological questions.
• Students will be able to apply mathematical descriptions to analyze physiological systems.
• Students will be able to explain how to interpret the results of modeling in the context of normal and abnormal physiology.

b) The following student learning outcomes will be directly assessed:
• Students will have an ability to apply knowledge of mathematics (including differential equations and statistics), science (including biology and physiology), and engineering to solve problems at the interface of engineering and biology.
• Students will have an ability to communicate effectively.
• Students will have a recognition of the need for, and an ability to engage in lifelong learning, specifically:
  ▪ students recognize the need to learn on their own by seeking out relevant information when facing an unfamiliar problem in homework or project
  ▪ students are able to integrate information gathered from multiple sources, such as textbooks, online resources, experts, and peer-to-peer discussions, to solve an unfamiliar problem
• Students will have an ability to use computational tools, such as modeling, pattern recognition, to understand living systems

Grading:
Two take home midterm exams (40%)
Homework and in-class exercises (15%)
Final Project (25%)
Final Exam (in class written exam) (20%)
<table>
<thead>
<tr>
<th>Week</th>
<th>Topics</th>
<th>Readings</th>
<th>Deadlines</th>
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| 1 (8/29, 8/31) | **Part 1: Lumped parameter models**  
**Topic 1:** Introduction to modeling  
- Multiscale organization of living organisms: cell to organs  
- Homeostasis. Examples of physiological control systems. Positive and negative feedback.  
- Why model? Basic concepts of modeling  
- Types of models  
- Modeling vs. Simulation  
- Verification and validation  
- Numerical considerations | Reading: The human physiome project  
Introduction to Simulink | |
| 2 (9/7) | **Topic 2:** Biophysical concepts in modeling  
- Electrical analogs (resistors and capacitors) in physiology. Blood pressure and flow, vascular impedance  
- Mechanical analogs (springs and dashpots) in physiology. | Reading: Chapter 2 of Khoo | |
| 3 (9/12, 9/14) | **Topic 3:** Steady state analysis of negative-feedback control systems  
- Coupled static model of cardiopulmonary system  
- Coupled static model of glucose-insulin system | Reading (Khoo): Chapter 3, sections 3.1-3.4  
Reading: Handout on Cardiac Output regulation  
Cardiac Failure handout | Deadline (9/14): Submit written project proposal, including bibliography |
| 4 (9/19, 9/21) | **Topic 4:** Physiological modeling using linear systems  
- Time-varying lumped parameter systems using ODEs  
- Windkessel model of circulation | Setting up first order systems in SIMULINK  
Reading: Arterial Windkessel paper | |
| 5 (9/26, 9/28) | **Topic 5:** Pharmacokinetics and Transport  
- Compartment models  
- Transport phenomena | Reading: Handouts on compartment modeling. | |
| 6 (10/3, | **Topic 6:** Model parameters  
- Model parameter estimation | Deadline (10/5): Project report: | |
<table>
<thead>
<tr>
<th>Date</th>
<th>Topic</th>
<th>Notes</th>
<th>Instructions</th>
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<tbody>
<tr>
<td>10/5</td>
<td>using optimization</td>
<td></td>
<td>Submit draft Introduction with literature review.</td>
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<tr>
<td>10/10</td>
<td>• Columbus Day. Class meets on Tuesday 10/11</td>
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<tr>
<td>7</td>
<td>(10/11, 10/12) • Continuum mechanics • Basic concepts of fluid dynamics</td>
<td>Notes posted on Blackboard</td>
<td>Take Home Exam I assigned 10/21 due 10/24 in class Topics: Part I of course</td>
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<tr>
<td>8</td>
<td>(10/17, 10/19) • Numerical approximation of differential equations • Numerical considerations for modeling.</td>
<td>Notes posted on Blackboard</td>
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<tr>
<td>9</td>
<td>(10/24, 10/26) • Introduction to the finite difference method • Examples of Finite Difference models • Diffusion models: Heat equation • RF ablation modeling</td>
<td>Notes posted on Blackboard</td>
<td></td>
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<tr>
<td>10</td>
<td>(10/31, 11/2) • Finite element models of structural mechanics • Elliptic equation</td>
<td>Notes posted on Blackboard</td>
<td>Deadline (11/4): Project report: Submit draft Methods and revisions to Introduction</td>
</tr>
<tr>
<td>11</td>
<td>(11/7, 11/9) • Finite element models of structural mechanics Contd.</td>
<td>Notes posted on Blackboard</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>(11/14, 11/16) • Computational fluid dynamic models • First-order Advection problem in 2D using finite differences • Stability issues</td>
<td>Notes posted on Blackboard</td>
<td></td>
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<tr>
<td>13</td>
<td>(11/21) • Computational fluid dynamic models Contd. • Convection and transport • Application using Navier Stokes</td>
<td>Notes posted on Blackboard</td>
<td>Deadline (11/23): Project report: Submit draft Results section including revisions to Methods and Introduction.</td>
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<td>11/23</td>
<td>Thanksgiving recess</td>
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## Course structure:

The course will consist of two weekly lectures, homework assignments, in-class quizzes, two take home exams, a final project and a final written exam. The homework assignments and take home exams will involve programming in MATLAB and SIMULINK and analysis of SIMULINK models. The final written exam will be closed book and closed notes. The project will involve hands-on implementation of a model of a physiological sub-system. This is a writing intensive class. The project report is an important component of the grade, and fulfills this requirement.

In addition to in-class lectures, we might use Blackboard Collaborate Ultra for review sessions and make-up classes. Details will be provided as needed.

## Homework:

There will be assigned homework throughout the semester. The homework will involve

### Part III: Nonlinear models

| 14  (11/28, 11/30) | Simple nonlinear modeling  
• Baroreceptor reflex  
• Pupil reflex  
• Rate sensitivity | Reading: Katona paper. | Take Home Exam II assigned 12/2, due 12/5 in class Topics: Part II of class |
|---|---|---|---|
| 15  (12/5) | Modeling spontaneously excitable/oscillatory systems  
• Action potentials, Sodium and Potassium channels  
• Hodgkin-Huxley model  
• Comparison with other models (Izhikevitch, Integrate and fire) | Reading: Hodgkin-Huxley paper |
| 15  (12/7) | A practical application: closed loop control of blood glucose in Type I diabetes  
• Insulin control of glucose  
• Glucose monitoring  
• Using a model for closed loop modeling of the glucose and insulin system | Reading: Bergman minimal model paper |
| 16  12/12 | • Reading day: Class Review |
| 16  12/14 | • Closed-book Final Exam  
• 10:30 am-1:15 pm  
**Topics: Cumulative exam covering all topics.** | Deadline (12/14): Final project report and project presentations due including all revisions |
will involve programming and analysis of models and processing and analysis of real signals. Homework will be assigned on Mondays and will be due the following Monday by midnight. Homework submitted after the due date will be penalized (15% penalty for each day late). No homework will be accepted after one week from the due date.

**Participation in discussion forums:**
This term we will be using Piazza for class discussion. The system is highly catered to getting you help fast and efficiently from classmates, and myself. Rather than emailing questions to me, or asking me during office hours, I encourage you to post your questions on Piazza. If you have any problems or feedback for the developers, email team@piazza.com. Find our class page at: https://piazza.com/gmu/fall2016/ben304/home

**In-class Exercises:**
Active participation in class has been shown to improve learning and retention. Each lecture will include in-class exercises to facilitate active engagement. The exercises will focus on the material covered in the lecture and in the assigned reading. They will range from simple exercises based on a single topic, to more complex exercises that require you to assimilate multiple concepts. Scoring for the in-class exercises is described below.

You are expected to attend and prepare for each class. This includes reviewing previously covered material, as well as completing the assigned reading.

You are responsible for all material covered in class and in the assigned reading.

**Scoring for in-class exercises:**

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<tr>
<th>Score</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>None</td>
</tr>
<tr>
<td>1</td>
<td>Incorrect</td>
</tr>
<tr>
<td>2</td>
<td>Correct</td>
</tr>
</tbody>
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**I>Clickers**
This course will use i>clickers, a classroom response system, to facilitate the in-class exercises. The system provides immediate feedback about overall class understanding, which can lead to class discussion to clarify misconceptions and common mistakes.

You are expected to purchase, or have purchased, an i>clicker device for use in this course. The devices that you can choose from include i>clicker, i>clicker2, and Web>clicker. To learn about each of these devices please visit the i>clicker website at http://www.iclicker.com.

You must register your i>clicker device online at http://www.iclicker.com/support/registeryourclicker/.

Important information when registering your i>clicker:
GMU uses a Learning Management System (Blackboard)
Your student ID is the prefix of your email address.

Guidelines for i>clicker use:

• You must register your i>clicker in order to use it in this course.
• You must bring your i>clicker to every class. If you do not bring your i>clicker to class you cannot get credit for the in-class exercises.
• You may use ONLY your i>clicker and no one else's. If you are caught using more than one i>clicker, all of them will be confiscated for the duration of class and you will receive a 0 for all in-class exercises. Only your i>clicker will be returned at the end of class.

Midterm Exams:
The there will be two take home midterm exams in the class. The midterm exams will be open book and notes. They will consist of numerical problems and problems involving analysis of models of physiological systems. The exams will test your understanding of mathematics, physics and physiology principles and the ability to apply them to solve physiological problems.

The exams will be assigned via Blackboard 24 hours in advance and will be due in hardcopy in class on the date noted in the Syllabus. Absence from exams must be notified ahead of time and alternative arrangements made with the instructor. The topics covered in the exams will not be cumulative, i.e., the second midterm exam will only cover material discussed after the first midterm.

The reason for the take home exam instead of a traditional in-class exam is to eliminate the artificial constraint of time to allow you to think critically about a problem. Prepare for the take home exam in the same way you would prepare for a traditional in-class exam. If you fail to prepare ahead of time, I can assure you that you will not do well on the exam.

Since the midterm exams are take home, particular attention will be paid to concerns about plagiarism and cheating. Please review the statement on Academic Integrity described later in the Syllabus. All suspicious cases will be referred to Honor Committee without exception. The sanction for an Honor Committee violation on an exam in this class is a straight F. In particular, do not even think about engaging in the following, since it is quite likely you will be caught and referred to Honor Committee.

1. DO NOT collaborate with anyone else on the exam. The exam is supposed to be entirely your own work. If two students make suspiciously similar mistakes that are unlikely to be caused by chance, you will be referred to Honor Committee and the burden will be on you to provide evidence that you did the work yourself. If your answers otherwise raise suspicions, I might ask you to orally defend the answer to me.

2. Do not try to find answers on the internet. You will waste a lot of time looking, and it is unlikely you will find the correct answer. If you fail to describe the steps that you used to arrive at your final answer or conclusions, or a critical logical step in arriving at the answer is suspiciously missing, it will be assumed that you have not done the work on your own, and you will be referred to Honor Committee.
Project:
The students will be required to do an individual course project that will integrate the material learnt in the course. The project presentations and final project report will substitute for a traditional comprehensive final exam. The project topic can be chosen from a list of suggested topics. Typically the project will involve development and analysis of a model of a physiological sub-system. The student will be expected to seek out and integrate relevant information and demonstrate an ability to apply knowledge of mathematics, physics, biology and engineering to analyze physiological systems and evaluate the results. Students will develop sections of the project report throughout the semester and receive feedback.

Writing Intensive Requirement:
This course has been approved by the Faculty Senate Writing Across the Curriculum Committee to fulfill all/in part the Writing Intensive requirement in the Bioengineering major. It does so through the 3500-word project report due 5/4/2016. The project report will be completed through a draft/feedback/revision process. The final project report should be formatted as a 4-page, 2-column, IEEE conference paper in 12-point Times New Roman font, with appropriate references in IEEE format. The project report is expected to consist of four sections: (1) Introduction and Background, (2) Methods and Materials, (3) Results and (4) Discussion and Summary. Students are expected to submit drafts of these four sections by the due dates indicated below. I will provide commentary on the draft, and the revised draft will be due by the dates indicated below. For more detailed description of the expected contents of the project report, please see the project assignment.

Academic Honesty and Collaboration:
The integrity of the University community is affected by the individual choices made by each of us. GMU has an Honor Code with clear guidelines regarding academic integrity. Three fundamental and rather simple principles to follow at all times are that: (1) all work submitted be your own; (2) when using the work or ideas of others, including fellow students, give full credit through accurate citations; and (3) if you are uncertain about the ground rules on a particular assignment, ask for clarification. No grade is important enough to justify academic misconduct.

With collaborative work, names of all the participants should appear on the work. Homework problems are designed to be undertaken independently. You may discuss your ideas with others and conference with peers; however, it is not appropriate to give your work to someone else to review. You are responsible for making certain that there is no question that the work you hand in is your own. If only your name appears on an assignment, your professor has the right to expect that you have done the work yourself, fully and independently.

Plagiarism means using the exact words, opinions, or factual information from another person without giving the person credit. Writers give credit through accepted documentation styles, such as parenthetical citation, footnotes, or endnotes. Paraphrased material must also be properly cited. A simple listing of books or articles is not sufficient. Plagiarism is the equivalent of intellectual robbery and cannot be tolerated in the academic setting.

There will be a zero tolerance policy in this course for plagiarism and cheating in the written project report, in homework submissions, and in take home exam. Every instance of plagiarism or cheating will be reported to the GMU Honor Committee. No excuses. No exceptions. If you have any doubts about what constitutes plagiarism, please see the instructor.
The sanction for an Honor Committee violation on an exam in this class will be a straight F.

Email Policy:

You must use your Mason email account for all email correspondence having anything to do with your work at Mason. Federal laws protecting your privacy rights require that we only communicate student information directly to students – and use of the university email system is our only way to validate your identity. You may forward your campus email elsewhere, but we can respond only to a Mason email account.

Relevant Campus and Academic Resources

Disability Services

Any student with documented learning disabilities or other conditions that may affect academic performance should: 1) make sure this documentation is on file with the Office of Disability Services (SUB I, Rm. 2500; 703-993-2474; http://ods.gmu.edu) to determine the accommodations you might need; and 2) talk with the instructor to discuss reasonable accommodations.

Office of Diversity, Inclusion and Multicultural Education

SUB 1, Rm. 2400; 703-993-2700; https://odime.gmu.edu

Writing Center

Robinson 114A; 703-993-1200; http://writingcenter.gmu.edu

WAVES: Wellness, Alcohol and Violence Education and Services

WAVES promotes wellness within the Mason community through health education, alcohol/drug assessment and education, and violence awareness, prevention and sexual assault response. We help students make healthy, safe choices and encourage lifelong, thoughtful healthy decision-making through individualized support, creative programming, and evidence-based education and outreach.

WAVES office 703-993-9999
SUB I, Suite 3200
24-Hour Sexual and Intimate Partner Violence Crisis Line 703-380-1434
waves.gmu.edu

- 703-360-7273 (Fairfax County Office for Women and Domestic and Sexual Violence Services 25 hotline)
- 703- 228-4848 (Arlington County Domestic Violence Services Hotline)
- 703-368-4141 (Prince William County Sexual Assault Victims Advocacy Services (SAVAS) hotline)
CAPS: Counseling and Psychological Services
Counseling and Psychological Services (CAPS) provides a wide range of free confidential services to students, faculty, and staff. Services are provided by a staff of professional clinical psychologists, social workers, counselors, learning specialists, and psychiatric providers. CAPS individual and group counseling, workshops, and outreach programs are designed to enhance students’ personal experience and academic performance. Visit us at caps.gmu.edu for additional resources.
- For consultation or emergency assistance during office hours call 703-993-2380.
- For assistance during non-office hours, call University Police at 703-993-4357.
- 703-527-4077 (CrisisLink)
- 1-800-273-8255 (National Suicide Prevention Lifeline)
- 1-877-838-2838 (Veterans' Crisis Hotline)

Student Health Services (SHS) — Provides confidential health care to enrolled students in emergency and non-emergency circumstances on the Fairfax, Arlington and Prince William campuses. If there is a medical emergency and Student Health Services (SHS) is closed, please contact the free after-hours nurse ((703) 993-2831), a hospital emergency room, an urgent care facility, or call 911.

SUB 1, Suite 2300
703-993-2831

University Police:
Emergency: 911 Non-Emergency: (703) 993-2810
Reporting a Crime (Crime Solvers Anonymous Tip Hot-Line): (703) 993-4111
Mason Police Website: http://police.gmu.edu/
Eric Heath, Chief of Police Phone: (703) 993-3840 E-mail: eheath2@gmu.edu