BME 5742 Bio-systems Modeling and Control

Credits: 3 credits

Textbook, Title, Author, and Year:

Mathematical Modeling in Systems Biology – An Introduction, Brian P. Ingalls the MIT Press, 2013

Modeling and Simulation in Medicine and the Life Sciences (2nd Edition) Frank C. Hoppensteadt and Charles S. Peskin, Springer, New York, 2002.

Reference Materials: Michael C.K. Khoo, "Physiological control Systems – Analysis, Simulation and Estimation", IEEE Press 1999. [*Book was used to prepare the lectures about the electrical analog models, and also to prepare the lectures about Glucose Metabolism and Diabetes. The book has too much Controls and too little Biology and Physiology*].

1. James Keener and James Sneyd, "Mathematical Physiology", Springer 1998 [*The second edition of this book is a two volume books – the first covers cellular-level models and the other covers organ-level models. The book is very mathematical, very comprehensive and not so easy to read. Some parts of the book are way beyond the scope of this course, involving partial differential equations. The book was used to create the lectures about Enzyme Kinetics*].

2. Robert B. Northrop, "Endogenous and Exogenous Regulation and Control of Physiological Systems", Chapman & Hall / CRC Press 2000. [*The book was used to create part of the Course Introduction and the lectures about Compartmental Modeling. The book has good coverage of Glucose Metabolism*].

3. Arthur C. Guyton and John E. Hall, "Medical Physiology" Tenth Edition, W.B. Saunders Company 2000. [*This is like a "Bible" for medical students. It is very comprehensive on the Physiology side and it is non-mathematical. None of the lectures was prepared based on anything taken from this book, but it is an important reference*]

4. Valerie C. Scanlon and Tina Sanders, "Essentials of Anatomy and Physiology", Fourth Edition, F.A. Davis Company 2002. [*There may be newer editions. The book has outstanding Physiology graphics and some physiological processes are explained in a very clear language*]

5. Geoffrey M. Cooper, "The Cell – A Molecular Approach", ASM Press 1997. [*There are newer editions. This is the "Bible" of Molecular Cell Biology. Some outstanding graphics and eye-opening clear explanation of all cellular-level processes. The book was used directly to prepare the lectures about the Hodgkin-Huxley model and related topics*]

6. Edward K. Yeargers, Ronald W. Shonkwiler and James V. Herod, "An Introduction to the Mathematics of Biology, With Computer Algebra Models", Birkhauser 1996. [*The book was extremely useful in preparing the early lectures about Population Growth models*]

7. J.D. Murray, "Mathematical Biology", Springer-Verlag 1989. [*This book too has a newer two-volume edition. It was used to prepare the Population Growth Dynamics lectures. It was also used to prepare the lectures about Spread of Infectious diseases. It is essentially an applied mathematics book. Many of its topics go far beyond the scope of this course*]

8. Nicholas F. Britton, "Essential Mathematical Biology", Springer 2003. [*The book was used to supplement the lectures about Spread of Infectious Diseases*]

9. James B. Dabney and Thomas L. Harman, "Mastering Simulink", Prentice Hall 2004. [*This is one of the better Simulink textbooks.*]

Specific Course Information

- **Catalog description:** The course develops understanding of basic linear and nonlinear dynamic properties, computer-aided analysis, simulation and control of selected physiological processes and biological systems
- **Prerequisites:** Prerequisites: Graduate standing in Bioengineering or senior level standing in Engineering and Computer Science; The course is one of four core courses in the MS in Bioengineering program

Specific Goals for the Course: The following are some of the course's interdisciplinary concepts and specific skills that a student is expected to master after completing the course:

1. Derivation of a mathematical model of a dynamic bio-system based on first physical principles, drawn from various engineering disciplines.
2. Construction of a system's dynamic model based on empirically obtained data.
3. Recognition and simulation of system nonlinearities and their effect on the system dynamic behavior.
4. Understanding of the process of linearization and its range of validity.
5. Understanding of the concept of stability, the causes for instability and the means to stabilize a system.
6. Understanding of the concept of feedback, and its role in Homeostasis.
7. Simulation, analysis and design of systems, using MATLAB, MATLAB SIMULINK

Bring Science and Engineering students to some sort of a common denominator – the engineering students will become more familiar with biology concepts, whereas science students will become more familiar with engineering software used for analysis and design.

Brief List of Topics to be covered:

The Logistic Model
Simulink Tutorial: Simulation of Malthusian Models, Scope data set up and transfer to Matlab
*Simulink Tutorial: Simulation of the logistic model, signals multiplexing, usage of the Fcn block;*Logistic Model with Extinction and Predation; Logistic Models with Time Delay Effects
Logistic Models with Time Delay Effects (cont'd); *Simulink Tutorial: More about Simulink's configuration parameters;*Predator-Prey models
Predator-Prey models (cont'd) *Simulink Tutorial: Running Simulink from Matlab*
Simulink Tutorial: Running Simulink from Matlab (cont'd); Competition-Symbiosis models
Linearization – basic concepts; *Simulink Tutorial: Linearization using Matlab and Simulink; Stability of Equilibrium Points*
The SIR model for Spread of Infectious Diseases; Chemical Reactions Rate: Law of Mass Action
Simulink Tutorial: SIR Model – elimination of dependent variable and the STOP block; Chemical ReactionsRate: Law of Mass Action (Cont'd)
Diffusion: Fick's Law; Mass Action combined with Diffusion (Simple inter-cellular control models)
Generalized Electrical Models in Biology and Physiology
Generalized Electrical Models in Biology (cont'd); *Control Tutorial by means of Simulink: Basic concepts of linear models*
Introduction to Enzymes; Introduction to Enzyme Kinetics
Simulink Simulation of a basic Enzyme Kinetics model; The Michaelis-Menten model for basic enzyme kinetics
Simulink Simulation of a basic Enzyme Kinetics model (cont'd); Advanced Enzyme Kinetics (Cooperation)
Example: Hemoglobin and Myoglobin Oxygen Dissociation Curves; Advanced Enzyme Kinetics (Competitive Inhibition)
Advanced Enzyme Kinetics (Allosteric Inhibition;The Insulin hormone: Glucose Metabolism models
Glucose Metabolism models (cont'd); *Simulink Models for normal patients and Type-1 Diabetic patients*
Simulink: Type-1 and Type-2 Diabetes models; Osmosis; Simplified Model of Cell Volume Control
Simplified Model of Cell Volume Control (cont'd); Cell Electrical Activity (Nernst Potentials); Ion Movement through Cell Membranes (including electrical phenomena)
Ion Movement through Cell Membranes (including electrical phenomena) (cont'd); Hodgkin-Huxley Nerve Activation model – general considerations
Hodgkin-Huxley Nerve Activation model - Sodium and Potassium Channels, the mathematical model of Action Potentials; Peskin's simulator for the nerve activation model; *Peskin's Hodgkin-Huxley's Matlab*
Heart & Blood Circulation: Introduction and Basic concepts; Static Flow-Pressure-Volume relationships
Heart & Blood Circulation: Sensitivity Analysis; The Need for Feedback Regulation; Heart & Blood Circulation: The Baro-receptor Loop
Heart & Blood Circulation: The Baro-receptor Loop (cont'd); Dynamic models Heart & Blood Circulation
Dynamic models Heart & Blood Circulation (cont'd); Peskin's Heart and Blood Circulation Matlab Simulator: Driven arterial system model; Left ventricle and arterial system model; Normal and diseased Valves
Peskin's Simulator: Heart Valves Modeling (cont'd); the general circulation model; Systemic arterial resistance auto-regulation
Model of Fetal Blood Circulation; *Simulation of Fetal Blood Circulation using Peskin's Matlab*
Case Studies Based on Recent Papers: Case Study 1: "Model for Spread of the H1N1 Epidemic and Vaccination Strategies"; Case Study 2: "Models of Viral Dynamics"
Case Study 3: "The Synthesis and Release of Dopamine"; Case Study 4: "Model of the Brain's Respiratory Center"