National University of Sciences & Technology (NUST)

Title : Computational Modeling & Simulation of Physiological Systems
Code : CSE-888
Credit Hours: 3-0

Course Brief:

The course introduces analytical and computational models of biomedical domain to elucidate the fundamental biophysical, electrical and mechanical functions of normal human systems. The course introduces and examines mathematical models, to quantify biomechanical principles at a level of finite discretization and tissue up to the complete organs. This course also addresses the force plots using principles of mechanics especially in heart, head and bones.
One of the most significant features of this course is to explain the influence of physics (electric, electrochemical, physiological and mechanical phenomena) on important biomechanical systems. In addition, numerical methods for solving the underlying systems of equations are also covered subject to its efficient implementation.

Objectives:

The course provides a detailed insight in modeling approaches, virtual reconstruction of natural systems and their mathematical description

Course Learning outcomes

1. The course will provide students with a guide to mathematical modeling techniques and tools for simulation of physiological systems.
2. Students will be able to classify modeling approaches and select appropriate models as research and development tools.
3. By using various mechanical models, students will be able to quantify etiology of each at multiple levels
4. Students will be able to demonstrate their understanding of cellular force development and tissue mechanics.
5. Students will be able to integrate electrochemical, physiological and mechanical phenomena into designing models to assess their inter-dependencies.
6. Student will be able to develop vocabulary and context for understanding recent literature in computational modeling and simulation

Course Contents (General)

1. Overview Modeling and simulation.
2. Modeling of force development in structures.
3. Digital Image processing
4. 3D modeling in Image processing suites.
5. Mechanical modeling of structures
6. Finite Element Method & application
7. Introduction to multi-physics and dynamics & simulations

8. Simulation platforms: ABAQUS & ANSYS
9. Case studies

Week Wise Contents:

Sr No	**Topics and Week-wise break down**
Week 1	Introduction to Modeling and Simulation
	Computational models Importance of efficient solutions
Week 2 and 3	Mathematical and Numerical modeling
	Mathematical Models & Implementation Implementation of vertebral model with disc modeling Numerical Methods
	Implementation of numerical models using case studies
Week 4	Direct and indirect approaches in modelling and simulation
	Modeling of force development Modeling for motion control
Week 5	Finite element method (FEM)
	Basic Methodology Implementation using 1D structural problem Implementation using 2D structural problem Finite element processes – Example Studies
Week 6	Simulation Solvers – Application based Research
Week 6 (Contd.)	Digital image processing – A new tool for Digital Modeling
Week 7	OHT1
Week 8	Advanced Image processing suites - Application based research in Imaging technologies
Week 9	**Midterm**
Week 10	• Multi-Physics Biomedical • Imaging & Imaging Modalities (i) Computed tomography (CT) (ii) Magnetic resonance imaging (MRI) basic principles and working (Introduction to Multi-physics) (iii) UltraSound
Week 10 (Contd.)	High End Visualization – ParaView –An interface to Para FEM

Week 11	Digital imaging and FEM at engineering interface
Week 11 (Contd.)	Physiological Systems
	Model development, model goodness and accuracy Modeling with Physiological Variable in discrete and temporal systems
Week 12	Classification Modeling
	Compartmental Modeling for Cholesterol control system Population Methods using Stochastic Modeling Mathematical modeling using Malthusian Models
Week 13	Modeling of muscles
	Development of musculoskeletal models Muscle function & Joint Loading Evaluation procedures in mechanical models
Week 14	Scientific Computing in Biomedical Engineering
	Approaches in Scientific Computing (Parallel computing, Scheduling, queuing etc) Introduction to ODE's in Scientific Computing (Surface Level) Introduction to PDE's in Scientific Computing (Surface Level – covered already in linear algebra course)
Week 16	Modeling of mechanical processes using case studies
Week 17 -18	End Semester Project & Presentation
Additional	**Suggested topics from Students**

Text Books/Reference Material:

1. *Nikita, Konstantina S., and Konstantinos P. Michmizos. "Physiological Systems Modeling, Simulation, and Control." Handbook of Research on Biomedical Engineering Education and Advanced Bioengineering Learning: Interdisciplinary Concepts. IGI Global, 2012. 745-787.*
2. *Bathe, Klaus-Jürgen. Finite element procedures. Klaus-Jurgen Bathe, 2006.*
3. *Rideout, Vincent C. Mathematical and computer modeling of physiological systems. Englewood Cliffs, NJ:Prentice Hall, 1991.*
4. *Research Methods in Biomechanics, Author: Robertson, D.G.E., Caldwell, G.E., Hamill, J., Kamen, G., & Whittlesey, S.N. Edition: 2004. Publisher: Champaign, IL: Human Kinetics*.

5. *Programming the Finite Element Method, 5th Edition* I. M. Smith, D. V. Griffiths, L. Margetts
ISBN: 978-1-119-97334-8 682 pages October 2013, ©2013 (New Book)

Nature of Assessments

Course format will include a lot of readings, lectures, active learning exercises, discussion, group activities, in-class quizzes, a mid-term exam, and a final exam