Biomechanics II: intermediate

immediate

1 de octubre de 2013

1. Course Description

Biomechanics is multi-disciplinary field related to the application of physics in mechanical aspects of biological systems and in particular human body. Obviously it is important for biomedical engineering students to master the basic foundations of the topics in this field. The intermediate biomechanics course is based on advanced physical rules applied to biomechanics.

The aim of the course is:

i to give students a clear understanding of the intermediate concepts of biomechanics

ii to teach how to analyse practical issues

To provide the concepts, different topics have been presented during the course. The presented material covers: (a) dynamics of linked bodies, (b) continum mechanics, (c) biofluid mechanics, (d) bioheat transfer and (e) thermodynamics.

2. Structure

The course is presented in three theory, seminar and practical classes.

2.1. Theory classes (26 h)

Block 1. kinematics and kinetics of multi-body systems ($\sim$ 25 %)

- theme 1. kinematics of human movement
  - Position and orientation:
    - Reference and coordinates system.
    - Position and trajectory of a point.
    - Measurement and signal processing.
    - Multibody system.
    - Angular coordinates, range of motion (ROM).
  - Movement:
    - Velocity and acceleration of a point.
    - Degrees of freedom of a multibody system.
    - Rigid body kinematics.
- theme 2. vectorial dynamics and muscle forces
  - Fundamental equations:
    - Dynamics of the particle. Second Newton's Law.
    - Linear Momentum Theorem.
    - Angular Momentum Theorem.
  - Anthropometric parameters:
    - Center of mass and moment of inertia.
    - Tables and regression equations.
  - Dynamic Forces:

- Classification of forces in human body motion analysis.
- Resultant wrench of a system of forces.
- Contact forces: friction and constraint forces.
- Joint forces.
- Muscle physiology and Hill's model.

Bloque 2. continuum mechanics in bioengineering ($\sim$ 25 %)

- theme 3. Kinematics of deformation
  - * Brief introduction
    - Why continuum mechanics are useful in medicine and biology?
    - Which notions should we take care of? (basically, why learning this in this course)
    - Short (3-5min) introductory video
  - * Kinematics of deformation
    - Reminder = Physical meaning and utility of the main operators: gradient, Jacobian (volume conservation and strain), divergence (incompressibility), Laplacian (curvature) and their apparition in simple constitutive equations
    - Reminder = (Displacement, velocity), 2D/3D strain, (strain rate). Practical interpretation of matrix notations.
    - Principal directions computation and meaning
  - * Details about computations in cylindrical coordinates
- theme 4. Strain-stress relationship
  - * Reminder = Link between stress and forces. 2D/3D extending the axial case.
  - * Strain-stress relationship
    - Reminder = Linear elasticity. 2D/3D extending the axial case.
    - How to reduce the dimensionality using material symmetries
    - Non-linear elasticity + examples. Focus on hyper-elastic materials.
- theme 5. Cauchy and Piola-Kirchhoff stress
  - * Lagrangian / Eulerian point-of-view
    - Computation of Lagrangian / Eulerian strain and relation with infinitesimal strain
    - Beware of differences between transformation (ϕ) and displacement ($u = \phi - Id$)
  - * Cauchy and Piola-Kirchhoff stress
  - * Integration into simple constitutive equations
  - * Conclusion: continuum mechanics
    - What do we need to improve to get a complete organ? (ex: heart = electrical coupling, cellular level, etc.)
    - Short concluding videos (5-10min)

Block 3. Biofluid mechanics ($\sim$ 25 %)

- theme 6. static flow
  - flow quantities
  - flow characteristics
  - stress-strain rate relationships
  - flow forces
  - bouyancy rule
- theme 7. Bernoulli and Navier-Stokes equations
  - Bernoulli equation and applications
  - Navier-Stokes equations and applications

- theme 8. Biological aspects of blood flow
  - blood components
  - blood rheology
  - flow properties
- theme 9. Similarity law, flow imaging modalities and circulatory system
  - non-dimensional Reynolds number
  - Womersley number
  - Phase contrast imaging
  - Medical flow image processing

Block 4. Bioheat transfer and biothermodynamics ($\sim$ 25 %)

- theme 10. Thermal conduction
  - mechanisms of heat exchange
  - Fourier law and the heat equation
  - heat flux and heat conduction in 1D and 2D
- theme 11. Convective heat transfer
  - thermal effects of flow
  - Newton law
  - convection in infinite media
  - free convection for simple geometries
- theme 12. Bioheat transfer
  - thermal properties of biological tissue
  - thermal threatment procedures (two examples)
  - thermal property of blood and perfusion term
  - bioheat transfer models
- theme 13. Thermodynamics principles
  - lows of thermodynamics
  - work, potential energy and kinetic energy
  - equations in control volume
  - p-v diagram
- theme 14. Thermodynamic systems
  - power cycles (Carnot and Stirling cycles)
  - enthalpy and entropy
- theme 15. Biological applications
  - heart
  - cells

2.2. Seminar classes (14 h)

- **Seminar 1 (2h):** kinematics problems (Block 1).
- **Seminar 2 (2h):** dynamics problems (Block 1).
- **Seminar 3 (2h):** eigen-value and eigen-vectors (Block 2).
- **Seminar 4 (2h):** non-linear material models (Block 2).
- **Seminar 5 (2h):** biofluid mechanics (Block 3).
- **Seminar 6 (2h):** bioheat transfer (Block 4).
- **Seminar 7 (2h):** biothermodynamics (Block 4).

2.3. Practical classes (12 h)

- Practice 1 (2h)
  title: *motion analysis lab*
- Practice 2 (2h)
  title: *data analysis for human movement*
- Practice 3 (2h)
  title: *motion/deformation extraction using speckle-tracking*
- Practice 4 (2h)
  title: *strain/stress extraction using speckle-tracking*
- Practice 5 (2h)
  title: *pulsatile flow in arteries*
- Practice 6 (2h)
  title: *flow image analysis*

3. Evaluation

Evaluation of the course will be based on the student activity during the course and the written exams. Below is the list used for evaluation:

* written exam: 60 % of final grade of the block. This part organised in two sessions:

  - partial exam (30/10/2013): written exams of blocks 1 and 2.
  - final exam (date to be announced on the website of the university): written exams of blocks 3 and 4.

* deliverable, including seminars, homeworks and reports for practical activities [1]: 40 % of the final grade in total.

Written exam is based on materials presented during the course. Each block's exam and evaluation will be independent from others. In order to pass the course it would be necesary to have the following results:

* having minimum grade of 5 from each block (including grades from exam and deliverables).

* to be present in all practical classes.

In case grades for all blocks are satisfied, your final grade will be the average of the grades from all blocks. If you failed in one block, your final grade will be the one of the failed block (less than 5).

There is the opportunity to repeat the failed subject in July. For this exam you will need to have minimum grade of 5 in the exam. if passed, the grade for that block will be 5/10.

The results of the evaluation for exam and deliveries will be announced in aula-global.

[1] It is mandatory to present in all practical classes. There is no possibility to repeat this part in the recovery exams of July.

4. Textbooks

- **Block 1**

[1] D.G.E. Robertson, G.E. Caldwell, J. Hamill, G. Kamen, S.N. Whittlesey, Research methods in biomechanics, Human Kinetics, 2004.

[2] D.A. Winter, Biomechanics and motor control of human movement, John Wiley and Sons, Inc., 1990.

[3] V.M. Zatsiorsky, Kinematics of human motion, Human Kinetics, 1998.

[4] V.M. Zatsiorsky, Kinetics of human motion, Human Kinetics, 2002.

[5] C.L. Vaughan, V.L. Davis, J.C. O'Connor, Dynamics of human gait, Kiboho Publishers, 1992.

[6] P. Allard, I.A.F. Stokes, J.P. Blanchi, Three-dimensional analysis of human movement, Human Kinetics, 1995.

- **Block 2**

[1] C.R. Ethier and C.A. Simmons. Introductory Biomechanics. From Cells to Organisms. Cambridge, 2007.

[2] Y.C. Fung. Biomechanics. Motion, Flow, Stress, and Growth. Springer. 1990.

[3] Y.C. Fung. Biomechanics. Circulation. Springer. 1984.

[4] A. Pytel and J. Kiusalaas, Engineering Mechanics: Dynamics,Gangage learning, 2009.

[5] Mokka. url: http://b-tk.googlecode.com/svn/web/mokka

[6] OpemSim. url: http://opensim.stanford.edu

- **Block 3**

[1] D.F. Young, B.R. Munson, T.H. Okiishi, A Brief Introduction to Fluid Mechanics, John Wiley & Sons, 2007.

[2] R.W. Fox, A.T. McDonald, Introduction to Fluid Mechanics, Wiley, 2011.

[3] I.H. Shames, Mechanics of Fluids, McGraw- Hill Higher Education, 2002.

[4] L. Waite, J. Fine, Applied Biofluid Mechanics, McGraw-Hill, 2007.

[5] J.D. Humphrey, S. L. Delange. An Introduction to Biomechanics. New York: Springer-Verlag, 2004.

[6] M. Zamir, The Physics of Pulsatile Flows. Springer Biological Physics Series, 2000.

- **Block 4**

[1] J.P. Holman, Heat Transfer (Si Units), McGraw-Hill, 2008.

[2] Y.A. Cengel, Heat Transfer: A Practical Approach, McGraw Hill Professional, 2003.

[3] Y.A. Cengel, Thermodynamics(Si Units), McGraw Hill, 2008.

[4] G.J. Van Wylen and R.E. Sonntag, Fundamentals of Classical Thermodynamics. John Wiley & Sons, 1994.

[5] P. Atkins, and J. de Paula. Physical Chemistry of the Life Sciences. W.H. Freeman and Company, New York, 2006.

[6] D.T. Haynie, Biological Thermodynamics. Oxford University Press, New York, 2001.