

Teaching Plan

Course name: Bioinstrumentation and Biosensors (Bioinstrumentació i Biosensors)



Academic year: 2013-2014

Trimester: 1st

Degree: Bachelor's degree in Biomedical Engineering

Year: 3rd

Course code: 22129

Number of ECTS credits: 5

Hours of student work: 125

Language in which the course is taught: English

Teachers: Antoni Ivorra, Antonio Berruezo

Responsible professor: Antoni Ivorra

1. Course descriptors

Course name: Bioinstrumentation and Biosensors (Bioinstrumentació I Biosensors)

Course acronym: BIS

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Hours of student work: 125

Language(s) in which the course is taught: English (all written materials).
Exceptionally, if students unanimously agree, lectures will be taught in Catalan or Spanish.

Teachers:	Antoni Ivorra	antoni.ivorra@upf.edu
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Lab assistant:	Genís Caminal	genis.caminal@upf.edu
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Responsible professor: Antoni Ivorra

2. Course presentation

This course mostly deals with theoretical and practical aspects regarding the acquisition of numerical data and signals from human body by means of electrodes and electronic sensors. The course aims three main teaching objectives: 1- to overview the fundamental features of modern medical measurement systems and the mathematical, physical and electronic foundations of those systems, 2- to introduce the principles of design for electronic circuits capable of safely interfacing electronic sensors and electrodes to digital systems and 3- to put in practice the above knowledge – and to get some lab and hardware prototyping skills – by implementing and testing a simple medical measurement system. In addition, some therapeutic uses of electricity will be overviewed.

Short syllabus: Introduction to measurement systems and error theory, overview of circuit theory fundamentals, biomedical electrodes and electrochemical sensors, overview of modern electronic technology and physical sensors, signal conditioning circuits based on operational amplifiers and instrumentation amplifiers, analog-to-digital converters, biopotential recording systems and their applications and therapeutic uses of electricity (pacemakers, defibrillation, RF ablation).

Prerequisites: 1- very basic knowledge of circuit theory (i.e. Ohm's law, Kirchhoff's circuit laws, RC circuits charge and discharge equations, ...), 2- undergrad level general physics (e.g. physics first year course in any engineering discipline), 3- signal theory basics (i.e. Fourier transform and sampling theory), 4- very basic probability theory and statistics (i.e. variance, probability density functions, confidence interval...) and 5- Matlab programming basics. In terms of courses from the Bachelor's degree in Biomedical Engineering at the UPF: "Bioelectromagnetisme", "Teoria de Senyals i Sistemes", "Biomodelatge Matemàtic II" i "Tècniques Computacionals en Biomedicina".

3. Competences the course aims to teach or to train

Transversal competences	Specific competences
Instrumental INS1. Ability for analysis and synthesis INS2. Organization and planning ability INS3. Ability for applying knowledge in practice INS7. Oral and written communication in English in academic or professional environments. Interpersonal INT1. Teamwork Systemic SIS1. Ability for applying flexibly and creatively the acquired knowledge to new scenarios. SIS4. Concern for quality	Professional specific competences B1. Ability for solving mathematical problems which may appear in engineering. Aptitude for applying knowledge on: linear algebra; geometry; differential geometry; differential and integral calculus; differential equations; numerical methods; numerical algorithms; and statistics. B2. Ability to use and program computers. Ability to use diverse operating systems, data bases and computer programs intended for engineering. B6. Knowledge on linear systems, circuit theory, electronic circuits, electronic and photonic devices, materials technology. P1. Ability for engineering projects preparation and development P5. Knowledge for taking measurements, performing calculations, technical reports, task planning and other analogous tasks. Fundamental learning specific competences IB1. Development and implementation of techniques for computational analysis of multimodal signals and images for diagnosis and monitoring. IB2. Design and development of technologies for acquisition, processing, modeling, visualization and interpretation of biological signals and physiological and clinical variables that can be used for medical prevention, diagnosis, treatment and rehabilitation. IB3. To understand the main physiopathological mechanisms and to computationally model the diverse organ systems of the human body, with emphasis on the cardiovascular system, the nervous system and the locomotor system. IB7. To understand and to distinguish diverse techniques and systems for biomedical signals and images which are capable of providing both structural and functional information from multiple biological and physiological processes. Other competences O1. Ability for implementing simple electronic circuit prototypes based on discrete components. O2. Ability for performing circuit analysis using a SPICE simulator.

4. Contents

Contents module identifier	Contents module title and main topics
Module 1 (M1)	Introduction to measurement systems - Sensors and transducers (definitions and main concepts) - General architecture of modern data acquisition systems - Measurement systems characteristics (Accuracy, Precision, Repeatability, Reproducibility, Resolution, Range, Span, Linearity, Transfer function, Sensitivity, Hysteresis, Drift, Selectivity) - Calibration and systematic and random errors - Measurement systems dynamics - Reporting uncertainty - Uncertainty estimation - Uncertainty propagation - Rejection of questionable samples - Least squares fit - Sensitivity and specificity
Module 2 (M2)	Overview of circuit theory fundamentals - Physical meaning of voltage and current. Ideal sources. Thermopiles. - Ohm's law - Kirchhoff's circuit laws - Voltage dividers - Superposition of independent sources - Equivalent circuits - Diodes - Transformers - Time transients in RC circuits - Impedance - Transfer function (frequency analysis) - Noise - Capacitively coupled interferences - Inductively coupled interferences - Simple passive filters - Electrical Safety (Electrical shock hazards, Macroshock and Microshock, Prevention of electrical hazards, Isolation)
Module 3 (M3)	Electrodes - Electrolytes - Galvanic cells - Ion Selective Electrodes - Double-layer - Polarizable and non-polarizable electrodes - Electrical models for electrodes - Recording electrodes, stimulation electrodes
Module 4 (M4)	Modern electronic technology - Semiconductors - Thermistors - PN junction, diodes - PN temperature sensors - LED, photodiode - Pulse oximeter - MOS transistor, digital CMOS circuits - Microelectronics fabrication
Module 5 (M5)	Signal conditioning circuits - Ideal operation amplifier (OA) - Inverting and non-inverting OA configurations - Common mode voltage and differential voltage - Output voltage saturation - Single supply OAs - Limitations of real OAs (offset voltage, bias currents, PSRR, CMRR, bandwidth, slew rate) - Differential amplifier configuration - Instrumentation amplifier - Wheatstone bridge - Strain gauges - Pressure sensors - Blood pressure monitors - Isolation for preventing ground loops

Module 6 (M6)	Analog-to-digital converters and digital sensors - Quantification errors - Sample-and-hold - Voltage-to-frequency converters - Flash ADC - Integrating ADC - Successive approximation ADC - Multiplexors - Aliasing in the context of low frequency data acquisition - Digital sensors
Module 7 (M7) (Dr. Antonio Berruezo)	Tools for identifying cardiac arrhythmias - (contents to be defined)
Module 8 (M8)	Therapeutic use of electricity - Electrical stimulation of excitable tissues - Pacemakers, defibrillation - Cochlear implants, Functional Electrical Stimulation (FES) - RF ablation - Irreversible electroporation
Module 9 (M9) (Laboratory)	Laboratory - Arduino microcontroller platform and its interface to Matlab - Acquisition and representation of DC and AC signals with Arduino + Matlab - Fabrication of a flow transducer - Design, SPICE simulation and physical implementation of signal conditioning electronics for differential pressure sensing. - Design and implementation of Matlab code for spirometry - Calibration, test and characterization of the implemented spirometry system

5. Methodology

This course follows a conventional academic structure in which lectures and problem solving seminars are combined with short tests – for feedback purposes – and a final written exam. In addition, five supervised laboratory sessions will be conducted.

Lectures and problem solving seminars. Contents modules M1 to M8 will be taught in a conventional manner. That is, lectures on theoretical and practical aspects, together with examples of solutions to problems, will be given by the professor. In seminars exclusively devoted to problem solving, the students will have the opportunity to interactively participate in the class.

Modules M4, M7 and M8 correspond to topics that are to be learnt by heart and, therefore, no problem solving seminars are devoted to them.

Lab sessions. The five supervised lab sessions, of two hours each, are aimed towards the development and characterization of a spirometry system (sensor + electronics + software).

The first two lab sessions – in which the Arduino platform and its interface with Matlab are introduced as a data acquisition system of unspecified application – will be fully guided. That is, the students will have to follow a lab guide in which all the consecutive steps for performing the circuits, the measurements and the software will be detailed. These two guided lab sessions will require that the students study in advance some specific materials contained or indicated in the lab guide. Such previous study will not be tested directly at the beginning of the sessions but it will be assessed in a short multiple-choice test at the end of the second lab session (AL1). No report will be required for any of these two guided lab sessions

The other three supervised lab sessions will be truly devoted to the development of the spirometry system. The first one (and a half) of these sessions – in which the sensing system and the electronics will be simulated and built – will be guided but the other two will only be loosely supervised. It is expected that each team comes with original implementations concerning software and system characterization. Performance of the implemented system will have to be demonstrated at the end of the fifth session. Two extra unsupervised lab sessions are allocated so that students can freely work on their developments with all lab resources at their disposal. The students will have to write a report detailing the implementation and the characterization of the system. A guide will be provided for preparation of such report.

Contents module	Hours in classroom (or supervised lab)			Hours outside the classroom (and unsupervised lab)
	Large group	Medium group	Small group	
M1	5	3	–	11
M2	4	4	–	10
M3	2	1	–	6
M4	2	0	–	6
M5	4	4	–	14
M6	1	0	–	4
M7	2	0	–	6
M8	2	0	–	6
M9	–	0	10	18
Total	22	12	10	81
				125

6. Assessment

Some common remarks:

- Deadlines for deliverables will be strictly enforced. Three points (over 10) will be subtracted from the corresponding activity grade per day of delay (integer “ceil” counting from minute 1 after scheduled time deadline).
- In case a student cannot attend a session in which a feedback test is performed (AC1, AC2, AC3 and AL1), his or her grade for that test will be 0. Under no circumstances feedback tests will be repeated for individual students.
- As a general rule, grades for lab activities AL2 and AL3 will be the same for both lab team members. In case a student cannot attend a lab session in which those activities are assessed (AL2), his or her labmate will carry out the activity by himself or herself and, under the agreement of the present labmate, the non-attending student will get the same grade as assessed student.
- Punctuality will be strictly enforced. Particularly in lab sessions: nobody will be admitted in lab 20 minutes after the scheduled start time and grades will be penalized since 5 minutes after the scheduled start time.
- The student is responsible for keeping electronic copies of all deliverables.
- Grade revision dates for tests and deliverables will be indicated in the Aula Global.
- **Very important: copies or plagiarism will not be tolerated at all!**

Assessed Competences	Assessment activity (and typology)	Assessment methodology and criteria	Minimum grade to pass the course	Recoverable (in July)	Weight on final grade
INS3, B1, B6, IB1, IB2	AL1. Lab introduction feedback test (Written Test)	Short multiple-choice test performed at the end of the second lab session.	0	No	5%
INS1, INS2, INS3, INT1, SIS1, SIS4, B1, B2, B6, P1, P5, IB1, IB2, O1, O2	AL2. Spirometry project demonstration (Execution test)	During the last session corresponding to this project, the professor will check the performance of the implemented system. The professor will assess it in terms of capability to perform the requested measurements and the accuracy of those measurements (35%), appearance and quality of the software interface (25%), correctness of the design and the implementation methodologies (25%) and originality and added difficulty of the implemented solutions (15%).	0	No	15%
INS1, INS2, INS3, INS7, INT1, SIS1, SIS4, B1, B2, B6, P1, P5, IB1, IB2, IB3, IB7, O1, O2	AL3. Spirometry project report (Written Test)	Each student team will write a report of about 20 pages on their implemented spirometry system. The professor will assess it in terms of quality and richness of the overall presentation (25%), insightfulness of problem statement (15%), insightfulness and correctness of performed uncertainty analysis (35%), clarity and attention to details in the presentation of methodologies and results (25%) Reports in English will be positively graded (+25% of the grade for this activity).	5 over 10	Yes (only the report, not the grade for AL2)	15%
INS1, INS3, INS7, B1, B6, P5, IB1, IB2, IB7	AC1. M1 feedback test (Written Product)	Multiple-choice test plus one or two problems.	0	No	5%
INS1, INS3, INS7, B1, B6, P5, IB1, IB2, IB7	AC2. M2 feedback test (Written Product)	Multiple-choice test plus one or two problems.	0	No	5%
INS1, INS3, INS7, B1, B6, P5, IB1, IB2, IB3, IB7	AC3. M3-M5 feedback test (Written Product)	Multiple-choice test plus one or two problems.	0	No	5%
INS1, INS3, INS7, B1, B6, P5, IB1, IB2, IB3, IB7	AF. Final exam (Written Test)	Modules 1 to 8 will be assessed by multiple choice questions plus two to five comprehensive problems to be solved.	5 over 10	Yes	50%

7. Schedule

week	First plenary slot Monday 8:30-10:30* (*unless otherwise noted) Plenary lesson or seminar (T1 & P101)	Second plenary slot Thursday 10:30-12:30* (*unless otherwise noted) Plenary lesson or seminar (T1 & P101)	Laboratory slots Wednesday, Thursday or Friday (S101 and S102)
1 Sept 23 – Sept 27	(no class)	Course presentation (M0) and intro. to meas. systs (M1) (Friday 10:30 – 12:30)	(no lab)
2 Sept 30 – Oct 04	Lecture M1	Lecture M1 Seminar M1	(no lab)
3 Oct 07 – Oct 11	AC1. M1 feedback test Seminar M1	Lecture M2	S101. Lab 1 (F 12:30 – 14:30) (S102. no lab)
4 Oct 14 – Oct 18	(no class)	Lecture M2	(S101. no lab) S102. Lab 1 (F 12:30 – 14:30)
5 Oct 21 – Oct 25	Seminar M2	(no class)	S101. Lab 2 (F 12:30 – 14:30) (S102. no lab)
6 Oct 28 – Nov 01	AC2. M2 feedback test Seminar M2	Lecture M3	(S101. no lab) S102. Lab 2 (Th 12:30 – 14:30)
7 Nov 04 – Nov 08	Seminar M3 Lecture M4	Lecture M4 Lecture M5	S101. Lab 3 (Th 12:30 – 14:30) S102. Lab 3 (F 12:30 – 14:30)
8 Nov 11 – Nov 15	Lecture M5	Seminar M5 (Friday 10:30 – 12:30)	S101. Lab 4 (F 12:30 – 14:30) (S102. no lab)
9 Nov 18 – Nov 22	AC3. M3-5 feedback test Seminar M5	Lecture M5 Lecture M6	(S101. no lab) S102. Lab 4 (F 12:30 – 14:30)
10 Nov 25 – Nov 29	Lecture M7 Prof. Antonio Berruezo	Lecture M8 (Wednesday 8:30 – 10:30)	S101. Lab 5 (Wd 10:30 – 12:30) S102. Lab 5 (F 12:30 – 14:30)
11-13 Dec 02 – Dec 20	AL3. Spirometry project report AF. Final exam (data and hour to be determined)		

Notes:

- Lecture M7 is to be given, at Campus Poble Nou, by Dr. Antonio Berruezo from Hospital Clínic. Allocated time slot will be confirmed later.
- Extra *unsupervised lab sessions* will be allocated between Lab 3 and Lab 5. In these *unsupervised lab sessions* – in which no professor will be present – the electronics lab 54.028 will be open for the students and the lab assistant, Genis Caminal, will be there for providing the materials and tools and to keep an eye on materials and instruments.
- At the end of Lab 2 and Lab 5 sessions, assessment activities AL1 and AL2, respectively, will be carried out.

Assessment activities list

Activity	Relevant dates
AL1. Lab intro. test	Test on 25/10/2013 for group S101 Test on 31/10/2013 for group S102 Grades publication on 07/11/2013
AC1. Feedback test on M1	Test on 7/10/2013 Grades publication on 14/10/2013
AC2. Feedback test on M2	Test on 28/10/2013 Grades publication on 4/11/2013
AC3. Feedback test on M3-M5	Test on 18/11/2013 Grades publication on 25/11/2013
AL2. Spirometry project demonstration	Demonstration on 28/11/2013 for group S101 Demonstration on 29/11/2013 for group S102 Grades publication on 1/12/2013
AL3. Spirometry project report	Report delivery deadline 12/12/2013 for both groups Grades publication on 23/12/2013
AF4. Final exam	(Exam date to be determined)

8. Bibliography and didactic resources

Suitable books available as free electronic resources at the web site of the UPF library (<http://www.upf.edu/bibtic/>):

1. "Biomedical Device Technology: Principles and Design", Anthony Y. K. Chan, publisher: Charles C Thomas Pub Ltd, 2008. ISBN 0398085773 (covers: ~M1, M3, M5, M7, M8).
2. "Medical Devices and Systems", (volume 3 of "The Biomedical Engineering Handbook"), 3rd edition, Joseph D. Bronzino (editor), publisher: CRC/Taylor & Francis, 2006. ISBN: 978-0-8493-2122-1 (covers: ~M1, M3, M5, M7, M8).
3. "Linear Circuit Design Handbook", edited by Hank Zumbahlenas with the engineering staff of Analog Devices, publisher: Elsevier/Newnes Press, 2008. ISBN: 978-0750687034 (covers, in excessive detail: M5).
4. "Bioimpedance and bioelectricity basics", 2nd edition, Sverre J. Grimnes and Orjan G. Martinsen, Publisher: Academic Press, 2008, ISBN: 978-0123740045 (covers: M3, M7, M8).

Additional suitable books available at the UPF library:

1. "Medical Instrumentation Application and Design", 4th edition, John G. Webster (editor), publisher: Wiley, 2009. ISBN: 978-0471676003 (covers: ~M1, M3, M5, M7, M8).
2. "Introduction to Biomedical Equipment Technology", 4th edition, Joseph J. Carr and John M. Brown, publisher: Prentice Hall, 2000. ISBN: 978-0130104922 (covers: ~M1, M3, M5, M7, M8).
3. "Introduction to Engineering Experimentation", 3rd Edition, Anthony J. Wheeler and Ahmad R. Ganji, publisher: Prentice Hall, 2009. 978-0131742765 (covers M1 in detail; good collection of problems)
4. "Principios de Electrónica" (Electronic Principles), Albert Paul Malvino, publisher: McGraw-Hill, 2007. ISBN: 978-8448156190 (covers: M2, M4 and M5; extensive collection of problems).

Note: all these books focus on different specific topics covered by the course. Unfortunately, each one of these books either does not cover some topics of the course or goes much deeper into the topics than what required in the BIS course, or both. That is, none of them should be considered as the reference book for the course (i.e. textbook). Nevertheless, two of them stand out as the closest ones to the ideal textbook for the BIS course:

1. "Biomedical device technology: principles and design", Anthony Y. K. Chan, publisher: Charles C Thomas Pub Ltd, 2008. ISBN 0398085773
2. "Medical Instrumentation Application and Design", 4th edition, John G. Webster (editor), publisher: Wiley, 2009. ISBN: 978-0471676003