2010-11 academic year

Signals and systems (21409)

Degree/study: Bachelor's Degree in Computer Sciences, Bachelor's degree in Telematics Engineering, Bachelors degree In Audiovisual Systems Engineering
Year: 2nd
Term:1st and 2nd
Number of ECTS credits: 8 credits
Hours of studi dedication: 200 hours
Teaching language or languages: catalan, spanish and english
Teaching Staff: Xavier Serra, Vicent Caselles, Azadeh Faridi

1. Presentation of the subject

It is an introductory course in digital signal processing designed for students of the second academic year of the Bachelor's degree in Computer Sciences, in Telematics Engineering, and in Audiovisual Systems Engineering. The objective of the course is that students finish understanding basic mathematical concepts used in the study of digital signals and systems and knowing how to use these concepts to specific problems that arise in the degrees where it is taught.

The course content includes a mathematical part and another part more focused on the signal processing from an engineering point of view. Among the topics included there are the mathematical study of complex numbers, the Fourier transform and the Z transform. In the part focused on signal processing there are the study of sinusoidal signals, its sampling and its spectral representation, and the study of digital filters, both FIR and IIR.

The course is organized methodologically depending on three types of learning activities: the lectures or theoretical sessions, the seminars, and the practical sessions or laboratories. In the lectures the teacher explains the theoretical concepts of the syllabus. In the seminars, where the teacher works with small groups of students, some problems related to each of the topics covered in lectures are discussed and solved, with active student participation. Finally, in laboratories, which are held in computer rooms, students do programming practical activities under the supervision of the teacher. During these practical activities students design and implement algorithms related to each of signal processing concepts covered in this course.

2. Competences to be attained

Competences to work with during the course according to the syllabus of the degree.

Transferable skills	Specific competences
Instrumental 1. Capacity to analyze and summarize. 2. Problem resolution. 3. Written and oral communication. ***Interpersonal*** 1. Teamwork. 2. Capacity of critics and self-critics. ***Systemic***	1. Understand and know how to use the appropriate mathematical concepts to analyze and represent digital signals and systems. 2. Understand the sinusoidal signal from a mathematical point of view, from a signal processing point of view, and from a physical point of view. 3. Understand Fourier Transform, DFT and their properties from a mathematical point of view. 4. Understand the concept of spectral representation and its use to represent temporal signals. 5. Know how to convert continuous temporal signals into discrete temporal signals and the way round. Understand

1. Capacity to integrate knowledge and methodologies in practice. 2. Interest in quality.	the sampling Shannon theorem and also aliasing and folding. 6. Understand and know how to use the Z transform in the study of digital systems. 7. Understand and know how to use several representations of FIR and IIR filters: Difference equation, impulsional response, frequential response, and transfer function. 8. Understand the spectral analysis methods by periodic and non-periodic temporal discrete signals. Know how to interpret the spectral representation and know how to identify the spectral characteristics of the signals. 9. Know how to design and implement audio processing algorithms.

3. Contents

List of contents, organized by units and terms.

Unit 1. Introduction to Signals and Systems

a. Definition of signals and systems in engineering
b. Mathematical representation of signals
c. Mathematical representation of systems

Unit 2. Complex numbers

a. Complex numbers notation
b. Operations with complex numbers
c. Polynomial factorization
d. Complex radicals
e. The complex plane
f. Euler's formula

Unit 3. Sinusoids and Exponentials

a. Sine and cosine functions
b. Sinusoidal signals
c. Complex sinusoidal
d. Phasors and phasors sum
e. Diapason physics

Unit 4. Fourier transform mathematics

a. Geometric series
b. Sinusoid orthogonality
c. Discrete Fourier Transform sinusoids
d. Discrete Fourier Transform equation
e. Matrix formulation of the Discrete Fourier Transform
f. Fourier theorems for the Discrete Fourier Transform

Unit 5. Temporal signals spectral representation

a. Sum of sinusoids spectrum
b. Amplitude modulation
c. Sinusoids product
d. Periodic waves, periodic sounds

e. Time-frequency spectrum
f. Modulation of frequency, xirp signals

Unit 6. Sampling and Aliasing of temporal signals

a. Sampling
b. Sampling theorems
c. Aliasing and Folding
d. Spectral vision of the sampling
e. Stroboscopic demonstration of the sampling
f. Conversion from discrete signals to continuous signals

Unit 7. Impulse Finite Response filters, FIR

a. Systems in a discrete time
b. Mobile average filter
c. General FIR filter
d. Impulse response of the FIR filters
e. Implementation of the FIR filters
f. Discrete convolution of signals
g. Lineal and static in time systems, LTI
h. Convolution, LTI systems, and FIR filters
i. LTI cascade systems

Unit 8. Frequency response of the FIR filters

a. Sinusoidal response of the FIR filter
b. Superposition and frequency response
c. Transitory response and in a static state
d. Frequency response properties
e. Graphic representation of the frequency response
f. LTI cascade systems
g. Mobile average filter
h. Filtering of sampled temporal signals

Unit 9. Z transform

a. Definition of the Z transform
b. The Z transform and the lineal systems
c. Properties of the Z transform
d. The Z transform as an operator
e. Convolution and Z transform
f. Relationship between the Z domain and the frequency domain
g. Useful filters
h. Practical design of band-pass filters
i. Properties of lineal phase filters

Unit 10. Infinite Impulse response filters, IIR

a. General difference equation of the IIR filters
b. Response in the temporal domain
c. System function of a IIR filter
d. Poles and zeros
e. Frequency response of a IIR filter
f. The three domains
g. The Z inverse transform and its applications
h. Stable state resting and stability
i. Second order filters
j. Frequency response of the second order filters
k. Example of a low-pass IIR filter

Unit 11. Spectral analysis of temporal signals

a. Fourier continuous transform
b. Revision of the Fourier discrete transform
c. Spectral analysis through filtering
d. Spectral analysis of periodic signals, DFT
e. Fast Fourier Transform, FFT
f. Spectral analysis of sampled periodic signals
g. Spectral analysis of sampled non-periodic signals
h. Short Time Fourier Transform, STFT
i. The spectrogram

4. Assessment

The course is organized according three types of teaching activities: lectures on theory, seminar sessions and practical sessions/laboratories. The final mark is the result of the combination of a continuous assessment and two partial exams and one final exam. The final exam includes the resit of the two partial examinations and a new part. If students pass the first two partial exams, they don't have to do the final examination of these parts, it is optional to raise the mark.

Each activity evaluation is as follows:

Theory (10 points)

- First partial examination, week 9 (4 points)
- Second partial examination, second term week 8 (4 points)
- Final examination of the two partial examinations (8 points) and third partial examination (2 points)
- Moodle weekly test (+1 points)

Laboratories (10 points)

- Weekly hand-in (2 points)
- Final report (2 points)
- First partial examination, week 9 (1 point)
- Second partial examination, week 8 of the second term (3 points)
- Final examination of the two partial examinations (4 points) and third partial examination (2 points)

Seminars (10 points)

- Team activities (6 points)
- Individual activity (4 points)

The final mark is calculated as follows:

Mark = Theory x 0.5 + Labs x 0.35 + Seminars x 0.15

The weekly Moodle test is optional and it must be done after each session of theory. The total punctuation of all tests will be added (+1) to the mark of the theory exam. To access to each test, students will be given a password in class and they will have 48 hours to answer it.

There are two partial exams and a final written exam to evaluate individual understanding of the content presented in the lectures and reinforced with seminars and laboratories. This evaluation is mandatory and it must be qualified with at least 50% to pass the subject. If the students pass both partial exams, on the final exam they only have to do the third part of the subject. Students can do the entire final exam in order to have a greater mark of the partial examinations.

In the laboratories, a series of practical activities that test students' ability to solve practical problems and the capacity to implement algorithms as programs on a computer are done. The practical activities must be hand in individually before the next practical activity. The evaluation is based on the monitoring done by the teacher in class and also on a written test that is done with the partial and final theory exams. This evaluation is also mandatory and it has to be qualified with at least 50% to pass the course.

Before each seminar, students will be given a collection of problems to solve individually before the session, as preparation before the seminar. These problems are related to concepts and skills studied in lectures and put into practice in laboratories. During the seminar, all students must participate in solving the problems previously given and other problems related. The evaluation of this activity is focused on students' participation in the seminars. In some seminars, without communicating it before, the resolution of problems is done individually and the results have to be hand in at the end of the class.

5. Bibliography and teaching resources

5.1. Basic bibliography

• Signal Processing First (SPF)
James H. McClellan, Ronald W. Schafer, and Mark A. Yoder
Prentice Hall, 2nd edition

• Mathematics of the Discrete Fourier Transform
Julius O. Smith, 2003. W3K Publishing.
Available online at: https://ccrma.stanford.edu/~jos/dft/

5.2. Specific resources for each unit

Unit 1. Introduction to Signals and Systems
SPF: Chapter 1 &

http://en.wikipedia.org/wiki/Signal_processing

Unit 2. Complex numbers

https://ccrma.stanford.edu/~jos/dft/Complex_Numbers.html

a. Complex numbers notation
http://en.wikipedia.org/wiki/Complex_numbers

b. Operations with complex numbers
http://en.wikipedia.org/wiki/Complex_numbers - Operations

c. Polynomial factorization
https://ccrma.stanford.edu/~jos/dft/Factoring_Polynomial.html

d. Complex radicals
https://ccrma.stanford.edu/~jos/dft/Quadratic_Formula.html

https://ccrma.stanford.edu/~jos/dft/Complex_Roots.html

https://ccrma.stanford.edu/~jos/dft/Fundamental_Theorem_Algebra.html

e. The complex plane
https://ccrma.stanford.edu/~jos/dft/Complex_Plane.html

f. Euler's formula
https://ccrma.stanford.edu/~jos/dft/Euler_s_Identity.html

Unit 3. Sinusoids and Exponentials
SPF: Chapter 2 &

https://ccrma.stanford.edu/~jos/mdft/Sinusoids_Exponentials.html

a. Sine and cosine functions
SPF: Section 2.2

http://en.wikipedia.org/wiki/Sine - Sine.2C_cosine_and_tangent

b. Sinusoidal signals
SPF: Section 2.3 & 2.4

https://ccrma.stanford.edu/~jos/mdft/Sinusoids.html
https://ccrma.stanford.edu/~jos/mdft/Example_Sinusoids.html
https://ccrma.stanford.edu/~jos/mdft/Why_Sinusoids_Important.html

c. Complex sinusoidal
SPF: Section 2.5

https://ccrma.stanford.edu/~jos/mdft/Complex_Sinusoids.html

d. Phasors and sum of phasors
SPF: Section 2.6

http://en.wikipedia.org/wiki/Phasor

e. Diapason physics
SPF: Section 2.7

http://en.wikipedia.org/wiki/Tuning_fork

Unit 4. Fourier Transform mathematics

https://ccrma.stanford.edu/~jos/dft/DFT_Derived.html

a. Geometric series
https://ccrma.stanford.edu/~jos/dft/Geometric_Series.html

b. Sinusoid orthogonality
https://ccrma.stanford.edu/~jos/dft/Orthogonality_Sinusoids.html

c. Discrete Fourier Transform sinusoids
https://ccrma.stanford.edu/~jos/dft/Nth_Roots_Unity.html
https://ccrma.stanford.edu/~jos/dft/DFT_Sinusoids.html
https://ccrma.stanford.edu/~jos/dft/Orthogonality_DFT_Sinusoids.html

d. Discrete Fourier Transform equation
https://ccrma.stanford.edu/~jos/dft/Discrete_Fourier_Transform_DFT.html

e. Matrix formulation of the Discrete Fourier Transform
https://ccrma.stanford.edu/~jos/dft/Matrix_Formulation_DFT.html

f. Fourier theorems for the Discrete Fourier transform
https://ccrma.stanford.edu/~jos/dft/Fourier_Theorems_DFT.html

Unit 5. Temporal signals spectral representation
SPF: Chapter 3

a. Sum of sinusoids spectrum
SPF: Section 3.1

b. Amplitude modulation
https://ccrma.stanford.edu/~jos/mdft/Sinusoidal_Amplitude_Modulation_AM.html

c. Sinusoids product
SPF: Section 3.2

d. Periodic waves, periodic sounds
SPF: Section 3.3

e. Time-frequency spectrumi
SPF: Section 3.5

f. Modulation of frequency, xirp signalsi
SPF: Section 3.6

Unit 6. Sampling and Aliasing of temporal signals
SPF: Chapter 4

a. Sampling
SPF: Section 4.1

b. Sampling theorem
SPF: Section 4.1.2

c. Aliasing and Folding
SPF: Section 4.1.3 & 4.1.4

d. Spectral vision of the sampling
SPF: Section 4.2

e. Stroboscopic demonstration of the sampling
SPF: Section 4.3

f. Conversion from discrete signals to continuous signals

Unit 7. Impulse Finite Response filters, FIR
SPF: Chapter 5

a. Systems in a discrete time
SPF: Section 5.1

b. Mobile average filter
SPF: Section 5.2

c. General FIR filter
SPF: Section 5.3

d. Impulse response of the FIR filters
SPF: Section 5.3.2

e. Implementation of the FIR filters
SPF: Section 5.4

f. Discrete convolution of signals
http://en.wikipedia.org/wiki/Convolution
https://ccrma.stanford.edu/~jos/dft/Convolution.html

g. Lineal and static in time systems, LTI
SPF: Section 5.5

h. Convolution, LTI systems, and FIR filters
SPF: Section 5.6

i. LTI cascade systems
SPF: Section 5.7

Unit 8. Frequency response of the FIR filters
SPF: Chapter 6

a. Sinusoidal response of the FIR filter
SPF: Section 6.1

b. Superposition and frequency response
SPF: Section 6.2

c. Transitory response and in a static state
SPF: Section 6.3

d. Frequency response properties
SPF: Section 6.4

e. Graphic representation of the frequency response
SPF: Section 6.5

f. LTI cascade systems
SPF: Section 6.6

g. Mobile average filter
SPF: Section 6.7

h. Filtering of sampled temporal signals
SPF: Section 6.8

Unit 9. Z transform
SPF: Chapter 7

a. Definition of the Z transform
SPF: Section 7.1

b. The Z transform and the lineal systems
SPF: Section 7.2

c. Properties of the Z transform
SPF: Section 7.3

d. The Z transform as an operator
SPF: Section 7.4

e. Convolution and Z transform
SPF: Section 7.5

f. Relationship between the Z domain and the frequency domain
SPF: Section 7.6

g. Useful filters
SPF: Section 7.7

h. Practical design of band-pass filters
SPF: Section 7.8

i. Properties of lineal phase filters
SPF: Section 7.9

Unit 10. Infinite Impulse Response filters, IIR
SPF: Chapter 8

a. General difference equation of the IIR filters
SPF: Section 8.1

b. Response in the temporal domain
SPF: Section 8.2

c. System function of a IIR filter
SPF: Section 8.3

d. Poles and zeros
SPF: Section 8.4

e. Frequency response of a IIR filter
SPF: Section 8.5

f. The three domains
SPF: Section 8.6

g. The Z inverse transform and its applications
SPF: Section 8.7

h. Stable state resting and stability
SPF: Section 8.8

i. Second order filters
SPF: Section 8.9

j. Frequency response of the second order filters
SPF: Section 8.10

k. Example of a low-pass IIR filter
SPF: Section 8.11

Unit 11. Spectral analysis
SPF: Chapter 9

a. Fourier continuous transform
http://en.wikipedia.org/wiki/Fourier_transform

b. Revision of the Fourier discrete transform
https://ccrma.stanford.edu/~jos/dft/Discrete_Fourier_Transform_DFT.html

c. Spectral analysis through filtering
SPF: Section 9.2

d. Spectral analysis of periodic signals, DFT
SPF: Section: 9.3

e. Fast Fourier Transform, FFT
SPF: Section 9.8

f. Spectral analysis of sampled periodic signals
SPF: Section 9.4

g. Spectral analysis of sampled non-periodic signals
SPF: Section 9.5

h. Short Time Fourier Transform, STFT
https://ccrma.stanford.edu/~jos/sasp/Short_Time_Fourier_Transform.html

i. The spectrogram
SPF: Section 9.6

5.3. Additional bibliography

- Discrete-Time Signal Processing.
  A. V. Oppenheim and R. W. Schafer. 1999. Prentice Hall.
- Tratamiento digital de señales
  John G. Proakis and Dimitris G. Manolakis. Prentice Hall, Madrid, 1998

- Ejercicios de Tratamiento de la Señal utilizando matlab v.4.
  C. Sidney Burrus et al. Prentice-Hall. 1998.

5.4. Didactic resources

- Resources for SP First: http://users.ece.gatech.edu/mcclella/SPFirst/
- For each seminar session, the students have a group of problems available in the subject's website.
- For each practical session, the students have the instructions for the practical session available in the subject's website.

6. Metodology

Units	Time in the classroom			Time out of the classroom	
	Lectures (Theory)	Laboratory sessions (Lab)	Practical sessions (Seminar)		
Unit 1	1	---	---	1,5	
Unit 2	3	---	2	7,5	
Unit 3	4	2	2	12	
Unit 4	4	2	3	13,5	
Exam 1				10	
Unit 5	2	2	1	7,5	
Unit 6	2	4	1	10,5	
Unit 7	4	2	1	10,5	
Unit 8	2	---	1	4,5	
Unit 9	4	2	2	12	
Unit 10	4	2	3	13,5	
Exam 2				10	
Unit 11	6	4	2	18	
Final Exam				12	

Total	**36**	**18**	**18**	**128**	# total of hours **200**

7. Planning of activities

Week	**Theory**	**Seminar**	**Laboratory**	**Exams**
Firs term				
2	Introduction to Signals and Systems (1) Complex Numbers (1)	Complex Numbers (1)		
3	Complex Numbers (2)	Complex Numbers (1)		
4	Sinusoids and Exponentials (2)	Sinusoids and Exponentials (1)		
5	Sinusoids and Exponentials (2)	Sinusoids and Exponentials (1)	Intro to Octave and Sinusoids (2)	
6	DFT mathematics (2)	DFT mathematics (1)		
7	DFT mathematics (2)	DFT mathematics (1)		
8	Spectral Representation (2)	DFT mathematics (1)	DFT (2)	
9		Spectral Representation (1)	Spectral Representation (2)	**First partial exam**
10	Sampling and Aliasing (2)	Sampling and Aliasing (1)		
11	FIR filters (2)		FIR filters (2)	
Second term				
1	FIR filters (2)	FIR filters (1)	FIR filters (2)	
2	Freq. FIR response (2)	Freq. FIR response (1)		
3	Z transform (2)	Z transform (1)	Z transform (2)	

4	Z transform (2)	Z transform (1)		
5	IIR filters (2)	IIR filters (1)		
6	IIR filters (2)	IIR filters (1)	IIR filters (2)	
7	Spectral analysis (2)	IIR filters (1)		
8		Spectral analysis (1)	Spectral analysis (2)	**Second partial exam**
9	Spectral analysis (2)		Spectral analysis (2)	
10	Spectral analysis (2)	Spectral analysis (1)		
				Final exam