Course Memo ver 1.0
Applied Signal Processing - SSY130 - Q2 - 2019

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1 Introduction

Signal processing has revolutionized not only industrial applications such as radar, process industry and medical electronics, but also our everyday life. Today, advanced computations involving signals are the foundation to provide the functionality offered in mobile phones, multimedia-players, GPS equipment, TV set-top boxes, medical instruments, advanced driver support systems (ADAS), self driving vehicles, and so on.

This course is aimed at providing understanding and examples of modern digital signal processing algorithms which are implemented using computers, embedded computers (also known as digital signal processors, DSPs) or digital circuits hardware (ASIC and FPGA). After completing the course you should have a basic understanding and ability to use and adapt such techniques. Particularly an understanding of fundamental limitations and aspects of tuning and implementation of signal processing algorithms should have been gained. The use of modern computer tools is well integrated in all the teaching. Use of signal processing hardware throughout the course will bring theory and application together.

2 Prerequisites

Working knowledge of linear algebra, probability theory and signals and systems (especially transforms, filtering, convolution, sampling theorem) and general knowledge of computer programming is required. Knowledge of random processes is very useful, but not essential. Hence, the course Random signals analysis is recommended. Experience of MATLAB is required.

3 Aim

Signal processing involves techniques to recover important information from signals and to suppress irrelevant parts of those signals. The aim of this course is to provide the students with knowledge of standard techniques and applications in digital signal processing. These are relevant for the design and implementation of communication systems, control systems and other measurement systems such as biomedical instrumentation systems. The students are also given the opportunity to practically apply some of the techniques to semi-real signal processing problems and will be given insight into current practice in industry.

4 Learning outcomes

After completion of this course, the student should be able to:

- in both time-domain and frequency-domain analyse the effect of sampling, linear filtering and signal reconstruction

- explain the relation between the Fourier transform, discrete Fourier transform and fast Fourier transform and apply the discrete Fourier transform to perform block based linear filtering
- derive the autocorrelation function and spectrum for signals modeled as filtered white noise
- apply linear filter design techniques to construct FIR and IIR filters satisfying given specifications
- apply LMS, RLS and Kalman filters to linear adaptive filtering problems and do simplified analysis regarding stability and rate of convergence
- apply multirate techniques to signal processing problems to increase efficiency
- explain how signal quantization effects the signal and algorithm quality and calculate the effect on the SNR
- discuss the effect of using a linear finite dimensional model as an approximation for an infinite dimensional linear systems.
- implement signal processing algorithms on a DSP-system

5 Content

- Review of signal theory concepts: continuous-time and sampled signal representation in both time and Fourier domain, sampling, linear processing (filtering) and continuous-time signal reconstruction (D/A conversion)
- Review of random processes: mean values, autocorrelation function, spectrum, linear filtering of a white noise process.
- Filter design and realization: FIR and IIR filter structures, design methodologies, implementation details, matched filters
- Discrete Fourier transform: Finite data length, Fast Fourier transform (FFT), use of DFT for linear block-based filtering
- Adaptive filters: Least mean square (LMS), recursive least squares (RLS) and Kalman filtering
- Multi-rate signal processing: Rate conversion, poly-phase representation, filter banks
- Quantization of signals
- Implementation on DSP systems

6 Course staff

- Tomas McKelvey, `mckelvey@chalmers.se`, room 7439, lecturer, examiner
- Arni Alfredsson `arnia@chalmers.se`, room 6414 teaching assistant
- Andreas Buchberger `andreas.buchberger@chalmers.se`, room 6414 teaching assistant
- Jacob Klintberg `jacobkl@chalmers.se`, room 7421 teaching assistant
- Jonathan Lock `lock@chalmers.se`, room 7410, teaching assistant.
- Roman Sokolovskii `romanso@chalmers.se`, room 6331, teaching assistant

7 Learning Platform

The course will use the learning platform Canvas.

8 Course material

- Course literature is:
  - T. McKelvey, SSY130 - Applied Signal Processing Lectures notes, Available for download on Canvas.
  - B. Mulgrew, P. Grant and J. Thompson. *Digital Signal Processing - Concepts and Applications*, 2nd ed. Palgrave McMillan 2003. Available at Store.
  - Hand in problems, project memos and computer studio session material will be posted on Canvas.
- Project hardware:
  - STM32F4DISCOVERY, a development board featuring the ARM based STM32F407 processor and audio interface. Each student participating in the course will be supplied with a STM32F4-board and a set of stereo loudspeakers to be used throughout the course. The board is specifically used for the projects.

9 Organization

The course is organized as follows:

- 15 Lectures (2 hours each)
- 3 Tutorials (2 hours each)
- 3 Hand-in problems
- 2 Projects

In the tutorial sessions the teaching assistants will help students solve paper and pen problems.

10 Groups

Projects are performed in groups of 4 students. The tutorials are split in space and time. You sign up in project groups and tutorial groups on Canvas.

11 Academic integrity

This course uses a combination of assessment techniques which sometimes are referred to as continuous examination. This format puts responsibility on the student to take an active part in the learning process throughout the course. Furthermore, it also involves assessed activities such as writing reports and answer hand-in problems, which are performed without teaching staff supervision. To make sure we get the best possible academic climate in the course, the course staff expects each student to respect the following points:

- Hand-in problems are *individual*. This means that each student should solve the problems, write necessary computer code and report the result *without* direct help from fellow students or anyone else. Discussions about general topics related to the hand-in problems are encouraged between students.

- The projects are group work. This means the group together work towards a solution and report the findings in a joint report which is *individual* for each group (see above for meaning of *individual*).
- When reporting solutions in writing, copying text from books, Internet or from other sources (like your fellow students) without referring to the source is not an accepted behavior and is not allowed.
- Students whom are suspected not to respect the rules of academic integrity will be reported to the President of Chalmers and risk possible disciplinary actions.

12 Projects

The laboratory activities consists of two projects where the first project is organized in two parts each spanning 2 weeks:

- Acoustic Communication System
  - Part A - Baseband equalization. Weeks 2-3.
  - Part B - Interpolation, Modulation, Demodulation and Decimation. Weeks 4-5.
- Noise Cancellation with adaptive filtering. Week 6-7

The projects concern solving specific problems by designing signal processing algorithms followed by implementation in Matlab and in C in for the STM32F4-board and testing the algorithms using acoustic signals. The project work is performed in groups of four students. Sign up for a group no later than later 13:00 on Thursday study week one. You decide whom to work with. Questions are welcome during the project consultation hours. Finished projects are to be reported both by a written report and assessed during an oral examination. Further instructions are given in the written project-material.

13 Hand-in problems

A total of three hand-in problems (HIP) will be given. Each problem should be solved individually. The problems are available on Canvas where further instructions on deadlines and how to submit your solutions can be found.

Handed in solutions should adhere to the following points:

- Solutions should be clearly written. All steps toward the solution should be motivated and easy to follow.
- The length of the solutions should be adequate. Please be concise.
- All supplied graphs should be numbered and explicitly be referred to in the solution text. The graphs should also have a title, axis have labels, and each curve be identified with a legend.

14 Consultation

Questions and comments from students to the course staff are most welcome during lectures and tutorials and the consultation times.

- Consultation times can be found on Canvas.

- Questions regarding hand in problems or tutorial material are answered by the course TAs during tutorial sessions. For questions outside these times please use the posted consultation times.
- Other questions and comments can be directed to Tomas McKelvey.

15 Examination

Requirements and assessment. In order to pass the course the three following requirements are compulsory:

- Pass the two oral project examinations
- A minimum score of 3 points for each of the three project reports.
- Total course score of 40 or more

The course ends with a written examination. Note that it is not required to take the written examination if you fulfill the three requirements above. The examination dates can be found at `student.portal.chalmers.se` (search for course SSY130). At the written exam, the following materials are allowed:

- L. Råde and B. Westergren, Mathematics Handbook (any edition, including the old editions called Beta) or similar.
- Any calculator.
- One A4 size single sheet of paper with *handwritten* notes on both sides.

The exam must be answered in English. For the examination of the project, see the project memos.

The final grade of the course is based on the performance on the

- 3 Hand-in problems, 0-4 points each, maximum 12 points
- 3 Projects

Part	**Points**
Report Project 1A	8
Report Project 1B	8
Oral Examination P1	6
Report Project 2	8
Oral Examination P2	6
Max number of points	**36**

- Final exam, score 0-52 points

The final grade is determined according to $g = f(e + h + p)$ where e is the final exam score, h is the total score for hand-in problems and p the total score for the projects and

$$f(x) = \begin{cases} \text{fail} & x < 40 \\ 3 & 40 \le x < 60 \\ 4 & 60 \le x < 80 \\ 5 & x \ge 80. \end{cases}$$

16 Plan

For exact time, group and location please consult the official TimeEdit web page. (Lx = lecture, Tx = tutorial)

Week	Day	Type	Group	What
1 - 45	Tue	L1	All	Introduction, SoS continuous time, Fourier transform
	Wed	L2	All	SoS discrete time, Fourier transform and sampling
	Fri	L3	All	Ideal and ZOH reconstruction
2 - 46	Mon		All	Project 1A starts
	Tue	L4	All	Frequency analysis, Periodogram, DFT, Filtering using DFT, Equalization
	Tue	T1	1,2,3	Tutorial 1
	Wed	T1	4,5,6	Tutorial 1
	Fri	L5	All	Window effects, FFT, block based filtering
3 - 47	Tue	L6	All	Filter specs, Linear phase filter, FIR window design method, FIRLS and FIRPM
	We	L7	All	IIR filter design
	Fri	L8	All	DSP-kit introduction, Code development
	Fri		All	Deadline Project 1A
4 - 48	Mon		All	Project 1B starts
	Mon		All	Deadline HIP1
	Tue	L9	All	Multirate SP, Oversampling techniques
	We	L10	All	Statistical SP, Wiener filtering
	Fri	L11	All	Finite causal Wiener filter, RLS
5 - 49	Tue	L12	All	LMS filtering
	Tue	T2	1,2,3	Tutorial 2
	Wed	T2	4,5,6	Tutorial 2
	Tue		All	Deadline Project 1B
	Wed		All	Oral exam Project 1
	Thu		All	Oral exam Project 1
	Fri		All	Oral exam Project 1
	Fri	L13	All	Analysis of LMS and RLS
6 - 50	Mon		All	Project 2 starts
	Mon		All	Deadline HIP2
	Tue	L14	All	Kalman filtering
	Tue	T3	1,2,3	Tutorial 3
	Wed	T3	4,5,6	Tutorial 3
	Fri	L15	All	Quantization errors, Signal matched filtering and detection
7-51	Tue	All		Deadline Project 2
	Wed		All	Oral exam Project 2
	Thu		All	Oral exam Project 2
	Fri		All	Oral exam Project 2
	Fri		All	Deadline HIP3
EW - 3	Wed		All	Written examination

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	Study Week	1					2					3					4					5					6					7					15-Jan-20	06-Apr-20	25-Aug-19
	Week number	45					46					47					48					49					50					51					3	15	35
What	Day	Mo	Tu	We	Th	Fr	Mo	Tu	We	Th	Fr	Mo	Tu	We	Th	Fr	Mo	Tu	We	Th	Fr	Mo	Tu	We	Th	Fr	Mo	Tu	We	Th	Fr	Mo	Tu	We	Th	Fr	We	Mo	Tu
L1	Introduction, SoS continuous time, Fourier transform		L1																																				
L2	SoS discretete time, Fourier transform and sampling			L2																																			
L3	Ideal and ZOH reconstruction					L3																																	
P1	Acoustic communication						P1																																
L4	Frequency analysis, Periodogram, DFT, Filtering using DFT, Equalization							L4																															
T1	SoS, Fourier transforms							T1																															
L5	Window effects, FFT, block based filtering										L5																												
HIP1	Sampling and reconstruction											HIP1																											
L6	Filter specs, Linear phase filter, FIR window design method, FIRLS and FIRPM												L6																										
L7	IIR filter design															L7																							
L8	DSP-kit introduction, Code development															L8																							
L9	Multirate SP, Oversampling techniques																	L9																					
L10	Statistical SP, Wiener filtering																		L10																				
HIP2	FIR filter design																					HIP2																	
L11	Finite causal Wiener filter, RLS																				L11																		
T2	FIR and IIR filter design																						T2																
L12	LMS filtering																						L12																
OEP1	Oral examination project 1																							OEP1															
P2	Adaptive noise cancellation																										P2												
L13	Analysis of LMS and RLS																									L13													
L14	Kalman filtering																											L14											
T3	Statistical SP, Wiener filter example																											T3	T3										
L15	Quantization errors, Signal matched filtering and detection																														L15								
HIP3	Kalman filtering																															HIP3							
OEP2	Oral examination project 2																																	OEP2					
Exam 1																																					Exam 1		
Exam 2																																						Exam 2	
Exam 3																																							Exam 3

Lectures	(green)
Projects	(blue)
Tutorials	(grey)
Hand-In-Prob.	(orange)
Exams	(red)
Deadlines	(purple)