IMPERIAL COLLEGE LONDON
DEPARTMENT of ELECTRICAL & ELECTRONIC ENGINEERING

Advanced Communications and Signal Processing Laboratory

Experiments Booklet

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INTRODUCTION to the LABORATORY in ADVANCED COMMUNICATIONS and SIGNAL PROCESSING

Dr. Cong Ling

Welcome to the Advanced Communications & Signal Processing Laboratory. This Laboratory will accommodate the experimental and project needs of two groups of students in the Electrical & Electronic Engineering Department, here at Imperial College. The first group is the students on the MSc in Communications & Signal Processing while the second is a number of senior undergraduates with intellectual and practical needs & interests which can be accommodated by this Laboratory. All the experiments, which are listed (see page 5) and briefly described in this booklet, are offered only to MSc students. Below are some guidelines which are directly addressed to the MSc students in Communications & Signal Processing.

Guidelines for MSc students

1. Introduction

All MSc students in Signal Processing and Communications will be expected to carry out in the laboratory **five experiments** in the Autumn term. Table 3 shows the time schedule of the experiments, with each experiment designed to take about 30 hours experimental and study time, conducted over a period of two weeks. Note that usually there will be three experiments running in parallel at any given time, but you cannot do two experiments simultaneously. For each experiment, a **demonstrator** (usually a PhD student) will be in the lab for three hours every Tuesday, from 9am to 12am, on both weeks of the experiment, and he/she will be on standby (often in his/her office) for a further 6 hours each week. The details of the timing are normally shown in the timetable, but could also be worked out individually for each experiment, between the students and the demonstrator, during their first meeting on the first week of the experiment. In particular, it may happen that the second three hour meeting is agreed to take place at a different time in the following week.

Specific points on any experiment may need to be answered by the **academic in charge** of the experiment. The laboratory is open all day and students are permitted and encouraged to work in the evenings and during the weekends. The College and departmental safety regulations should be observed at all times.

The address of the lab website is

http://www.ee.ic.ac.uk/msc_csp/ACSPLab.html

where you can find the detailed notes of all experiments.

2. How To Choose Your Experiments

In this booklet you will find a list, and brief descriptions, of the experiments offered to the MSc students. The times of each experiment are indicated and some experiments are repeated (i.e., you have two possible times for doing them). Using the online experiment choice submission form (https://intranet.ee.ic.ac.uk/scripts2/tsg/accsplab_expform.php), you are asked to select five experiments and one extra choice. This will be used if there is an experiment is oversubscribed or does not run through lack of interest. Pleas ensure that you have submitted your choices by 13:00 Friday afternoon, Week 1. The timetable will be published on the lab's website no later than Friday afternoon, Week 1. If you have any queries regarding your choices, please contact the lab technician, Paul Norman (p.norman@ic.ac.uk). Regardless of the allocation, you will have to be in the lab at 9am on Monday, Week 2, to start your first experiment (one of the three that are available on the first week). If a particular experiment is oversubscribed or if there are other administrative reasons, the lab technician, Paul Norman, has the right to change the allocation of experiments. Experimental work will start in Week 2.

Note that your choices are limited: you cannot do two experiments simultaneously and each two-week period has only three experiments being done at that time. Of course, you cannot do the same experiment twice.

Experiment AM is compulsory (because it is associated with a compulsory lecture module), but you don't have to write a formal report on it.

3. Logbook (for all five experiments)

You will be expected to *keep a logbook*, not scrappy pieces of paper. The entry for each experiment should start with the experiment title and the demonstrator's name. Basically, the log-book should be an adequate time-record (diary) of your work, so that several weeks later both you and the demonstrator can understand your experimental work, and be able to check the results that you obtained. Brief notes on the relevant theory may also be included in your logbook, while each experiment should be concluded with an informal assessment and a discussion of your results. Logbooks should be shown for examination to the associated de-monstrator of the experiment *within one week* of the completion of the experiment. Do not prepare beautifully printed and/or edited materi-al for your logbook, as this would demonstrate a misunderstanding of the concept of a logbook and would not be accepted as evidence that you have actually done the experiment. The logbook is a hand-written record of the experiment, quickly written down while performing the experiment, as if writing only for yourself, to have the data available later.

4. Formal reports (for two experiments)

You should write up two formal reports for two out of the five experiments (any two are fine, not necessarily AM). Your logbook should be the main source of the results which should be presented in your formal reports. A formal report should be written up as if it were a paper for a scientific journal. Look at some published technical journal papers if you are not sure what this means. It should adequately in-troduce the topic area, but not include too much history and duplicated book work. Reference to relevant theory and background should be given. You should include a discussion of your results and end with a summary and conclusions. The total document should be less than 20 A4 size pages (line spacing:1.5; fonts: 10 or 12 points).
Excessive length will be penalized.

The two formal reports should be submitted in the PDF format via Blackboard

http://learn.imperial.ac.uk

Log in then you should be able to see EE9-SLAB Communications and Signal Processing Laboratory. Then after clicking "Assessment", "Submit Assignments", "Formal Report 1(2)", enter the title of the experiment for your report, and attach the PDF file. You can take back and resubmit your report before the deadlines indicated in Table 4.

5. An important note

All formal reports should be submitted to Blackboard, **NOT to the academic in charge of the experiment nor to the demon-strator,** before the appropriate deadline. Reports submitted up to 24 hours after the deadline will be capped at the pass mark, while **beyond 24 hours the mark will be zero.** Table 4 shows the time schedule for the formal reports.

6. Laboratory pass criteria.

i) A 'Pass' mark must be obtained in each of the individual experiments. This is a "logbook exa-mination" with a Pass/Fail marking scheme. The person in charge of the "logbook examination" is the demonstrator for the respective experiment. He/she will judge based on your logbook as well as his contacts with you during the experiment. Basically, "Pass" means that you have done the experiment.

ii) A mark not less than 50% must be obtained for each formal report.

TABLE 1		
Academic weeks - Autumn term		
Week-A1	5 Oct.	9 Oct.
Week-A2	12 Oct.	16 Oct.
Week-A3	19 Oct.	23 Oct.
Week-A4	26 Oct.	30 Oct.
Week-A5	2 Nov.	6 Nov.
Week-A6	9 Nov.	13 Nov.
Week-A7	16 Nov.	20 Nov.
Week-A8	23 Nov.	27 Nov.
Week-A9	30 Nov.	4 Dec.
Week-A10	7 Dec.	11 Dec.
Week-A11	14 Dec.	18 Dec.

TABLE 2		
Academic weeks - Spring term		
Week-S1	11 Jan.	15 Jan.
Week-S2		
Week-S3		
Week-S4		
Week-S5		
Week-S6		
Week-S7		
Week-S8		
Week-S9		
Week-S10		
Week-S11		

TABLE 3	
Time schedule for experiments	
1st experiment	
Duration	Week A2 to Week A3
Logbook examination	Week A4*
2nd experiment	
Duration	Week A4 to Week A5
Logbook examination	Week A6*
3rd experiment	
Duration	Week A6 to Week A7
Logbook examination	Week A8*
4th experiment	
Duration	Week A8 to Week A9
Logbook examination	Week A10*
5th experiment	
Duration	Week A10 to Week A11
Logbook examination	Week S1*

TABLE 4	
Time schedule for formal reports	
1st formal report:	
Submission	5.30pm, Friday, Week A8
2nd formal report:	
Submission	5.30pm, Friday, Week S1

* appointments for logbook inspection: to be arranged in due course.

Academics associated with the laboratory:

MB: Dr M. Brookes

BC: Dr B. Clerckx

WD: Dr W. Dai

PLD: Dr P.L. Dragotti

CL: Dr C. Ling (laboratory organiser)

DM: Dr D. Mandic

AM: Dr A. Manikas

PN: Dr P. Naylor

TS: Dr T. Stathaki

Laboratory technician:

Mr Paul Norman, room 303,
tel. 759-46233, p.norman@imperial.ac.uk

Laboratory demonstrators:

TBD (for DM1, DM2)

Michalis Lazarou (for TS)

Herman Verinaz Jadan (for PLD)

Vincent Neo Weisheng (for PN)

Su Yan (for CL, MB)

Yang Zhao (for BC, WD)

Zhuqing Tang (for AM)

The list of demonstrators might change during the term.

List of experiments:

MB: Digital filter design, weeks A8-A9, repeated in A10-A11.

PLD: Discrete cosine transform vs wavelet transform, weeks A6-A7, repeated in A10-A11.

WD: Recover sparse signals from under-sampled observations,
weeks A2-A3, repeated in A4-A5.

BC: Simultaneous transmission of information and power,
weeks A6-A7.

CL: Multi-input multi-output communication,
weeks A2-A3, repeated in A4-A5.

DM1: Adaptive signal processing and adaptive systems,
NOT running.

DM2: Spectral estimation techniques,
NOT running.

AM: Array communications & processing,
weeks A2-A3, repeated in A8-A9.

PN: Speech processing, weeks A4-A5, repeated in weeks A6-A7.

TS: Image processing, weeks A8-A9, repeated in weeks A10-A11.

Note:

* Some experiments may be offered to research (PhD) students. Applications for laboratory registration should be made via their supervisor.

EXPERIMENT MB

Digital filter design

Academic in charge: Dr. Mike Brookes (room 807a, ext. 46165)

Equipment:
MATLAB.

Aims & Outline:
The aim of this experiment is to make the student familiar with the advantages and disadvantages of different ways of designing and implementing discrete time filters. A test signal is provided that wanted tonal components added to unwanted tonal components and broadband noise. The filters designed as part of the experiment are evaluated by assessing the extent to which they attenuate the noise without modifying the wanted signal components.

Initially students determine the best possible performance by calculating the effects of ideal lowpass and bandpass filters on the test signal. They then asses the performance of a Butterworth lowpass filter using provided MATALB code that designs the filter and applies it to the test signal.

In the next part of the experiment evaluate the performance of elliptic infinite impulse response filters of different orders and also investigate alternative ways of implementing them with different stability properties.

Students then use two alternative methods to design a finite impulse response filter and evaluate both a direct implementation of the filter and a more computationally efficient implementation using polyphase multirate techniques.

In a final, optional, section students are encouraged to design a bandpass filter to maximize the signal-to-noise ratio of the filtered signal and also to investigate the impact of sample frequency on the performance of the filters.

References:

[1] Brookes M. Digital signal processing and digital filters. Course notes, Imperial College, 2016. URL http://www.ee.ic.ac.uk/hp/staff/dmb/courses/DSPDF/dspdf.htm..

[2] Mitra S.K. Digital Signal Processing. McGraw-Hill, 4 edition, 2011.

EXPERIMENT PLD

Discrete cosine transform vs wavelet transform

Academic in charge: Dr. Pier Luigi Dragotti (room 814, ext. 46192)

Equipment:
MATLAB simulation package

Aims & outline:
The main aim of this experiment is to make the students familiar with some typical image processing applications and also to give him/her an idea of why wavelets are better than other commonly used bases such as the Discrete Cosine Transform.

All the numerical experiments will be performed on the grayscale image 'Cameraman'. To run the experiments, students can use either the Matlab wavelet toolbox or the free software 'Wavelab802', or can write any piece of software themselves.

In the first section, students will write a MATLAB programme to compute the Discrete Cosine Transform and to display the reconstrued image. Students will also write a programme to compute the Wavelet Transform and Inverse Wavelet Transform.

Then, students will compare the non-linear approximation properties of the Discrete Cosine Transform and Wavelet Transform. A basis with better approximation properties is more suited for compression.

The third section is to compare their performance in the denoising application. Denoising usually refers to the removal of noise from a corrupted signal. One way to remove the noise is by computing the wavelet or cosine transform and shrinking the wavelet or cosine coefficients which are below a certain threshold. That is, all the coefficients whose amplitude is below a threshold T are set to zero.

References:

[1] Dragotti P.L., "Experimental Handout on Discrete Cosine Transform vs Wavelet Transform", September 2007.

EXPERIMENT WD

Recover sparse signals from under-sampled observations

Academic in charge: Dr. Wei Dai
(room 811, ext. 46333)

Equipment:
MATLAB simulation package

Aims & outline:
Sparse signal processing has become a major component in modern signal processing theory, underpinning compressed sensing, linear regression, machine learning, big data processing, etc. It is based on the observation that most signals, under certain transform or dictionary, only contain a few significant components. Based on this sparsity, efficient ways for data acquisition, processing, and analysis can be developed.

The main aim of this experiment is to familar students with the concept of sparse signals and the easy-to-understand techniques for sparse signal recovery.

In the first section, we highlight the limitations of least squares methods when applied to sparse signal processing, and suggest the paradigm shift from least squares approach to modern sparse recovery techniques.

In the second section, three greedy algorithms are introduced to solve sparse recovery problem. Matlab implementations and numerical comparison of these three algorithms are required.

References:

[1] Pati Y., Rezaiifar R., and Krishnaprasad P., "Orthogonal Matching Pursuit: recursive function approximation with application to wavelet decomposition", in Asilomar Conf. on Signals, Systems and Comput., 1993.

[2] Dai W. and Milenkovic O., "Subspace Pursuit for Compressive Sensing Signal Reconstruction", IEEE Trans. Inf. Theory, 2009, 55, 2230-2249.

[3] Blumensath T. and Davies M., "Iterative hard thresholding for compressed sensing", Appl. Comput. Harmon. Anal., 2009, 27, 265 - 274.

EXPERIMENT CL

Multi-input multi-output communication

Academic in charge: Dr. Cong Ling
(room 815, ext. 46214)

Equipment:
MATLAB simulation package

Aims & outline:

Multi-input multi-output (MIMO) communication is a key enabling technology for broadband wireless. It makes use of multiple antennas to send the data in parallel.

The main aim of this experiment is to give the students the concept of MIMO communication. Moreover, it will give them the ideas of channel capacity, fading channel, QAM modulation, MIMO detection, and computer simulation of MIMO communication. All the experiments will be performed using MATLAB.

In the first section, students will write a MATLAB programme to compute the capacity of MIMO fading channels. Students should be careful about the definition of signal to noise ratio (SNR), which is commonly used in communications.

The second section is to simulate the performance of some typical MIMO detectors. These include the maximum-likelihood (ML) detector, zero-forcing, and minimum mean-square-error (MMSE). Students are asked to compare the performance and draw some conclusions.

Another task is to simulate the famous Alamouti code, which is a 2x2 space-time code.

References:

[1] Ling C., "Experimental Handout on Multi-Input Multi-Output Communication", 2016.

[2] Biglieri, E., *MIMO Wireless Communications*, Cambridge University Press, 2007.

[3] Paulraj A., Nabar R. and Gore D., *Introduction to Space-Time Wireless Communications*, Cambridge Univ. Press, May 2003.

EXPERIMENT DM1

Adaptive signal processing & adaptive systems

Academic in charge: Dr. Danilo Mandic (room 813, ext. 46271)

Equipment:
Any computing Facility.
MATLAB and SIMULINK.

Aims & Outline:
Adaptive digital signal processing is the study of algorithms and techniques which have the capacity to vary in sympathy with changing statistical properties, characteristic of many real signals. Such techniques have been successfully applied in many application areas, for example, channel equalisation in communications, beam-forming for seismic prospecting, ECG monitoring in medicine, analysis of multiphase flow and the control of dynamic systems.
The purpose of this experiment is to study algorithms for adaptive signal processing with particular emphasis given on the Least Mean Square (LMS) and Recursive Least Square (RLS) adaptive algorithms. The performance of the above algorithms will be investigated when they are used for echo cancellation, system identification and channel equalisation.
For instance, in "hands-free" mobile telecommunications, the mobile unit which contains the loudspeaker and microphone is placed, for convenience, at some distance from the local speaker. Therefore, when the remote (far-end) speaker is talking, there is acoustic coupling between the loudspeaker and microphone of the mobile unit, which leads to the far-end speaker hearing a disturbing echo of his own voice. Elimination of this echo can be achieved with an adaptive filter, which models the time-varying acoustic coupling.

References:

[1] Chambers J., "Experimental Handout on Adaptive Signal Processing", October 1994.
[2] Haykin, S., "Adaptive Filter Theory", Second Edition, Prentice-Hall, 1992,
Much improved on first edition, good sections on numerical issues in adaptive filtering and emerging adaptive techniques.
[3] Widrow, B., and Stearns S.D., "Adaptive Signal Processing", Prentice-Hall, 1985.
Widrow was in the vanguard of adaptive filtering, introductory but strong on applications.
[4] Bellanger, M., "Adaptive Digital Filters and Signal Analysis", Marcel Dekker, 1987.
A first-class book, he has really worked with adaptive filters.

EXPERIMENT DM2

Spectral estimation techniques

Academic in charge: Dr. Danilo Mandic (room 813, ext. 46271)

Equipment:
This experiment requires access to a UNIX workstation or a PC running MATLAB

Aims & outline
Aims: To compare the properties of conventional Fourier transform-based techniques with modern model-based methods for power spectral density estimation.
Background: Estimation of the Power Spectral Density (PSD) of a finite length, temporal or spatial, random signal, is a basic preprocessing operation in many applications, for example target analysis in passive sonar, speech recognition, seismic prospecting, measurement of multiphase flow and performance monitoring. Classical spectrum estimation is based upon the use of the Fast Fourier Transform (FFT) and makes no model assumption for the measurement signal. Some windowed portion of the measurement is applied directly to the FFT, the output of which is used to estimate the PSD. Modern spectrum estimation, however, is based upon the assumption that the measurement signal is generated by a prescribed model which is characterised by a number of parameters. Modern spectrum estimation, therefore, involves algorithms to estimate from the measurement the number and values of these model parameters. The estimated parameters are then inserted directly into an analytical expression to estimate the PSD.
The properties of classical and modern spectrum estimation techniques govern their suitability for a particular application. Therefore, these will be investigated in this assignment. Further background information pertaining to this assignment can be found in sections 4.3, 4.4, 7.3 and 7.4 of [2].

References

[1] Chambers J., "Experimental Handout on Spectral Estimation Techniques", October 1994.
[2] Kay S.M., *Modern Spectral Estimation: Theory and Applications,* Prentice-Hall, 1988. Comprehensive coverage of the area.
[3] Marple S.L., *Digital Spectral Analysis with Applications,* Prentice-Hall, 1987.
This is a companion for Kay's book [1], strong on applications.
[4] Burrus C.S., et. al., *Computer-Based Exercises for Signal Processing Using MATLAB*, Prentice-Hall, 1994.
Further exercises on spectral estimation can be found in Chapter 6.
[5] Bendat, J.S., Piersol A.G., *Random Data: Analysis and Measurement Procedures,* Second Edition, John Wiley, 1986.
Useful, practically-orientated discussion of real signal analysis.

EXPERIMENT: BC

Simultaneous transmission of information and power

Academic in charge: Dr. Bruno Clerckx (room 816, ext. 46234)

Equipment:
MATLAB

Aims and outline:

The problem of communication is usually cast as one of transmitting a message generated at one point to another point. Therefore, electricity in the wires became merely a carrier of messages, not a source of power. Although quite reasonable, many engineering systems actually deal with both energy and information.

Are there scenarios where one would want to transmit energy and information simultaneously over a single line? If there is a power-limited receiver that can harvest received energy, then one should want both things. Modern communication systems that operate under severe energy constraints may also benefit from harvesting received energy. A powerful base station, may effectively be used to recharge mobile devices.

This experiment deals with the tradeoff between transferring energy and transmitting information over a single noisy line, with two goals:
1) large transferred energy per unit time, and
2) large transmitted information per unit time.

References :

[1] D. Tse and P. Viswanath, Fundamentals of Wireless Communication. Cambridge University Press, 2005.
[2] S. Boyd and L. Vandenberghe, Convex optimization. Cambridge Univ Press, 2004.
[3] P. Grover and A. Sahai, “Shannon meets Tesla: Wireless information and power transfer,” in IEEE Int. Sym. Inf. Theory, Jun. 2010, pp. 2363–2367.

EXPERIMENT: AM

Array communications and processing

Academic in charge: Prof. Athanassios Manikas (room 801, ext. 46266)

Equipment:
In-house array processing toolbox for . MATLAB. See Dr Manikas' web-site and click "software" to download the material associated with this experiment.

Aims & outline:
A new 'hot' application of *arrays* is in the area of digital communications where *space-time* and not just *time* information associated with the communication signals can be utilized to provide more sophisticated and powerful communication systems. Thus, by integrating array theory with digital communication theory, new communication system architectures are being proposed which have a considerable impact, for instance, on the capacity and performance of a mobile communication network. These improvements can be achieved in a number of different ways, for example, by suppressing co-channel interferences, combating fading effects, locating/tracing the mobile users, estimating other signal environment parameters, etc.

This experiment aims to provide a theoretical framework for handling various problems in a number of different applications. Emphasis will be given to the so called "superresolution" approaches.

References:

[1] Manikas A., "Experimental Handout on Array Communications and Processing", October 1998.
[2] Manikas A., "*Notes* on Array Systems for Interference Cancellation & Parameter Estimation", October 1994.

EXPERIMENT PN

Speech processing

Academic in charge: Dr. Patrick Naylor (room 803, ext. 46235)

Aims & outline:
The aim of this experiment is to implement a speech coder based on Linear Predictive Coding (LPC) and to investigate LPC analysis through a series of tests on some speech data. The work will be done using MATLAB and an extended instruction-sheet with the objectives and tasks of the experiment will be provided by the Lab Manager.

Students will get familar with the Winner-Hopf equations which are a classical technique to solve for the optimum linear-prediction cofficients for a second-order stationary stochastic process. Linear prediction will then be applied to speech signals. A number of excercises will be carried out to see the effects of the model order, the window, the preemphasise filter etc.

References:

[1] Naylor P., "Experimental Handout on *Linear Predictive Coding*", October 1994.

EXPERIMENT: TS

Image processing

Academic in charge: Dr. Tania Stathaki (room 812, ext. 46229)

Equipment :
Image Processing Toolbox for MATLAB.

Aims and outline:
Digital Image Processing is a rapidly evolving field with growing applications in science and engineering. Examples are: remote sensing via satellites, image transmission and storage for business applications, medical image processing, radar, sonar, robotics etc.

The purpose of this experiment is to examine and implement several fundamental image processing algorithms, ranging from elementary operations to more complicated image processing techniques such as image restoration and compression. The experiment tackles the following Image Processing topics.

The experiment is divided into four parts.
Part I: ***Image transforms***
Several image transforms (Fourier Transform, Discrete Cosine Transform, Hadamard Transform) are studied, implemented and compared.
Part II: ***Image enhancement***
This topic is addressing spatial methods (histogram manipulations, linear and nonlinear filters) for the purpose of visual improvement, edge detection and denoising.
Part III: ***Image restoration***
In this topic we attempt to reconstruct or recover an image that has been degraded, by using some a priori knowledge of the degradation phenomenon. The basic deterministic and stochastic techniques are attempted.
Part IV: ***Image compression***
This topic involves aspects of lossless and lossy compression in relation also with the study of image transforms.

References:

[1] MATLAB, Image Processing Toolbox.
[2] Gonzalez R.C. and Woods R.C., Digital Image Processing, Third Edition, Prentice Hall.