Digital Signal Processing — Lab 1
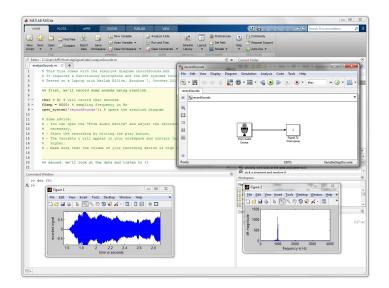# Fundamental Signal Processing

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Name: _____

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Date: _____

Passed: _____

1 Introduction

The purpose of the first lab in the Digital Signal Processing course is to let you do some practical work with the theory and algorithms covered in the lecture and lessons. In groups of two, you will work on the following assignments.

Whistle: How purely can you whistle?

Vowel: How can the sound of a vowel be modeled?

Speech encoding as in GSM: How much non-vital information does regular speech contain?

Each assignment is covered in greater detail below. To solve the assignments, MATLAB (or an equivalent software) is required.

2 Layout of the Lab

The lab can be divided into four stages:

1. **Recording of sound files.** You will do the recordings with your own hardware, for example with the microphone in your laptop or a smartphone. MATLAB and SIMULINK files for recording can be downloaded from the lab web page. See Section 3 for more information.

2. **Calculations in Matlab.** You will analyze your recordings with the methods that you learn in the computer lessons. The required theory is covered in Chapters 2–6 of the course book and Lectures 1–7. The specific tasks are detailed in Sections 4 to 6.

3. **Documentation of your results in a technical report.** The report should be self-contained. That is, someone who has never seen these lab instructions should be able to understand the problems that you are solving and how you are solving them. All the choices you have made should be clearly motivated. Comment and explain all your plots and your MATLAB-code, so as to make it easy to follow your way of thinking. The reports should be written in groups of two students and will be peer reviewed. Sloppy reports that do not fulfill the required standards will not be processed by the teaching staff. See Section 7 for more information and check the course web page for due dates.

4. **Peer review.** In peer review, your task is 1) to read and correct a report by another group and to provide constructive feedback, and 2) to use feedback from another group on your report to improve it. Note that the process is double-blind, i.e., the identities of the authors and the reviewers are unknown. Therefore, it is important that you do not write your names on the report or review. See Section 8 and the course web page for more information about the peer reviewing process.

3 Recording the Data

There are two options for recording sounds for this lab. Either you can use a computer with microphone and SIMULINK (Alternative 1) or you can record a sound file with, for example, your smartphone (Alternative 2) and then read it into MATLAB. The required MATLAB and SIMULINK files for both methods can be downloaded from the lab section of the course web page.

For each of the sounds that you will record (whistle, vowels, sentence), make sure to collect enough data. For example, record about 10 seconds of whistling and then pick out the best 2 seconds for your analysis. All the data should be recorded at 8000Hz sampling frequency.

3.1 Alternative 1: Recording using Simulink

Download and unpack the files from the web page. In MATLAB, open the file `alternativeOne_recordInSimulink.m`. Read the instructions and evaluate the code section by section.

3.2 Alternative 2: Recording with your smartphone

Instead of using SIMULINK, you can also record a `wav`-file with your smartphone. For Android, there are several simple apps that allow you to specify a sampling frequency and record. You can find the link to a suggested app on the web page.

The file `alternativeTwo_readWavFile.m` from the web page shows how to read a sound file into MATLAB.

4 Assignment: Whistle

4.1 Goal

The assignment is to try to whistle as pure a sine as humanly possible and then investigate how pure the whistle actually was.

4.2 Implement and Present

Record a whistle at 8000Hz and extract the best two seconds. Evaluate how pure it is by the two different "purity measures" explained below.

One way to measure the purity of a periodic signal is to use harmonic distortion. It is defined as

$$1 - \frac{E_{\text{dom. freq.}}}{E_{\text{tot.}}}, \tag{1}$$

where $E_{\text{dom. freq.}}$ denotes the energy contents in the dominating frequency and $E_{\text{tot.}}$ denotes the total energy contents in the signal.

A different purity measure is to estimate a second order AR model and use the pole's distance to the unit circle as a measure of distortion.

Address the following questions/tasks:

1. Calculate the energy of the entire whistle in the time domain. Also compute the energy of the dominant frequency component in the time domain.

2. Do the same calculations in the frequency domain.

3. Calculate the harmonic distortion using the energies from both time and frequency domains. The two measures of harmonic distortion should not differ too much. How pure is the whistle?

4. Estimate the purity measure based on an AR(2) model and motivate why this model is suitable. How can this measure be compared to the harmonic distortion?

5. Compute the spectrum of the whistle and estimate the dominating frequency using both a non-parametric and a parametric method.

Note:

- Do not blow straight into the microphone. Hold the microphone from the side, so the sound is recorded from the side. This will reduce the incidence of disturbing blowing sounds.

- The energy calculations should be done in both time and frequency domain. In the time domain the signal is filtered using a band-pass filter. In the frequency domain a couple of samples are chosen near the peak.

- Do not forget to scale the figure axes correctly! The frequency of the whistle should be easily read (in Hz or rad/s). You can check your frequency axis by locating the Nyquist frequency.

5 Assignment: Vowel

5.1 Goal

The assignment is to try to model the sound of a vowel using an AR model of an appropriate order and then simulate the model using a suitable input signal and listen to the result.

5.2 Implement and Present

Record two vowels for two seconds each using the sampling frequency 8000 Hz, for example an *a* and an *o*. Remove transients in the beginning and the end of the recording, if necessary. Consider the following questions/tasks:

1. Model the vowels using AR models of appropriate order. How can the model orders be estimated?

2. Validate the models. Are the estimated models any good? To answer this question you should use at least two of the validation methods outlined in the course book. For example, compare model predictions with real data, compare the spectrum of the model with a non-parametric spectrum estimate and/or by estimating the covariance functions of the residuals. Validate more than one model order and then motivate your choice of model order.

3. Simulate the AR models and listen to the result. Do the simulations sound like the recordings? Since the sound of a vowel is a periodic signal, it's appropriate to use a pulse train as input signal when simulating. Use the signal period as pulse interval.

Note:

- When a system is identified using a parametric method, like AR, it is important to distinguish between estimation data and validation data.

- Can the FFT of a vowel be used to get a rough model order estimate? Include a plot of the FFT.

6 Assignment: Speech encoding as in GSM

6.1 Goal

The assignment is to implement a simple version of the speech encoding used in GSM and to investigate the result.

6.2 Implement and Present

Record a sentence about $2\,\text{s}$ long using the the sampling frequency $8000\,\text{Hz}$ (if you have really bad imagination try "The clever fox surprised the rabbit"). The simplified GSM encoding looks like this: Divide the signal into segments of 160 samples each. Estimate an AR(8) to model the sound of each segment. Use a pulse train as input signal. The pulse period, D, and the amplitude of each pulse, A, is estimated by taking the maximum of the covariance function of the residuals. The covariance function, $R_e(t)$, can be calculated as:

```
>> e=filter(m1.a,1,y); % m1 <-> AR model of the segment
>> r=covf(e,100);
```

The time lag D and the amplitude A can be found by using the maximum of $R_e(t)$, $t > 19$. Create a pulse train that is 160 samples long with amplitude $\sqrt{A}$ and period D and call the vector `ehat`. The sound of each segment can be simulated using:

```
>> yhat=filter(1,m1.a,ehat);
```

Consider the following questions/tasks:

1. Implement the GSM encoding as described above. Ensure that unstable poles are detected and dealt with so that no unstable filters are simulated. (Your code should handle unstable poles, no matter if your signal generates any or not.) Do not forget to detrend the signal by removing the mean of each segment before identification (using `detrend`). What does the reconstructed speech sound like?

2. Set the pulse amplitude to 1 in *all* segments. What is the result?

3. Vary the model order and listen to see if it sounds better or worse.

4. In GSM, AR models are used to compress the speech. What data must be sent to ensure that the receiver can simulate the sound of each segment? What is the corresponding level of compression when compared to the raw signal?

Note:

- One way to handle any unstable filters is to mirror the unstable poles in the unit circle while leaving the stable poles unchanged. This preserves the filter spectrum.

7 How to write a report

The lab is examined through a written report. Check the course web page to find out when the report is due. Here are some instructions concerning the report:

- The purpose of each assignment should be included in the report so that it can be read independently, i.e., the report should be a self-contained document.

- It should be easy to follow your way of reasoning. Every figure should be clearly referenced from the text and all interpretations and conclusions should be included in the text. Enumerate all figures to simplify referencing.

- All figures should have graded axes and a title. Multiple curves in a single figure should be easily distinguishable and interpretable by the caption. In MATLAB, the command `legend` includes a frame in the plot to simplify curve differentiation.

- The figure texts should be self explanatory.

- Always ensure your figures are readable in printed form. If not, try altering line thickness, type of line or text size. Dotted lines should never be used, since they are very hard to see in printed form.

- The purpose of including figures, appendices and code is *not* to use them to summarize the practice/solution. Summary and conclusions should be in the text and figures etc. are used for verification and clarity.

- In a report, it is important to explain what the result of the assignment means.

- Include your MATLAB code in the report.

- See the course web page for further instructions.

8 Peer Review

In peer review, your task is to provide feedback that will help other students to improve their reports, and to use feedback to improve your own report. A few days after handing in your lab report you will receive another group's lab report from the course assistant. Read this lab report and write a review report. Check the course web page to find out when the review report is due. In the review report you should respond to and discuss the following questions

1. Are the data sets presented clearly? Are the procedures to acquire data described in enough detail for the experiment to be repeated by someone else?

2. Is there a clear explanation of the solutions of the tasks in Section 4–6? Discuss each task separately.

3. Are the conclusions well supported by the data, the experiment and the results? Do you agree with the conclusions? What would you like to add to the conclusions, based on the data and the results of the task?

4. What is a particular strength in this lab report? Discuss the content, not the format.

5. What suggestions can you make for improving the overall quality of the writing in this report? Discuss clarity, readability and technical accuracy.

The questions shall be answered in the form of a discussion, present arguments for your point of view and propose alternative methods. Some more specific tips:

- Present useful criticism and make sure your comments are constructive.

- Use a positive tone and consider how you would feel if someone sent your review to you.

- Be clear and specific about things you think could be improved.

- Point out strengths as well as weaknesses.

- Use a courteous language.

- Avoid comments that might be read as insulting or inappropriately personal.

Most people ignore feedback that they find hostile, vague, or confusing. Try to keep your comments positive and specific: this will make your review report much more useful to your peers.

The length of the review report shall be 1-2 pages, see the course web page for further instructions.

9 Examination

Both the lab and the review reports will be read by the assistant and given one of the following grades: pass, revision needed, or fail. If a revision is needed, a new version of the report/review report must be handed in within one week of its return to the student. If the revised version is not passed or the report is failed at first hand in, a new version will be read and graded in conjunction with the next course exam.

All important dates will be listed on the web page.