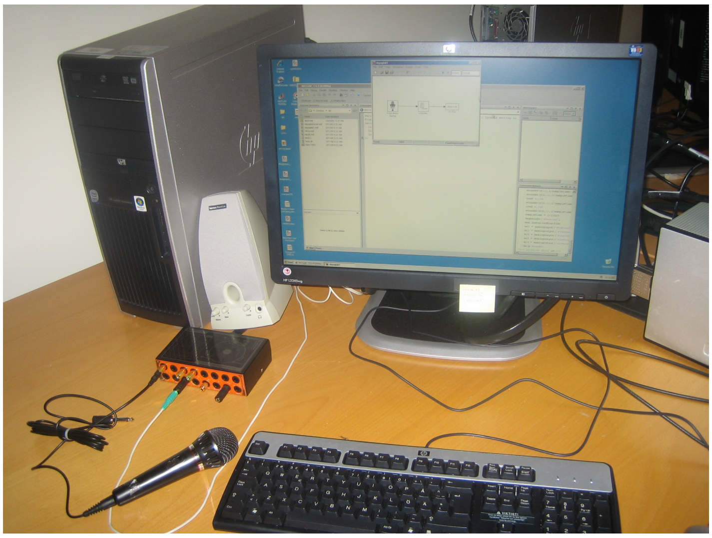
Digital Signal Processing — Lab 1

Fundamental Signal Processing

This version: October 2010



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1 Introduction

The purpose of the first lab assignment in the Digital Signal Processing course is to let you do some practical work with the theories and algorithms covered in the course. The lab is divided into three assignments.

Whistle: How purely can you whistle?

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

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 — is required.

2 Layout of Lab

The practical can be divided into four phases:

1. **Collect data in Laboteket.** Performed during scheduled lab session and should not take more than an hour.

2. **Calculations using Matlab.** Will be performed during the course. The theory related to the assignments is covered in chapters 2–6 and lectures 1–7. The data collection is done early in the course, making it hard to actually solve any of the assignments during the scheduled lab session. However, as the course progress you will gradually learn all you need.

3. **Document the results in a technical report.** The report should be written so that the lab compendium (i.e. the one you are reading right now) should not be needed in order to understand the assignments and your solutions. All the choices you have made should be clearly motivated. Comment and explain all your plots and your MATLAB-code making it easy to follow your way of thinking. The reports are written in groups of two students. Note that sloppy reports will not even be processed by the teaching staff. More important information and tips about how to write the lab report is covered in Section 7. Each group is given an ID by the lab assistant when collecting the measurements in the lab. This ID should be written on the lab report, do NOT write your names or personnummer on the lab report. The report shall be sent as a pdf file to the course assistant and Urkund (the e-mail addresses are stated on the course homepage). Name your pdf-file according to you given ID, for example if you are given 54 as ID, you name the pdf-file `report54.pdf`. This will simplify the administration a lot.

4. **Peer review.** In peer review, your task is to provide feedback that will help other students. Some 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. Note that the process is double-blind, i.e., the identities of the authors and the reviewers are unknown. Check the course homepage to find out when the review report is due. See Section 8 for more information about the peer reviewing process.

3 Data Collection

If your computer has an external sound card (a small black and orange box), some additional settings might be required, see Appendix A.

First you need to copy some files to a local folder. In Windows, select Start – Run, write `\\site\edu\rt\lab` and press enter. Copy the folder named *speechcoding* into your student account.

The folder contains a SimuLink-file, `digsiglab1.mdl`, used for data collection. Open this file in Matlab, either by doubleclicking the icon, or if Matlabis already running, ensure that the current directory is the one containing the SimuLink-file and write `digsiglab1`.

The sample rate is set by assigning an appropriate value to the variable `sampletime` in the command window. The variable `rectime` determines the length of the recording in seconds. Assign these variables to appropriate values.

```
>> sampletime = 1/8000;
>> rectime = 2;
```

The sounds you record are saved in a `.mat`-file. The name of the file can be changed by doubleclicking the block `To file` and changing the name. The signal and a time vector is saved as a matrix `y` containing two rows. Start the simulation and speak into the microphone. To study the recording, write:

```
>> load a_sound          % Load data (a_sound <-> name of file)
>> plot(y(1,:),y(2,:))  % Signal amplitude vs. time
>> soundsc(y(2,:),8000) % Listen to the sound
```

Don't forget to save the data files in your own accounts on `h:\` before leaving the lab session. Anything saved on `c:\` will be deleted when you log out.

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

As previously, choose a sampling frequency of 8000 Hz and record a 2 s whistle. Load the data into Matlab and eliminate the transients in the beginning and the end of the signal, if necessary. One way to measure the purity of a periodic signal is to use harmonic distorsion. It is defined

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

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 distorsion. Consider 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 distorsion using the energies from both time and frequency domains. The two measures of harmonic distorsion 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 distorsion?
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 grade the figure axes correctly! The frequency of the whistle should be easily read (in Hz or rad/s).

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 2 s 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 s long using the the sampling frequency 8000 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 not examined at site, but through a written report. Check the course homepage 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 practise/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.
- Each group is given an ID by the lab assistant when collecting the measurements in the lab. This ID should be written on the lab report, do NOT write your names or personnummer on the lab report. The report shall be sent as a pdf file to the course assistant and Urkund (the e-mail addresses are stated on the course homepage). Name your pdf-file according to you given ID, for example if you are given 54 as ID, you name the pdf-file `report54.pdf`. Your report will not be processed until this naming convention is enforced.

8 Peer Review

In peer review, your task is to provide feedback that will help other students to improve their reports. 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 homepage 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, and you shall quote your group ID as well as the group ID of the lab report you reviewed. Do NOT write any names on the report. The report shall be send as a pdf-file to the course assistant (the e-mail address is stated on the course homepage). The naming convention for the review report is as follows. If ID1 is the ID for the group who's report is being reviewed and ID2 is the ID for the group who is conducting the review, name the review report `reviewID1byID2.pdf`.

Hence, if for example your group's ID is ID2 = 54, and the ID of the group who's report you have reviewed is ID1 = 65, then the review report should be named `review65by54.pdf`. Your report will not be processed until this naming convention is enforced.

9 Examination

Both the lab and the review reports will be read by the assistant and given one of the following grades; pass, complement needed, or fail. If complement 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 complemented 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.

A External sound card settings

Only for computers that has an external sound card (orange box).

Plug your microphone into input 1 and your speakers into output 3.

If you are experiencing problems when recording or listening, some sound card settings should be checked. If available, click the I-symbol in the bottom right corner, see Figure 1. If the icon is not available, enter `c:\programs\INCA88_v3_601` and click the icon named `IncaPan` and the I will appear. Start by ensuring that 'HeadPhone and Monitor' in the top right is activated (green). Then change the settings according to Table 1.

Figure 1: Start symbol for sound card settings application

Channel	Input select	Mic preamp	Volym	Mix
IN 1,2	MIC	+20 db ON, Phantom OFF	+4.5	OFF
IN 3,4	MIC	+20 db ON, Phantom OFF	+12	OFF
IN 5,6	—	—	—	—
IN 7,8	—	—	—	—
WAVE 1,2	—	—	—	—
WAVE 3,4	—	—	(max)	ON
WAVE 5,6	—	—	(max)	OFF
WAVE 7,8	—	—	(max)	OFF
MASTER	—	—	(max)	ON

Table 1: The rows only containing lines in all columns are channels not being used why their settings are irrelevant.

When these settings are made it should look something like Figure 2.

The sampling frequency and the delay of the sound card is set to 44100 Hz and 128 samples, respectively, according to Figure 3 and Figure 4.

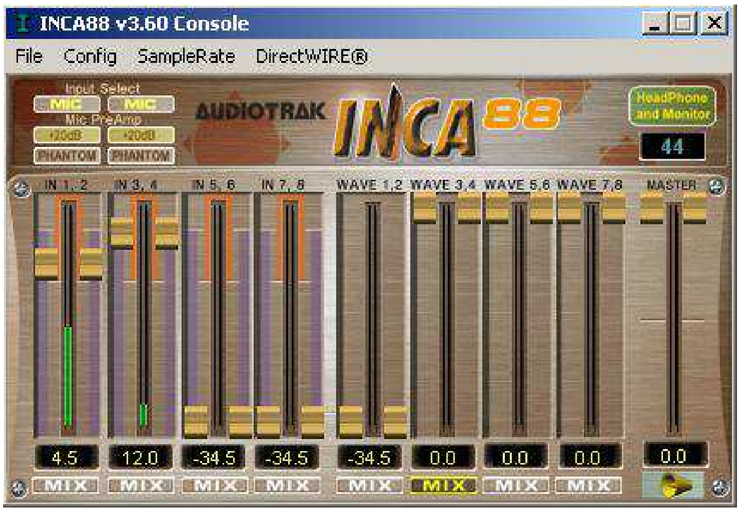

Figure 2: This is what it should look like after all settings in Table 1 are checked.

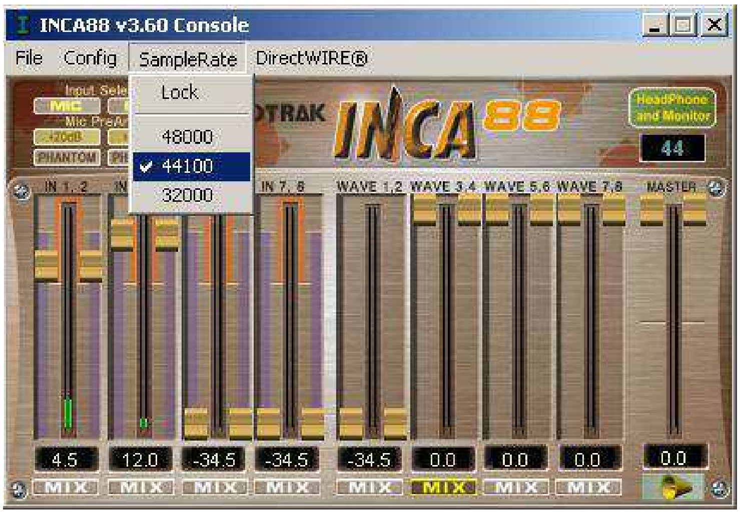

Figure 3: Sample frequency setting.

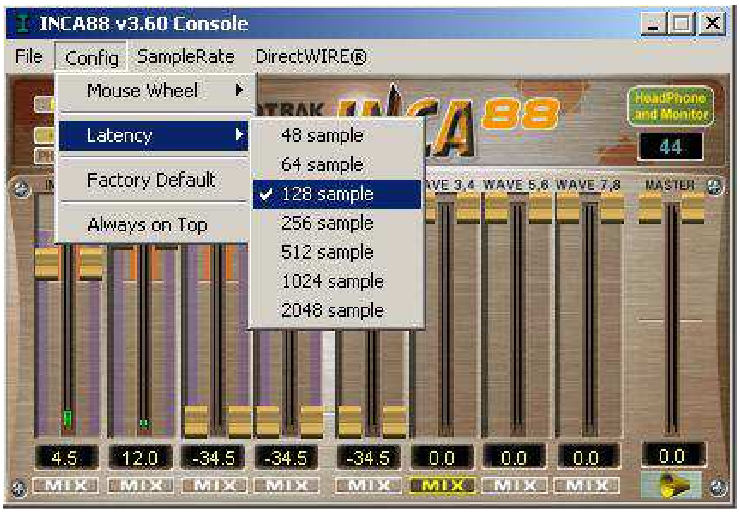

Figure 4: Delay setting.