Department of Electrical and Electronic Engineering

Dedan Kimathi University of Technology

Digital Signal Processing Laboratory Manual

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Contents

1 Introduction

This laboratory manual is designed to accompany the Digital Signal Processing (DSP) course at Dedan Kimathi University of Technology. It describes laboratory exercises aimed at integrating the Raspberry Pi into the curriculum. The development of these laboratory exercises was made possible by a generous grant from The Kenya Education Network (KENET).

The Raspberry Pi which retails at approximately $30 was developed with the aim of improving computing education by providing access to an affordable computer with most of the capabilities of a modern computer. It is about the size of a credit card (see Figure 1) and as we will see in the labs described here, it can perform a number of important DSP tasks.

Figure 1: The Raspberry Pi. A Kenyan bank card is shown for comparison.

1.1 Safety Information

A number of safety precautions must be observed when handling and operating the Raspberry Pi. You will have received a copy before starting the labs.

2 System Setup

The computing environment used in this lab is the raspbian Debian Wheezy operating system. This operating system is quite similar to Ubuntu. The labs will be based on Octave, which is very similar to MATLAB, and will make use of other open source tools such as SoX, the Swiss Army knife of sound processing programs. The exercises have been tested on Octave version 3.6.2.

2.1 Software Installation

To run the labs, Octave and SoX must be installed.

- To install Octave, ensure you are connected to the internet and type `sudo apt-get install octave`
- We will also require the signals package which can be installed by typing `sudo apt-get install octave-signal`

- To install SoX type `sudo apt-get install sox`

These software has already been installed on the devices that will be issued to you. To verify that the pieces of software are installed you should type `octave --version` and `sox --version` on the command line.

3 Laboratory 3: Estimation of Fundamental Frequency

3.1 Objectives

The objectives of this laboratory are:

1. To introduce the idea of fundamental frequency.
2. To introduce the idea of using parameters extracted from speech signals for various applications

3.2 Equipment

For this lab you will need the following (If an item is not provided the student is expected to come with their own to the lab):

1. Raspberry Pi Model B+
2. USB Microphone
3. Mini USB cable (not provided)
4. Ear phones or speakers (not provided)

3.3 Background

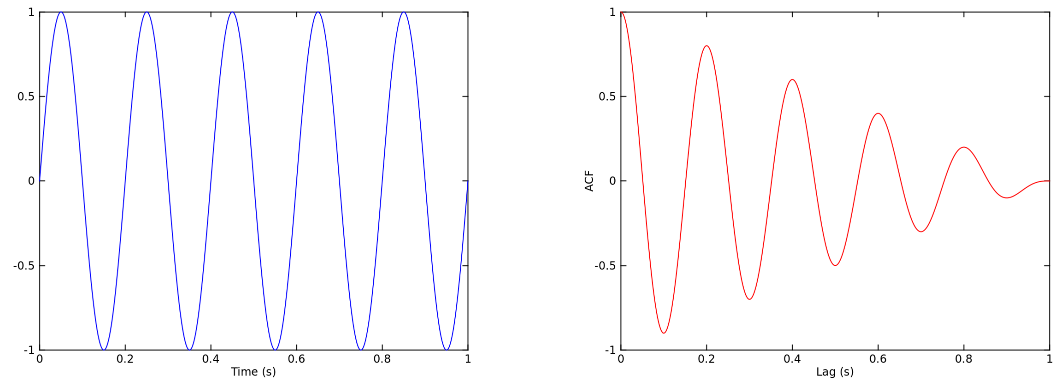
When speech is voiced, it is seen to exhibit periodicity and it is often important in speech applications to estimate the pitch of these signals. To achieve this, we estimate the *fundamental frequency* of this signal also refered to as $F0$. A popular method for estimation of $F0$ is based on the autocorrelation function (ACF).

Consider a periodic signal $\cos(2\pi f_0 t)$ which oscillates at a frequency f_0. To work with this signal on a computer we sample it at a frequency $f_s = \frac{1}{T_s}$ to form a discrete time signal $x[n] = \cos(2\pi f_0 n T_s)$. We can compute the ACF of the signal $x[n]$ using

$$R_x[k] = \frac{1}{N} \sum_{n=0}^{N-k-1} x[n]x[n+k] \quad 0 \leq k \leq N-1 \tag{1}$$

where k is the time lag and N is the length of the signal in samples. This function measures the similarity between samples at particular times and those obtained at particular time lags. If the signal is periodic we expect this function to have peaks at lags equivalent to integer multiples of the signal period in addition to a peak at zero lag.

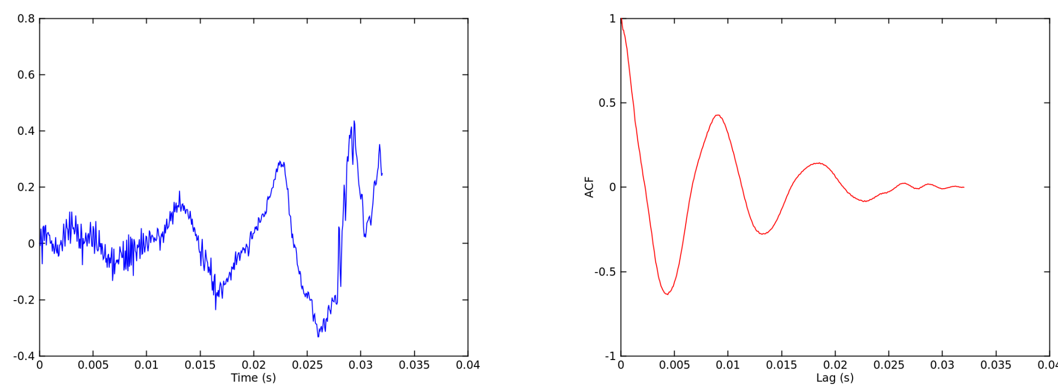
If we form a finite duration signal from $x[n]$ by considering the signal over a finite interval and we compute the ACF, we notice that it has peaks at lags corresponding to integer multiples of the period as shown in Figures 2(a) and 2(b) .



(a) (b)

Figure 2: A periodic sine wave (a) and the corresponding autocorrelation function (b).

To apply this method to a speech signal, we compute the ACF of a finite duration signal corresponding to a short speech segment (32ms in this case). Over this short segment the characteristics of the signal can be assumed to be stationary. Figures 3(a) and 3(b) show the speech signal and ACF of a speech signal obtained from the author vocalising the word 'moja' which means 'one' in Kiswahili. From the plot of the ACF we see that the first non zero peak is obtained at aproximately $0.01s$ which corresponds to an estimate of $F0 = 100$Hz.



(a) (b)

Figure 3: Speech waveform of a voiced speech segment (a) and the corresponding autocorrelation function (b).

3.4 Procedure

3.4.1 Frequency Estimation

1. Generate a sinusoidal signal over the interval $0 \le t \le 1$ oscillating at a frequency of 5 Hz.

```
t=0:0.001:1;
x=sin(2*pi*5*t);
```

2. Plot this function

   ```
   figure(1)
   clf()
   plot(t,x,"linewidth", 2)
   xlabel('Time (s)', "fontsize", 18)
   ```

3. Compute the autocorrelation function and plot it

   ```
   rx=autocor(x);
   figure(2)
   clf()
   plot(t,rx,'r',"linewidth", 2)
   xlabel('Lag (s)', "fontsize", 18)
   ylabel('ACF', "fontsize", 18)
   ```

4. Determine the location of the first peak of the ACF after the peak at $t = 0$. The estimated value of the frequency of oscillation is the reciprocal of this value. What is your estimate? Is it accurate?

3.4.2 $F0$ Estimation

We will now estimate the fundamental frequency of a speech segment using the autocorrelation method.

1. From the audio recorded in Lab 2 and the spectrogram computed, determine a time point t in the speech signal with distinct peaks in the magnitude spectrum.

2. Obtain a segment 32ms long from this region with speech and plot this time domain signal with time in seconds as the x-axis. Comment on the nature of the signal. Does it exhibit any periodicity? If not obtain another segment from this speech region.

3. Compute the autocorrelation function of the segment and plot the ACF with time in seconds as the x-axis.

4. Now like we did when estimating the frequency of the sinusoid, determine the location of the first peak of the ACF after the peak at $t = 0$. The estimated value of $F0$ is the reciprocal of this value.

5. Compare your value of $F0$ with colleagues. Do you notice any differences with colleagues of the opposite gender?

A Laboratory Report Format

For each of the laboratory exercises in this manual, you will be required to had in a report. Each report should have the following sections:

1. Title page:

   The title page should include

   - Course code and title
   - Title of the lab
   - Name and registration number of the student
   - Date

2. Introduction:

   In the introduction you should indicate the objectives of the laboratory and give any necessary background information such as relevant theory.

3. Procedure:

   Here you should describe in detail the steps carried out in the lab. The details should allow someone else to reproduce your work. You can include short code segments here but code listings should be placed in the appendix.

4. Results and Discussion:

   Here you should describe all the results obtained and compare them with what was theoretically expected. Data should be presented appropriately using tables and figure which are clearly labelled

5. Conclusion:

   Summarize the laboratory report and indicate whether the objectives of the lab were achieved.

6. References:

   Include any references using the IEEE format `http://www.ieee.org/documents/ieeecitationref.pdf`.

7. Appendix:

   Include any additional information such as detailed schematics and code listings here.