This document has been created as a part of the Erasmus+ -project “Developing Digital Physics Laboratory Work for Distance Learning” (DigiPhysLab). More info: www.jyu.fi/digiphyslab

Digital Signal Processing

Student version

31.1.2023

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Digital Signal Processing Instructor version

Overview of the experiment

- Topic: Mechanics, vibrations, discrete Fourier transforms, digital signal processing
- Target group: Physics and physics teacher training students. Suitable for students familiar with complex numbers and with some experience of laboratory work. Programming skills are not necessary.
- Timeframe: 4 hours for the basic task with more detailed reporting left as homework.
- Recommended to work in individually, or in pairs so that both students can follow and work through the examples in the notebook on their own screen.

The discrete Fourier transform and the FFT algorithm lay a basis for a multitude of applications. In this experimental task the students explore on a basic and intuitive level what the Fourier transform does and how it can be applied to collected data to find the frequency or frequencies present in a periodic signal.

Required equipment

- Smartphone accelerometer
- Computer with internet access to edit and run the python notebook

This experiment requires little preparation beforehand besides having the listed equipment available. Students will benefit of downloading the free smartphone app phyphox before the session if the lab is done in presence.

Quick guide to the measuring app

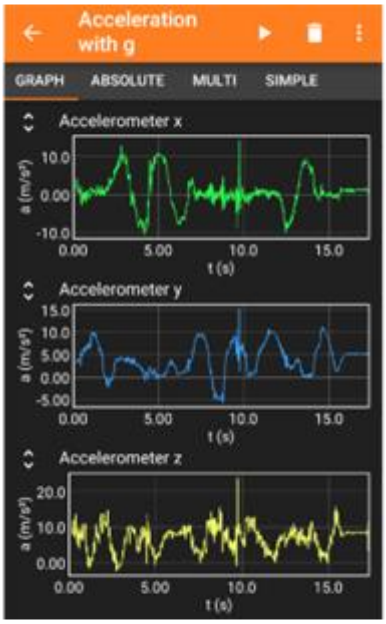

Figure 1: Example view of a measurement of acceleration in the app phyphox.

For this experiment one needs to measure acceleration to determine the frequency of a vibration or other periodical signal. In Figure 1 we show the accelerometer tool in the app phyphox. As a default, students are not given step-by-step instruction for using the app, but they should rather look for information and experiment on the app itself to find out how to make the measurement they need.

The essential thing is to attribute each axis in the accelerometer to a direction on the smartphone, and to keep this in mind when making measurements.

Note that there are two accelerometer tools in phyphox: Acceleration with g and Acceleration without g (linear accelerometer). These typically have an important difference between them: the linear accelerometer has a lower sampling frequency than Acceleration with g (for example 200 Hz vs 400 Hz). If the higher sampling frequency is needed then Acceleration with g should be used.

To export data from phyphox, one clicks the three dots in the upper right corner of the app and selects export data to open different possibilities for exporting.

Example narrative with comments and suggestions

In its basic form the experiment is quite open and there is a lot of decision-making left for the student. In the following we will outline possible directions that the experiment can take and some common problems that students faced in our pilot runs.

The notebook examples

In Figure 2 we show an example of one weirdest looking sine function that a student was able to make. It looks wild until one notices the very small multiplier on the y-axis.

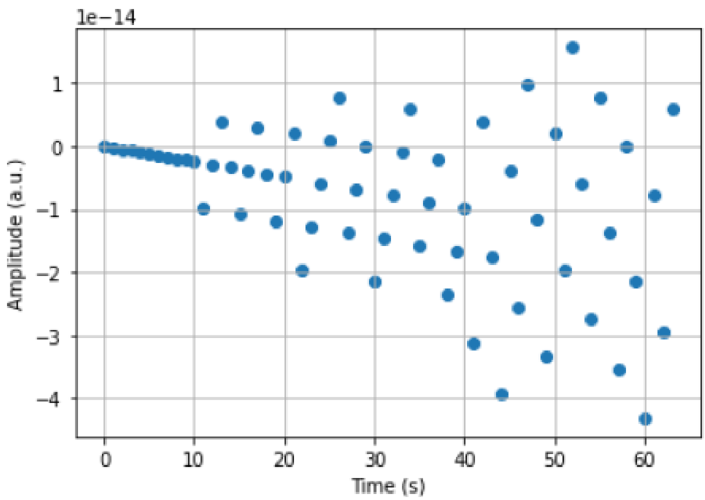

Figure 2: A strange sine function created by conveniently chosen sampling.

Adding a couple of sine functions with different frequencies (here 1 Hz, 8 Hz, and 24 Hz), the Fourier spectrum looks something like Figure 3.

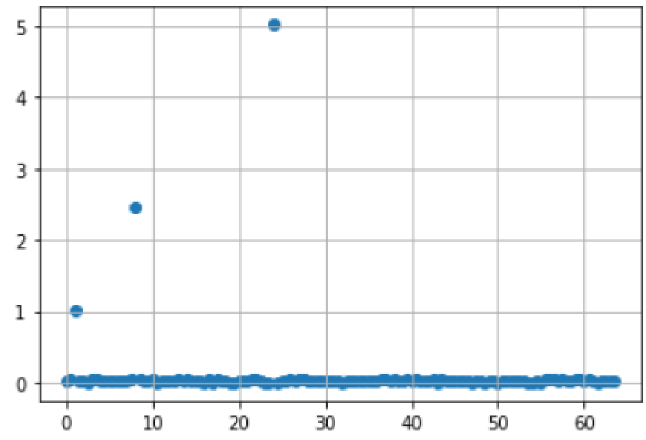

Figure 3: Fourier transform of a signal consisting of sine components with frequencies of roughly 1, 8, and 24 Hz.

Here aliasing does not happen, but if the student chooses to add a high frequency, they will end up with a peak at some frequency that is not actually present in their signal. For example adding an 80 Hz component to the signal with a sampling frequency of 128 Hz looks like Figure 4, and the 80 Hz component shows up at roughly 48 Hz.

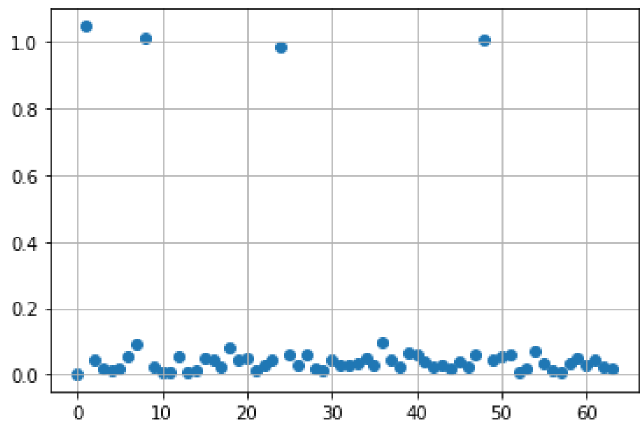

Figure 4: Amplitude spectrum of a similar signal as in Figure 3 but with an added 80 Hz component, which shows up at 48 Hz due to aliasing.

Planning the experiment

Here the students need to consider a few things:

- Which component of acceleration should they use?
  - Finding out how the accelerometer data is logged requires some testing. In phyphox, one gets the x-, y-, and z-components of the acceleration, and these are based on a fixed coordinate system on the phone. Students need to think about the orientation of the phone when making the measurements, and also in which of these components the periodic signal to be examined is the most visible.
- How long to run the measurement for? How much data does one need? Is there a possibility for a repeated measurement?
- Choose a signal that they are interested in finding out about. There are examples in the task document, but students are encouraged to come up with their own target.

- How to estimate measuring uncertainty?

A quick note about the measurement of heart rate via the method provided in the task instructions: it is possible, but the interpretation of the Fourier transform data might not be as clear as in the other cases. The resulting spectrum might look something like Figure 5. Here the signal consists of a lot of components with small amplitudes. The lowest peak is at the actual heart rate and the other peaks are multiples of it.

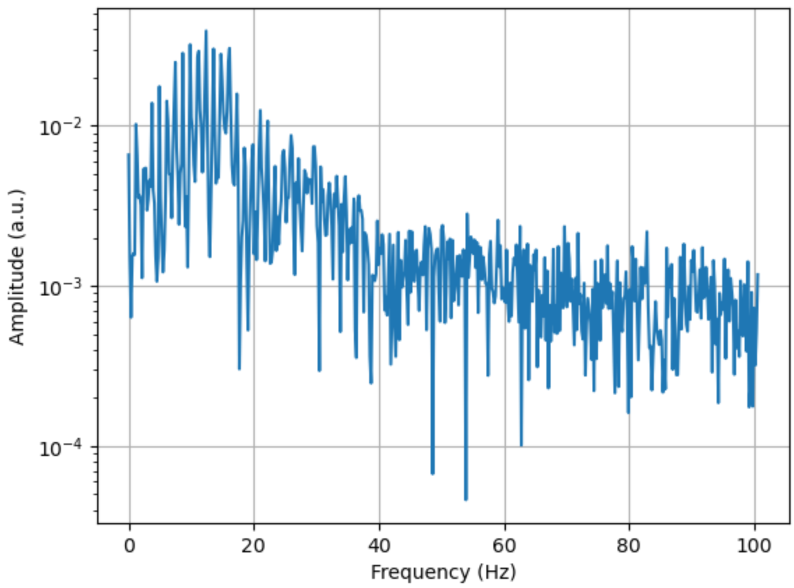

Figure 5: Amplitude spectrum of a heartbeat signal measured by holding a phone to one's chest.

Testing the equipment

Finding out how the accelerometer works requires some testing. It is advisable to do some tests to familiarize with the digital tool and to make sure one knows which axis points to which direction on the phone.

Data collection

A student in a pilot decided to measure vibrations in a desktop computer. The computer was mounted on a rack under a table, and they were able to use the rack as a kind of a pendulum to see also a low-frequency component of the swinging computer system. They set the phone on the rack with the computer so that the vibrations were most visible in the x-component of the accelerometer data.

Data representation and analysis

The data and frequency spectrum are shown in Figure 6 (axis labels missing: on the left is the x-component of acceleration as a function of time, on the right is the frequency spectrum in Hz).

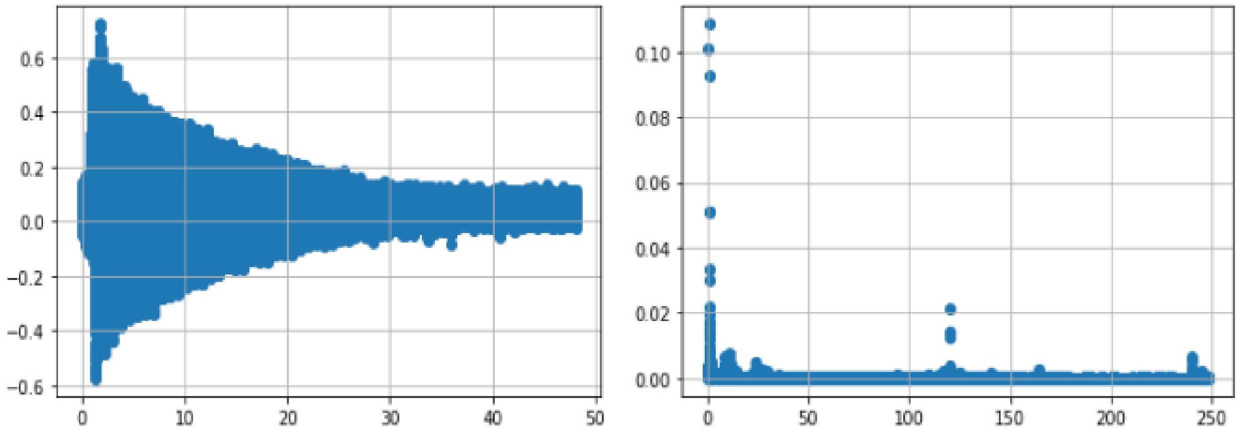

Figure 6: Left panel: The acceleration measured by a phone placed on a computer on a swinging computer rack. Right panel: The resulting amplitude spectrum.

They identified peaks around 1 Hz, 10 Hz, 25 Hz, and 120 Hz. The lowest frequency was attributed to the swinging of the computer rack. There was a hypothesis that the main vibration comes from the cooling fan of the computer, but this can explain basically only the peaks around 10 Hz and 25 Hz. Information search showed that 120 Hz is a typical frequency of a HDD hard disk, and the computer used in the experiment turned out to have one. Therefore, the clear peak at 120 Hz was attributed to the hard disk of the computer.

A more rigorous analysis could be done by fitting a gaussian to the peaks to also get an estimate of the peak width and the uncertainty. Instructors can decide whether they want to focus on the method or if they want to go deeper into the analysis.

Reporting

We have used a concise computational essay as an example of a report that students can create from this experiment. It is important that instructors provide students with their own criteria for what is expected of students in this assessment.

Possible modifications

- If time for reporting is limited, you can opt for having a discussion about the main points of the assessment at the end of the experimentation.
- If there is more time available for the task, one can include more examples and aspects of digital signal processing, for example windowing.