Final Assignment:
Data Analysis from Physical Phone Experiments

Programming and Linear Algebra
Dept. of Chemical Engineering and Chemistry

Objective

In this assignment, you will collect real-world data using the sensors in your phone through the **Phyphox – Physical Phone Experiments** app, and use Python to analyze it. You will explore how to extract physical quantities from raw sensor signals and fit models to experimental data.

Organizational remarks

You will work in pairs. The assignment consists of three provided tasks, followed by two self-designed tasks:

- Tasks 1–3: Provided experiments and analysis.
- Tasks 4–5: Designed by you and your partner, following the same style and level of complexity.

Your final submission is a single, well-structured `.ipynb` notebook, including:

- Code cells (with `%reset -f` between tasks to keep contexts separate),
- Markdown cells with:
  - Clear explanations of your approach and results,
  - Plots and short discussions (again, discussions of reading materials in Markdown cells),
  - Brief conclusions for each task,
- The notebook also contains a short statement on how (if at all) you used AI tools to generate code or guide your analysis.

Note that this assignment leaves a lot of freedom for interpretation. Discuss your choices with the teaching assistants to find out if a task or solution is feasible.

Upon submission, check the points mentioned above. Please also include your `.csv` data files from Phyphox. Submission is through Canvas (again: include both `.ipynb` and data files).

The Phyphox App

We want to make sure that you take regular breaks during your programming sessions, as part of building healthy working habits. So, we are sending you outside! This is a great opportunity to get to know our beautiful campus and, at the same time, to record some data that we can work with.

Phyphox (Physical Phone Experiments) is a free app that allows you to record data from your phone's internal sensors (accelerometer, gyroscope, magnetometer, barometer, microphone, etc.). Download it from:

- Google Play Store

- Apple App Store
- phyphox.org

You can either record a single sensor or design an experiment and record a variety of sensors simultaneously. Also, check out the mechanism for timing an experiment or delaying the start. After recording, you can export your data as `.csv` or Excel format via the share button or by email/upload to your computer. Make sure to note which sensors you used and the meaning of each column in the exported file.[1]

Note: We are not responsible for any damage to your phone caused by scientific curiosity, gravity, or bad luck. Perform all experiments safely and at your own risk!

Tasks

Task 1: Step Frequency from Walking Data

Objective

Record your walking motion using the phone's accelerometer. From the acceleration signal, determine your step frequency (pace).

Experimental Setup

Place the phone securely in your pocket or hold it steadily while walking naturally for about 20–30 seconds on flat ground. Use the Accelerometer experiment in Phyphox and export the data (`time, ax , ay, az`). Start by importing and inspecting the data (e.g. by plotting) and selecting an appropriate interval for analysis. Do a preliminary estimation for pace. Decide whether you need a particular acceleration direction or use the total acceleration magnitude:

$$a_{\text{mag}}(t) = \sqrt{a_x(t)^2 + a_y(t)^2 + a_z(t)^2}.$$

Analysis tasks

1. From the signal, identify peaks corresponding to your steps and compute the step frequency (without using fft). Aim for a generally applicable algorithm that can be used on a range of similar data sets;
2. Plot of acceleration magnitude vs time with the detected peaks and test the data analysis on various data sets e.g. walking up a stair, hill or running.
3. (Optional) You will learn about Fourier transforms at a later point in your study; for now it suffices that *fast fourier transforms* (`fft`) from packages like `numpy` or `scipy` can also report dominant frequencies. Verify your result using a Fourier transform and compare with your manual peak detection.

Task 2: Elevator Power Estimation

Objective

Use your phone's accelerometer (and optionally barometer) to characterize the traveling velocity, floor height, and to estimate the power output of the motor of the Helix elevator (or any elevator you might find interesting)[2].

[1] This assignment should be accessible to everyone. If, for any personal, physical, or practical reason, performing one of the experiments is difficult, please contact the teaching team. We will provide a suitable data set so that you can complete the task without disadvantage.

[2] Please be considerate of our colleagues using the elevator in their day to day routines.

Experimental Setup

Place your phone flat and steady on the elevator floor or wall handles. Start the recording before the elevator moves and stop it after the doors reopen. If we assume that the counterweight equals the empty car mass[3], the motor only needs to lift the *extra* mass in the elevator (your mass):

$$P = Fv = m(g + a)\, v$$

Here, F represents the force in $\mathrm{kg\,m\,s^{-2}}$, v represents the velocity in $\mathrm{m\,s^{-1}}$, and g represents the gravitational acceleration in $\mathrm{m\,s^{-2}}$; m in kg is the mass inside the elevator (yes, that is your weight, but we will treat it with the highest confidentiality[4]).

0.0.1 Analysis tasks

- Plot the acceleration, velocity, and position of the elevator over time
- Use this data to characterize various aspects of the elevator drive, e.g., the power of the motor to drive the elevator, the peak power produced, or whether there is a difference with a heavier load.

Practical Notes

To find the velocity v, you will need to integrate the acceleration data a (in $\mathrm{m\,s^{-2}}$ since:

$$v(t) = \int a(t)dt$$

And for the position x in m:

$$x(t) = \int v(t)dt$$

A full data integration using the functions discussed in the lectures (e.g. `trapz`) yields only the average velocity. Since we are interested in the velocity *profile* over time, cumulative integration functions are more useful. This can be done using cumulative integration (e.g. `scipy.integrate.cumtrapz` or `scipy.integrate.cumulative_trapezoid`, depending on your installed version of `scipy`).

Important: The "Linear Acceleration" sensor on some phones uses an aggressive gravity-filtering algorithm. This removes all low-frequency acceleration, and the resulting signal resembles more closely the "jerk" $j = \frac{da}{dt}\ \mathrm{m\,s^{-3}}$ rather than true acceleration. For the elevator task, always use the *raw accelerometer* (including gravity) and subtract g manually if needed.

Task 3: Damped Oscillation on a Swing

Objective

Measure the motion of a swing as it slows down and extract the *damping ratio* by fitting a mathematical model to the data.

Experimental Setup

Attach or hold your phone securely on a swing. Pull back to a small angle and release (or large angle: go wild!). Record acceleration data during several oscillations until the swing comes nearly to rest. You will need your mass and the swing length L.

[3] This is a little dubious assumption, is you have a more substantiated claim, feel free to use it.

[4] If you are sincerely bothered by supplying your weight, change the mass inside the elevator by bringing a crate of beer or 352 helium balloons, depending on whether you want to increase or decrease your weight

Physical Model

The swing behaves approximately as a *damped harmonic oscillator*, which can be described by the following ordinary differential equation:

$$\frac{d^2\theta}{dt^2} + 2\zeta\omega_0\frac{d\theta}{dt} + \omega_0^2\theta = 0,$$

where:

- $\theta(t)$ = angular displacement in rad s^{-1},
- $\omega_0 = \sqrt{\frac{g}{L}}$ = natural angular frequency in Hz,
- ζ = dimensionless damping ratio.

The analytical solution is:

$$\theta(t) = \theta_0 e^{-\zeta\omega_0 t}\cos(\omega_d t + \phi), \quad \omega_d = \omega_0\sqrt{1-\zeta^2}.$$

Analysis Tasks

1. Fit the analytical model above to your measured data and estimate ω_0 and ζ.
2. Compare the fitted ω_0 to the theoretical value $\sqrt{g/L}$.

Practical Notes

The phone's orientation changes during the swinging motion, so the acceleration axes may mix. To obtain a consistent signal:

- If you need directions to find a swing, use these links or Plus Codes `FFJC+V8` or `FF2W+WR` in Google Maps.
- Use the acceleration magnitude $a_{\mathrm{mag}} = \sqrt{a_x^2 + a_y^2 + a_z^2}$, or
- Record the rotation/orientation data and transform acceleration to a fixed (world) frame if you wish.

Tasks 4 and 5: Your Own Experiments

Objective

Design and perform two additional experiments using any of the sensors available in Phyphox (any sensor, really).

Each task should be of comparable scope and structure to the first three. You should:

1. Clearly define the physical question you want to answer.
2. Describe your experimental setup and sensor choice.
3. Derive or present the relevant equations (with definitions of all symbols), if required
4. Analyze the data and compute or fit the relevant physical quantities.
5. Present plots, brief conclusions, and reflections on limitations or uncertainty.

Be creative but safe. Examples could include the rotational damping of a spinning chair, estimating your power while climbing stairs, or measuring the sizzling intensity of a freshly poured soda drink.