WISSEN
TECHNIK
LEIDENSCHAFT

Lab programme 2
Pedestrian Dead Reckoning

Navigation Systems

WS 2025/26

Given dataset

- **Smartphone data**
  - Time *[ms]*
  - 3-axis accelerometer *(acc_x, acc_y, acc_z) [m/s²]*
  - 3-axis magnetometer *(mag_x, mag_y, mag_z) [μT]*
  - *3-axis gyroscope ($gyro_x$, $gyro_y$, $gyro_z$) [rad/s]*
  - Barometer (pressure) *[hPa]*

$$\boldsymbol{a} = \begin{bmatrix} a_x \\ a_y \\ a_z \end{bmatrix}$$

$$\boldsymbol{m} = \begin{bmatrix} m_x \\ m_y \\ m_z \end{bmatrix}$$

- ***Reference/ground truth data***
  - *Reference orientation (roll, pitch, yaw) [rad]*
  - *Ground truth path (x [m], y [m], latitude [°], longitude [°]) from a camera-based tracking system (only available in one room – represents start and ending)*

Goal

- Compute the indoor trajectory of the pedestrian using step-based PDR
  1. Step detection
  2. Step length estimation
  3. Direction estimation
  4. Step counting (computing displacement)

- Starting point: $\varphi = 47.06422°,\ \lambda = 15.45291°$

Dead reckoning: formulas

1. Step detection: Peak detection

- $acc_{total} = \sqrt{acc_x^2 + acc_y^2 + acc_z^2}$

2. Step length estimation

Step length models:

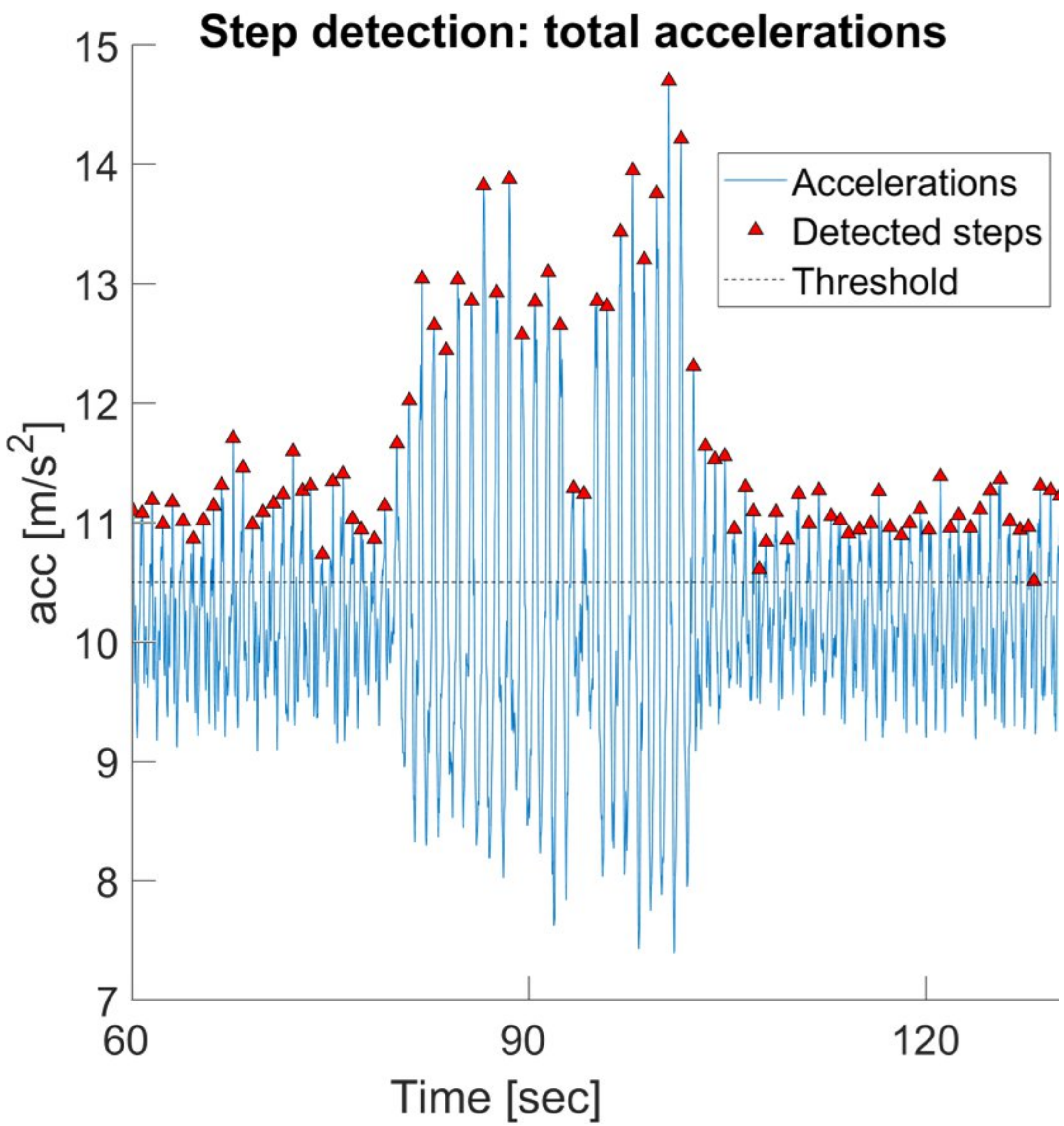
- Constant:

  $$step = 0.8\ m\ (0.3m\ on\ stairs)$$

- Weinberg model:

  $$step = k \cdot \sqrt[4]{a_{max} - a_{min}}$$

- ...



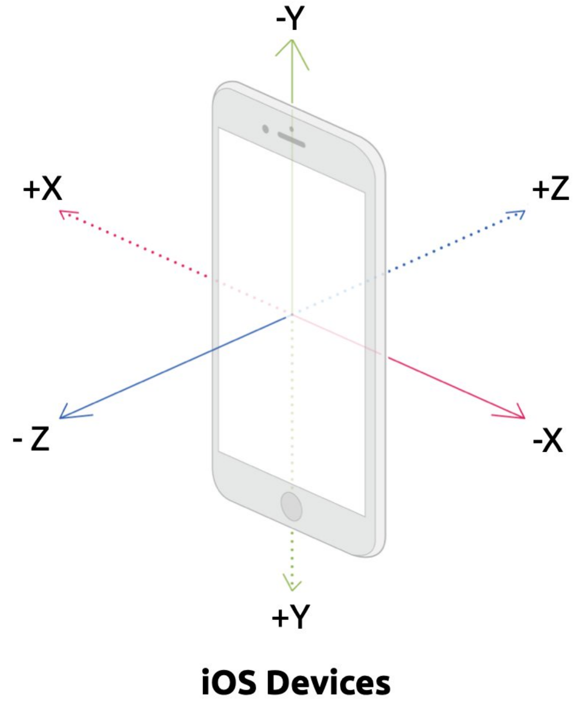
Dead reckoning: formulas

3. Direction estimation

- Magnetic orientation

roll: $r = tan^{-1}\left(\frac{-a_x}{-a_z}\right)$ *pitch:* $p = tan^{-1}\left(\frac{a_y}{\sqrt{a_x^2+a_z^2}}\right)$

yaw (heading): $y_{mag} = tan^{-1}\left(\frac{-m_x cos(r)+m_z sin(r)}{m_y cos(p)+m_x sin(p) sin(r)+m_z sin(p) cos(r)}\right)$



4. Step counting

- $N_{t+1} = N_t + StepLength_t \cdot \cos(heading)$
- $E_{t+1} = E_t + StepLength_t \cdot \sin(heading)$

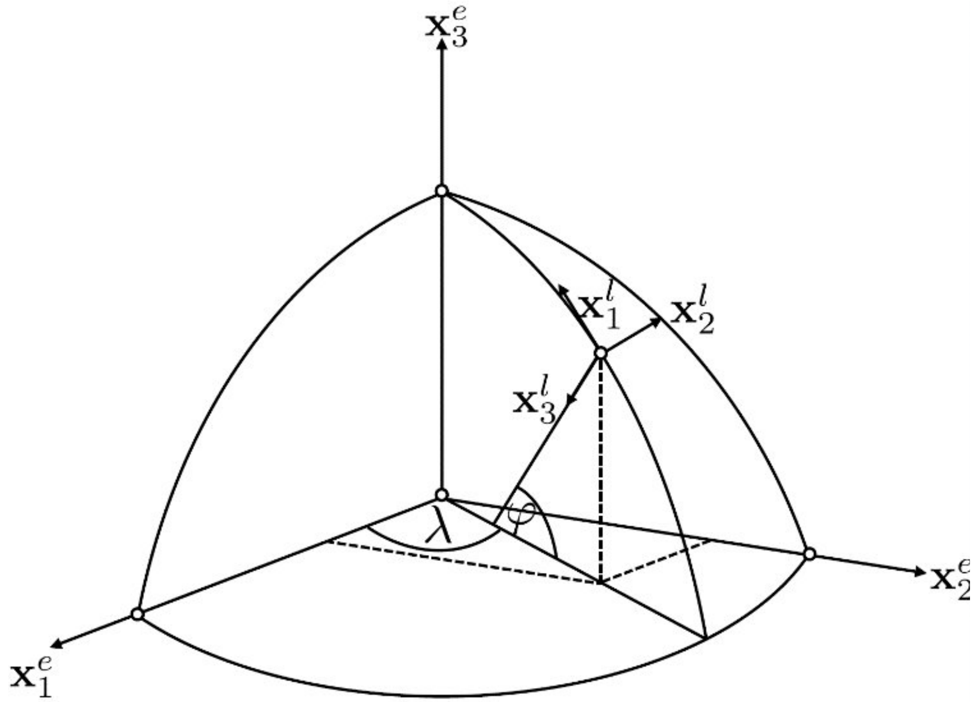
$tan^{-1} \rightarrow$ Python: use **np.arctan2()**

Coordinate transformations

- Starting point given in geographic coordinates (φ, λ) [°]
- Step counting: in local-level frame (N, E) [m]

- Starting point in local level frame: (0,0)

- Compute displacements dN, dE
  & then transform to displacements
  in geographic coordinates ($d\varphi, d\lambda$)

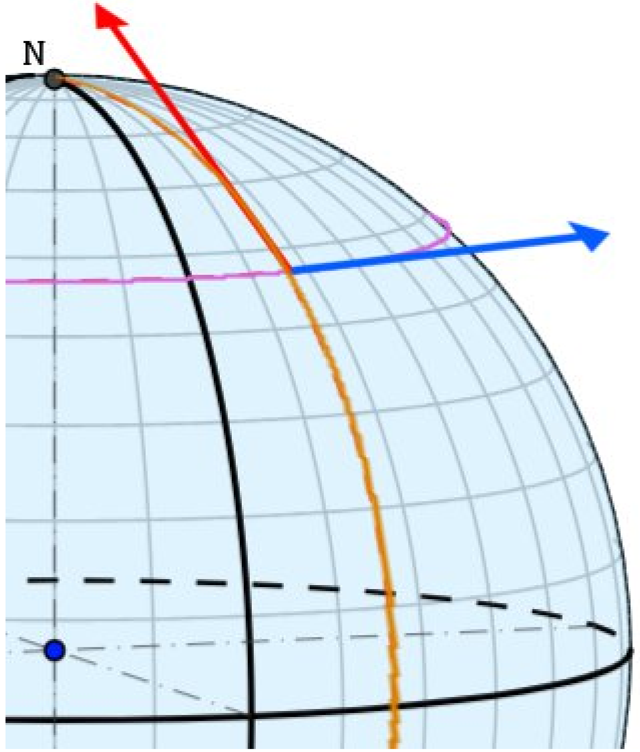


Coordinate transformation: spherical approximation

- Transformation: spherical approximation (valid for building scale)
- $R = 6378137\ m$

$$\underset{[\mathrm{rad}]}{d\varphi} = \underset{[\mathrm{m}]}{dN} / \underset{[\mathrm{m}]}{R}$$

$$\underset{[\mathrm{rad}]}{d\lambda} = \underset{[\mathrm{m}]}{dE} / (\underset{[\mathrm{m}]}{R} \cdot \underset{[\mathrm{rad}]}{\cos\varphi})$$



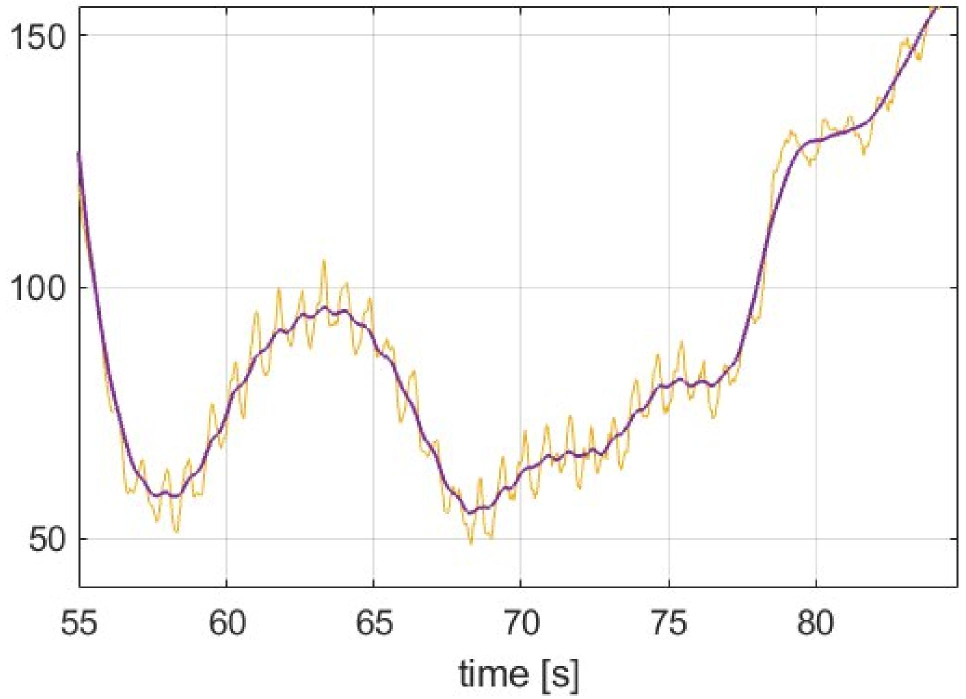
Height

- **Barometer**
- $$\Delta h_{0,t} = \frac{293.15}{6.5 \cdot 10^{-3}} \left[\left(\frac{p_t}{p_0} \right)^{-\left(\frac{287.1 \cdot 6.5 \cdot 10^{-3}}{9.81} \right)} - 1 \right]$$

p_t … pressure at time t
p_0 … reference pressure at t=0

- Filtering if necessary
- Detect stairs & adapt step length in corresponding intervals
- Note: relative height only

Data preprocessing



- Keep in mind that raw smartphone inertial data is very noisy and inaccurate!
- Try using appropriate filtering methods
  - eg. scipy.signal library
  - Smoothing (eg. Savitzky-Golay, moving average)
  - Peak detection

```
import scipy.signal as sp
sp.savgol_filter()
```

```
pd.DataFrame.rolling()
```

```
peaks, properties = sp.find_peaks(accelerometer[...])
```

Visualization - Basemaps

- **QGIS:**
  - Ctrl + 2 (Browser)
  - XYZ Tiles – new connection
  - URL: https://mt1.google.com/vt/lyrs=m&x={x}&y={y}&z={z}
  - Max. zoom level: 22

- **Python**
  - contextily
  - Tile provider

```
import contextily as cx
from xyzservices import TileProvider

google_map = TileProvider(
    name="...", url="...",max_zoom=...)

cx.add_basemap(ax,source=google_map)
```

(https://contextily.readthedocs.io/en/latest/reference.html)

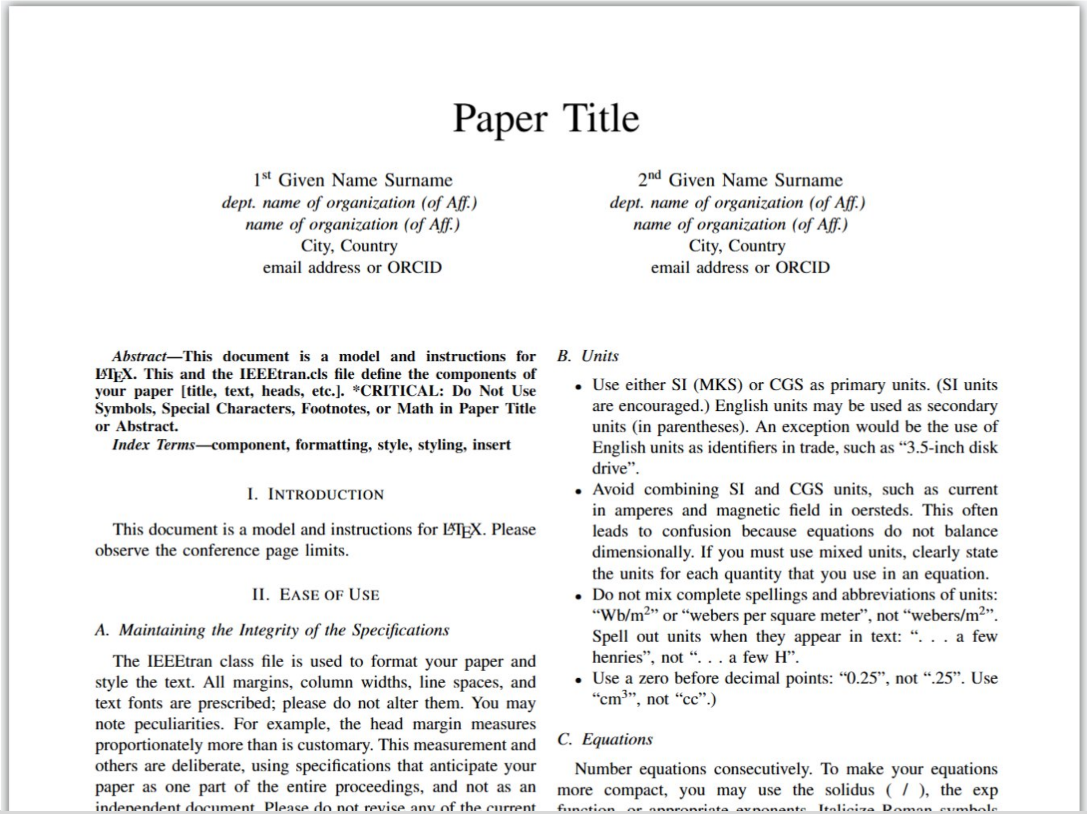
Deliverables

- Source code
  - Name your files according to the following convention:
  - *lab02_ws2025_26_GROUP#_SURNAME1_SURNAME2.py*
  - *Use suffix if needed (eg. _main.py)*

- Short technical paper
  - IEEE format, 3 pages in English & use the template provided

Short paper

- Abstract
- Introduction
- Clear explanation of your methodology, including
  - Analysis of the given dataset
  - Explanation of your algorithm, including all formulas
  - Explanation of the chosen step length estimation
  - Explanation of any other used models or assumptions
- Results
  - Visualization of step detection and step direction estimation
  - Visualization of the estimated heights
  - Visualization of the derived trajectory indoors
- Analysis and interpretation of your results
- References



Paper Title

1st Given Name Surname
dept. name of organization (of Aff.)
name of organization (of Aff.)
City, Country
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***Index Terms*—component, formatting, style, styling, insert**

I. Introduction

This document is a model and instructions for LaTeX. Please observe the conference page limits.

II. Ease of Use

A. Maintaining the Integrity of the Specifications

The IEEEtran class file is used to format your paper and style the text. All margins, column widths, line spaces, and text fonts are prescribed; please do not alter them. You may note peculiarities. For example, the head margin measures proportionately more than is customary. This measurement and others are deliberate, using specifications that anticipate your paper as one part of the entire proceedings, and not as an independent document. Please do not revise any of the current

B. Units

- Use either SI (MKS) or CGS as primary units. (SI units are encouraged.) English units may be used as secondary units (in parentheses). An exception would be the use of English units as identifiers in trade, such as "3.5-inch disk drive".
- Avoid combining SI and CGS units, such as current in amperes and magnetic field in oersteds. This often leads to confusion because equations do not balance dimensionally. If you must use mixed units, clearly state the units for each quantity that you use in an equation.
- Do not mix complete spellings and abbreviations of units: "Wb/m^2" or "webers per square meter", not "webers/m^2". Spell out units when they appear in text: ". . . a few henries", not ". . . a few H".
- Use a zero before decimal points: "0.25", not ".25". Use "cm^3", not "cc".)

C. Equations

Number equations consecutively. To make your equations more compact, you may use the solidus (/), the exp

Organizational matters

- Groups of 2
  - Same groups as for the first lab program

- Important dates
  - January 12: Submission of lab program #2
  - January 19: Interviews: register for a time slot