30.203 Design and Fabrication Microelectromechanical Systems

Indoor Positioning System Design

Outline

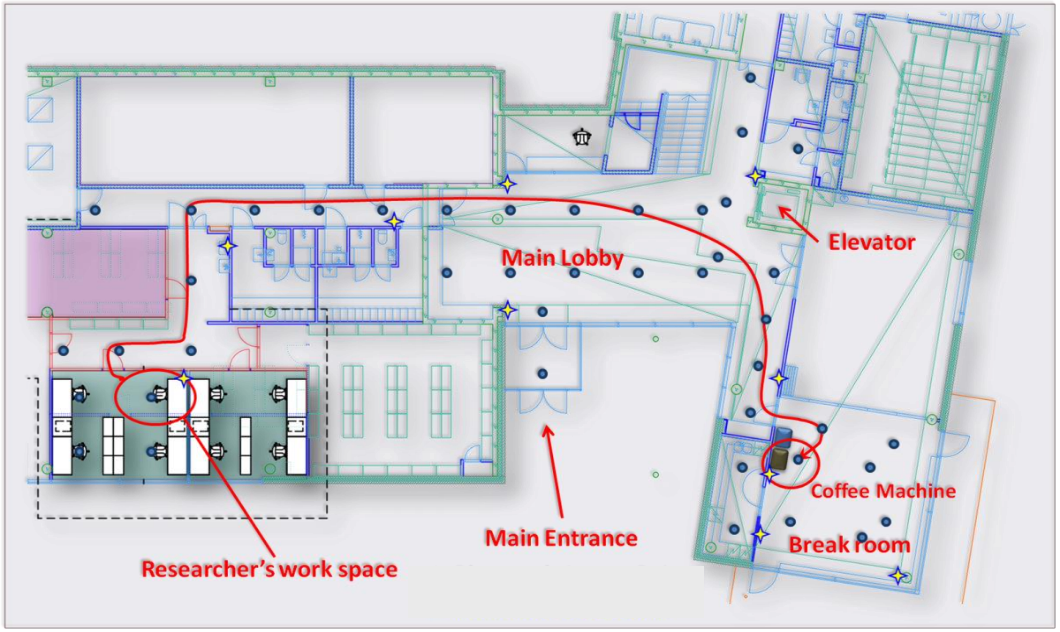
- Introduction of Indoor Positioning System (IPS)
- Tasks
- IPS Design Example

Indoor Positioning System (IPS)

- An **indoor positioning system (IPS)** is a solution to locate objects or people inside a building
- Wireless technologies, WIFI, Bluetooth, RFID, etc.
  - Many different systems take advantage of existing wireless infrastructure for indoor positioning.
- Magnetic position
  - Based on the iron inside buildings that create local variations in the Earth's magnetic field.
- **Inertial Measurement Unit (IMU)**
  - Pedestrian Dead Reckoning (PDR) and other approaches for positioning of pedestrians propose an inertial measurement unit carried by the pedestrian by measuring steps and step length.

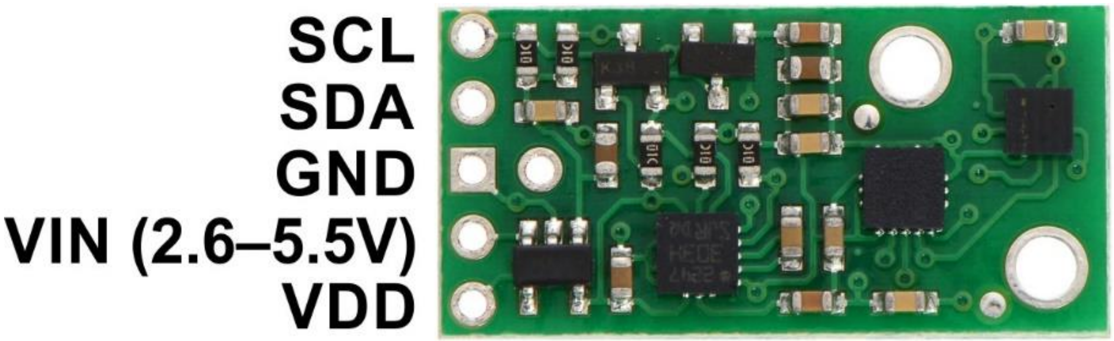
IPS Design

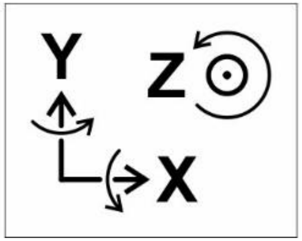
- Objectives of the IPS project:
  - ❑ Detect the position by using MEMS sensors.
  - ❑ Estimate the walking distance between the initial point and the final point.
  - ❑ Estimate the level in the building.



IPS Design

- Hardware:
  - Microcontroller: Arduino UNO V3
  - MEMS sensors: altIMU-10 V4
    - **ST L3GD20H (Gyroscope)**
    - **ST LSM303D (Accelerometer and magnetometer)**
    - **ST LPS25H (Pressure and temperature sensors)**





altIMU-10 V4

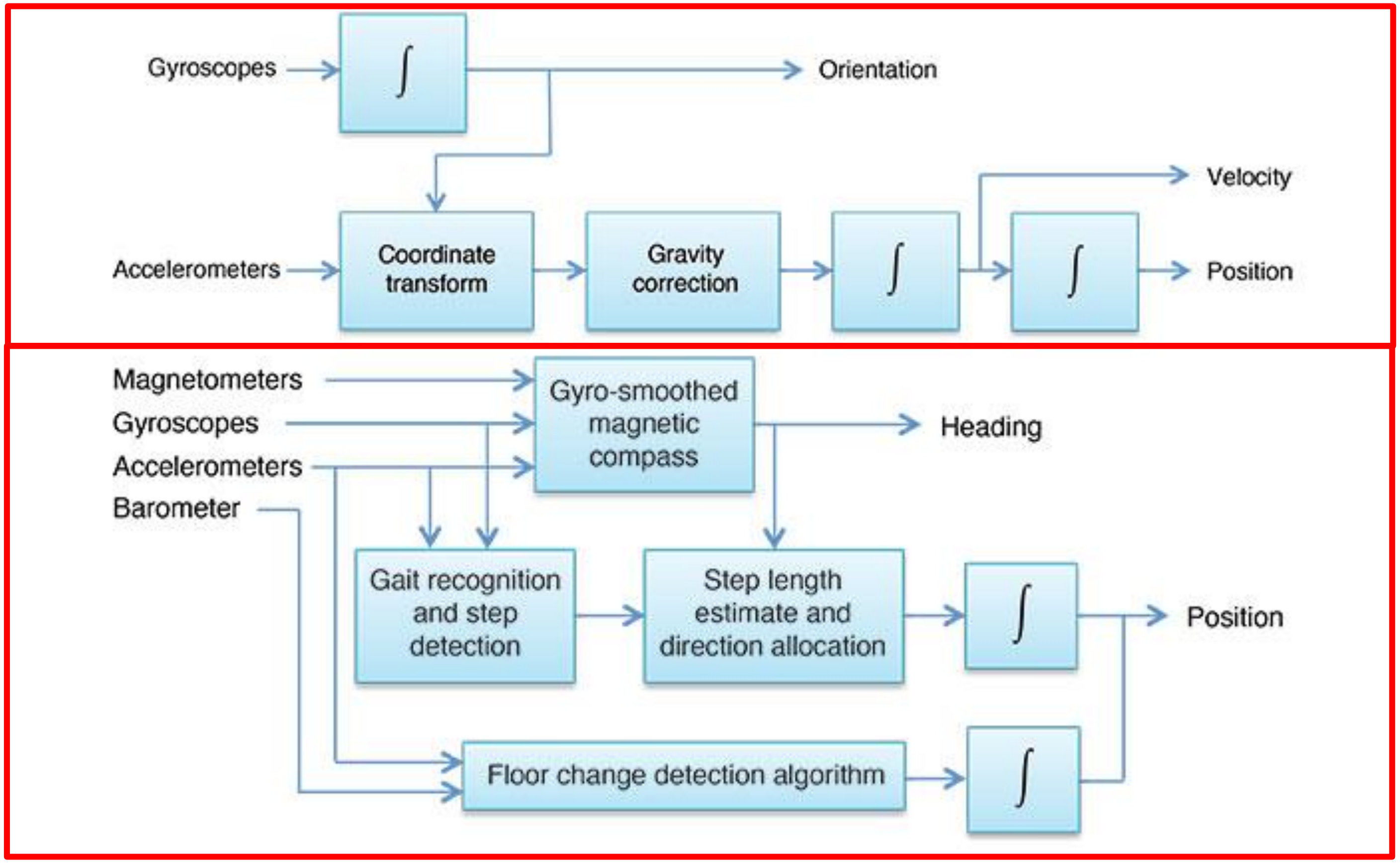
10 degree of freedom IMU (altIMU10-V4)

- Sensors Introduction
  - https://www.pololu.com/product/1269

- 3-axis Accelerometer + 3-axis Magnetometer (LSM303D)
  - ±2/±4/±8/±12 gauss dynamically selectable magnetic full-scale
  - ±2/±4/±6/±8/±16 g dynamically selectable linear acceleration full-scale
- 3-axis Gyroscope (L3GD20H)
  - a full scale of ±245/±500/±2000 dps
- Pressure sensor + temperature sensor (LPS25H)
  - 260 to 1260 hPa absolute pressure range
  - High-resolution mode: 1 Pa RMS
  - Absolute accuracy temperature: 2 °C

Block Diagrams of the INS and PDR

http://gpsworld.com/innovation-getting-closer-to-everywhere-accurately-tracking-smartphones-indoors/

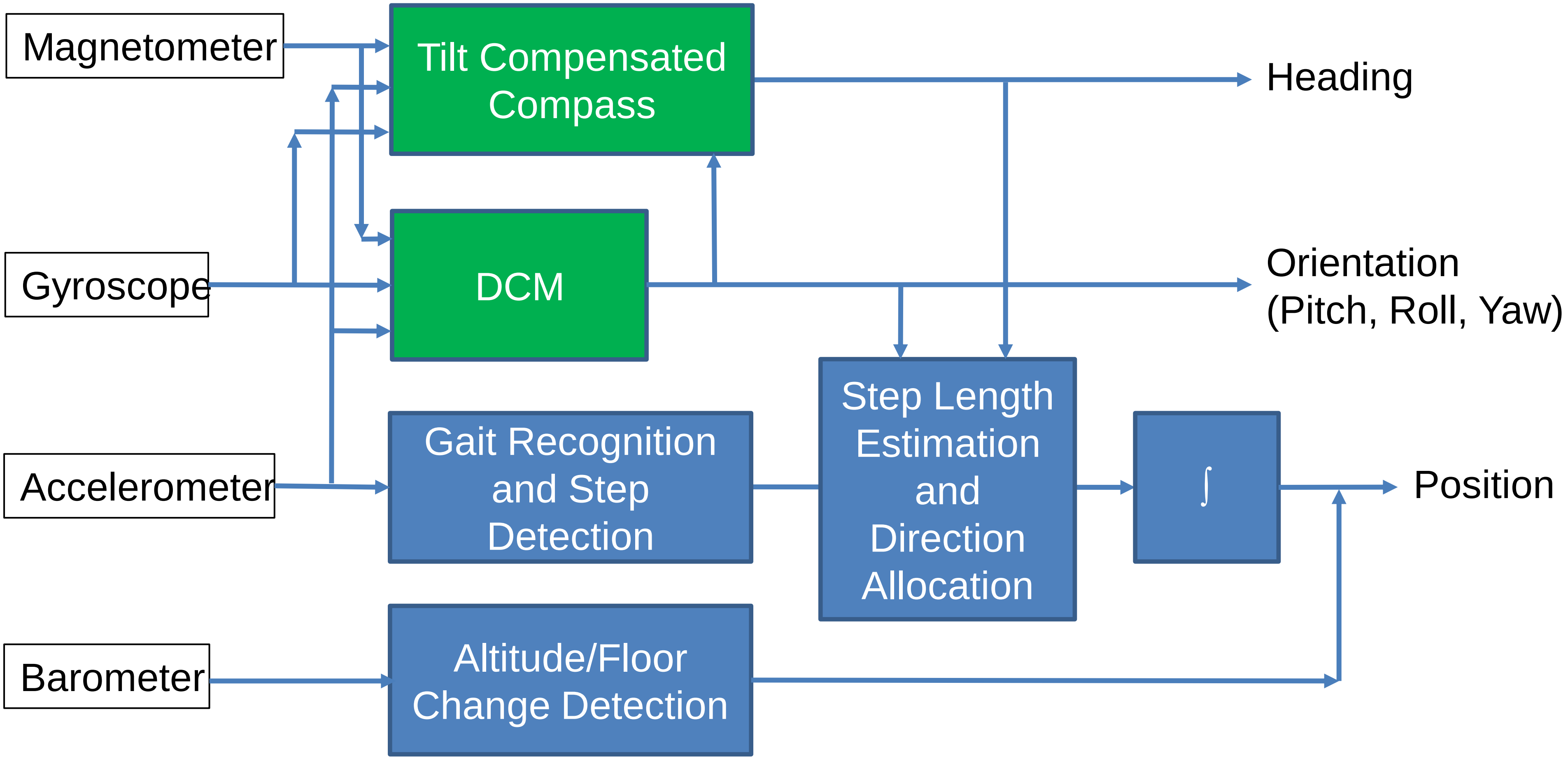


Inertial Navigation System (INS)

Pedestrian dead-reckoning (PDR)

- PDR scheme accumulates error more slowly than the INS scheme
- Magnetometer based heading systems do not drift with time
- Barometer based floor change detection system do not drift with time

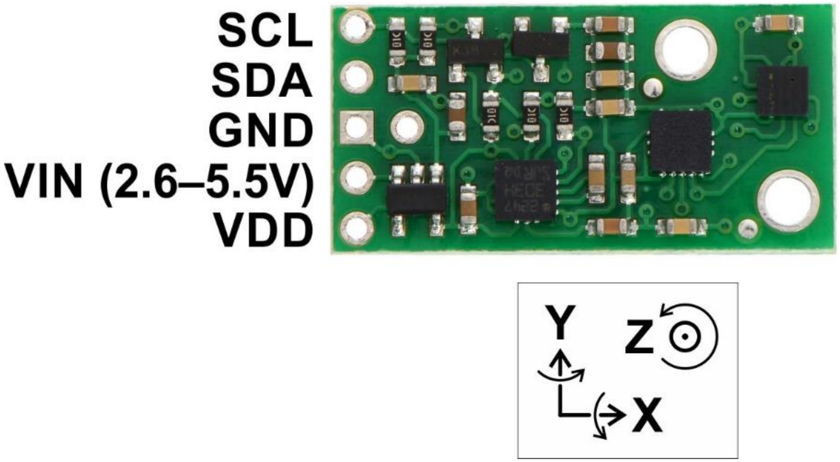
Block Diagram of the IPS

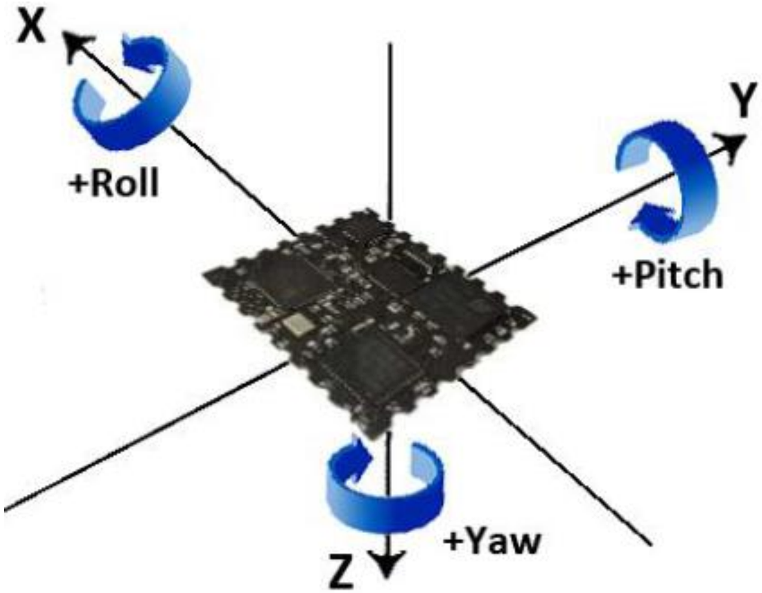


- The system is designed based on existing compass code and DCM code.
- Three sub-blocks have to be developed – **step detection**, **step length estimation** and **level detection**.

Euler Angles

- Euler angles provide a way to represent the 3D orientation of an object using a combination of three rotations about different axes.
- The inertial frame
  - The "inertial frame" is an Earth-fixed set of axes that is used as an unmoving reference.
- The body frame
  - The body frame is the coordinate system that is aligned with the body of the sensor.





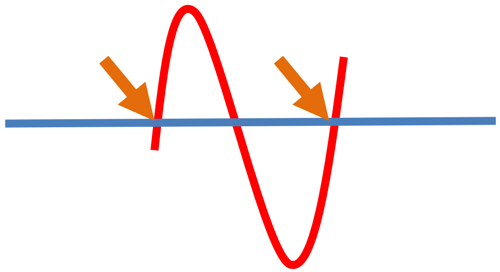
Step Detection

- Gyroscope
  - Foot mounted
- Accelerometer
  - Handheld
- Foot mounted
  - Bag, pocket, etc.
  - Euler Angles
  - Foot mounted

- Step Detection Methods
  - Peaking detection
  - Threshold crossing detection

Step Detection Methods

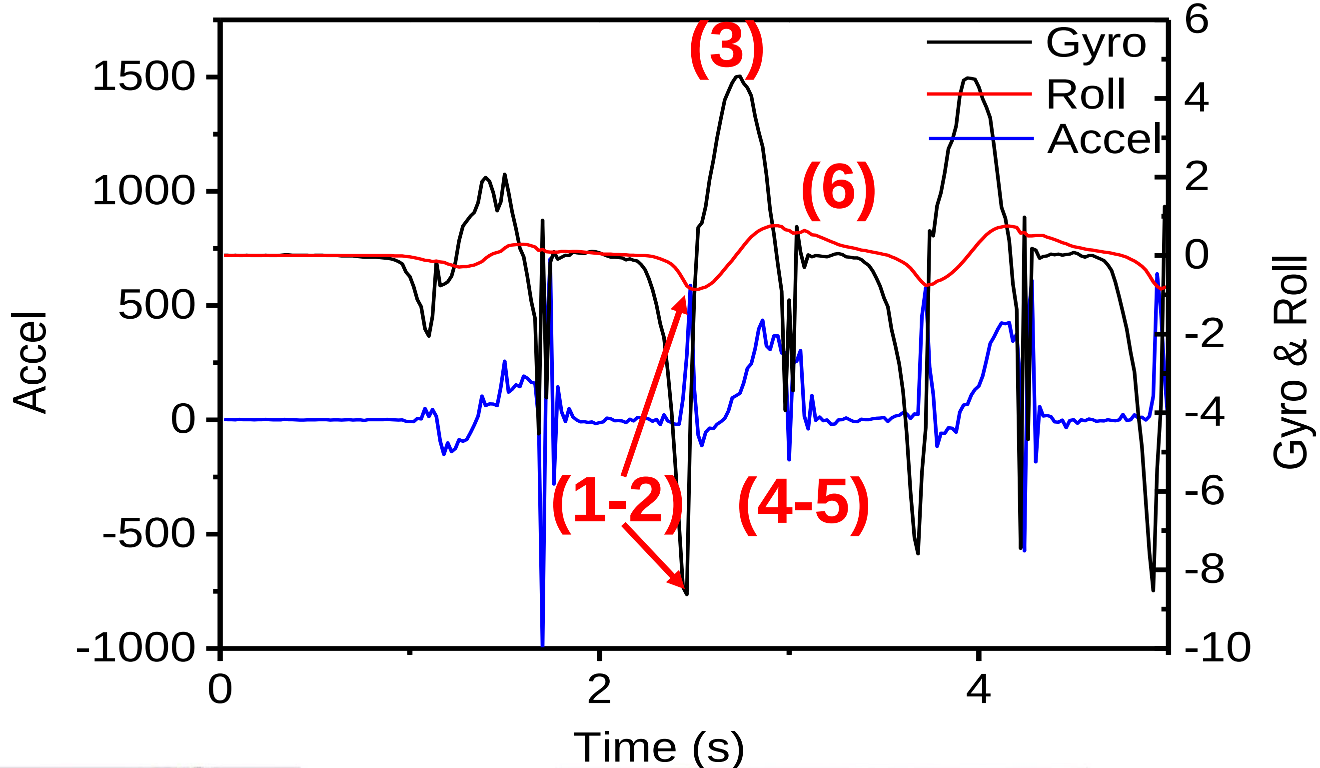
- **Step threshold**
  - Deterministic, i.e., zero crossing
  - Adaptive, i.e., max and min average

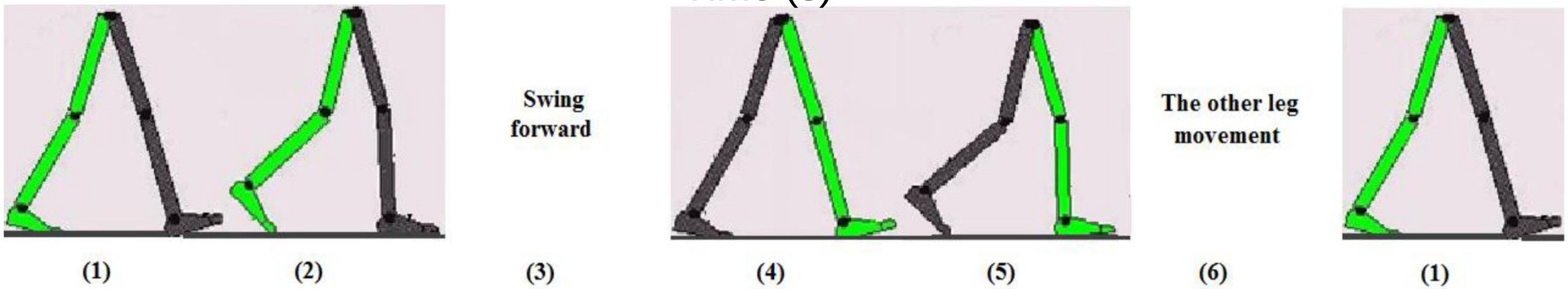


- **Peak detection**
  - If sample k minus sample $k-1$ is positive it means that is the rising edge of the data norm;
  - If the result is negative it means that a falling edge of the data norm is detected.
  - *Formula for Detection of Peaks on Norm*
  - *if*($N_k - N_{k-1} >= 0$ && $N_{k+1} - N_k < 0$) *then* : *Step is detected*
- **Filtering – low pass filter**
  - Local peak or local spur may cause unintended step detection

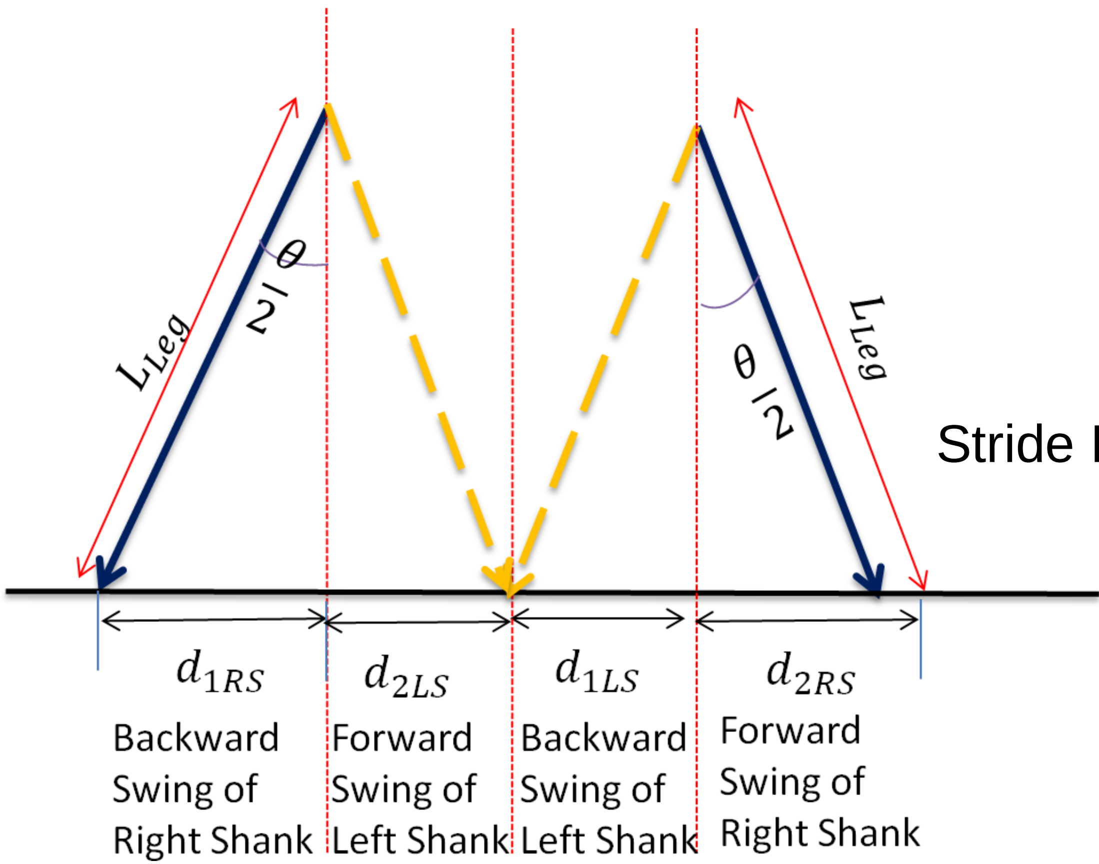
Foot Mounted Step Detection

Gyroscope, accelerometer and Euler Angles can be used to detect the steps





Step Length Computation



$L_{Leg}: Leg\ Length$

$$d_1 = \sin(\frac{\theta}{2}) \times L_{Leg}$$

$$d_2 = \sin(\frac{\theta}{2})\times L_{Leg}$$

$$\text{Stride Length} = d_{1RS}+d_{2LS}+d_{1LS}+d_{2RS}$$

Reference Model

S. Miyazaki, "Long-Term Unrestrained Measurement of Stride Length and Walking Velocity Utilizing a Piezoelectric Gyroscope"

Other Models of Step Length Estimation

- **Frequency based** step length model **1** [1]

$$s = h * \left(a * f_{step} + b\right) + c$$

h is the user's height, f_{step} is the step frequency, a, b, c are the parameters.

- **Frequency based** step length model **2** [2]

$$s = \alpha * f_{step} + \beta * v + \gamma$$

α,β,γ are the parameters, v is the difference between the accelerometer signal at time t, the average of accelerometer signals during one step.

- **Swing speed based** step length model [3]

$$s = K_1 \overline{z_t} + K_2$$

K_1, K_2 are subject-specific coefficients, $\overline{z_t}$ is the average swing rate

[1]. Renaudin, et al. "Step length estimation using handheld inertial sensors." 2012
[2] Shin, S. H., et al. "Adaptive step length estimation algorithm using low-cost MEMS inertial sensors." 2007
[3]. Zhang, Zhiqiang, et al. "A Simple and Robust Stride Length Estimation Method using Foot-mounted Micro Gyroscopes." 2014

Use Pressure Sensor to Measure Altitude/Barometer

Weather Conditions (up to 11 km)

$$h = h_b + \frac{T_b}{L_b}[\left(\frac{P}{P_b}\right)^{\frac{-RL_b}{g_0 M}} - 1]$$

$$P = P_b[1 + \frac{L_b}{T_b}(h - h_b)]^{\frac{-g_0 M}{RL_b}}$$

where,

P_b= static pressure (pressure at sea level) [Pa]

T_b= standard temperature (temperature at sea level) [K]

L_b= standard temperature lapse rate [K/m] = -0.0065 [K/m]

h = height about sea level [m]

h_b = height at the bottom of atmospheric layer [m]

R = universal gas constant = 8.31432 $\left[\frac{N \cdot m}{mol \cdot K}\right]$

g_0 = gravitational acceleration constant = 9.80665 $\left[\frac{m}{s^2}\right]$

M = molar mass of Earth's air = 0.0289644 [kg/mol]

Earth's Atmosphere (from 11km to 20km)

$$h = h_b + \frac{RT_b \ln\left(\frac{P}{P_b}\right)}{-g_0 M}$$

$$P = P_b exp[\frac{-g_0 M(h - h_b)}{RT_b}]$$

Useful Resources

- AltIMU 10 resources
  - https://github.com/pololu/minimu-9-ahrs-arduino
- Filter (smoothing)
  - http://playground.arduino.cc/Main/Smooth
- FFT
  - http://wiki.openmusiclabs.com/wiki/ArduinoFFT
- Peak Detection
  - http://www.tigoe.com/pcomp/code/arduinowiring/46/
- Frequency Detection
  - http://interface.khm.de/index.php/lab/interfaces-advanced/arduino-frequency-counter-library/
- Rotation Matrix Conversion
  - http://en.wikipedia.org/wiki/Rotation_formalisms_in_three_dimensions
- Simplot
  - http://www.negtronics.com/simplot

Tasks To Be Done

- **Design IPS**
  - Design methods and algorithms
- **Arduino coding**
  - Program the codes
  - Code to be submitted with the project
- **Presentation**
  - Present the IPS design including methods and algorithms, 10 minutes for each group (Thursday, week 9)
- **Measurement**
  - Track the walking, and measure the distance and level. For example, start at the entrance of one stop center, and end at the classroom.
- **Demonstration**
  - Demo the final IPS, 20 minutes for each group (Monday, week 13)
- **Final Report**
  - Include the IPS design and the measurement results (week 13)

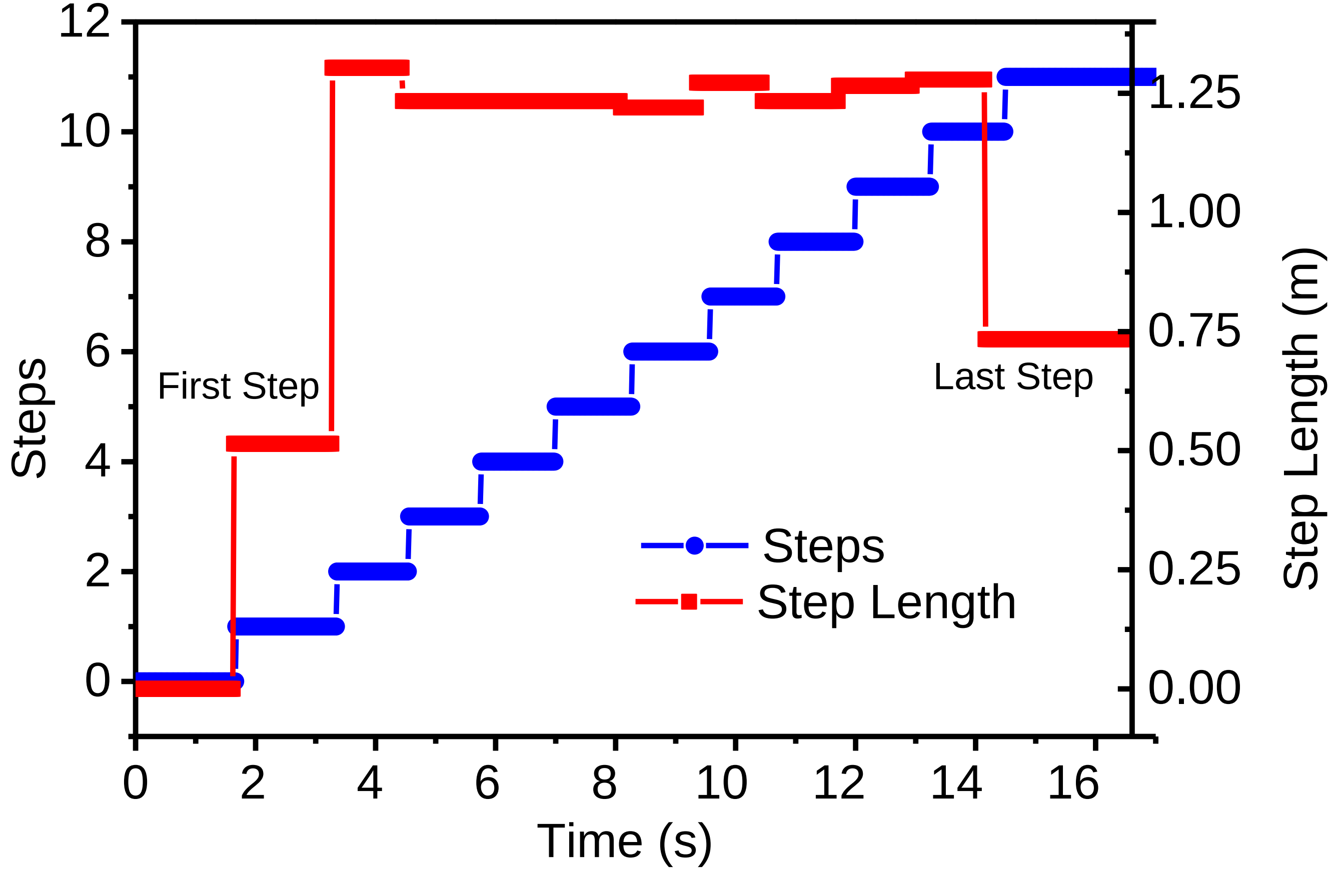
Project Marking (40%)

- Introduction of the IPS project (Thursday, **Week 6**).
- Group presentation on the IPS design (Thursday, **Week 9**).
- Submission of final report (**Week 13**).
- Demo/presentation of the IPS (Monday, **Week 13**).
- Marking is based on the **novelty** and **accuracy** of the IPS.

Project	Mark
Level detection	10
Gait detection	10
Step length evaluation	5
Final system	15

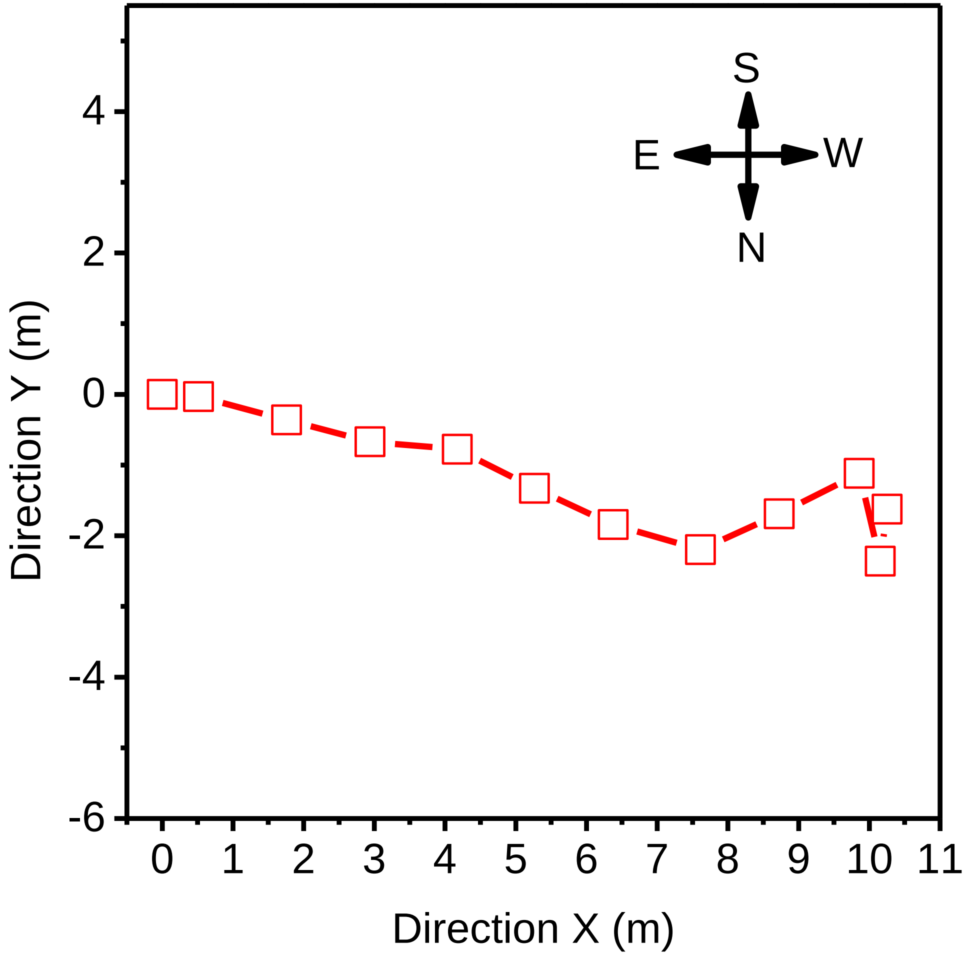
Step Counter and Step Length Estimation

- Averaged step speed: 0.8 step/s
- Averaged step length: 1.14 m (With first and last steps), 1.25 m (without first and last steps)



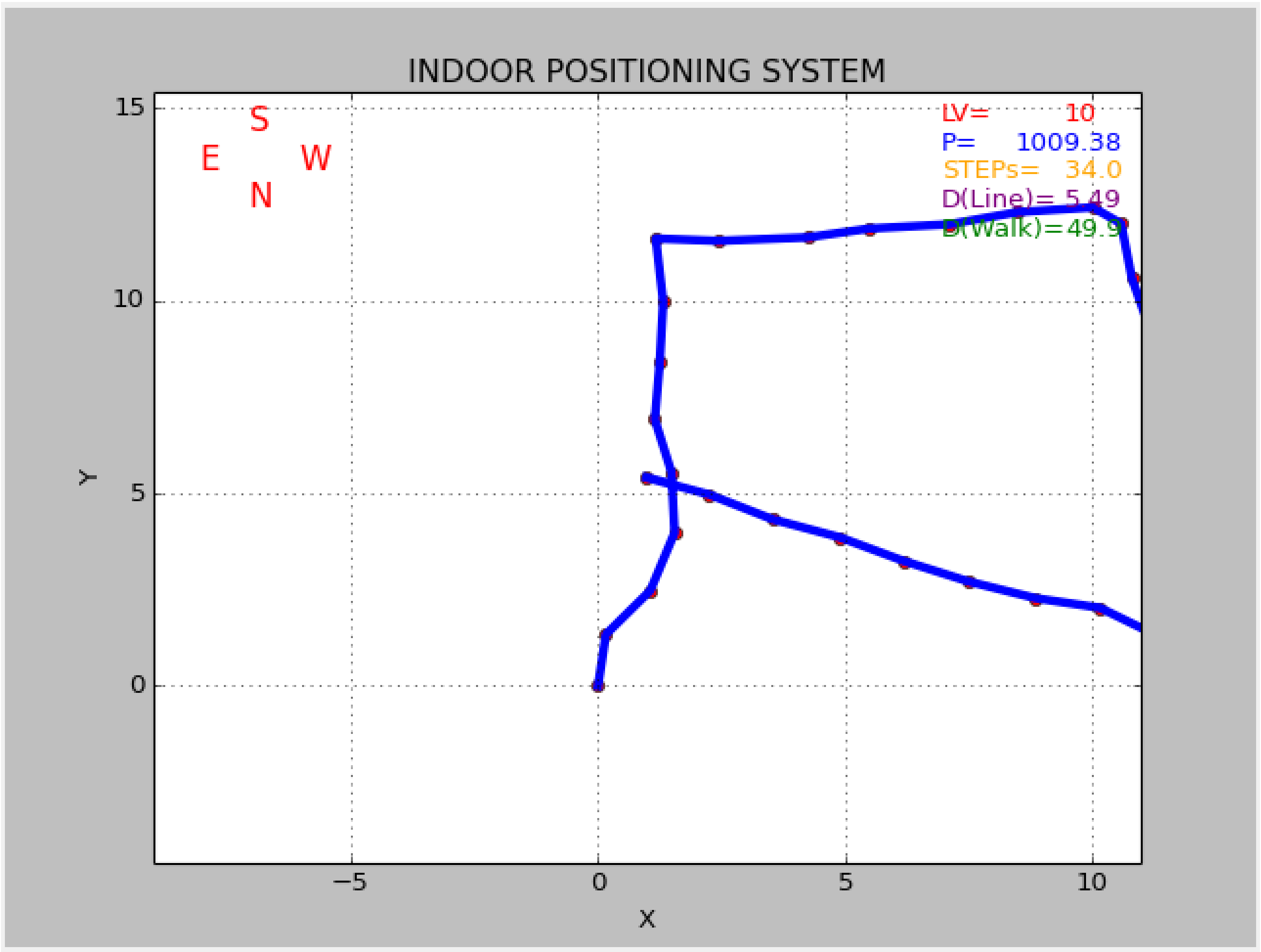
Gait Tracking

- Total walking distance: 12.54 m
- Straight line distance: 10.38 m

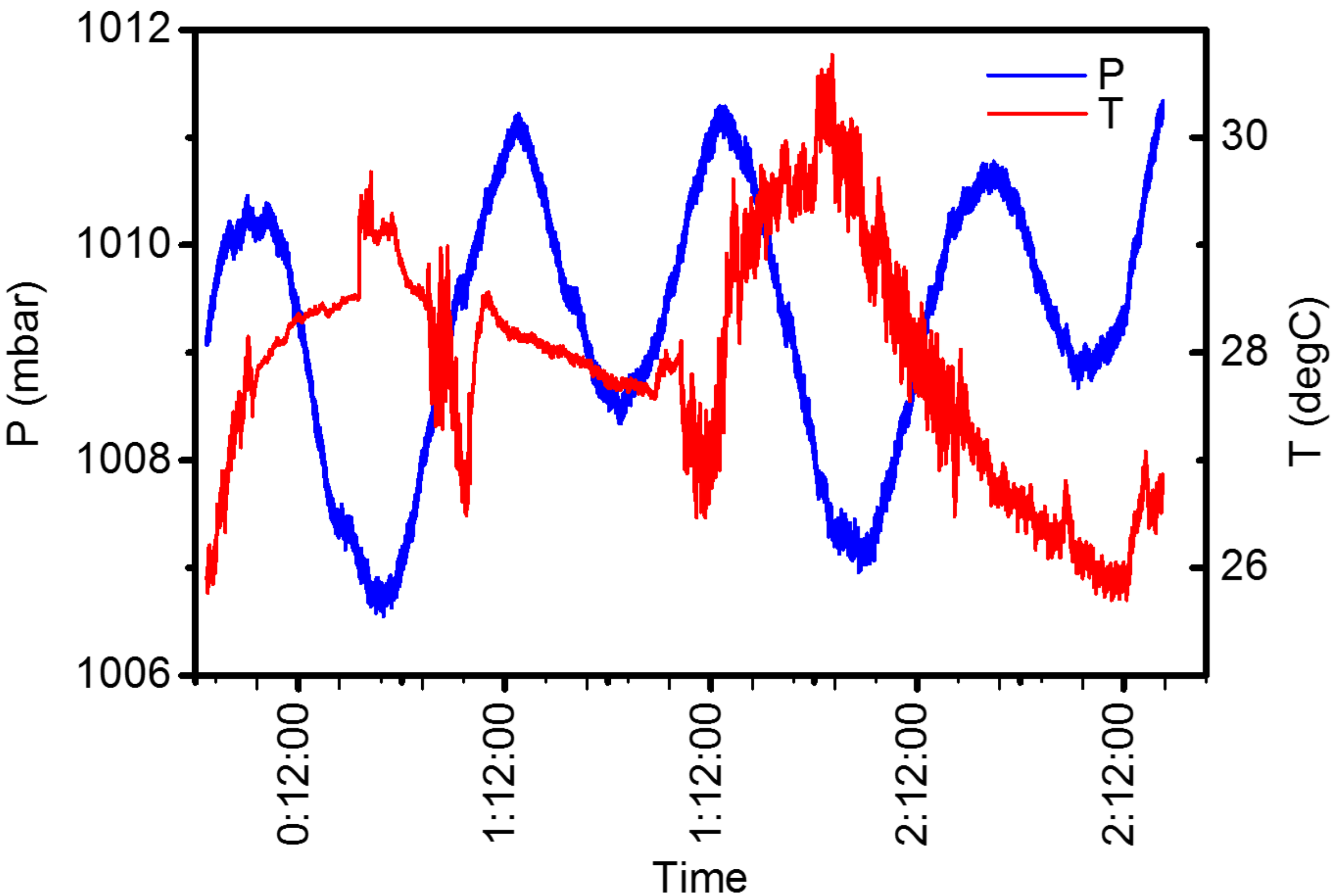


Gait Tracking GUI

Each step is tracked and plotted in a window by a python program



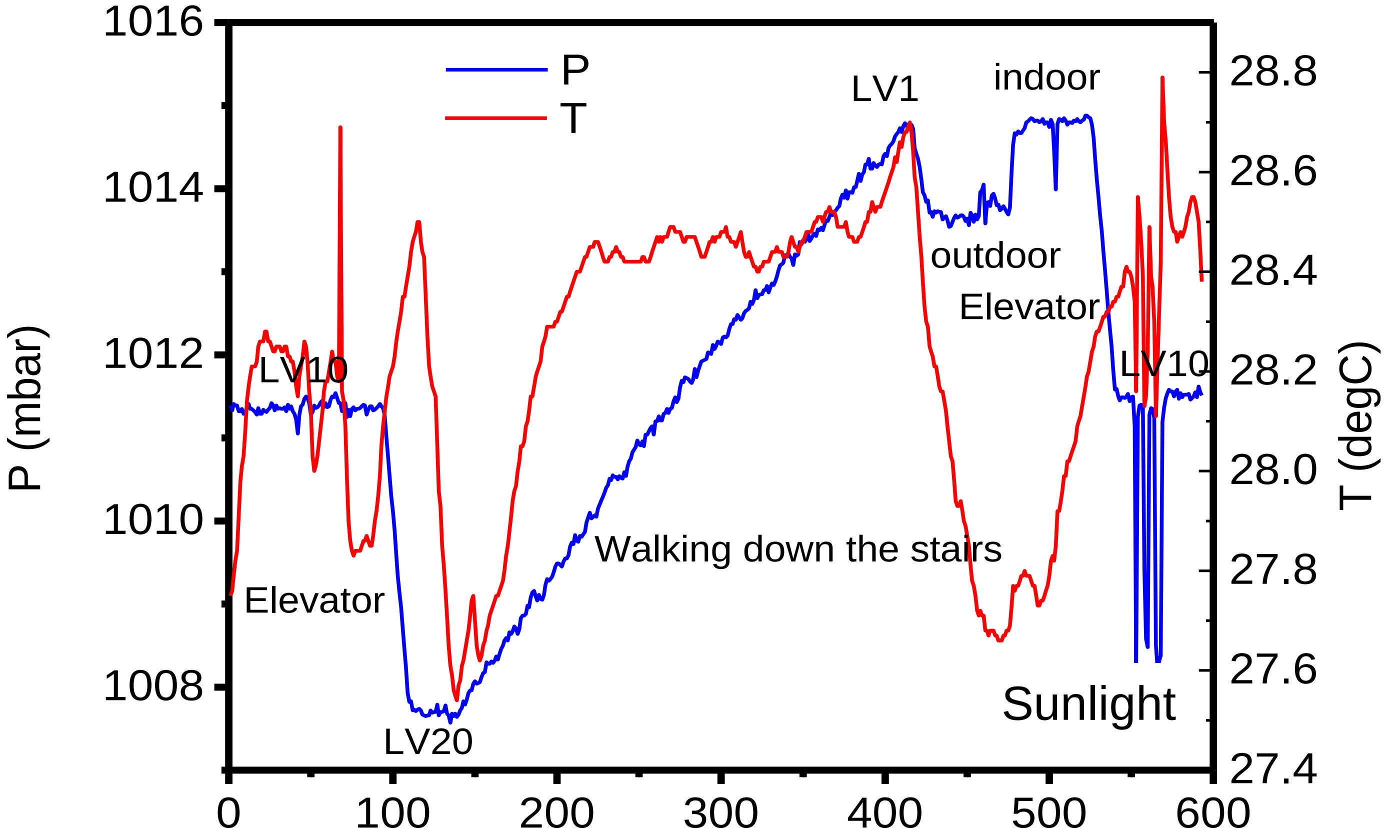
P and T changes in 50 hours



- Both temperature and pressure may change at different conditions
- Assume the conditions do not change when measuring the system

PT Changes in 20 levels@10 AM

- Pressure = 1015 @ LV1, 1007 @ LV20
- Indoor and outdoor pressures different
- Sunlight affects the pressure



PT Changes in 20 levels@15 PM

- Pressure = 1013 @ LV1, 1005 @ LV20
- Pressure at different time is different
- Relative pressure difference can be used to detect the level