Laboratory for Electrical Instrumentation and Embedded Systems
IMTEK – Department of Microsystems Engineering
University of Freiburg

Sensors Lab Course
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Lab Report M1

Pressure and Acceleration Sensors

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1 Introduction

Barometric pressure sensors specifically measure atmospheric pressure and are used in weather forecasting and altitude determination. Calculation of altitude is very important in many small to critical applications. The pressure falls with rising altitude. In this module, pressure and acceleration readings are determined from the sensors embedded into Arduino Nicla Sense ME and the altitude of the elevator ride is calculated, and data is compared.

2 Theory

The atmospheric pressure depends on temperature and weather conditions but also the altitude [1]. Barometric formula is used to model pressure change with altitude and altitude can be determined at any instant using temperature which doesn't change the results significantly because of small altitude difference.

$$p = p_{\circ} \exp\left(-\frac{gMh}{RT}\right) \qquad (1)$$

where p_0 is the reference pressure, and T is the absolute temperature. The constants are standard gravity = 9.81 m s^{-2}, the molar mass of air M = 0.02896 kg mol^{-1}, and the universal gas constant R = 8.314 J mol^{-1} K^{-1}

Velocity is achieved by integrating acceleration and displacement by integrating velocity. The displacement in z-direction is the height. An acceleration change in the z-direction can be used to calculate altitude.

2.1 Pressure Sensor

In everyday life, sensors are utilized in a wide range of unique applications in medical equipment, mobile gadgets, and harsh or corrosive environments. Numerous automotive, medical, industrial, consumer, and building devices rely on precise and stable pressure measurements for stable operation. Pressure sensors offer a wide range of technologies, packages, performance levels, and features to meet these demands.

Among the vast array of pressure sensors available in today's market, they are largely categorized according to the type of pressure measurement they make, the employed principle, the output signal and media they are measuring [2].

BMP390 absolute pressure sensor shown in figure 1 is used in our experiments which is very small, low power and low noise 24-bit absolute barometric pressure sensor. These sensors are suited for a wide range of altitude tracking applications with their high-performance pressure range 300 to 1250 hPa. It also offers outstanding design flexibility, providing single package solutions [3].

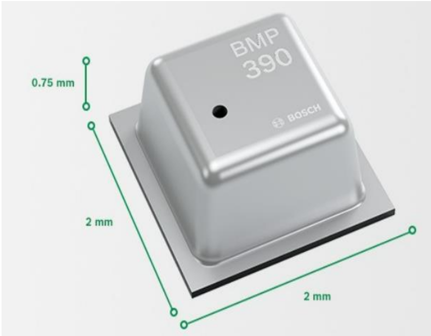

Figure 1: BMP390 absolute pressure sensor [3]

2.2 Acceleration Sensor

An acceleration sensor is a device which is also known as accelerometer, measures the rate of change of velocity of an object. It detects the direction and speed at which an object is changing. Accelerometers operate based on the principle of inertia where it contains mass suspended within the device. Because of inertia, the mass opposes the acceleration experienced by the accelerometer. The amount of deflection or strain on the suspended mass is measured and used to calculate the acceleration.

Accelerometers can measure both static and dynamic acceleration. Static acceleration refers to the force of gravity and dynamic acceleration measures changes in velocity that is during movements or vibrations.

Many accelerometers are designed to measure acceleration in X, Y, and Z direction. It captures the movement in three-dimensional space which is particularly useful to track the movement of an object precisely.

Many modern accelerometers are based on MEMS technology. The BHI260AP shown in figure 2 is specifically a 6-axis sensor hub which uses MEMS technology incorporates both an accelerometer and a gyroscope [4]. These sensors are often used in various electronic devices to measure motion, orientation, and acceleration. The combination of accelerometer and gyroscope data allows for more accurate motion sensing and tracking. Acceleration is measured in units of meters per second squared ($m\ s^{-2}$) or in multiples of the acceleration due to gravity (g), where 1 g is approximately equal to 9.81 $m\ s^{-2}$.

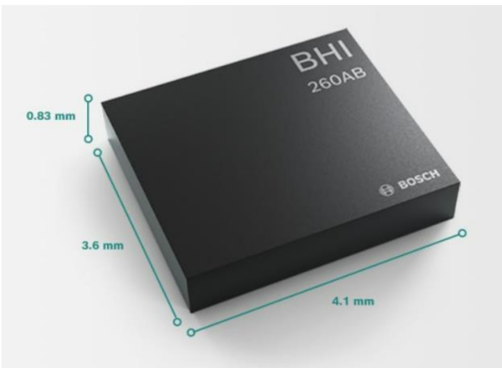

Figure 2: BHI260AP smart sensor [4]

3 Methods

The Arduino Nicla Sense ME boards typically come with a variety of sensors, including those for environmental sensing such as temperature, humidity and pressure and also motion sensing such as accelerometers and gyroscopes. The Arduino Nicla Sense ME board's integrated BHI260AP pressure sensor and BMP390 smart sensor, which incorporates an accelerometer are used in this module to measure pressure and acceleration respectively.

The board is used in standalone mode, connected to laptop via USB and data is transmitted serially. The board is programmed using the Arduino IDE version 2.0 with the Arduino_BHY2 library version 1.5 (Bosch Sensortec). A serial terminal software, Coolterm is used to record the sensor's readings in a text file and display it on a serial monitor.

The Arduino program read sensors using virtual sensors (SENSOR_ID_BARO) for pressure and (SENSOR_ID_ACC_PASS) for acceleration. The readings are taken every 100ms and a total of 1000 values were documented.

In tasks 1 and 2, sensors are kept in steady conditions to record the pressure and acceleration in all three directions and inspect if there is any drift in the recorded values. The data is then imported into a python script for calculation of mean and offset to process and plot the corresponding graphs.

In task 3, the board is placed parallel to the floor in the elevator and made sure that the board is not moved. The recording of pressure and acceleration values in z-direction started a few seconds before the elevator's movement and elevator moved upwards from ground floor to third floor and back from third floor to ground floor.

Along with pressure and acceleration values, temperature is also recorded which were needed to substitute in barometric formula in equation (1) to calculate height of the elevator ride. The recorded values are plotted against time. Further acceleration data was integrated to compute velocity and once again integrated to compute displacement which is the height in z-direction, and both are plotted against time. The resulting graphs of both height vs time are compared.

4 Results and Discussion

Task 1

The performance of pressure sensor is addressed in task 1. Arduino Nicla Sense ME is placed on flat board under steady condition to record the readings. Pressure readings for 1000 samples in intervals of 100ms are recorded and plotted on a graph where no significant drift is observed. Figure 3 shows the pressure readings of 1000 samples.

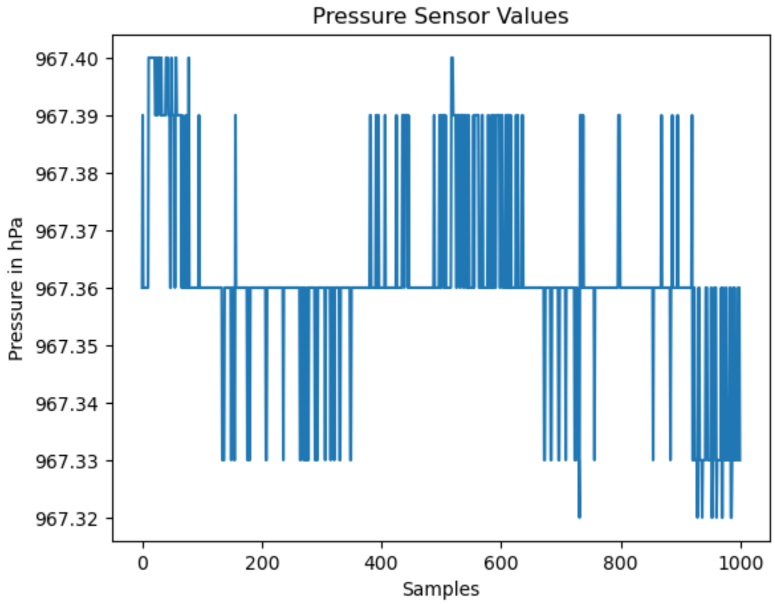

Figure 3: Pressure sensor readings at rest

Multiple iterations of 1000 readings are captured on monitor to observe drift in the value and only minimal decimal drift is noticeable when the sensor is at rest. The raw sensor output values of pressure are in hPa.

The mean and offset of all the values were calculated. It is noted that the subtracted mean of all values is considerably small and falls within the acceptable tolerance range, indicating minimal noise levels.

The subtracted mean values ($p-\bar{p}$) vs frequency is represented through a histogram in figure 4. The measured mean pressure value is 967.3615 and standard deviation is 0.01752. Most of the values lie around 0 in the mean subtracted histogram, which shows the samples don't drift much in the steady condition.

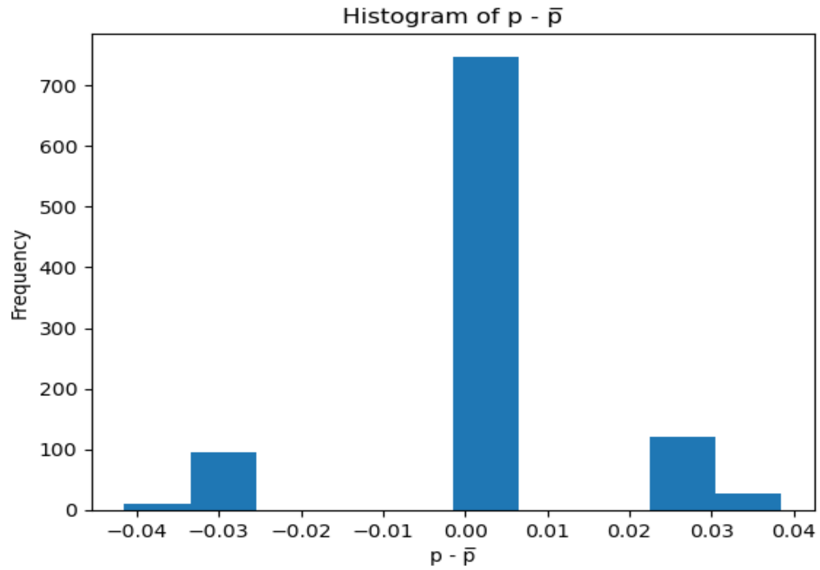

Figure 4: Histogram of mean subtracted values (p-p̄) of 1000 readings

Task 2

Task 2 is similar to the Task 1 where the Nicla Sense ME board is placed on flat board under steady condition and 1000 pressure readings are recorded in X, Y and Z directions. The raw values obtained in all three directions are divided by 4096 and then multiplied by gravity (9.81m s^{-2}) The acceleration plot of 1000 values in x-y-z direction is shown in figure 5. No drift was observed in the readings.

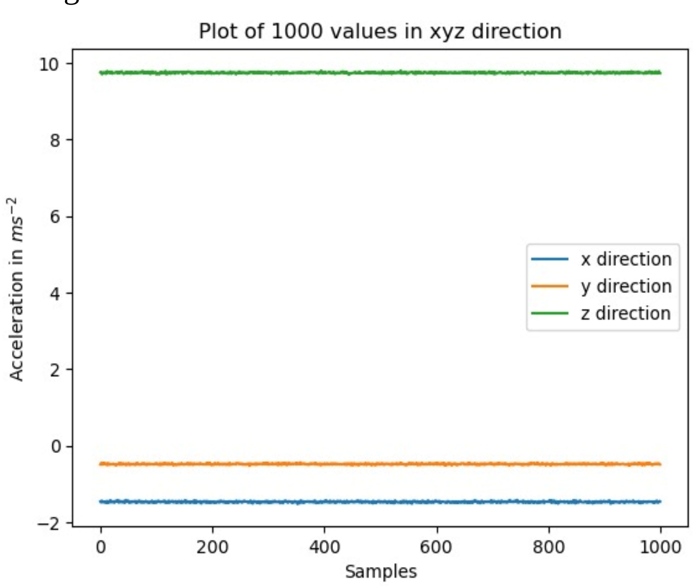

Figure 5: Acceleration values in x-y-z directions

The mean value of 1000 readings for each direction is calculated and recorded in table 1 below.

Direction	Mean ($m\ s^{-2}$)	Standard Deviation ($m\ s^{-2}$)
X	1.4704	0.0166
Y	0.4819	0.1435
Z	9.7390	0.0155

Table 1: Mean and Standard Deviation of 1000 values

The histogram of acceleration readings in x- $\bar{x}$ values, y-$\bar{y}$ values, z-$\bar{z}$ values are shown below in figure 6, figure 7, figure 8 respectively.

The mean and a-$\bar{a}$ values indicate a minimal offset, with a notable distinction observed across the X, Y and Z directions. Most of the values lie around 0 in the mean subtracted histogram in X, Y and Z directions which shows the samples don't drift much in the steady condition.

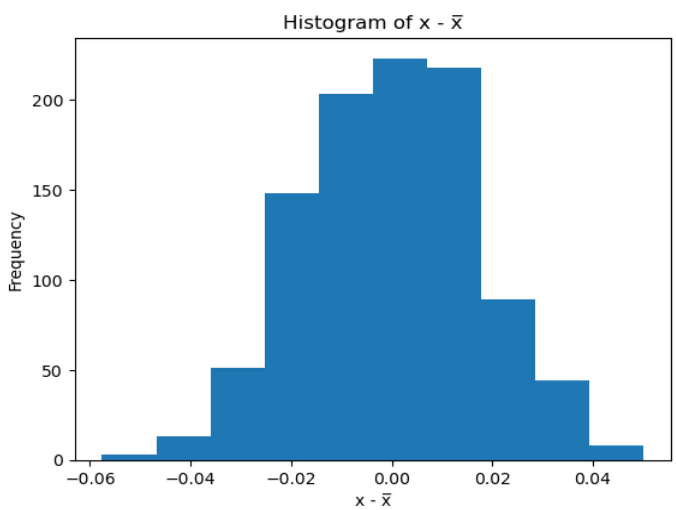

Figure 6: Histogram of acceleration reading in x- $\bar{x}$ values

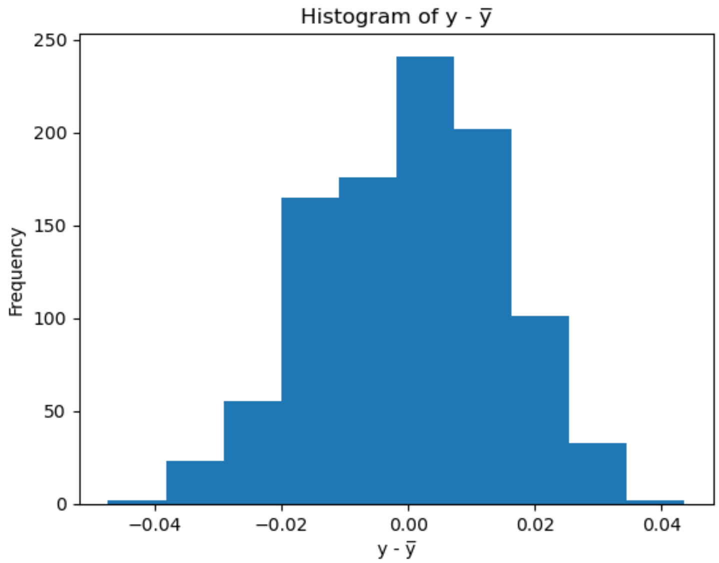

Figure 7: Histogram of acceleration reading in y-ȳ values

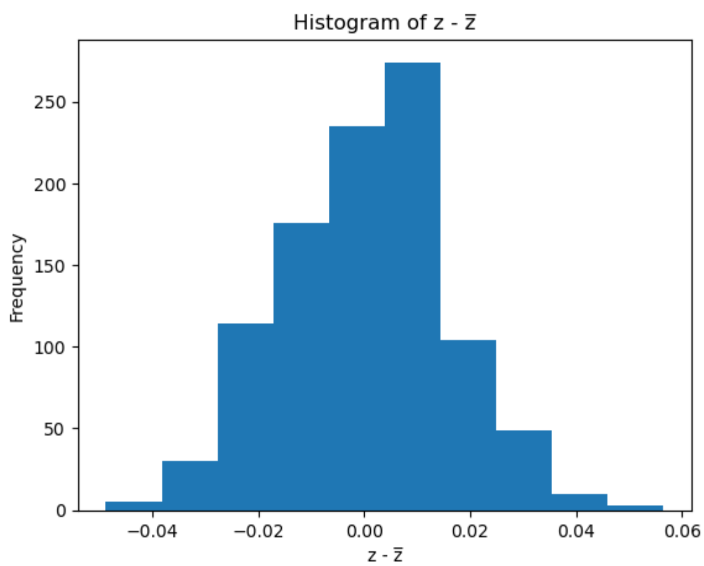

Figure 8: Histogram of acceleration reading in z-z̄ values

Task 3

In task 3, the acceleration sensor is placed parallel to the floor in the elevator and made sure that the board is not moved. It is programmed to measure the pressure and the acceleration every 100ms for 1000 counts. The measurements are taken while the elevator is moved from the ground floor to third floor and back to the ground floor. The figure 9 below shows the plot of pressure sensor values and figure 10 shows the plot of elevation vs time.

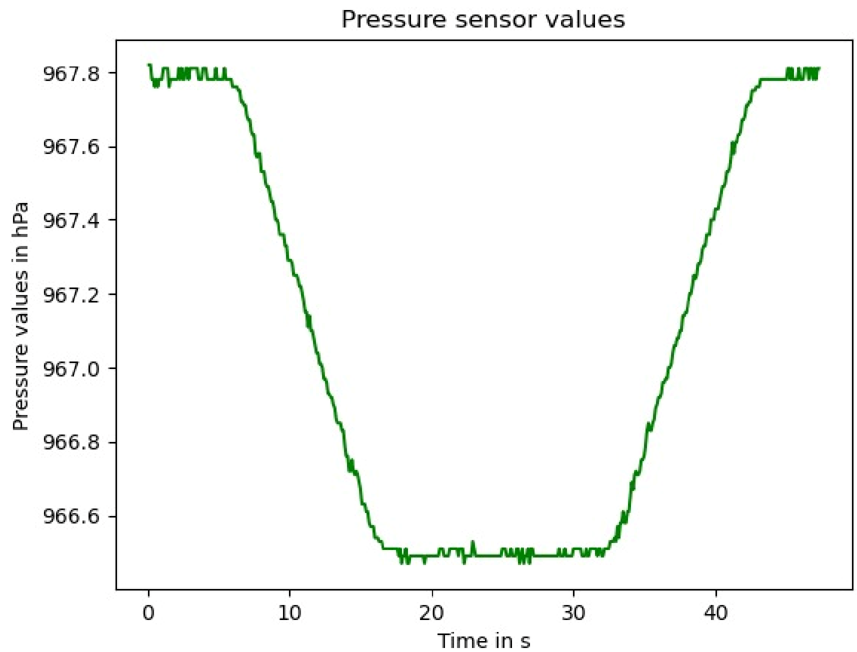

Figure 9: Pressure sensor values

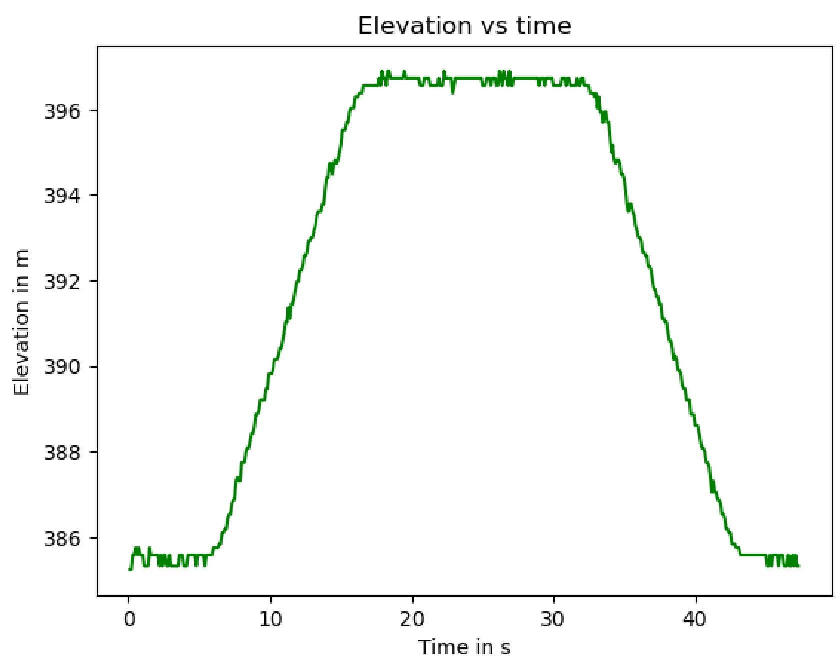

Figure 10: Plot of elevation vs time

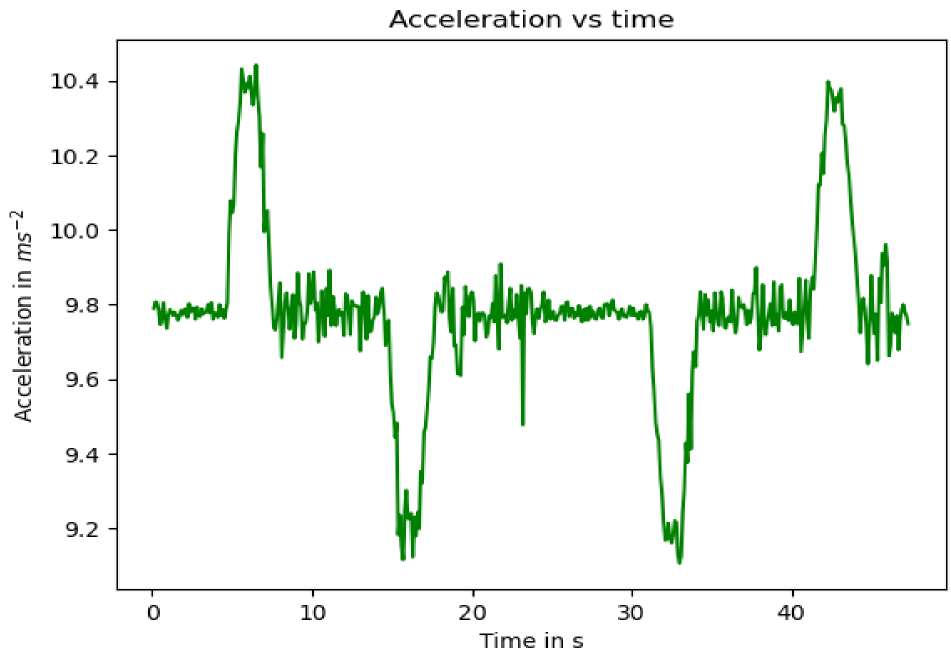

Figure 11: Plot of Acceleration sensor values

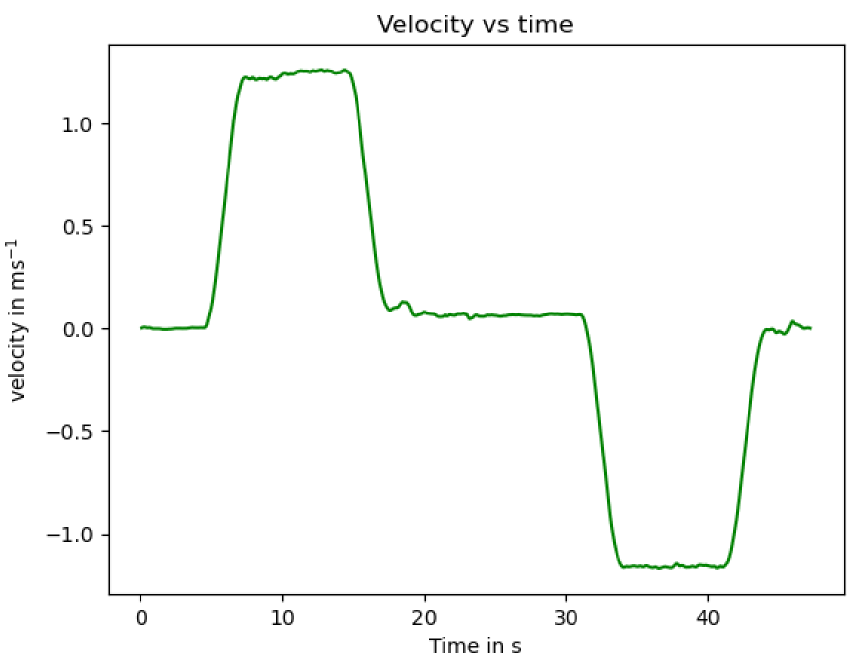

Figure 12: Plot of Velocity vs time

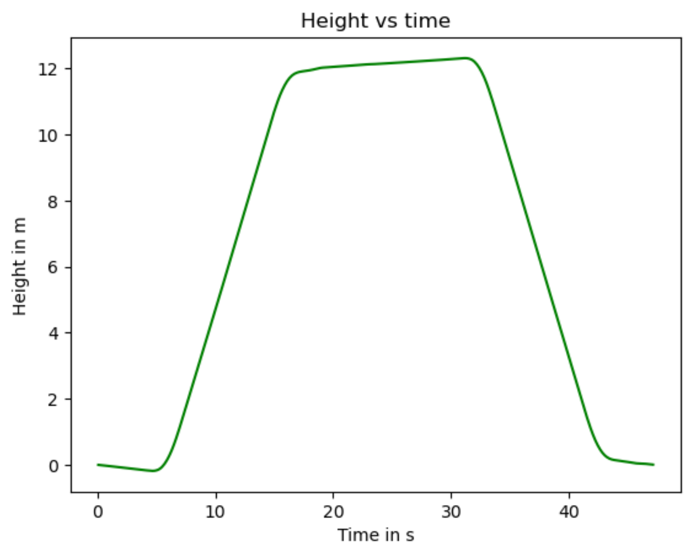

Figure 13: Plot of Height vs time after integrating acceleration twice

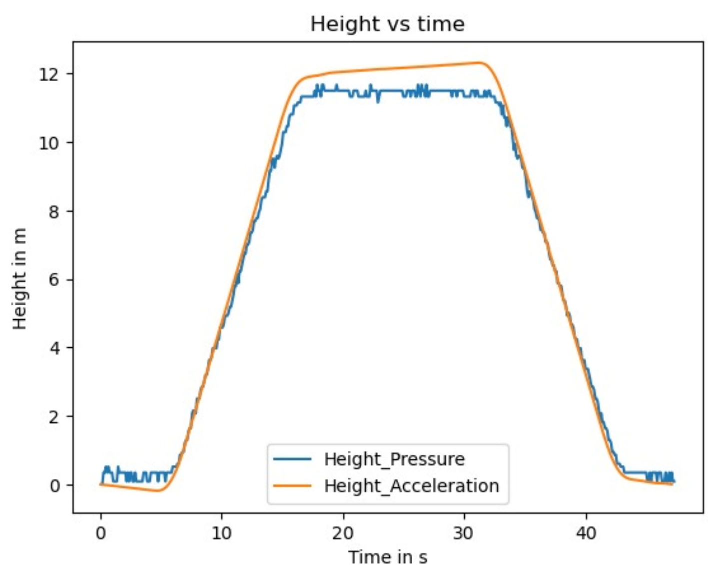

Figure 14: Comparison of height vs time plots taken from acceleration sensor and barometric formula.

The figures 11 shows the plot of acceleration sensor values, figure 12 shows the plot of velocity vs time which is obtained from integrating acceleration and figure 13 shows the plot of height vs time which is obtained from double integration of acceleration.

After the evaluation of samples, we obtain a height of 11.67m from pressure data and 12.496m from acceleration data. The height derived from both datasets closely approximates reality. However, the height calculated from acceleration data exhibited instability due to the sensor's oversensitivity shown in figure 14 and thus the altitude measurement from the pressure sensor is preferred over the double integrated values of accelerometer values.

Summary

The performance of pressure and acceleration sensors are examined, and both show very low offset. The raw data recorded are transformed into corresponding parameters, which are then analyzed through the plotting of graphs.

In the elevator experiment, the pressure sensor values prove to be more precise for altitude measurement, exhibiting lower noise levels than the values obtained from accelerometers for the measurement of heights.

References

[1] J. Kieninger, S. J. Rupitsch, Sensors Lab Course. University Freiburg. Winter term 2023/24.

[2] https://www.avnet.com/wps/portal/abacus/solutions/technologies/sensors/pressure-sensors/applications/

[3] https://www.bosch-sensortec.com/products/environmental-sensors/pressure-sensors/pressure- sensors-bmp390.html

[4] https://www.bosch-sensortec.com/products/smart-sensor-systems/bhi260ap/