Aalto University
School of Electrical Engineering

ELEC-E8740 - Basics of Sensor Fusion D

Project Work

Part I: Sensor modeling

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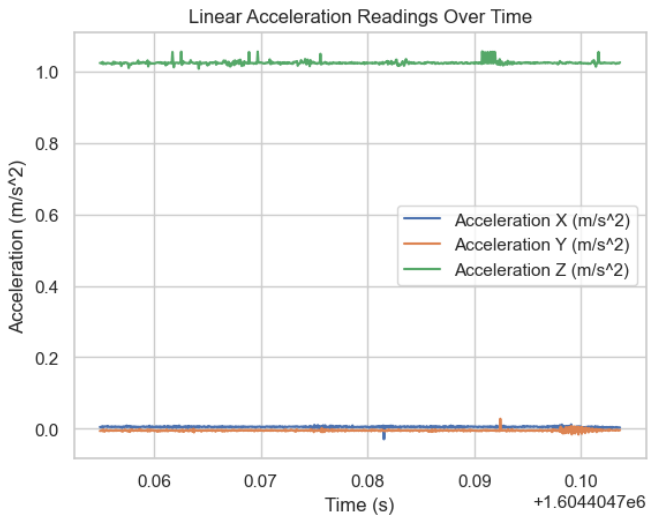
Static IMU experiment

Task 1.a

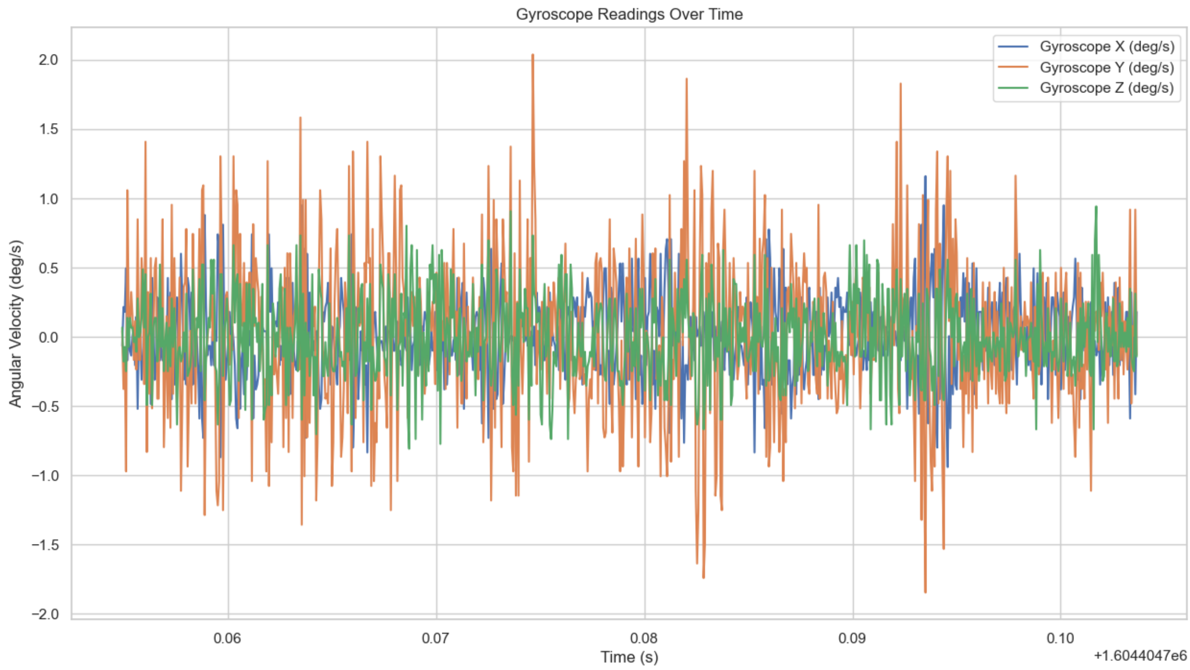
Linear acceleration reading

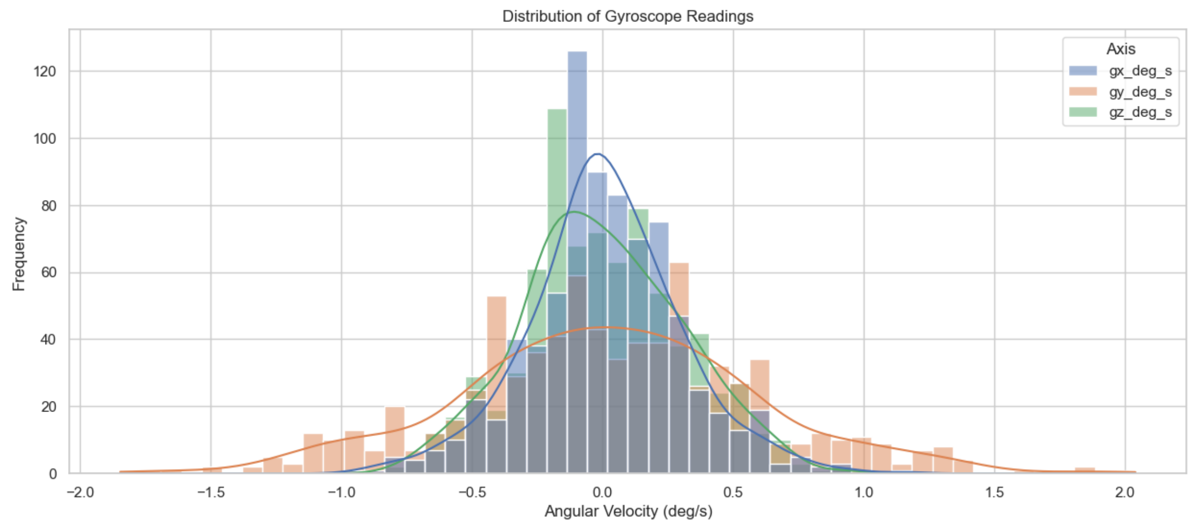
Looking at the acceleration measurements, It is possible to understand that movement or vibrations are limited. The X and Y axes display minor fluctuation around zero, which could represent small later movements or, most probably, sensor noise, which is common in stationary conditions. The Z axis shows a constant value of about 1 m/s^2 , suggesting that the sensor is aligned with gravity.



Gyroscope reading

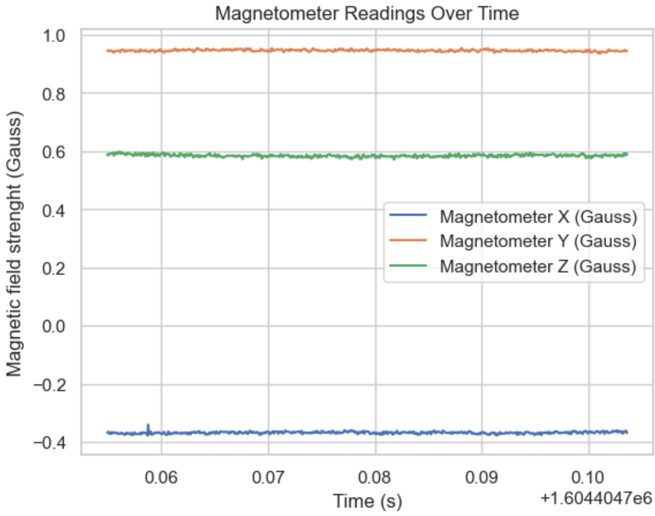
The gyroscope readings, both in their distribution and over time, indicate limited rotational movement around each axis, suggesting the sensor was mostly static. The data is centered around zero for all axes, with minor oscillations likely due to sensor noise or small, unintentional rotations in the environment. This zero-centered pattern is typical for a stationary or balanced state, where rotational forces are minimal. The slight variations around zero could provide insights into the gyroscope's sensitivity and calibration. Calculating the standard deviation of this noise would help quantify the minor rotational perturbations and improve understanding of the sensor's performance in stable conditions.





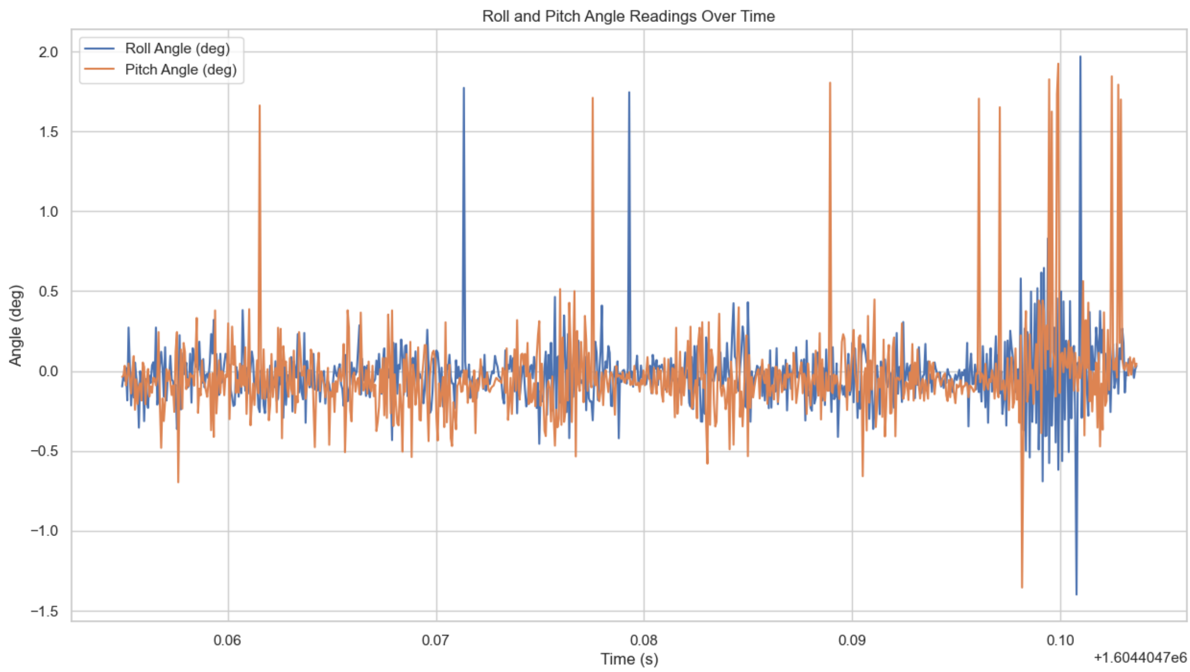
Magnetometer reading

The magnetometer readings over time show stable magnetic field values across all three axes, reflecting a consistent magnetic environment without any major disturbances. The Z-axis shows a slightly higher reading, while the X-axis is centered around -0.4 Gauss, which could indicate the sensor's orientation within the Earth's magnetic field. This stability implies an absence of external magnetic interference, suggesting the environment was relatively unaffected by nearby electronics or magnetic objects. If these values differ from expected readings based on the sensor's orientation, a calibration process may be necessary to achieve more accurate measurements in future setups.



Roll and pitch angle reading

Finally, the roll and pitch angle readings demonstrate minor fluctuations around zero, indicating that the sensor's orientation remained largely unchanged during the recording period. The small spikes observed in these angles could be the result of brief disturbances or sensor noise, yet overall, the data implies that the sensor was nearly horizontal and experienced minimal tilt. The stability in roll and pitch provides further evidence of the sensor's stationary state, with minimal alignment changes. These spikes might benefit from filtering to isolate noise from genuine orientation shifts, especially in dynamic environments where precise orientation tracking is necessary.



Task 1.b

The bias values, representing the mean angular velocity for each axis, indicate slight offsets from zero, with the Y-axis showing the largest bias. This suggests a small, consistent drift in the Y-axis measurements. The variance values provide insights into the stability of each axis's readings, with the Y-axis again displaying the highest variance, indicating more variability in its measurements compared to the X and Z axes. This information is crucial for understanding and correcting the gyroscope's behavior in sensor fusion applications, as it highlights potential areas where calibration or filtering may be needed.

Table 1: Gyroscope Bias and Variance for Each Axis

Axis	**Bias (Mean) [deg/s]**	**Variance [(deg/s)^2]**
gx_deg_s	0.008971	0.085087
gy_deg_s	0.016855	0.327209
gz_deg_s	-0.001298	0.094086

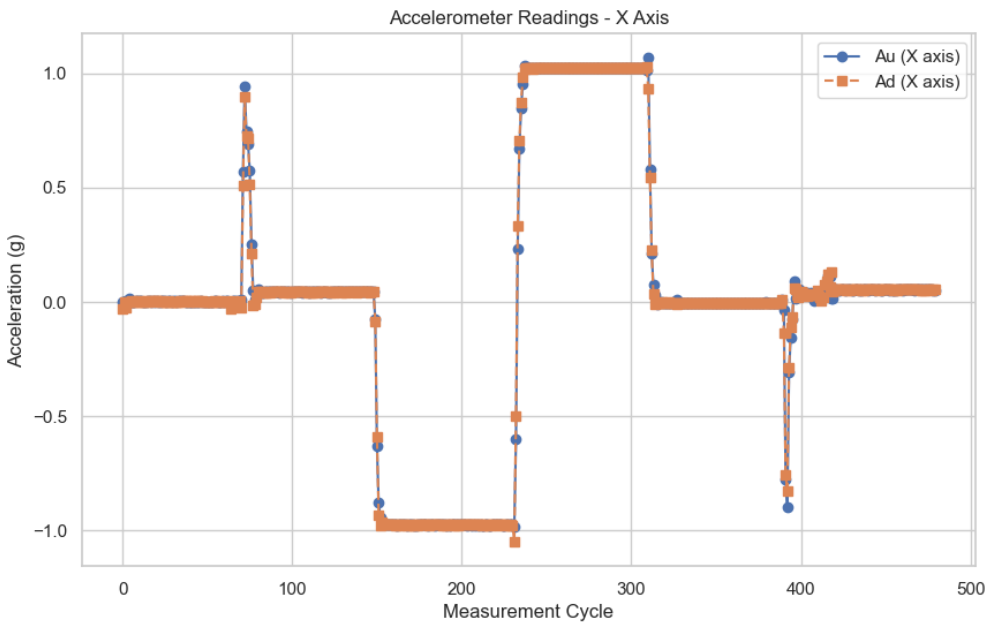
IMU calibration (accelerometer calibration)

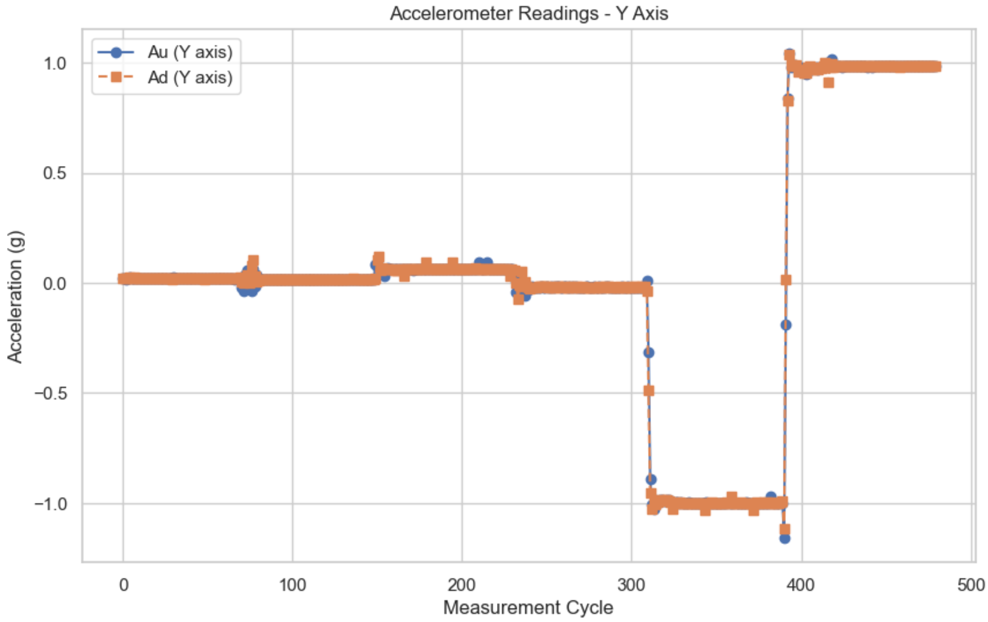
Task 2

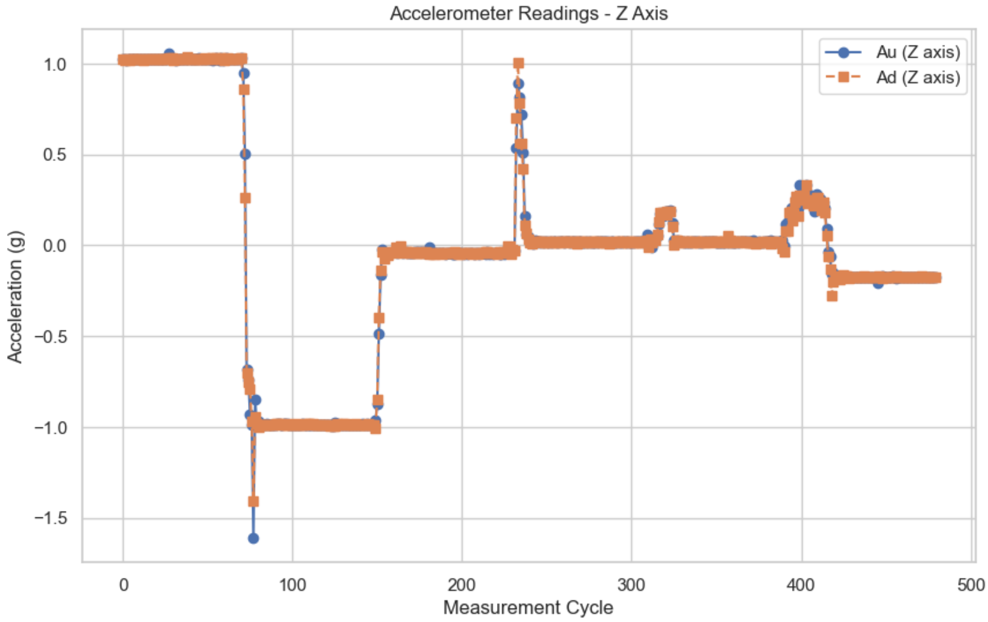
The accelerometer plots for the X, Y, and Z axes show clear transitions between positive, near-zero, and negative values, corresponding to changes in orientation. For the X-axis, the calculated gain $k_x = 0.000422$ and bias $b_x = 0.015253\,g$ suggest a slight offset and a small scaling adjustment needed to bring the values closer to ideal measurements. The plot displays stable plateaus between transitions, indicating consistent readings in each orientation. The Y-axis exhibits similar stepping behavior, but the negative gain $k_y = -0.000259$ may indicate that the raw values are inverted, potentially requiring further calibration to match expected results. Its higher bias $b_y = 0.025903\,g$ indicates a slightly larger offset than observed in the X-axis. The Z-axis shows larger fluctuations, with a higher gain $k_z = 0.000763$ and a slight downward bias $b_z = -0.007498\,g$. These variations could be due to the sensor's alignment with gravity or minor environmental disturbances. Overall, these gain and bias values are essential for calibrating the accelerometer, enabling the sensor to produce measurements that align more accurately with real-world physical quantities.

Table 2: Calculated Gain and Bias for Accelerometer Axes

Axis	**Gain (k_i)**	**Bias (b_i) [g]**
X axis	0.000422	0.015253
Y axis	-0.000259	0.025903
Z axis	0.000763	-0.007498



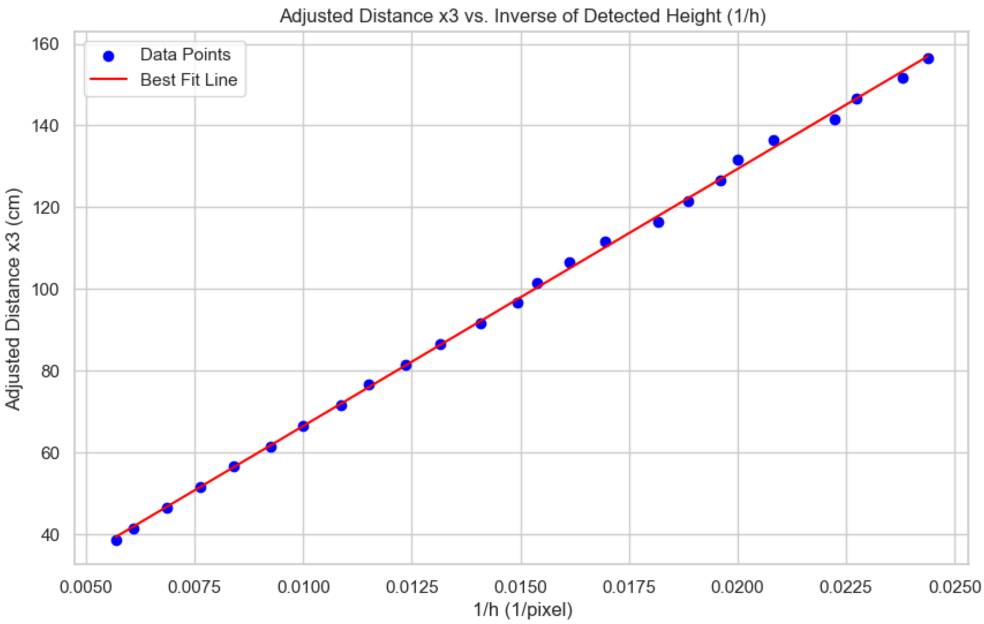

Accelerometer Readings - Y Axis
Au (Y axis)
Ad (Y axis)
Acceleration (g)
Measurement Cycle
1.0
0.5
0.0
−0.5
−1.0
0
100
200
300
400
500


Accelerometer Readings - Z Axis
Au (Z axis)
Ad (Z axis)
Acceleration (g)
Measurement Cycle
1.0
0.5
0.0
−0.5
−1.0
−1.5
0
100
200
300
400
500

Camera module calibration

Task 3.a

In Task 3a, the plot of adjusted distance ($x3$) versus the inverse of detected height ($1/h$) reveals a strong linear relationship, allowing for the calculation of the gradient $k = 6285.20$ cm·pixels and bias $b = 3.68$ cm. The gradient represents the rate at which the adjusted distance changes with respect to the inverse of the detected height, acting as a scaling factor between these variables. The bias, on the other hand, accounts for any initial offset in the measurements, likely resulting from the fixed distance of the camera from the surface, as specified in the setup.



Task 3.b

For Task 3b, the focal length f was determined using the equation:

$$x3 = \frac{h_0 f}{h} + b \tag{1}$$

with the known height $h_0 = 11.5$ cm of the QR code. This calculation resulted in a focal length of $f = 546.54$ pixels. The focal length is a crucial parameter in the imaging system, as it allows the translation of pixel measurements into real-world distances. This value is essential for accurately determining object distances and performing reliable localization in the camera's field of view.

Motor control

Task 4

In Task 4, the relationship between the robot's speed and its distance from the camera is shown. The calculated speeds at different distances display slight fluctuations, ranging from approximately 5.8 to 6.3 cm/s. Despite these variations, the overall average speed of the robot is determined to be 6.09 cm/s. This average speed provides a consistent measure of the robot's movement across the range of distances, suggesting relatively stable motion with minor variations likely due to external factors or measurement precision.