# Final Smartphone Project

Yongzhao Chen(yongzhao@chalmers.se)

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# 1 Q1: Choices of input and output

Task 1: Discuss pros and cons regarding this choice of input. Can you imagine a situation where this would not be a good choice? When would it be better to include angular velocities in the state vector? You do not need to provide a long discussion, but your statements/examples should be clearly explained.

**Pros of selecting $u_k = w_k$ (using angular velocities as inputs):**

1. Accuracy: Gyroscope measurements of angular velocities are typically more accurate and less prone to noise compared to other sensor measurements. Using them as inputs can improve the accuracy of the estimation process.

2. High update rate: Gyroscopes usually provide measurements at a high sampling rate, allowing for more frequent updates to the estimation algorithm. This can lead to faster and more responsive estimation of the system's orientation.

3. Reduced computational complexity: By using angular velocities as inputs, the dimensionality of the state vector is reduced. This simplifies the estimation algorithm and reduces computational requirements, leading to faster execution and lower resource consumption.

4. Elimination of bias estimation: If the gyroscope measurements are known to be unbiased, using them as inputs eliminates the need to estimate gyroscope biases. This simplifies the estimation problem and reduces the number of parameters to estimate.

**Cons of selecting $u_k = w_k$:**

1. Limited observability: By using angular velocities as inputs, the estimation algorithm relies solely on the gyroscope measurements to estimate the system's orientation. This can result in limited observability, especially if the gyroscope measurements are affected by biases or inaccuracies. In such cases, incorporating additional sensor measurements may be necessary to improve observability.

2. Susceptibility to gyro drift: Gyroscopes can experience drift over time, leading to errors in the estimated orientation. If the system operates for an extended period without any external reference or correction, the estimated orientation can gradually deviate from the true orientation.

3. Lack of absolute reference: Using angular velocities as inputs does not provide an absolute reference for the system's orientation. The estimated orientation may drift over time, especially if there is no external measurement or reference available to correct for cumulative errors.

4. Vulnerability to measurement disturbances: If the gyroscope measurements are affected by external disturbances, such as vibrations or shocks, the estimation process relying solely on these measurements may be more susceptible to inaccuracies and performance degradation.

In summary, selecting $u_k = w_k$ (using angular velocities as inputs) offers advantages such as accuracy, high update rate, reduced computational complexity, and elimination of bias estimation. However, it may suffer from limited observability, gyro drift, lack of absolute reference, and vulnerability to measurement disturbances. The suitability of this choice depends on the specific system requirements, the quality of gyroscope measurements, and the availability of additional sensor measurements for improved estimation performance.

**When would it be better to include angular velocities in the state vector?**

Including angular velocities in the state vector can be beneficial in the following situations:

1. Dynamic Systems: If the system being modeled exhibits complex dynamics that cannot be accurately captured solely by the measurements, incorporating angular velocities as state variables can provide a more comprehensive representation of the system's behavior. This is particularly useful when the system undergoes rapid changes or has nonlinear dynamics.

2. Noisy Measurements: If the measurements of angular velocities are noisy or subject to significant disturbances, using them as state variables can help mitigate the impact of measurement uncertainties. By incorporating the measurements directly into the state vector, the estimation algorithm can account for the noise and improve the overall accuracy of the state estimation.

3. Biased Measurements: In some cases, the measurements of angular velocities may suffer from biases due to sensor imperfections or environmental factors. By including angular velocities as state variables and estimating the biases,

the estimation algorithm can compensate for these biases and provide more accurate results.

4. System Identification: Including angular velocities as state variables can facilitate system identification and parameter estimation. By considering the dynamics of angular velocities within the state vector, it becomes possible to estimate system parameters, such as inertia properties or damping coefficients, along with the orientation.

5. Integration with Other Sensors: Incorporating angular velocities in the state vector can enhance the fusion of multiple sensor modalities. By including the gyroscope measurements as state variables, they can be combined with measurements from other sensors, such as accelerometers or magnetometers, to improve the accuracy and reliability of the overall estimation process.

It's important to note that the decision to include angular velocities in the state vector should consider the specific characteristics of the system, the quality of the measurements, and the computational complexity of the estimation algorithm. In some cases, the additional complexity and computational burden may outweigh the benefits, and it may be more suitable to rely solely on the measurements of angular velocities without including them in the state vector.

# 2 Task 2

In this task, I placed the phone on the table without any touch or movement.

When the phone is placed flat on a table, the accelerometer should read the gravitational acceleration on the Z-axis, while the readings on the X and Y axes should be zero. The readings of the gyroscope should be zero in all three directions, while the magnetometer readings should reflect the magnetic field strength of the phone's current position.

Just note myself: 3pm 5.24 from library

Since the last moment I touched the screen to stop stream, so in calculation I should remove a little bit tail data.

## 2.1 True state

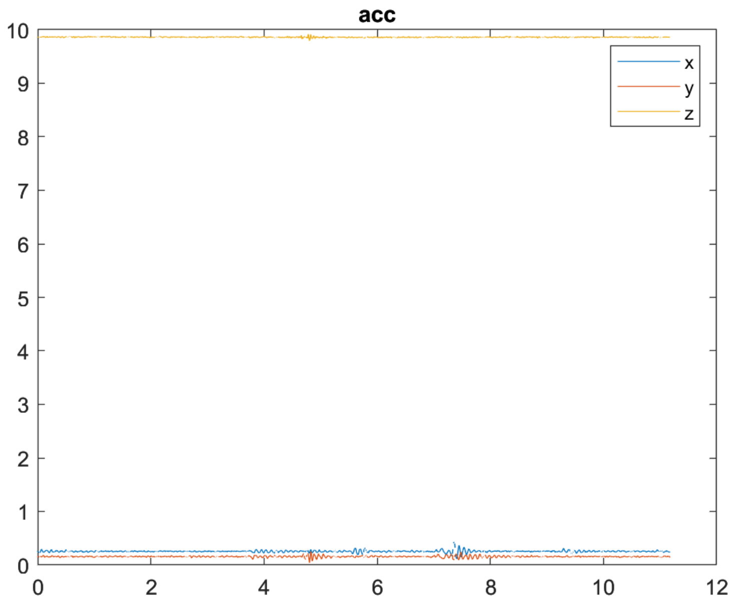


*Figure 1: Accelerometers*

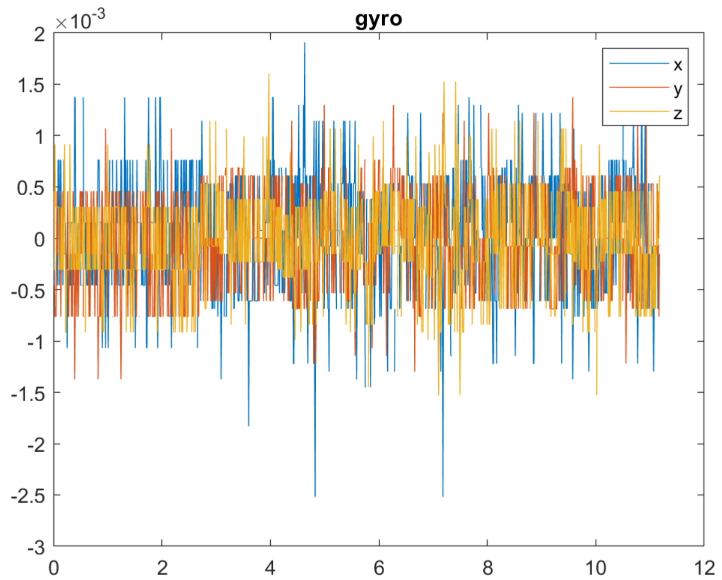


*Figure 2: Gyroscope*

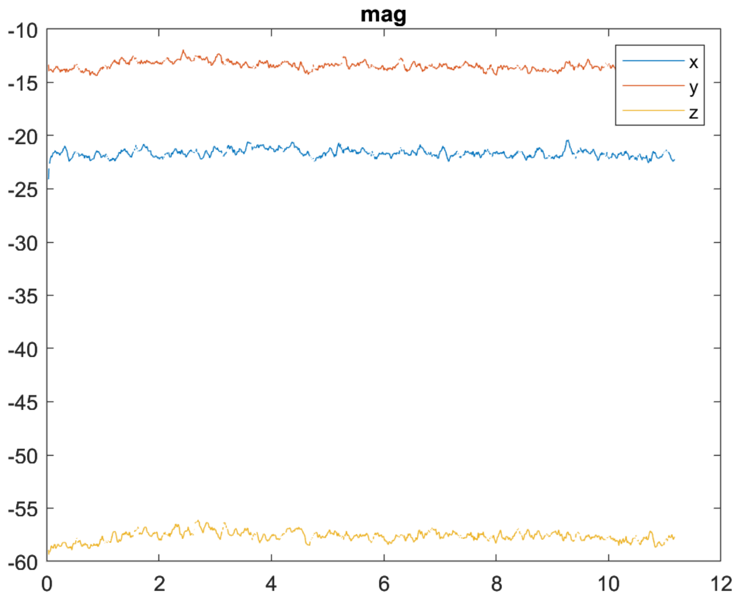


*Figure 3: Magnetometers*

By observing the plots of the sensors, it can be noted that when the phone is placed flat on a table, the readings from all three sensors exhibit a stable trend without significant disturbances.

## 2.2 Mean and covariance and histograms

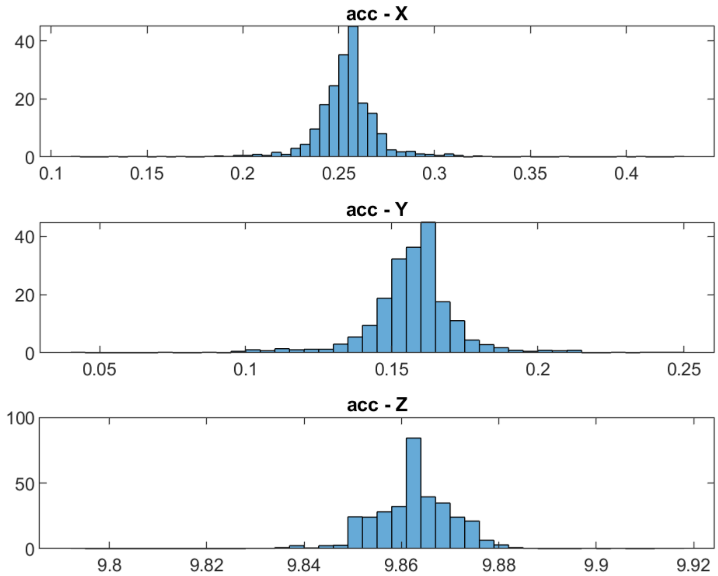


*Figure 4: Histograms for accelerometers*

The mean of acc -X is 0.254171 , the covariance of acc -X is 0.019724

The mean of acc -Y is 0.157052 , the covariance of acc -Y is 0.016096

The mean of acc -Z is 9.862452 , the covariance of acc -Z is 0.008445

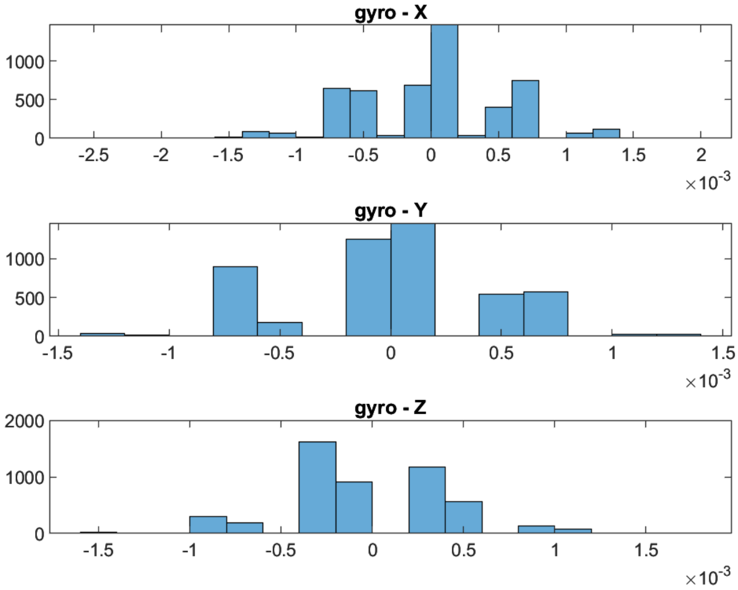


*Figure 5: Histograms for gyroscope*

The mean of gyro -X is 0.000014 , the covariance of gyro -X is 0.000554

The mean of gyro -Y is -0.000031 , the covariance of gyro -Y is 0.000449

The mean of gyro -Z is -0.000025 , the covariance of gyro -Z is 0.000453

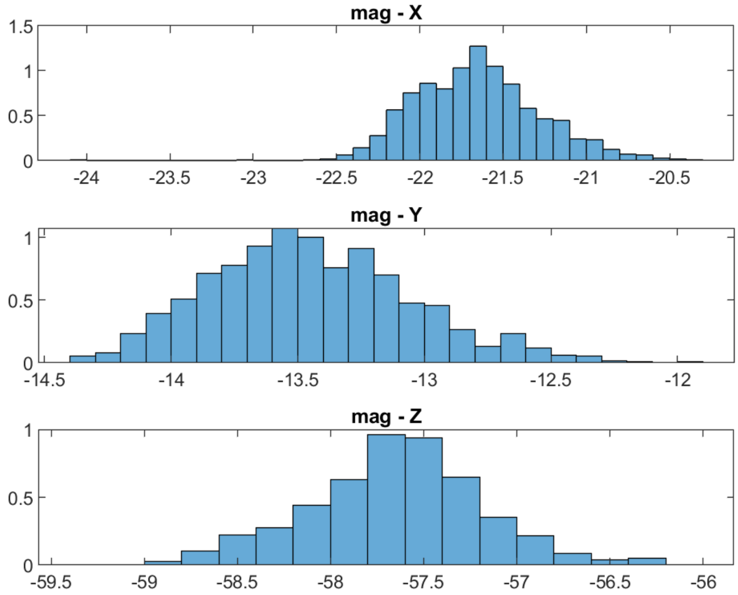


*Figure 6: Histograms for magnetometers*

The mean of mag -X is -21.648532 , the covariance of mag -X is 0.377973

The mean of mag -Y is -13.445163 , the covariance of mag -Y is 0.401212

The mean of mag -Z is -57.647071 , the covariance of mag -Z is 0.477309

The histogram of the accelerometer (acc) exhibits a shape close to a Gaussian distribution, with a small offset around the mean. This offset may be attributed to initial calibration errors present during sensor measurements. Considering the protrusion of the rear camera on my phone, the mean offset of the accelerometer is likely caused by the components of gravitational acceleration along the corresponding coordinate axes. Since the phone is unlikely to be placed on a table for measurements in future use, this error can be avoided. Therefore, it is reasonable to treat the noise in the accelerometer as Gaussian noise.

The histogram of the gyroscope (gyro) does not perfectly match a Gaussian distribution. This discrepancy could be due to the gyroscope's measurement errors being extremely small. Even if there are some offsets, the histogram shape may not be as pronounced as a Gaussian distribution due to the minimal presence of noise. The noise in the gyroscope is extremely small. During the subsequent tuning process, it can be considered completely reliable, and its measurement model's noise can be set to zero.

The histogram of the magnetometer (mag) exhibits a shape similar to a Gaussian distribution but with an overall offset. This offset may be caused by environmental noise in the magnetic field or biases in the magnetometer. The magnetometer should be calibrated based on the current environment before each use, depending on the specific requirements of the subsequent content.