Introduction

The purpose of this report is to estimate roll and pitch angles using IMU data from an iPhone 15 Max and compare the complementary filter output with the ground truth provided by the device's orientation sensor. The collected data includes accelerometer (in m/s^2) and gyroscope data (in rad/s) readings from a calibrated SensorLogger app, running at 100 Hz sampling frequency. Roll and pitch estimates were calculated for various static phone orientations using a complementary filter.

This report will go into the details of methodology for data collection, the complementary filter implementation, and an analysis of the results including comparisons with ground truth.

Data Collection

Data was collected using the SensorLogger app under the following conditions:

- Sampling frequency: 100 Hz for accelerometer, gyroscope, and orientation sensors.
- Setup: Device was placed on a flat surface (base side down) and tilted at specific angles using books for elevation. The phone remained static for 20 seconds during each reading

The angles used for data collection include:

1. Baseline
   a. Screen facing up, back placed on surface (0 degrees)
2. Pitch Changes
   a. Top of the phone inclined at 20°, 40°, 60°, 80°, and 90°
3. Roll Changes
   a. Right side of the phone inclined at 20°, 40°, 60°, 80°, and 90°

Methodology

1. Pre-processing
   - Low-pass Filtering:
     1. The data coming from the SensorLogger app is already calibrated but were passed through a low-pass filter to remove any high-frequency noise
   - Timestamp Synchronization:
     1. All sensor data was interpolated and resampled to align timestamps using a common time base at 100 Hz
2. Complementary Filter Implementation
   The complementary filter combines accelerometer and gyroscope data to estimate roll and pitch angles using the following steps:
     1. Initialization:
        a. Set initial roll (ϕ) and pitch (θ) values
     2. Gyroscope-based Estimate:

    a. Integrate angular velocity from the gyroscope to calculate changes in roll and pitch

$$\phi_{gyro}[i] = \phi_{gyro}[i - 1] + \omega_x[i] \cdot \Delta t$$

$$\theta_{gyro}[i] = \theta_{gyro}[i - 1] + \omega_y[i] \cdot \Delta t$$

3. Accelerometer-based Estimate:
    a. Calculate roll and pitch directly using accelerometer readings

$$\phi_{acc}[i] = arctan(\frac{a_y[i]}{a_z[i]})$$

$$\theta_{acc}[i] = arctan(\frac{-a_x[i]}{\sqrt{a_y^2[i]+a_z^2[i]}})$$

4. Combinations
    a. Combine the gyroscope and accelerometer estimates using a weighting factor of α

$$\phi\ [i] = \alpha \cdot \phi_{gyro}[i] + (1 - \alpha) \cdot \phi_{acc}[i]$$

$$\theta\ [i] = \alpha \cdot \theta_{gyro}[i] + (1 - \alpha) \cdot \theta_{acc}[i]$$

Results and Discussion

The following figures illustrate the roll and pitch estimates from the complementary filters compared to the ground truth orientation from the iOS device. The results are shown for baseline, pitch changes (20 deg, 60 deg) and roll changes (20 deg, 60 deg).

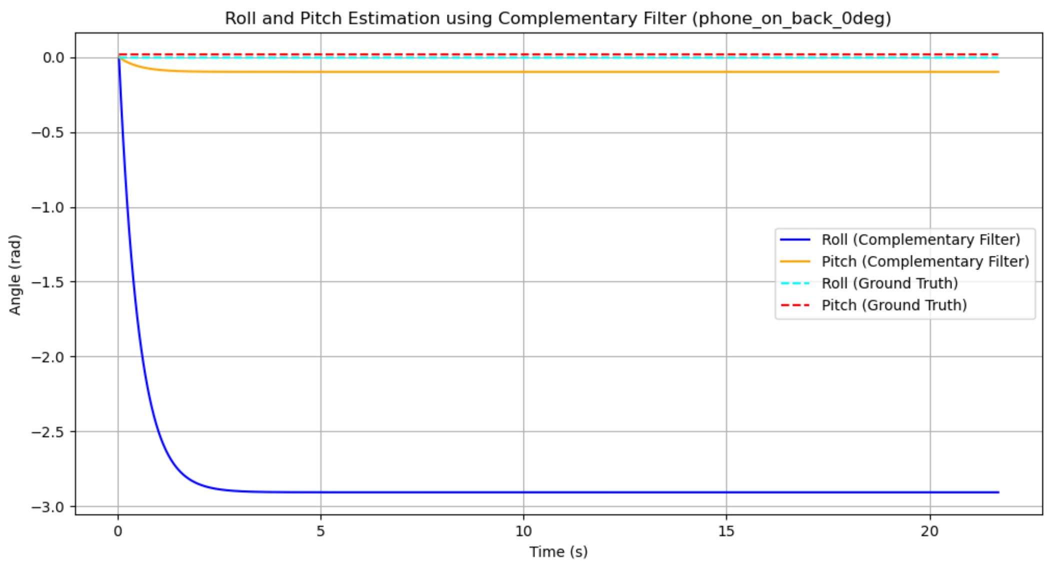

Figure 1. Baseline roll and pitch estimation vs ground truth

Roll: The roll estimation starts with significant negative drift and stabilizes over time. This drift is caused by the reliance on gyroscope data, which accumulates error over time. The filter eventually balances the accelerometer input to stabilize the roll near zero, but it does not converge perfectly to the ground truth (cyan dashed line).
Pitch: The pitch estimation aligns closely with the ground truth (red dashed line) and remains stable. This demonstrates that the complementary filter effectively captures pitch when the phone is stationary.
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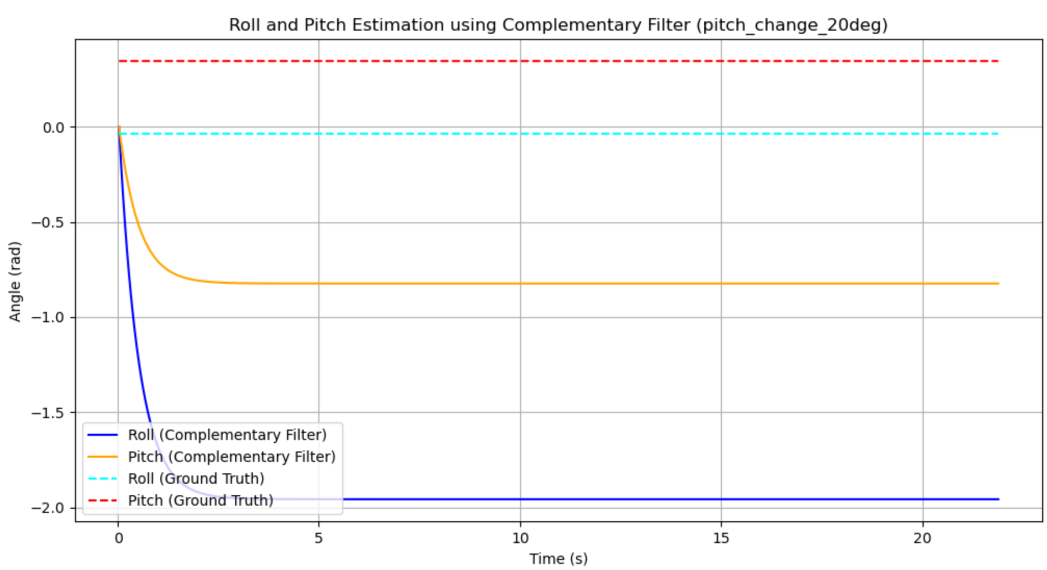

Figure 2. Pitch change 20 degrees roll and pitch estimation vs ground truth

Roll (Complementary Filter): Again, it can be seen that there is significant drift and then stabilization.

Pitch (Complementary Filter): The pitch estimation error can be seen to increase indicating that drift is affecting this signal as well

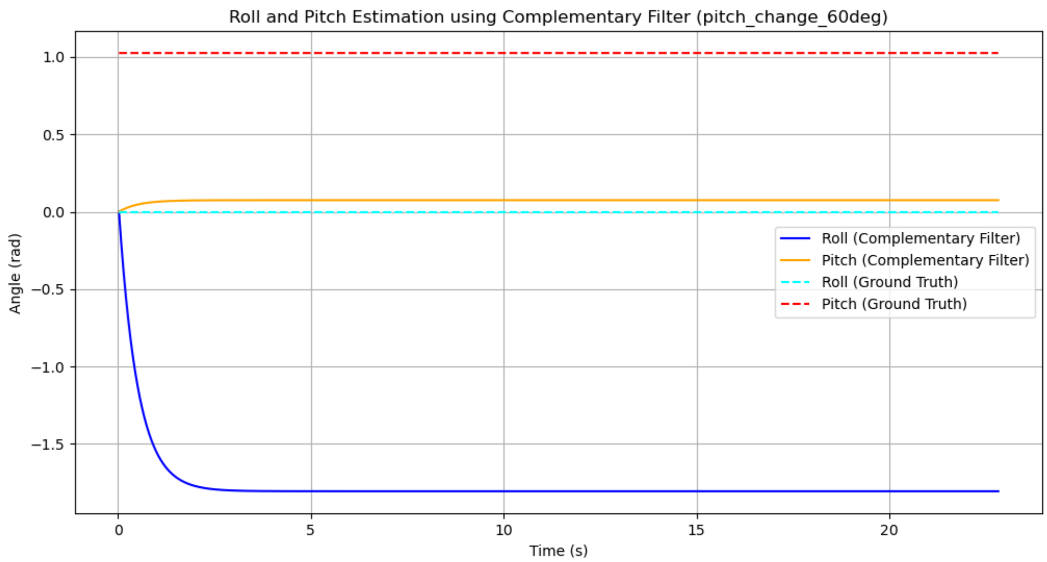

Figure 3. Pitch change 60 degrees roll and pitch estimation vs ground truth

Roll: Same as before

Pitch: The expected pitch should be 60 degree but is near zero.

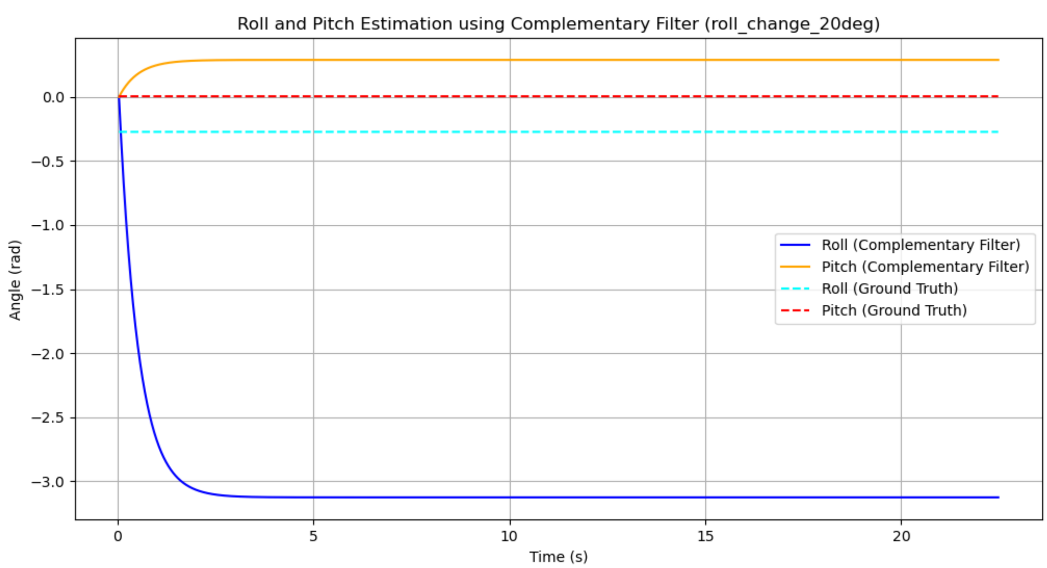

Figure 4. Roll change 20 degrees roll and pitch estimation vs ground truth

Roll: Behaves as before in the pitch change readings.

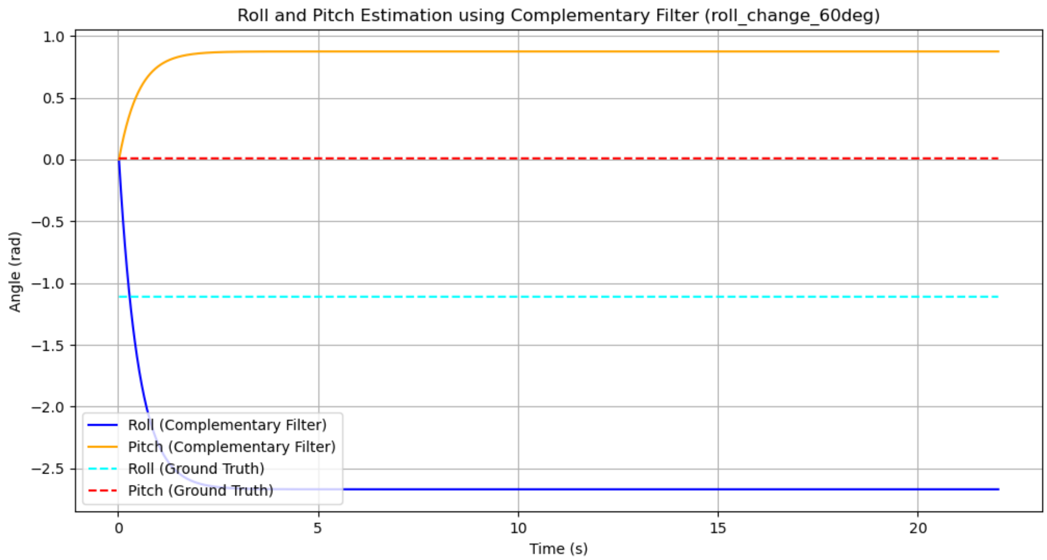

Figure 5. Roll change 60 degrees roll and pitch estimation vs ground truth

From the images above, it can be seen that the estimation of the pitch and roll angles from the IMU sensor using a complementary filter will not result in good estimations. Of course, this is the case for an IMU within an iPhone, perhaps with better filter such as a Kalman filter, the estimation error could be mitigated. It is also important to note that this data was already calibrated from the SensorLogger app, however the uncalibrated raw signals can also be accessed so there is some interest for me to look into the raw data and calibrate it on my own and test to see how the filter would work from there.