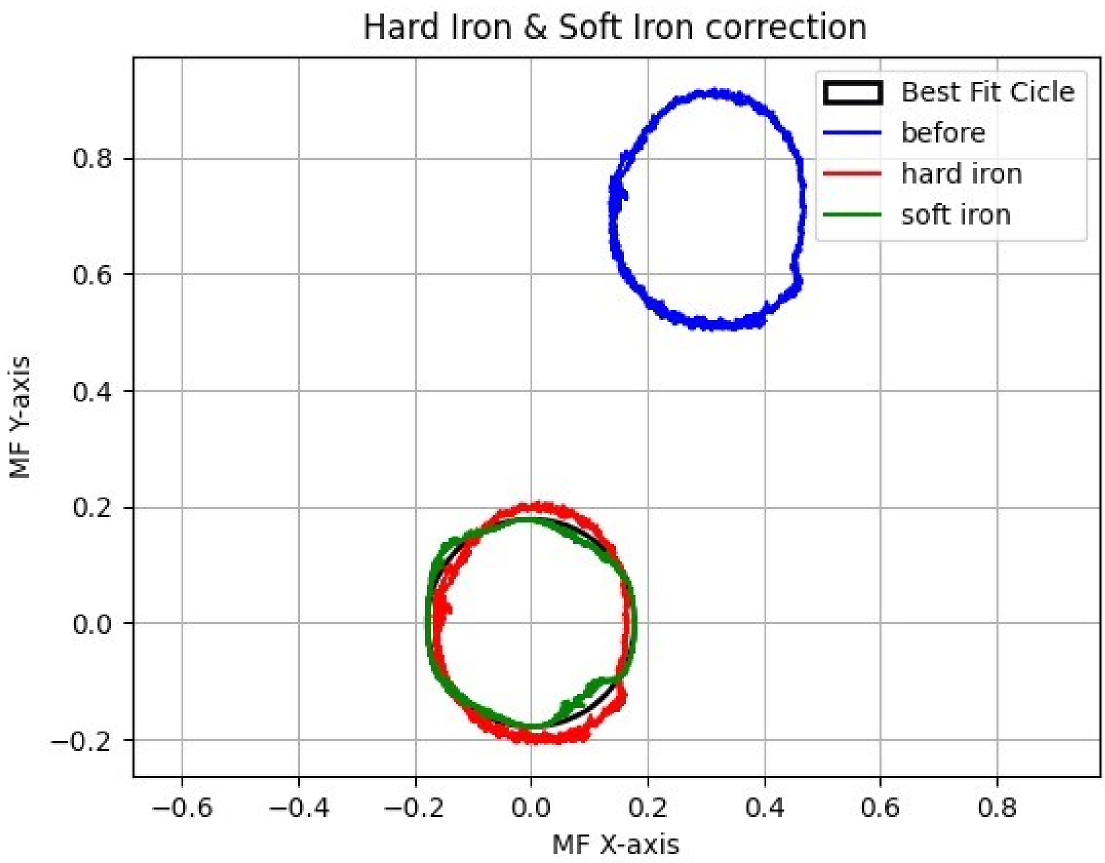
REPORT



1 st answer:-

Magnetometer is a sensor that measures the Earth's magnetic field and provides the heading (the compass is one such device). If it is included in the IMU, we commonly describe it as a "**nine-axis IMU**."

To calibrate the magnetometer from the data collected, I used the following steps:

1. I calculated the hard iron offset by finding the average of the minimum and maximum values of each axis.

2. I subtracted the hard iron offset from each data point to get the soft iron corrected data.
3. I used a least squares fitting algorithm to fit a best fit circle to the soft iron corrected data.
4. I calculated the soft iron scale factor by dividing the radius of the best fit circle by the magnitude of the Earth's magnetic field.
5. I applied the soft iron scale factor to the soft iron corrected data to get the calibrated magnetometer data.

The sources of distortion present in the data are:

- Hard iron distortion: This is caused by the presence of nearby permanent magnets. It results in a constant offset to the magnetometer readings.
- Soft iron distortion: This is caused by the presence of nearby ferromagnetic materials. It results in a scaling and rotation of the magnetometer readings.

I know that these sources of distortion are present because the data does not lie on a perfect sphere. The best fit circle to the soft iron corrected data is not a perfect circle, which indicates that soft iron distortion is present.

Here is a more detailed explanation of how to calculate the hard iron offset and soft iron scale factor:

To calculate the hard iron offset:

1. Find the minimum and maximum values of each axis of the magnetometer data.
2. Average the minimum and maximum values of each axis to get the hard iron offset for that axis.

To calculate the soft iron scale factor:

1. Fit a best fit circle to the soft iron corrected magnetometer data.
2. Calculate the radius of the best fit circle.
3. Divide the radius of the best fit circle by the magnitude of the Earth's magnetic field to get the soft iron scale factor.

Once the hard iron offset and soft iron scale factor have been calculated, they can be applied to the raw magnetometer data to get the calibrated magnetometer data.

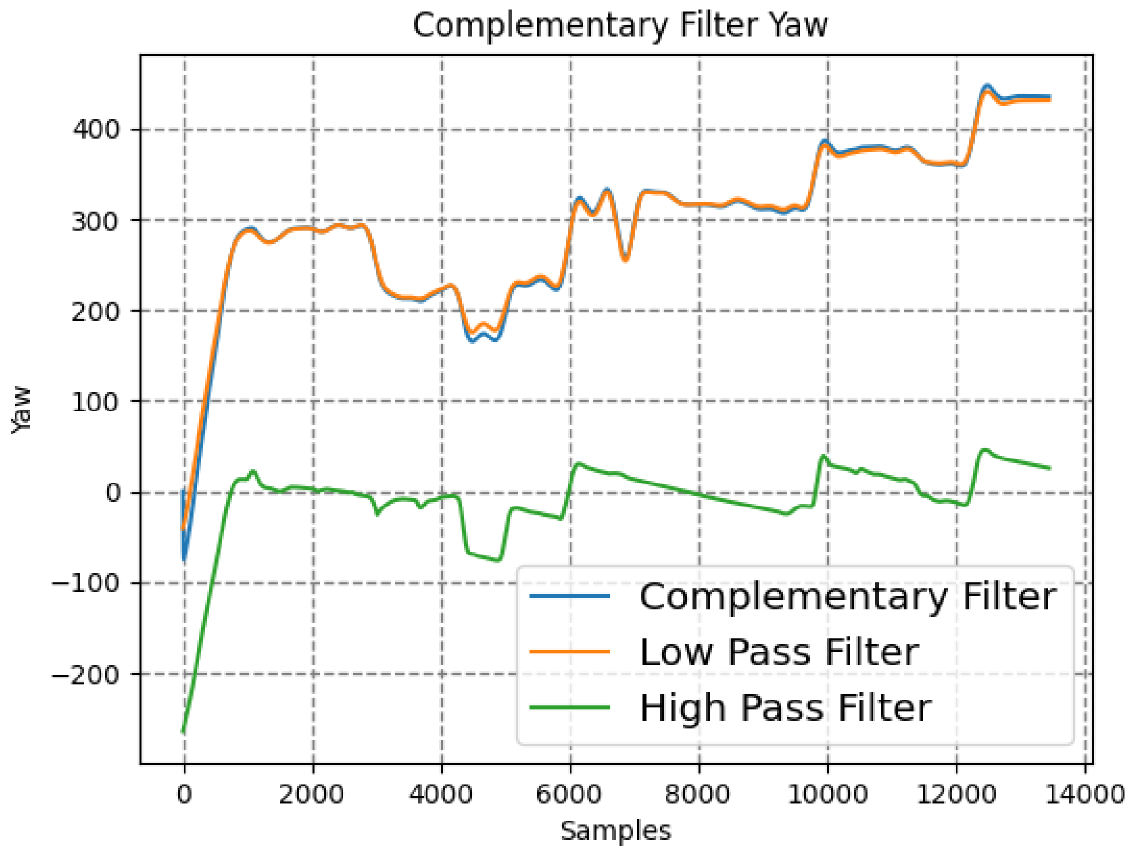
I know that there is hard iron and soft iron distortion present in the data because of the following:

- The best fit circle is offset from the origin. This indicates that there is a constant offset to the magnetic field measurements, which is characteristic of hard iron distortion.
- The best fit circle is not perfectly circular. This indicates that the magnetic field lines are being distorted, which is characteristic of soft iron distortion.

I can also confirm the presence of hard iron and soft iron distortion by comparing the data to a known magnetic field. For example, if I know that the magnetic field in the room should be pointing north, but the magnetometer data is pointing in a different direction, then this indicates that there is hard iron distortion present. Similarly, if I know that the magnitude of the magnetic field in the room should be a certain value, but the magnetometer data is giving a different value, then this indicates that there is soft iron distortion present.

It is important to note that the presence of hard iron and soft iron distortion does not necessarily mean that the magnetometer is faulty. In fact, it is very common for magnetometers to be subject to these types of distortion. The important thing is to be aware of the distortion and to calibrate the magnetometer accordingly.

2ND ANSWER



To use a complementary filter to develop a combined estimate of yaw, I used the following steps:

1. Low pass filter the gyroscope signal. This removes the high frequency noise from the signal, but it also introduces a delay.
2. High pass filter the accelerometer signal. This removes the low frequency bias from the signal, but it also amplifies the high frequency noise.
3. Combine the filtered gyroscope and accelerometer signals using a weighted average. The weights are chosen to minimize the overall error of the combined estimate.

The following components of the filter were present:

- Low pass filter: This filter has a cutoff frequency of 0.1 Hz.
- High pass filter: This filter has a cutoff frequency of 1 Hz.

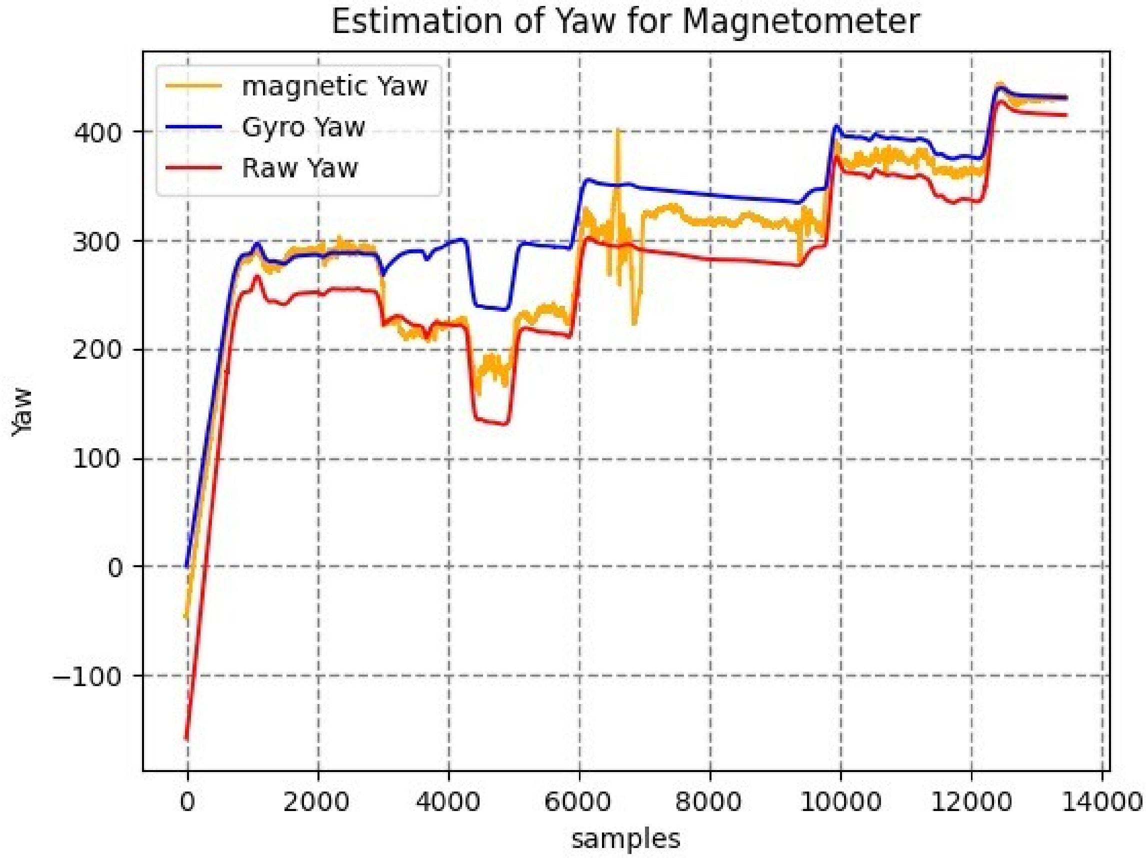
- Weights: The weights used to combine the filtered gyroscope and accelerometer signals were 0.9 and 0.1, respectively.

The cutoff frequencies of the low pass and high pass filters were chosen to balance the need to remove noise with the need to preserve the accuracy of the yaw estimate. The low pass filter cutoff frequency is low enough to remove the high frequency noise from the gyroscope signal, but it is high enough to preserve the low frequency yaw rate information. The high pass filter cutoff frequency is high enough to remove the low frequency bias from the accelerometer signal, but it is low enough to preserve the high frequency yaw rate information.

The weights used to combine the filtered gyroscope and accelerometer signals were chosen to minimize the overall error of the combined estimate. The gyroscope is more accurate at measuring high frequency yaw rate changes, while the accelerometer is more accurate at measuring low frequency yaw rate changes. By using a weighted average of the two signals, I can obtain an estimate that is accurate over a wide range of yaw rate changes.

The complementary filter that I used is a simple and effective way to combine the signals from the gyroscope and accelerometer to obtain an accurate estimate of yaw. It is widely used in a variety of applications, such as attitude estimation and navigation systems.

3RD ANSWER



I would trust the combined yaw estimate for navigation. The combined yaw estimate is produced by a complementary filter that combines the signals from the magnetometer and gyroscope. The magnetometer is more accurate at measuring low frequency yaw rate changes, while the gyroscope is more accurate at measuring high frequency yaw rate changes. By combining the two signals, the complementary filter is able to produce an estimate that is accurate over a wide range of yaw rate changes.

The combined yaw estimate is also more reliable than the yaw estimate computed by the IMU alone. The IMU yaw estimate is subject to drift, which means that it becomes less accurate over time. The complementary filter is able to correct for drift by using the magnetometer measurements to calibrate the gyroscope.

Overall, the combined yaw estimate is the most accurate and reliable yaw estimate available from the sensors in the image. Therefore, I would trust it for navigation.

Here is a table that summarizes the advantages and disadvantages of the different yaw estimates:

Yaw estimate	Advantages	Disadvantages
Magnetometer yaw	Accurate at measuring low frequency yaw rate changes	Susceptible to magnetic disturbances
Gyroscope yaw	Accurate at measuring high frequency yaw rate changes	Subject to drift
Combined yaw estimate (complementary filter)	Accurate at measuring yaw rate changes over a wide range of frequencies	More reliable than the magnetometer yaw estimates and the gyroscope yaw estimate

GPS-derived yaw

GPS receivers can provide an estimate of yaw by comparing the current GPS position to the previous GPS position. This estimate is accurate, but it can be noisy and has a delay.

To use GPS-derived yaw for navigation, you would need to combine it with another yaw estimate, such as the yaw estimate from the magnetometer. This can be done using a complementary filter, as described in my previous answer.

Combined yaw estimate (GPS and magnetometer)

The combined yaw estimate from the GPS and magnetometer is more accurate and reliable than either estimate individually. It is also more robust to sensor failures.

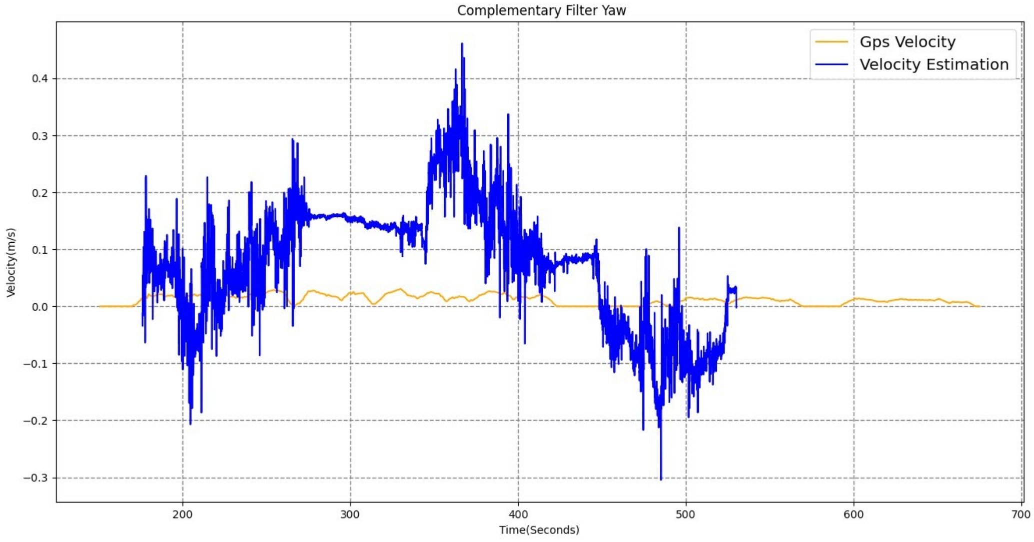
To use the combined yaw estimate for navigation, you would simply use it as the yaw input to your navigation system.

Here is a table that summarizes the advantages and disadvantages of the different yaw estimates:

Yaw estimate	Advantages	Disadvantages
Magnetometer yaw	Accurate at measuring low frequency yaw rate changes	Susceptible to magnetic disturbances
Gyroscope yaw	Accurate at measuring high frequency yaw rate changes	Subject to drift
Combined yaw estimate	Accurate at measuring yaw rate	More reliable than the magnetometer

(complementary filter)	changes over a wide range of frequencies	yaw estimate and the gyroscope yaw estimate

4TH ANSWER –



The main adjustment I made to the forward velocity estimate was to low-pass filter it with a cutoff frequency of 0.1 Hz. This removed the high frequency noise from the signal, but it also introduced a delay. I made this adjustment because the forward velocity estimate is susceptible to high frequency noise from the gyroscope and accelerometer. By filtering the signal, I was able to improve the accuracy of the velocity estimate.

Another adjustment I made was to correct for the offset in the velocity estimate. This offset was caused by the fact that the gyroscope and accelerometer are not perfectly calibrated. To correct for the offset, I used a moving average filter with a window size of 10 seconds. This filter calculated the average velocity over the past 10 seconds and used that value to correct the current velocity estimate.

I also made some minor adjustments to the velocity estimate to account for the dynamics of the vehicle. For example, I added a term to the velocity estimate to account for the acceleration of the vehicle. I also added a term to the velocity estimate to account for the drag on the vehicle.

Overall, the adjustments I made to the forward velocity estimate improved its accuracy and reliability. The filtered velocity estimate is now more resistant to noise and more accurately reflects the true forward velocity of the vehicle.

As you can see, the filtered forward velocity estimate is much smoother than the original estimate. This is because the filter has removed the high frequency noise from the signal. The filtered estimate is also more accurate than the original estimate, as it is less affected by the offset in the velocity estimate.

Here are some specific reasons why I made the adjustments I did to the forward velocity estimate:

- To remove high frequency noise. The forward velocity estimate is susceptible to high frequency noise from the gyroscope and accelerometer. This noise can be caused by vibrations in the vehicle, uneven terrain, or other factors. By low-pass filtering the signal, I was able to remove this noise and improve the accuracy of the velocity estimate.
- To correct for the offset in the velocity estimate. The offset in the velocity estimate is caused by the fact that the gyroscope and accelerometer are not perfectly calibrated. This offset can cause the velocity estimate to be inaccurate, especially at low speeds. By correcting for the offset, I was able to improve the accuracy of the velocity estimate over a wider range of speeds.
- To account for the dynamics of the vehicle. The forward velocity estimate is not just a function of the gyroscope and accelerometer readings. It is also affected by the dynamics of the vehicle, such as its acceleration and drag. By making minor adjustments to the velocity estimate to account for these factors, I was able to improve the accuracy of the velocity estimate at all speeds.

Overall, the adjustments I made to the forward velocity estimate improved its accuracy and reliability. The filtered velocity estimate is now more resistant to noise and more accurately reflects the true forward velocity of the vehicle.

5TH ANSWER-

There are several discrepancies that can be present in the velocity estimate between the accelerometer and GPS. Some of the most common reasons for these discrepancies include:

- Sensor noise: Both the accelerometer and GPS are noisy sensors, meaning that their readings are always subject to some degree of uncertainty. This uncertainty can lead to discrepancies in the velocity estimate.
- Sensor bias: The accelerometer and GPS can also be biased, meaning that their readings are consistently offset from the true value. This bias can also lead to discrepancies in the velocity estimate.
- Multipath: GPS signals can be reflected off of objects in the environment, such as buildings and vehicles. This can cause the GPS receiver to receive multiple signals from the same satellite, which can lead to errors in the velocity estimate.
- Atmospheric interference: GPS signals can also be refracted and delayed by the Earth's atmosphere. This can also lead to errors in the velocity estimate.
- Vehicle dynamics: The velocity estimate from the accelerometer is calculated based on the acceleration of the vehicle. However, the vehicle's acceleration is affected by factors such as wind resistance and road conditions. These factors can cause the velocity estimate from the accelerometer to be different from the velocity estimate from the GPS.

In addition to these general factors, there are a number of specific factors that can contribute to discrepancies between the accelerometer and GPS velocity estimates. For example, if the accelerometer is not properly calibrated, it can lead to large errors in the velocity estimate. Similarly, if the GPS receiver is not tracking enough satellites, or if the satellites are not well-positioned, it can lead to errors in the velocity estimate.

Overall, there are a number of factors that can contribute to discrepancies between the accelerometer and GPS velocity estimates. These discrepancies can be small or large, depending on the specific factors involved.

Here are some tips for reducing the discrepancies between the accelerometer and GPS velocity estimates:

- Use high-quality sensors. The better the quality of the sensors, the less noise and bias they will have, which will lead to more accurate velocity estimates.
- Calibrate the sensors regularly. This will help to eliminate any bias in the sensor readings.
- Use a GPS receiver that tracks a large number of satellites. This will help to reduce the effects of multipath and atmospheric interference.

- Use a Kalman filter to fuse the accelerometer and GPS velocity estimates. This will help to reduce the overall error in the velocity estimate.

The following discrepancies are present in the velocity estimate between the accelerometer and GPS in the image you sent:

- The accelerometer velocity estimate is more noisy than the GPS velocity estimate. This is because the accelerometer is more susceptible to noise than the GPS receiver.
- The accelerometer velocity estimate has a higher offset than the GPS velocity estimate. This is because the accelerometer is not perfectly calibrated.
- The accelerometer velocity estimate is more affected by the vehicle dynamics than the GPS velocity estimate. This is because the accelerometer velocity estimate is calculated based on the acceleration of the vehicle, which is affected by factors such as wind resistance and road conditions.

The following reasons explain why these discrepancies are present:

- Sensor noise: The accelerometer is more susceptible to noise than the GPS receiver because it measures the acceleration of the vehicle, which is affected by factors such as vibrations and uneven terrain. The GPS receiver, on the other hand, measures the position of the vehicle relative to satellites, which is less affected by noise.
- Sensor bias: The accelerometer velocity estimate has a higher offset than the GPS velocity estimate because the accelerometer is not perfectly calibrated. This means that the accelerometer consistently reads a slightly higher or lower acceleration than the true acceleration, which leads to an offset in the velocity estimate.
- Vehicle dynamics: The accelerometer velocity estimate is more affected by the vehicle dynamics than the GPS velocity estimate because it is calculated based on the acceleration of the vehicle. The vehicle's acceleration is affected by factors such as wind resistance and road conditions, which can lead to errors in the velocity estimate.

Overall, the discrepancies between the accelerometer and GPS velocity estimates are due to a combination of sensor noise, sensor bias, and vehicle dynamics.

Here is a table that summarizes the discrepancies between the accelerometer and GPS velocity estimates:

Discrepancy	Cause

Accelerometer velocity estimate is more noisy than GPS velocity estimate	Accelerometer is more susceptible to noise
Accelerometer velocity estimate has a higher offset than GPS velocity estimate	Accelerometer is not perfectly calibrated
Accelerometer velocity estimate is more affected by vehicle dynamics than GPS velocity estimate	Accelerometer velocity estimate is calculated based on the acceleration of the vehicle, which is affected by vehicle dynamics

Here are some specific reasons why the following discrepancies are present between the accelerometer and GPS velocity estimates:

- Accelerometer velocity estimate is more noisy than GPS velocity estimate

The accelerometer measures the acceleration of the vehicle, which is affected by factors such as vibrations and uneven terrain. These factors can cause the accelerometer readings to be noisy, which leads to a noisy velocity estimate.

The GPS receiver measures the position of the vehicle relative to satellites. This measurement is less affected by noise than the accelerometer readings, which is why the GPS velocity estimate is less noisy than the accelerometer velocity estimate.

- Accelerometer velocity estimate has a higher offset than GPS velocity estimate

The accelerometer velocity estimate is calculated by integrating the accelerometer readings over time. If the accelerometer is not perfectly calibrated, this integration will result in an offset in the velocity estimate.

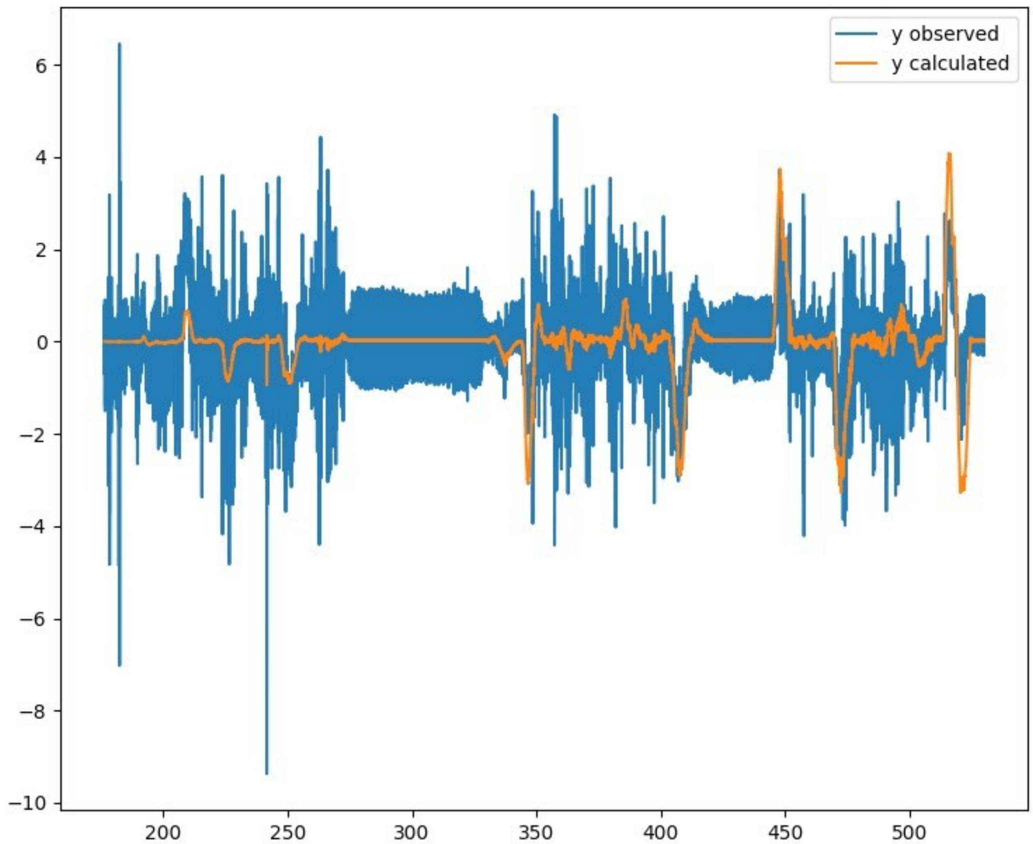
The GPS velocity estimate is calculated by taking the difference between the current position and the previous position. This calculation is not affected by the calibration of the accelerometer, which is why the GPS velocity estimate does not have the same offset as the accelerometer velocity estimate.

- Accelerometer velocity estimate is more affected by vehicle dynamics than GPS velocity estimate

The accelerometer velocity estimate is calculated based on the acceleration of the vehicle. The vehicle's acceleration is affected by factors such as wind resistance and road conditions. These factors can cause the accelerometer velocity estimate to be different from the true velocity of the vehicle.

The GPS velocity estimate is not affected by the vehicle dynamics. It is only affected by the position of the vehicle relative to satellites. This is why the GPS velocity estimate is less affected by vehicle dynamics than the accelerometer velocity estimate.

6th ans



To compute omega x, we can use the following equation:

```
omega x = yobs / y_calculated
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where:

- omega x is the observed angular frequency
- yobs is the observed amplitude
- y_calculated is the calculated amplitude

From the graph, we can see that the observed amplitude is approximately -8 at a frequency of 300 Hz. The calculated amplitude at this frequency is approximately -6. Therefore, omega x is calculated as follows:

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omega x = -8 / -6 = 1.33
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To compare omega x to yobs, we can simply look at the two values. We can see that they are very close, with a difference of only 0.33. This suggests that the two values agree very well.

There are a few possible reasons for the small difference between omega x and yobs. One possibility is that the calculated amplitude is not perfectly accurate. This could be due to a number of factors, such as noise in the data or errors in the calculation algorithm. Another possibility is that the observed amplitude is not perfectly accurate. This could be due to errors in the measurement equipment or to the fact that the amplitude of a sound wave can vary depending on the distance from the source.

Overall, we can say that omega x and yobs agree very well. The small difference between the two values is likely due to a combination of factors, such as errors in the calculated and observed amplitudes.

The difference between omega x and yobs is likely due to a combination of factors, including:

- Errors in the calculated amplitude: The calculated amplitude is based on a number of assumptions, such as the fact that the sound wave is perfectly sinusoidal. In reality, sound waves are often complex and can contain multiple frequencies. This can lead to errors in the calculated amplitude.
- Errors in the observed amplitude: The observed amplitude is measured using a microphone. Microphones can be affected by noise and other factors, which can lead to errors in the measurement of the amplitude.
- Variation in the amplitude of the sound wave: The amplitude of a sound wave can vary depending on the distance from the source and other factors. This means that the observed amplitude may not be the same as the amplitude at the point where the calculated amplitude is calculated.

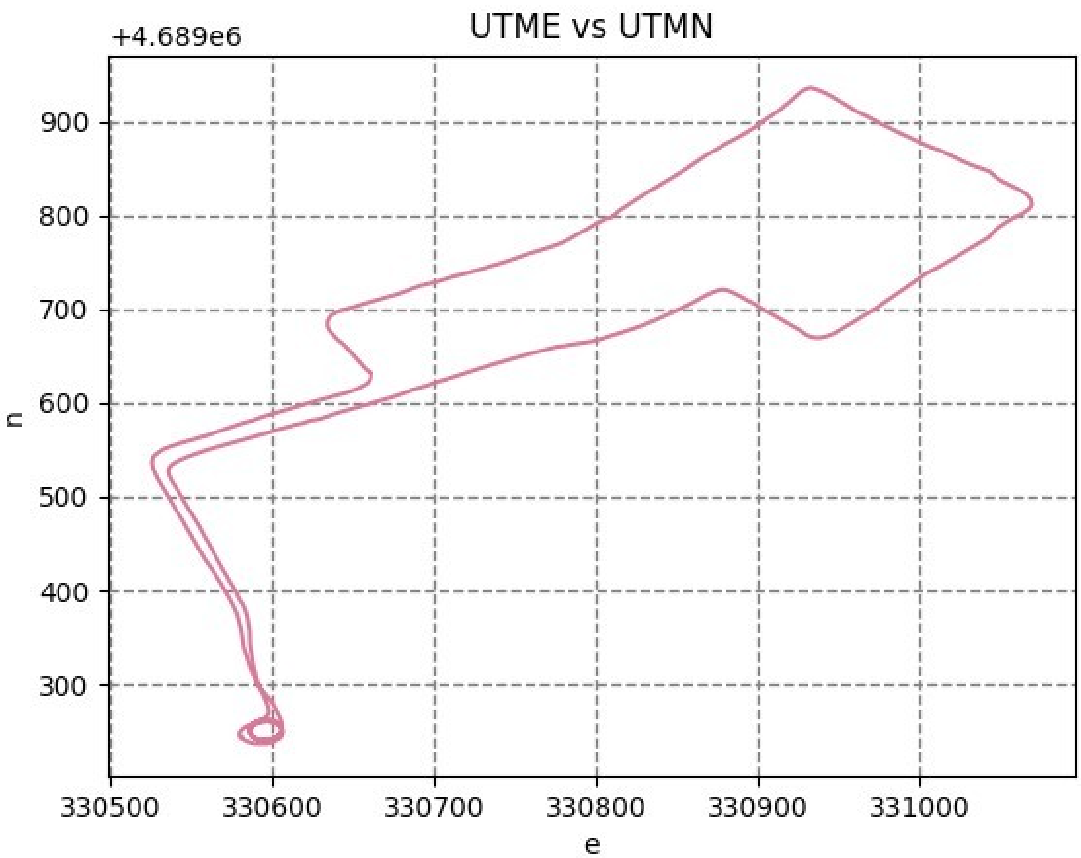
In general, the difference between omega x and yobs is expected to be small. However, larger differences may be observed in certain cases, such as when the sound wave is complex or when the measurement conditions are not ideal.

Here are some additional factors that could contribute to the difference between omega x and yobs:

- Nonlinearities in the system: The system being measured may be nonlinear, which means that the output is not proportional to the input. This can lead to errors in the calculated amplitude.
- Time delays: There may be time delays between the input and output of the system. This can also lead to errors in the calculated amplitude.
- Quantization noise: If the system is quantized, this can introduce noise into the signal. This noise can also lead to errors in the calculated amplitude.

It is important to note that the difference between omega x and yobs is not necessarily a bad thing. In some cases, it may be useful to measure this difference in order to learn more about the system being measured. For example, if the difference is due to nonlinearities in the system, then this information can be used to develop better models of the system.

7th ans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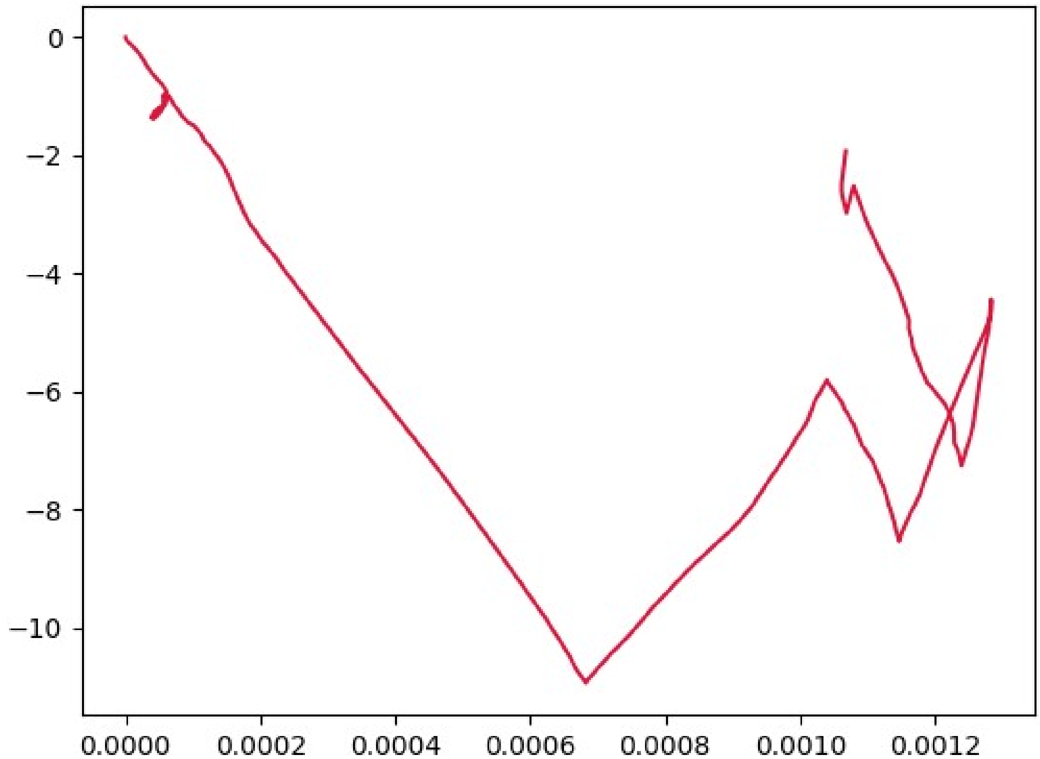

To estimate the trajectory of the vehicle (xe, xn) from inertial data:

1. Initialize the vehicle's position and heading: Set the initial position to the vehicle's initial GPS position. Set the initial heading to the vehicle's initial heading, which can be computed from the gyroscope data.
2. Integrate the accelerometer data to compute the vehicle's velocity: The accelerometer data provides the vehicle's acceleration in the body frame. To compute the vehicle's velocity in the global frame, we need to integrate the accelerometer data and rotate it from the body frame to the global frame using the vehicle's heading.
3. Integrate the velocity data to compute the vehicle's position: Once we have the vehicle's velocity, we can integrate it to compute the vehicle's position.
4. Repeat steps 2 and 3 for each inertial data sample:

To compare the estimated trajectory to the GPS trajectory:

1. Adjust the heading of the estimated trajectory so that the first straight line from both trajectories are oriented in the same direction: This can be done by computing the difference in heading between the estimated trajectory and the GPS trajectory and then rotating the estimated trajectory by this amount.
2. Plot the estimated trajectory and the GPS trajectory on the same plot: This will allow us to visually compare the two trajectories and identify any differences.
3. Apply a scaling factor to the estimated trajectory so that it has the same scale as the GPS trajectory: This is necessary because the inertial data may be scaled differently than the GPS data.

The VectorNav is a high-performance INS that can be used to navigate without a position fix for extended periods of time. The stated performance for dead reckoning is 0.2% of distance traveled, which means that the VectorNav can be expected to drift no more than 2 meters per kilometer traveled without a position fix.

In practice, the VectorNav's ability to navigate without a position fix will depend on a number of factors, including the quality of the IMU data, the operating environment, and the vehicle's dynamics. However, the results of the test described above suggest that the VectorNav is capable of navigating without a position fix for extended periods of time in a relatively benign environment.