Measurement uncertainty

FizziQ activity · High school · 25 min

Scan to open in FizziQ

Recording a smartphone gyroscope at rest then in rotation, students build histograms, compute standard deviation and separate signal from noise in FizziQ.

Learning objectives

- Record gyroscope data in two conditions: stationary (noise only) and rotating (signal + noise)
- Construct histograms of both datasets and compare their distributions
- Calculate the standard deviation of the noise distribution as a measure of sensor precision
- Determine the signal-to-noise ratio for the rotation measurement
- Understand the concepts of precision, accuracy, and minimum detectable signal

Instruments and sensors

Gyroscope (angular velocity meter) · MEMS gyroscope

Materials

- Smartphone with the FizziQ application
- Clear space to turn safely
- Optional: turntable for additional comparison
- FizziQ experience notebook
- Note: the protocol remains adaptable to any comparable rotational-rate sensor with histogram and statistical analysis capabilities.

Protocol

1. Open FizziQ and select the Gyroscope sensor (Z-axis angular velocity, in degrees per second or radians per second).
2. Place the smartphone on a flat, stable surface. Ensure it is completely stationary.
3. Record data for 20 seconds at the maximum sampling rate. This is your noise measurement.
4. Save this recording. Without looking at the data yet, predict: what should the average value be? What should the distribution look like?
5. Now pick up the phone and rotate it slowly and steadily around the Z-axis (yaw rotation) for 20 seconds. This is your signal measurement.
6. Save this recording.
7. Examine the noise data (stationary). Plot a histogram of the values. It should form a bell-shaped curve centered near zero.
8. Calculate the mean and standard deviation (σ) of the noise data.
9. Examine the signal data (rotating). Plot its histogram. It should be shifted away from zero and may be broader.
10. Calculate the mean and standard deviation of the signal data.
11. Calculate the signal-to-noise ratio (SNR): $SNR = |mean\_signal| / \sigma\_noise$.
12. Discuss: a signal is generally considered detectable when SNR > 2-3 (the signal exceeds 2-3 standard deviations of the noise). Based on your noise level, what is the minimum rotation speed the gyroscope can reliably detect?

Expected results

The stationary gyroscope should produce values fluctuating around zero with a standard deviation of typically 0.01-0.10 °/s for a modern smartphone. The histogram should approximate a Gaussian (normal) distribution. During slow rotation, the mean shifts to a non-zero value (e.g., 5-50 °/s depending on rotation speed), and the distribution shifts accordingly. The SNR for a moderate rotation should be 10-100, well above the detection threshold. The minimum detectable rotation speed is approximately 2-3 times the noise standard deviation, typically 0.03-0.30 °/s. Students should clearly see the difference between the noise-only and signal+noise distributions.

Questions

- What is the physical origin of the noise in the gyroscope readings when the phone is stationary?
- Why is the standard deviation a good measure of sensor precision?
- What does a signal-to-noise ratio of 1 mean? Why is SNR > 3 typically required for reliable detection?
- How does averaging multiple measurements improve the effective precision of a sensor?
- What is the difference between precision (random error) and accuracy (systematic error)?
- How do these concepts apply to measurements in other fields of science?

Going further

- Compare the noise characteristics of the gyroscope, accelerometer, and magnetometer on the same phone
- Investigate how the noise standard deviation changes with different sampling rates
- Record gyroscope data at multiple rotation speeds and plot SNR versus rotation speed
- Compare the noise levels of two different smartphone models
- Investigate whether temperature affects the gyroscope noise level by measuring in warm and cold environments