Advanced Projects

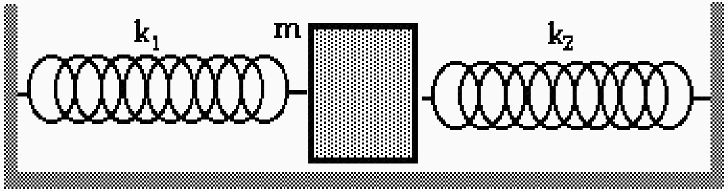
Lecture 2: Sensor Fusion

Motivation: What Is Sensor Fusion, and Why Do We Need It?

- Combining data from multiple sensors for more accurate results
- We need it to keep our quadcopters upright
- Motors are imprecise, sensors provide feedback
- Quads need inertial sensors
  - Accelerometer
  - Gyroscope

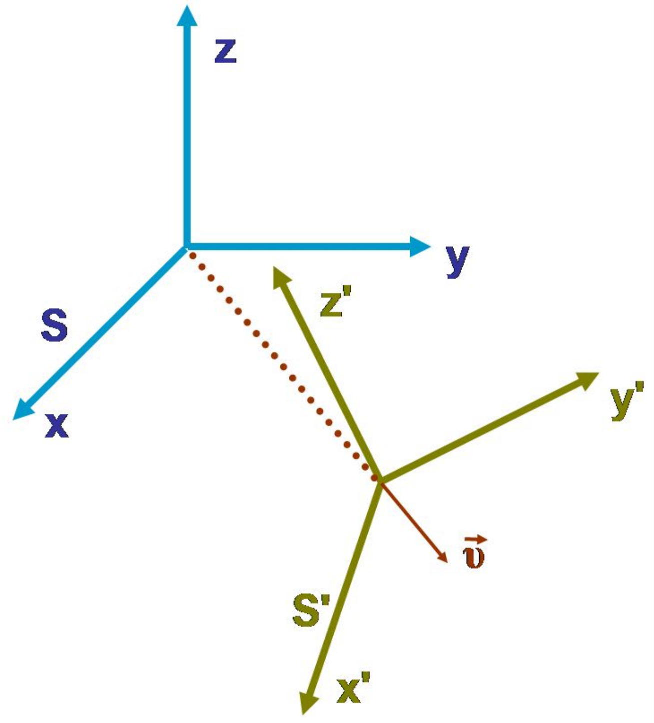
Accelerometers

- Consists of a mass suspended between two springs
- Acceleration causes mass to shift position
- Accelerometer calculates acceleration based on position
- Most accelerometers contain 3 of these structures, one for each axis
- We read acceleration vector from the device



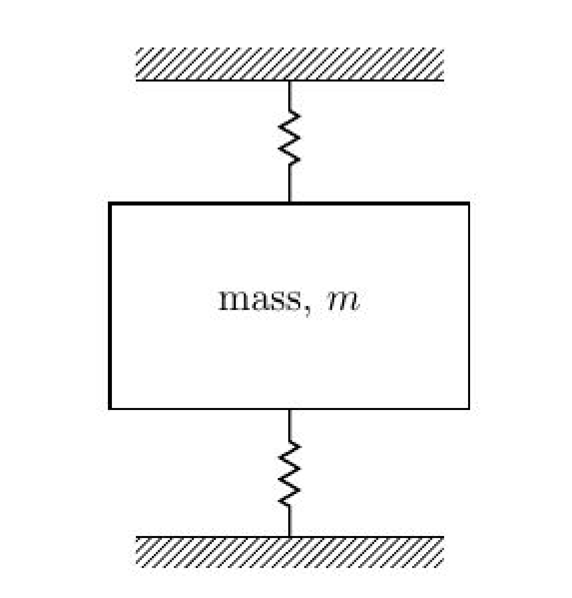
Reference Frames

- External reference frame is constant
- Internal reference frame changes when quadcopter rotates
- All inertial readings are with respect to the internal reference frame



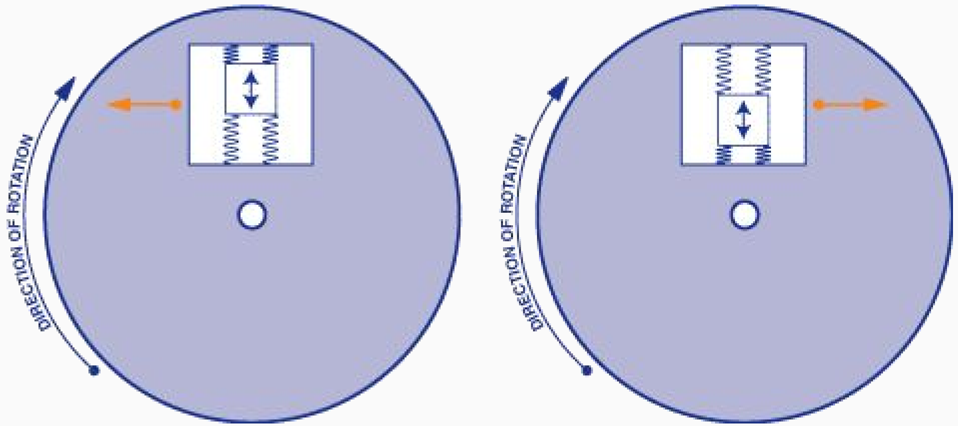
Proper Acceleration and Orientation

- No acceleration is detected in free fall
- An upwards acceleration is detected when sitting in place
- Measured acceleration is with respect to free fall: this is called proper acceleration
- Proper acceleration compared to internal Z-axis gives orientation, when at constant real velocity
- Rotation around external Z-axis not detected



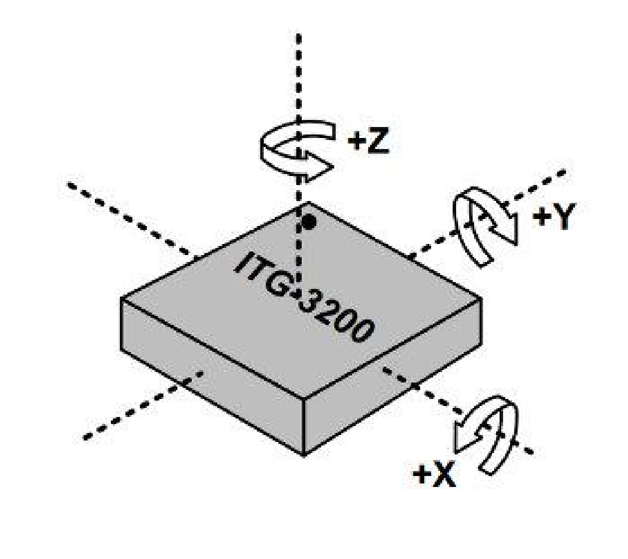
Gyroscopes

- Similar to accelerometer, but detects centrifugal force, and therefore rotation rate
- Contains one gyroscope unit for each axis
- Output is a vector
    - Magnitude is overall rotation rate
    - Direction is axis of rotation



Tracking Orientation with a Gyroscope

- Convert gyroscope reading to rotation rate and axis
- Use time between gyroscopes to calculate total rotation
- Apply rotation to orientation vector
- Gyroscope also uses internal reference frame
- Gyroscope can detect rotation around external Z-axis

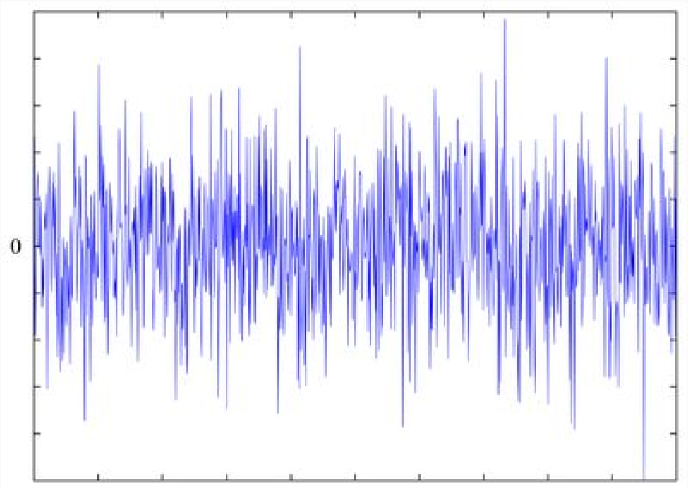


Bias Error

- reading = actual value + bias
- Bias is effectively constant with time
- Calculate bias once per usage, then subtract from all readings
- Bias is temperature-dependent, so recalibrate each time you use your quadcopter

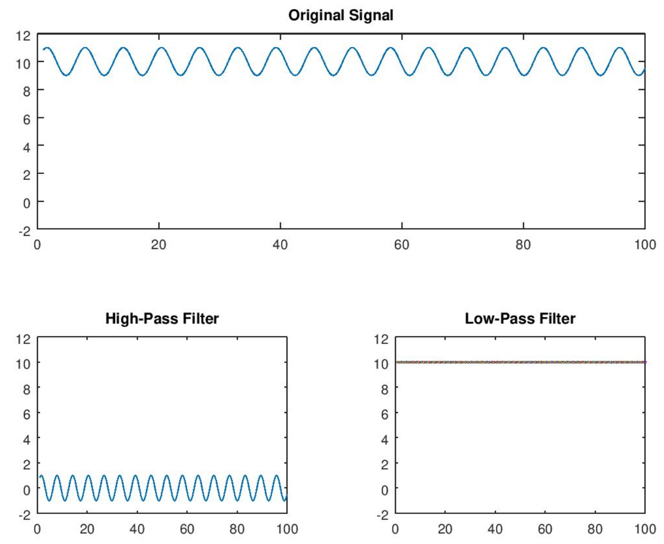
Noise and Drift

- All sensors readings have white noise as error
    - Changes randomly with time
    - Average value of error is 0
    - Usually a small magnitude
- For the accelerometer we can mostly ignore noise, as error is small and mean is zero
- For the gyroscope the small errors in rotation add up, causing our orientation to drift
- Gyroscope drift cannot be corrected without another sensor



Signals and Filters

- Gyroscope is accurate in the short term, drifts in the long term
- Accelerometer is inaccurate (from acceleration) in the short term, but accurate in the long term
- Short term data corresponds to high frequency, long term to low frequency
- Digital filters can be used to remove the inaccurate data



Complementary Filter

- Apply a high pass filter to the gyroscope
- Apply a low pass filter to the accelerometer
- Combine the two using an adjustable weight
- n = normalize(αa + (1 - α)rotate(n))
  - n is filtered orientation vector
  - a is raw orientation vector from accelerometer
  - α is the weight for adjusting between accelerometer and gyro
  - We normalize to keep our orientation a unit vector