By Matan Pazi and Robert Landau

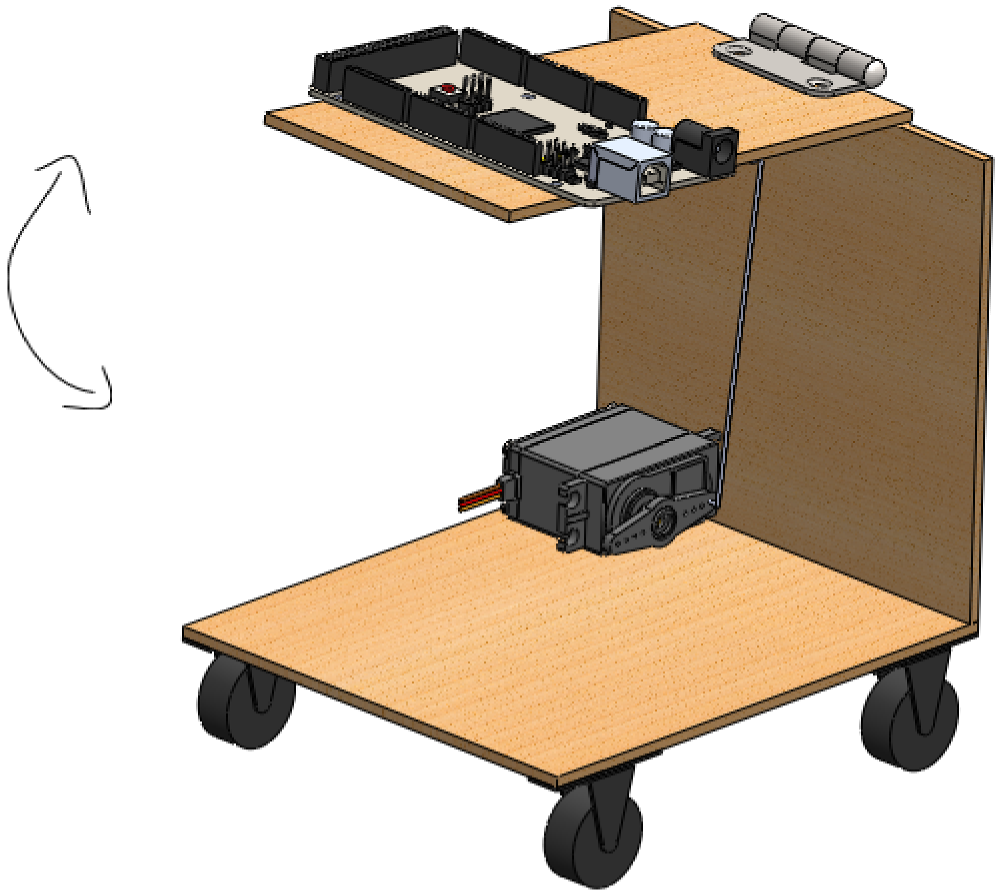
4 State Kalman Filter

Goal:

Implementing a Kalman filter to estimate the pitch angle of our “truck”.

Compare to a complementary filter.

Background:



Our IMU has a gyroscope and an accelerometer.

We use the gyroscope to measure the angular velocity.

We use the accelerometer in 2 ways:

1. Use it to estimate the angle by the measurement of the gravitational force.

2. Calculate the angular acceleration.

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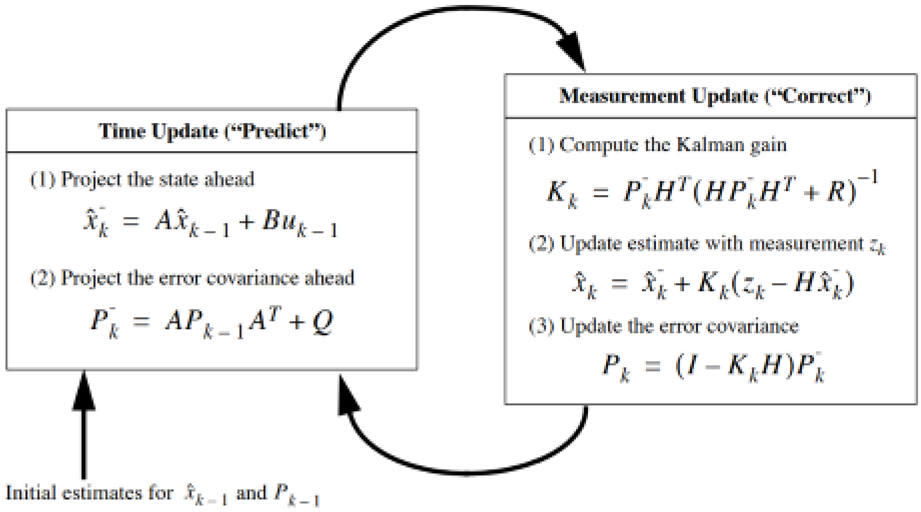
First, watch Kalman Filter video series by Mathworks

Equations from “An Introduction to the Kalman Filter” by Greg Welch and Gary Bishop

State Space Equations:



$$x = \begin{bmatrix} \theta \\ \omega \\ \alpha \\ b \end{bmatrix} \quad , \qquad A = \begin{bmatrix} 1 & \Delta t & \frac{\Delta t^2}{2} & 0 \\ 0 & 1 & \Delta t & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$H = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{bmatrix} \quad , \qquad Ignoring\ B.$$

$$P_0 = \begin{bmatrix} \sigma^2(\theta) & 0 & 0 & 0 \\ 0 & \sigma^2(\omega) & 0 & 0 \\ 0 & 0 & \sigma^2(\alpha) & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

$$R = \begin{bmatrix} \sigma^2(\theta) & 0 & 0 \\ 0 & \sigma^2(\omega) & 0 \\ 0 & 0 & \sigma^2(\alpha) \end{bmatrix} \quad , \qquad Q = \begin{bmatrix} 0.01 & 0 & 0 & 0 \\ 0 & 0.01 & 0 & 0 \\ 0 & 0 & 0.01 & 0 \\ 0 & 0 & 0 & 0.01 \end{bmatrix}$$

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Gyro Data:

GYROSCOPE NOISE PERFORMANCE	**FS_SEL=0**					
Total RMS Noise	DLPFCFG=2 (100Hz)		0.05		°/s-rms	
Low-frequency RMS noise	Bandwidth 1Hz to10Hz		0.033		°/s-rms	
Rate Noise Spectral Density	At 10Hz		0.005		°/s/ √ Hz	

Accelerometer Data:

NOISE PERFORMANCE						
Power Spectral Density	@10Hz, AFS_SEL=0 & ODR=1kHz		400		µg/ √ Hz	

I included the bias (b) in the state space because we assume that the angular velocity measured by the gyro is included in the measurements. $\omega = \omega_{measured} + bias$, and I saw it's common practice.

The system is observable, Rank(A,C) = 4

R and Q:

The smaller R is the more weight we put on the measurements

The smaller Q is, the less aggressive the filter was when I changed it.