Kalman Filtering for Robotics

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March 21, 2021

Project Description and Methodology

Parameter estimation for robotics can be challenging due to noisy sensor data and inexact motion models. Kalman filtering is a technique that uses properties of the **Gaussian distribution** to minimize error in the state of an agent. The Kalman filter uses a motion model to predict the future state of the agent, and corrects these predictions based on sensor measurements with **Bayes Theorem**. Here, I designed a Kalman filter to track the relative distance of a cone.

Every timestep, the Kalman filter makes a prediction on the future distane of the cone ($\hat{x}$) using measured velocity (v) and acceleration (a) (1). The Kalman filter also predicts the uncertainty of the state (2). Each timestep, the robot measures a new distance (x) to the cone. Based on a measure of how uncertain the prediction and measurement are (called the Kalman gain K)(3), a corrected state is determined (4).

1. $\hat{\sigma}_{\hat{x}}^2 = \sigma_x^2 + \Delta t \sigma_v^2 + \frac{1}{2}\Delta t^2 \sigma_a^2$
2. $\hat{\sigma}_{\hat{x}}^2 = \sigma_x^2 + \Delta t \sigma_v^2 + \frac{1}{2}\Delta t^2 \sigma_a^2$
3. $K = \frac{\hat{\sigma}_{\hat{x}}^2}{\hat{\sigma}_{\hat{x}}^2 + \sigma_z^2}$
4. $x = \hat{x} + K(z - \hat{x})$

Implementation

Simulations were performed using the MIT Lincoln Laboratory RacecarSim. I used OpenCV functions to track the center of the cone, and used LIDAR measurements to track relative distance.
I first used the Kalman filter to track a cone while the robot was stationary, then implemented the motion models to track the cone while the robot was accelerating. Both implementations improved signal variance.

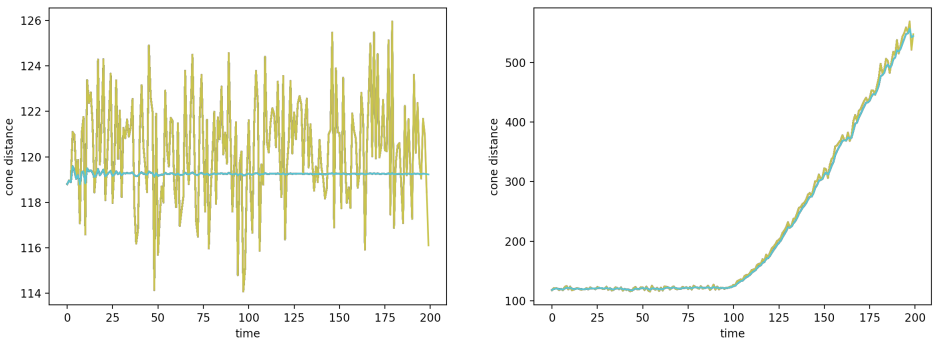

Figure 1: Distance estimates (blue) compared to sensor measurements while stationary (left) and during acceleration (right).

Future Work

The RACECAR program provides open-source robotics curriculum that is taught to high schoolers and college students. Last year, I had the chance to teach the curriculum to a cohort of under-resourced students from across the US through an MIT Lincoln Laboratories program. Sensor fusion and state estimation are not yet part of the curriculum, and I intend to develop an extended lab on Kalman filtering for the program.
(citation: kalmanfilter.net)
video: https://youtu.be/0QNv9v4wk14