Lab 2 – Sensor Fusion with EKF

Goals:

- Develop a simulation of a sensor fusion system that uses the Extended Kalman Filter to fuse competitive information from multiple distance sensors that sense an object in motion
- Characterize the performance of the fusion system in simulation
- Compare the results of the simulation to the actual performance of the system

Note: You will use your sensor models from Lab 1 as part of Lab 2. If you feel there are issues with your models (e.g., problems with the reference voltage, broken sensor, etc.) you are welcome to use Lab 1 information from another group so long as you acknowledge their contribution.

Description

In this lab, you apply the Extended Kalman Filter in a laboratory setting. Before being able to apply the filter, you will develop the motion model of a block and simulate its motion in MATLAB. The simulated results will be compared to those obtained in the lab and evaluated using appropriate metrics.

In-Lab Activity

Data Collection

You will use two (or more) IR distance sensors to localize an object as it is slowly moved.

1. Determine the sensors to be used for the measurements.
2. Choose a method to move the object with respect to the sensors.
   a. The motion should take place over the range of the sensors over a period between 5-10 seconds
3. Configure your sensors as in Lab 1
   a. Take a photo of your setup

Collect data for the following motion patterns. Make sure to measure the beginning and end distances to compare with the end distance of your EKF estimation:

1. Smooth (constant velocity) point-to-point object motion, from point *a* to *b,* with stops at the beginning and ends.
2. Point-to-point with more variations of velocity pattern.
3. Random motion.
4. Stationary object.
5. Under poor sensing conditions (e.g. one of poor reflection, near the edge of the sensor's operating range, different object, or another condition).

Post-Lab Activity

Extended Kalman Filter Formulation

1. Define the state vector, x_k, to be used for the system.
   Recall: $x_{k+1} = Ax_k + \omega$
   When selecting states, think about what is needed to completely characterize the system in terms of position, velocity, and possibly acceleration for the intended movements.
2. Describe the method you used to move the object.
   a. Define a suitable linear system model for the movement.
   b. If needed, what is a reasonable time step, T, and why?
   c. Give the system matrix A, and a noise matrix Q (select the values to reflect how well you think your actual motion in the lab will match your linear model of motion), and briefly explain your choices.
3. Describe the sensor configuration and explain your reasoning.
   a. How many sensors and which types do you need to use?
   b. How many sensor measurements are needed, given the number of states?
   c. Provide a diagram for the setup of the sensors.
4. Referring to your results from Lab 1, define a suitable nonlinear sensor model for the system.

   Recall: $z_k = h(x_k) + \eta$

   a. Provide the sensor model function $h(x_k)$
   b. Obtain the linearized model (Jacobian matrix) $H_k = \left.\frac{\partial h}{\partial x}\right|_{\hat{x}_{k|k-1}}$
   c. Define a suitable sensor noise matrix R; You can assume the noise is zero-mean Gaussian noise (even though this is inaccurate for the sensors) and that the sensor noise is independent; refer to your results from Lab 1 to justify your choices.

Simulation Implementation

Use MATLAB, Simulink, or another suitable tool to develop a simulation of your system. You will be able to compare the state estimates of your lab measurements with the known values of your simulated object motion and examine the covariances as a measure of uncertainty. Figure 1 shows a block diagram of the simulation.

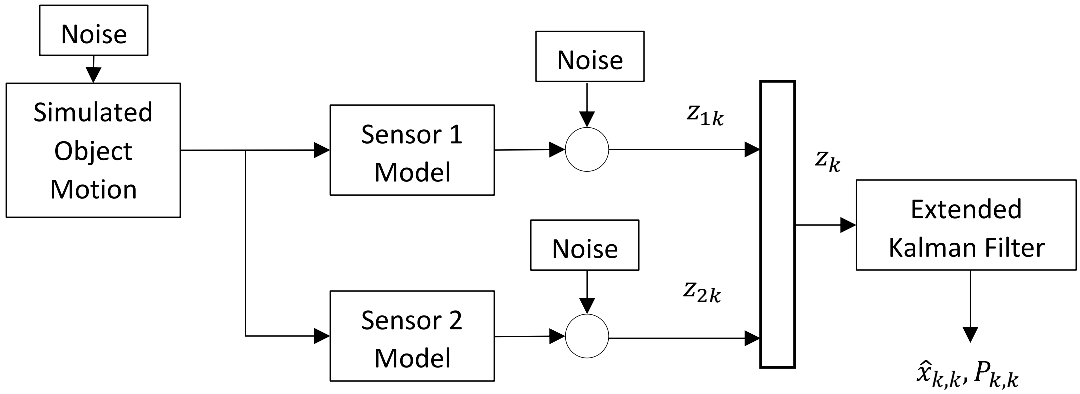

Figure 1 – Simulation Layout

1. To explore the operation of the Extended Kalman Filter, simulated sensors are used to generate measurements under more controlled conditions.
   a. Implement the sensors models for the selected sensors $z_k = h(x_k) + \eta$ in the simulation.
   b. Verify that the measurements generated are reasonable, given your results from Lab 1.
   c. Implement object motions that represent the motions to be tested in the lab.
2. Implement the Extended Kalman Filter based on your equations from above.

Simulation

Run the simulation with the defined object motions and simulated sensors with:

1. Two different initial state estimates and comment on any differences seen in the resulting state estimates.
   a. One good initial estimate, one poor.
2. Two different sets of sensor noise and comment on the resulting state estimates compared to the "known" values under the different conditions.
   a. One simulation with covariances similar to those represented by your sensor model, one with higher levels of noise.
3. Two different sets of system noise and comment on the resulting state estimates compared to the "known" values and the covariance matrix P, under the different conditions.
   a. One simulation with covariances similar to those represented by your system model, one with much higher levels of noise.
4. Three different motions of the object and comment on the resulting state estimates compared to the "known" values and the covariance matrix P , under the different conditions.
   a. One motion similar to the system model, one significantly different, one where the object does not move.

Include the code and screenshots of your simulation in your report, as appropriate.

Extended Kalman Filter Evaluation

Run the Extended Kalman filter on your data (you can replace the simulated motion and simulated sensor parts of your simulation with your measurements).

For each of the above, compare the end distance of you measured with the EKF estimates and comment on the accuracy of the results obtained and how they compared to your simulated results.

Report

Submit the report file with answers to questions, plots, and any photos to the dropbox on UW-Learn.