Cooperative state estimation based on Covariance Intersection

1 Problem Statement

Consider two autonomous vehicles that are driving in a platoon in a straight lane. We consider only a one dimensional model where the state of the leader vehicle X_l is the position x_l and the state of the follower X_f is the position x_f.

Each vehicle is equipped with a GNSS receiver which gives an observation of the position, an odometer which gives the speed measurement and rangefinder which gives the distance to the other vehicle.

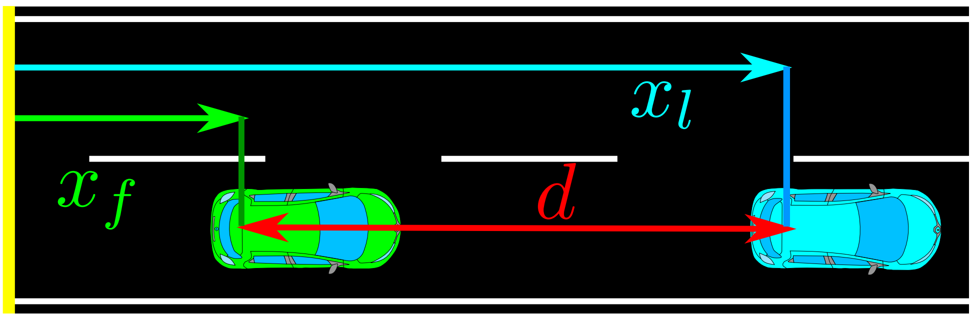

Figure 1: Leader and follower vehicles in a platoon in a straight lane.

The given dataset contains the following data.

The reference positions of the leader and follower vehicles are “x_l_ref” and “x_f_ref”.

The GNSS estimated positions of the leader and follower vehicles are “x_l” and “x_f”, with there standard deviations “x_l_std” and “x_f_std”.

The measured distances between the two vehicles by the leader and the follower are “d_l” and “d_f”, with there standard deviations “d_l_std” and “d_f_std”.

The speeds of the leader and follower vehicles are “v_l” and “v_f”, with there standard deviations “v_l_std” and “v_f_std”.

The time is denoted by t and the sampling period is T_e.

In this practical work, all data are sampled at the same frequency and transmission delays are assumed to be smaller than the sampling period and negligible.

2 Standalone Kalman Filters

In this part, the vehicles don’t cooperate and only use their GNSS receiver to estimate their own position.

In the given zip file, there are several template functions. Open the data player script. Note that the two filters are implemented in the same loop. So, every step has to be duplicated for every vehicle.

Complete the Kalman filter update function and the Kalman filter prediction function using the speed as an input for each vehicle. Use them in the data player script using only the GNSS position observation for each vehicle.

Percentage Points of the Chi-Square Distribution

Degrees of Freedom	Probability of a larger value of x^2								
	0.99	0.95	0.90	0.75	0.50	0.25	0.10	0.05	0.01
1	0.000	0.004	0.016	0.102	0.455	1.32	2.71	3.84	6.63
2	0.020	0.103	0.211	0.575	1.386	2.77	4.61	5.99	9.21
3	0.115	0.352	0.584	1.212	2.366	4.11	6.25	7.81	11.34
4	0.297	0.711	1.064	1.923	3.357	5.39	7.78	9.49	13.28
5	0.554	1.145	1.610	2.675	4.351	6.63	9.24	11.07	15.09
6	0.872	1.635	2.204	3.455	5.348	7.84	10.64	12.59	16.81
7	1.239	2.167	2.833	4.255	6.346	9.04	12.02	14.07	18.48
8	1.647	2.733	3.490	5.071	7.344	10.22	13.36	15.51	20.09
9	2.088	3.325	4.168	5.899	8.343	11.39	14.68	16.92	21.67
10	2.558	3.940	4.865	6.737	9.342	12.55	15.99	18.31	23.21

At the end of the data player script, there are plot functions and the computation of the consistency of the estimate based on a χ-square law test. Look how this test is implemented for a 95% consistency level. The consistency is computed for a probability error of 5% and with the degree of freedom 1 with a χ^2 test. The consistency C corresponds to:

$$C = Pr\left\{(X_{ref} - X)^T P^{-1} (X_{ref} - X) < \chi^2_{1;0.05}\right\} \tag{1}$$

The value used for this test can be found on a table of the chi square distribution.

Observe the estimation errors and the consistencies of the two filters.

3 Cooperative localization with Kalman updates

Now, the vehicles cooperate and exchange their estimated position with the covariance matrix.

Each vehicle uses now the measured distance it gets from its own rangefinder. Give the two new observation models that involve the state of one vehicle and the one of the other. Give the covariances of these tow observations.

In the data player script, add a new update stage by using the same Kalman filter update function but now with these new observations.

Observe the estimation errors and the consistencies of the two filters.

What problem can you observe?

4 Cooperative localization with Covariance Intersection updates

Complete now the template of the covariance intersection filter update function.

Replace the last Kalman filter updates with the cooperative observations with these new covariance intersection filter updates.

Observe the estimation errors and the consistencies of the two filters.

What can you observe?

5 Propagation of an accurate position on a platoon

Now, suppose that a vehicle has an accurate GNSS receiver. We want to see how this information propagates in the data fusion process.

Uncomment the two lines at the beginning of the data player script to simulate an accurate position for the leader vehicle.

Observe the estimation errors and the consistencies of the two filters.