Mini Project **ARS04**

December 16, 2020

1 Problem Statement

Let consider two cooperative cars (see figure 1). The vehicles are moving in a plane which is assumed tangent to the surface of the Earth (altitude z almost constant). The working frame R_O is East - North - Up (ENU). The body frame (denoted R_M) associated with each vehicle is centered at the middle of the rear wheels. It is front-looking.

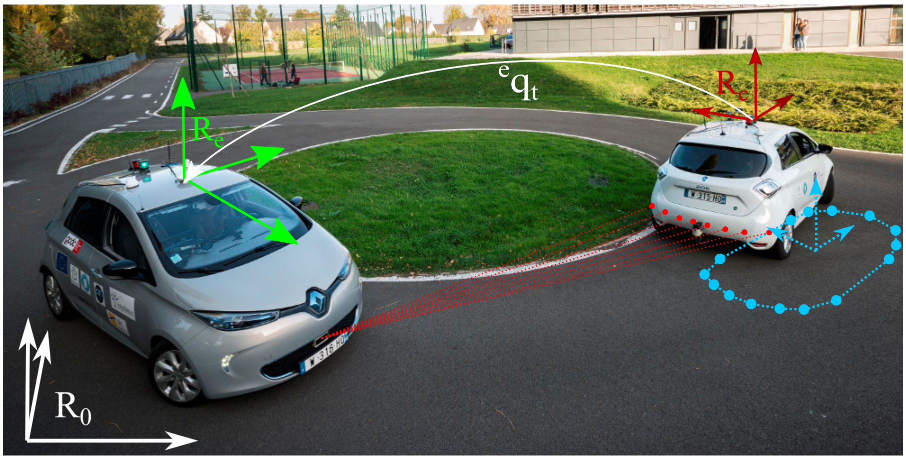

Figure 1: Two Zoe cars in the test track SEVILLE at UTC.

Both cars are equipped with a low cost GNSS receiver (a UBlox 8) and a SPAN-IMU RTK GNSS receiver which is very accurate and which defines the ground truth. The cars have also communication modems such that the follower can receive for instance the pose of the leader (in figure 2, the drawing is in one dimension for simplification). We neglect the transmission latency. The follower has also a lidar and is able to measure the relative pose of the leader in its body frame.

The objective of this project is to study and evaluate on real experiments data fusion methods that improve the localization estimates of the two communicating vehicles that share information, one vehicle being equipped with a lidar.

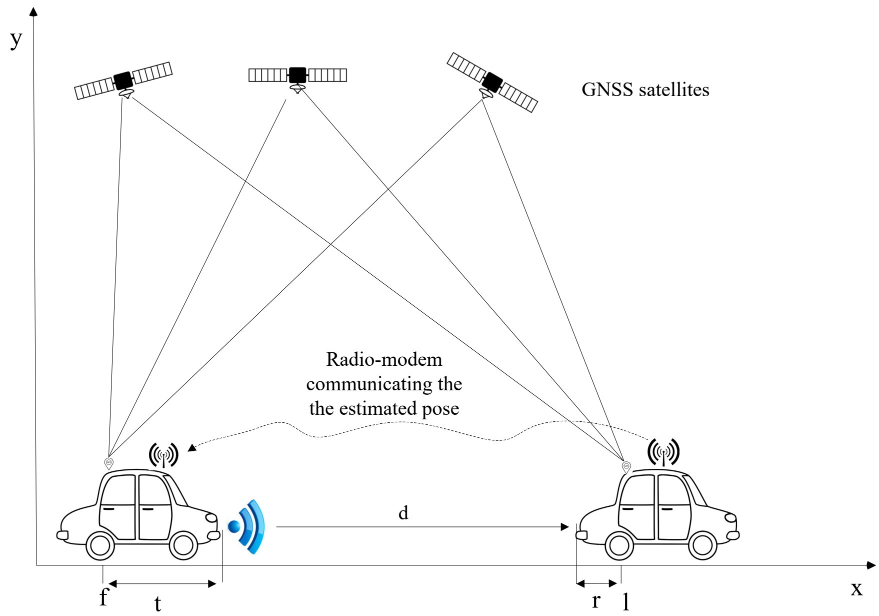

Figure 2: Two cooperative cars. l is the position of the leader and f is the position of the follower. t is the translation of the lidar of the follower in its body frame and r is the distance of the back bumper of the leader in its body frame. In the dataset that you will use, t and r have been compensated so you don't have to handle them.

2 Description of the dataset

2.1 Sensors on both cars

The follower has the following sensors:

- A low cost L1-GNSS (GPS and GLONASS) receiver ublox8T which provides:
  - The position of the GPS antenna that is centered on point M of the vehicle body frame,
  - The position is computed by a Kalman filter integrated in the receiver (this is "pos_gnss_f, cov_gnss_f"). Please note that a track angle is also computed by the GNSS receiver. This track angle is equal the heading of the car as long as there is no slippage. You can use it if you want or not.
- Dead-Reckoning (DR) sensors:
  - The vehicle speed measurement is obtained from the sensors of the rear wheels (this is the first component of "vel_f").
  - A yaw rate gyro measuring the angular velocity is also available from the CAN bus (this is the second component of "vel_f").
- Ground truth. An Inertial Measurement Unit (IMU - SpanCPT) with a very accurate dual-frequency GPS receiver that serves as ground truth (this "pos_ref_f" and "cov_ref_f").
- A front looking lidar SICK LD-MRS. The processing of the lidar impacts has been done by Elwan Héry. The center of the cluster corresponding to the leader has been computed in the body frame of the follower (this is "pos_lidar_f" and cov_lidar_f"). Translations have been compensated such that this estimate corresponds to the pose of the body frame of the leader (at point M) in the body frame of the follower (see Figure 3).

The leader is equipped with the same sensors without the lidar.

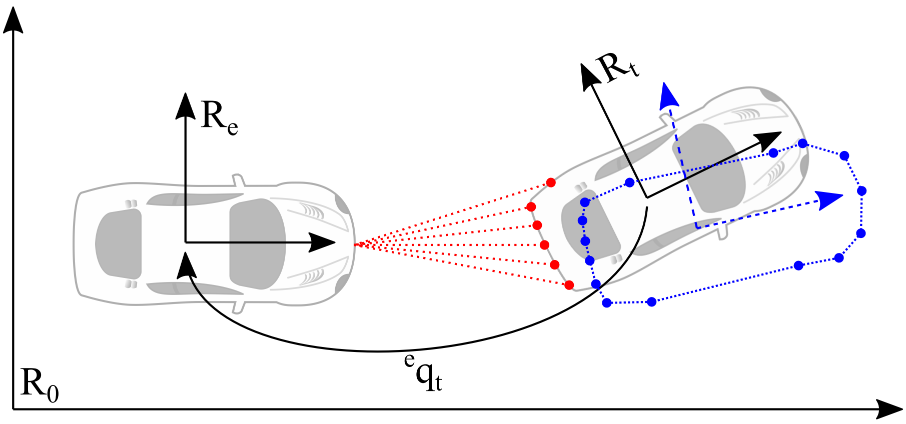

Figure 3: Lidar impacts and clustering and relative pose estimation.

2.2 Data set

The dataset has been recorded by Elwan Héry, Stéphane Bonnet and Anthony Welte in July 2018 at UTC. A very accurate map of the evolution area is also provided for visualization only (see figure 4).

The dataset is available at the address : https://cloud.utc.fr/index.php/s/NkKWTSHQNM7kEyy

With the password : QdmyY8gC

The data is describe in its documentation (see section 4 for the CSV datasets).

In the experiment, the information transmitted by the communication modems has not been logged. The data of both vehicles have been logged by two separated computers with timestamps in the same reference time, thanks to an accurate GPS time synchronization mechanism.

Moreover, even if the raw measurements are asynchronous, they have been re-synchronized at the frequency of the lidar for simplification the sampling time is around 0.0800 s. Note that this frequency is not exactly constant (the standard deviation of the sampling time is 0.0020 s) and we recommend you to compute it at each iteration in your filters.

Run the script “dataset_viewer.m” to have an overview of the experiment (see figure 5).

Warning: The data you are going to use are not public. Do not pass it on to anyone and do not drag it on the web or in the cloud.

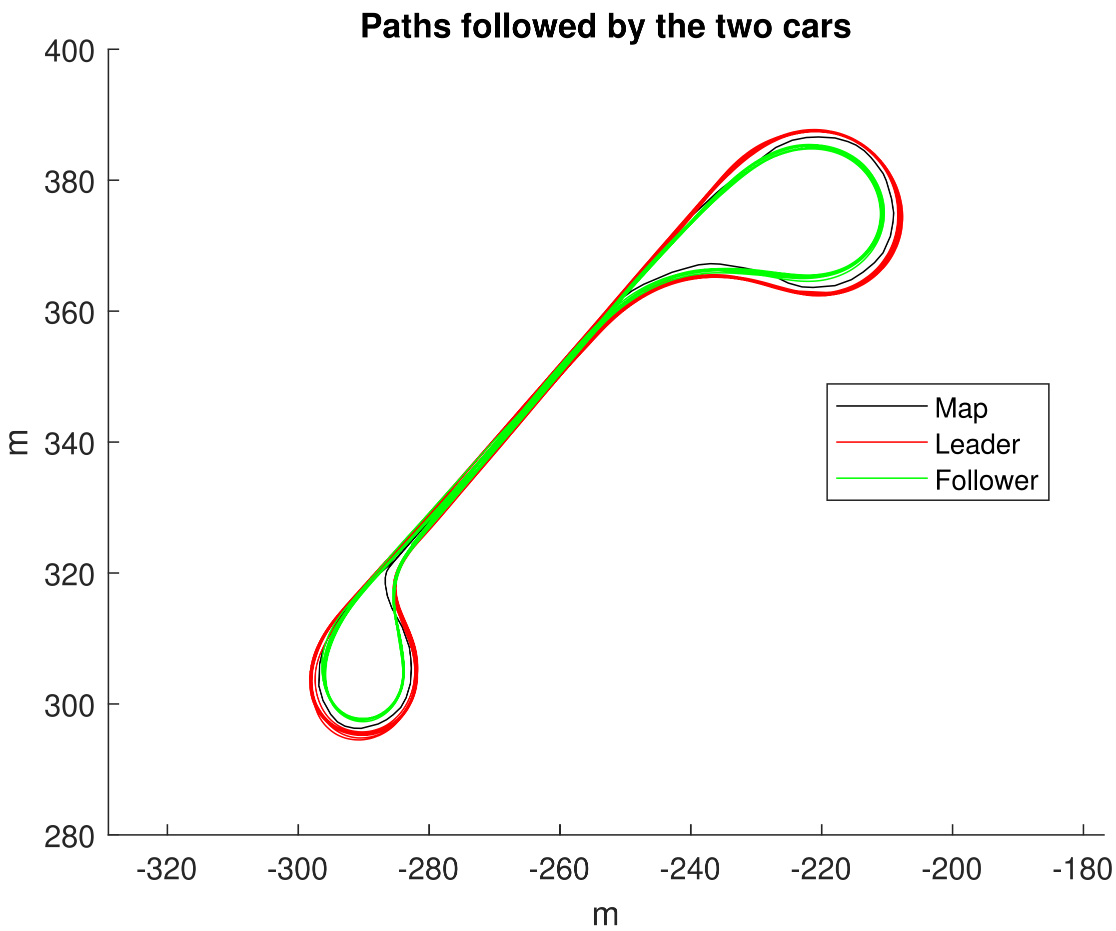

Figure 4: Paths followed by the two cars on SEVILLE. It can be noticed that their are quite different such that the follower can always see the leader in its lidar field of view.

3 Work to be done

We want to estimate the poses X of the two vehicles characterized by the Cartesian position x, y in the local ENU frame, and θ the heading of each vehicle.

There are 4 problems. Try to solve them all.

3.1 Problem A

The vehicles are not communicating.

The goal is to improve the localization of each vehicle by doing the data fusion of its Ublox with its DR sensors in a loosely coupled way.

Give the state space model that you use and implement an EKF for each vehicle.

For the implementation, note that the standard deviations of the Ublox pose and of the speed are given.

Analyze your results in terms of accuracy and consistency. Explain how you compute the consistency.

3.2 Problem B

The vehicles communicate and the leader sends **only** its estimated pose with the associated covariance matrix (from their EKF).

The goal is to improve the localization of the follower by doing the data fusion of its DR sensors with its own Ublox and the received pose of the leader translated into its own body

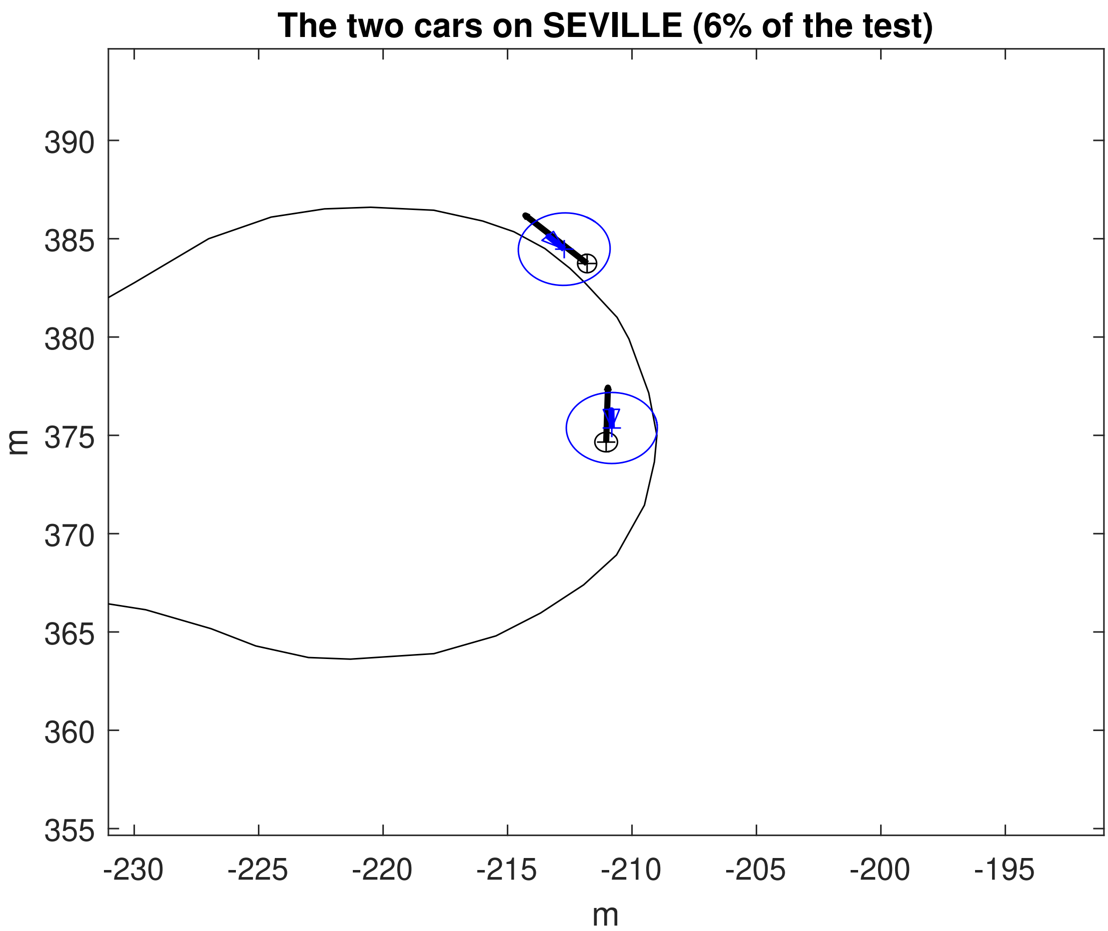

Figure 5: The two cars on SEVILLE. In black, the ground truths, in blue the Ublox estimates.

frame thanks to the estimated relative pose obtained from the lidar measurements. In this problem, the estimated position of the leader can be seen as a deported GPS antenna.

Use the $\oplus$ and $\ominus$ functions given in the toolkit to determine a new pose measurement for the follower thanks to the measured relative pose and the received pose of the leader.

Analyze your results in terms of accuracy and consistency.

3.3 Problem C

This problem is the same as Problem B but we want to test more consistent $\oplus$ and $\ominus$ functions by using Unscented Transformation (UT).

Explain how to modify these functions with Sigma Points when propagating the uncertainty (instead of using Jacobian matrices).

Compare your results with the one of Problem B (still in terms of accuracy and consistency).

3.4 Problem D

The vehicles communicate and still exchange their estimated pose with the associated covariance matrix but now the follower sends also its measured relative pose (done by the lidar).

The goal is to improve the localization of the two vehicles by doing the data fusion of all the sensors. In other words, each vehicle has to merge its DR sensors with its own Ublox and to use the pose received from the other. The follower has to solve the same problem as before (Problem B) but the leader has now to exploit the received relative pose and the received estimated pose of the follower.

Show that, for the leader, the $\oplus$ function is sufficient to get an observation from the information sent by the follower.

In this problem, use the Covariance Intersection (instead of a Kalman update) because there is now a cycle in the information exchange.

Analyze your results in terms of accuracy and consistency.

3.5 Guidelines

Every student in a group has AT LEAST to solve one problem or a part of it.

- A report is expected per group in which, for each problem,
  - Describe the state space (state vector and models).
  - Describe your observers.
  - Draw curves (including error curves of {x, y} with confidence domains because you have the true values of the parameters) and discuss your results.
  - Explain how you have tune the filters.
  - Compare the performance between the filters.
- Give the Matlab code of your observers and indicate what is the program to launch in order to test it.
- The whole in a zip file has to be uploaded in the Moodle site the day before the oral defense no later than midnight, Paris time.
- Prepare an oral presentation (5 minutes maximum per student). You will also deliver a paper copy of your report at this time.