Project: Sensor Fusion and Object Detection

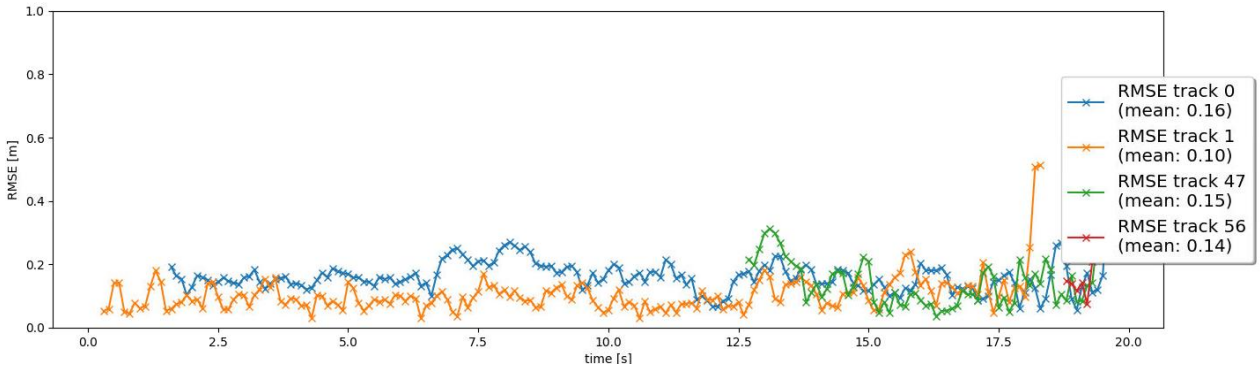
- *Write a short recap of the four tracking steps and what you implemented there (EKF, track management, data association, camera-lidar sensor fusion). Which results did you achieve? Which part of the project was most difficult for you to complete, and why?*

This project is about the tracking of objects and sensor fusion, which is an essential part of self-driving cars because it improves the reliability and robustness of perception systems by merging measurements from different sensors.

The project consists of four main steps:

- Step 1: Implement an Extended Kalman filter.
- Step 2: Implement track management including track state and track score, track initialization and deletion.
- Step 3: Implement single nearest neighbour data association and gating.
- Step 4: Apply sensor fusion by implementing the nonlinear camera measurement model and a sensor visibility check.

I've obtained quite good results in tracking vehicles over time with camera and lidar measurements. Here is the RMSE plot. We can see that as expected two of the tracks are tracked from beginning to end of the sequence (0s - 200s) without track loss and mean values are below 0.25:



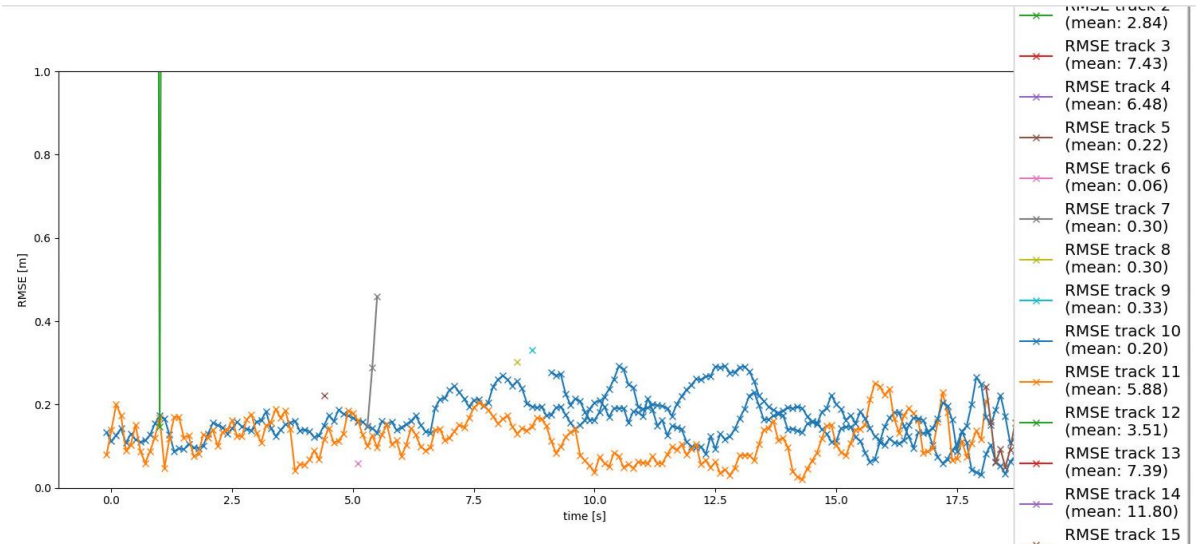
For me the most difficult part was to tune the design parameters for the track management system in order to find a trade off between not having too many not expected tracks and not having missing detections. The reason is that they are heuristic parameters so they require a lot of experiments to find the optimal values. I could improve my tracking performances by tuning for example the track score threshold to delete tentative or initialized tracks and the window for track score calculation:

```
# track management parameters (Step 2)
confirmed_threshold = 0.8 # track score threshold to switch from 'tentative' to 'confirmed'
delete_threshold = 0.6 # track score threshold to delete confirmed tracks
delete_threshold_newtrack = 0.17 # track score threshold to delete tentative or initialized tracks
window = 10 # number of frames for track score calculation
```

- *Do you see any benefits in camera-lidar fusion compared to lidar-only tracking (in theory and in your concrete results)?*

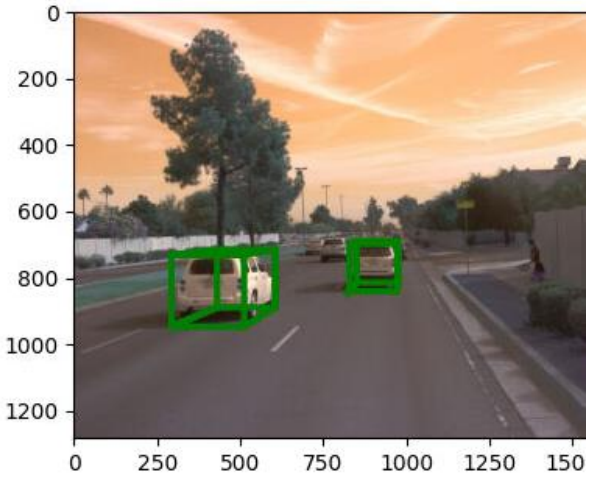
For sure, sensor fusion improves the reliability and robustness of any perception system by allowing to compensate for sensor failures and specific weaknesses.

In this particular project I found benefits in adding camera measurements to lidar-only tracking. The RMSE means are a little bit better for the two main tracks. Another big benefit of fusion in my results was to reduce the number of not expected tracks, as you can see by comparing the following plot obtained with lidar-only tracking respect to the previous one:



- *Which challenges will a sensor fusion system face in real-life scenarios? Did you see any of these challenges in the project?*

One challenge is about assumptions that we do on data but that are not always met in real-life scenario. For example in our data the lidar detections contain a y-offset, so in same frames we can see that the green boxes do not fit the exactly the car in the image, like in this frame:



- *Can you think of ways to improve your tracking results in the future?*

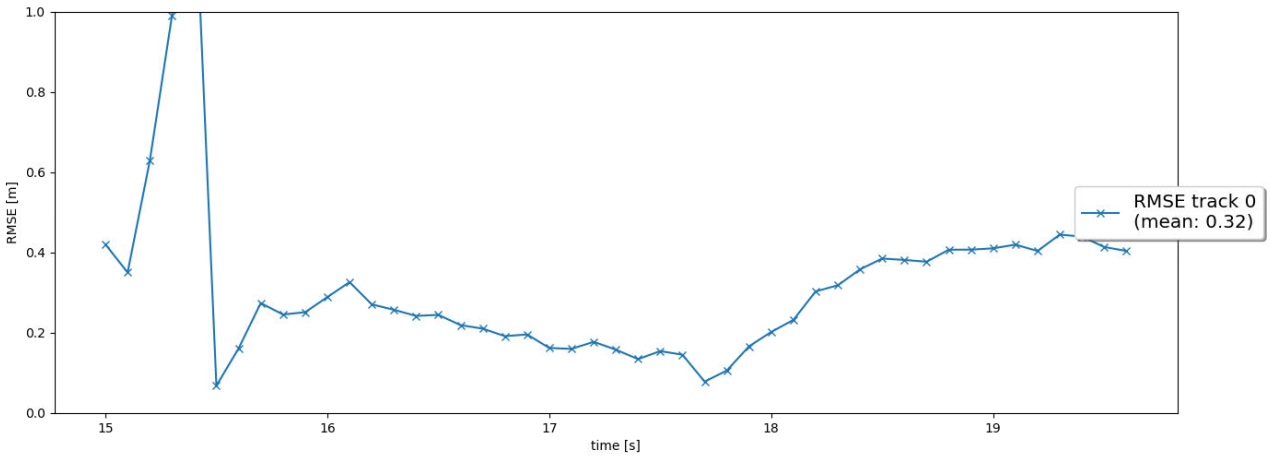
There are different tasks that could improve my tracking results.

One could be for example a more accurate tuning of the design parameters or using a more advanced data association like GNN or JPDA for the track management system. Another limit on the tracking system that we used a linear motion model that could be not so appropriate for vehicle movements. So maybe a non-linear model could help to improve the tracking results as well.

These are the steps of the project:

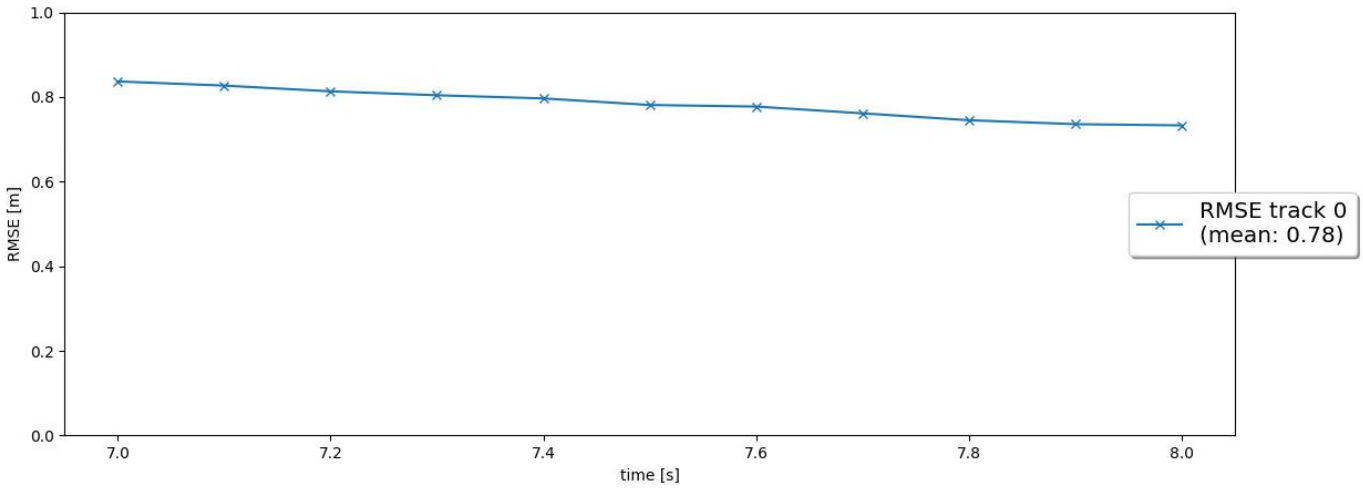
Step 1 | Tracking - Implement an Extended Kalman Filter

The goal of this first task is about implementing an Extended Kalman Filter and applying to a simple-target scenario with Lidar only. This is the mean RMSE behavior:



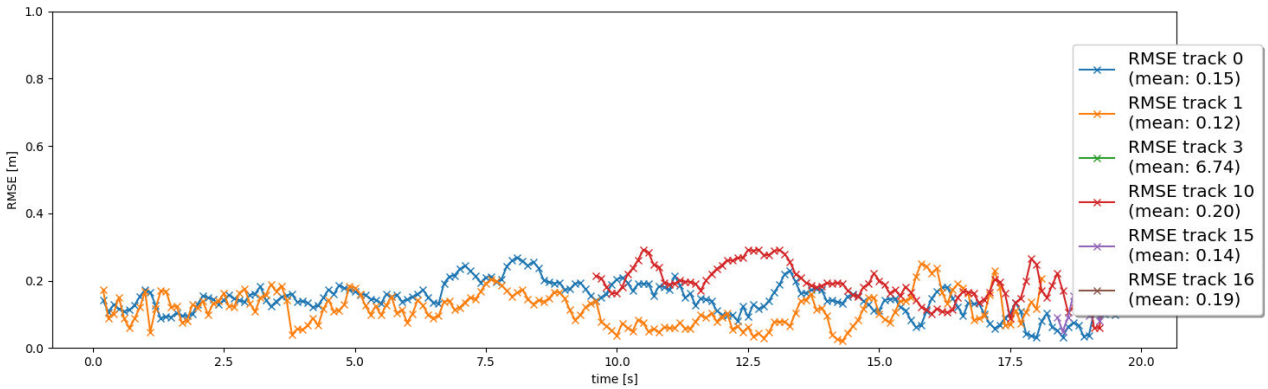
Step 2 | Track Management | Implement an Extended Kalman Filter

The goal of this first task is about implementing some parts of a track management algorithm like track initialization, track score, track state definition and track deletion. The RMSE for single tracking is as below:



Step 3 | Data Association

The goal of this first task is about implementing an algorithm to associate measurements with tracks. In this part only measurements from Lidar are used. Although the plot shows low values al RMSE mean, we can see that some not expected tracks are confirmed for a very short time:



Step 4 | Sensor Fusion

The goal of this first task is about adding camera measurements to the previous task. We can see that as expected two of the tracks are tracked from beginning to end of the sequence (0s - 200s) without track loss and mean values are below 0.25: