Automated Driving Using External Perception

Individual Lab Report

MRSD Project Course II

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Shreyas Jha

Team E: OuterSense

Teammates: Atharv Pulapaka, Dhanesh Pamnani, Jash Shah, Ronit Hire

ILR08

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Table of Contents

Individual Progress

Over the past two weeks, I have worked on the data association and state estimation pipeline for the OuterSense system (refer to Figure 1 for the system architecture). After calibrating the VESC IMU and the ERPM-based odometry, the objective was to fuse these measurements with global (map frame) pose estimates from the multi-object tracker in the perception pipeline.

As shown in Figure 1, an individual sensor fusion module is initialized for each controlled vehicle. Since each vehicle controlled by the OuterSense system needs to be uniquely identified, the initial step is to know the unique IP address of the vehicle being added to the system along with its initial pose. With this prior information, communication is established with the vehicle to receive odometry and IMU data. The raw IMU data from the VESC is first smoothed using a Madgwick filter that fuses the accelerometer and gyroscope measurements. Finally, an Unscented Kalman Filter (UKF) is initialized to fuse all sensor measurements associated with this vehicle. The output from the UKF node is passed downstream to the planning subsystem.

To distinguish between measurements made by the multi-object tracker, the last known state estimate of all controlled vehicles currently in the OuterSense system is utilized. As a measurement is received from the perception module, the Mahalanobis distance to the state estimate of each vehicle is computed. This allows identification of the vehicle to which this measurement corresponds, and the measurement is used to update the state estimate by passing it to the UKF module. However, it is ensured that the measurement falls within a bounded region and forced data association is avoided. In other words, if a measurement from the perception module does not correspond to any of the controlled vehicles, it is treated as an obstacle in the environment. This measurement is provided to the world modeling and mapping module used by downstream obstacle avoidance modules in the planning subsystem.

The implementation of individual sensor fusion modules for each vehicle has been completed and tested. This adds value to the autonomy system in two aspects. Firstly, it produces much smoother state estimates leading to more continuous trajectories generated for each vehicle by the MPC module. Secondly, it solves the issue of unreliable yaw estimates for static vehicles, avoiding vehicles getting stuck after stopping. The work involved setting up the localization package, integrating it with data streams, managing coordinate transforms between sensors, converting IMU measurements between frames, ensuring consistent frame IDs in measurements and transforms, and fusing specific degrees of freedom from sensors.

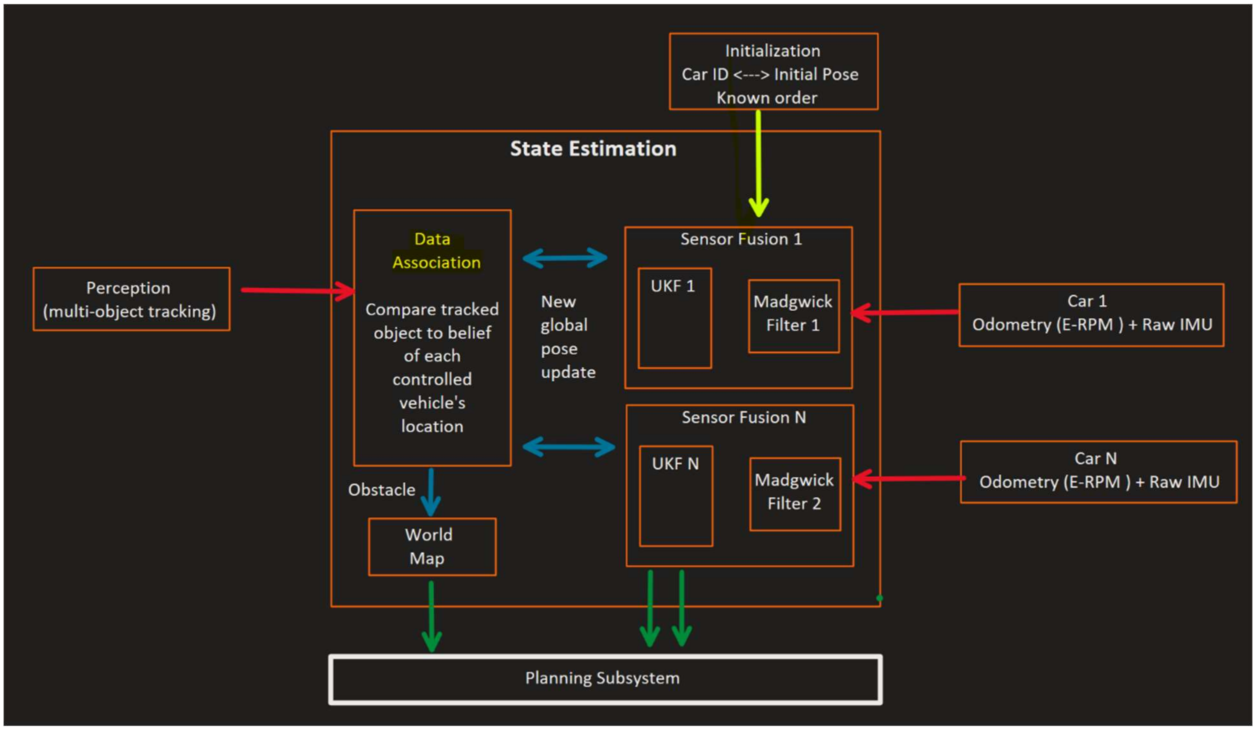

Figure 1: State estimation architecture for OuterSense

Challenges

Asymmetrical Turning Radii of RC Cars for Left and Right Turns

During testing on the new track covered by three infrastructure sensors, it was observed that the RC cars did not turn as sharply towards the right compared to the left. Since I have been responsible for developing the RC car and its low-level motion control, I investigated this issue. This posed an unforeseen challenge as there were no major software or hardware changes made to the RC car, and unit tests functioned as expected.

I first computed the theoretical turning radii for our cars based on Ackermann geometry to confirm the asymmetric behavior. The investigation revealed an issue intrinsic to the RC car rather than the control software. It was determined that the issue stemmed from the RC car itself rather than the upstream controller. I began by re-tuning the low-level controls, which did not resolve the problem. Further debugging revealed that the VESC was truncating commands sent to the steering servo above a specific range. By adjusting this clipping threshold, uniform turning behavior was achieved for both left and right turns. Adjusting the clipping threshold ensured consistent performance for turns in both directions.

Teamwork

Atharv Pulapaka: Atharv worked on developing an adaptive cruise control system to avoid collisions between controlled vehicles and maintaining a safe distance between them.

Dhanesh Pamnani: Dhanesh focused on building the new track and designing the planning architecture of OuterSense and defining interfacing requirements with other subsystems.

Jash Shah: Jash collaborated with Dhanesh on the planning subsystem. He has been working on a hybrid A* planner that incorporates kinematic constraints for feasible Ackermann steering.

Ronit Hire: Ronit collaborated with Atharv on the PID-based adaptive cruise control. He also researched Minimum Cost Flow graph algorithms to maintain stable object IDs in multi-object tracking.

Future Work

My priorities for future development are:

1. Tuning measurement noise parameters for sensors and UKF parameters to improve sensor fusion convergence and robustness. (Estimated completion: 10/15)

2. Implementing data association using unlabeled measurements from perception, and testing robustness to obstacles in close proximity. (Estimated completion: 10/18)

3. Constructing a 2D occupancy grid map representation of the track environment in the world frame using ROS map server. (Estimated completion: 10/23)

4. Updating the base map at 10Hz (global planner rate) by incorporating static and dynamic obstacles published as nav_msgs/OccupancyGrid messages. (Estimated completion: 10/27)

The team demonstrated effective collaboration in developing core system functionality. My future work will focus on enhancing sensor fusion, data association, and mapping components to improve vehicle localization and navigation.