

OMS Race Application Report

Introduction

ARUS Andalucía Racing Team is the Formula Student team of the University of Seville, composed of more than 100 engineering students covering all areas involved in the design, manufacturing, and validation of a high-performance electric racing car.

The 2024–2025 season marked the culmination of a multi-year development plan, focused on achieving cutting edge vehicle architecture to position ARUS among the most advanced teams in the competition. In just three years, we transitioned from a tubular chassis with a rear-wheel driven powertrain to a carbon fiber monocoque chassis with four in-wheel motors, additionally implementing a full autonomous racing system.

The acquisition of precise vehicle state data such as speed and accelerations are essential for the validation of our vehicle's design and the correct functioning of the control algorithms, which allow us to extract the full potential of our racecar on every dynamic event.

Due to technical challenges of this season, development time was highly constrained and on-track testing opportunities were extremely limited, so we really needed to develop a reliable state estimation within a short period of time.

State estimation using Ground Speed Sensor

Prior to the integration of the OMS Race sensor, our data acquisition system was mainly composed of:

- A 3-axis Inertial Measurement Unit (IMU), which calculates accelerations, rates and angles around the X, Y and Z axis.
- A linear extensometer for the steering angle.
- The in-wheel motor encoders, which provide the angular speed of the respective motor (consequently the angular speed of the wheel).

Our main goal was to accurately estimate the vehicle's longitudinal and lateral speed (v_x , v_y) and its yaw rate (r), since these three components describe the planar movement of the vehicle and are necessary for the correct functioning of the SLAM and the autonomous control algorithms, which allow the car to locate itself and follow its trajectory and speed profile in Driverless mode.

Moreover, the knowledge of these variables allow us to optimize the torque distribution between the 4 in-wheel motors, improving the car's lateral behaviour and ensuring maximum grip on each tire, thus improving the overall vehicle performance.

We initially relied on the inverter's wheel speed measurements for the vehicle speed estimation, but this approach suffered from limited observability under high slip conditions, which are frequent during aggressive driving and transient maneuvers. To assess this issue, we implemented a sensor-fusion algorithm based on a linear Kalman Filter (KF), which models the vehicle with a linearized bicycle model. A scheme of the state estimation algorithm is shown in Figure 1.1.

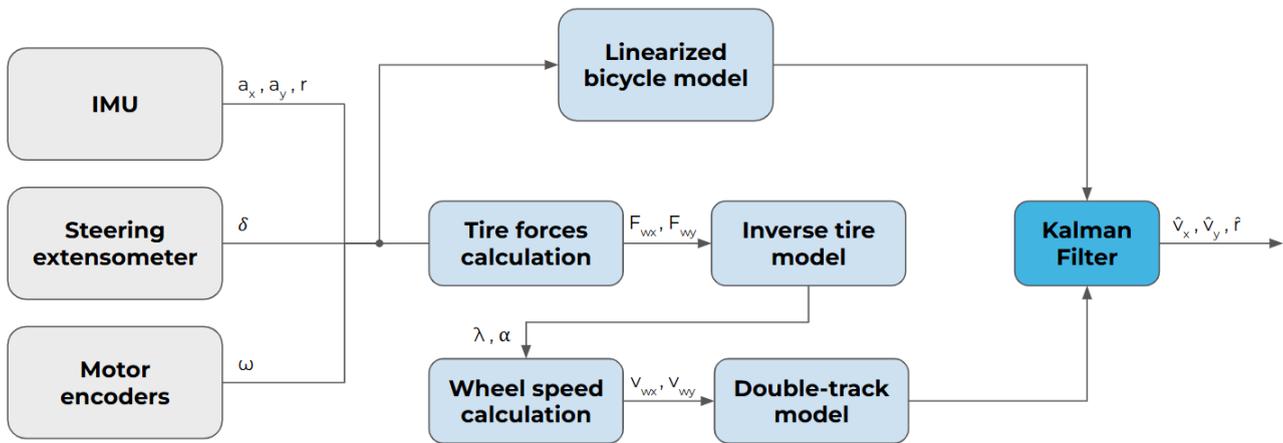


Figure 1.1: State estimation algorithm without GSS

Its distinctive component was the integration of wheels' longitudinal and lateral speed measurements based on an inverse tire model: using approximations of the tire longitudinal and lateral forces and a semi-invertible tire model, we obtained a prior estimate of the slip ratio and slip angle of each wheel, which can be used to calculate its speed in the X and Y direction.

This algorithm has great potential, but it relies on a tire model, which has to be fitted using test data to faithfully represent the tire-road interaction. The ever-changing surface conditions make this approach highly sensible to tire model inaccuracies.

To enhance our state estimation we decided to integrate the OMS Race ground speed sensor, which provides highly accurate measurements of a wide range of dynamic variables at a rate of up to 1000 Hz. Most importantly, it provides non-contact optical measurements of the vehicle speed and side slip angle, which are then filtered and fused with the inertial data acquired by its own integrated IMU, achieving unmatched precision.

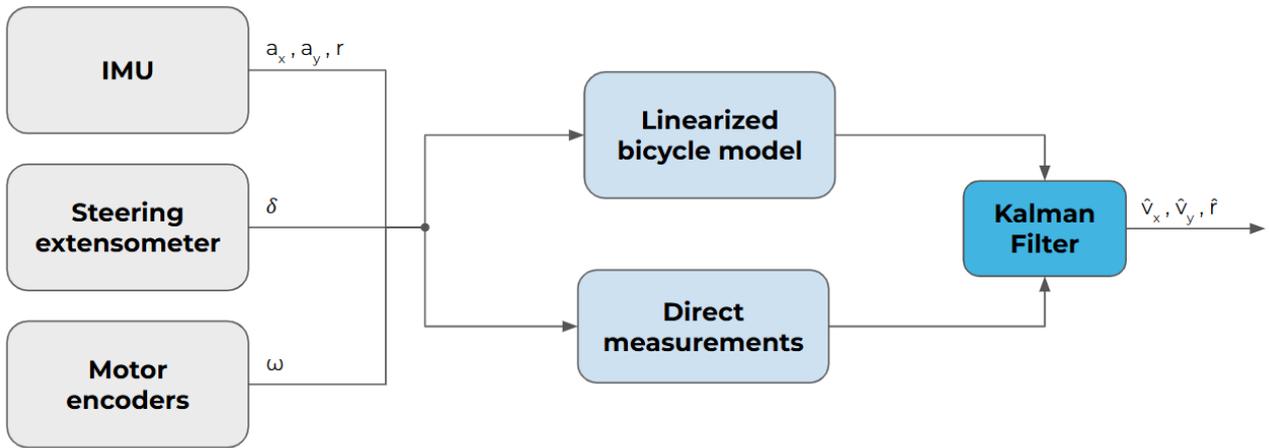


Figure 1.2: State estimation algorithm with GSS

Having precise measurements of the longitudinal and lateral speed allowed us to both simplify our estimation algorithm and improve its reliability and accuracy, since the optical measurements provided by the ground speed sensor are robust under any challenging condition. The simplified algorithm is depicted in Figure 1.2, and the comparison of the results obtained prior and after the integration of the OMS Race are shown on Figure 2.1 and Figure 2.2.

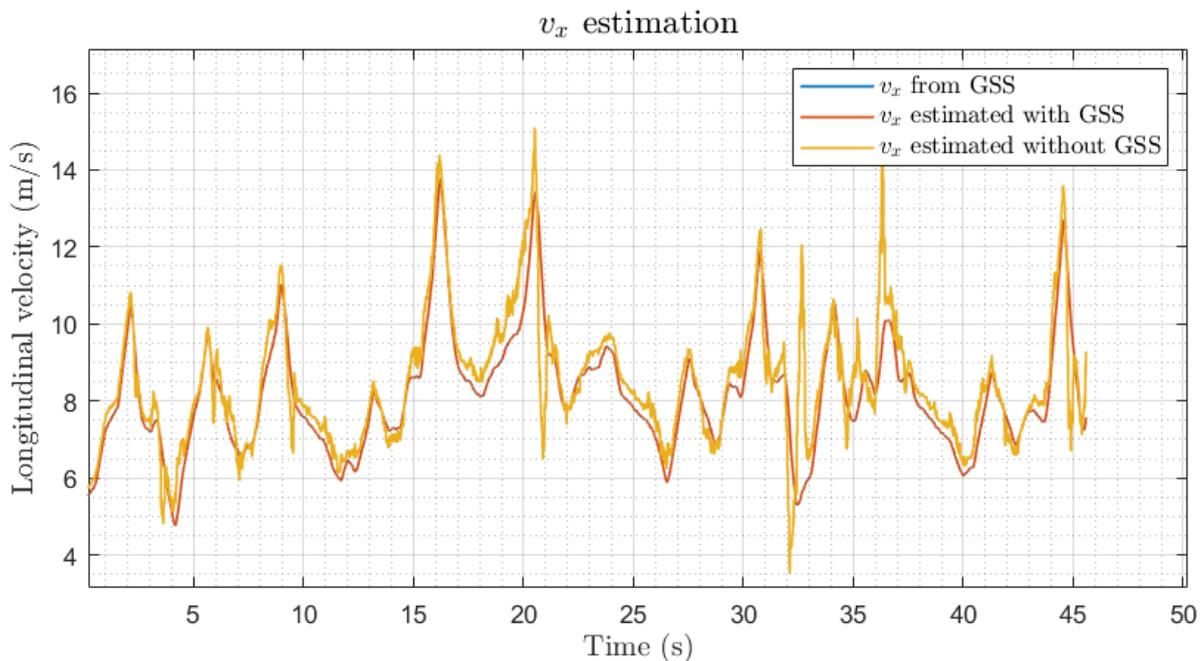


Figure 2.1: Longitudinal speed estimation

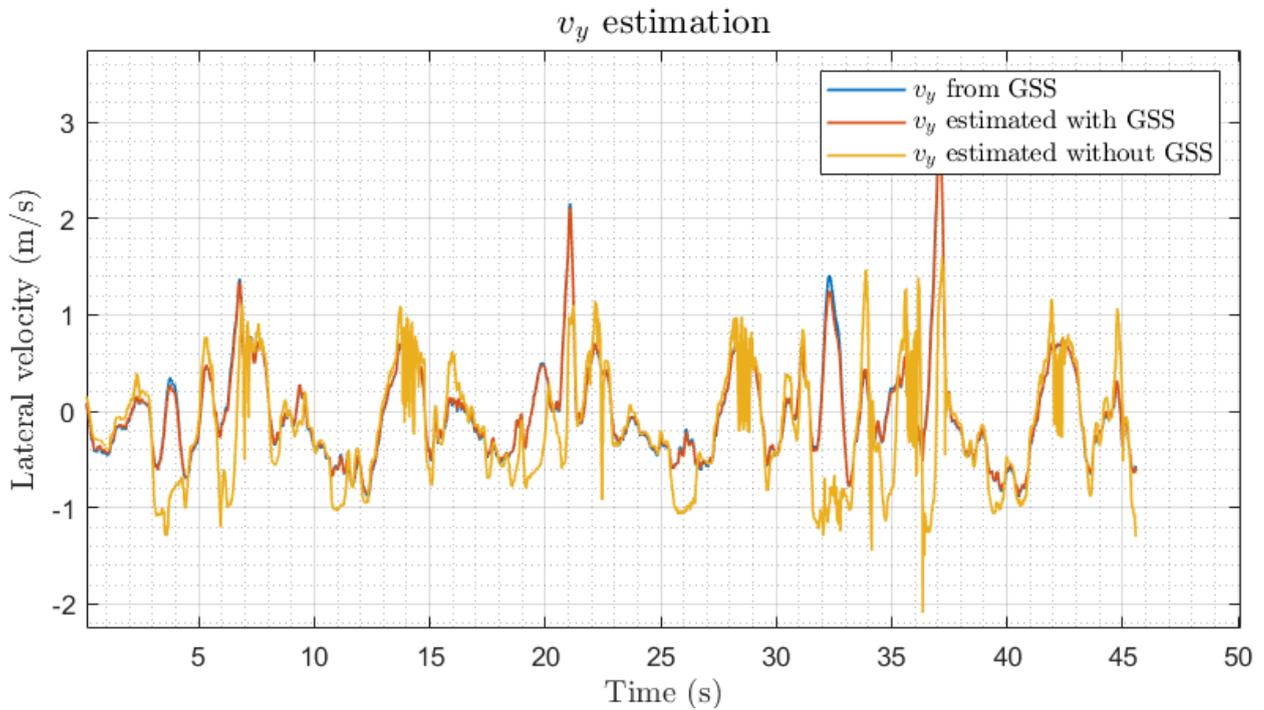


Figure 2.2: Lateral speed estimation

Here we observe that our original approach lacks precision and stability under high slip conditions, obtaining a standard deviation of 0.81 m/s in longitudinal and 0.52 m/s in lateral, whereas the ground speed sensor data gives us a stable and accurate measurement of the vehicle speeds at any time.

Installation of the sensor

Taking into account the optimized design of the ART-25D, we decided to install the sensor behind the left side tunnel, minimizing any effect to the vehicle's aerodynamic performance. This position doesn't affect the sensors functioning at all, it only requires to be positioned perpendicularly to the ground and at a height in its working range. The sensor installation is shown in Figure 3.



Figure 3: OMS Race installation

The OMS Race comes with several features implemented on its ECU that help it achieve a seamless integration, like the definition of the Point Of Interest, which enables the conversion of the sensor signals to any point of the vehicle. This, combined with the configuration of the sensor mounting angle with respect to its longitudinal axis (which can also be automatically tuned), allow us to obtain the vehicle speeds at its center of gravity (COG) without any additional post-processing.

Additionally, the system accounts for extensive configuration of the Controller Area Network (CAN) communication, allowing for output rate and signals selection and calculating an approximation of the added bus load. This was especially helpful for us, since the increasingly complex architecture of our vehicle communication system made the bus load a threat for the CAN bus integrity.

Summary

The integration of the OMS Race ground speed sensor allowed us to improve our state estimation accuracy and stability with minimum effort during a season where testing and development time was critical for the team's success.

This allowed for fast tuning of the vehicle controls and for the successful performance of the autonomous racing pipeline. Moreover, it helped us validate the design and manufacturing of our racecar, which is the foundation of this season's design choices and improvements on our manufacturing methods.

We highly recommend the OMS Race Sensor to any Formula Student team looking to enhance their state estimation both for data analysis and real-time applications.