



SLOVAK UNIVERSITY OF TECHNOLOGY IN BRATISLAVA

# Formula Student Driverless

## Autonomous system design

**Bc. Patrik Anton Knaperek**
Team Captain
STUBA Green Team

# Content

- STUBA Green Team
- Formula Student
  - Formula Student Driverless
- DV Hardware
  - Autonomous System Brake
- DV Software
  - Perception & Data Processing
  - Path planning & Control
  - CAN Interface

# STUBA Green Team

- 2009
- 9 monoposts
- 4 divisions
- 30 members


# Formula Student

- 1981: Society of Automotive Engineers (USA)
- 1998: Institution of Mechanical Engineers (UK)
- 2009: Electric category
- 2018: Driverless category

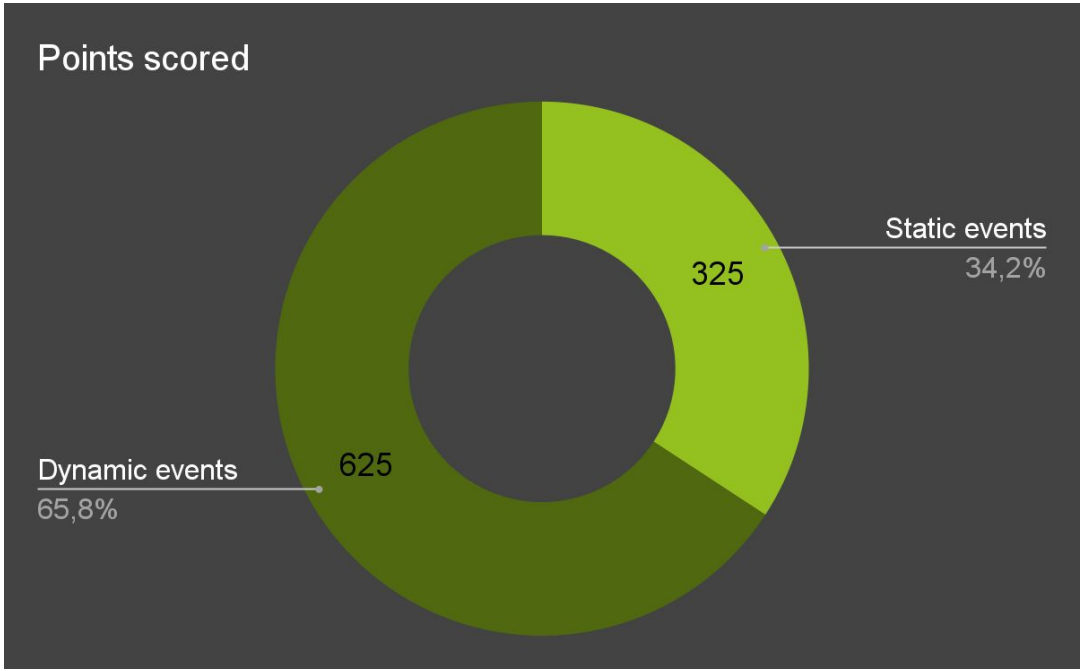

# Formula Student

- Ross Brawn
  - Managing & Technical Director, Formula One Group
  - Patron of Formula Student since 2006


***„There are two really innovative forms of motorsport left: Formula One and Formula Student.“***

# Formula Student

- Technical Inspections
- Static Events
  - Business Plan Presentation
  - Cost and Manufacturing
  - Engineering Design
- Dynamic events
  - Skidpad
  - Acceleration
  - Autocross
  - Endurance / Trackdrive (DV) & Efficiency



# Formula Student Driverless

- Track specification

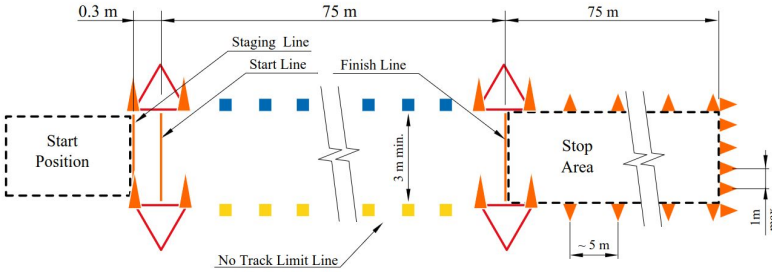
big orange cone
two white stripes

small orange cone
single white stripe

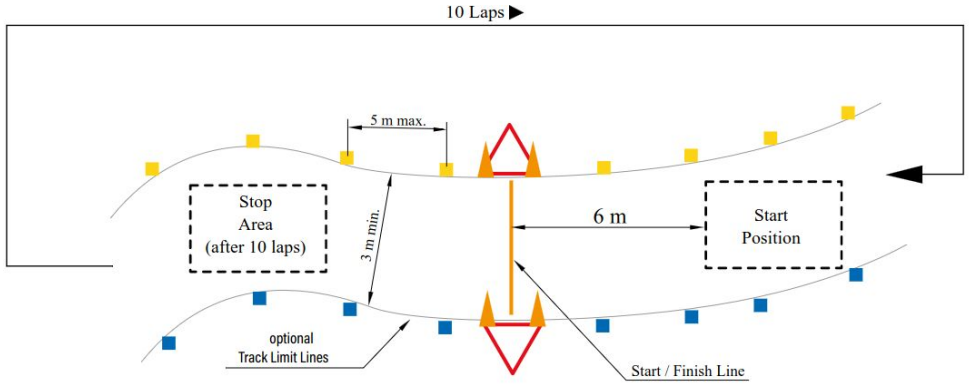
small yellow cone
single black stripe

small blue cone
single white stripe

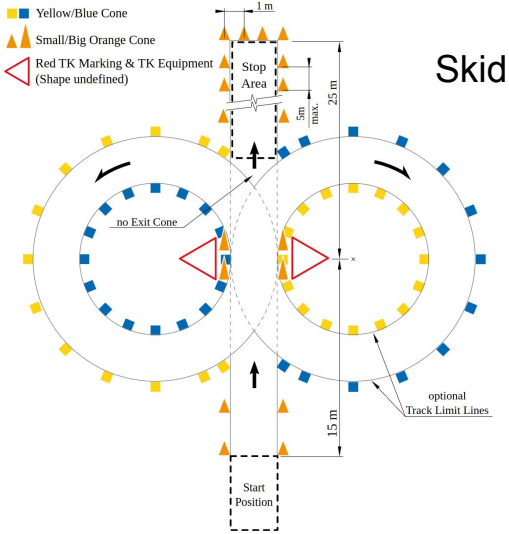
## Acceleration



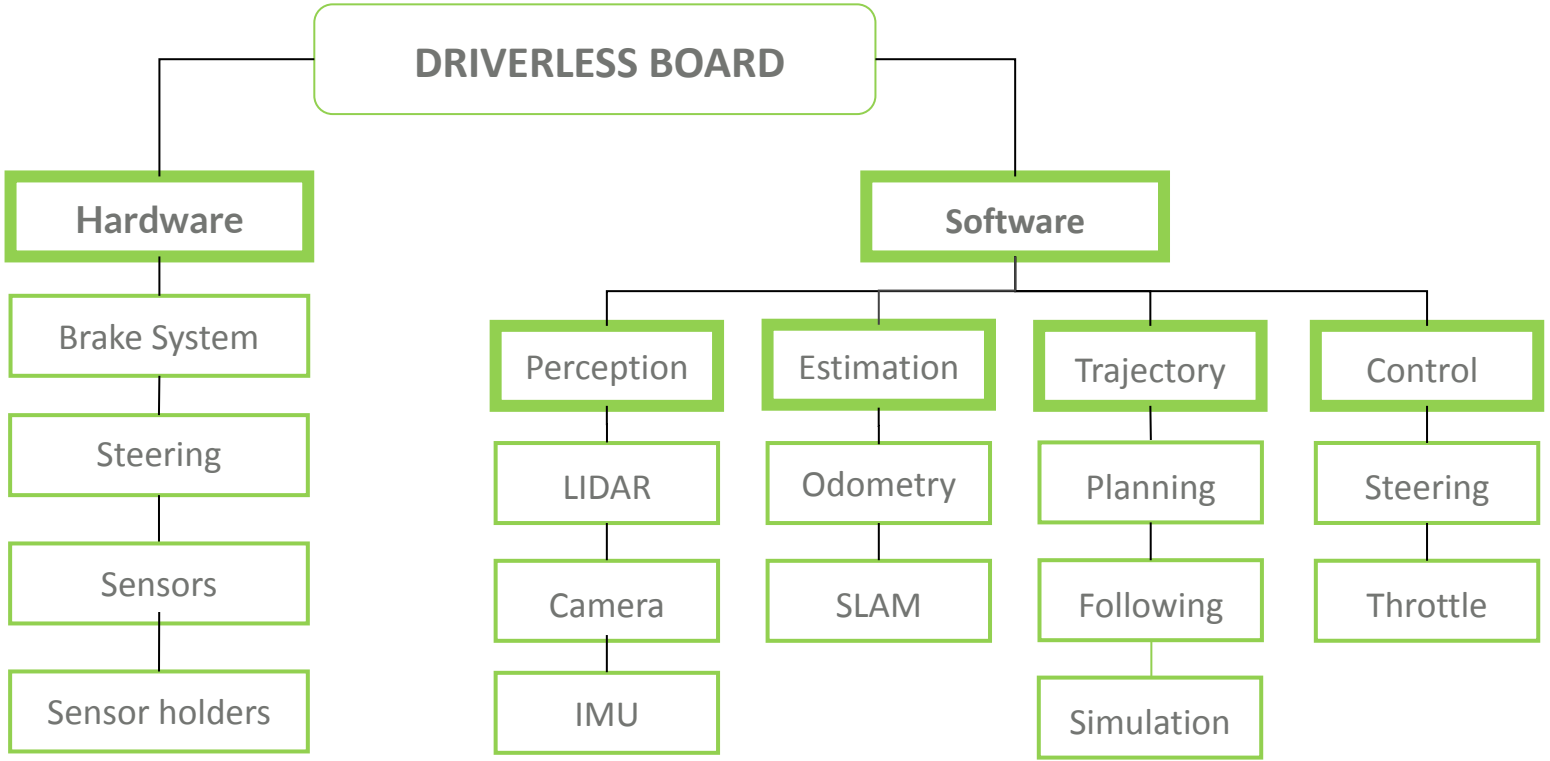

## Trackdrive / Autocross




## Skidpad



# SGT Driverless

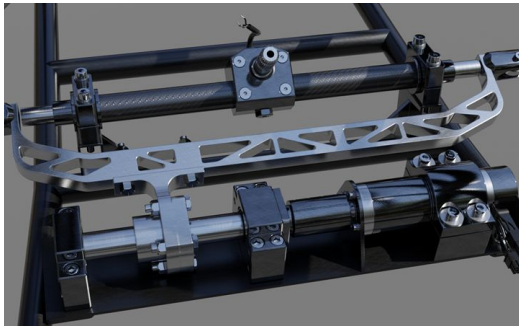


# DV Hardware

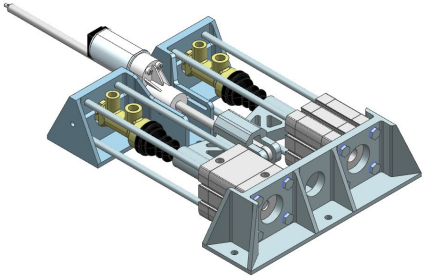

STEREOCAMERA


LiDAR

IMU



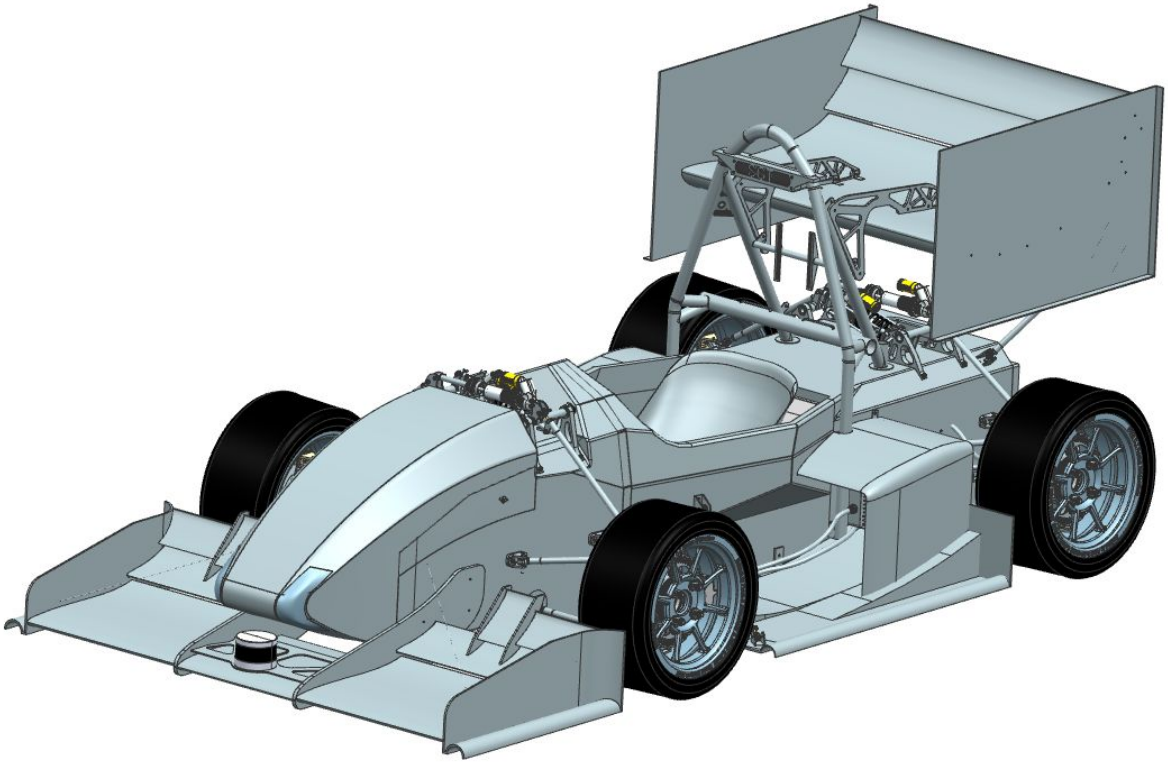
Steering actuator



ASB


Onboard PC

# DV Hardware

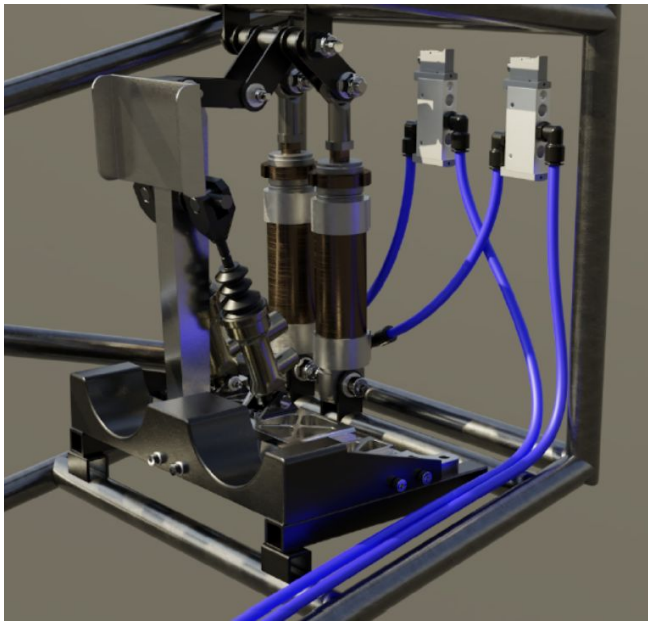


# Autonomous System Brake

- To run in autonomous mode, the vehicle must be equipped with an ASB that features an EBS as part of it.
- Manual braking must always be possible. In case of manual and autonomous braking simultaneously, always the highest of both pressures must be applied to the brakes.
- The EBS must only use passive systems with mechanical energy storage. Electrical powerloss at EBS must lead to a direct emergency brake maneuver.
- The system reaction time (the time between opening of the SDC and the start of the deceleration) must not exceed 200 ms.
- The average deceleration must be greater than 8 m / s 2 under dry track conditions.

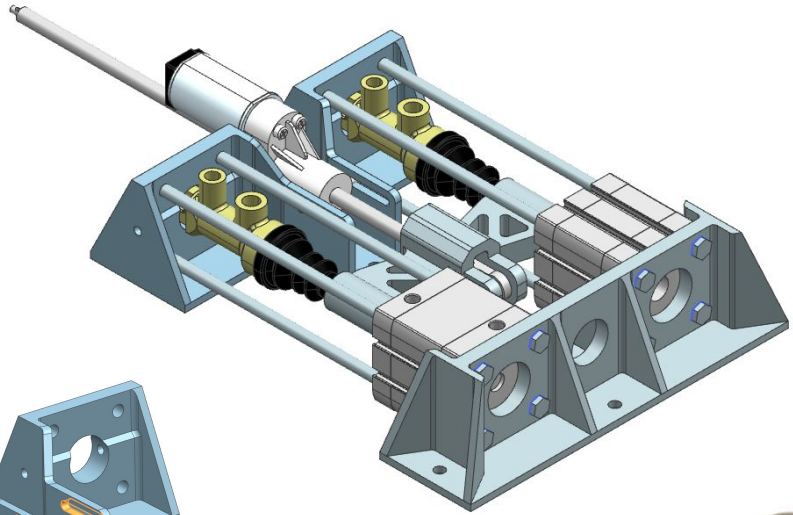
# Autonomous System Brake

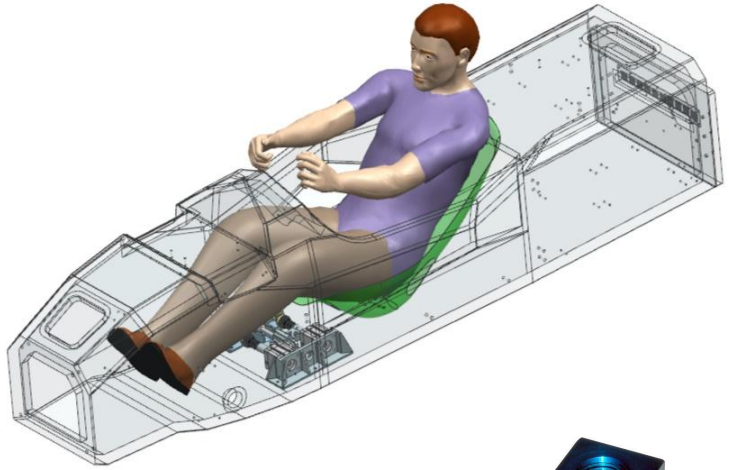
- Previous concept of Emergency Brake System

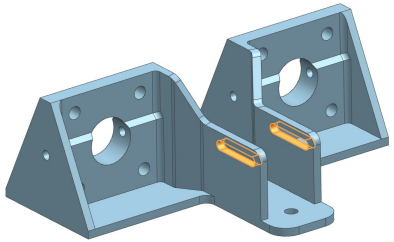


# Autonomous System Brake

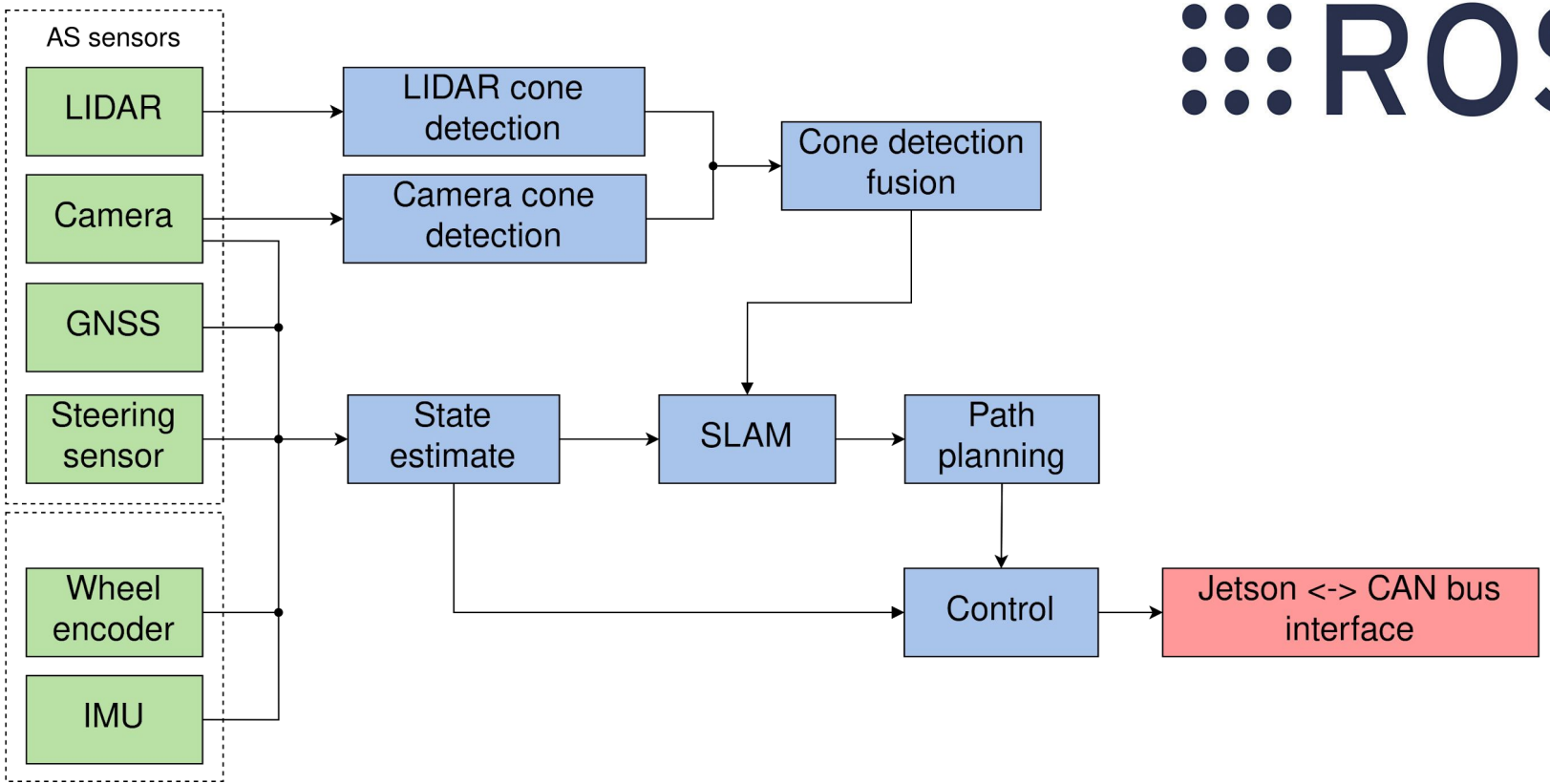
- Current concept





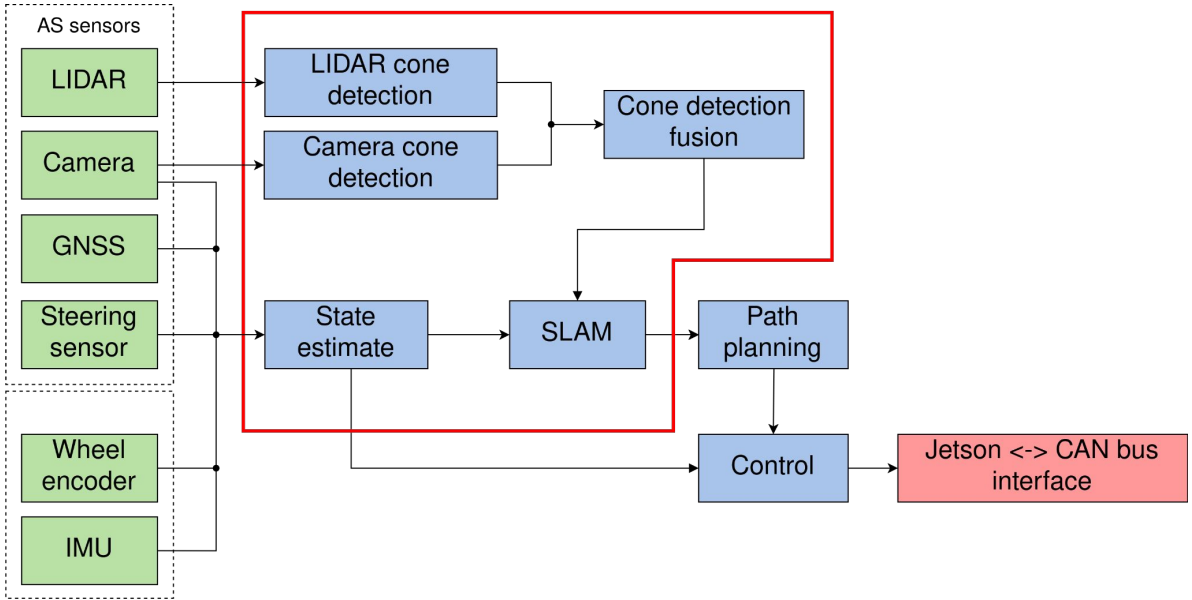


# DV Software

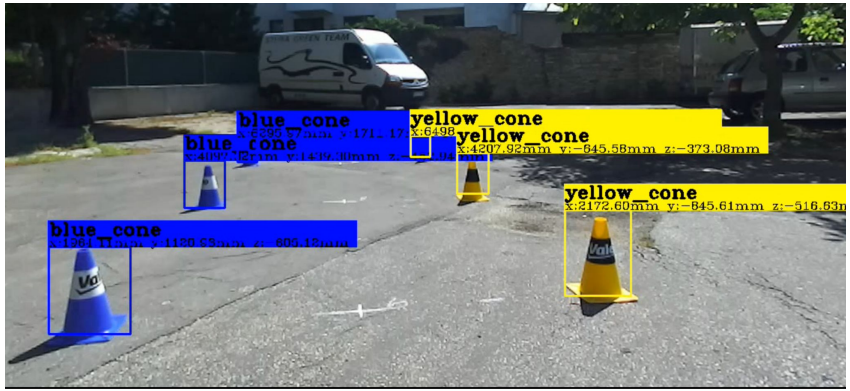

AS sensors
LIDAR
Camera
GNSS
Steering sensor
Wheel encoder
IMU
LIDAR cone detection
Camera cone detection
Cone detection fusion
State estimate
SLAM
Path planning
Control
Jetson <-> CAN bus interface
ROS

# Perception & Data Processing

- Camera Cone Detection
- Lidar Cone Detection
- Cone Detection Fusion
- State Estimate
- SLAM

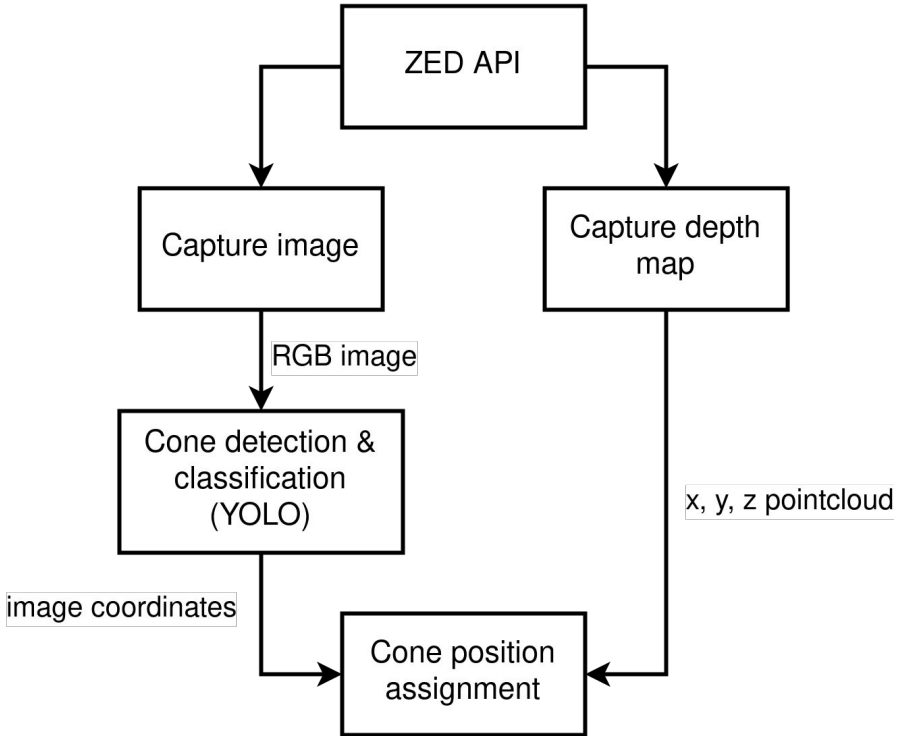


# Camera Cone Detection

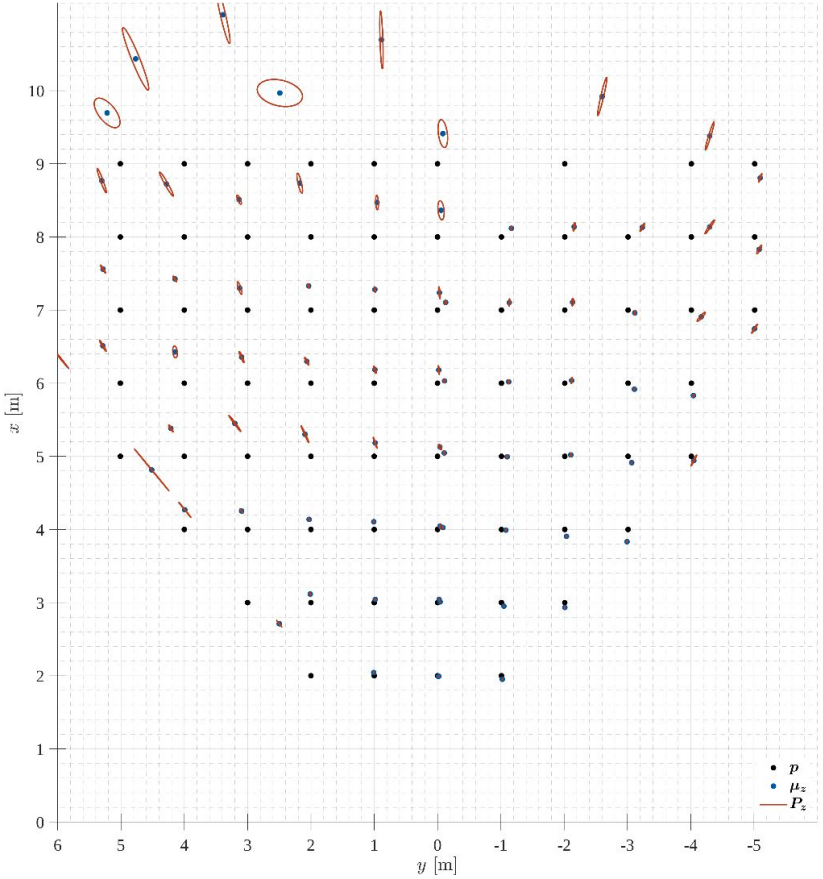


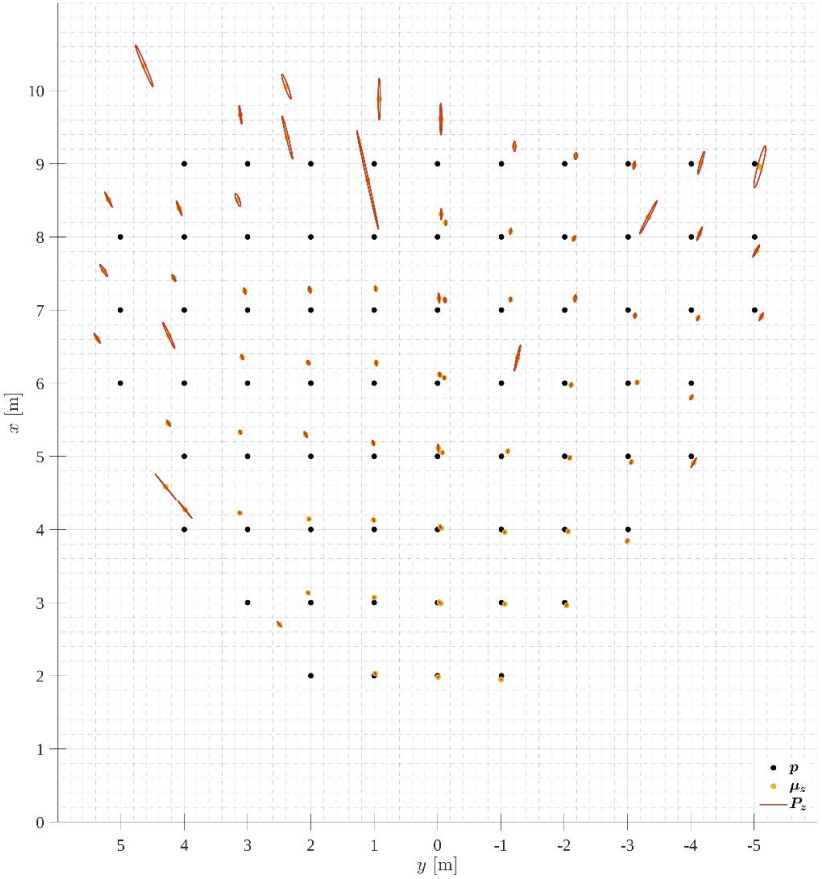

| Model | Precision | Time(sec/obr) | FPS |
|---|---|---|---|
| **YOLOv2** | 0.78 | 0.036 | 28 |
| **YOLOv2-Tiny** | 0.62 | 0.02 | 50 |
| **YOLOv3** | 0.89 | 0.058 | 17.2 |
| **YOLOv3-Tiny** | 0.72 | 0.023 | 45 |

Neural networks comparison

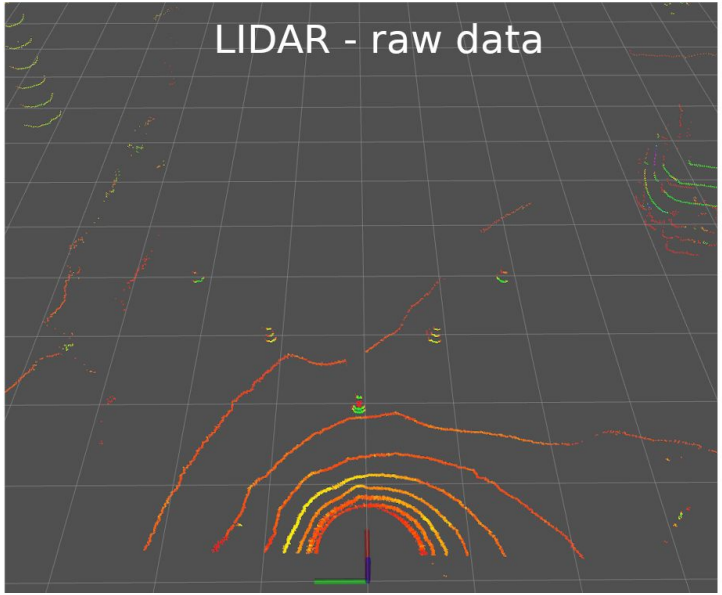


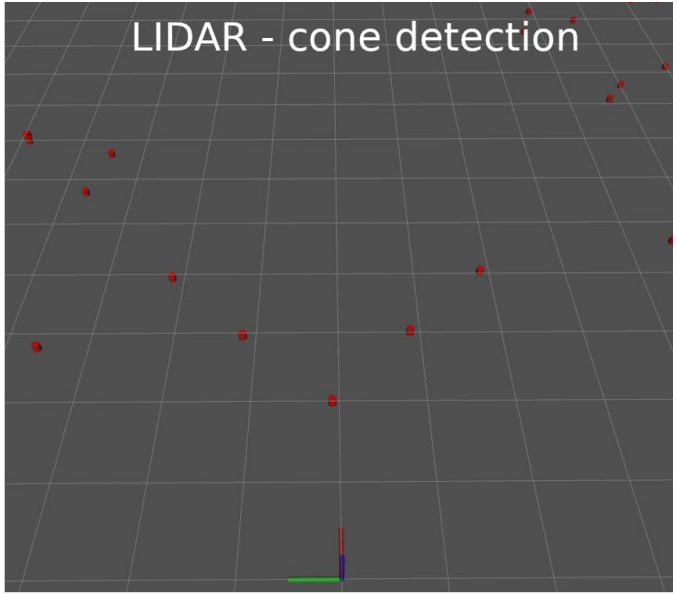
# Camera Cone Detection

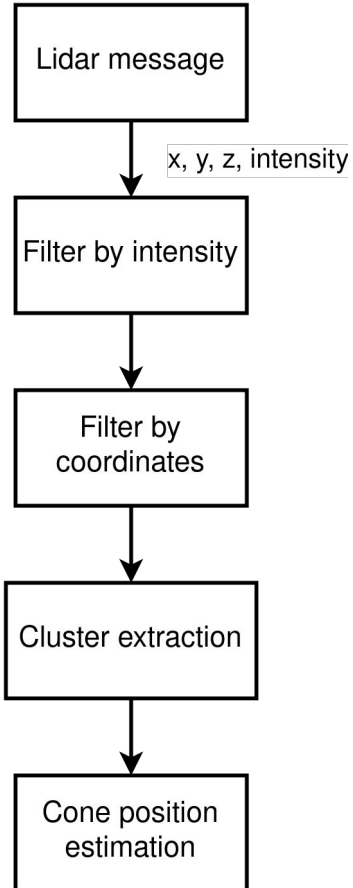


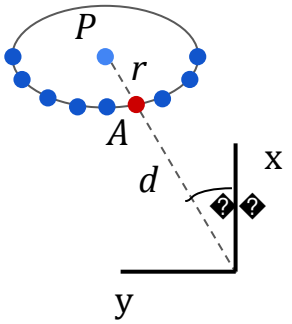
# Lidar Cone Detection



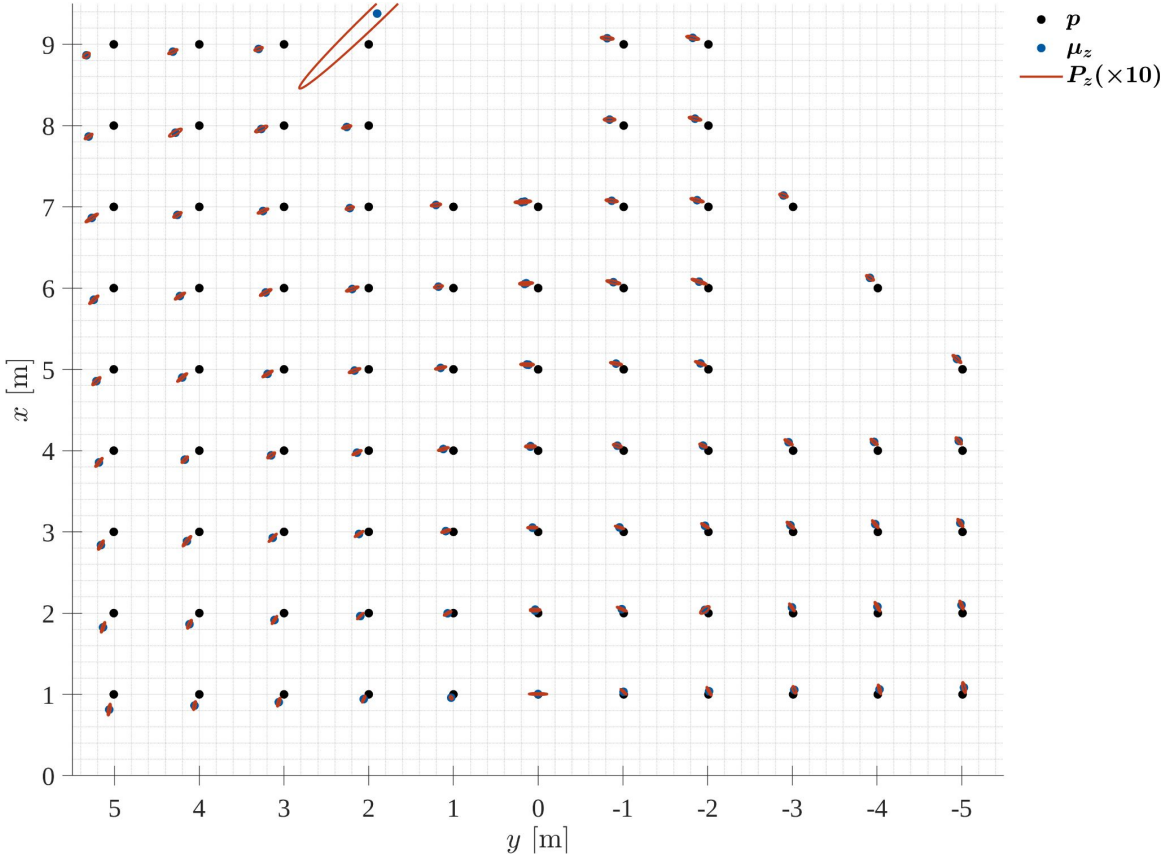



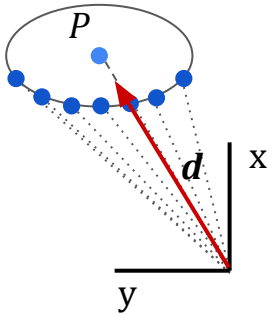
# Lidar Cone Detection



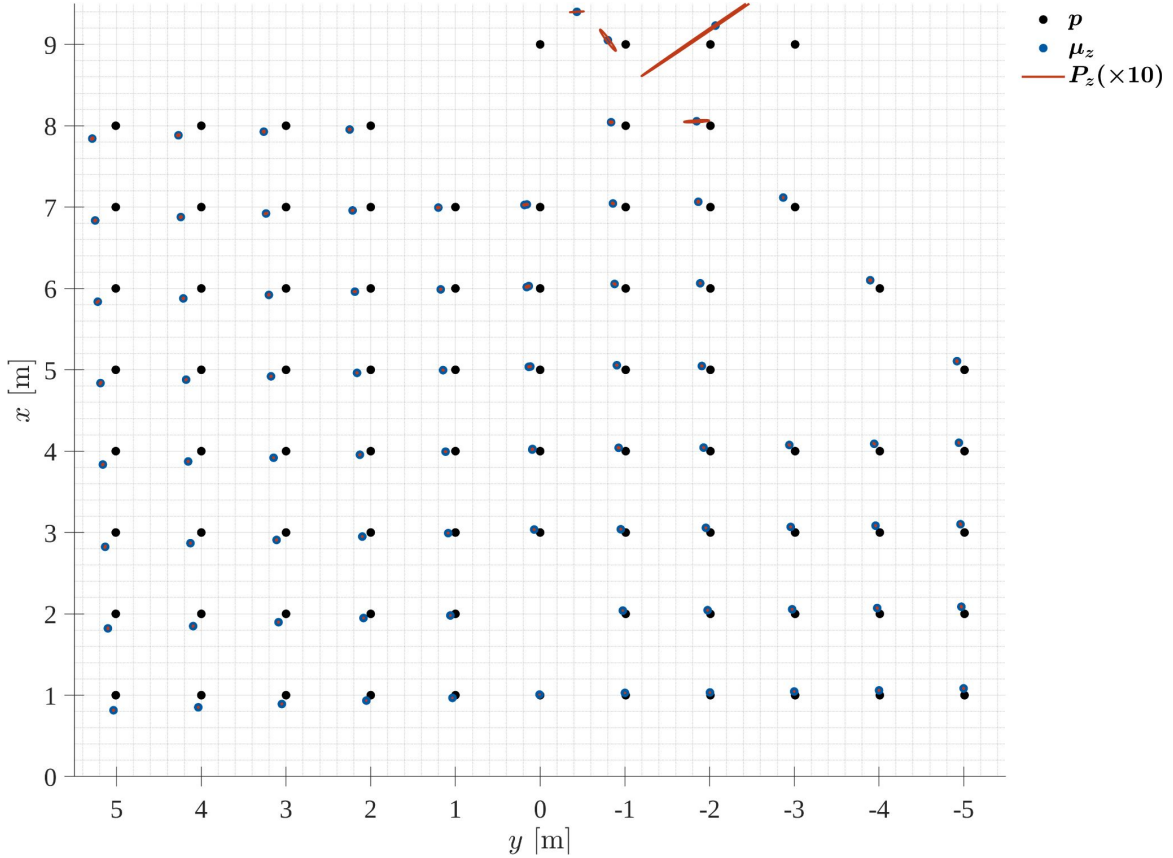

$$p_x = a_x + r\cos(\alpha)$$
$$p_y = a_y + r\sin(\alpha)$$



# Lidar Cone Detection




$$
\begin{aligned}
k &= 1 + \frac{2r}{\pi |d|} \\
p_x &= d_x k \\
p_y &= d_y k
\end{aligned}
$$

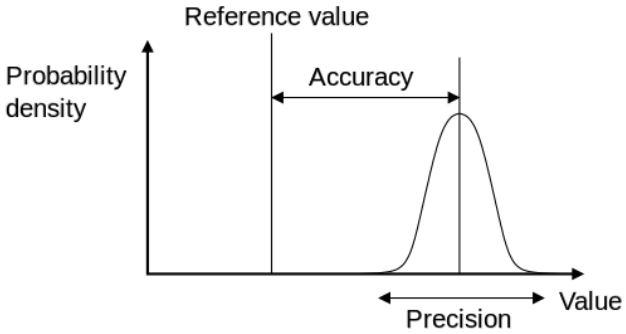


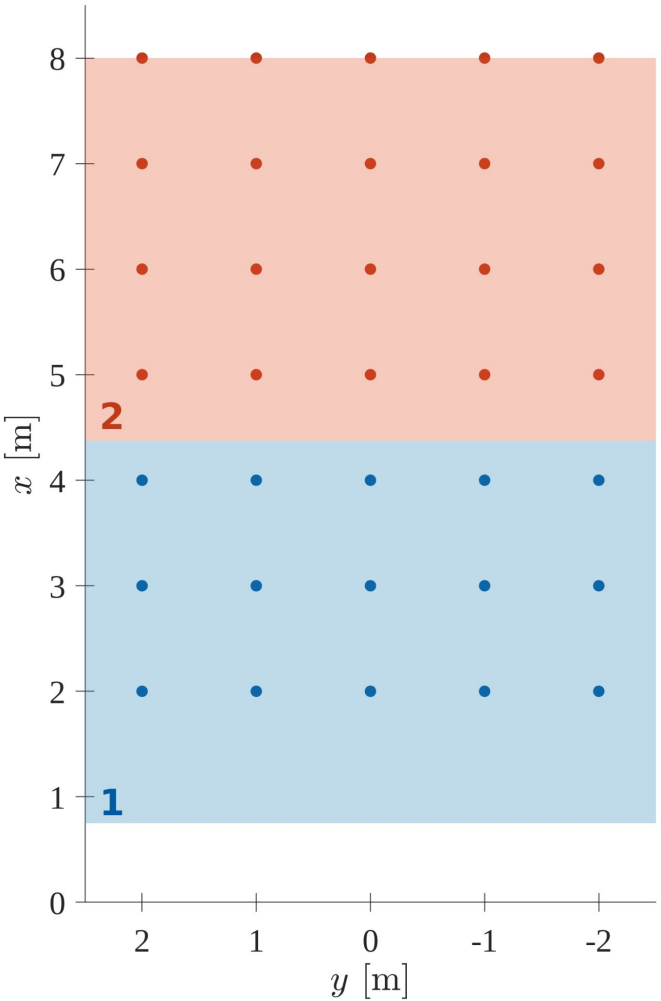
# Measurement model

- Precision and Accuracy

$$\boldsymbol{e} = \begin{pmatrix} e_x \\ e_y \end{pmatrix}$$

$$\boldsymbol{R} = \begin{pmatrix} \sigma_x^2 & \sigma_{xy} \\ \sigma_{xy} & \sigma_y^2 \end{pmatrix}$$



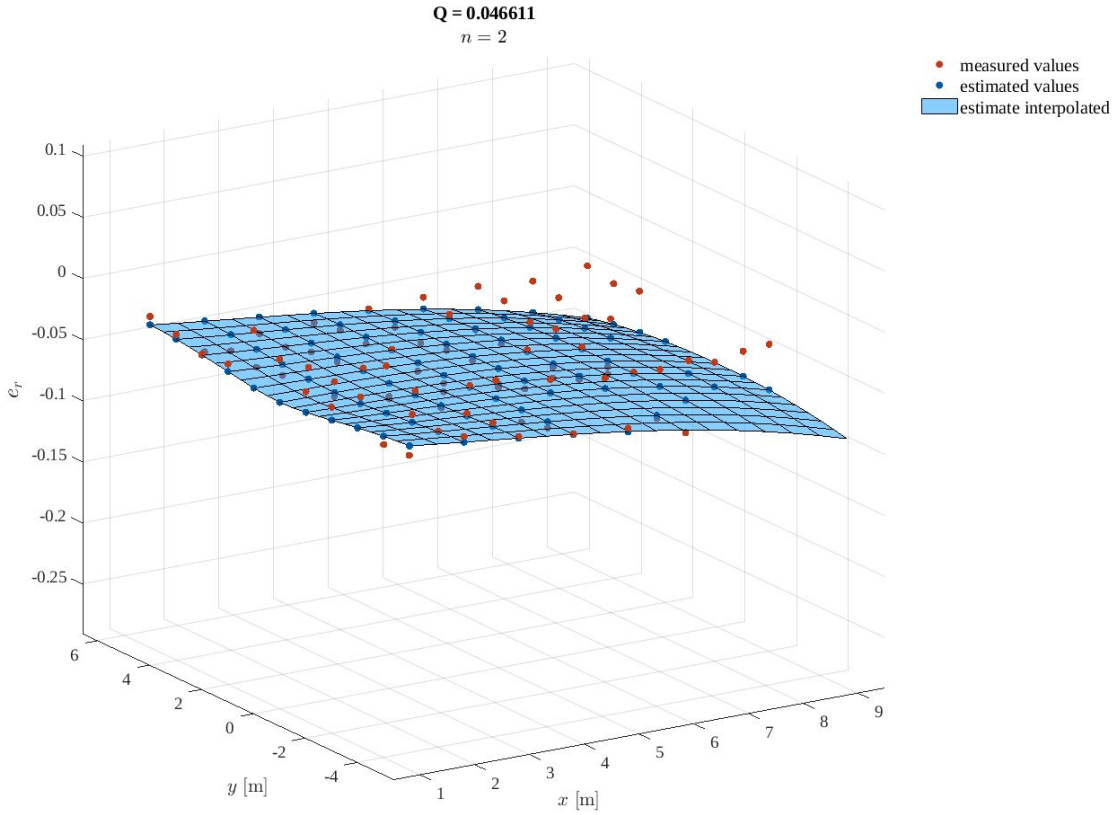



# Measurement model

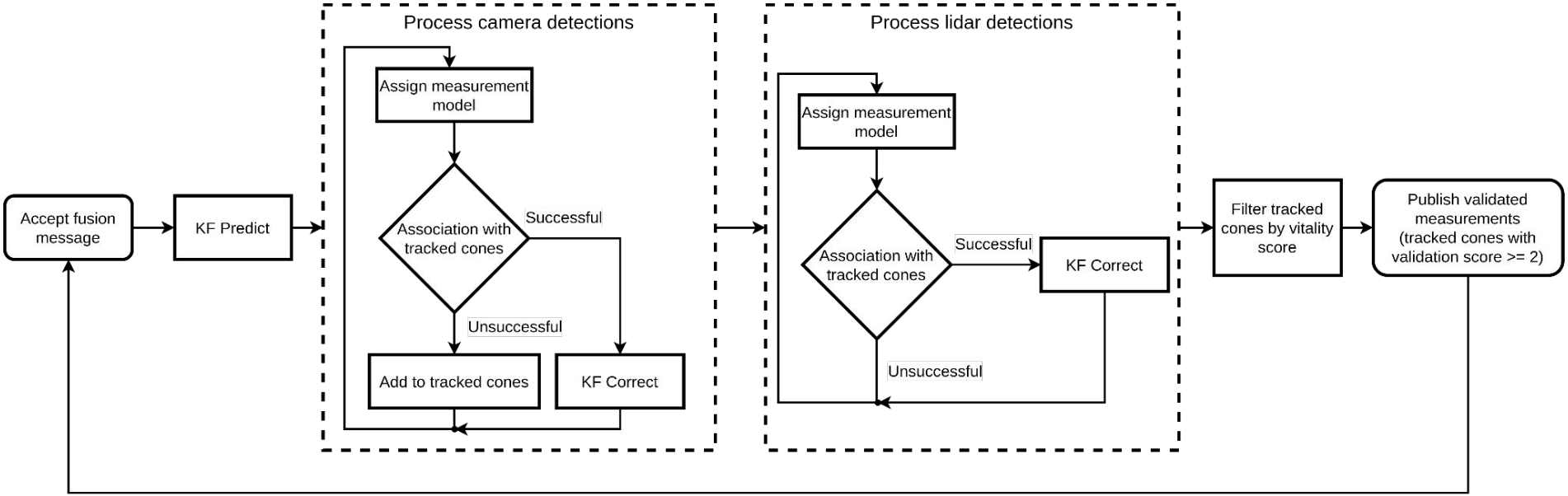
$$\boldsymbol{e} = \begin{pmatrix} e_r \\ e_\varphi \end{pmatrix}$$

$$\boldsymbol{R} = \begin{pmatrix} \sigma_r^2 & \sigma_{r\varphi} \\ \sigma_{r\varphi} & \sigma_\varphi^2 \end{pmatrix}$$

$$\hat{e}_r = \hat{\theta}_0 + \hat{\theta}_1 r^2 + \hat{\theta}_2 r\varphi + \varphi^2$$



# Cone Detection Fusion



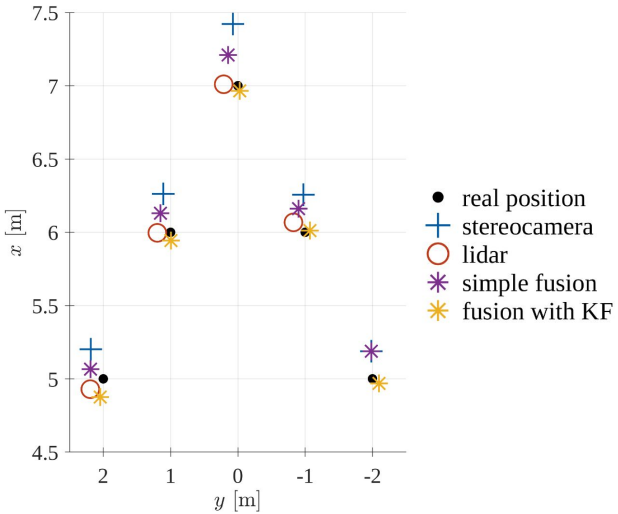

KF Predict

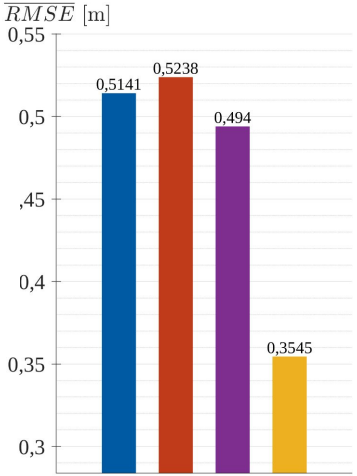
$$\hat{\boldsymbol{x}}_k = \boldsymbol{A}\boldsymbol{x}_{k-1} + \boldsymbol{w}_k$$
$$\hat{\boldsymbol{P}}_k = \boldsymbol{A}\boldsymbol{P}_{k-1}\boldsymbol{A}^T + \boldsymbol{Q}_k$$

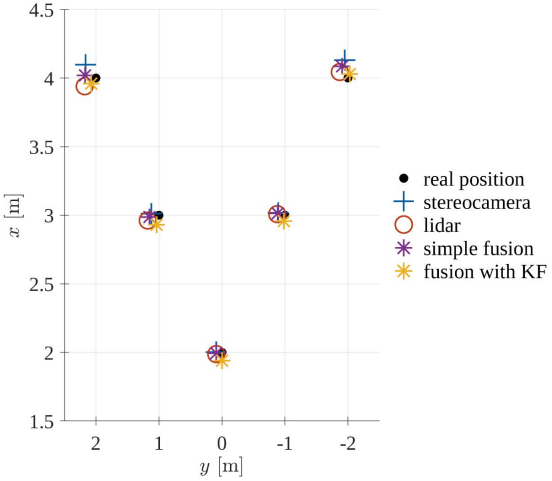
KF Correct

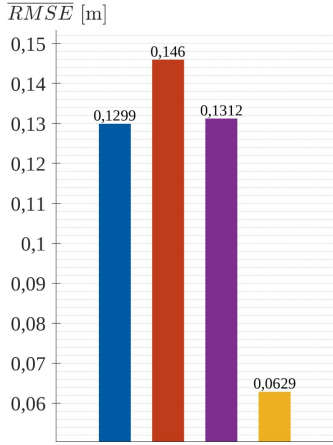
$$K = \hat{\boldsymbol{P}}_k\boldsymbol{H}^T(\boldsymbol{H}\hat{\boldsymbol{P}}_k\boldsymbol{H}^T + \boldsymbol{R})^{-1}$$
$$\boldsymbol{x}_k = \hat{\boldsymbol{x}}_k + K\left(\boldsymbol{z}_k - \boldsymbol{H}\hat{\boldsymbol{x}}_k\right)$$
$$\boldsymbol{P}_k = (\boldsymbol{I} - K\boldsymbol{H})\hat{\boldsymbol{P}}_k$$

# Cone Detection Fusion



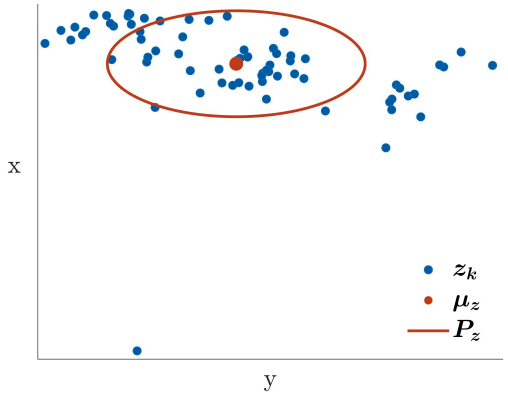



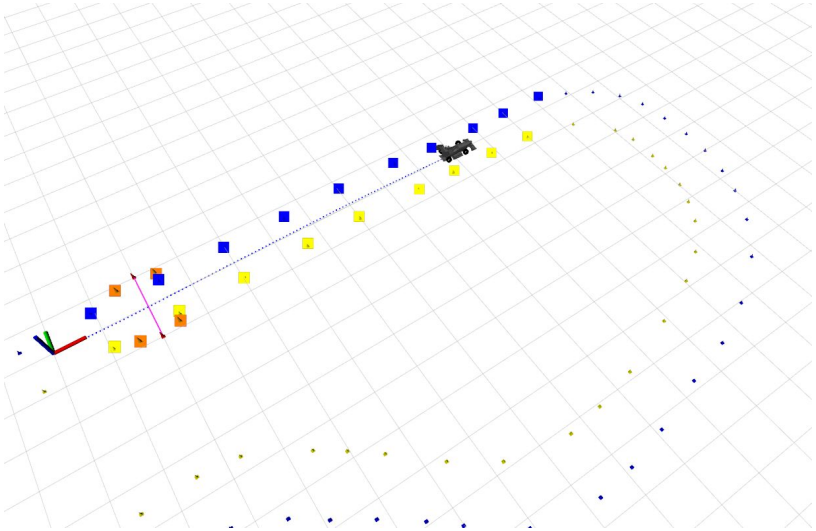



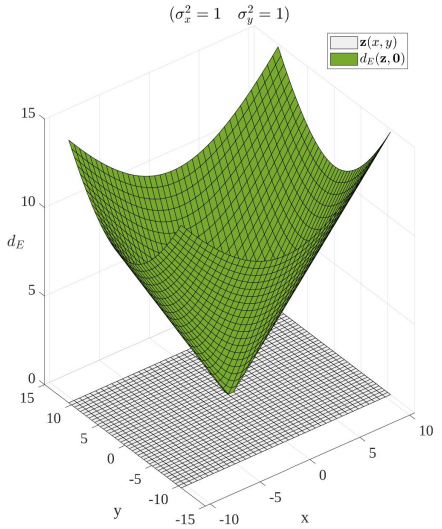
# SLAM

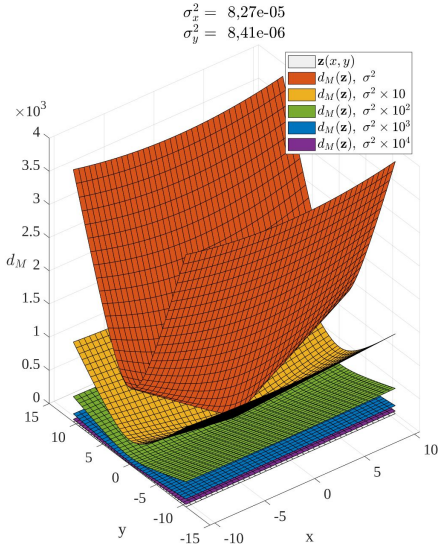
- Data Association
- Extended Kalman Filter

$$\boldsymbol{x} = \begin{pmatrix} x \\ y \\ \theta \\ m_{1x} \\ m_{1y} \\ \vdots \\ m_{nx} \\ m_{ny} \end{pmatrix}$$



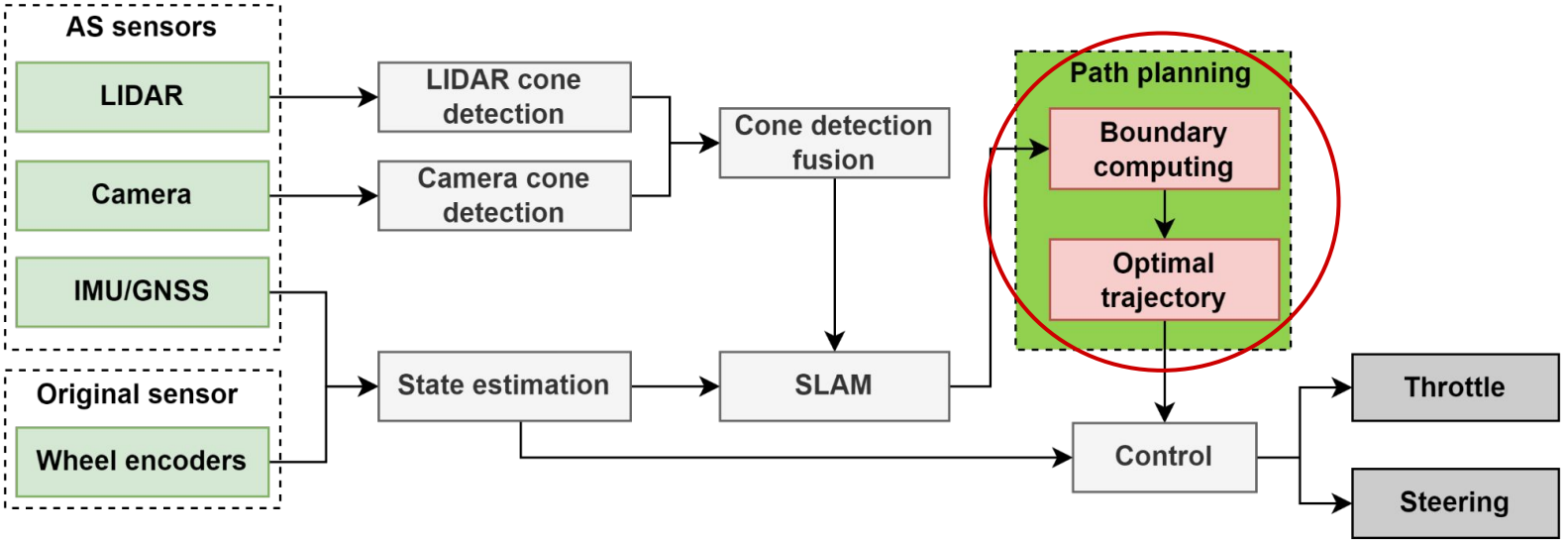





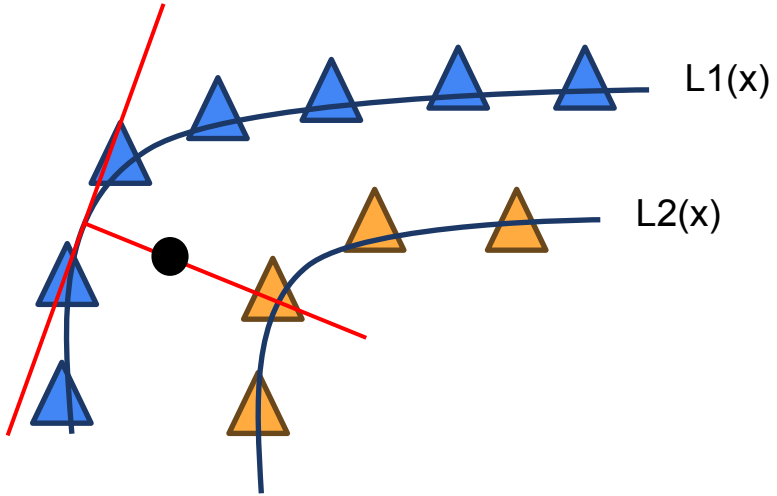
# Path planning

- Reactive navigation
- Global navigation



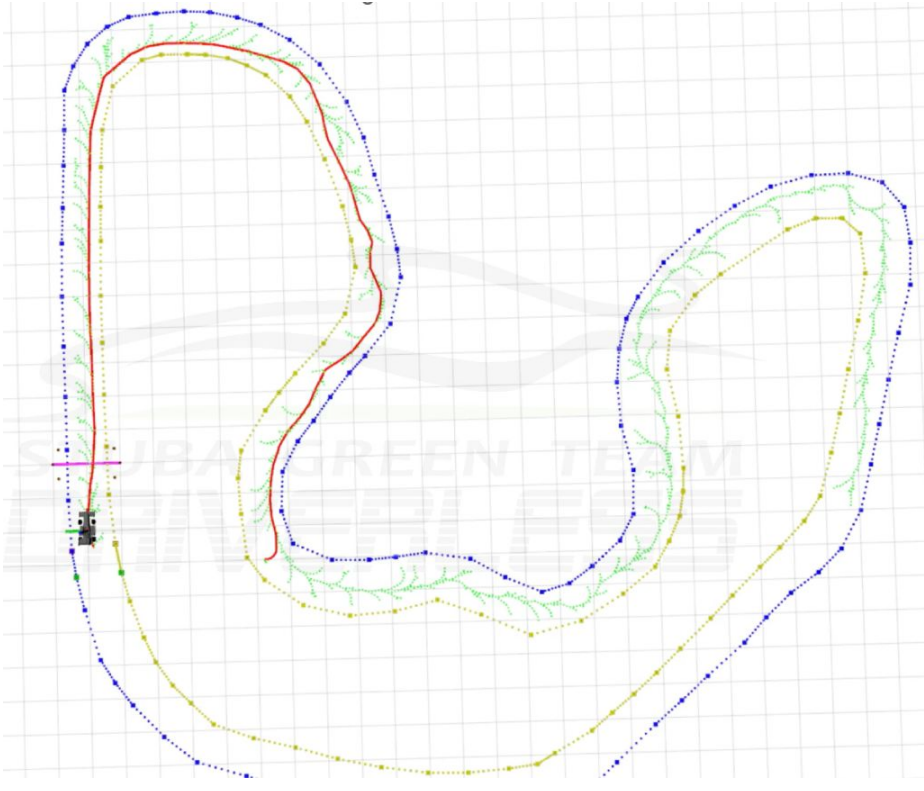
# Reactive navigation

- Unknown map
- Lagrange polynomial interpolation for calculating function of curvature
- Generating points in middle of track
- Constant speed



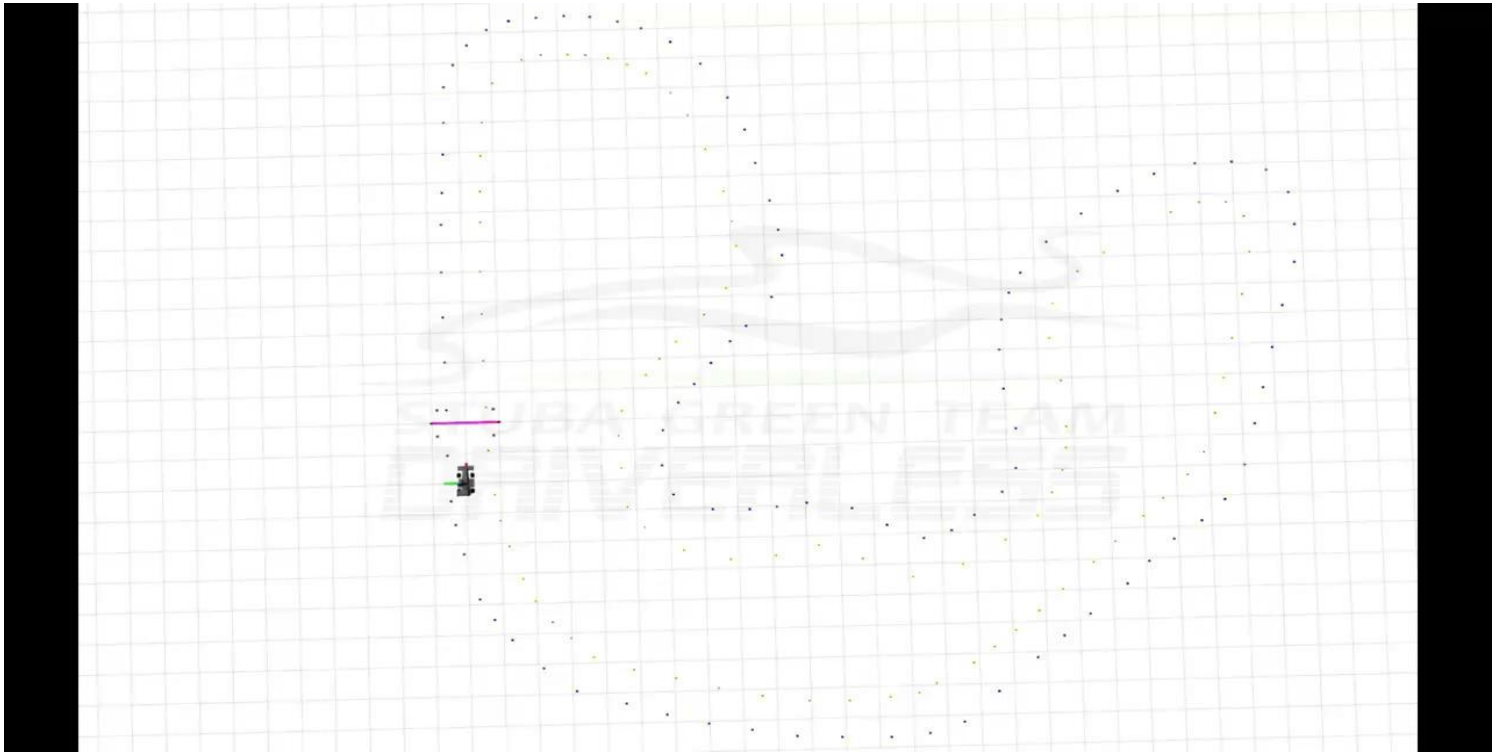
# Global navigation

- Known map
- Rapidly-exploring random trees (RRT*)
- Use simplified Dynamic window algorithm (DWA) to dynamically calculate velocity



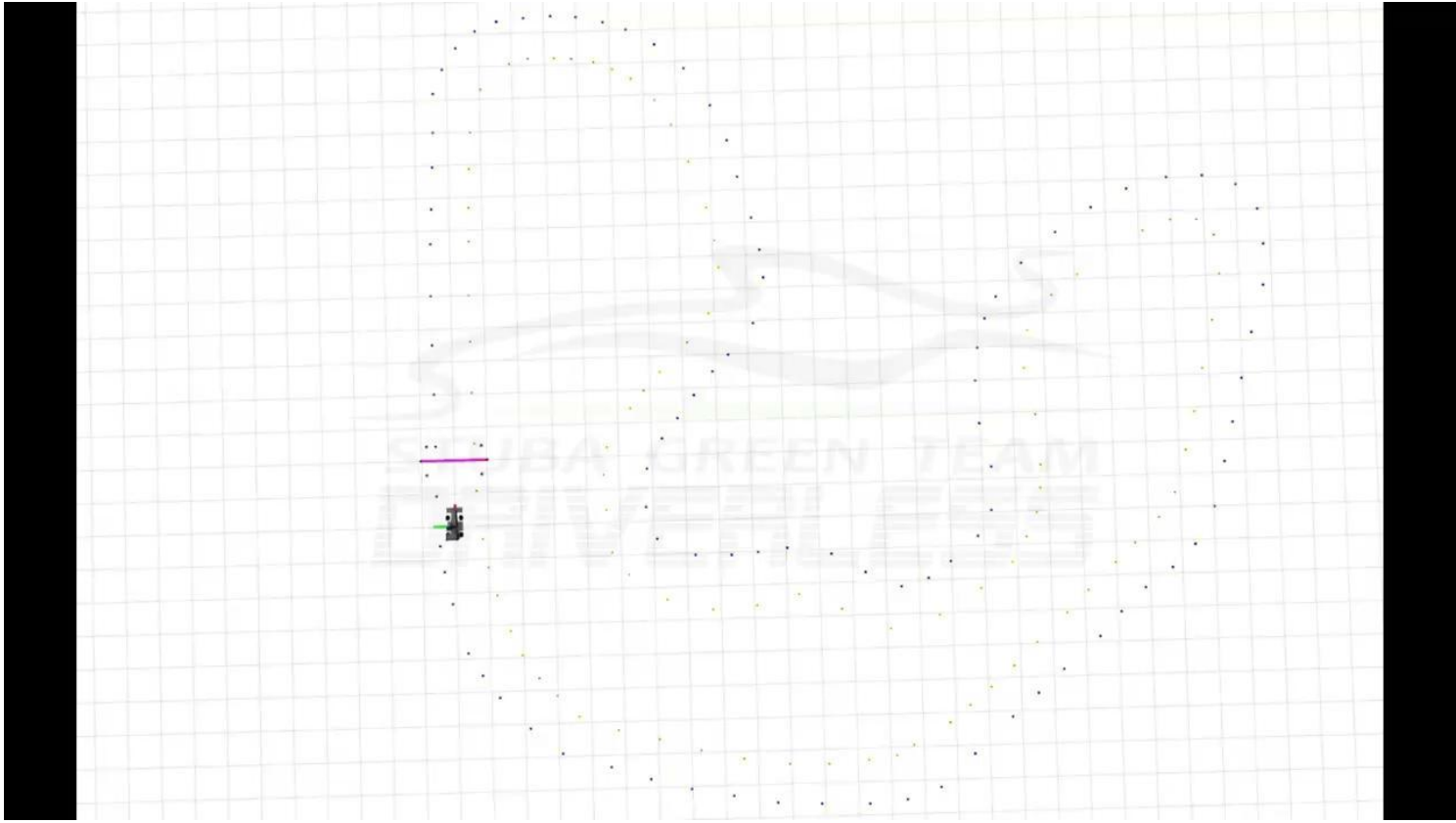
# Global navigation

- RRT

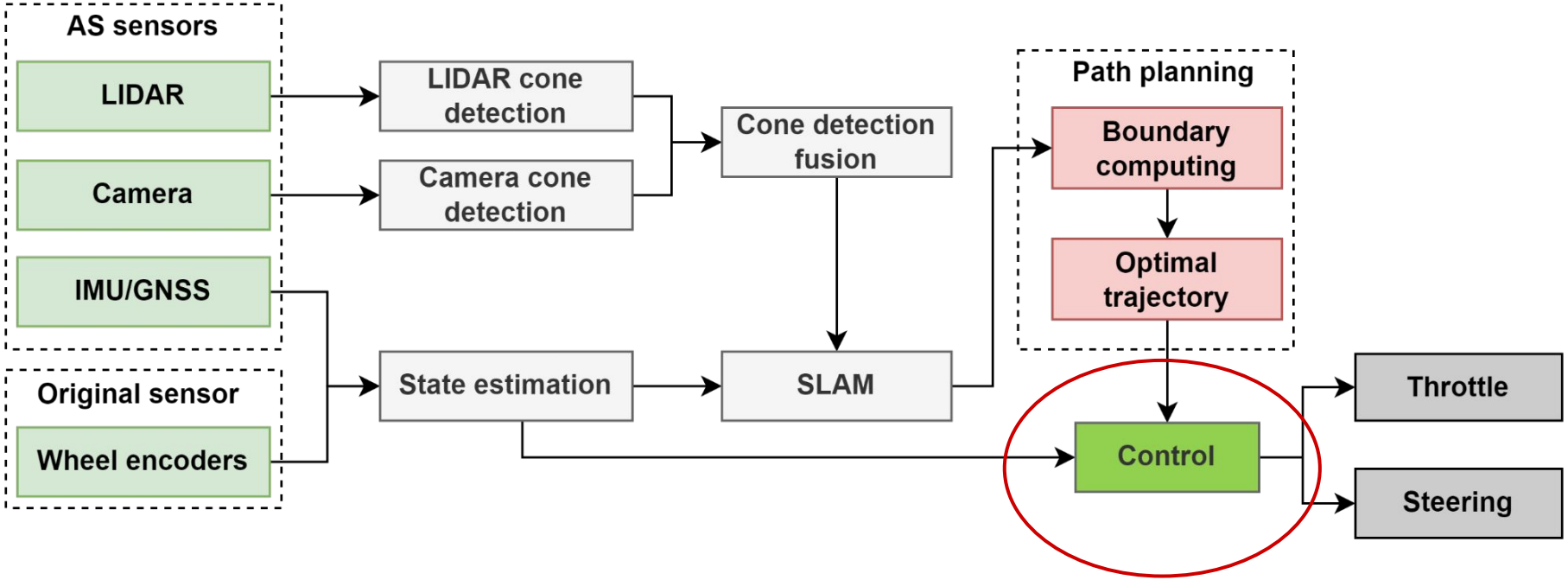


# Global navigation

- RRT*

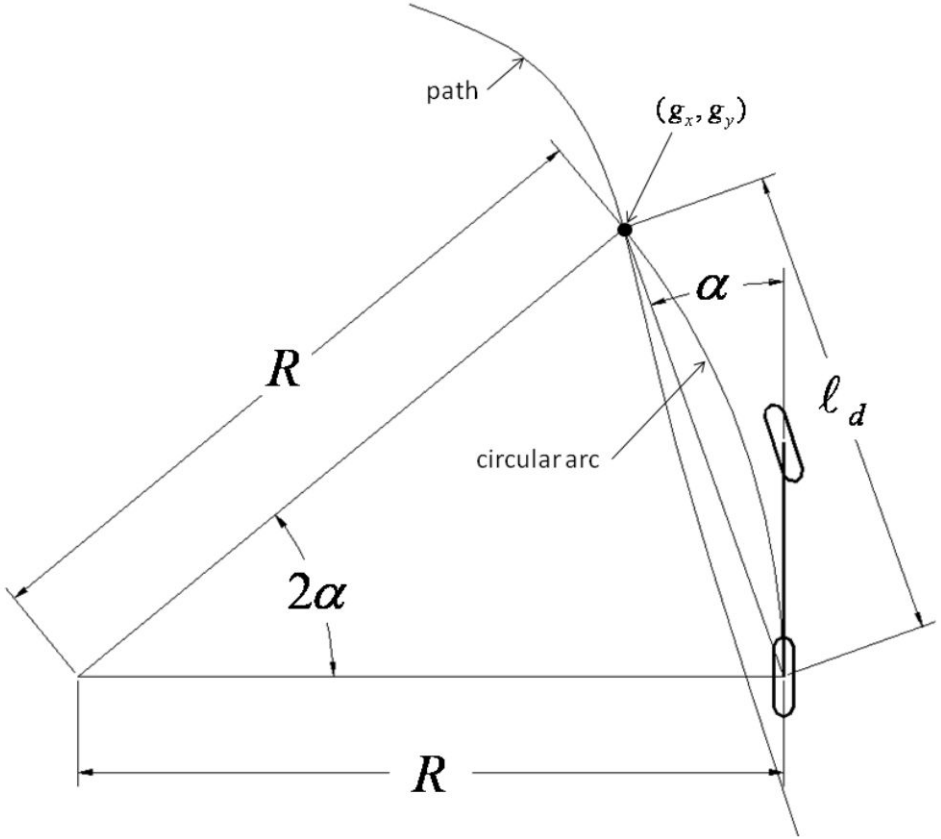


# Path tracking (Control)

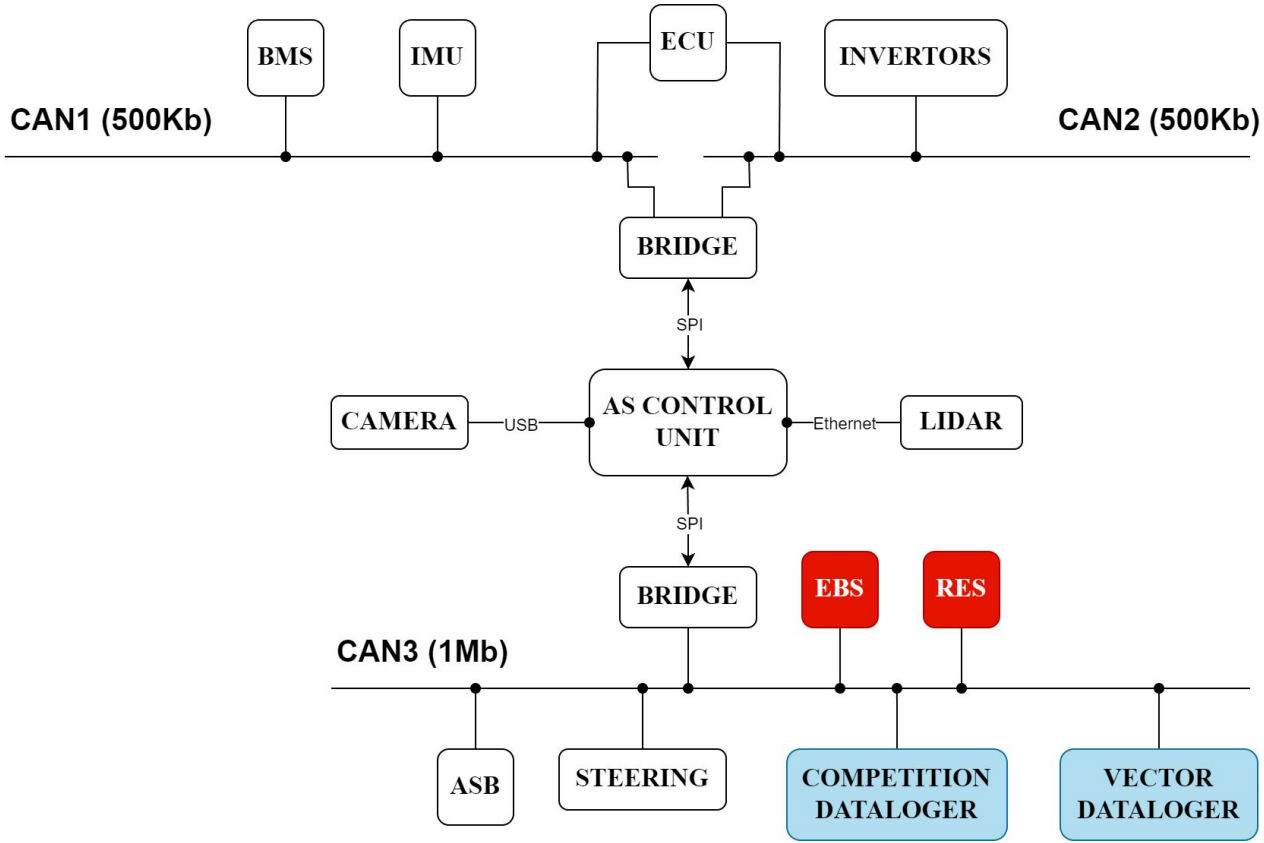


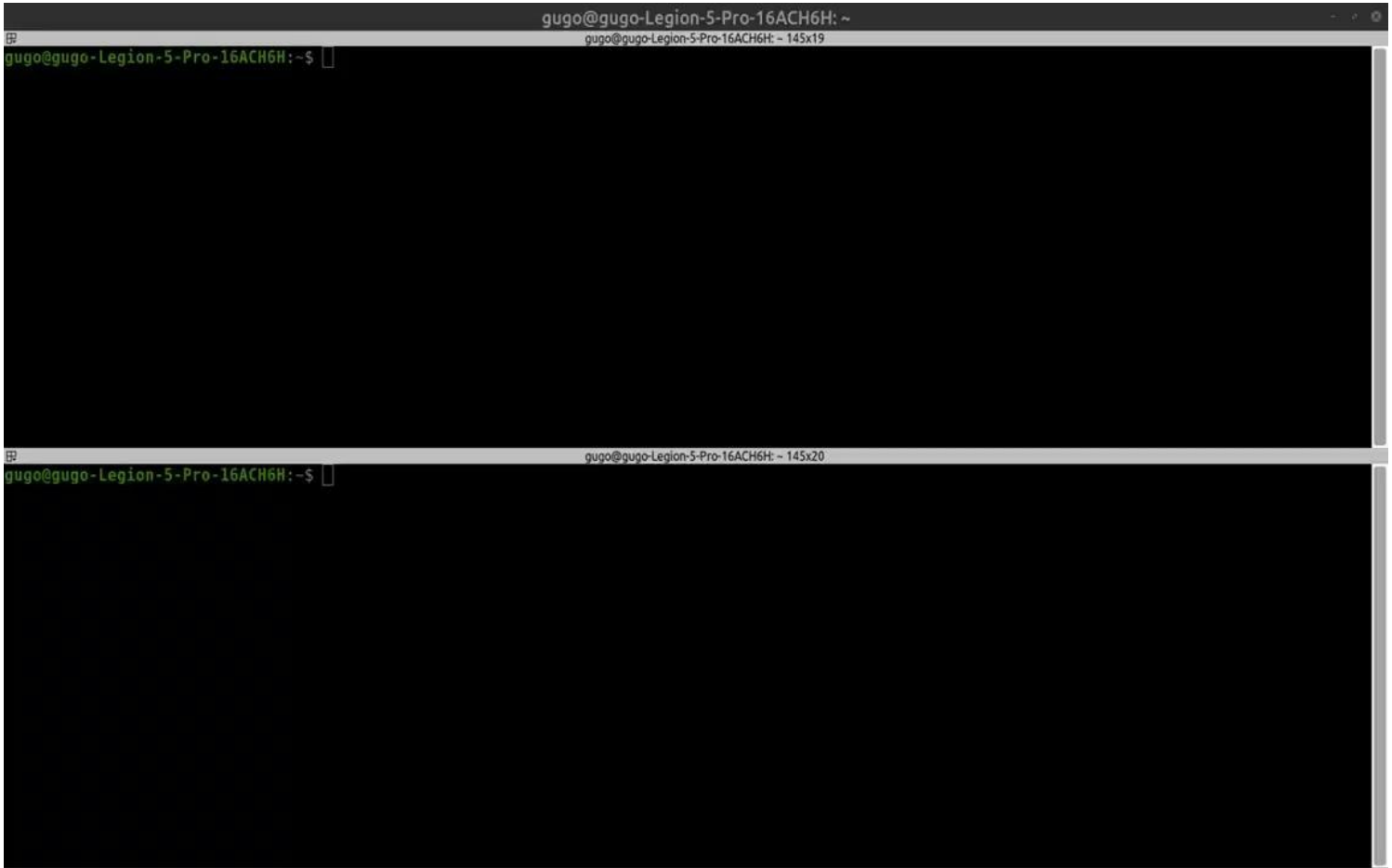
# Path tracking (Control)

- Steering control - Pure Pursuit
- Velocity control



# CAN Interface




gugo@gugo-Legion-5-Pro-16ACH6H: ~
gugo@gugo-Legion-5-Pro-16ACH6H: ~ 145x19
gugo@gugo-Legion-5-Pro-16ACH6H:~$
gugo@gugo-Legion-5-Pro-16ACH6H: ~ 145x20
gugo@gugo-Legion-5-Pro-16ACH6H:~$

STUBA GREEN TEAM
DRIVERLESS

# Thank you!

STU

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TECHNOLOGY IN BRATISLAVA