Highly Skilled Autonomous Vehicles

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21 March 2017, University of Cambridge.

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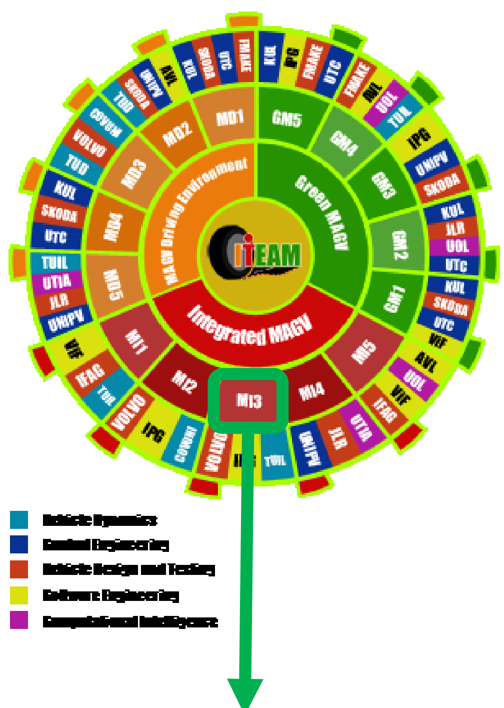
ITEAM Project

- Interdisciplinary Training Network in Multi-Actuated Ground Vehicles



- *Total Contribution:* **3 833 413,2 €**

- *Participants*

ESR 13: Manuel Acosta
Ph.D. "*ADAS function development based on direct wheel force estimation*."

1. Introduction

- **Highly Skilled Autonomous Vehicles**: “Development of autonomous vehicles capable of performing safely at the limit of adhesion”.

We dominate **asphalt**:

-*ESC* is the best solution.

-Minimize the body-slip for maximum vehicle controllability.

Loose surfaces…?

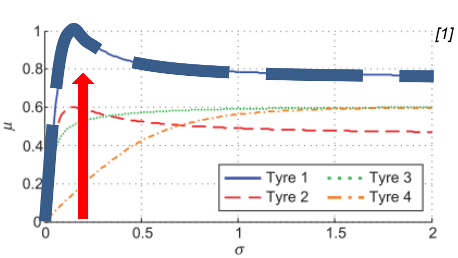
-Tire friction characteristics change.

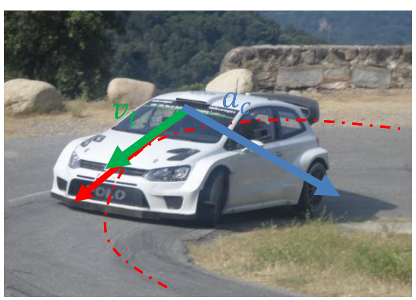
-“Aggressive” manoeuvres are required to maintain the vehicle stability (e.g. drift control)

1. Introduction

- Achieving **maximum lateral acceleration** in loose surfaces

Asphalt *(Peak force occurs at low slip angles)*





Youtube.com

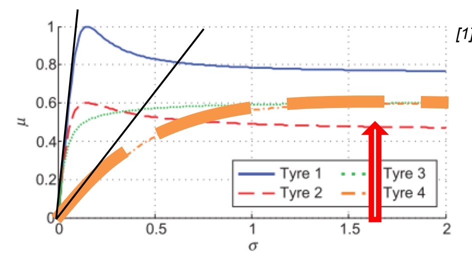
Friction-slip shape changes

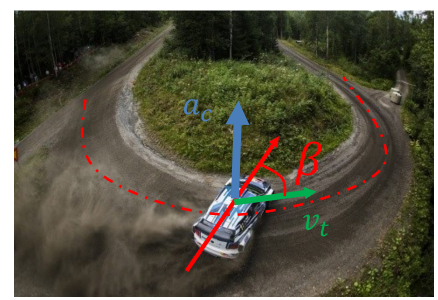
Increased modelling complexity

Alternatives?

- *Tyre model-less* approaches
- *Data-based* approaches

Gravel *(Peak force occurs at high slip angles)*





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1. Introduction

State estimation

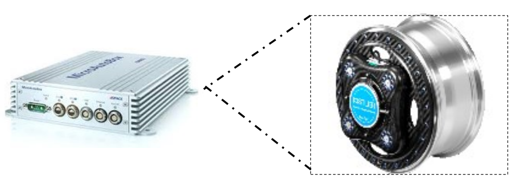
Agile Autonomous Vehicles

Control

Automotive Virtual Sensing

- Three-axis tyre forces
- Road properties

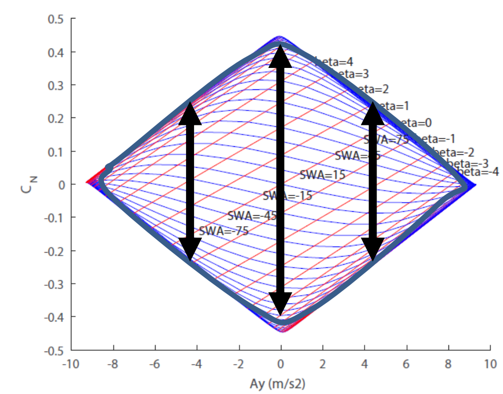
Virtual Tyre Force sensors



State feedback

Expert driving skills

- Drift control + Path following
- Yaw moment tracking



2. Vehicle State Estimation

- 2.1. Virtual Tyre Force Sensors (Lateral Forces):
  - **Tyre modelling**: Data-based approach (Neural Networks).
  - **Planar dynamics modelling**: Kalman Filtering (UKF, EKF).

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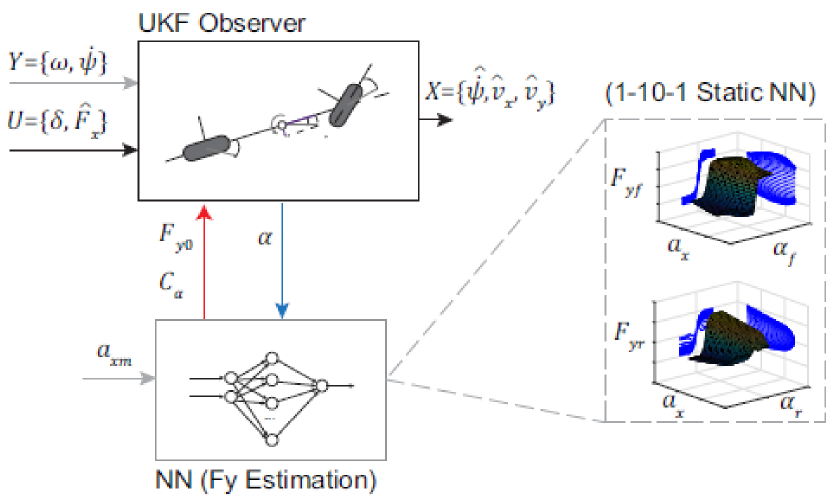
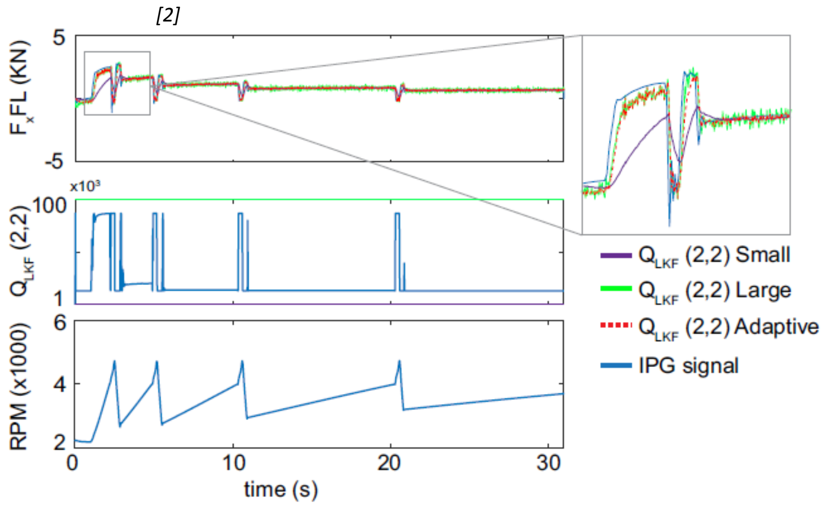


- **Training Datasets:** Step Steer Manoeuvres
- **Inputs to NN**: Axle wheel slip, Longitudinal acceleration.
- **Advantages**:
  - Tyre model-less approach.
  - Accurate estimation of lateral velocity in non-constant speed manoeuvres (e.g. braking in a turn).

2. Vehicle State Estimation

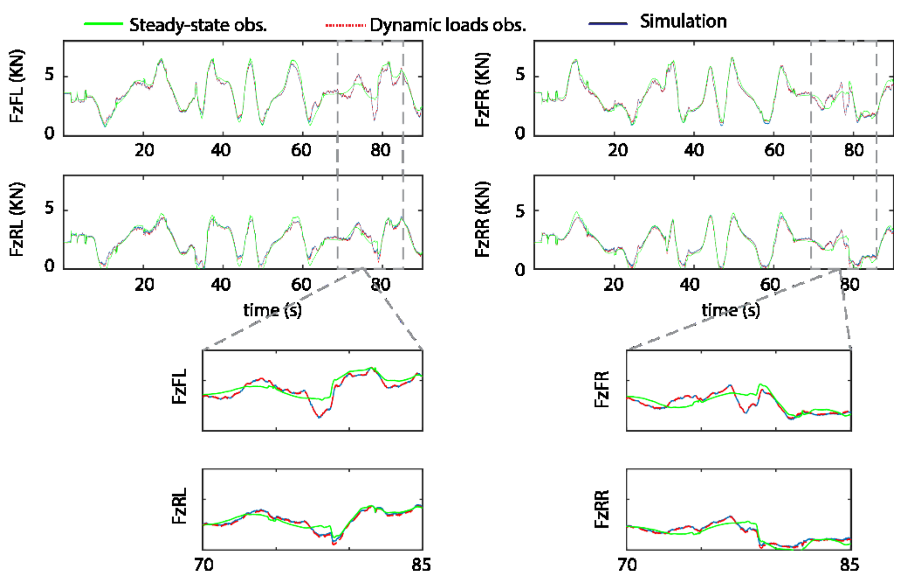
- 2.1. Virtual Tyre Force Sensors (Longitudinal Forces):
  - **Tyre modelling**: Stochastic, Adaptive Random-Walk approach.
  - **Wheel rotating dynamics modelling**: Linear Kalman Filter



- **Concept:** Adjust the process covariance matrix according to the longitudinal transient content. (RPM's, Brake pedal position)
- **Advantages**:
  - Wheel speed differentiation is avoided.
  - Tyre model-less.

2. Vehicle State Estimation

- 2.1. Virtual Tyre Force Sensors (Vertical Forces):
  - **Weight Transfer Model**: Elastic and Geometric Weight Transfer (WT).
  - **Road disturbances**: Wheel dynamic Loads.



- **Objectives:** Individual vertical tyre force estimation considering road disturbances.
- **Advantages**:
  - Delay (front-rear axles) and timing (kinematic WT, damping WT, Springs WT) is considered.
  - Avoid complex suspension kinematics modelling using a data-based approach. (e.g. roll centre migration)

2. Vehicle State Estimation

- 2.1. Virtual Tyre Force Sensors (Integration / Three-axis sensor)
  - **Integration**: Modular structure.

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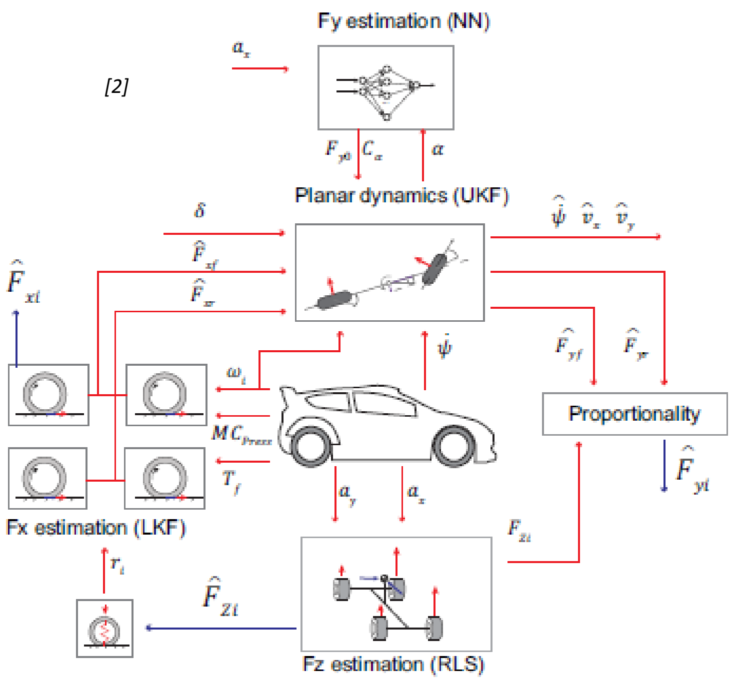
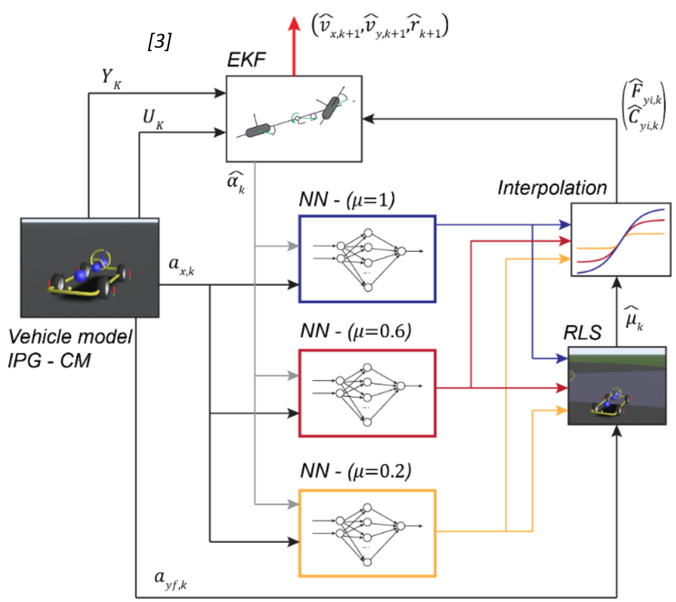


- **Objectives:** Avoid the complexity of tuning a single state estimator of large dimensions. Use sensors available in commercial vehicles.
- **Advantages**:
  - Improved longitudinal “true” velocity estimation. Use of longitudinal tyre forces instead of integrating the longitudinal acceleration.

2. Vehicle State Estimation

- 2.2. Road identification (Grip potential):
  - **Methodology**: Lateral slip-based approach.
  - **Road friction properties**: Neural Networks trained at different grip coefficients.



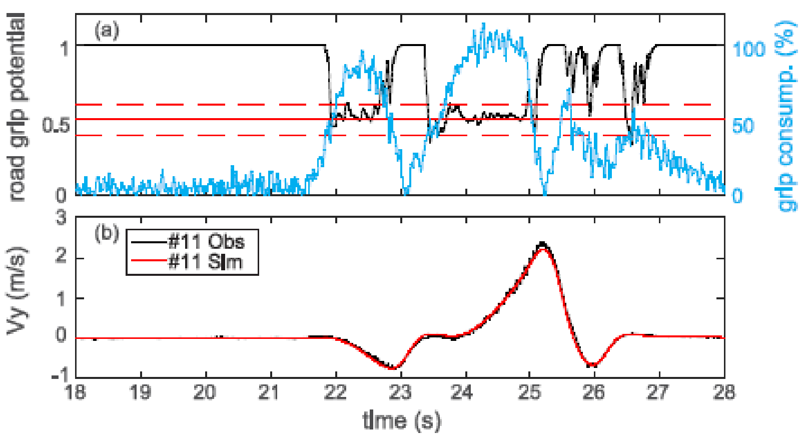
- **Objectives:** Propose an alternative to nonlinear regression methods. Reduce the lateral excitation threshold.
- **Advantages**:
  - Analytical friction model is not required.
  - Simple linear interpolation algorithm combined with Recursive Least Squares.

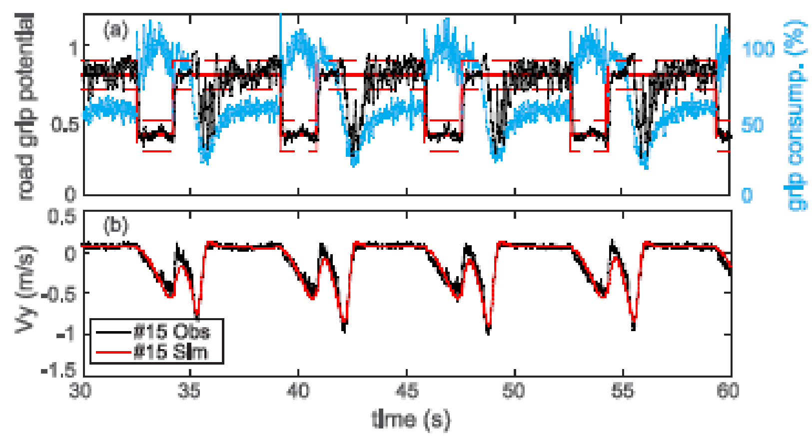
2. Vehicle State Estimation

- 2.2. Road identification (Grip potential):

  – **Simulations** in IPG Car Maker. Tyre model: MF 6.1 205_65 / R16

[3]





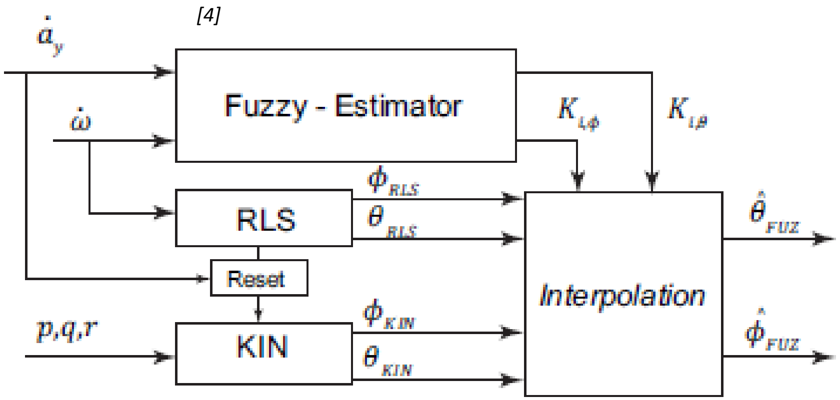
ADAC Lane Change in low mu ($\mu = 0.5$)

Circle mu-jump transitions

  – Next steps → Try to apply a similar methodology in loose surfaces.

2. Vehicle State Estimation

- 2.2. Road identification (Grade and bank angle):
  - **Chassis orientation angles**: Kinematic-based (Euler angle rate integration), steady-state (Recursive Least Squares) models.
  - **Signal Fusion**: Gain scheduling using a Fuzzy Logic Controller.



- **Objectives:** Must be suitable for transient and steady-state situations. Use sensors available in commercial vehicles.
- **Advantages**:
  - GPS not required.
  - Robust against kinematic drift (RLS provides absolute measurements).

2. Vehicle State Estimation

- 2.2. Road identification (Grade and bank angle):
  - **Simulations** in IPG Car Maker. Axle lateral forces in Nordschleife Track.

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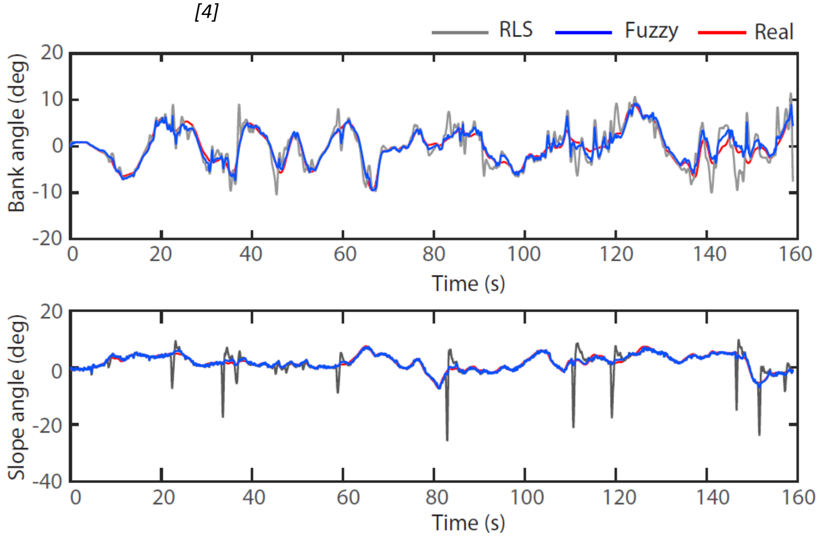
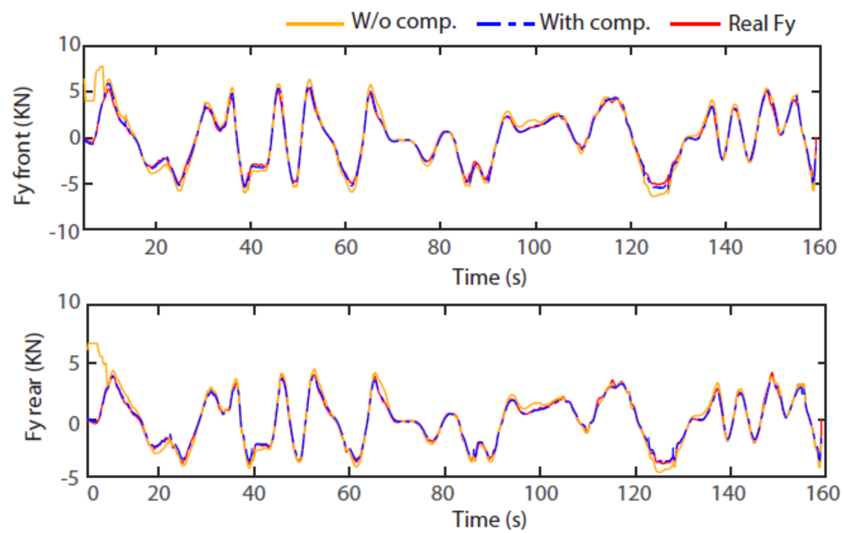
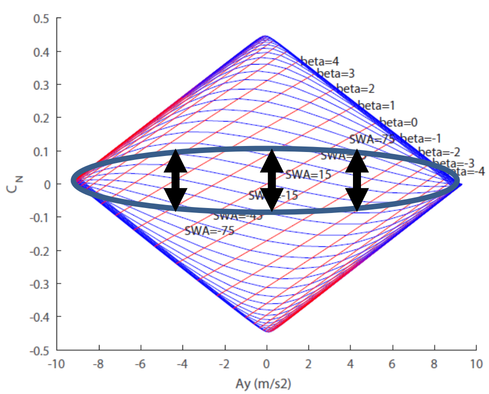


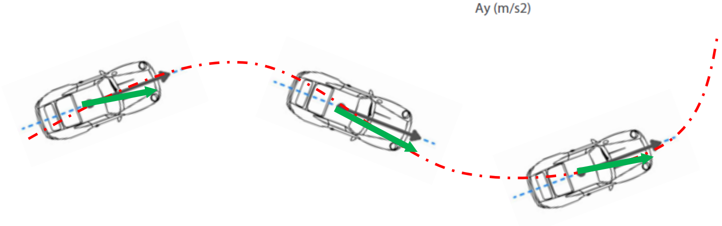


3. Agile Manoeuvring

- 3.1. Yaw Moment Tracking:
  - **Operating with large body-slips:** High yaw moments are required to change the vehicle attitude fast.

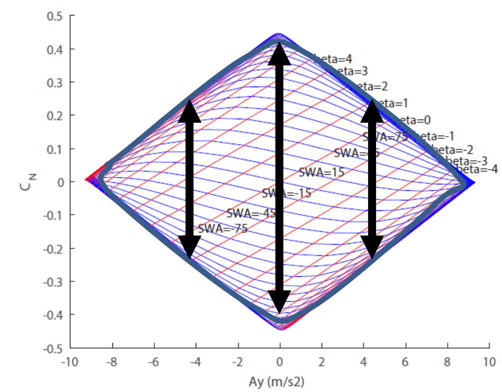
Asphalt

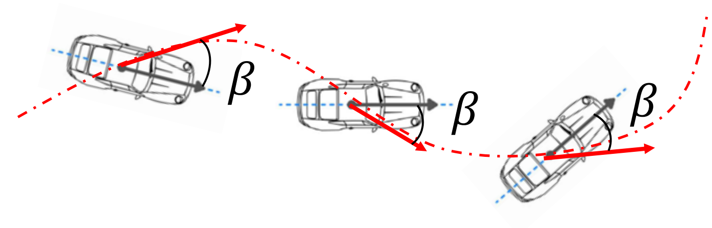




Operation over the full handling region (MMD) is necessary.

Gravel





3. Agile Manoeuvring

- High agility regions

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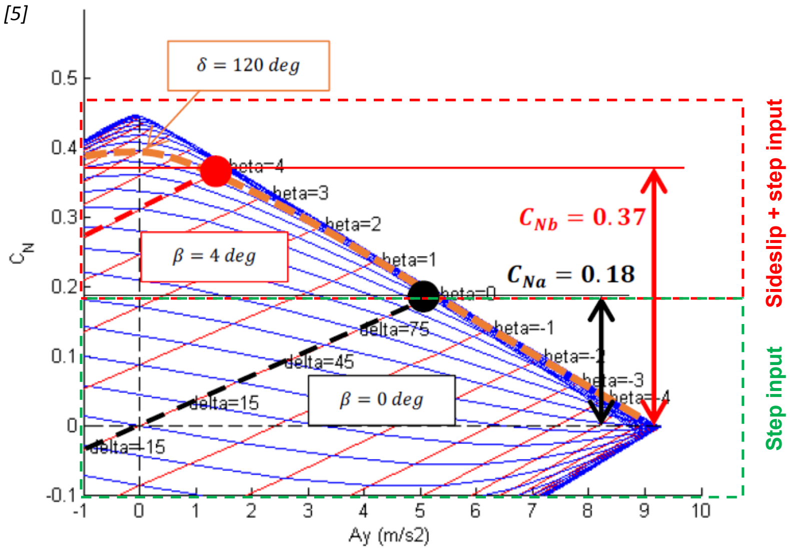
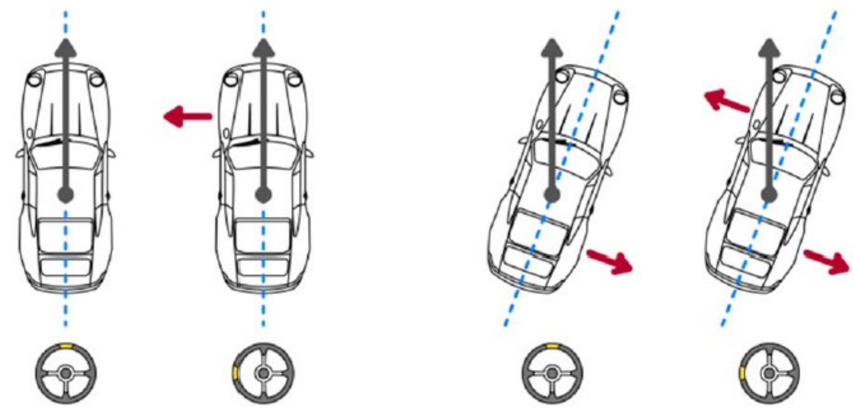


- How to achieve **high agility regions**?
- A combination of **sideslip + steering input** is required.
- Is this intuitive / easy to perform? No!! autonomous action → **Finite State Machine**

- Sideslip + Steering input

[5]



Step input **Sideslip + step input**

- **Step input:** Maximum yaw moment given by the front axle lateral force.
- **Sideslip + step input**: Max. yaw moment generated by rear and front axle forces.

3. Agile Manoeuvring

- 3.2. Rally Driver Modelling
  - **Regular "racing line" driver models:** Try to minimize the heading error.
  - **Rally "drift" driver model**: Path following and drift control must be carried out simultaneously.

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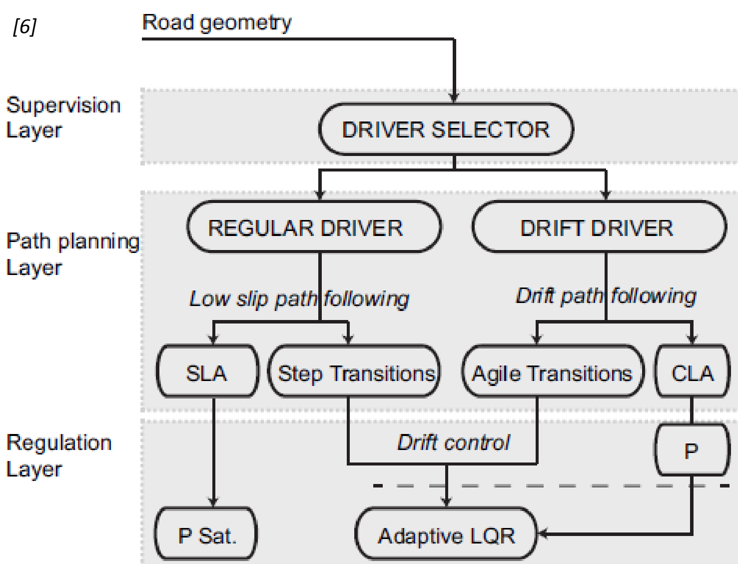

- **Concept:** Alternate between a regular driver model and a rally driver model depending on the road characteristics.
  - *Low body-slip* driving at high speed. (Straight line)
  - *High body-slip* control for reduced radii. (Maximum lateral acceleration)

3. Agile Manoeuvring

- 3.2. Rally Driver Modelling
  - **Drift control + Path following**: Proportional curvature correction of the drift equilibrium solutions. Adaptive LQR control.

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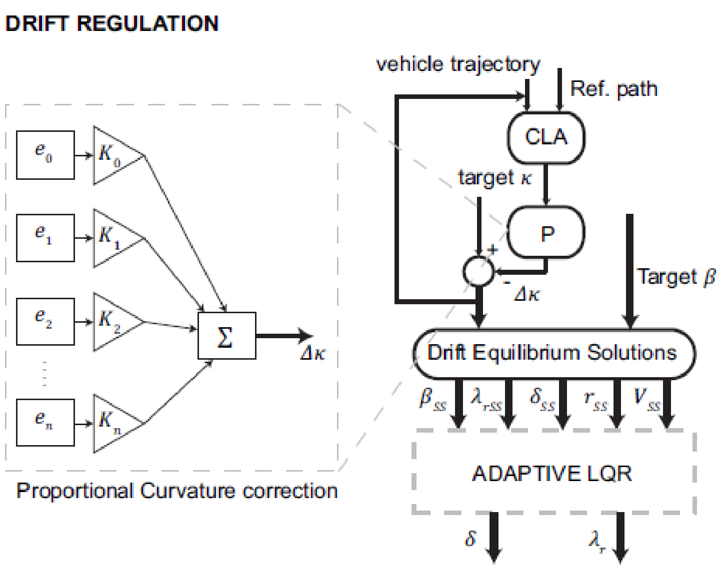
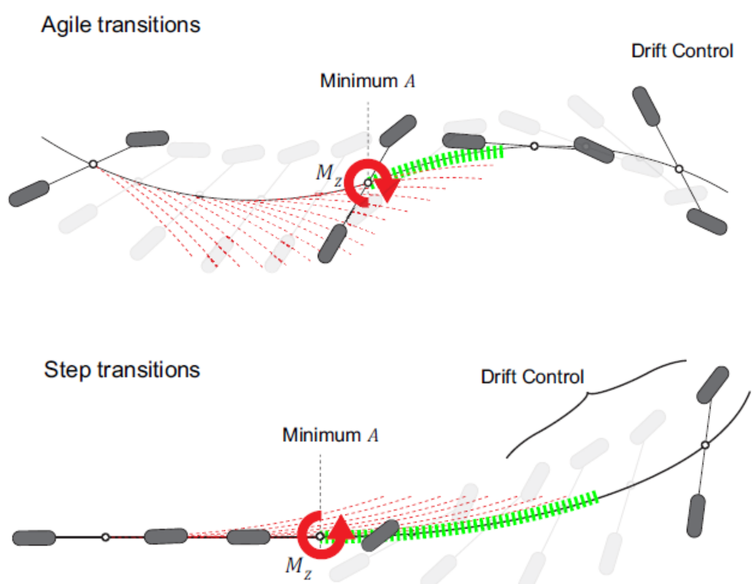


- **Concept:** “Correct” the drift equilibrium solutions in an upper-level layer to minimize the lateral deviation error.
- Use an Adaptive LQR to control the vehicle around the operating points dictated by the upper-level layer.

3. Agile Manoeuvring

- 3.2. Rally Driver Modelling:
  - **Drift control + Path following:** Agile and Step Transitions. Change the vehicle attitude with minimum lateral deviation.

[6]

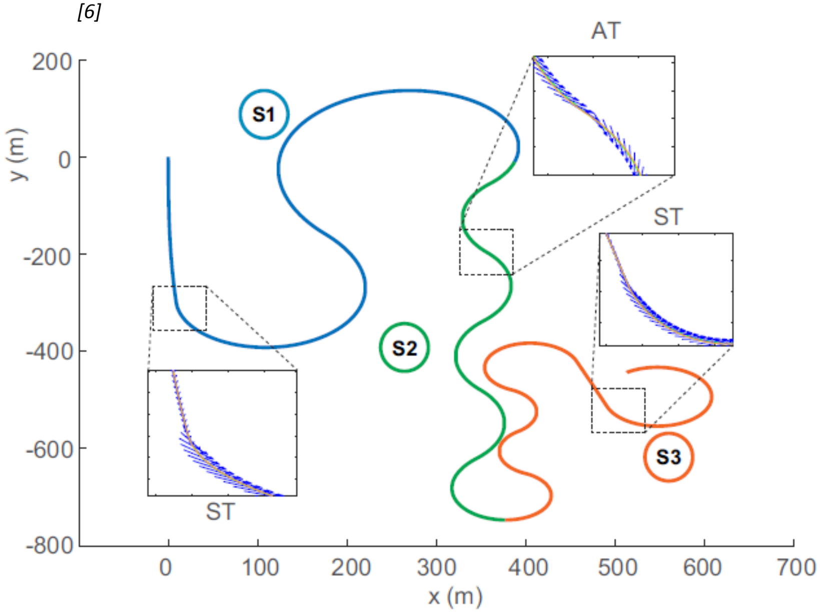


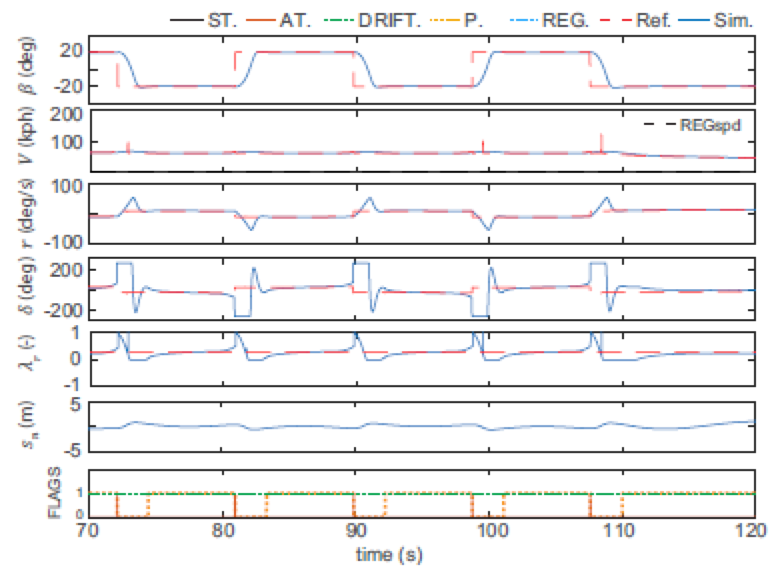
- A set of trajectories is computed offline.
- The transition is executed when the area between the predicted trajectory and the reference path is minimum.
- **Objective for next steps**: Integration of *yaw moment tracking* and *motion planning* for minimum lateral deviation.

3. Agile Manoeuvring

- 3.2. Rally Driver Modelling:
  - **Drift control + Path Following:** Simulation case on arbitrary path (arc, clothoid, and straight line segments) using a Single Track vehicle model.

[6]

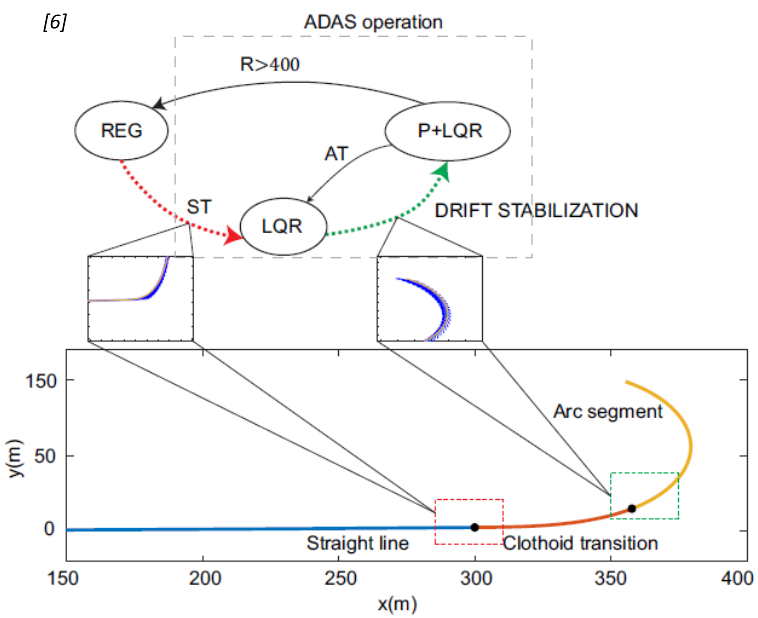




3. Agile Manoeuvring

- Co-Pilot Concept:
  - **ADAS system:** Lateral collision avoidance on loose surfaces.

[6]



- **Concept:** Perform an aggressive drift manoeuvre to maximize the lateral acceleration.
- Step transition (high yaw moment) is required to build up a large body-slip.
- The system stabilise the vehicle around the operating body-slip with drift control.

3. Agile Manoeuvring

- Co-Pilot Concept:
  - **ADAS system:** Simulation scenario. Vehicle approaching a turn at excessive speed in gravel.

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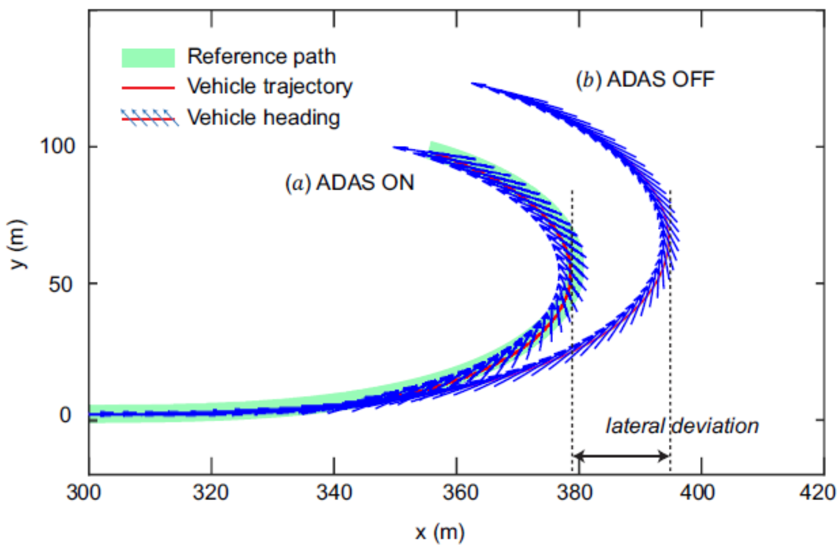

- Large deviation with a racing line driver model (ADAS OFF). Can be seen as a conventional stability system that seeks to minimize the body-slip.
- Deviation is minimized when the ADAS system is active. The lateral acceleration is maximized and the vehicle follows the path at high speed.

4. Conclusions

- Non-conventional approaches to vehicle stability (agile manoeuvring) might be beneficial in loose surfaces.
- Accurate vehicle state estimation is fundamental to implement these solutions.
- Virtual Sensing is required in order to offer affordable and robust alternatives to Wheel Force Transducers or SmartTyre concepts.

Future Directions

- Integration of vehicle state estimation and drift control.

References

[1] D. Tavernini, M. Massaro, E. Velenis, D. Katzourakis, R. Lot "Minimum time cornering: the effect of road surface and car transmission layout". Vehicle System Dynamics, 2013.

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[3] M. Acosta, S. Kanarachos, "Tyre Lateral Force Estimation and Road grip recognition using Extended Kalman Filter, Neural Networks and Recursive Least Squares", Neural Computing and Applications, Springer, 2017.

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[6] M. Acosta, S. Kanarachos, M.E. Fitzpatrick, "A hybrid hierarchical Rally Driver Model for vehicle agile maneuvering on loose surfaces", International Conference on Informatics in Control, Automation and Robotics 2017, (Under review)