State observers based on full-vehicle multi-body system dynamics models

A new approach to vehicle state estimation for Integral Chassis Control systems

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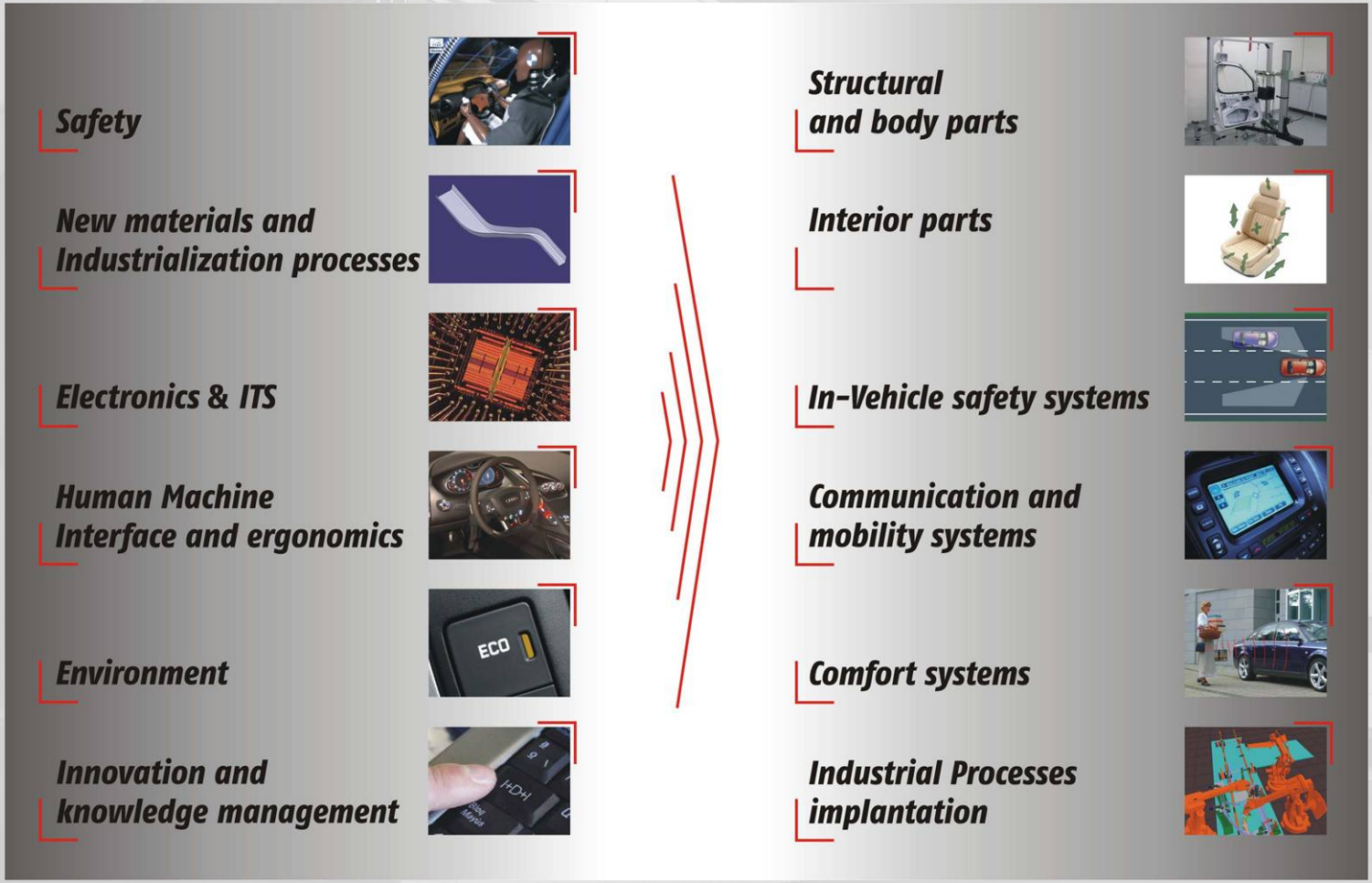

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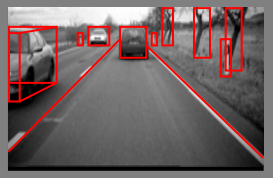
HW / SW ELECTRONIC ARCHITECTURE			

Challenges in Integral Chassis Control

Several active systems involved:

- Yaw Control by Brake (ESP)
- Torque Vectoring
- Active Front & Rear Steering
- Active Damping
- Active Roll Control

Questions:

- What is the current state of the vehicle?
- What will it be in the near future?
- How much correcting yaw moment should I apply?
- What much grip can I expect from each tyre?
- What should I do with this or that tyre? Steer it? Brake it? Load/unload it?
- What is the best possible combination of individual actuations of each system?

How can they be answered?

- State observers with embedded virtual models have been used
  - Bicycle model
  - Simplified four wheel model
- But these models
  - Don't take advantage of all the sensors we could use
  - Are too specificly oriented to the observation of certain variables
- Which models do we use for Vehicle Dynamics off-line simulations? Multibody

Can we find a more general approach to the observation problem?
Is it possible to run a State Observer over a MBS model?
What possibilities can it open?

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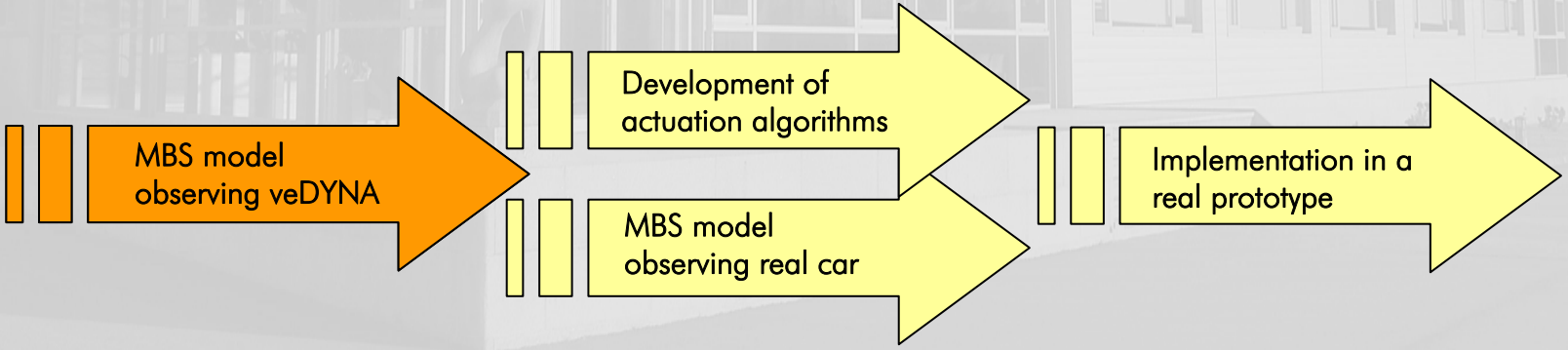


State observer – Extended Kalman Filter

State observer – Extended Kalman Filter

State observer – Extended Kalman Filter

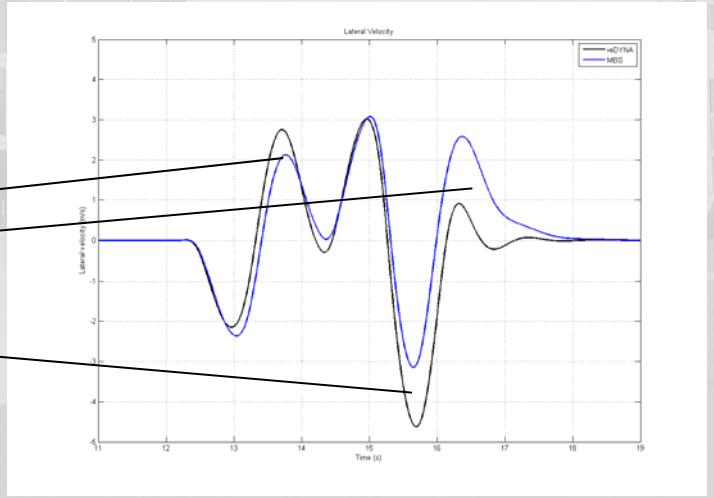
Disturbances
Wind gusts, changes in grip…

Inputs
Steering, pedals, gear shifter

Outputs
Positions, velocities, accelerations, rotations, temperatures, pressures, volumes, wear…

Outputs
As many as variables defined in the model

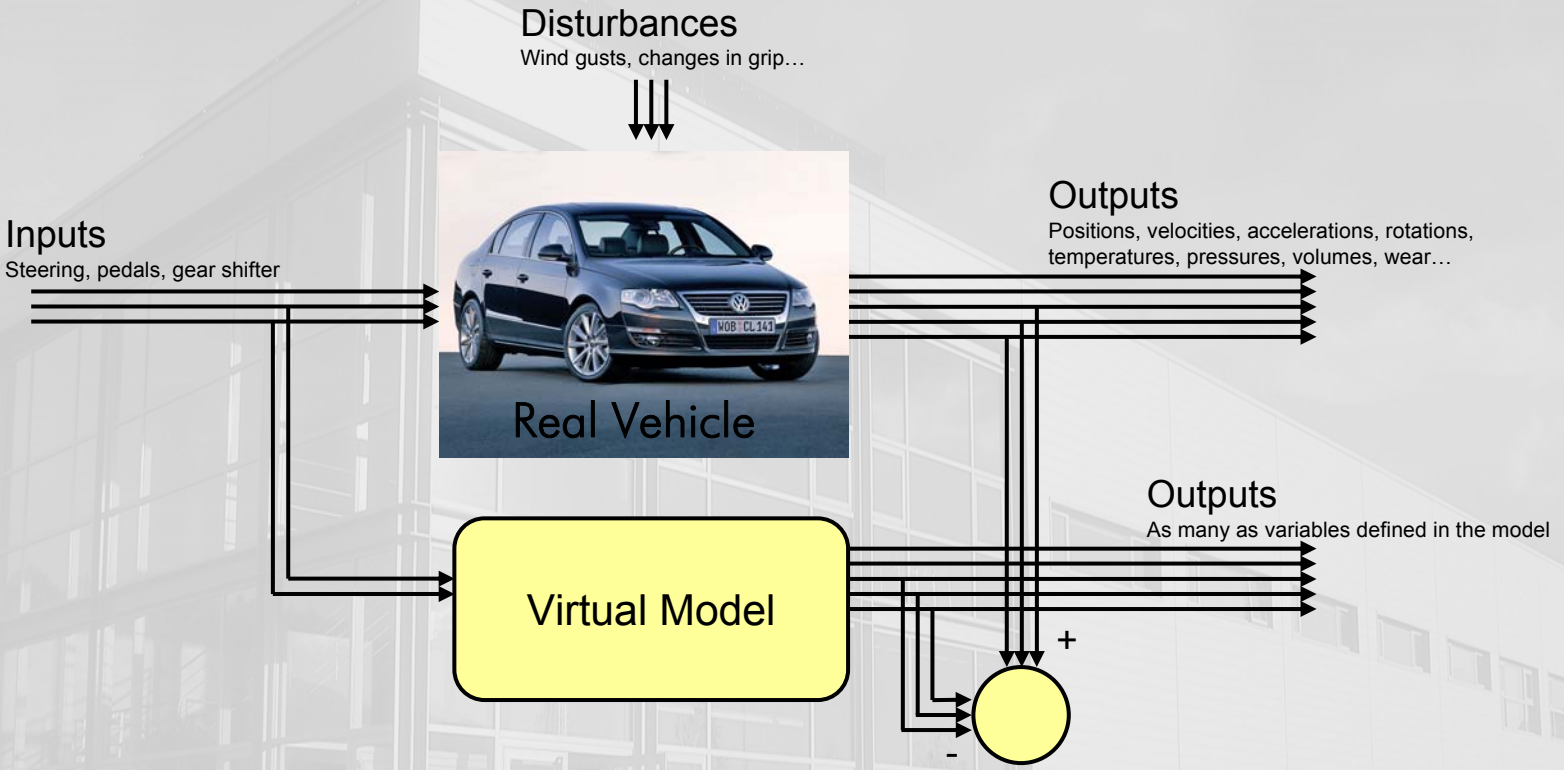
Virtual Model



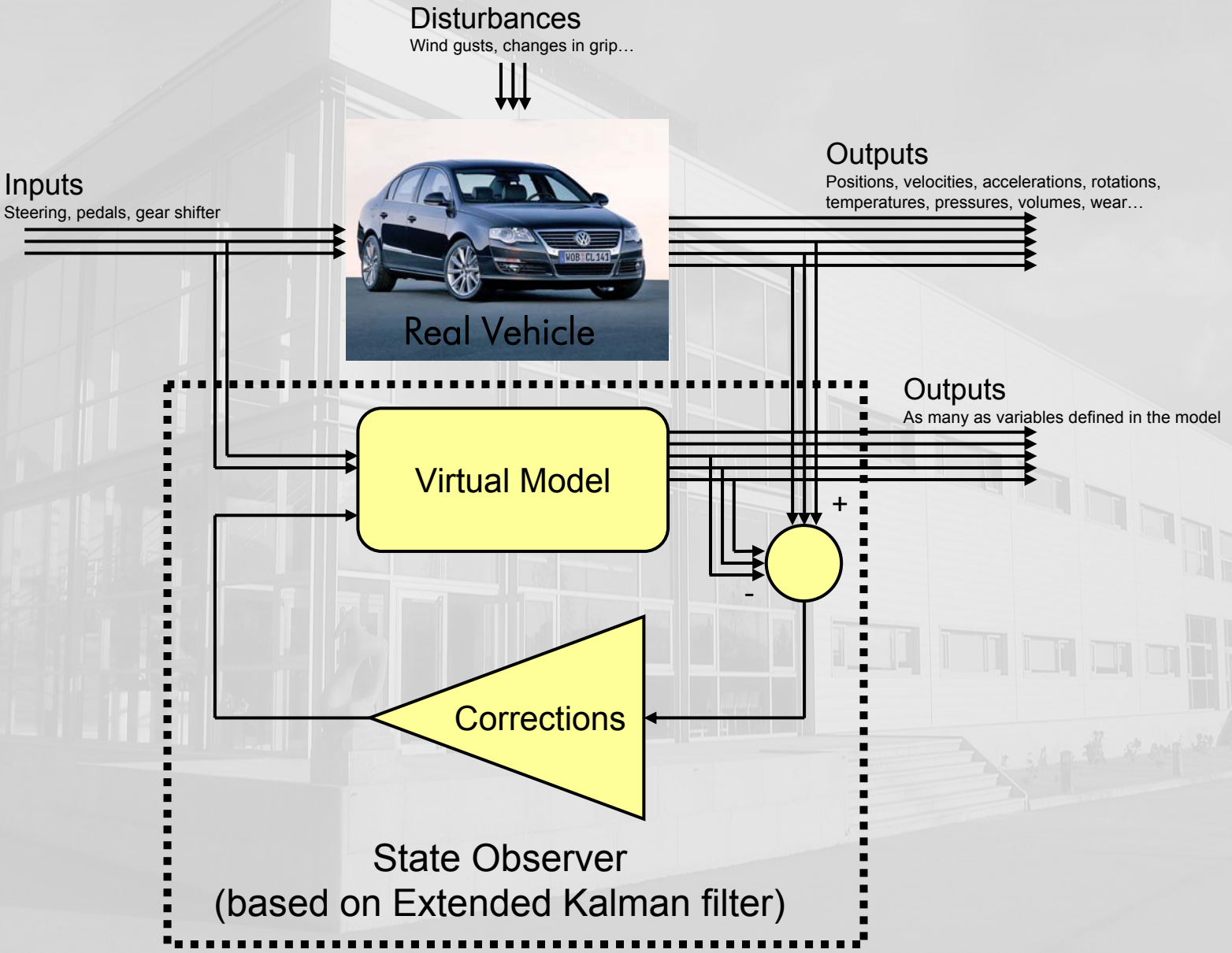
It doesn't matter how good our model is
It will always:

- Have errors
- Diverge with time
- Kalman Filter matches the virtual model with the real car

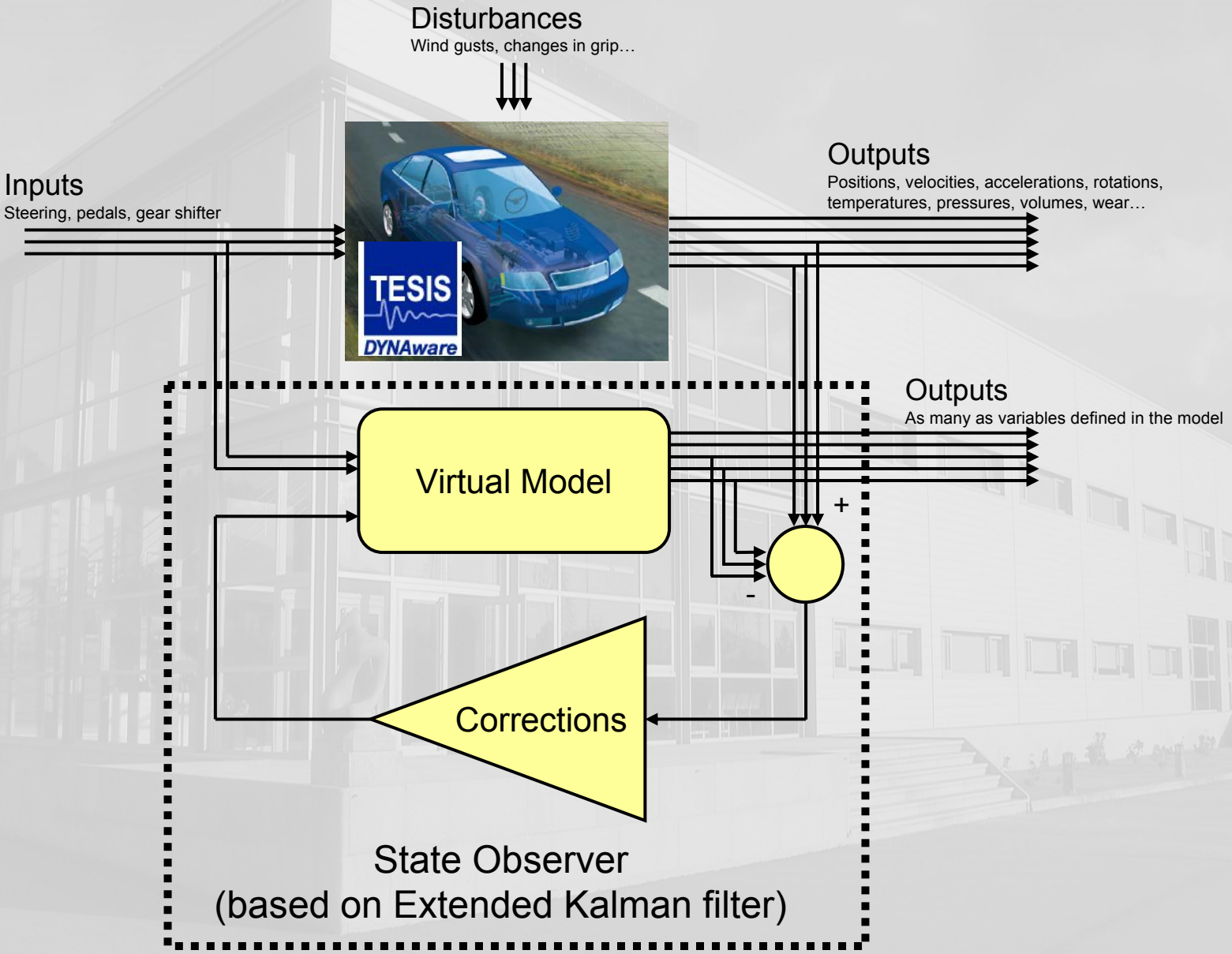
State observer – Extended Kalman Filter



State observer – Extended Kalman Filter



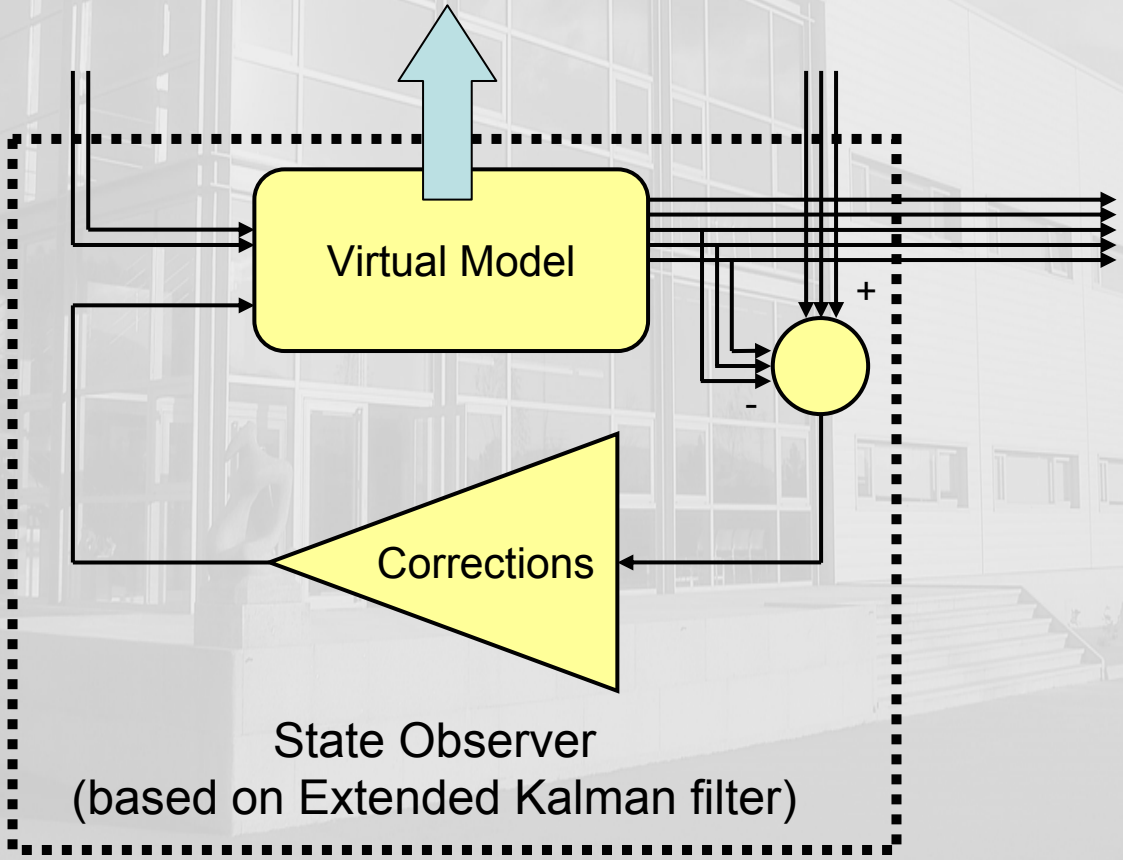
State observer – Extended Kalman Filter



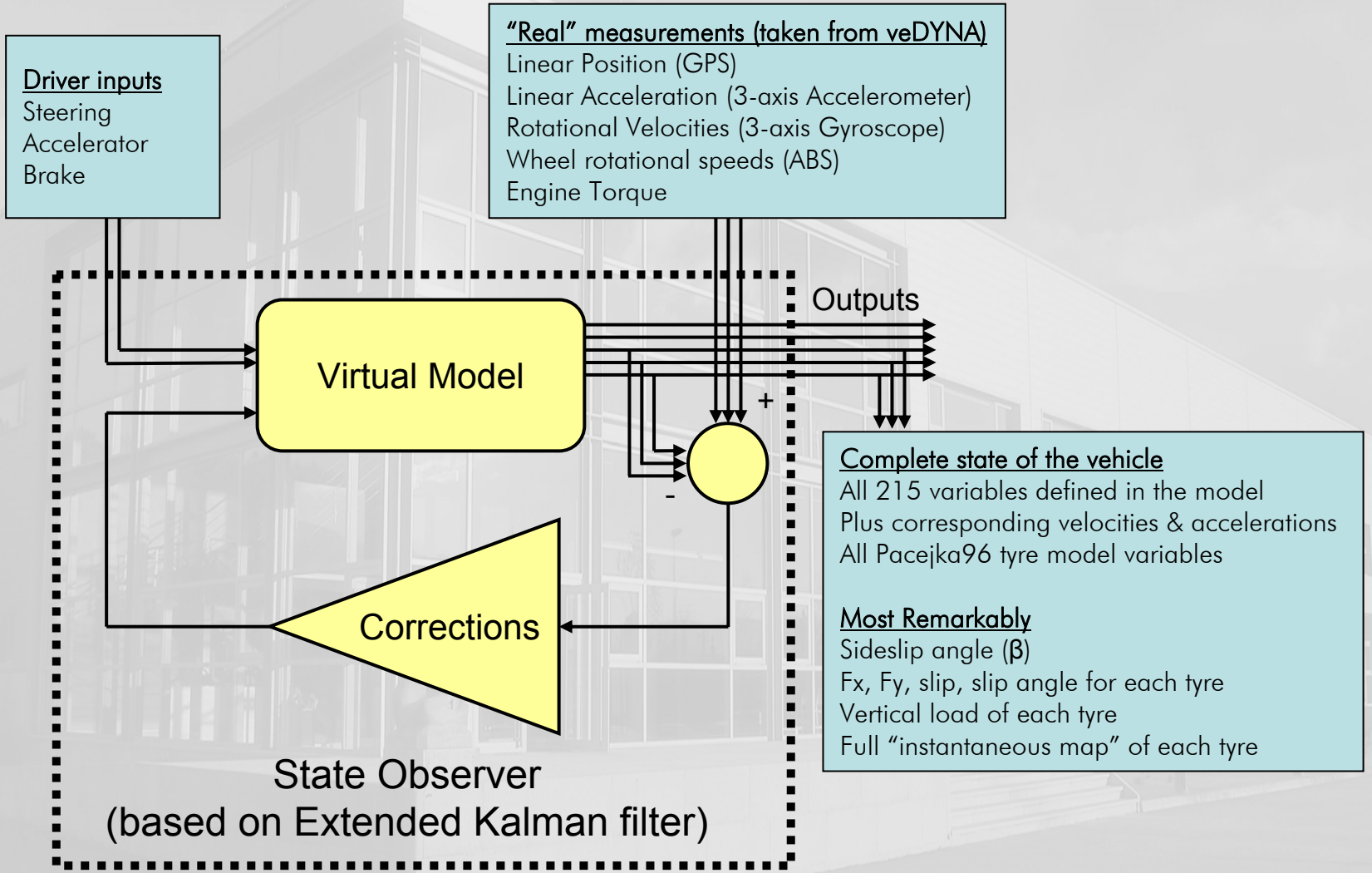
State observer – Extended Kalman Filter

Mutibody System model

McPherson / Multilink suspensions
Still simpler than veDYNA (no bushings, slightly different rear suspension)
26 objects – 215 variables
14 Degrees of Freedom
Pacejka 96 tyre model



State observer – Extended Kalman Filter

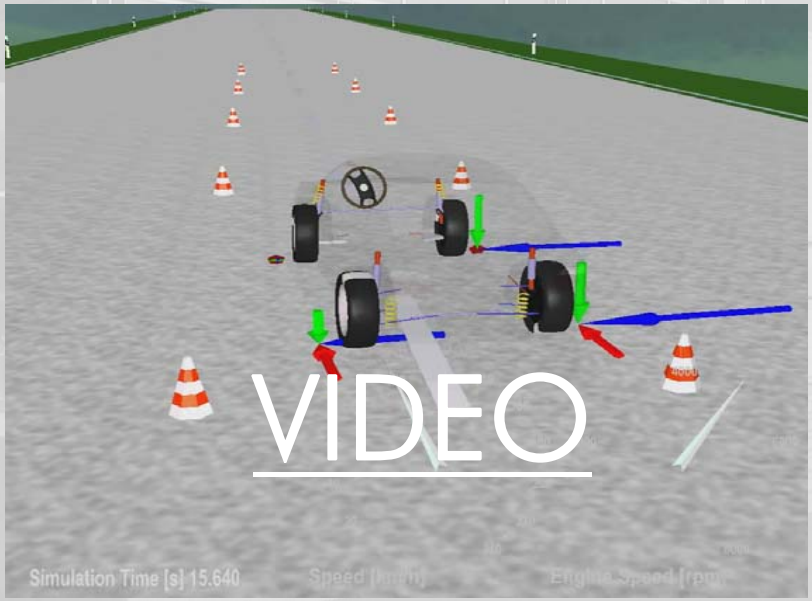


Case study – Double Lane Change

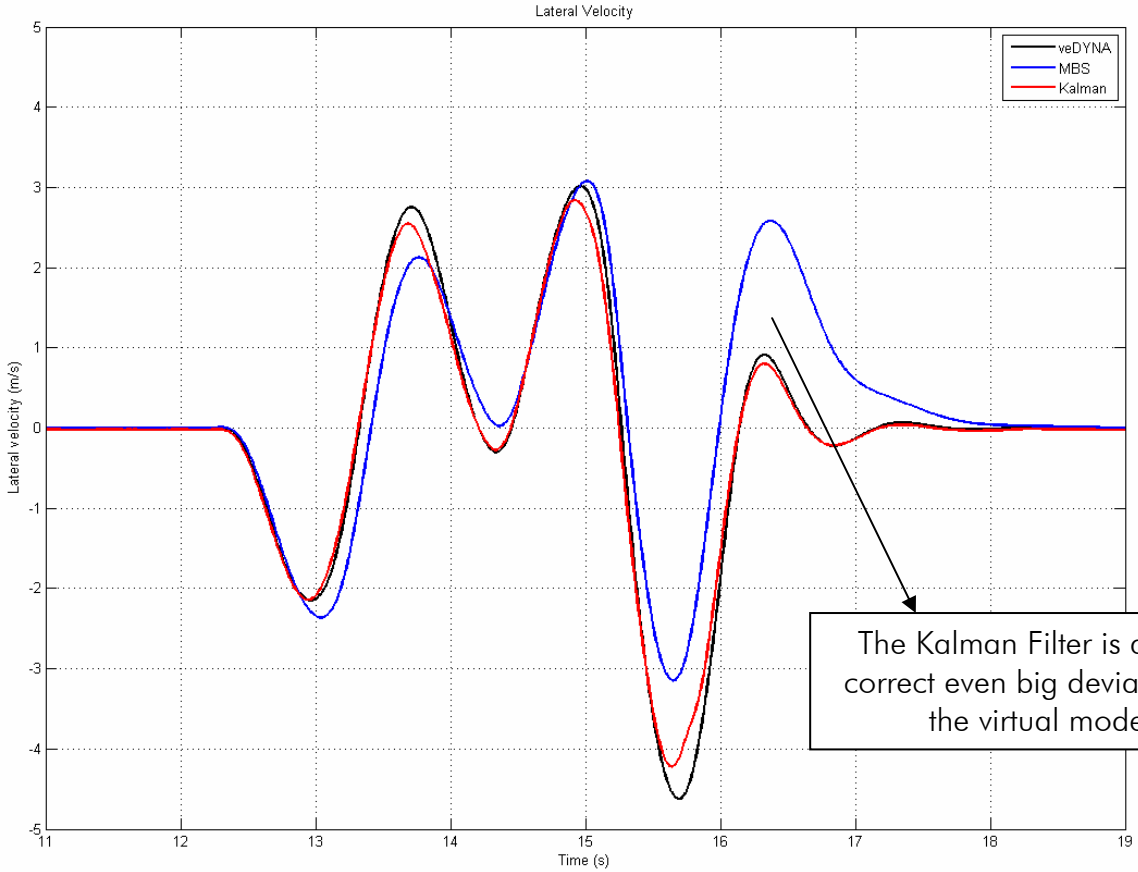
Example maneuver: Double Lange Change @ 100 km/h

Three plots are shown for each graph:

- veDYNA vehicle, playing the role of the real car.
- MBS model without corrections.
- Kalman Filter, correcting the calculations of the MBS model

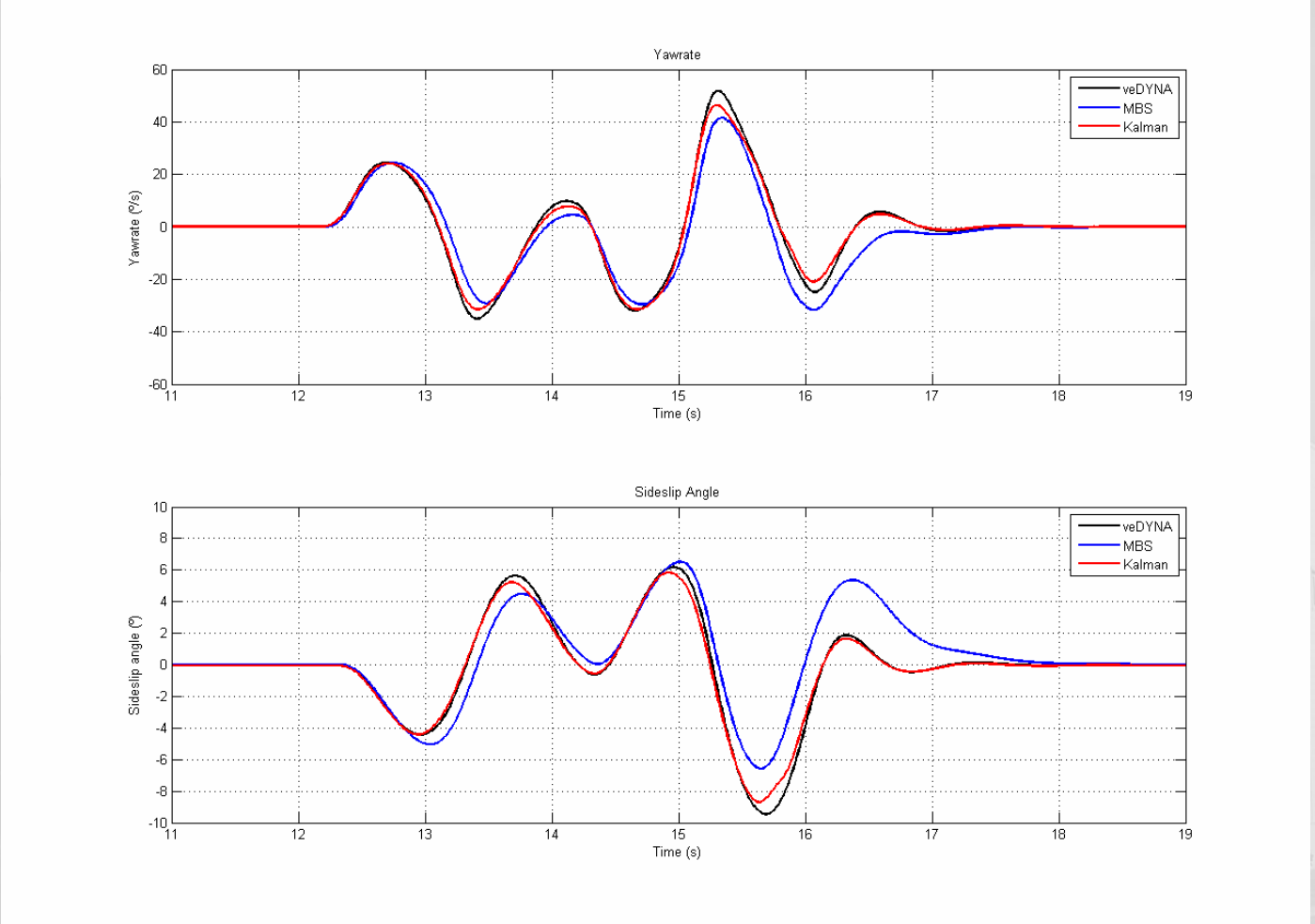


Some results: Lateral Velocity (chassis reference)



Black lines: veDYNA's results, playing the role of the real car.
Blue lines: MBS virtual model's results without corrections. The model alone will never perfectly match the real car.
Red lines: Results corrected by the Kalman Filter, very accurately matching those of the real car.

Some results : Yawrate and Sideslip angle



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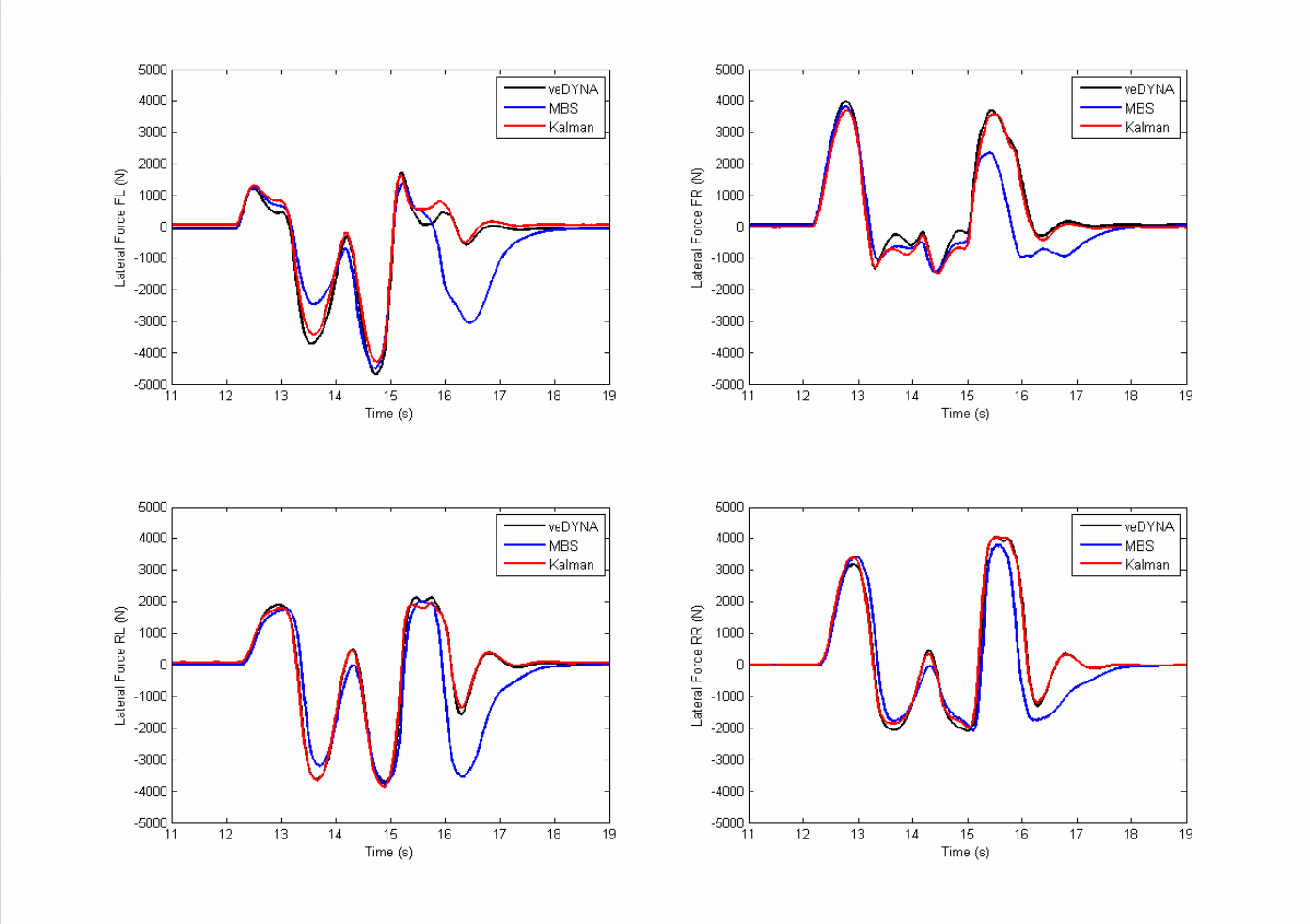
Some results : Lateral Forces



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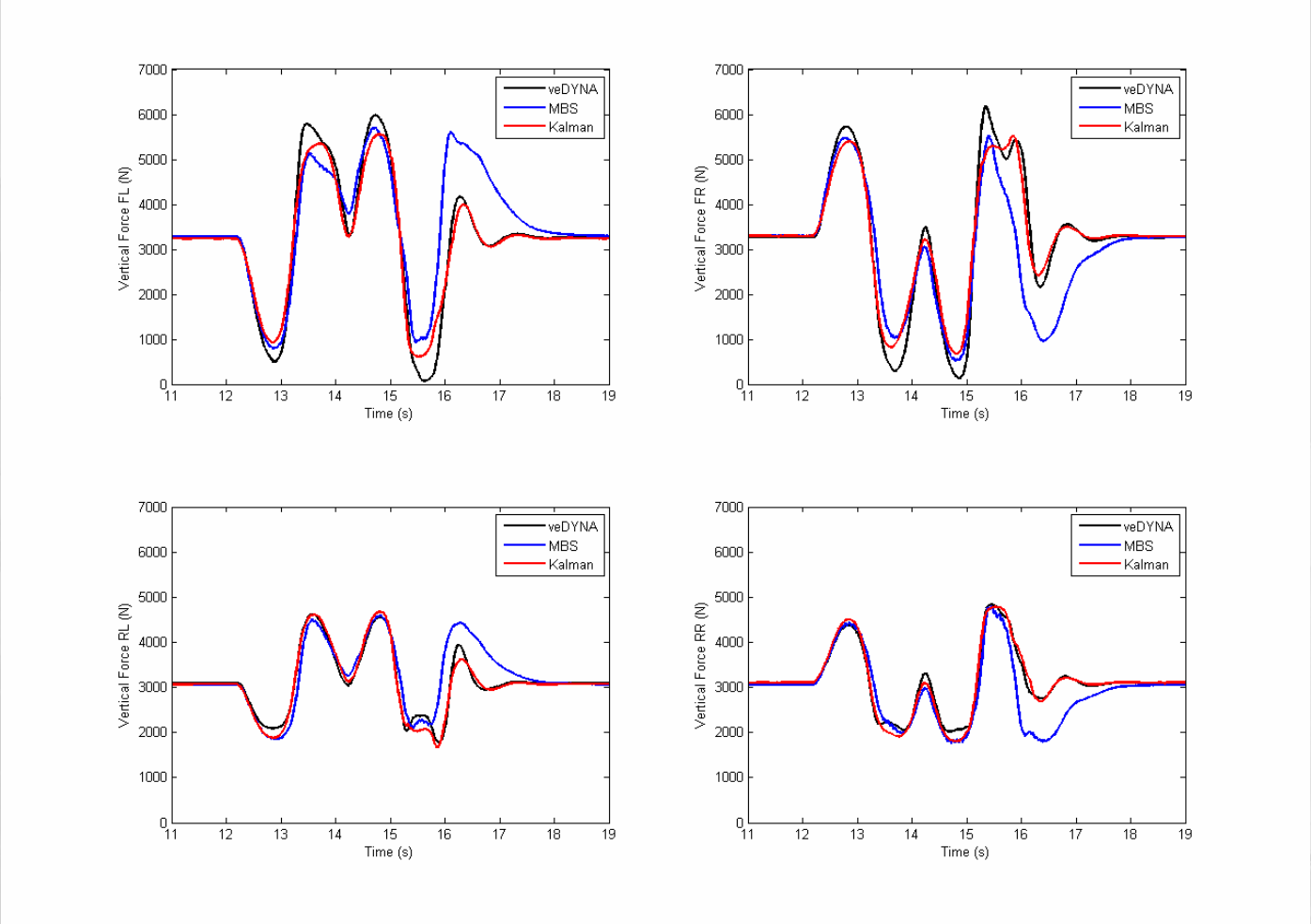
Some results : Vertical Loads



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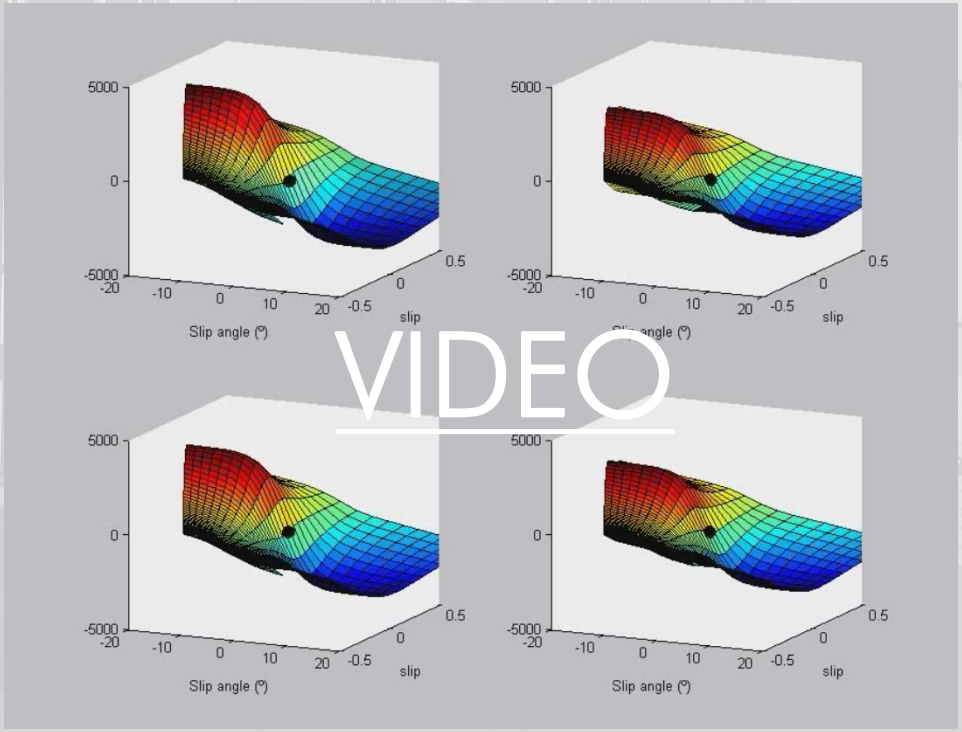
Some results : Tire working state recognition

Pac96 tyre model is fed with accurate information of the working point of the tyre

- Tyre longitudinal and lateral velocities (according to its orientation)
- Wheel load
- Camber angle

The model "knows" every reachable point:

- Within current and following working conditions
- Affected by any combination of chassis control actuation



Summary and Possibilities

Integral management of different types of sensors

- 3-axial accelerometers and gyroscopes
- GPS antennas
- ABS sensors
- Tyre sensors, torque sensing shafts…?

Provide comprehensive information of the state of the vehicle

- As many virtual sensors as variables defined in the model
- Current and reachable working point of the tyres (available grip, load state)

Fully exploit complex tyre models

- Accurate wheel loads
- Accurate orientation through suspension and steering kinematics
- Include Pacejka's parameters as states and continously adjust them

Predict the state of the vehicle in the near future

- Anticipate corrections
- Smoother actuation

Summary and Possibilities

Calculate the best combined actuation

- What's more profitable? To steer this tyre? To brake it? To send more torque? To (un)load it?
- The Kalman Filter already involves a sort of "inversion" of the system (desired outputs -> inputs)
- Maximizing correction of yaw moment? Agility? Roll-over mitigation?
- Minimizing perception of the driver? Loss of velocity?

Self-adaptation to changing vehicle or environmental conditions

- Changes in mass/inertia of the vehicle (roof rack, passengers…)
- Aging elements like dampers or tyres (with slow dynamics states)
- Changing coefficient of friction

Very general and modular approach for

- Different combinations of active systems
- Sensor data management
- Integration of different tyre models

Thank you!

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