SyRI seminar

ITEAM Project

State Estimation for Vehicle Dynamics

KU Leuven Concept Car Platform

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FLANDERS MAKE
DRIVING INNOVATION IN MANUFACTURING

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KU LEUVEN

ITEAM Network Concept: Motivation

X-by-wire vehicles

Low-emission vehicles

Automated vehicles

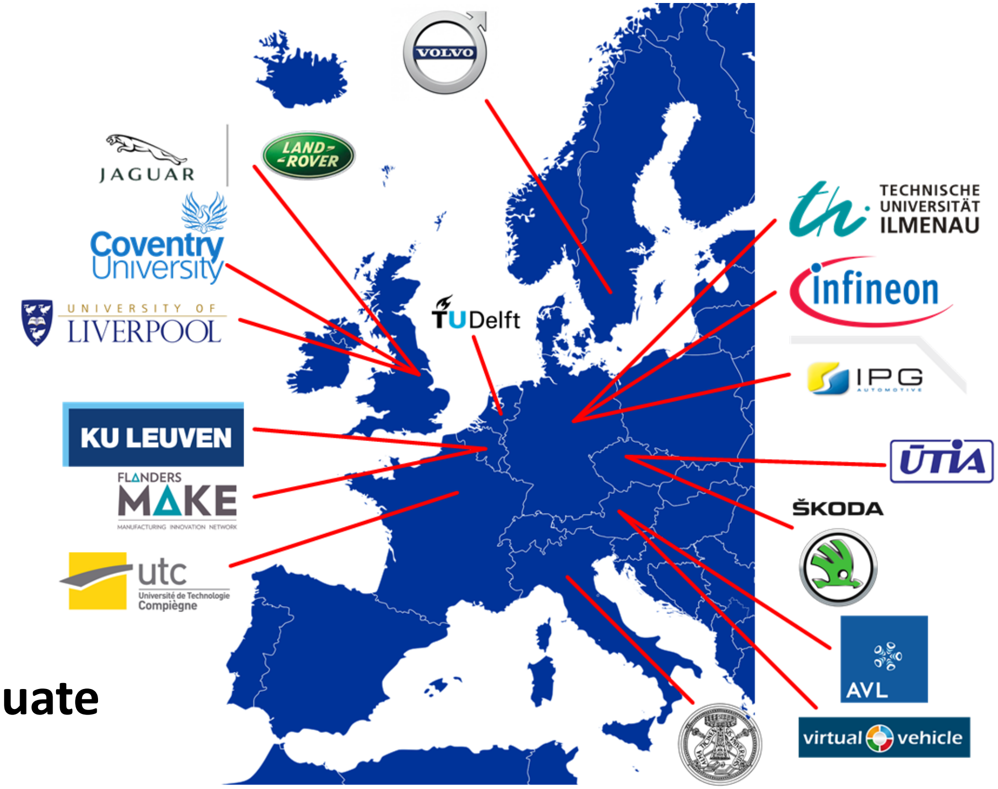
Insufficient consideration of integration

Studies on Multi-Actuated Ground Vehicles (MAGV)

ITEAM Network Concept: Consortium and Goals

Consortium:

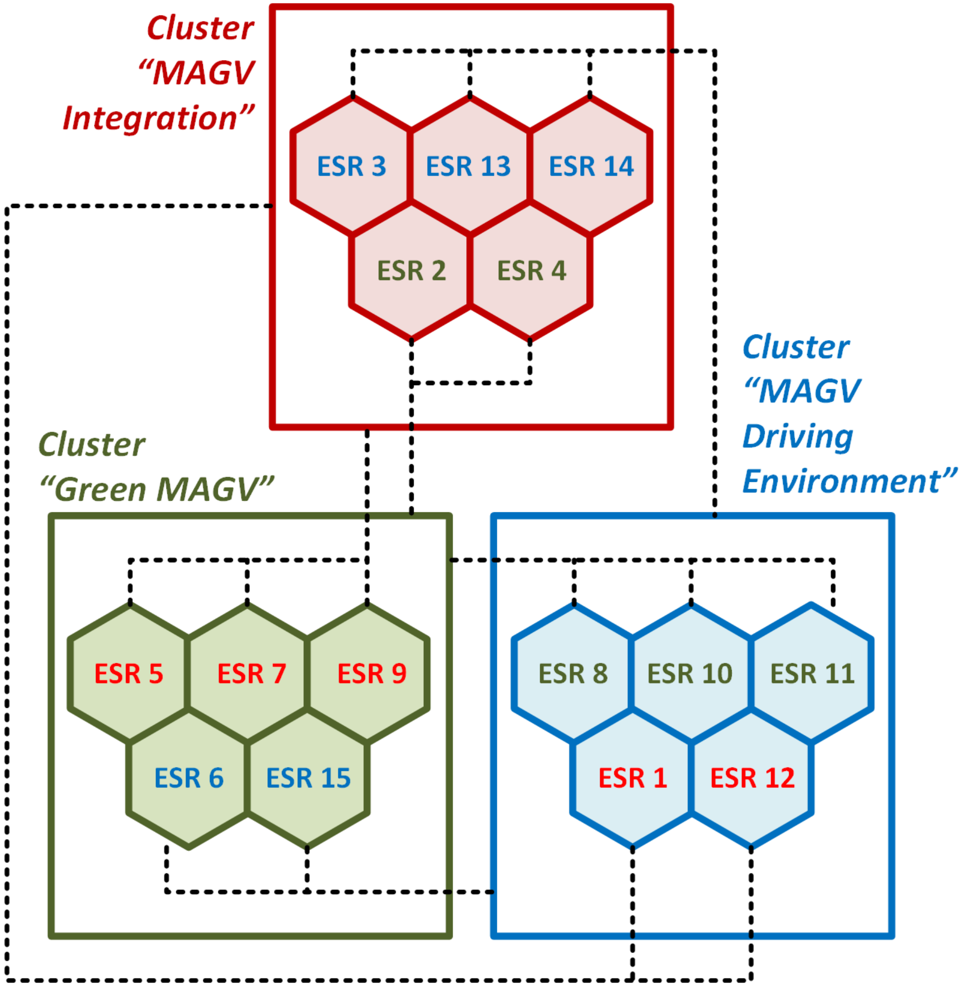
10 universities
2 research institutions
3 automotive OEMs
2 suppliers
2 SMEs



Global goals:

1. Advance the automotive postgraduate education
2. Improve career perspectives of PhDs in both public and private sectors
3. Create R&D group with determinant contributions to next generations of multi-actuated ground vehicles

ITEAM Network Concept: Clusters



Cluster MAGV Integration

- ESR2 and ESR3 (VOLVO)
- ESR4 (University of Pavia)
- ESR13 (Coventry University)
- **ESR14 (KU Leuven)**

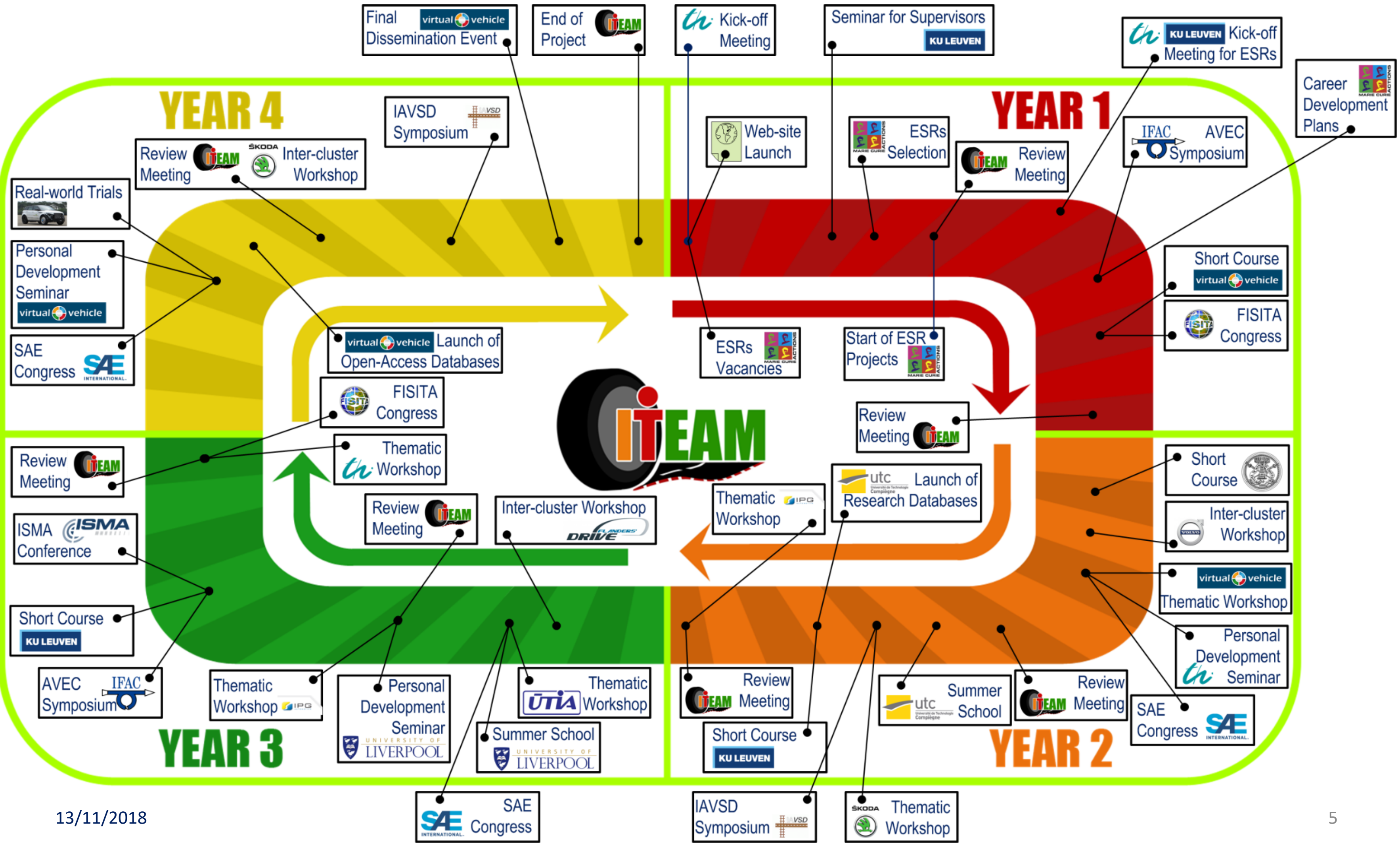
Cluster Green MAGV

- ESR5 (Infineon)
- ESR6 (VIF)
- ESR7 (University Compiègne)
- ESR9 and ESR15 (TU Ilmenau)

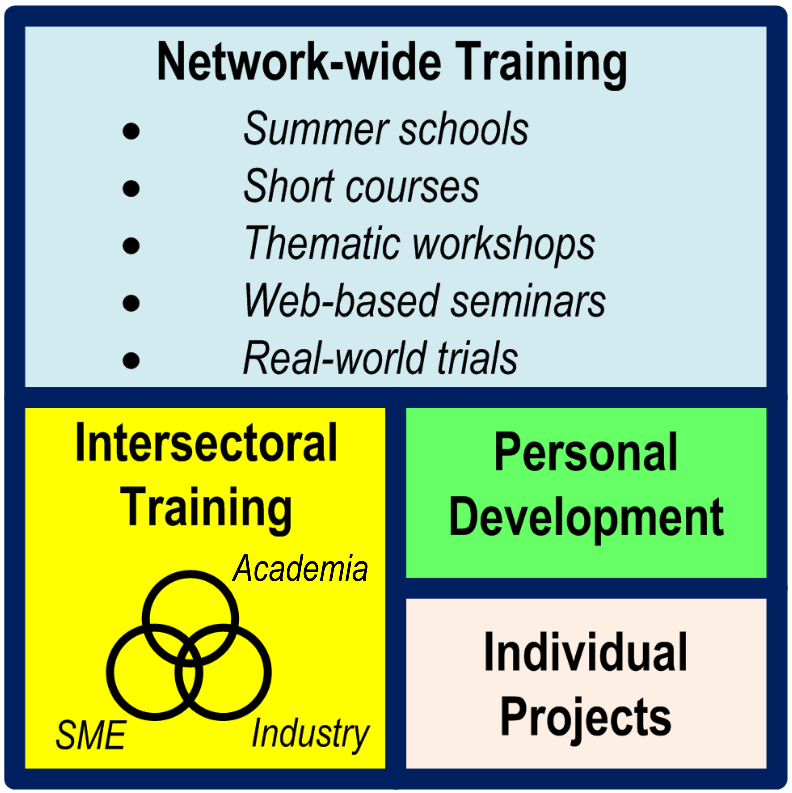
Cluster MAGV Driving Environment

- ESR1 (VIF)
- ESR8 (SKODA)
- ESR10 (University Compiègne)
- **ESR11 (Flanders Make)**
- ESR12 (AVL)

ITEAM Network Concept: Roadmap



ITEAM Network Concept: Training Program Approach



Training objectives

- Develop an **interdisciplinary project-based training network** to enhance vehicle design quality and performance;
- Establish and sustain a new type of **continuous, consecutive and successive research community,** recognizable on an international scale, with the high potential to make significant contributions to next generations of intelligent, safe and energy-efficient multi-actuated ground vehicles;
- Establish and promote **(i) professional advancement** of the participating institutions in cutting-edge technologies through **intersectoral collaboration** and **(ii) technical and cultural exchange** between academic and non-academic environments

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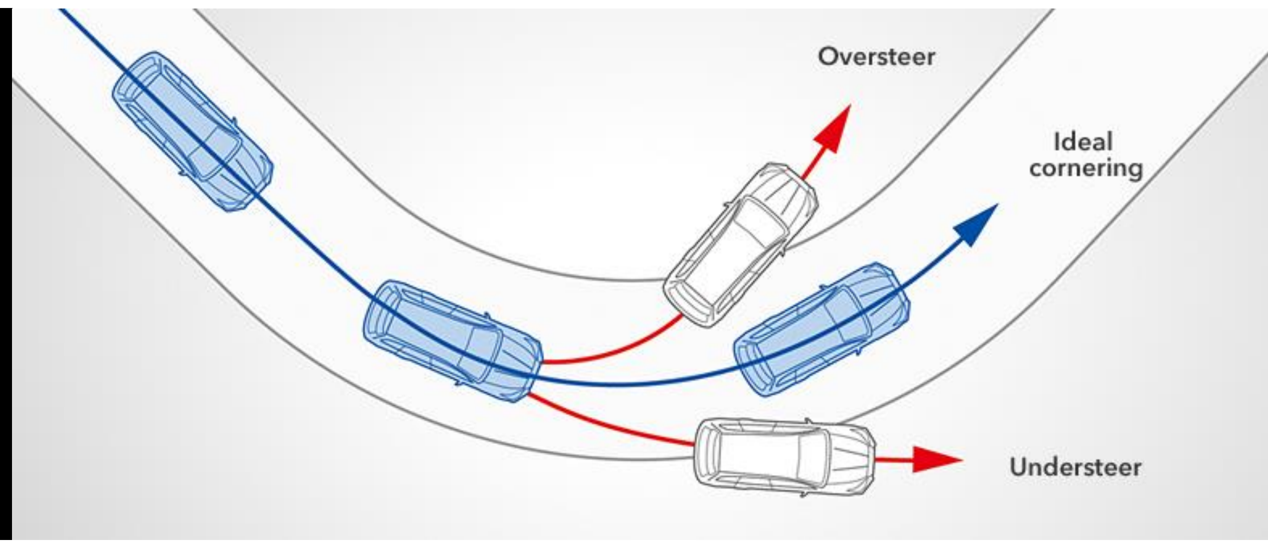
State Estimation – Motivation

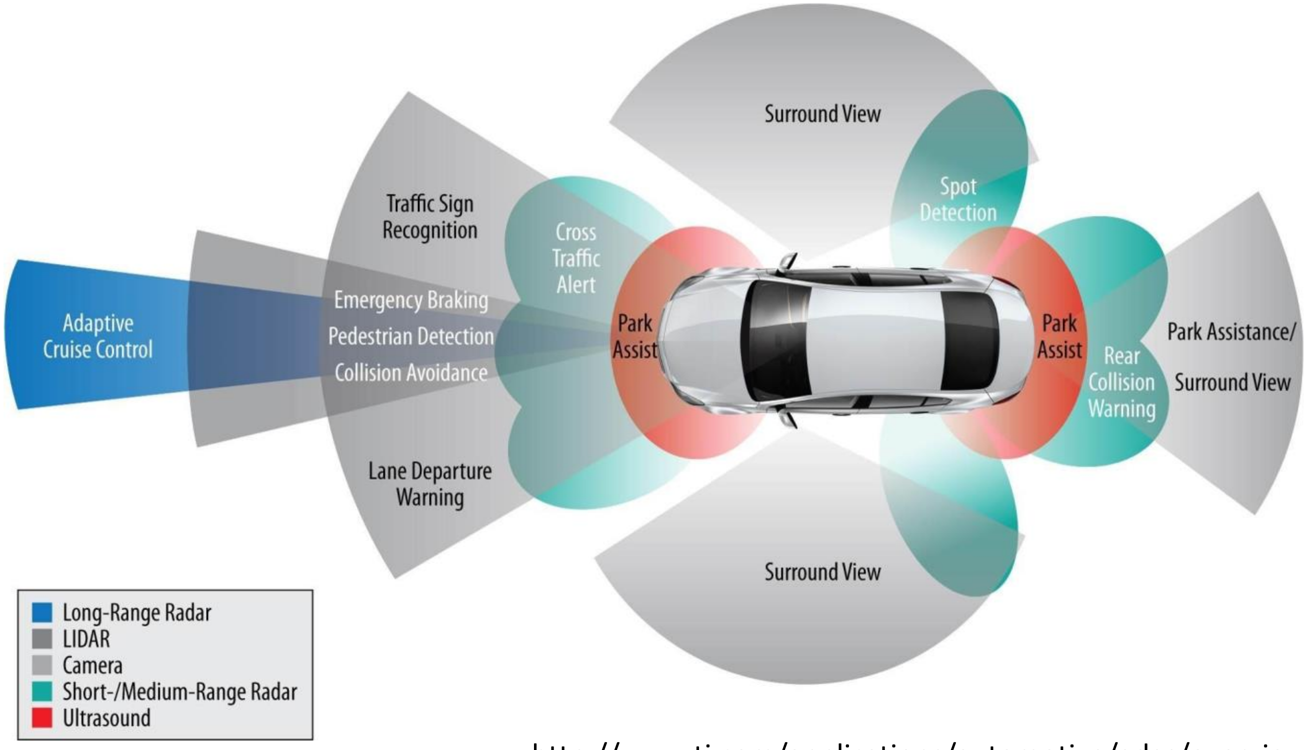
Past and current: vehicle dynamics control



Source: Subaru

State Estimation – Motivation

Future: ADAS and automated driving



http://www.ti.com/applications/automotive/adas/overview.html

State Estimation – Motivation

Future: ADAS and automated driving

Source: General Motors

State Estimation – Motivation

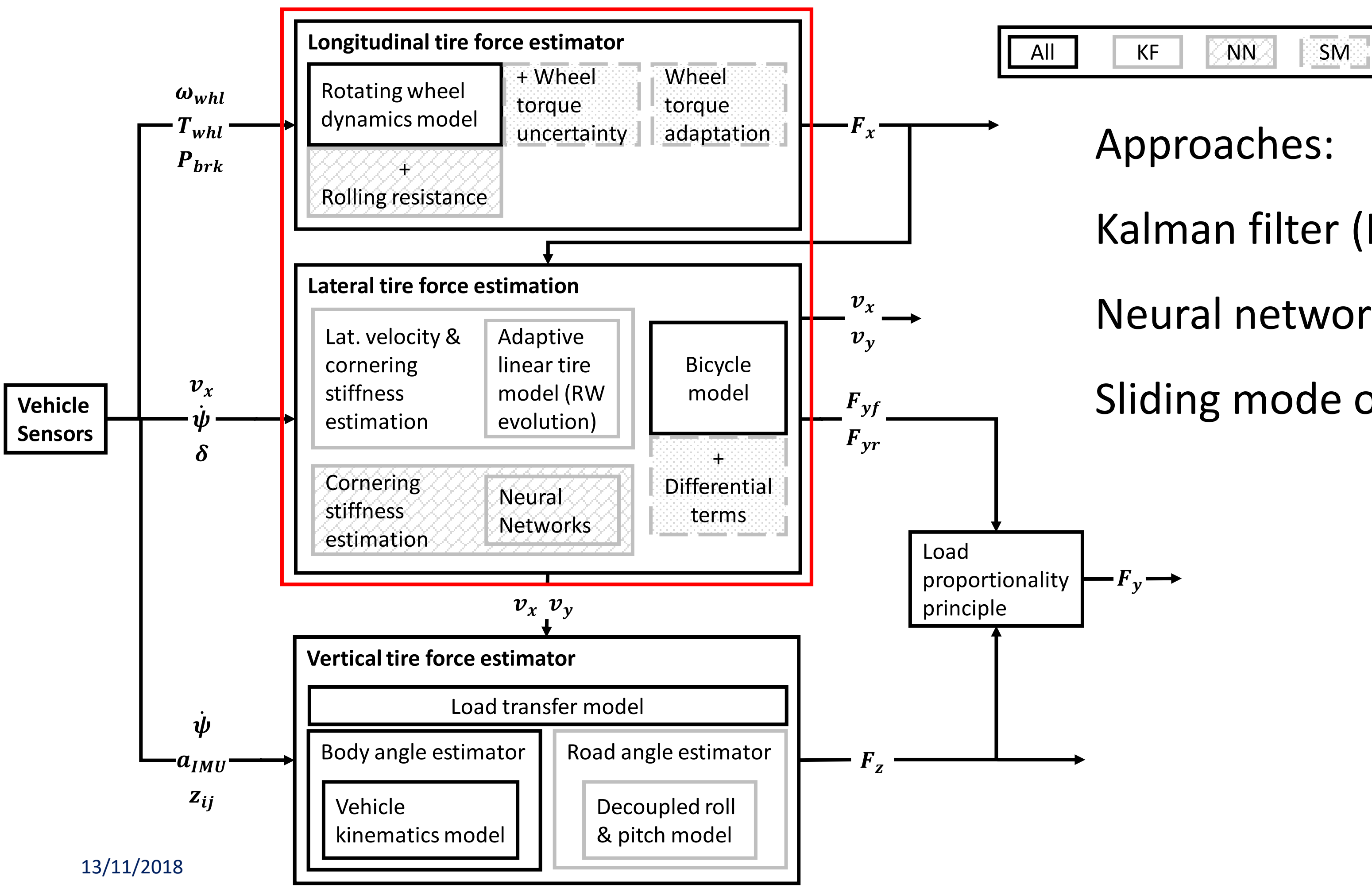
https://www.kistler.com/en/applications/automotive-research-test/vehicle-dynamics-durability/

However, some sensors are still too costly and/or intrusive.

- Components of velocity
- Vehicle sideslip angle
- Tire forces

→ Virtual Sensing

State estimation for vehicle dynamics



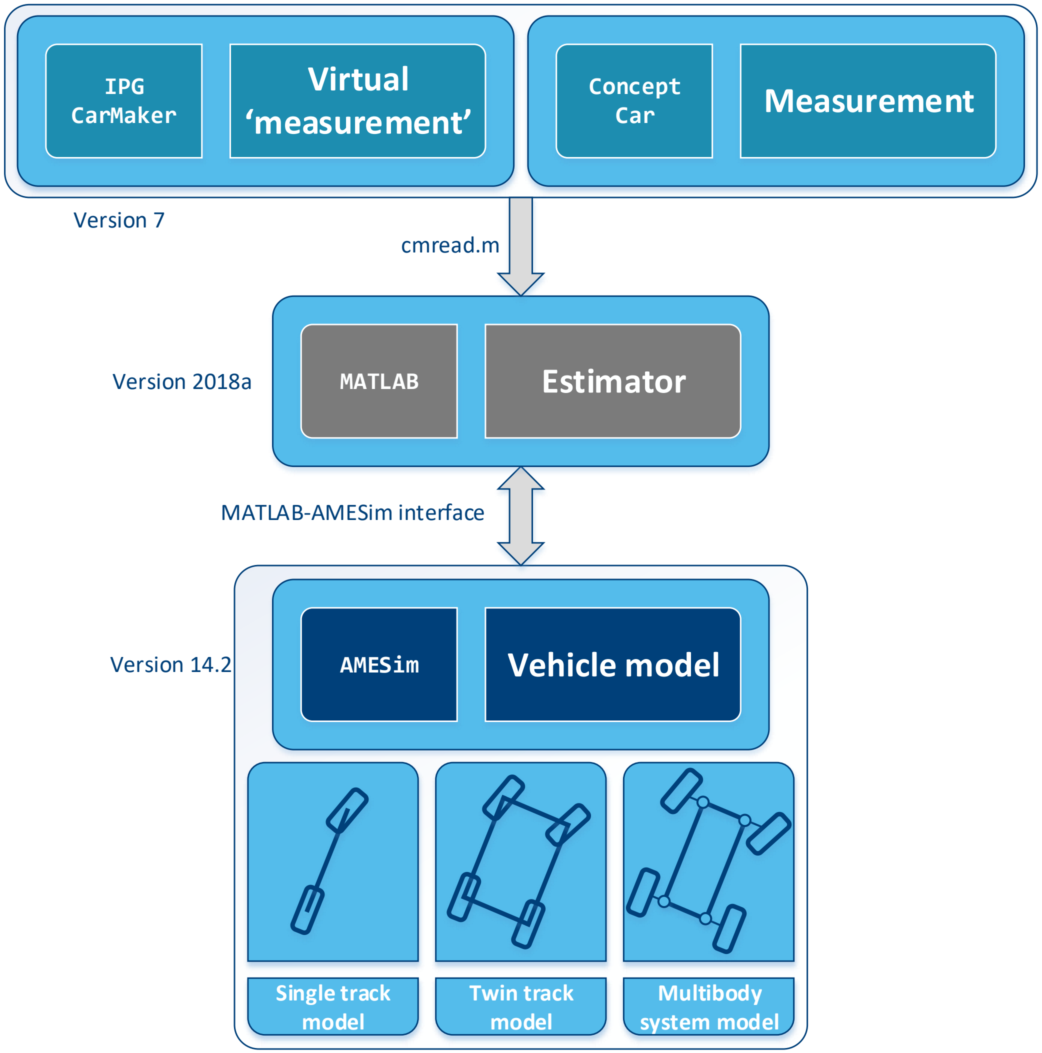
Approaches:

Kalman filter (KF)

Neural networks + KF (NN)

Sliding mode observer (SM)

Automotive state estimation environment



Automotive state estimation environment

Advanced **M**odeling **E**nvironment for performing **Sim**ulations of engineering systems: AMESim

LMS AMESim

Software tool for modeling and analysis of multi-domain systems (originally by *Imagine S.A.*; acquired by *LMS International*; acquired by *Siemens AG*)

Based on Modelica and bond graph theory

Causal: in- and outputs of icons are linked (in contrast to e.g. Simulink)

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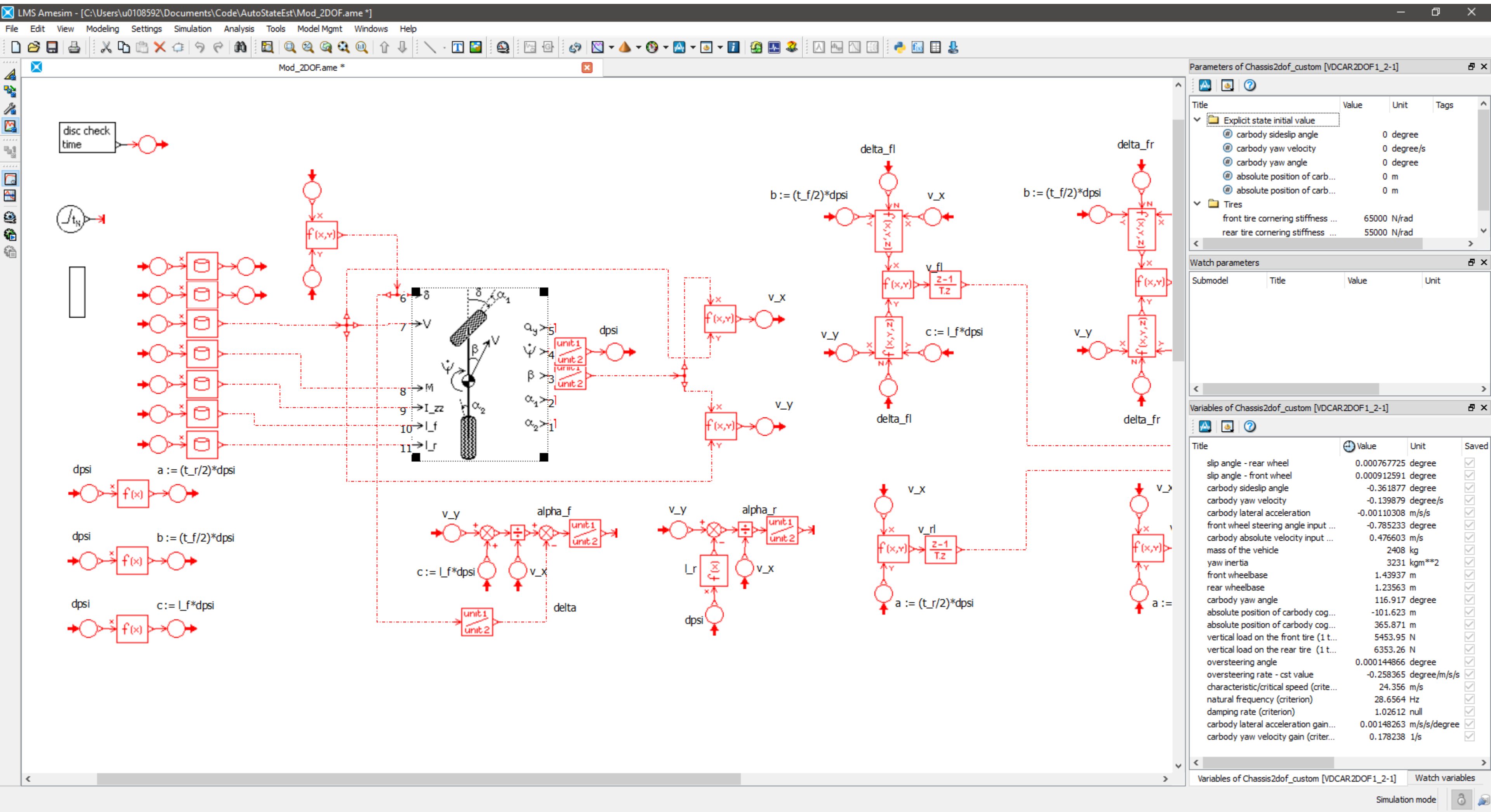
Automotive state estimation environment



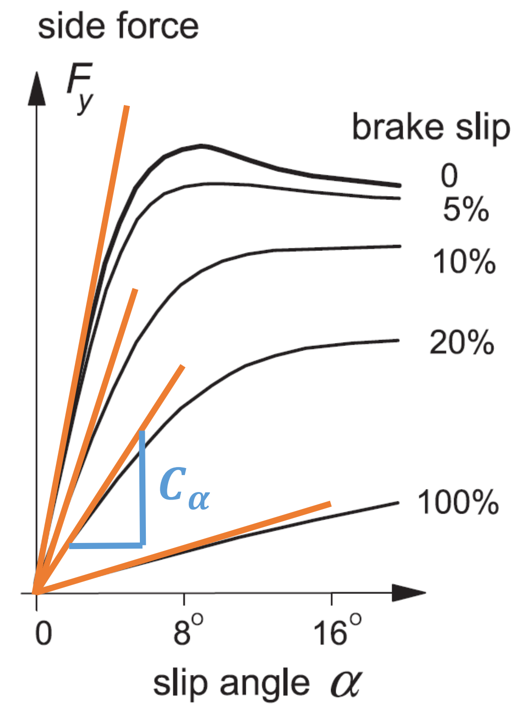
Automotive state estimation environment

Standard set of sensors already available in current production vehicles

Virtual sensing approach based on dynamic vehicle model to correct for sensor inaccuracies

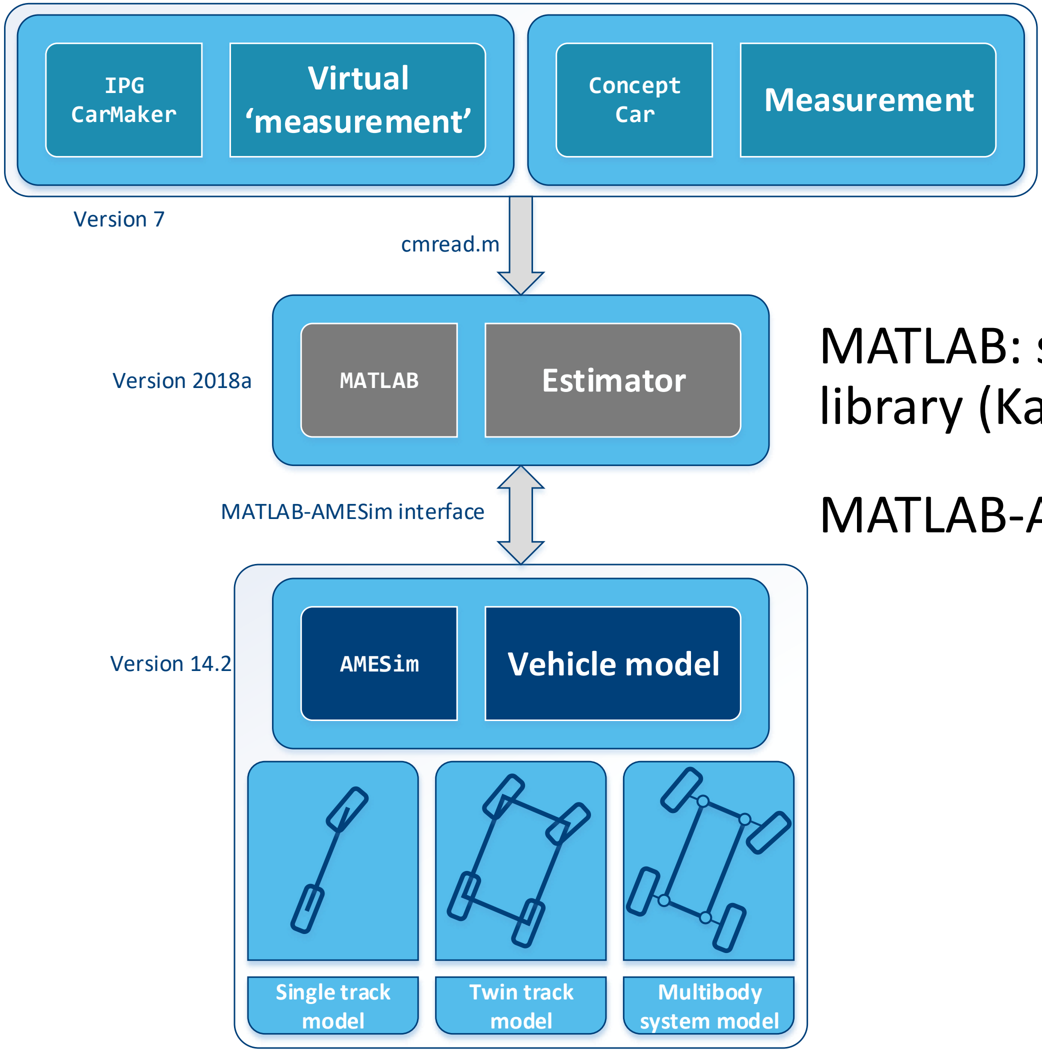
Tire cornering stiffness estimation with random walk (adds robustness against unknown and variable tire/road behavior)

'Adaptive linear tire model'



Source: Tire and Vehicle Dynamics (Pacejka)

Automotive state estimation environment

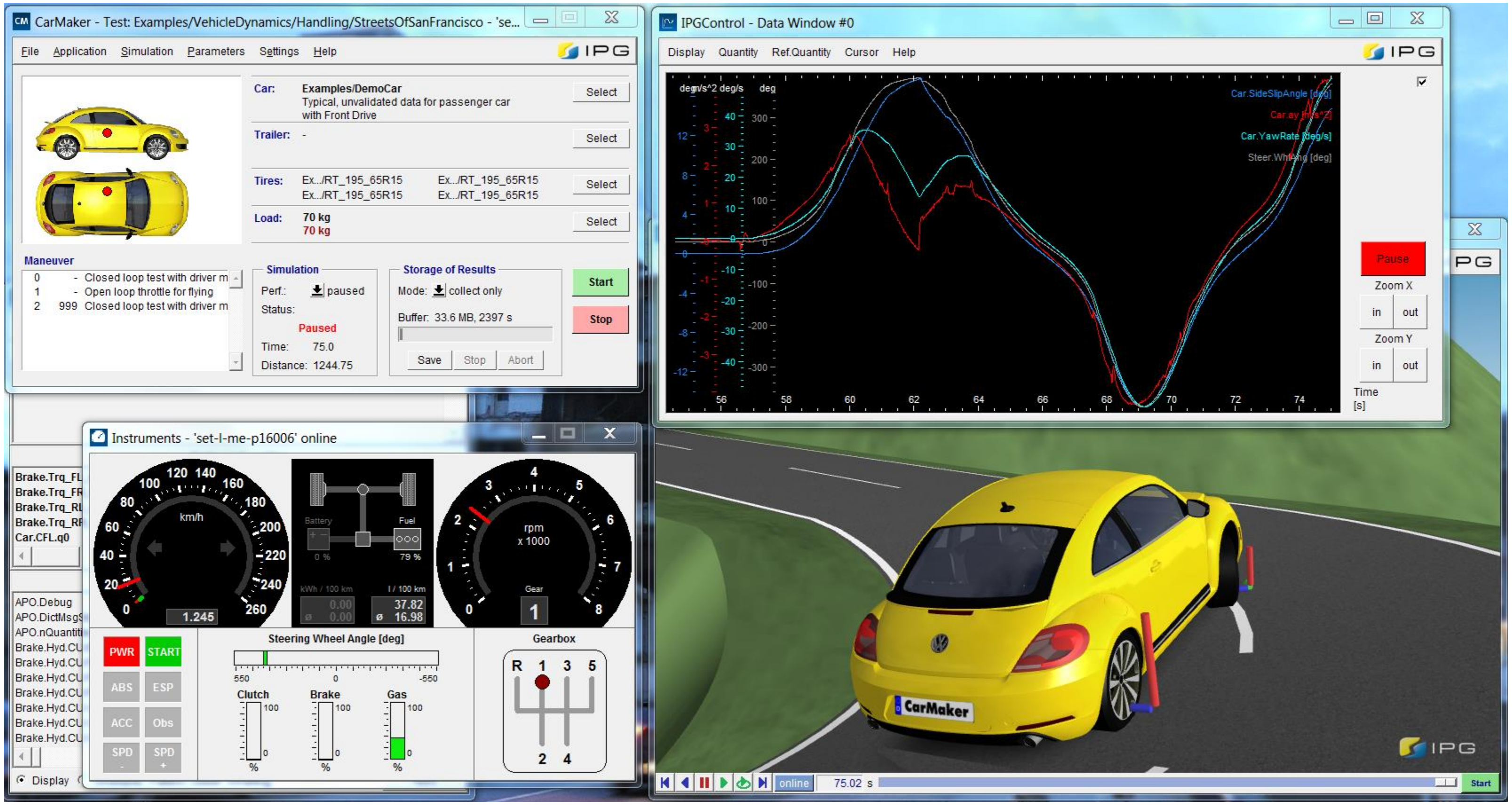


MATLAB: state estimation library (Kalman filter)

MATLAB-AMESim interface

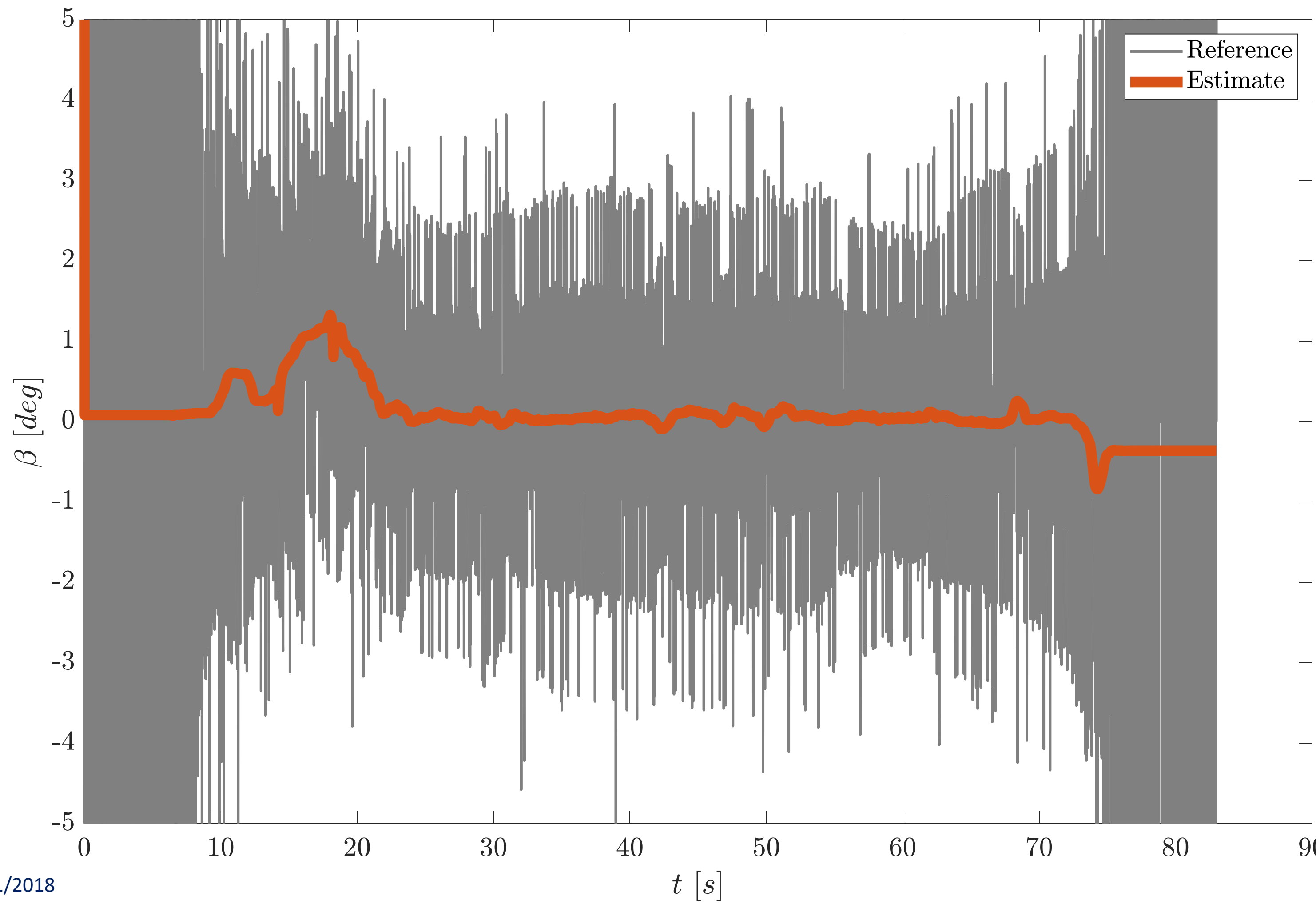
Automotive state estimation environment

IPG CarMaker

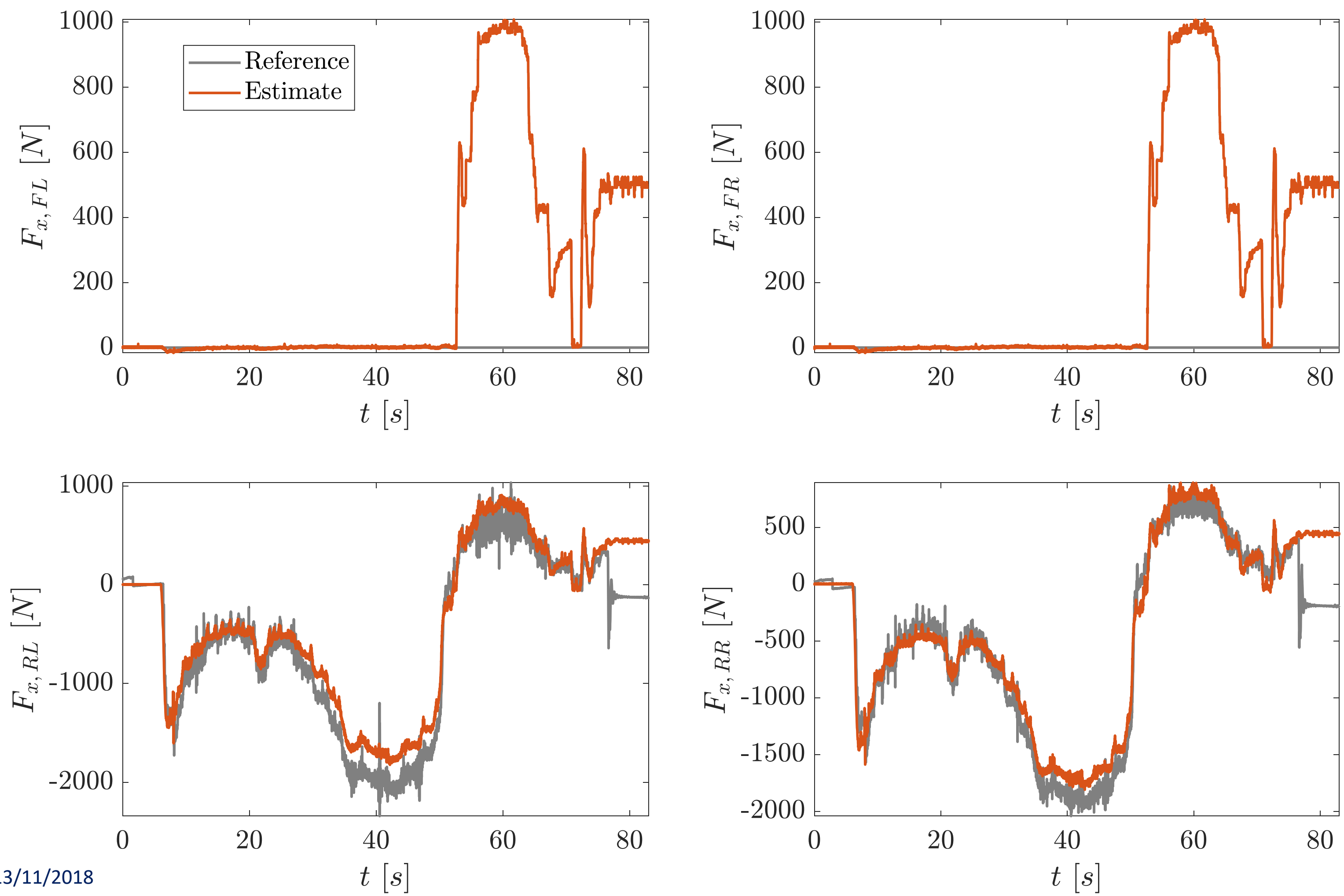


Flanders Make electrified Evoque test vehicle

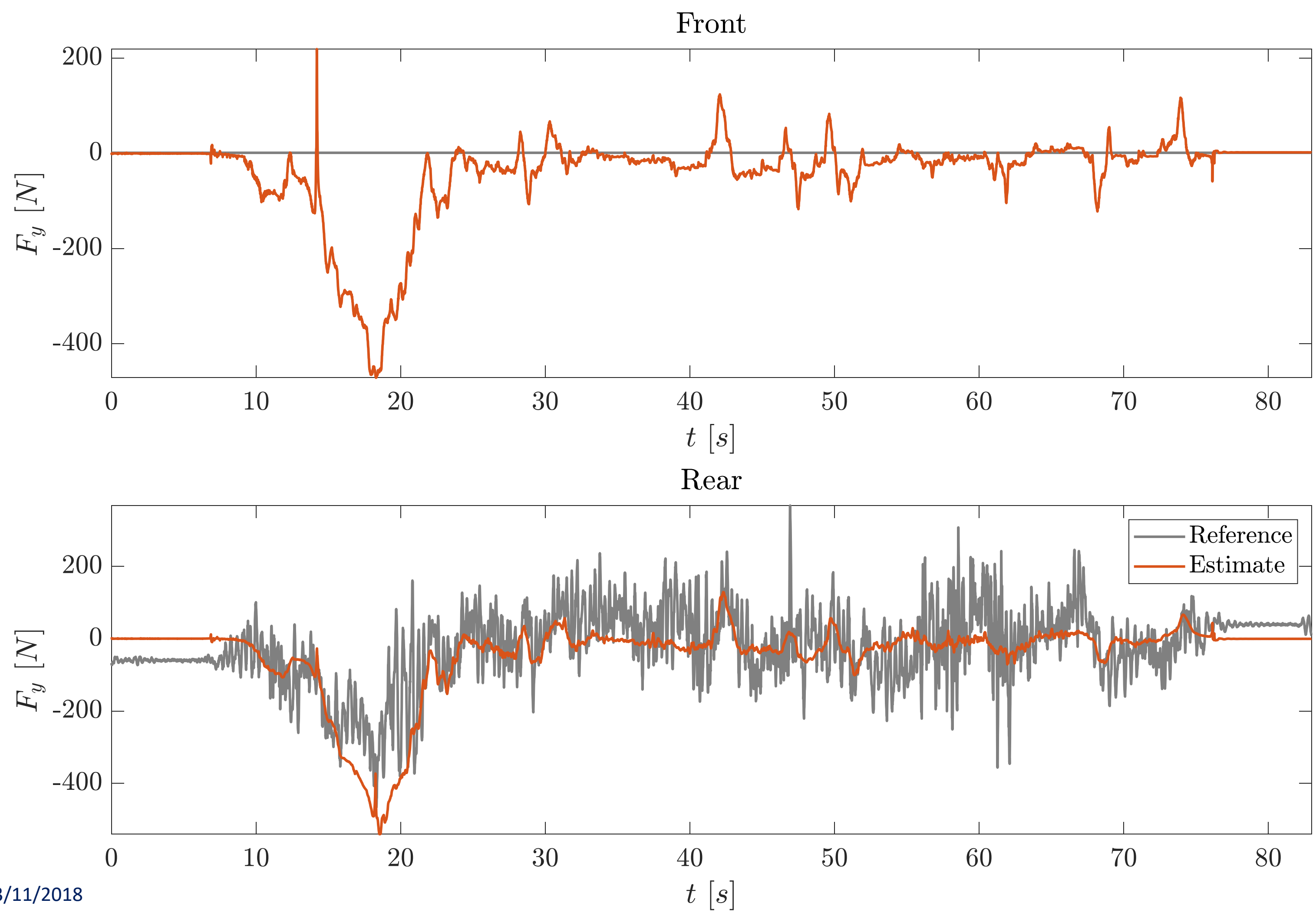
State estimation results – vehicle sideslip angle



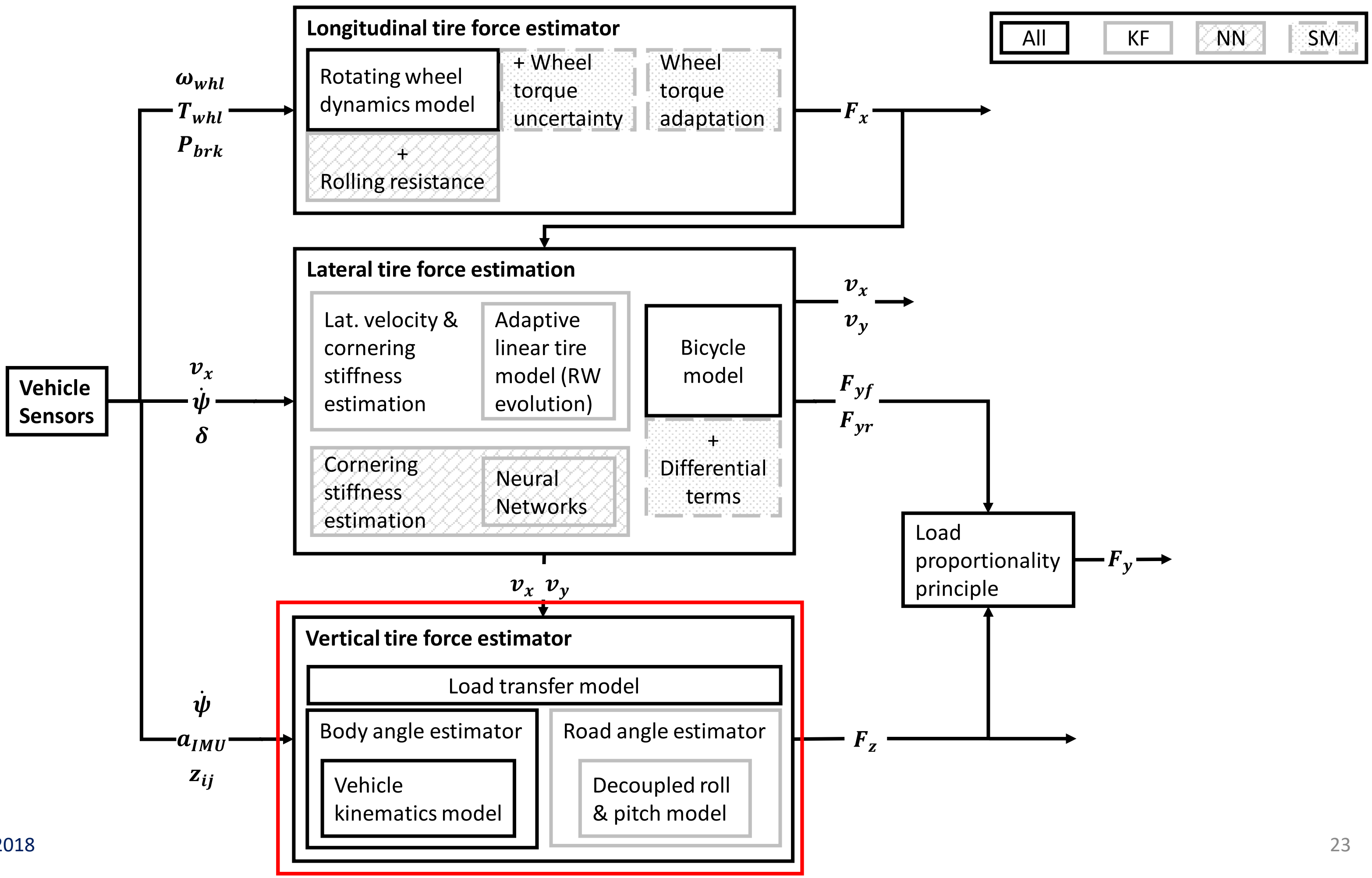
State estimation results – longitudinal tire forces



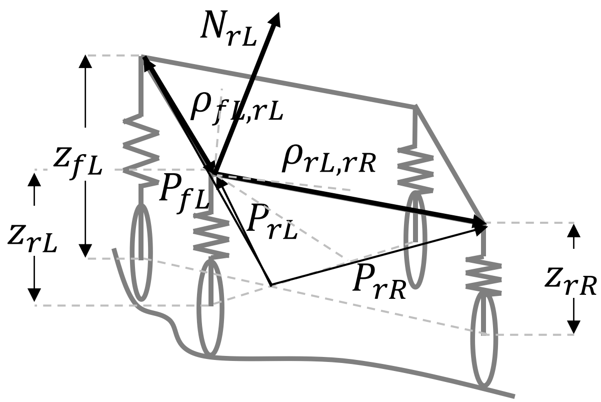
State estimation results – lateral tire/axle forces

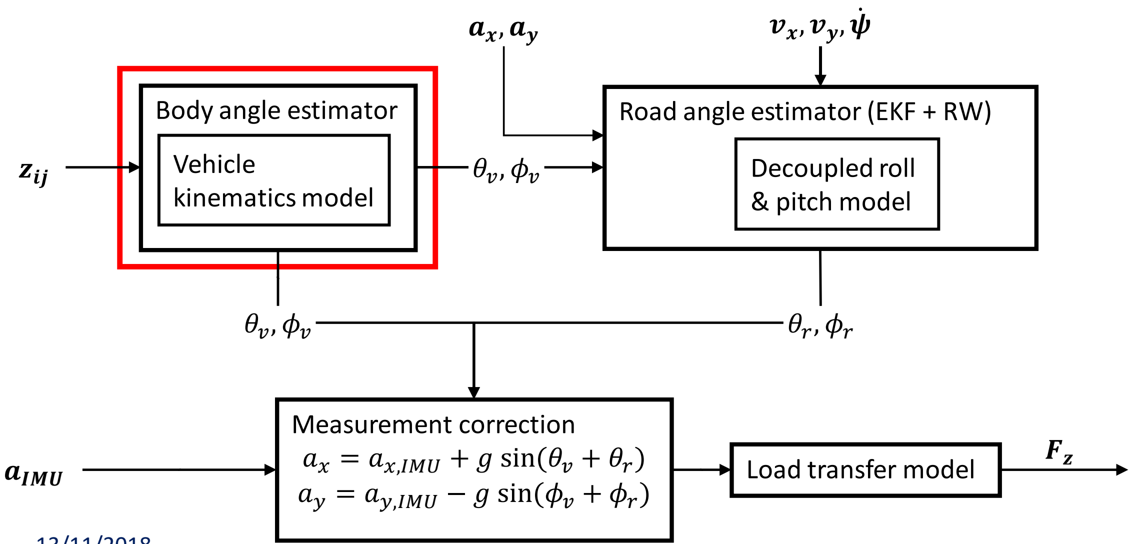


Estimation framework

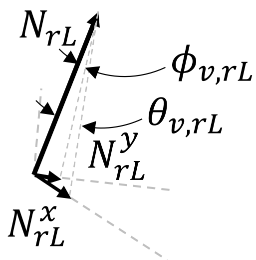


Body and Road angle estimation & Vertical tire force estimation



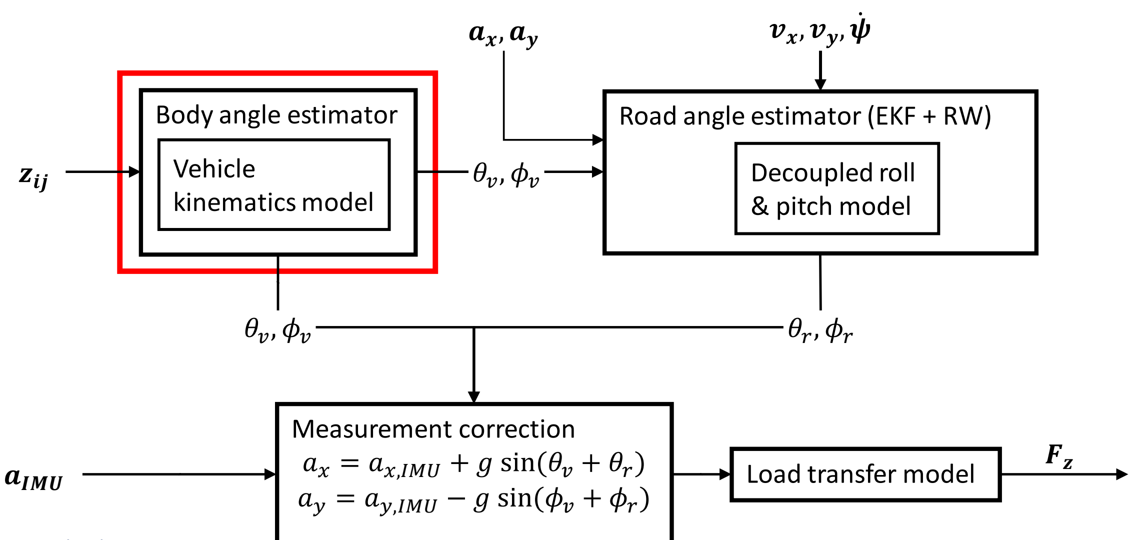


Body and Road angle estimation & Vertical tire force estimation



$$\phi_{v,ij} = \cos^{-1}\frac{N_{ij}^{y}}{\|N_{ij}\|}$$

$$\theta_{v,ij} = \cos^{-1}\frac{N_{ij}^{x}}{\|N_{ij}\|}$$



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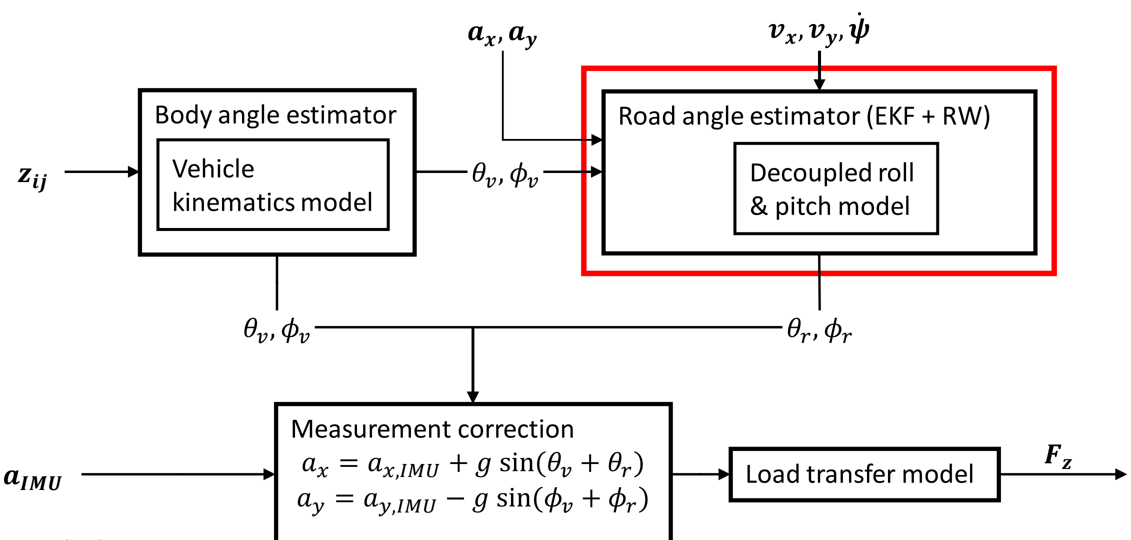
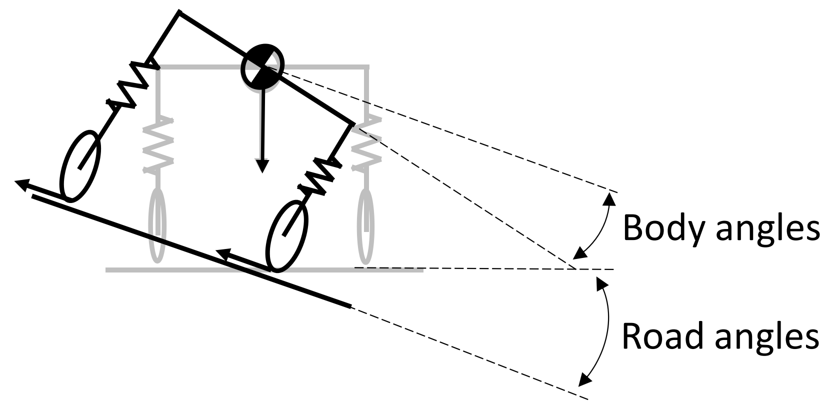
Body and Road angle estimation & Vertical tire force estimation

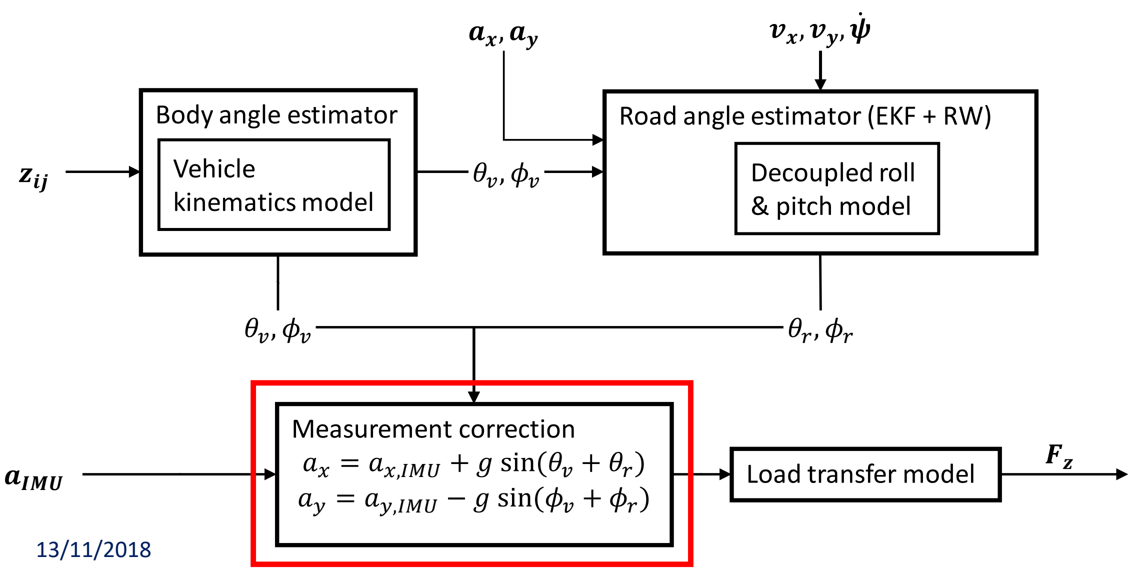
$$\begin{bmatrix} \dot{\phi}_v \\ \ddot{\phi}_v \\ \dot{\phi}_r \\ \dot{\theta}_v \\ \ddot{\theta}_v \\ \dot{\theta}_r \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 \\ {}^{-K_{\phi_v}+gm}/_{I_{\phi_v}} & {}^{-C_{\phi_v}}/_{I_{\phi_v}} & {}^{gm}/_{I_{\phi_v}} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & {}^{-K_{\theta_v}+gm}/_{I_{\theta_v}} & {}^{-C_{\theta_v}}/_{I_{\theta_v}} & {}^{gm}/_{I_{\theta_v}} \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} \phi_v \\ \dot{\phi}_v \\ \phi_r \\ \theta_v \\ \dot{\theta}_v \\ \theta_r \end{bmatrix} + \begin{bmatrix} 0 & 0 & 0 \\ {}^{m}/_{I_\phi} & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & {}^{m}/_{I_\theta} & 0 \\ 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} \dot{v}_y + \dot{\psi} v_y \\ -\dot{v}_x + \dot{\psi} v_x \\ 0 \end{bmatrix}$$

$$\begin{bmatrix} \dot{\phi}_v \\ \dot{\theta}_v \\ a_x \\ a_y \\ \phi_v \\ \theta_v \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -g & 0 & -g \\ g & 0 & g & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \end{bmatrix} \begin{bmatrix} \phi_v \\ \dot{\phi}_v \\ \phi_r \\ \theta_v \\ \dot{\theta}_v \\ \theta_r \end{bmatrix} + \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & -1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} \dot{v}_y + \dot{\psi} v_y \\ -\dot{v}_x + \dot{\psi} v_x \\ 0 \end{bmatrix}$$



Body and Road angle estimation & Vertical tire force estimation



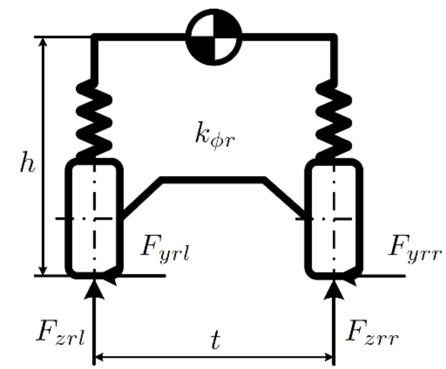


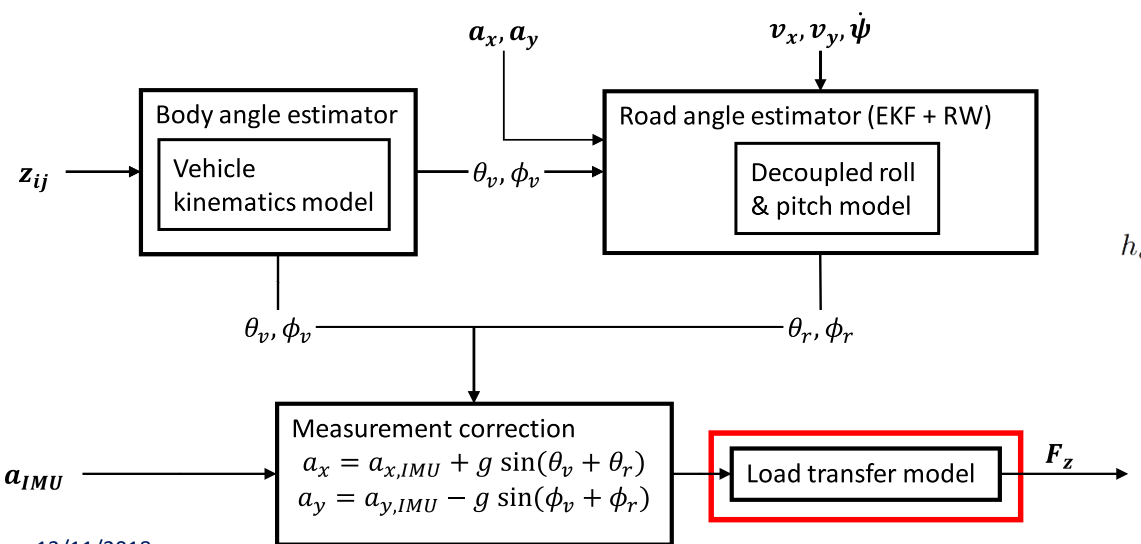
Body and Road angle estimation & Vertical tire force estimation

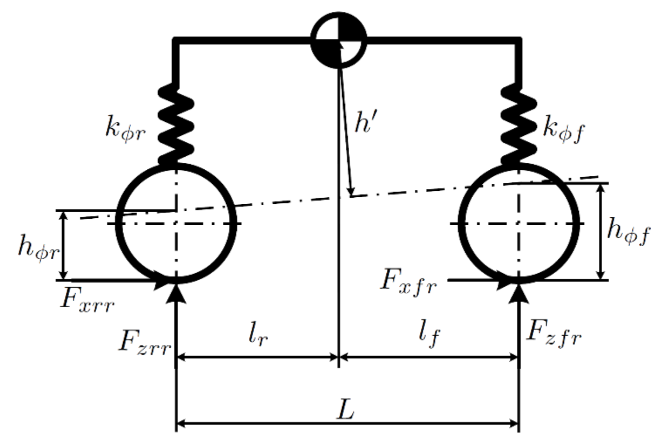
$$F_{zij} = \frac{(L - l_i)\, mg}{2L} \pm \Delta F_{z\phi i} \pm \Delta F_{z\theta i}$$

$$\Delta F_{z\phi i} = \frac{1}{t_i}\left(\frac{k_{\phi i}}{k_{\phi f} + k_{\phi r} - mgh'} h' + \frac{L - l_i}{L} h_{\phi i}\right) m a_y$$

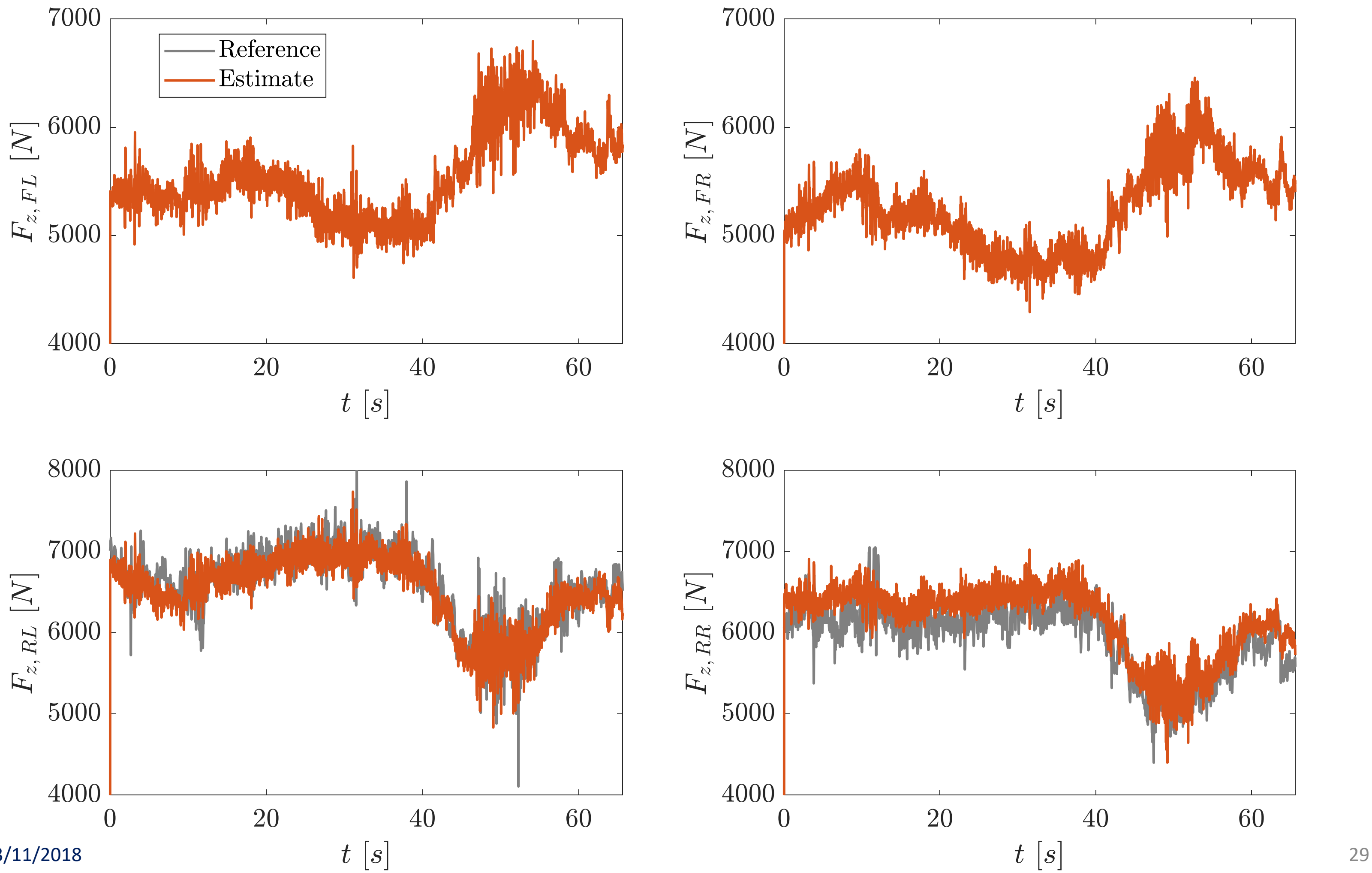
$$\Delta F_{z\theta i} = \pm \frac{m a_x h}{2L}$$



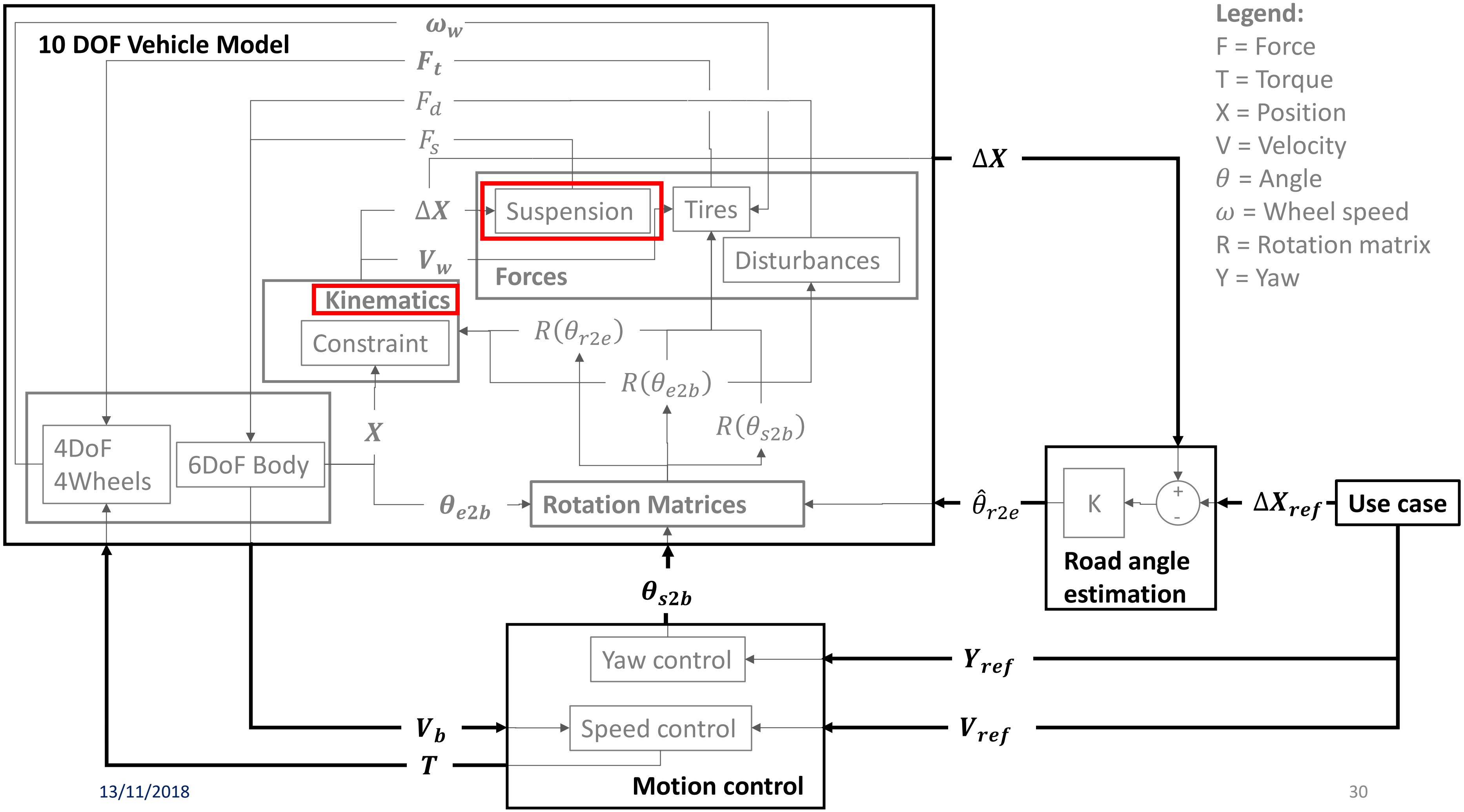




State estimation results



10 DOF Vehicle Model



Legend:
F = Force
T = Torque
X = Position
V = Velocity
θ = Angle
ω = Wheel speed
R = Rotation matrix
Y = Yaw

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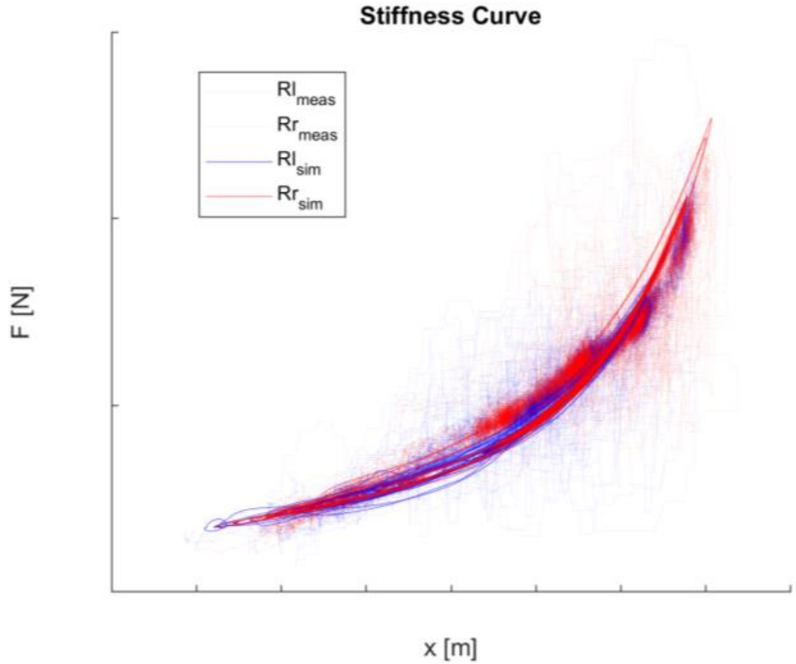
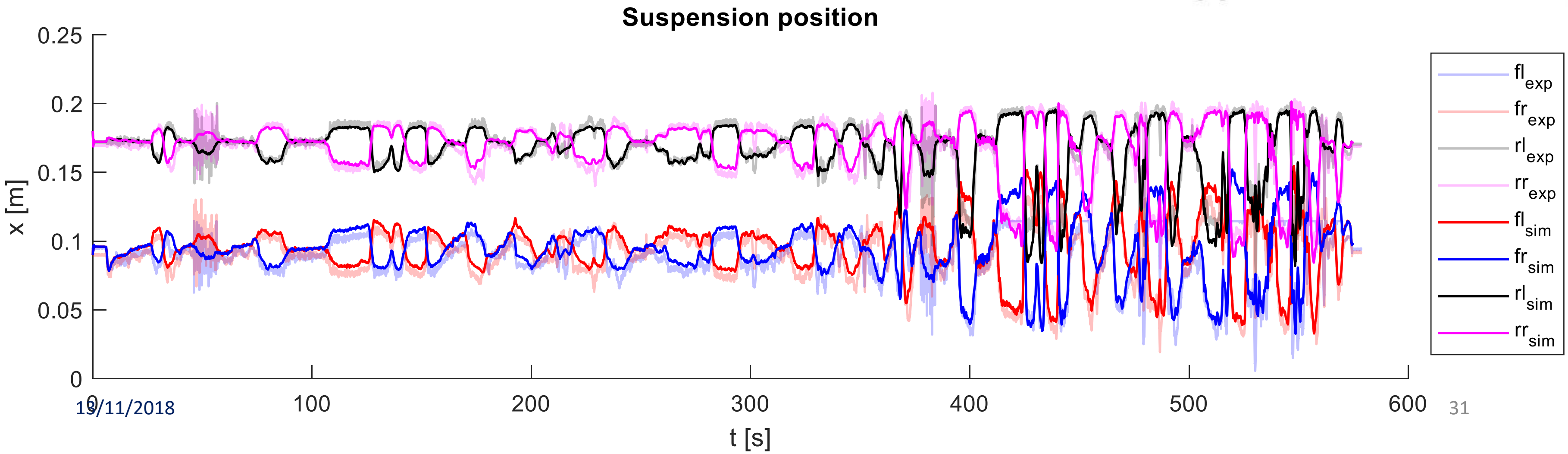
Nonlinear suspension stiffness:

$$F = e^{ax} + bx$$

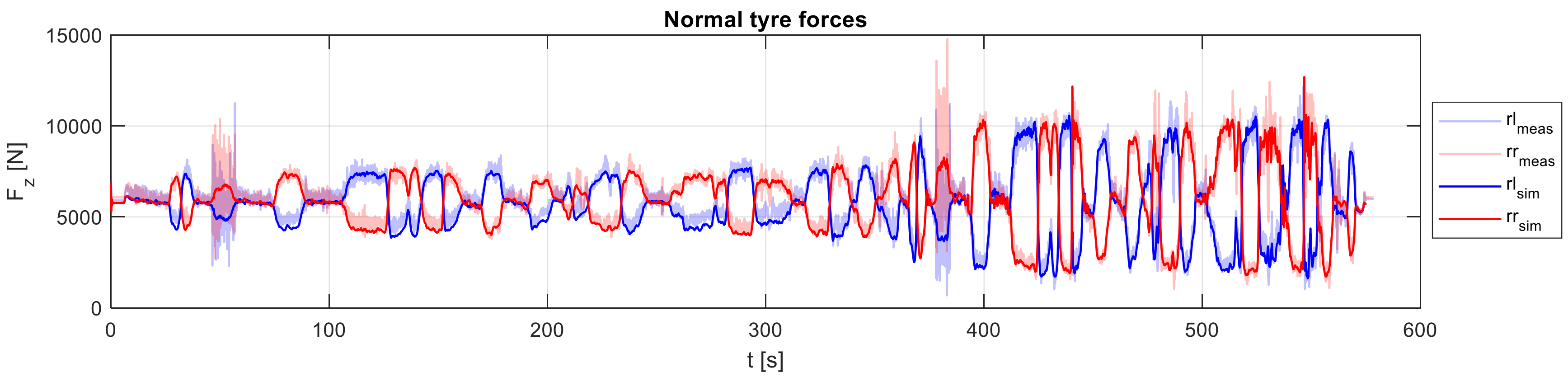
Suspension strokes:

$$\boldsymbol{x} = \boldsymbol{x_{CoM}} + R_{v2e} * \boldsymbol{r}$$





Calculated normal tire forces (Limit handling test)



Concept Car Platform – Introduction

Modular powertrain architecture

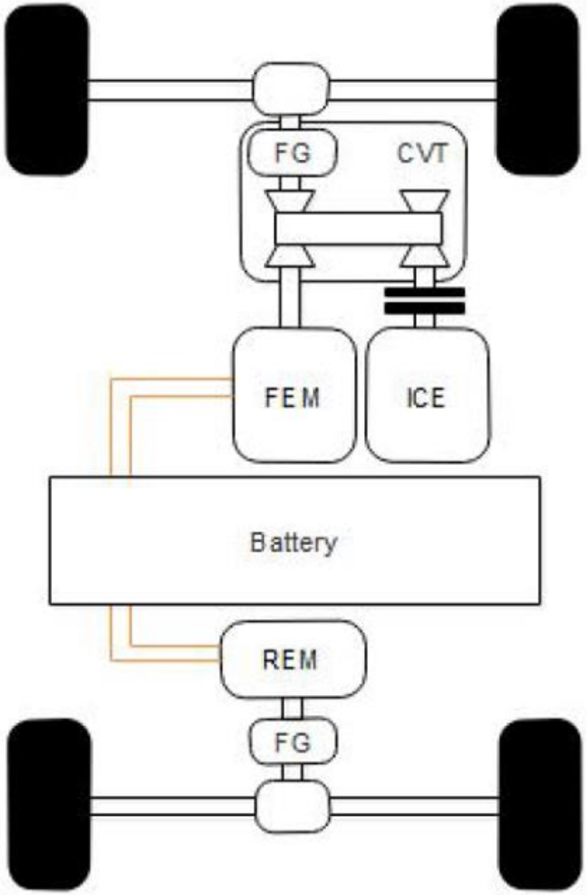
Including conventional, hybrid, and fully electric options

Goal: creation of automotive platform for versatile research and validation purposes

In cooperation with *Punch Powertrain,* Belgian supplier of powertrain technology

Supported by a number of Master's theses

Development/optimization is ongoing



Concept Car Platform – Student work

2016/2017: initial frame design; hybrid controller for energy optimization; powertrain implementation strategy & battery pack design

2017/2018: Brake-By-Wire; ElectricPowerAssistedSteering

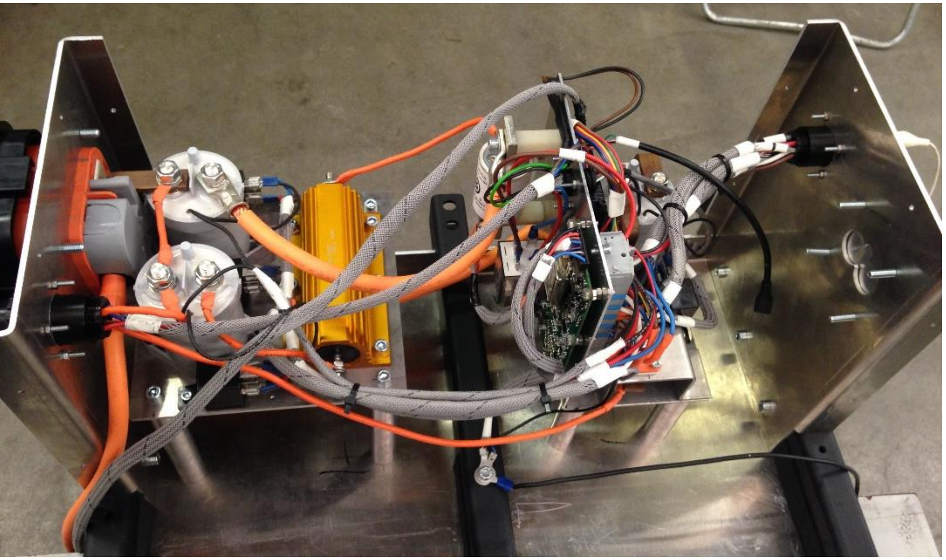
2018/2019: suspension redesign; vehicle dynamics controller (ABS, TCS, ESC)

Concept Car Platform – High voltage battery

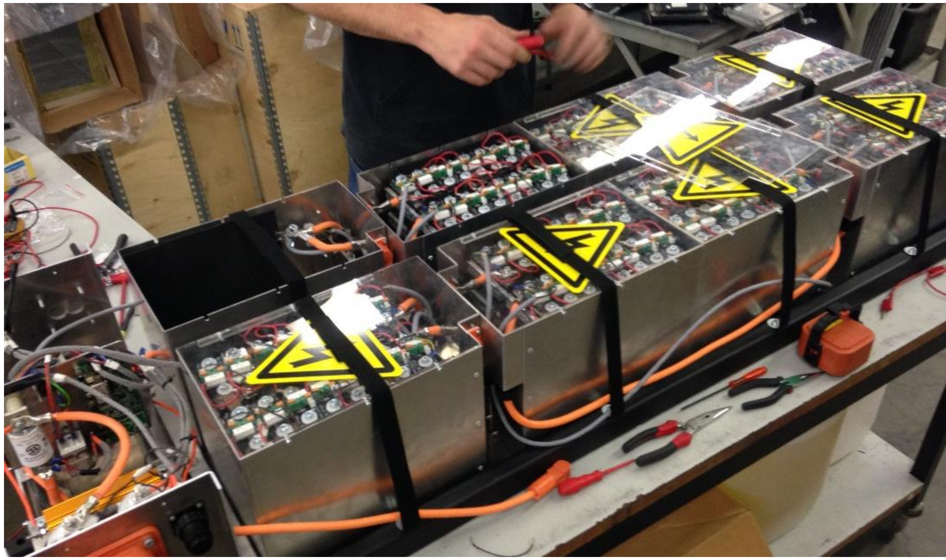
Lithium Ferro Phosphate (LiFePO4)

12 kWh usable 360 V 50+ km full electric range

60 kW peak 160+ kg



Junction box interfacing internal/external connections and hosting safety features



Complete battery pack assembled from seven modules and a total of 112 cells

Concept Car Platform – Energy optimization

Constrained optimization of (equivalent) fuel consumption

Rule-based mode selection
- Combustion only
- Hybrid mode
- Full electric mode

'High level' control

	Performance	**limits**
ICE	engine map (fuel consumption)	Torque min/max rpm min/max
CVT	CVT losses	Ratio min/max Rate of change min/max
Motor	motor map (efficiency)	Torque min/max rpm min/max
Battery	Charge/discharge efficiency	Power min/max

Concept Car Platform – Energy optimization

Constrained optimization of (equivalent) fuel consumption

Rule-based mode selection
- Combustion only
- Hybrid mode
- Full electric mode

'High level' control

Transition	Conditions	Actions
a1	$T_{request} < 0$	switch to braking mode stop engine
a2	$T_{request} < 0$	switch to braking mode
b	hybrid trigger	start engine
c1	engine ready	no action
c2	engine speed sufficient	switch to hybrid mode close clutch
d	clutch is closed	no action
e	electric trigger	switch to electric mode open clutch
f	clutch is open	stop engine
g	engine off	no action
h1	$T_{request} > 0$	switch to electric mode
h2	$T_{request} > 0$ engine ready clutch closed	switch to hybrid mode
h3	$T_{request} > 0$ engine ready	switch to hybrid mode close clutch
h4	$T_{request} > 0$ engine not ready	switch to electric mode

Concept Car Platform – Energy optimization

'Low level' control: instantaneous optimization based on look-up tables

Global optimization not possible as we do not know the future trajectory

→ Offline optimization (also less demanding on computational power)

	Combustion Mode	Hybrid Mode	Percentual reduction
SFC ICE [g/kWh]	304,99	249,41	18.22%
SFC ICE during charging [g/kWh]	-	243,99	-
Total fuel consumption [g]	1793,64	1705,47	4.92%
Equivalent electric consumption [g]	-	-483,48	-
Total consumption [g]	1793,64	1221,99	31.87%
Fuel consumption 6x MOL [g]	10817,4065	7249,80	32.98%

Not taking change of SOC into account

Total reduction over six runs of 'MOL' drive cycle

Concept Car Platform – Tubular vehicle frame

Manufactured by local supplier *Engie Fabricom*, Antwerp

Combined tubular/sheet metal structure, welded and bolted

Experimental modal analysis is planned

Assembly of subsystems: suspension, brakes, steering, powertrains including battery pack, seats

Control systems

Thank you
for your attention!