Advances in Vehicle Dynamics, Simulators, Safety and Controls

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COSYS-PICSL, Perceptions, Interactions, Behaviors & Simulations **Lab**

for road and street users

University Gustave Eiffel, France

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Short Bio

Imine received his Master Degree and his PhD in Robotics and Automation from Versailles University, France, respectively in 2000 and 2003. He received Accreditation to Supervise Research (Habilitation à Diriger des Recherches, HDR) on March 2012 from University of Valenciennes et du Hainaut Cambresis, France. In 2005, he joined IFSTTAR (Today University Gustave Eiffel), where he is currently Research Director. He is involved in different French and European projects. His research interests include Intelligent Transportation Systems, vehicle modeling and stability, diagnosis, nonlinear observation, nonlinear control. He published 2 books, over 80 technical papers, and several industrial technical reports.

Summary

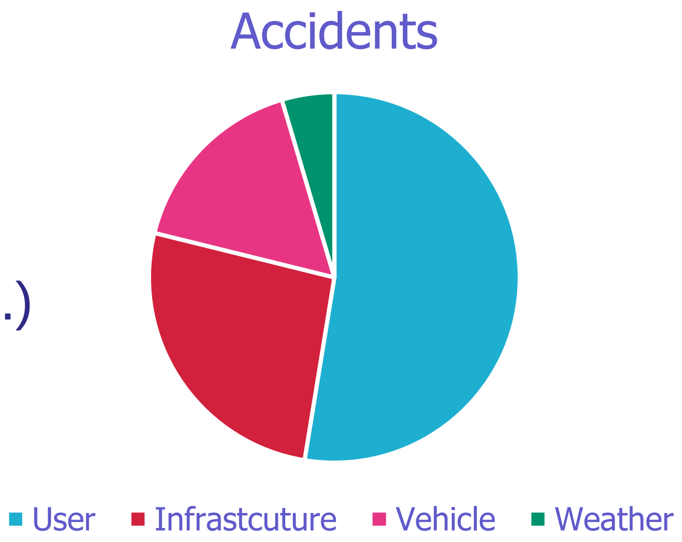
- *Introduction/Motivation*
- *Road characteristics*
- *Vehicle dynamics*
  - ✓ *States estimation*
  - ✓ *Impact forces identification*
- *Vehicle safety study*
  - ✓ *Rollover risk*
- *Experimental results*
- *Actual and future works*

Context

The road accident can be caused by several factors

Some data

– 92 % caused by driver (speed, presence of alcohol, fatigue ,..)
– 46% related to Infrastructure
– 29% related to Vehicle
– 8% related to divers causes (Weather, Warning,..)

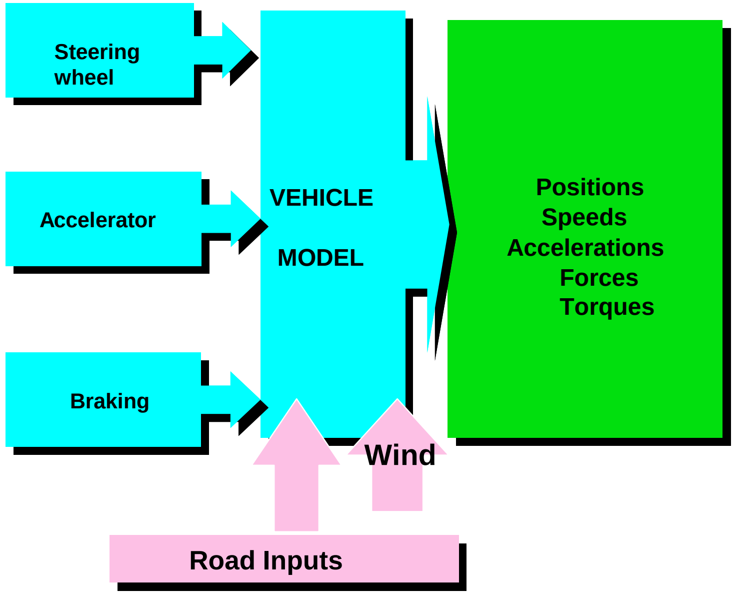


Different types of accidents:

- Lane departure (Transverse instability)
- Rollover (Roll instability)
- Jackknifing, implied especially in Heavy vehicle accidents (Yaw instability)

Road characteristics

Geometric and surface characteristics of the road have a direct effect on the forces generated in the tire contact footprint, under the action of applied commands.



Vehicle/Infrastructure interaction

- Road Profile ➔ Vertical deformation of the road
- Road adhesion ➔ Skid resistance is a friction to prevent a tire from sliding along the pavement surface
- Longitudinal and lateral slope
- Radius of curvature

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Road characteristics

The radius of curvature, the longitudinal and lateral slopes are measured using Véhicule d’Analyse d’Itinéraire (VANI*).

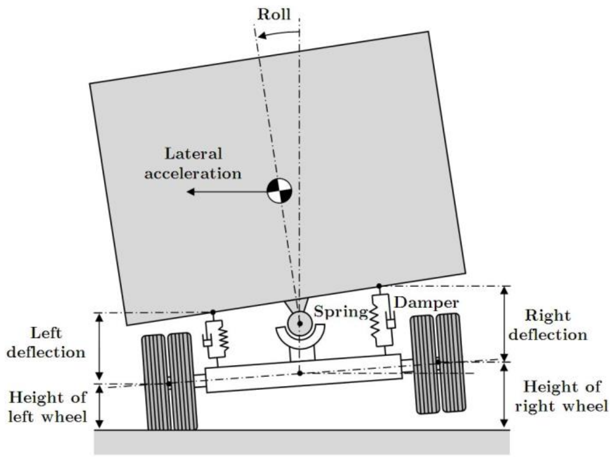
VANI was realized by the Regional Laboratory of Lyon, France.

It is equipped with different sensors : Gyrometers, GPS, laser sensors,...

** G. Gratia, “VANI (Véhicule d’Analyse d’Itinéraire): Un matériel multifonction pour les études de sécurité,” in Bull. Liaison Lab. Ponts Chaussées, Dec. 1994, no. Spécial 17, pp. 69–74.*

Road profile and Road adhesion in vehicle dynamics

– Road Profile ➔ can cause rollover and control loss of the vehicle



– Road adhesion ➔ sliding and control loss, lane departure of the vehicle

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Road profile

Road Profile

Road Construction

- ➢ **Qualify serviceability of road pavement**

Vehicle safety

- ➢ **inputs (vehicule wheels positions) for studying Vehicle-Road Interaction**

Several profiles ⇒ road surface

Road profile measure

Topographic survey
(Theodolite, Rule ...)

- Hard to implement
- measure only one dof

GM Profilometer
(Inertial reference)

- long wavelength not measured
- measure only one dof

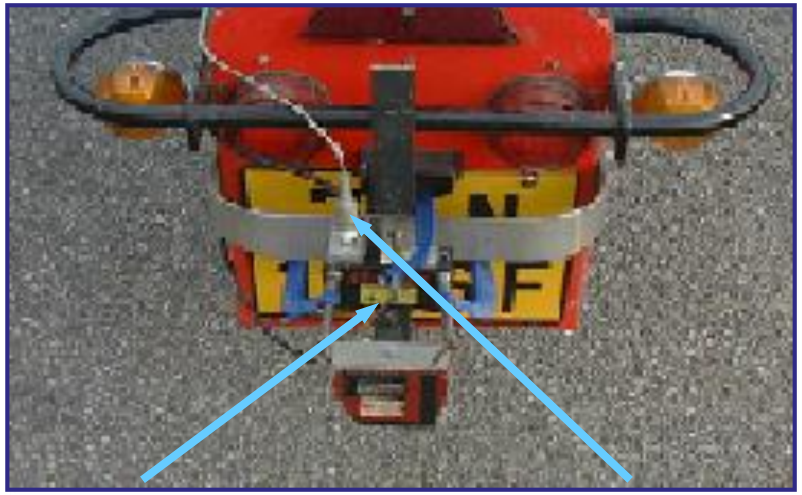
Contribution

Develop an easily implemented method

- Based on non lineare observers
- Take into account a vehicle dynamic

Reconstruction Methods

Measured by
Longitudinal Profile Analyser (APL*)



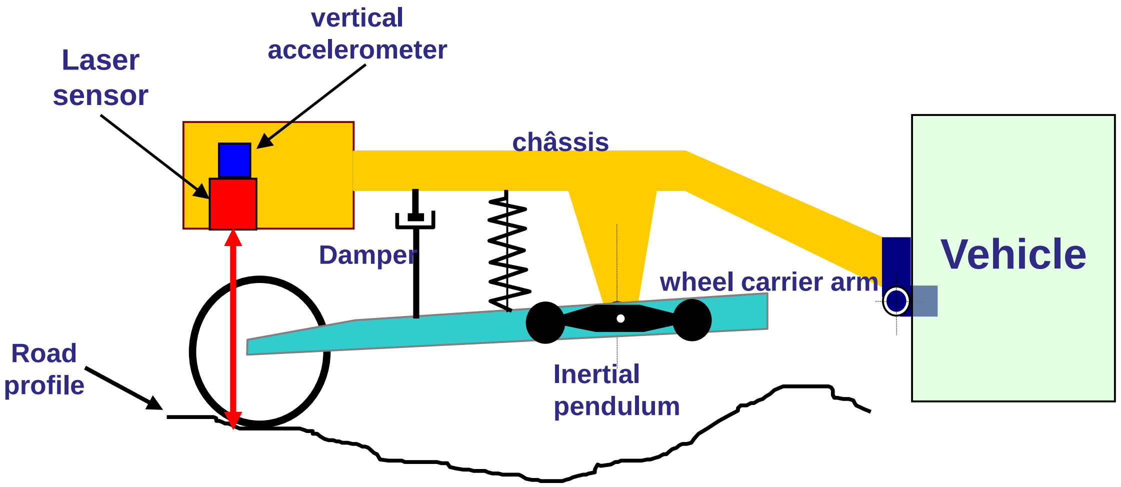
Laser

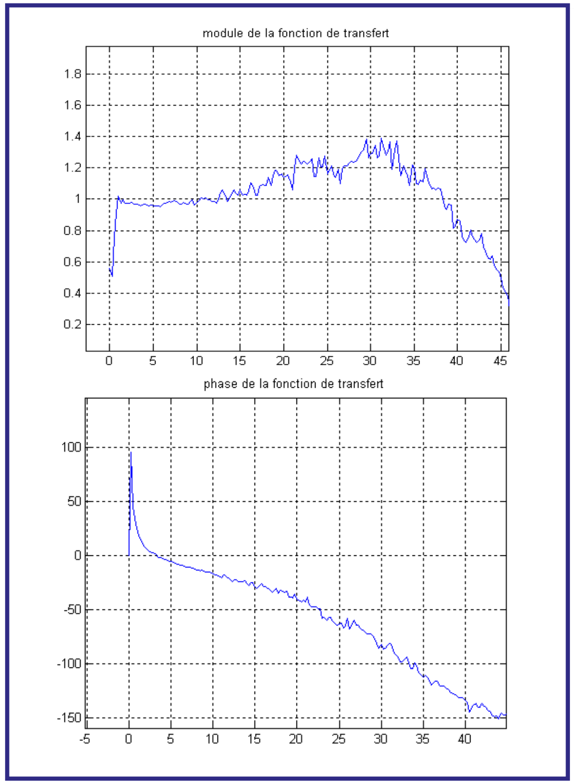
Accelerometer

Reconstruction by
Inertial Method (GMR)

H. Imine, Y. Delanne, and N. K. M'Sirdi, "Road profiles inputs estimation in vehicle dynamics simulation," Int. J. Veh. Syst. Dyn., vol. 44, no. 4, pp. 285-303, 2006.

APL measure





Transfert function

$$H(z) = K \frac{(1-z^{-1})^3(1+z^{-1})^2}{(1-p_0 z^{-1})(1-p_1 z^{-1})(1-p^*_1 z^{-1})(1-p_2 z^{-1})(1-p^*_2 z^{-1})}$$

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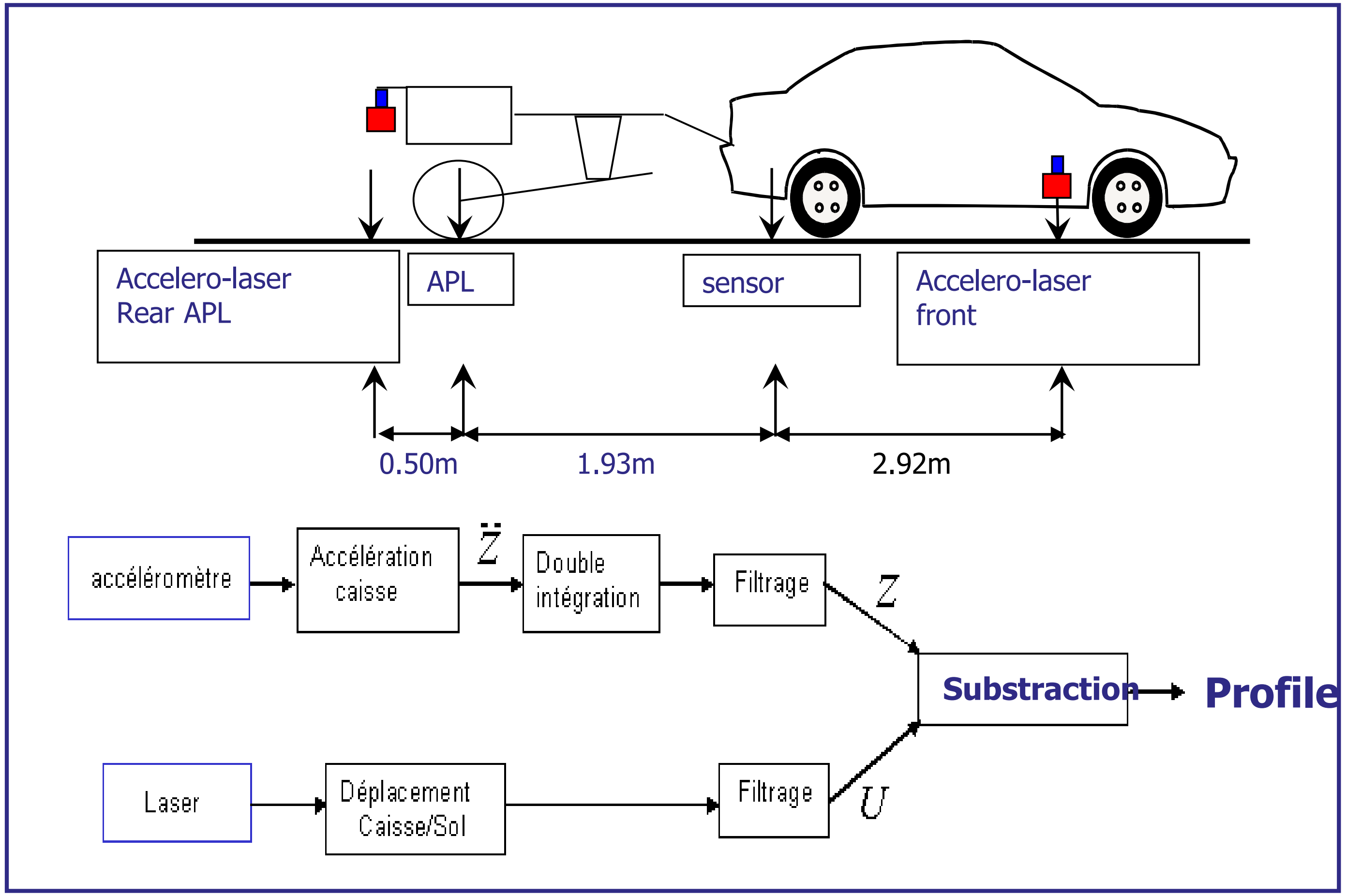
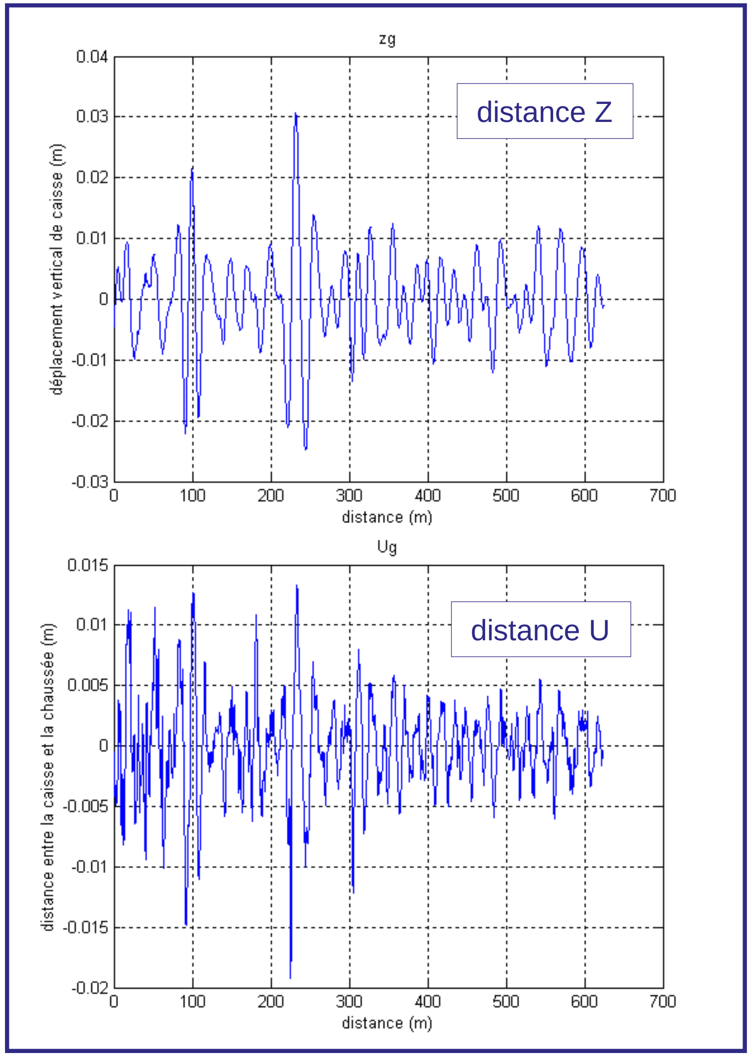
Inertial Method



Profile = Z – U



Profile : APL and inertial method

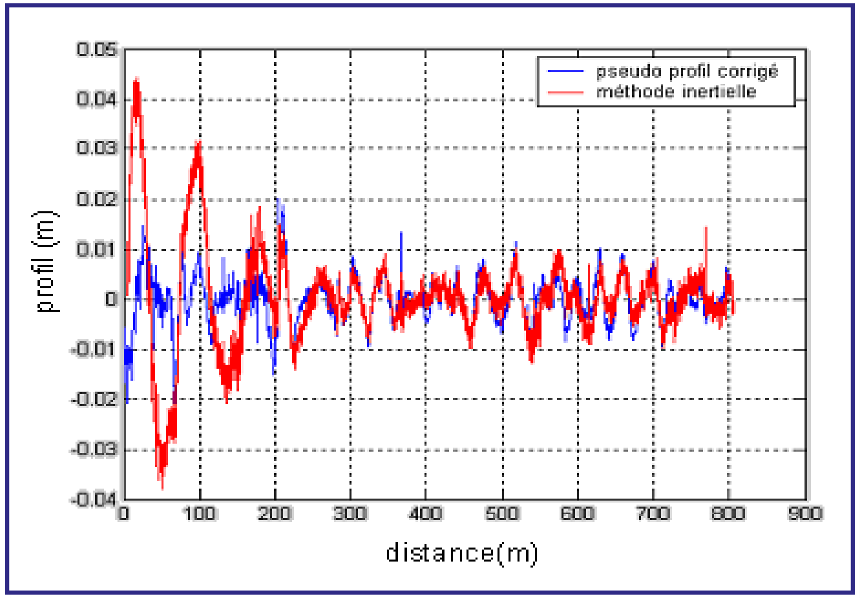


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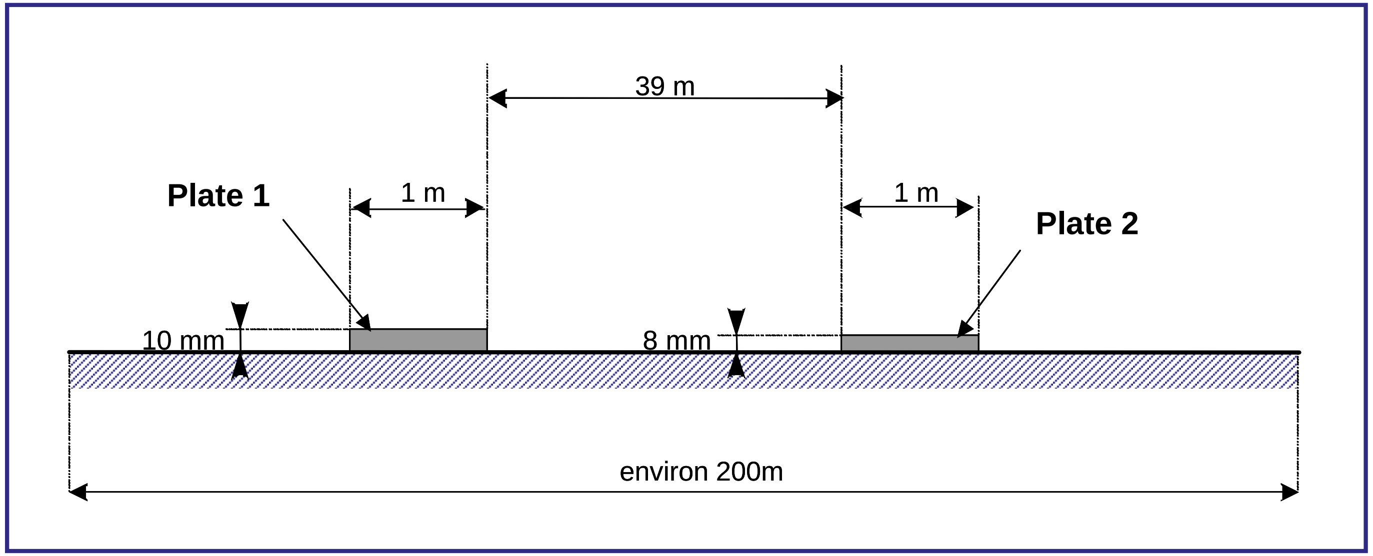
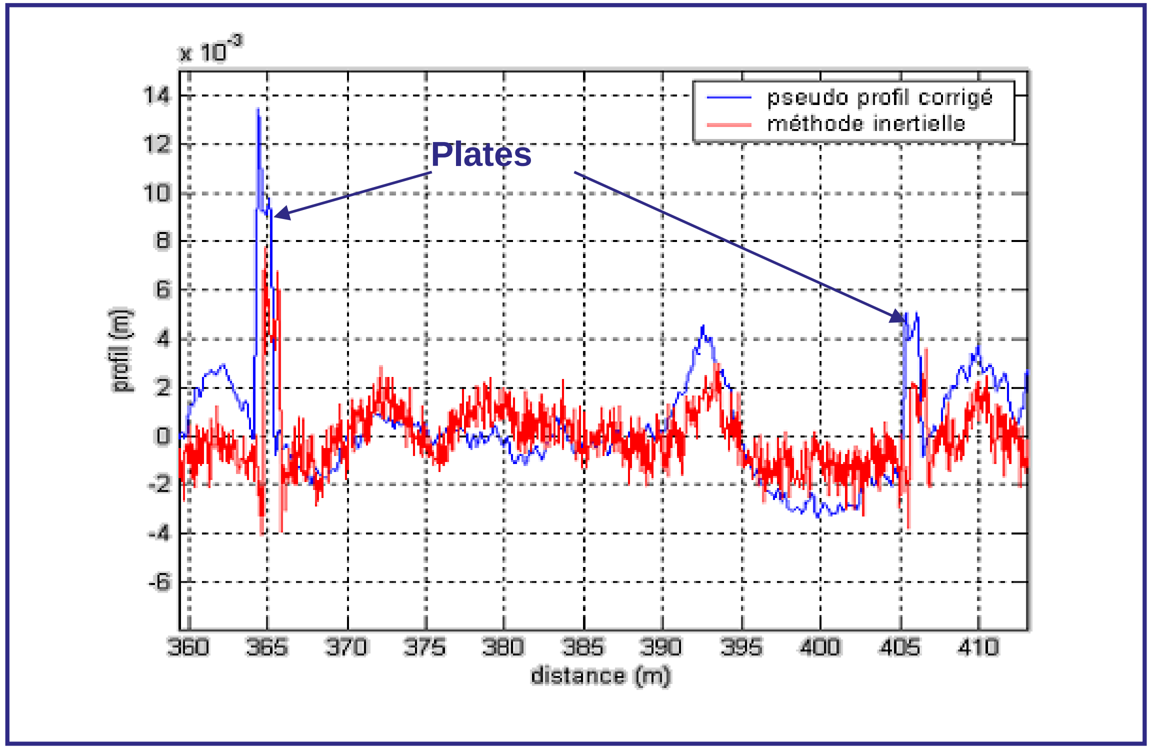
Plate on the track

Position of the plates on the track



Reconstruction of the two plates



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Road adhesion

The road adhesion depends on the characteristics of the tire (type, quality, wear, inflation pressure, temperature) and the condition of the road (wet, dry, ice ..)

$\mu \Rightarrow 0$ The road is icy

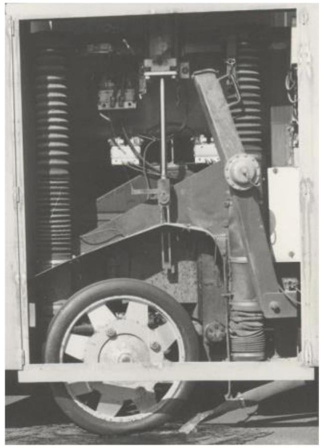
$\mu \Rightarrow 0.3$ The road is sliding

$\mu \Rightarrow 0.6$ The road is wet

$\mu \Rightarrow 1$ The adhesion is maximum and the tire / ground contact is considered excellent

Inadequate skid resistance will lead to higher risks of accidents

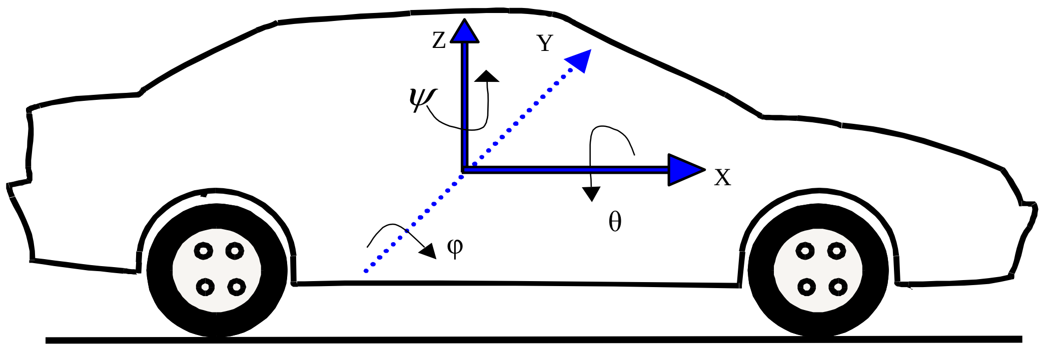
The transversal friction coefficient (CFT) of the road surface is measured by the Sideway Force Coefficient Routine Investigation Machine (SCRIM*)

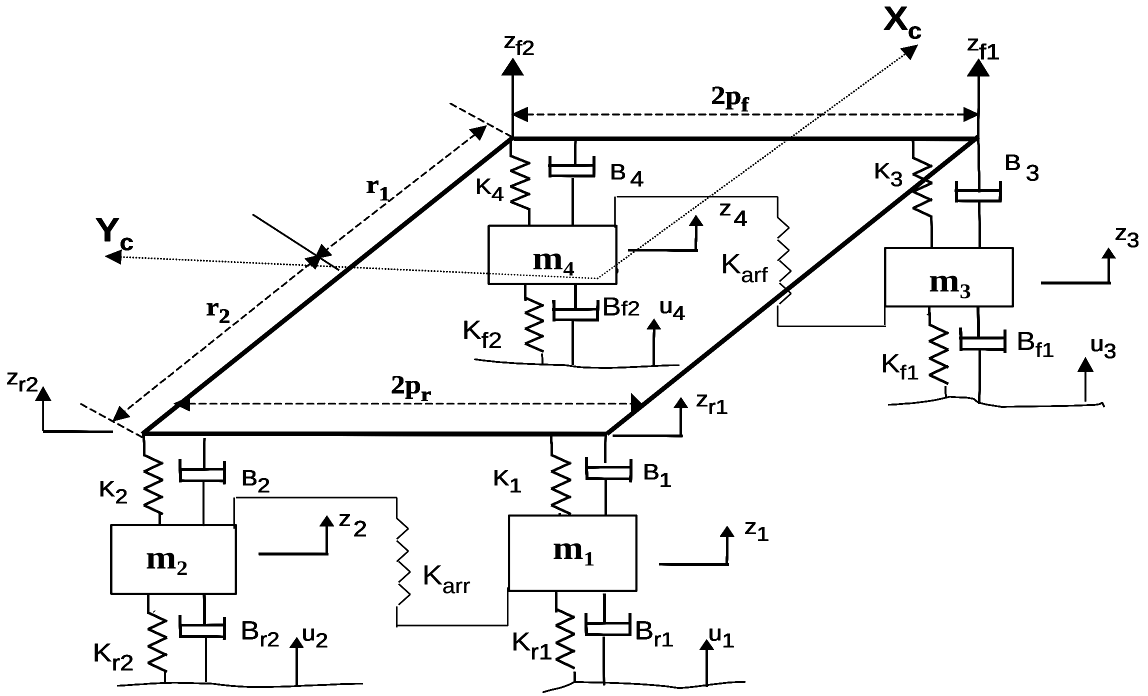


Continuous measurement of a CFT with:
- a step of 10 m
- a speed of 60 km/h

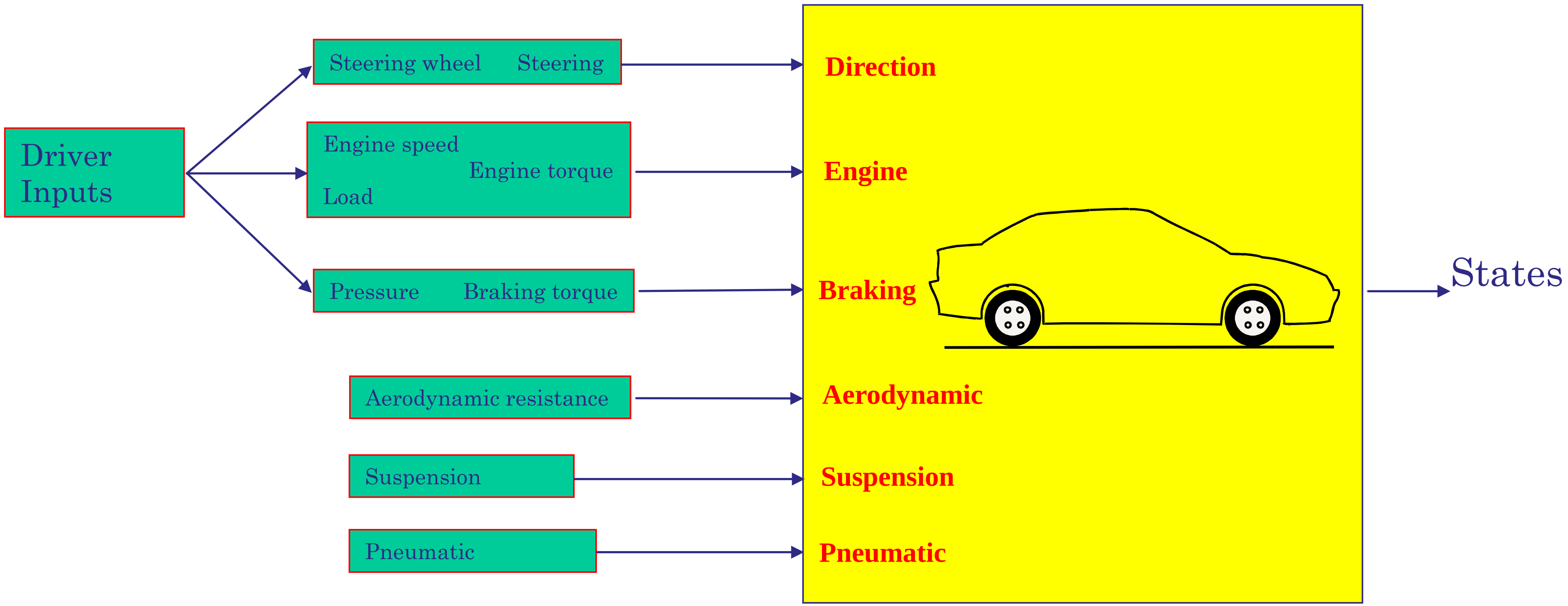
Certu - Instruction sur les conditions techniques d’aménagement des voies rapides urbaines (ICTAVRU), 1991.

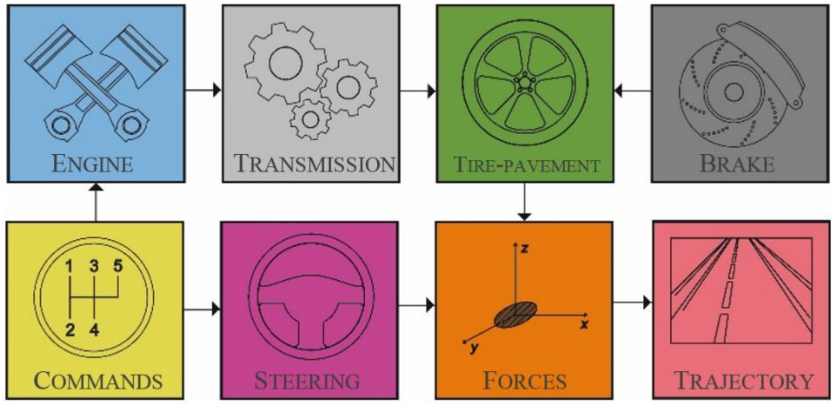
Vehicle modeling





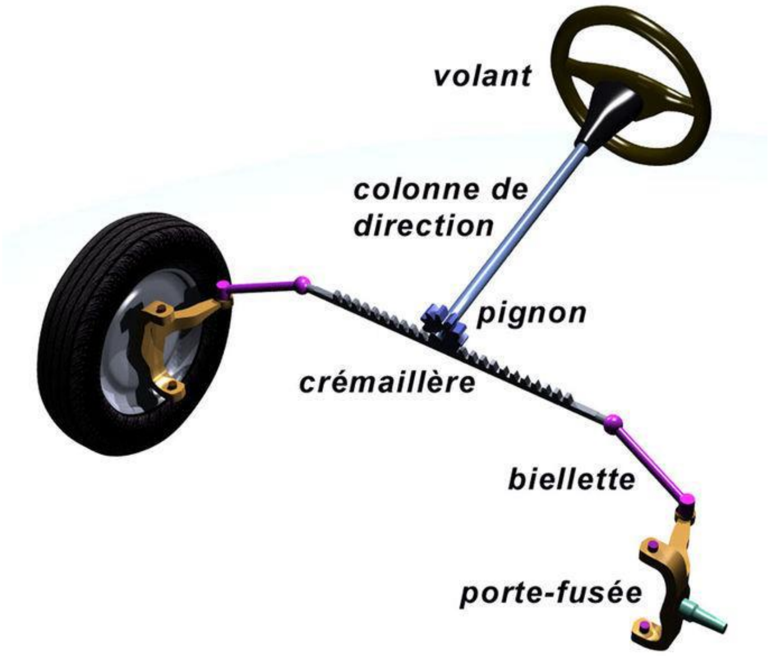
Vehicle model





Steering wheel

The angle at the steering wheel is usually measured



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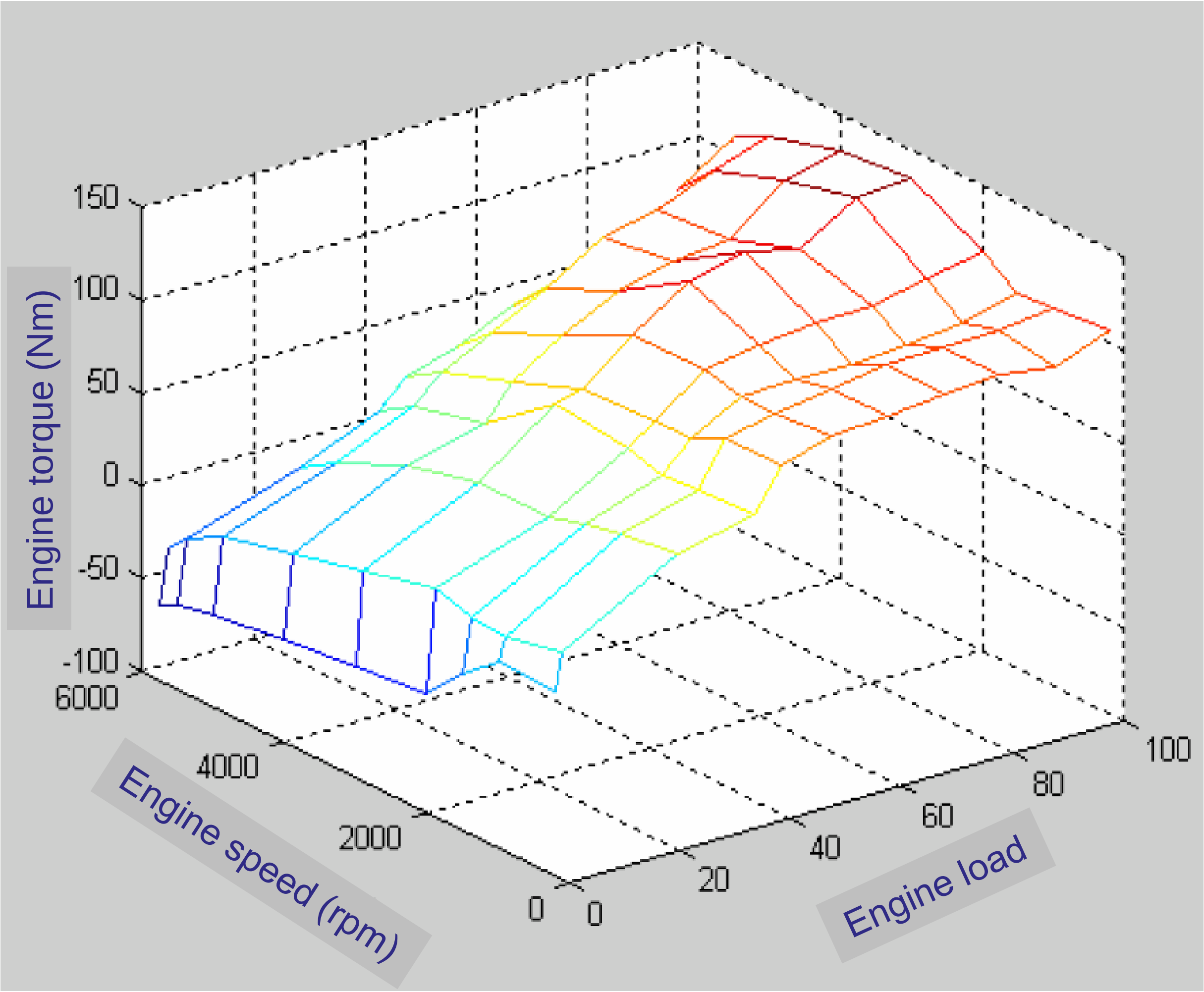
Engine torque

In order to obtain the engine torque, the engine field map is used.

Peugeot 406, type de moteur : Essence

Régime (tr/min)					Charge (%)						corr.	Servit.
	0.0	1.5	22.0	36.0	41.0	50.0	60.0	70.0	80.0	90.0	100.0		
200	0.0	2.00	5.50	6.40	8.60	9.40	9.60	9.80	10.00	9.50	10.70	1.05	0.0
1000	0.0	1.30	5.00	6.20	8.50	9.00	9.50	9.90	10.00	10.00	10.30	1.07	0.0
1500	-1.50	1.30	4.60	6.00	7.50	9.00	9.00	9.00	9.10	9.50	10.10	1.13	0.0
2000	-3.50	2.00	4.00	6.50	7.50	9.50	10.00	10.30	10.30	10.90	11.40	1.03	0.0
3000	-4.00	1.00	4.00	7.00	7.30	9.50	11.50	12.20	11.50	13.40	13.50	0.92	0.0
4000	-4.50	0.0	3.00	4.00	5.80	7.50	9.00	9.80	10.00	12.40	13.00	0.98	0.0
5000	-5.00	-1.00	1.20	3.00	4.50	5.70	7.20	9.20	9.70	11.00	12.00	1.04	0.0
5500	-5.50	-2.00	0.0	1.80	3.20	4.00	5.40	6.10	6.70	9.00	11.00	1.02	0.0
5750	-6.00	-3.00	-2.00	0.0	1.50	2.50	3.00	3.50	5.00	7.00	9.00	1.03	0.0
correc.	1.20	1.00	0.99	1.00	1.00	1.00	1.01	1.00	1.02	1.01	1.00	1.25	1.00

Engine Torque related to speed



150
100
50
0
-50
-100
6000
4000
2000
0
0
20
40
60
80
100
Engine torque (Nm)
Engine speed (rpm)
Engine load

Engine map

Braking torque

Use pressure measurements to calculate braking torques according to the table:

										Correc.
Pression (bar)	0.0	15.00	30.00	45.00	60.00	75.00	90.00	105.00	120.00	1.00
Couple train 1 gauche (m.daN)	0.0	50.00	100.00	150.00	200.00	250.00	300.00	350.00	400.00	0.57
Couple train 1 droite (m.daN)	0.0	50.00	100.00	150.00	200.00	250.00	300.00	350.00	400.00	0.65
Couple train 2 gauche (m.daN)	0.0	10.00	20.00	30.00	40.00	50.00	60.00	70.00	80.00	0.70
Couple train 2 droite (m.daN)	0.0	10.00	20.00	30.00	40.00	50.00	60.00	70.00	80.00	0.70

Braking torque related to pressure

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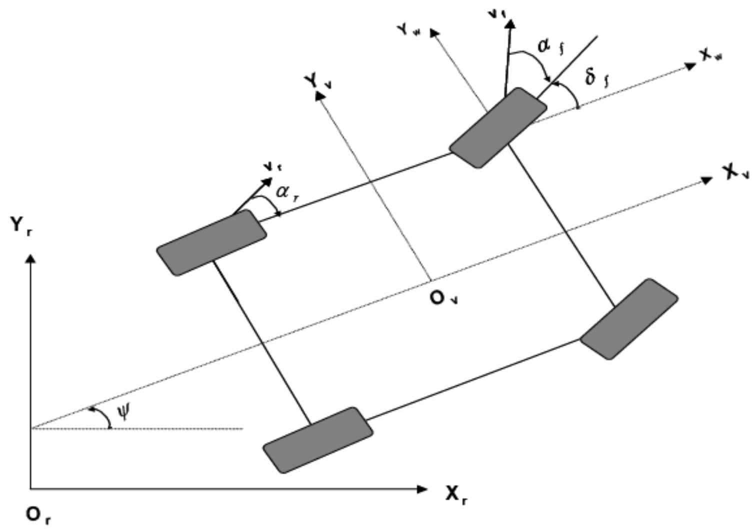
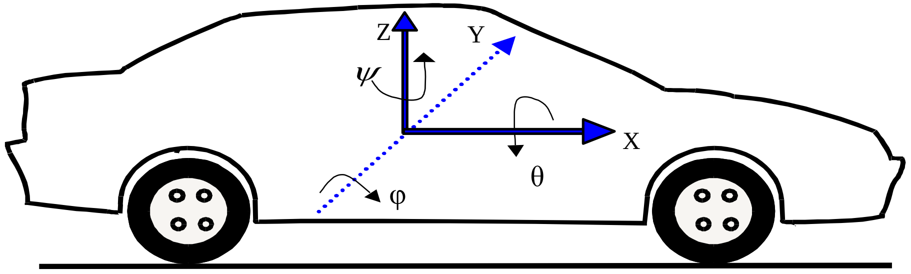
Dynamic chassis behavior

3 translation movements
- Longitudinal
- Transversal
- Vertical



3 rotational movements
- Roll
- Pitch
- Yaw



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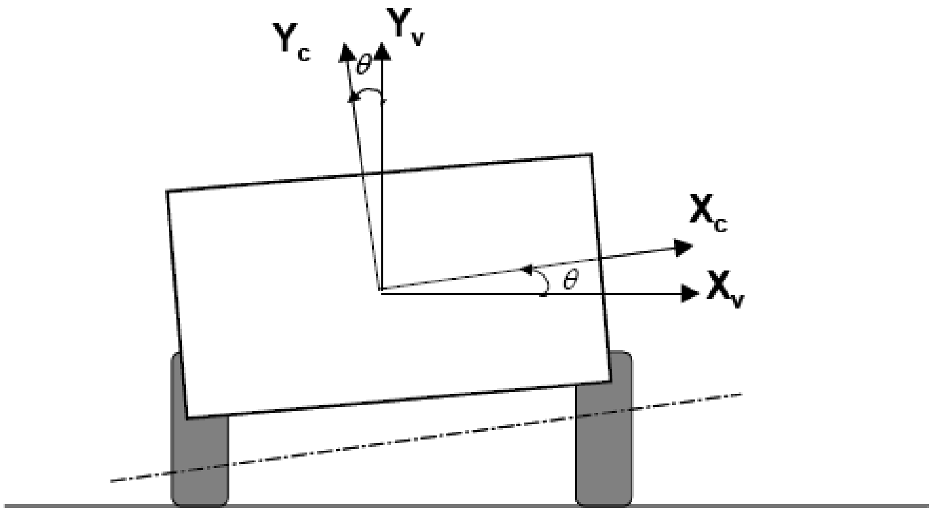
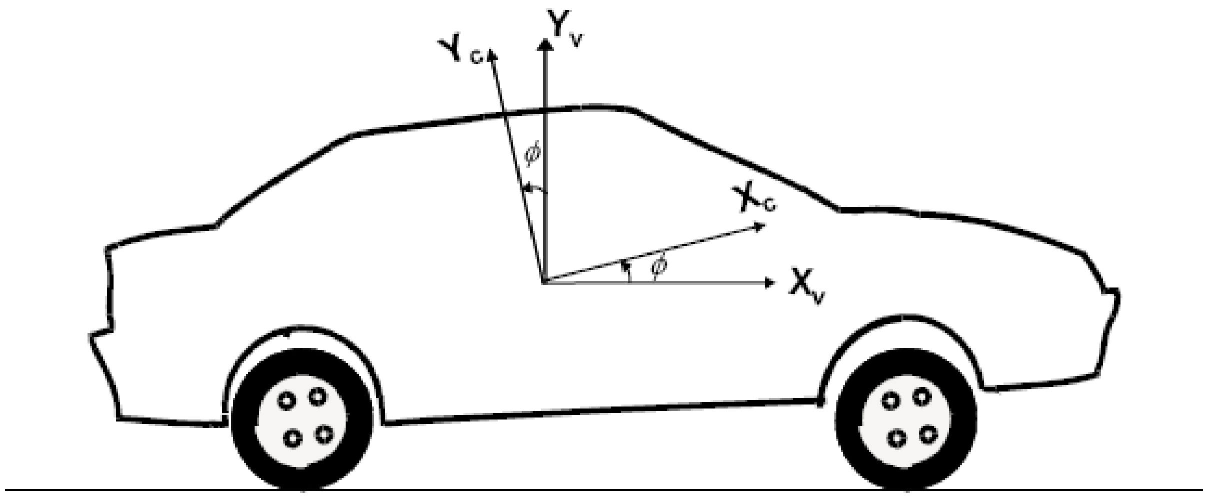
Roll



Pitch



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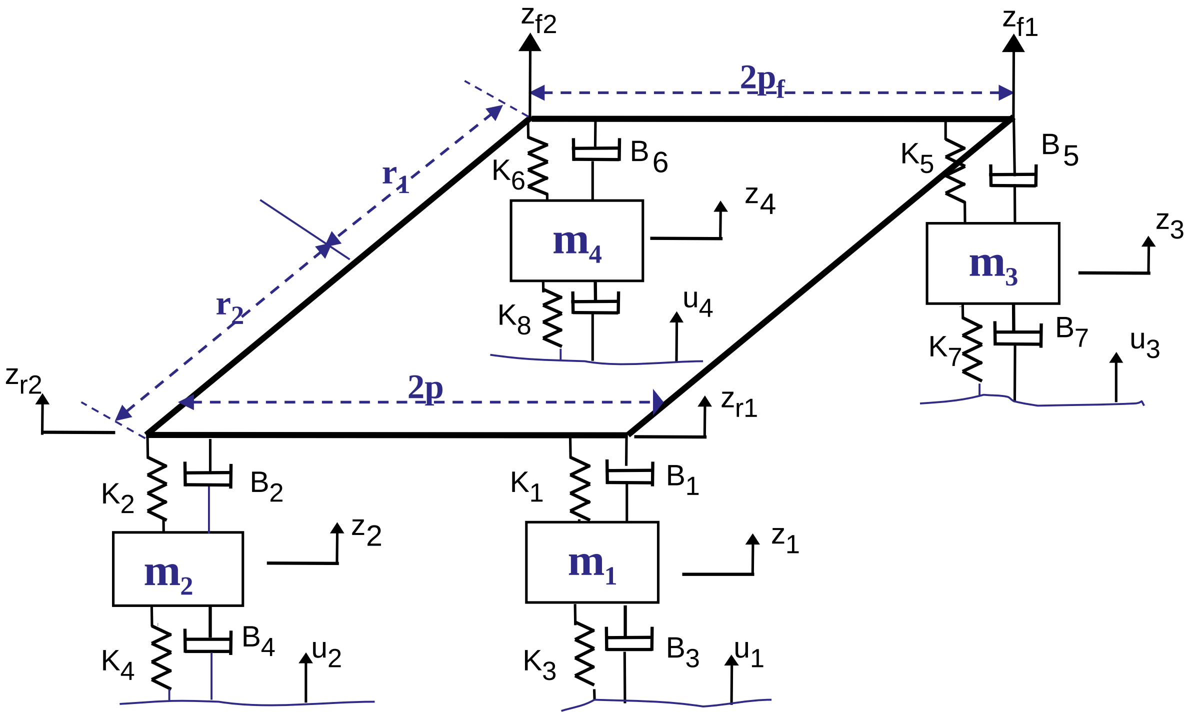
$$m\begin{bmatrix}\dot{v}_x\\ \dot{v}_y\\ \dot{v}_z\end{bmatrix}=T_r\begin{bmatrix}F_{xf1}+F_{xf2}+F_{xr1}+F_{xr2}\\ F_{yf1}+F_{yf2}+F_{yr1}+F_{yr2}\\ F_{zf1}+F_{zf2}+F_{zr1}+F_{zr2}\end{bmatrix}$$

$$\mathrm{T}_r=\begin{bmatrix}\cos\theta\cos\psi & \sin\theta\sin\phi\cos\psi & \cos\theta\sin\phi\cos\psi+\sin\theta\sin\phi\\ \cos\phi\cos\psi & \sin\theta\sin\phi\sin\psi+\cos\theta\cos\psi & \cos\theta\sin\theta\sin\phi-\sin\theta\cos\psi\\ -\sin\psi & \sin\theta\cos\phi & \cos\theta\cos\phi\end{bmatrix}$$

$$\mathrm{J}\begin{bmatrix}\ddot{\theta}\\ \ddot{\phi}\\ \ddot{\psi}\end{bmatrix}=\begin{bmatrix}(F_{zf1}-F_{zf2})p_f+(F_{zr1}-F_{zr2})p_r\\ -(F_{zf1}+F_{zf2})r_1+(F_{zr1}+F_{zr2})r_2\\ [(F_{yf1}+F_{yf2})r_1-(F_{yr1}+F_{yr2})r_2+\\ (F_{xf2}-F_{xf1})p_f+(F_{xr2}-F_{xr1})p_r]\end{bmatrix}_{\Re c}$$

Suspension modeling



$$\ddot{z}_i = \frac{1}{m_i}\left(-F_{kri} - F_{cri} + k_{ri}(u_i - z_i) + B_{ri}(\dot{u}_i - \dot{z}_i)\right)$$

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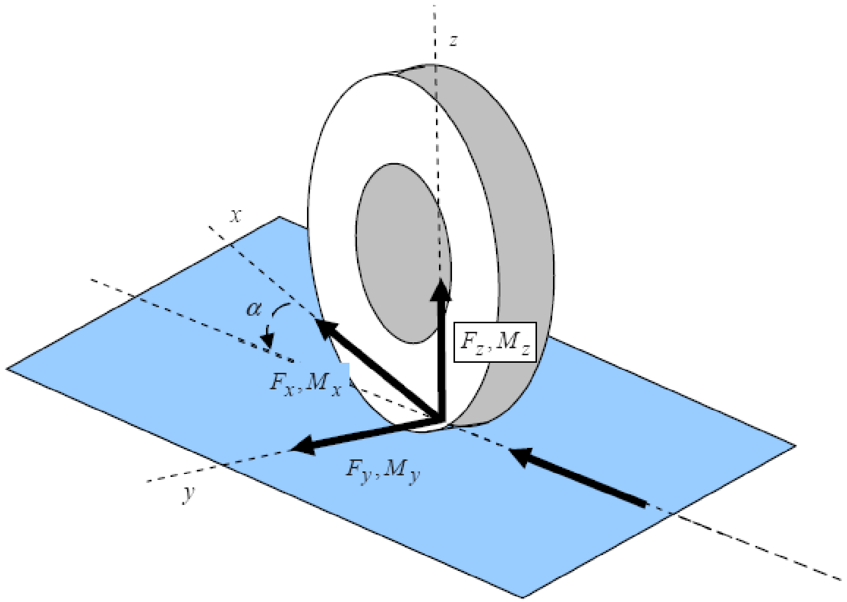
Dynamic behavior of the tire

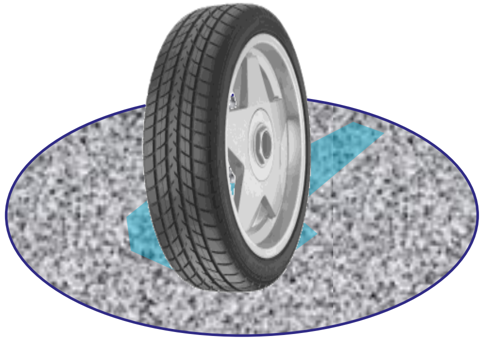
The resulting force and torque under each wheel depends on:

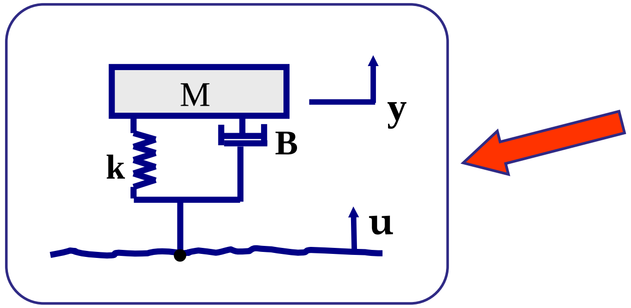
- the mechanical properties of the tires,
- surface texture (microtexture and pavement macrotexture),
- local deformations of the megatexture domain,
- the operating conditions.



Fx : longitudinal force
Fy : transverse force
Fz : normal force (vertical)

Wheel road vertical modeling





$$\begin{cases} F_{zri} = k_{ri}(z_{ri} - u_i) + B_{ri}(\dot{z}_{ri} - \dot{u}_i) \;\; ; \quad i = 1,2 \\ F_{zfi} = k_{fi}(z_{fi} - u_j) + B_{fi}(\dot{z}_{fi} - \dot{u}_j) \;; \quad \mathrm{j} = 3,4 \end{cases}$$

Longitudinal modeling

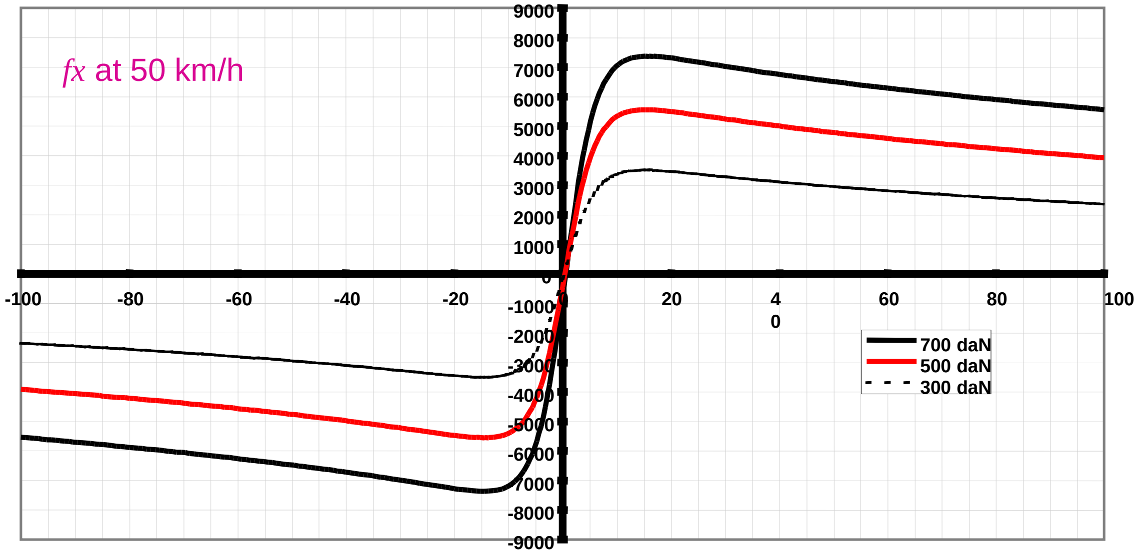
$$f_{xi} = \mu \; f_{ni} \; , \mathrm{i} = 1..4$$

f_{xi} Longitudinal force

f_{ni} Normal force

μ Road adhesion coefficient

Longitudinal Force in function of f_n at given Velocity



In the acceleration or braking phases, a driving or braking torque is applied to the tire ➔ a longitudinal force is generated at the contact surface.

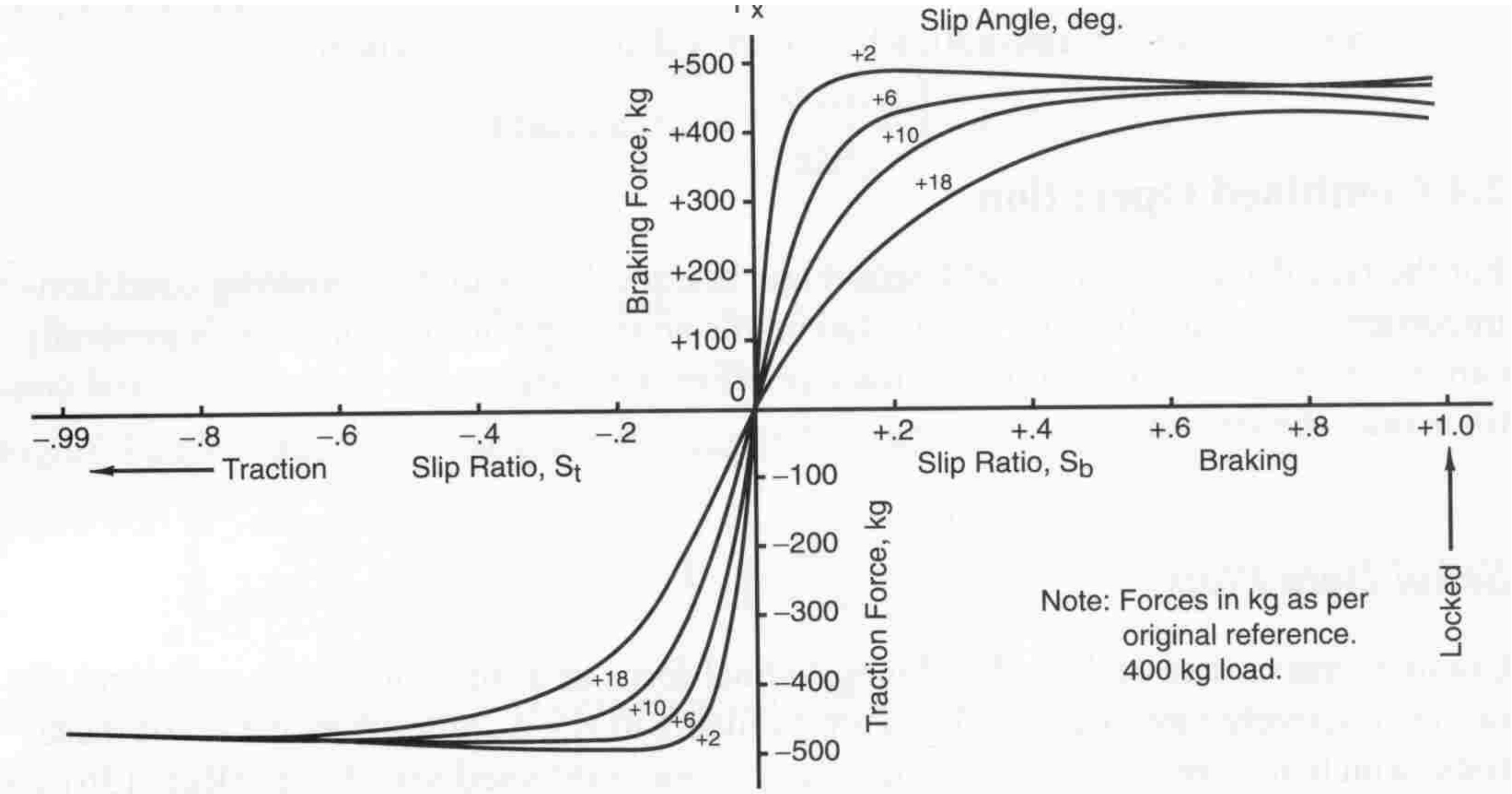
The relative speed of the tire with respect to the ground defines a longitudinal slip.

$$\lambda = 100 \times \left| \frac{v_x - rw}{\max(v_x, rw)} \right|$$

$$\begin{cases} \lambda = \dfrac{rw}{v_x} - 1 \text{ si } v_x > rw \Rightarrow \text{braking} \\ \lambda = 1 - \dfrac{rw}{v_x} \text{ si } v_x < rw \Rightarrow \text{acceleration} \end{cases}$$

v_x : Vehicle speed

rw : Wheel speed



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Lateral modelling

$$\text{Pseudo sliding} \Rightarrow \begin{cases} F_{yf} = C_y \alpha_f \\ F_{yr} = C_y \alpha_r \end{cases}$$

$\mathrm{F_y}$: Lateral force

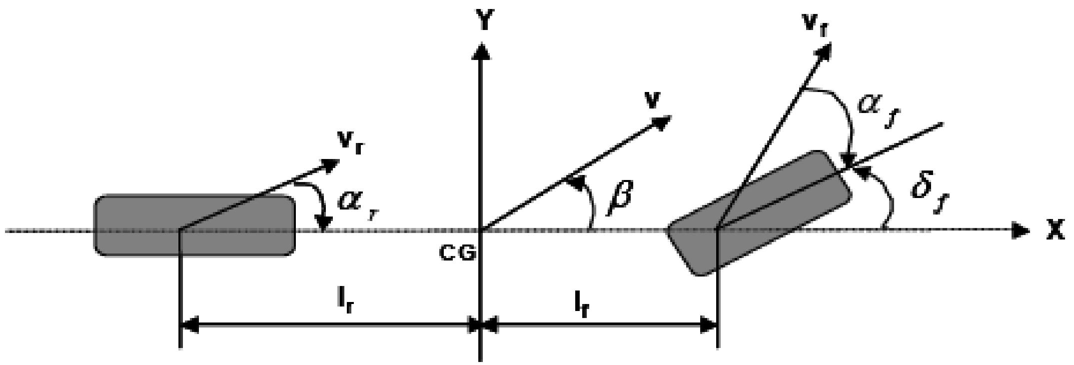
$\alpha_{f,r}$: *Slip* angle

C_y : *Stiffeness coefficient*

δ_f : *Side slip* angle

$\dot{\psi}$: Yaw speed

$$\begin{cases} \alpha_f = \delta_f - \beta - \dot{\psi} r_1 / v \\ \alpha_r = -\beta - \dot{\psi} r_2 / v \end{cases}$$



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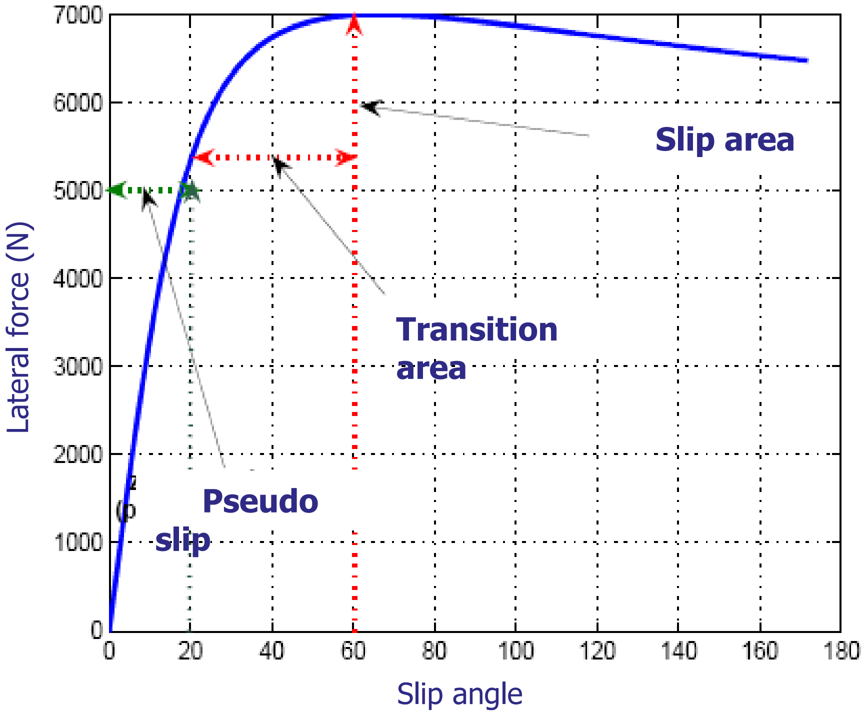
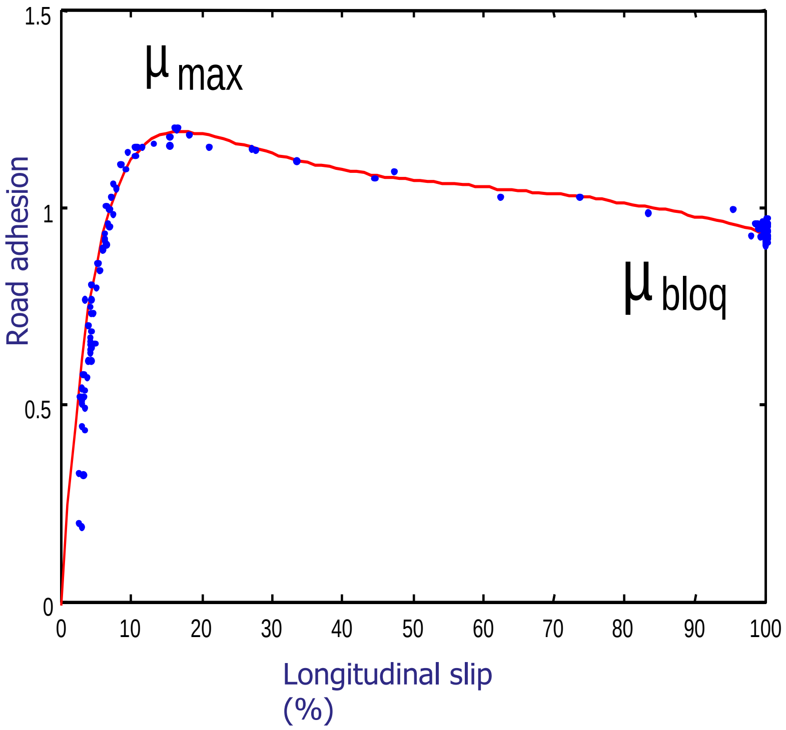




In the case of small slip angles (pseudo slip area) :

$$\mu = C_1(1 - e^{-C_2\lambda}) - C_3\lambda \qquad \text{(Burckhardt Model*)}$$

M. Burckhardt. Fahrwerktechnik, radschlupfregelsysteme. Vogel Verlag, Germany, 1993.

In case of higher slip angles, the behavior of the tire is often described by empirical formula proposed by Bakker and Pacejka*:

$$Y(X) = y(x) + S_v$$

$$y(x) = D\sin(C\arctan(Bx - E(Bx - \arctan(Bx))))$$
$$x = X + S_h$$

Y and X ➔ longitudinal force and longitudinal slip
Or lateral force and slip angle

Other models of:

- Kiencke and Daiss
- Lugre
- Dugoff
- Guo
- Brosse and Gim

** H. Pacejka & E. Bakker. The magic Formula Tyre Model. In Proceedings, Ist International Colloq on Tyre models for vehicle dynamics analysis, pp. 1-18, 1991.*

Wheel's rotational movement

$$J\dot{w} = \tau - rF_x$$

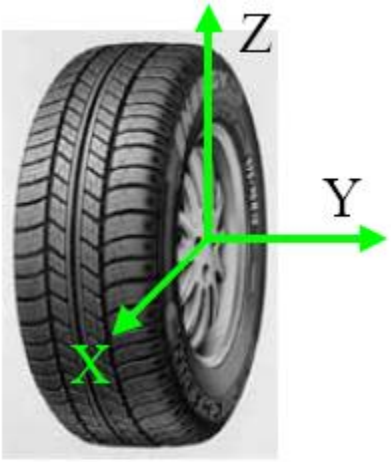
$w:$ *Speed of wheel*

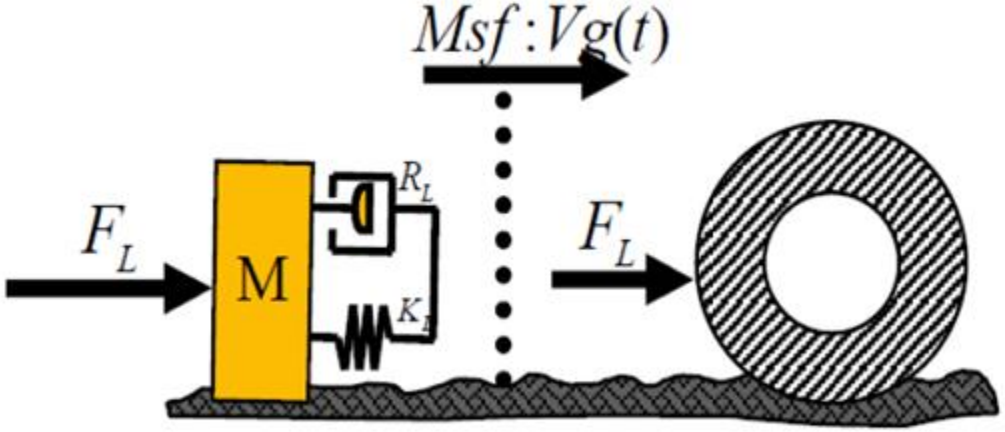
$\tau:$ *Engine torque*

$F_x:$ *Longitudinal force*

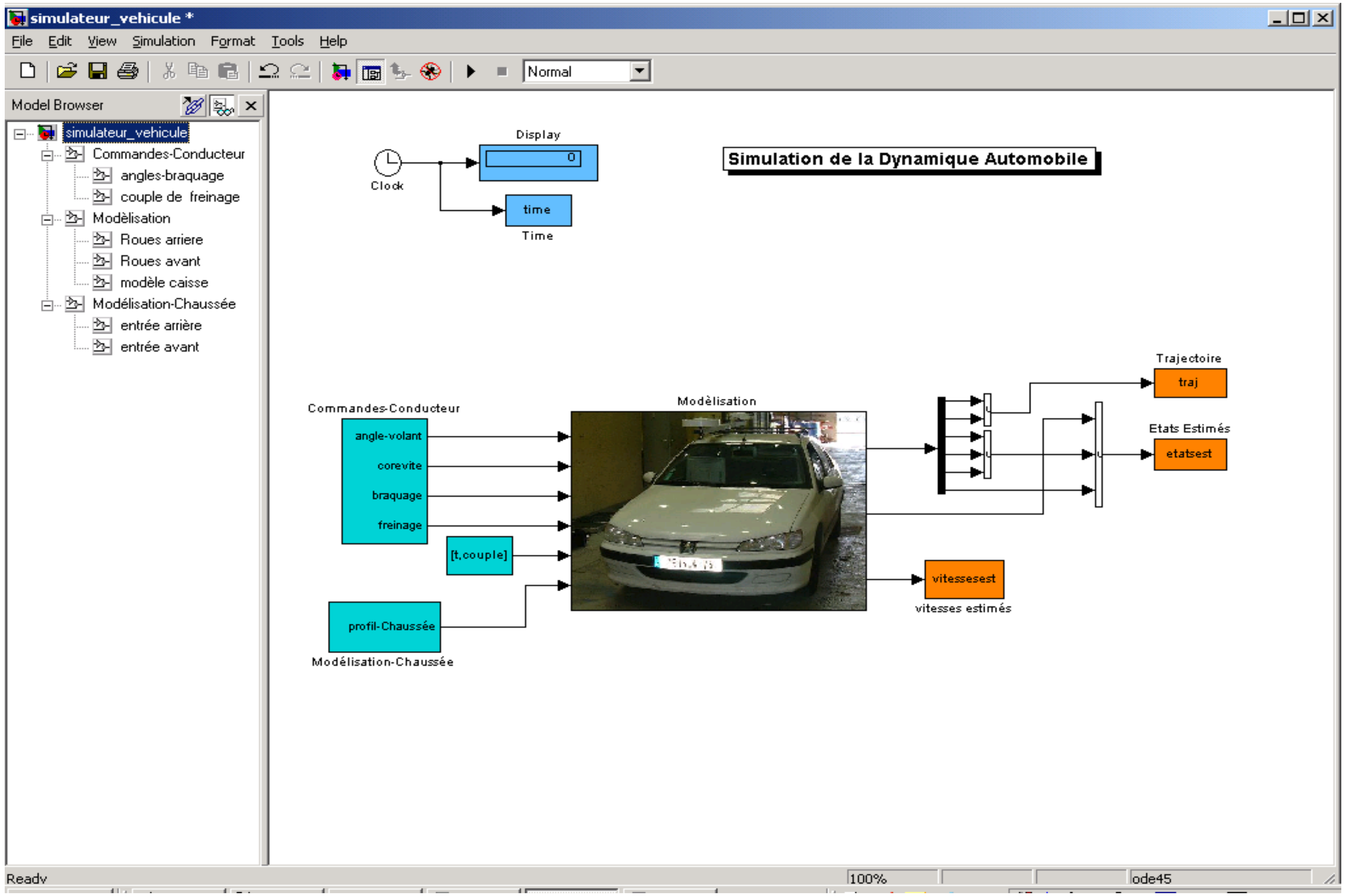
$r:$ *Radius of wheel*

$J:$ *Inertia of wheel*





Model simulation



Experimentation

The vehicle is equipped with 39 sensors at a spatial frequency of 5 cm, in order to validate the developed models

Control sensors

- Steering wheel control
- Brake control (brake pressure)
- Throttle control (throttle opening)
- Gearbox control
- Handbrake control
- Clutch control

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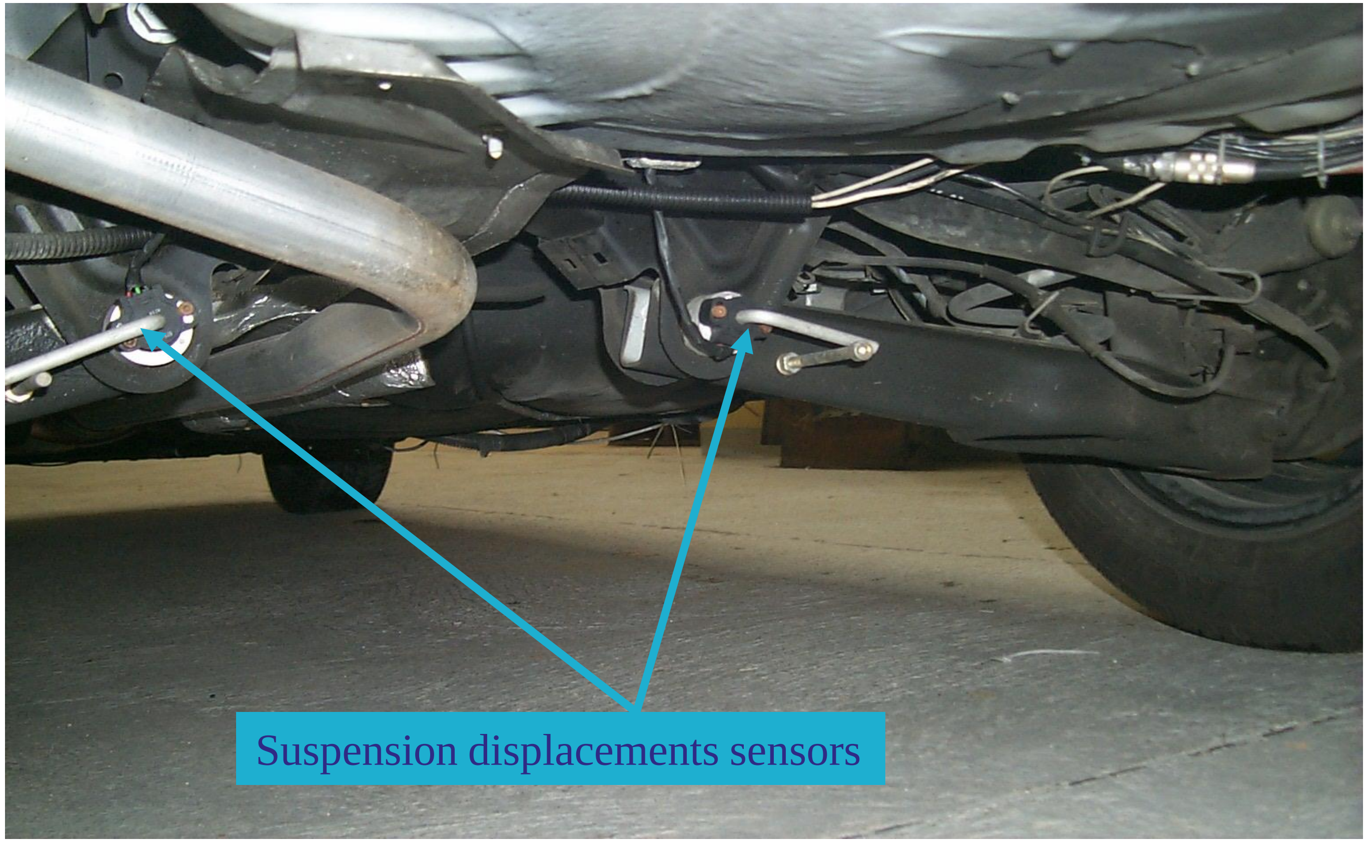
Acceleration sensor

Vehicle Behavior Sensors

- Vertical, transverse and longitudinal accelerometers
- Vertical wheels accelerometers
- Vertical, transverse and longitudinal gyrometers (roll, pitch and yaw)
- Suspension displacements sensors


Accelerometers and gyrometers box



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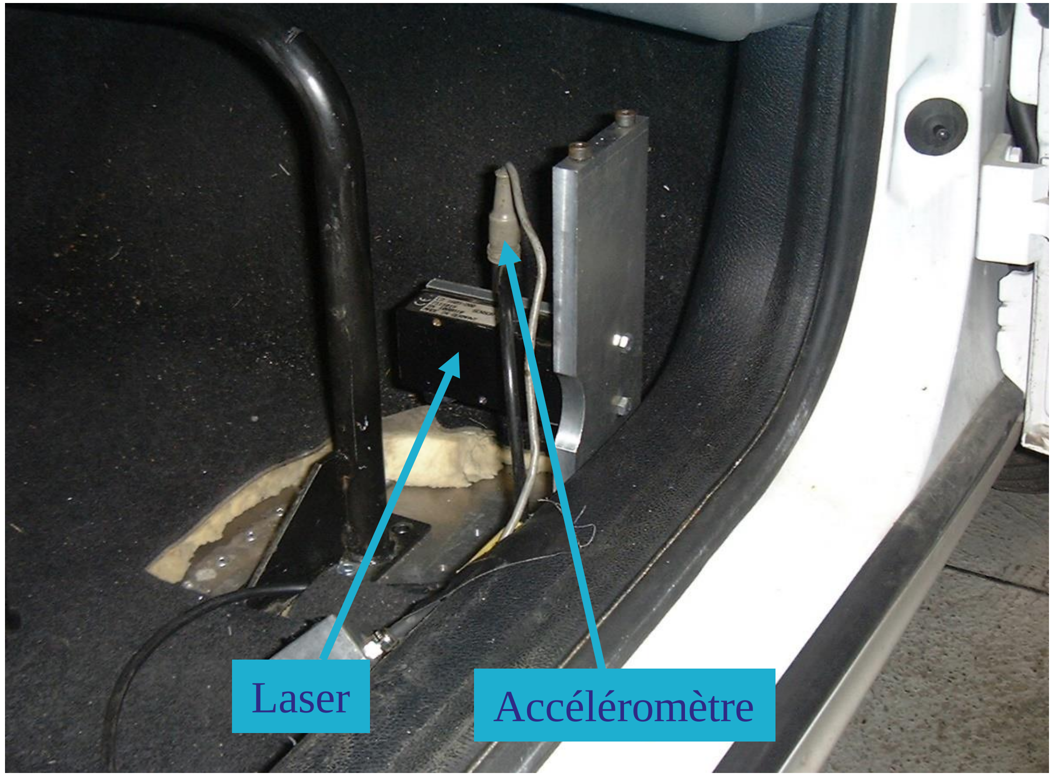
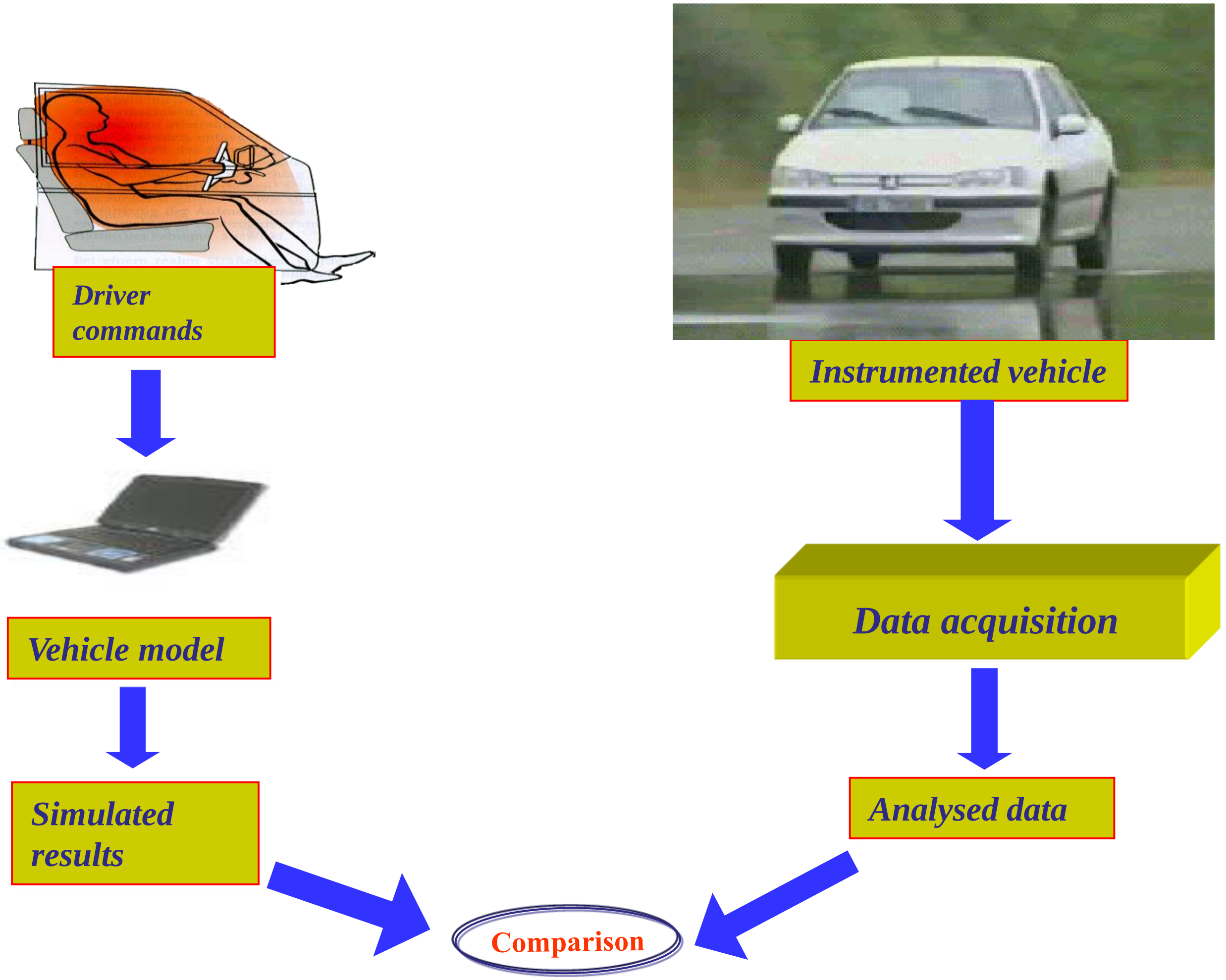

Laser
Accéléromètre


Inertial central

GPS

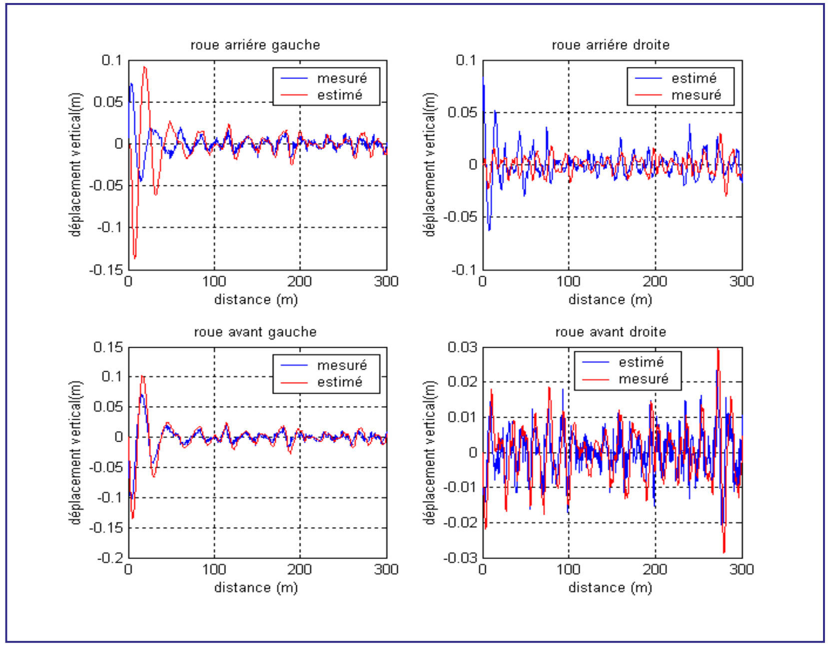
Validation



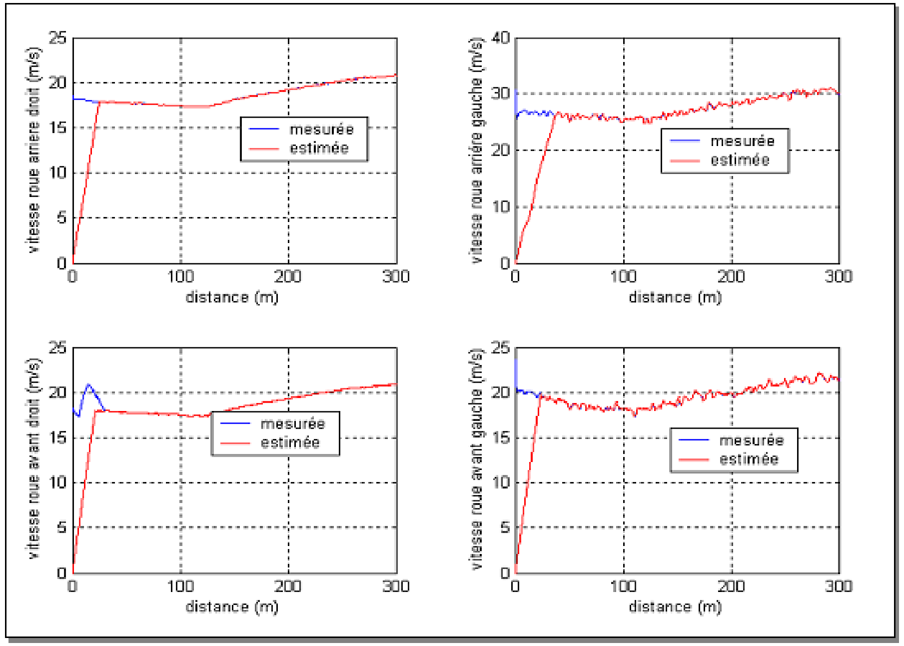
Driver commands
Instrumented vehicle
Vehicle model
Data acquisition
Simulated results
Analysed data
Comparison

Validation results

Vertical displacements of wheels



Wheels speeds



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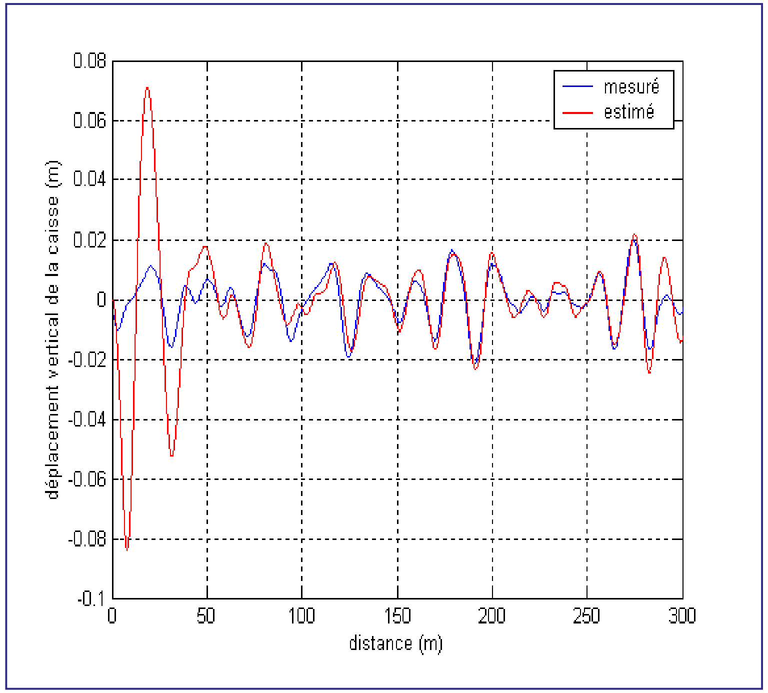
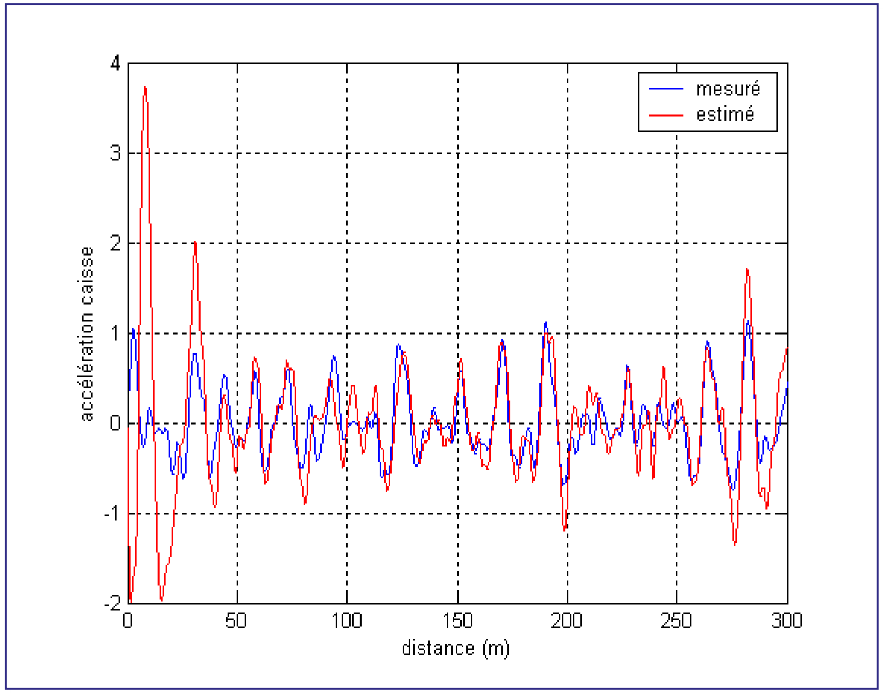
Vertical displacements of chassis



Vertical acceleration of chassis



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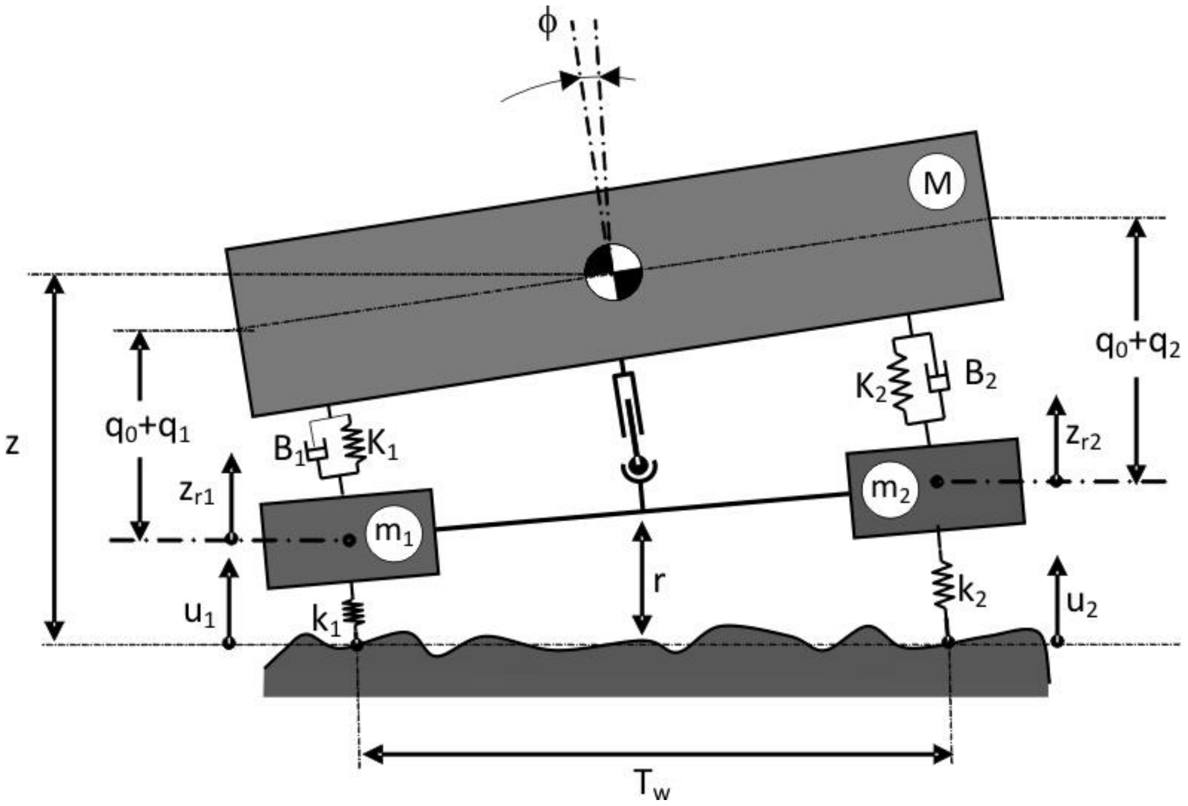
Impact forces identification

➔ Estimate on-board the tyre forces for monitoring the behavior of the vehicle and to control the load.



→ Developing a precise and low-cost system for on-board evaluation of vertical forces

Main objectives

- **Improving the road safety (rollover avoidance).**

- **Protecting infrastructure by stabilizing the variations of vertical forces.**

State of the art

The mainly existing works consist of

1) Estimating the forces through the observation of dynamic variables of the vehicle (centre height of gravity).

➔ This method involves knowing accurately the parameters of the vehicle and the pneumatic and also the road profile.

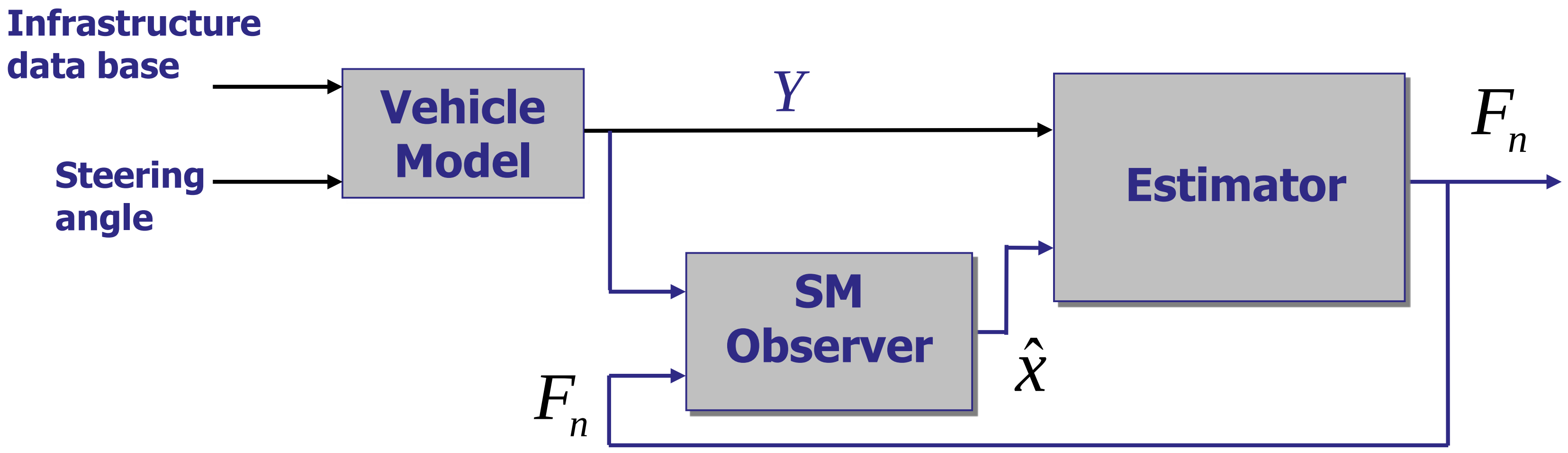
2) Estimating the forces by use of strain gauges in a hub

➔ A precise but expensive solution and it is limited to straight constant speed maneuvers and doesn’t suite to cornering maneuvers with large lateral forces.

3) Measuring by use of dynamo wheel sensor

➔ A precise method but very expansive and not practical

Methodology



System (S) →

$$\begin{cases} \dot{x}_1 = x_2 \\ \dot{x}_2 = M^{-1}(F_g - C(x_1, x_2)x_2 - K(x_1)) \\ y = x_1 \end{cases}$$

$$y = q = [q_1, q_2, q_3, q_4, \theta]$$

y is the measured outputs (suspensions deflections, roll angle)

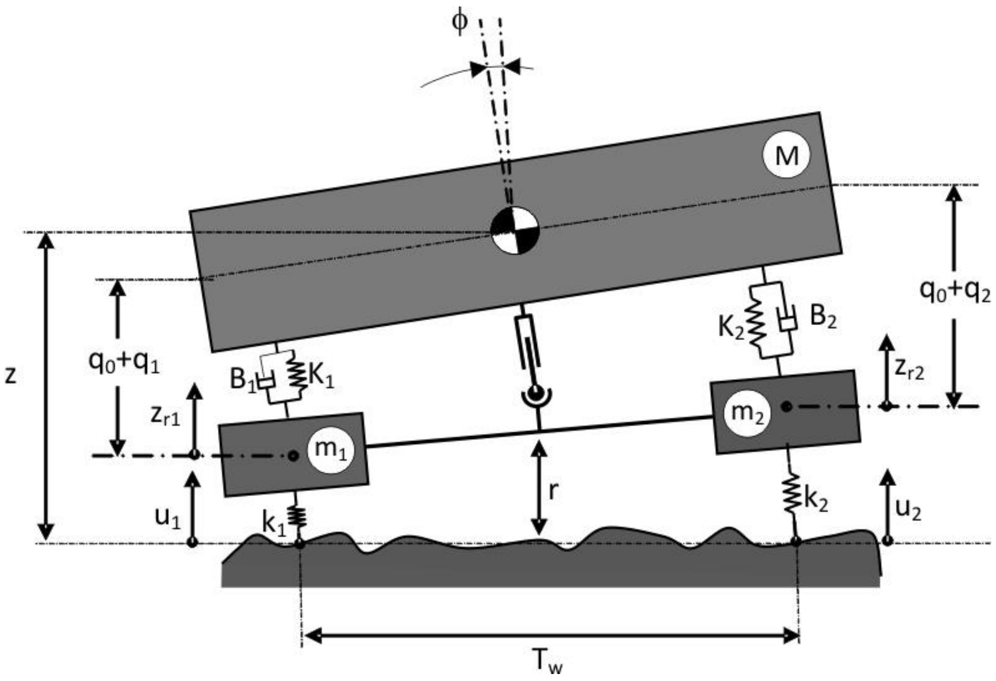
Vertical displacements wheels →

$$\begin{cases} z_{r1} = z - q_1 + \frac{T}{2}\sin(\theta) - r \\ z_{r2} = z - q_2 - \frac{T}{2}\sin(\theta) - r \end{cases}$$

$$z_{ri} = f(q, \dot{q}, \ddot{z}_{ri}), i = 1..4$$

Vertical forces →

$$F_{ni} = F_{ci} + k_i(u_i - z_{ri}), \mathrm{i} = 1..4$$



$$
\begin{cases}
\ddot{z}_{r1} = (B_1\dot{q}_1 + K_1\frac{T_w}{2}\sin(\phi) + B_1\frac{T_w}{2}\cos(\phi)\dot{\phi} \\
\qquad +K_1q_1 - k_1z_{r1} + k_1u_1)/m_1 \\
\\
\ddot{z}_{r2} = (B_2\dot{q}_2 - K_2\frac{T_w}{2}\sin(\phi) - B_2\frac{T_w}{2}\cos(\phi)\dot{\phi} \\
\qquad +K_2q_2 - k_2z_{r2} + k_2u_2)/m_2
\end{cases}
$$

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Second order sliding mode observer

Observer ➡

$$\begin{cases} \dot{\hat{x}}_1 = \hat{x}_2 + Z_1 \\ \dot{\hat{x}}_2 = f(\hat{x}_1, \hat{x}_2, u) + Z_2 \end{cases}$$

$$\begin{cases} Z_1 = \lambda \left| \tilde{x}_1 \right|^{1/2} sign(x_1 - \hat{x}_1) \\ Z_2 = \alpha sign(\tilde{x}_1) \end{cases} \qquad \begin{cases} \tilde{x}_1 = x_1 - \hat{x}_1 \\ \tilde{x}_2 = x_2 - \hat{x}_2 \end{cases}$$

Dynamic states errors:

$$\begin{cases} \dot{\tilde{x}}_1 = \tilde{x}_2 - Z_1 \\ \dot{\tilde{x}}_2 = F(x_1, x_2, \hat{x}_2) - Z_2 \end{cases}$$

$$F(x_1, x_2, \hat{x}_2) = f(x_1, x_2, u) - f(\hat{x}_1, \hat{x}_2, u)$$

Convergence analysis

$$\left|F(x_1, x_2, \hat{x}_2)\right| = \left|f(x_1, x_2, u) - f(\hat{x}_1, \hat{x}_2, u)\right| < f^+$$

$$f^+ = 2Max\left|x_2\right|$$

$$\alpha > f^+$$

$$\lambda > \sqrt{\frac{2}{\alpha - f^+}}\frac{(\alpha + f^+)(1+p)}{1-p};\ 0 < p < 1$$

$$(\hat{x}_1, \hat{x}_2) \rightarrow (x_1, x_2)$$

$$\begin{cases} \dot{\tilde{x}}_1 = \tilde{x}_2 - Z_1 \rightarrow 0 \\ \dot{\tilde{x}}_2 = F(x_1, x_2, \hat{x}_2) - Z_2 \rightarrow 0 \end{cases}$$

Suspension deflections and speeds convergence

→ Convergence of vertical displacements of wheels

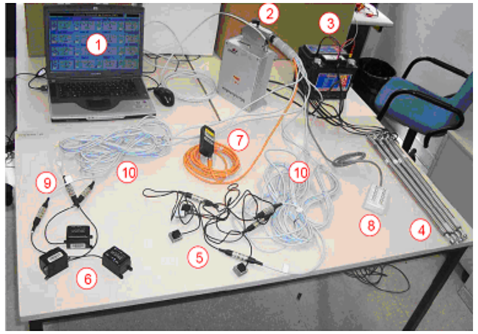
→ Estimation of vertical forces

Experimental results

1. Vehicle excited in vertical way

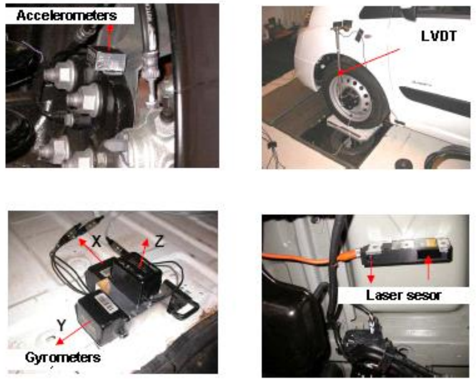
The instrumented vehicle

1. Hydraulic jack
2. Vehicle
3. LVDT sensor



1. Control desk software
2. Micro-Autobox
3. Battery
4. LVDT sensors
5. Accelerometers
6. Gyrometers
7. Laser sensor
8. BNC connectors

The acquisition material



The installed sensors

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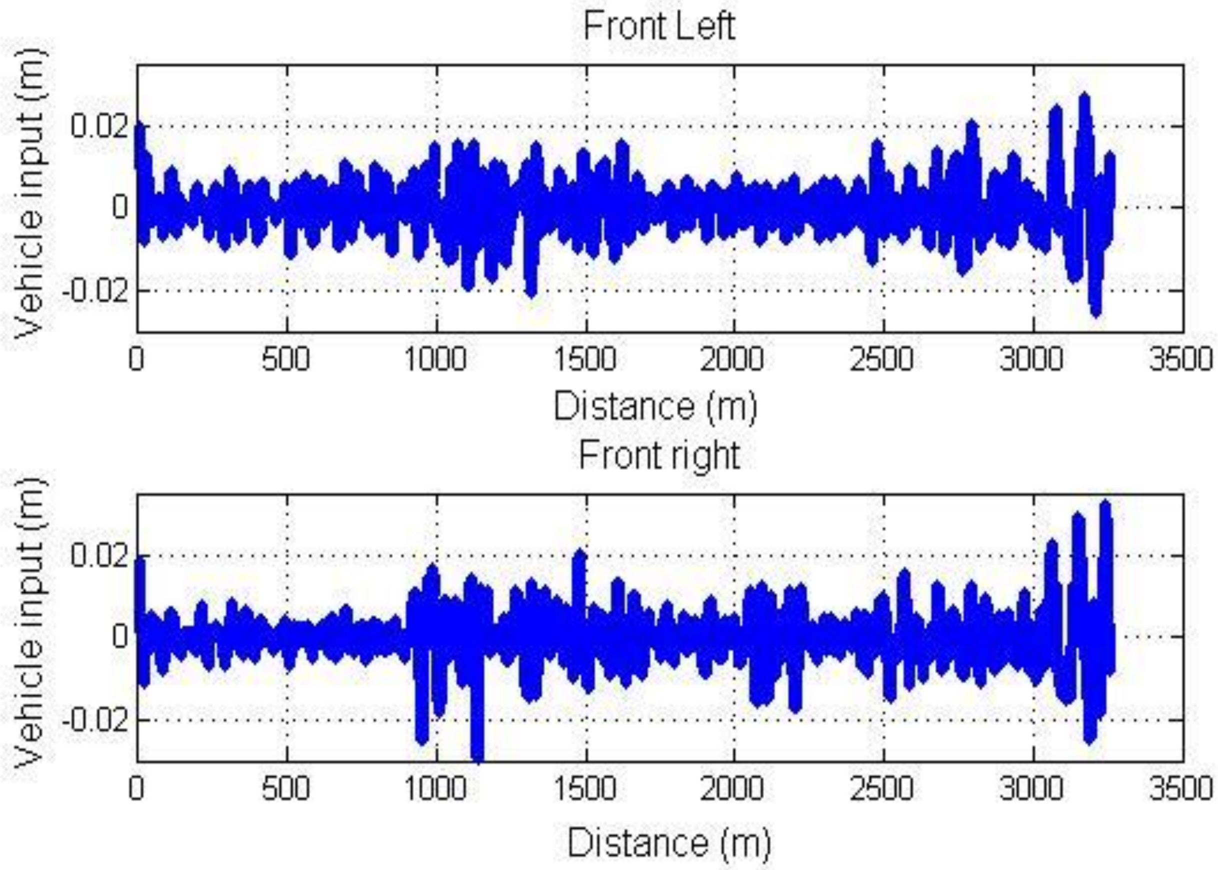
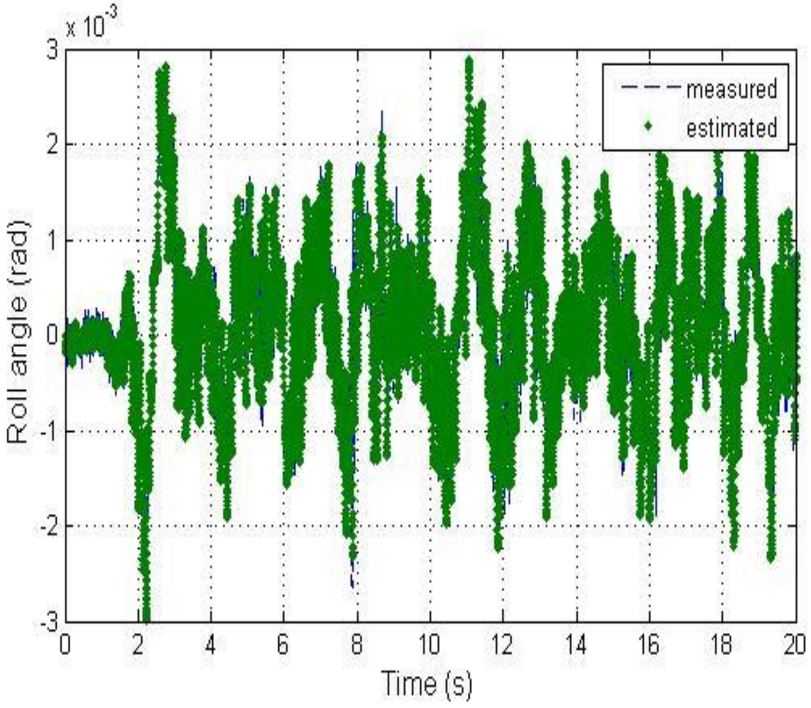
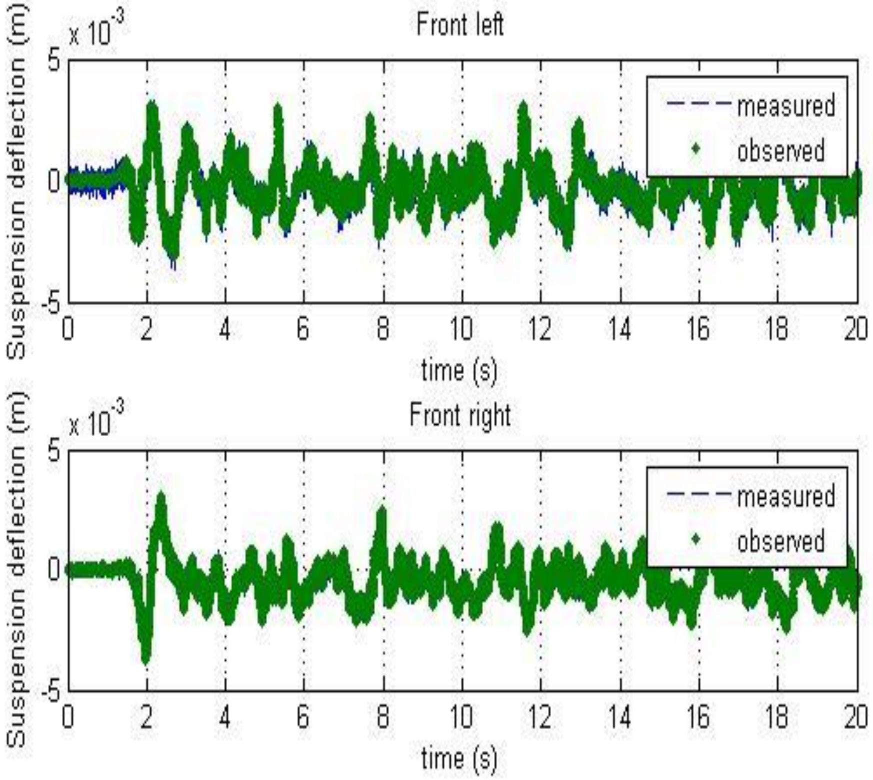
Test bench



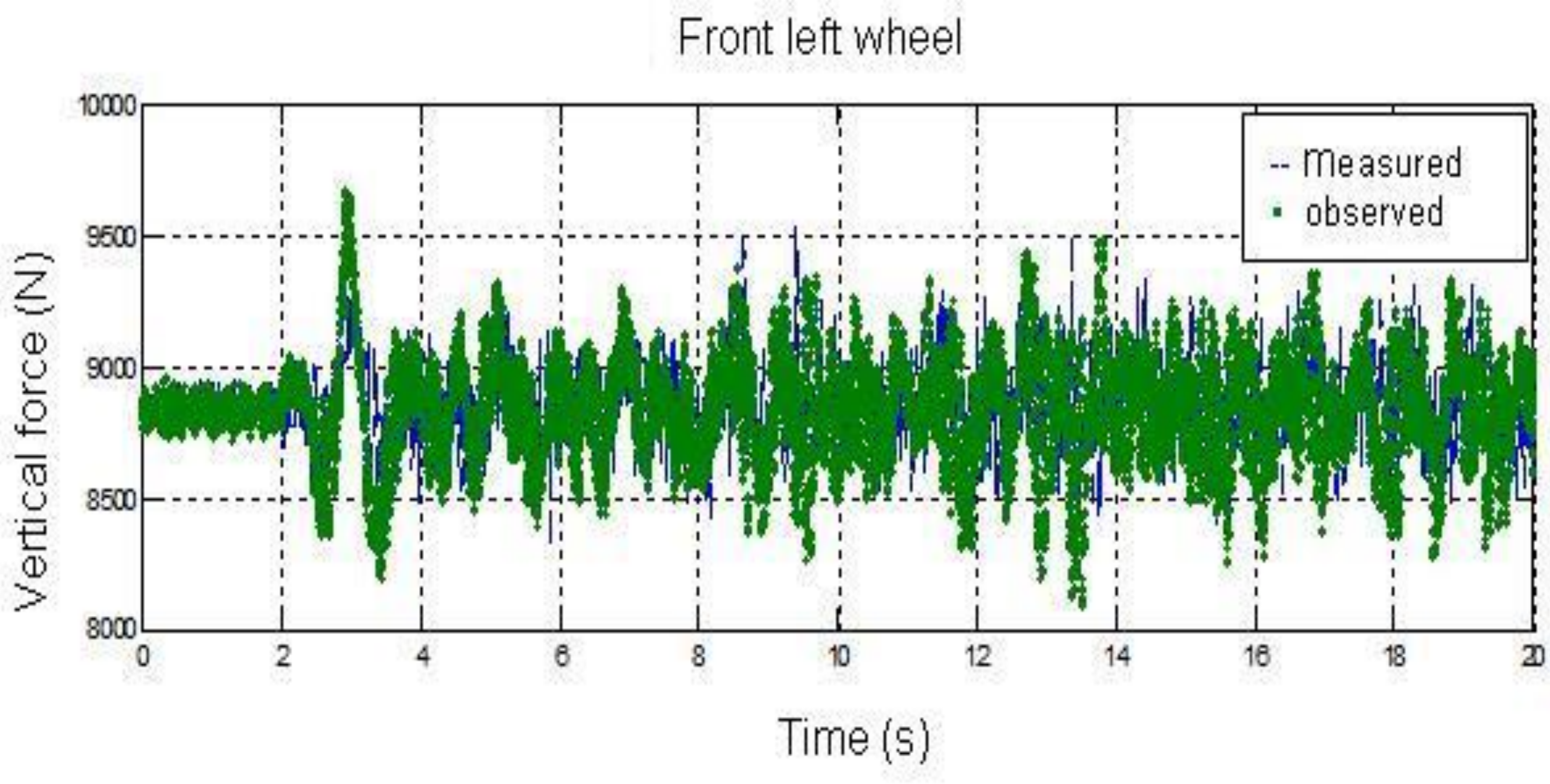
Vehicle inputs (road profile)



Roll angle estimation



Suspension deflection estimation



Impact force estimation

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2. Experiments with ALF

- Test the estimation algorithm using the ALF (Accelerated Load Facility)
- Sensors are fitted to the ALF: LVDT, APT and Accelerometers

Real road profile (french national road) – 40 T static load

65

HEAVY VEHICLE RISKS STUDY

Rollover simulation

Speed limit respected (30km/h)

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Rollover simulation

Speed limit not respected (45km/h)

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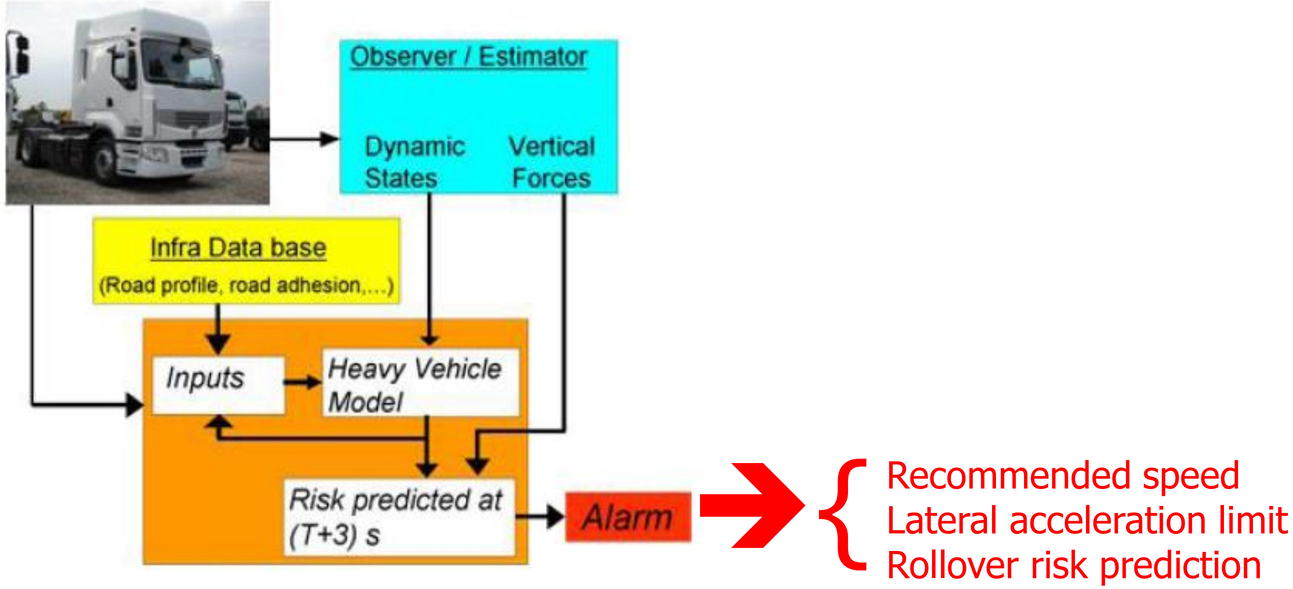
Rollover simulation

Load Transfert

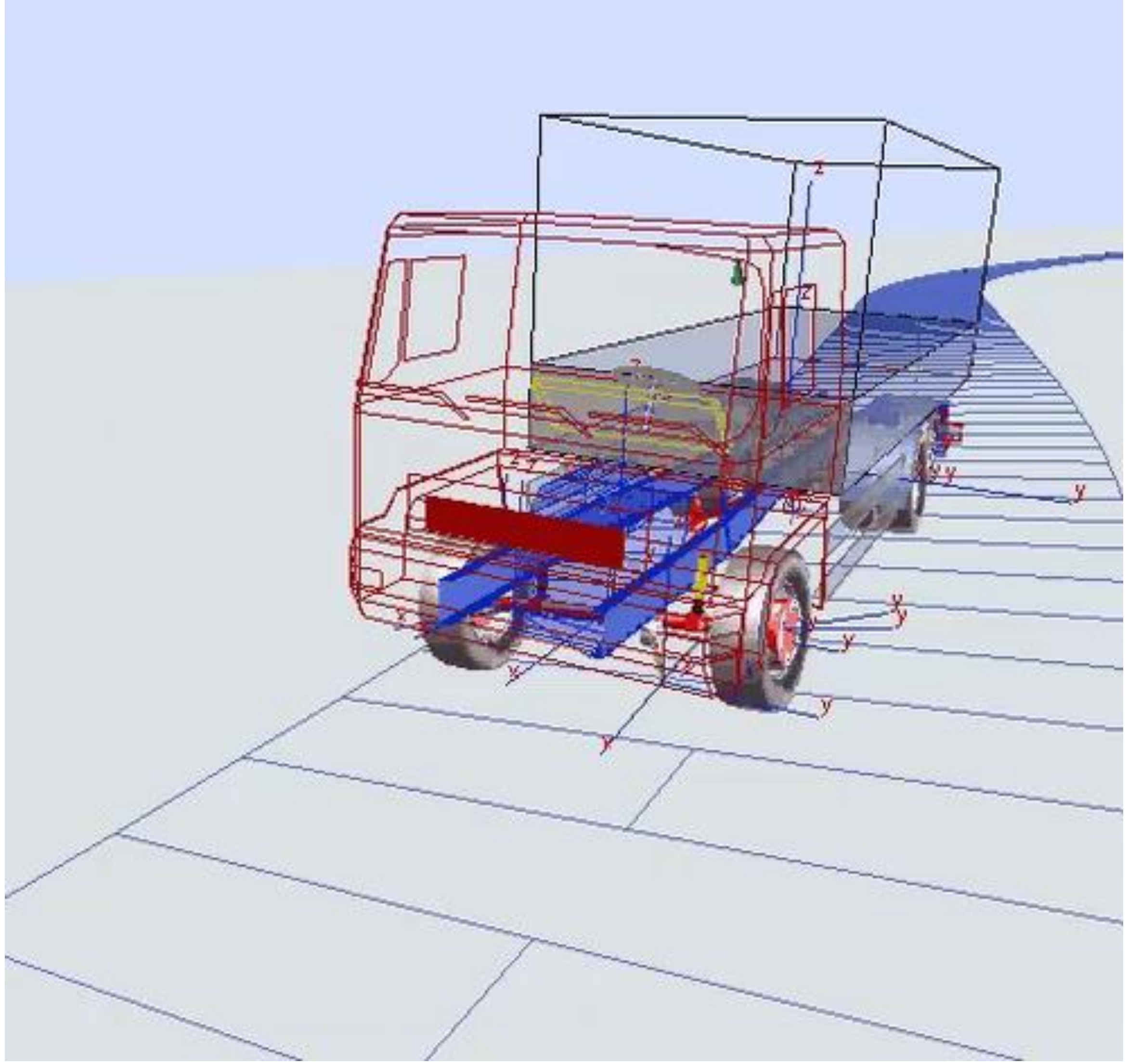
Rollover risk prediction system

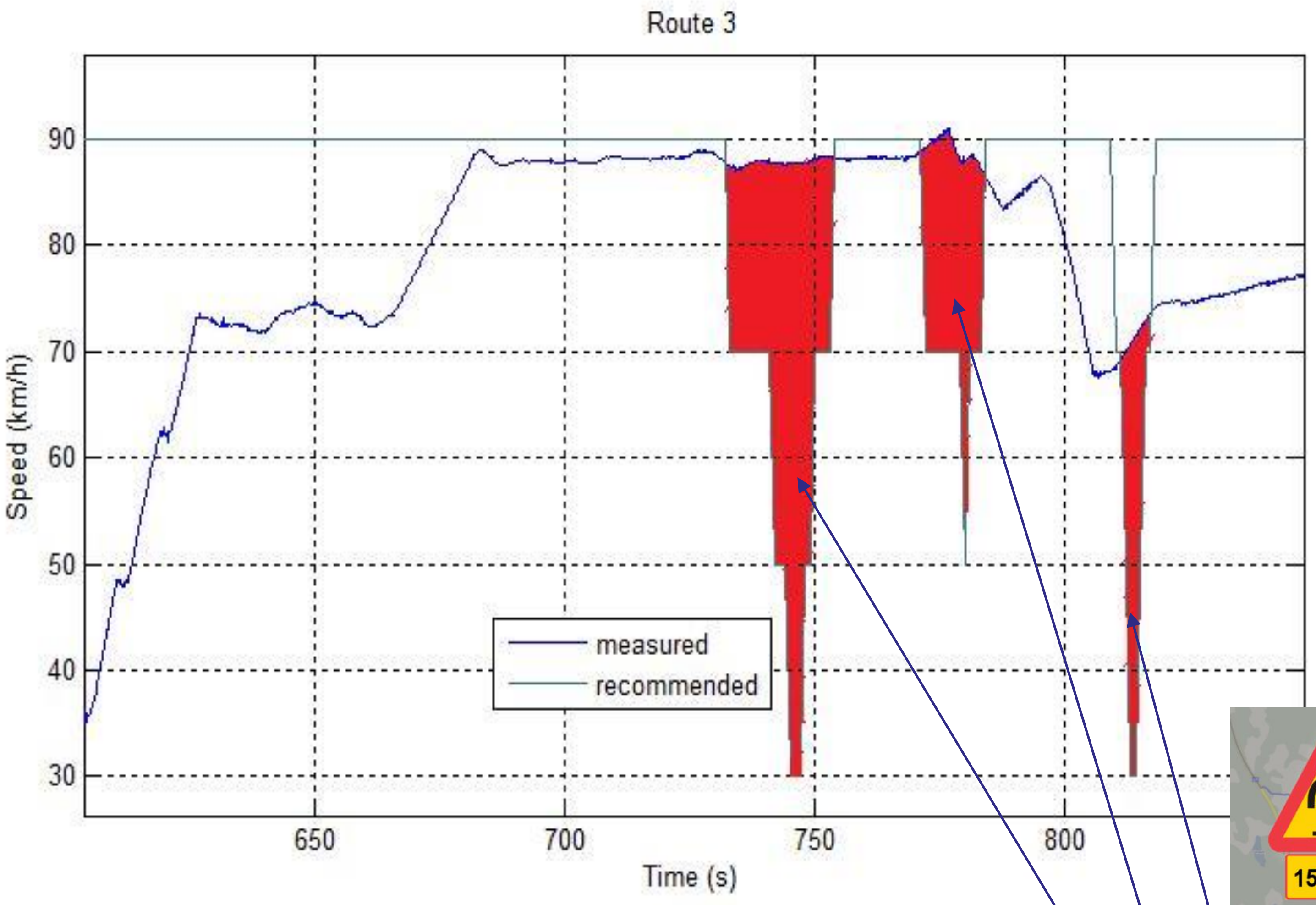


The rollover is predicted at *(t+3)s* using

- Infrastructure data base (radius, slops, road adhesion, road profile)
- Measures from sensors
- Estimated vertical forces
- Estimated states

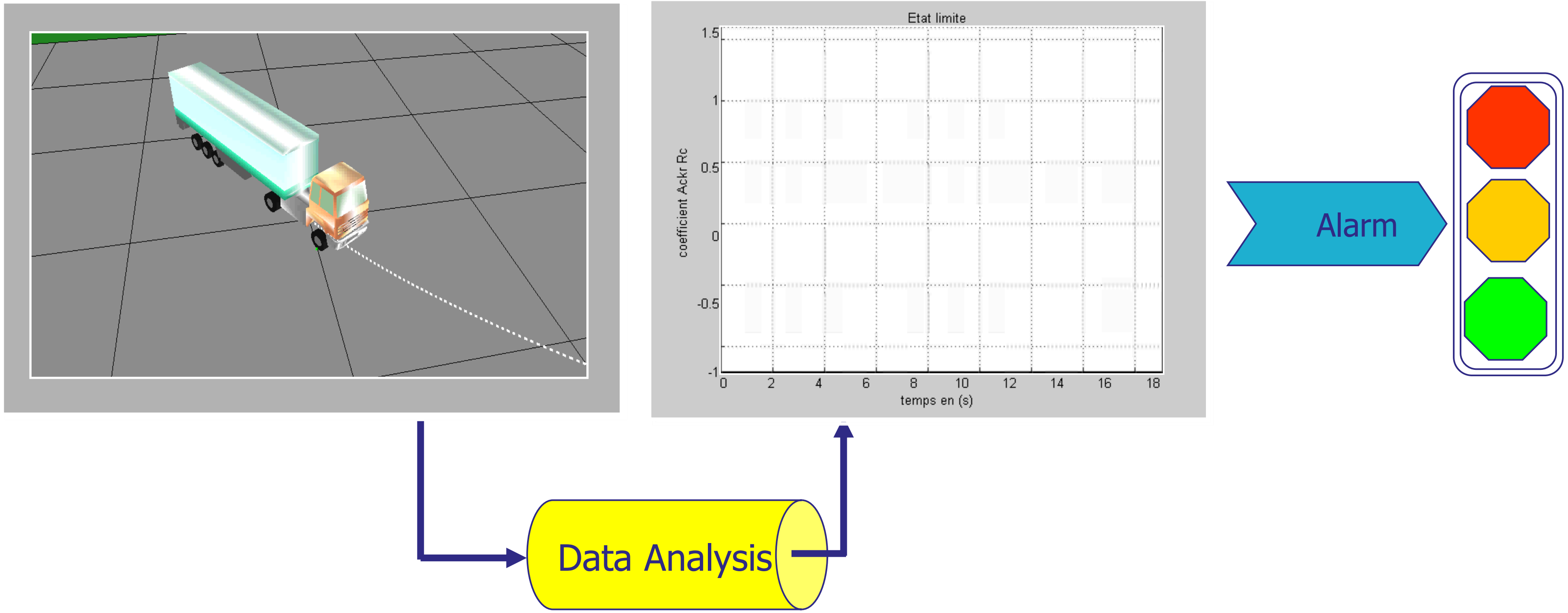
Load Transfert





Rollover risk area

Rollover simulation



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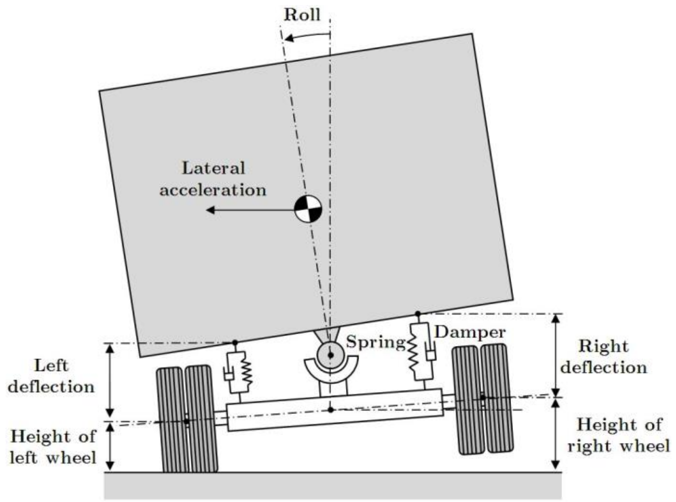
Rollover risk is detected when one of the two wheels of the same axle, lift off the road

➔ LTR (Load Transfer Ratio)



$$LTR = \frac{|F_{zL} - F_{zR}|}{F_{zL} + F_{zR}} = \frac{2m_2}{m \cdot T}\left|(h_0 + h\cos\phi)\frac{a_y}{g} + h\sin\phi\right| < R_{\lim} = 1$$

$$a_y = \dot{v}_y + v\dot{\psi} - h\ddot{\phi}$$

$\sum F_{z,r} = 0$ ➔ Right wheel lift off the road ➔ rollover risk ➔ LTR = -1.

$\sum F_{z,l} = 0$ ➔ Left wheel lift off the road ➔ rollover risk ➔ LTR = 1.

$\sum F_{z,r} = \sum F_{z,l}$ ➔ No rollover risk ➔ LTR = 0.

High Order Sliding Mode Observer

Vehicle states and Load Transfer Ratio computed using High Order Sliding Mode Observer :

- Robustness against perturbation and parameters variations
- Quick and finite time convergence of positions, speeds and accelerations
- Easier implementation

System modelling

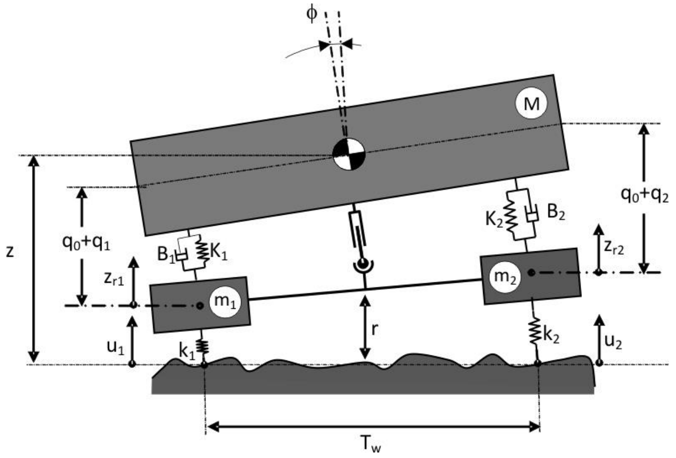
$$F_{ni} = F_{ci} + k_i(u_i - z_{ri}), \mathrm{i} = 1..4$$

$$\begin{cases} \ddot{z}_{r1} = (K_1 q_1 - K_1 \dfrac{T}{2}\sin(\phi) + B_1\dot{q}_1 - B_1\dfrac{T}{2}\cos(\phi)\dot{\phi} - k_1 z_{r1} + k_1 u_1)\dfrac{1}{m_1} \\ \ddot{z}_{r2} = (K_2 q_2 + K_2 \dfrac{T}{2}\sin(\phi) + B_2\dot{q}_2 + B_2\dfrac{T}{2}\cos(\phi)\dot{\phi} - k_2 z_{r2} + k_2 u_2)\dfrac{1}{m_2} \end{cases}$$

$$\ddot{z} = (K_1 q_1 + K_2 q_2 + (K_1 - K_2)\frac{T}{2}\sin(\phi) + B_1\dot{q}_1 + B_2\dot{q}_2 - (B_1 - B_2)\frac{T}{2}\cos(\phi)\dot{\phi})\frac{1}{M}$$

$$\begin{cases} z_{r1} = z - q_1 + \dfrac{T}{2}\sin(\phi) - r \\ z_{r2} = z - q_2 - \dfrac{T}{2}\sin(\phi) - r \end{cases}$$

z: Centre heigh of gravity
r: weel radius
F_{ci} : static load
F_{ni} : vertical force
k_i : stifness
U_i : Road profile
$\ddot{z}_{ri}$: vertical acceleration of wheel i



Suspension model

HOSM Observer →

$$\begin{cases} \dot{\hat{x}}_1 = \hat{x}_2 - \lambda_0 \left|\hat{x}_1 - x_1\right|^{2/3} sign(\hat{x}_1 - x_1) \\ \dot{\hat{x}}_2 = \hat{x}_3 - \lambda_1 \left|\hat{x}_2 - \dot{\hat{x}}_1\right|^{1/2} sign(\hat{x}_2 - \dot{\hat{x}}_1) \\ \dot{\hat{x}}_3 = -\lambda_2 sign(\hat{x}_3 - \dot{\hat{x}}_2) \end{cases}$$

$\hat{x}_1, \hat{x}_2$ and $\hat{x}_3$ are the estimated of x_1, x_2 et $\dot{x}_2$

λ_0, λ_1 and λ_2 are the observer gains

Dynamics error:

$$\begin{cases} \dot{\tilde{x}}_1 = x_2 - \hat{x}_2 + \lambda_0 \left|\hat{x}_1 - x_1\right|^{2/3} sign(\hat{x}_1 - x_1) \\ \dot{\tilde{x}}_2 = \dot{x}_2 - \hat{x}_3 + \lambda_1 \left|\hat{x}_2 - \dot{\hat{x}}_1\right|^{1/2} sign(\hat{x}_2 - \dot{\hat{x}}_1) \\ \dot{\tilde{x}}_3 = \ddot{x}_2 + \lambda_2 sign(\hat{x}_3 - \dot{\hat{x}}_2) \end{cases}$$

$$
\begin{cases}
\hat{z}_{r1} = (-m_1 \ddot{z}_{r1} + B_1 \dot{\hat{q}}_1 + K_1 \frac{T_w}{2} \sin(\hat{\phi}) \\
+B_1 \frac{T_w}{2} \cos(\hat{\phi}) \dot{\hat{\phi}} + K_1 \hat{q}_1 + k_1 u_1)/k_1 \\
\\
\hat{z}_{r2} = (-m_2 \ddot{z}_{r2} + B_2 \dot{\hat{q}}_2 - K_2 \frac{T_w}{2} \sin(\hat{\phi}) \\
-B_2 \frac{T_w}{2} \cos(\hat{\phi}) \dot{\hat{\phi}} + K_2 \hat{q}_2 + k_2 u_2)/k_4
\end{cases}
$$

Suspension deflections and speeds estimated

➔ Wheel's vertical displacements estimated

$$\ddot{z}_{ri} \text{ measured} \Rightarrow \hat{z}_{ri} \rightarrow z_{ri}$$

$$F_{ni} = F_{ci} + k_i(u_i - z_i), \mathrm{i} = 1..4$$

Vertical forces estimated

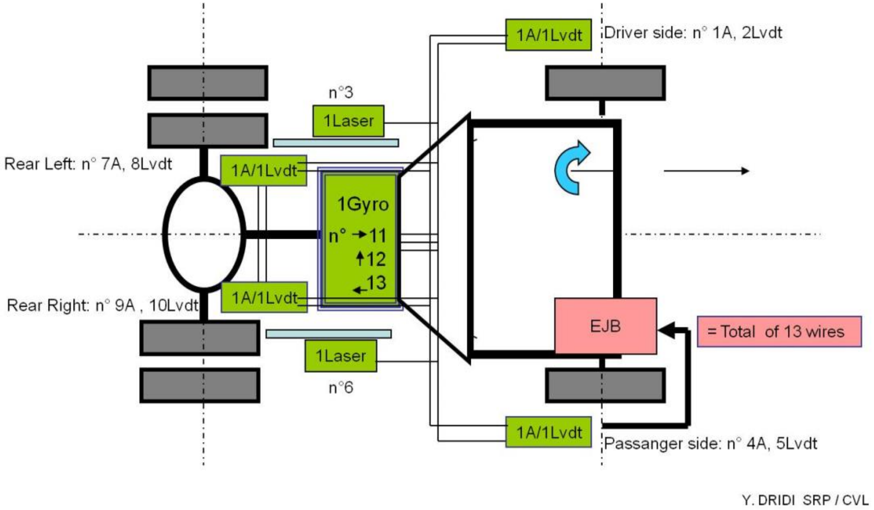
Load Transfer Ratio calculated

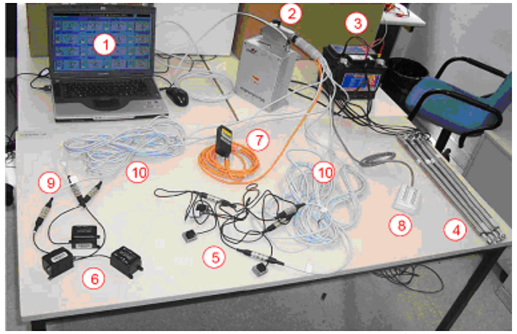
Experimental results

Instrumented vehicle

Infrastructure data base (Road profile, Longitudinal and lateral slopes, Adhesion)

Sensors inside the vehicle





1. Control desk software
2. Autobox
3. Battery
4. LVDT sensors
5. Accelerometers
6. Gyrometers
7. Laser sensor
8. BNC connectors

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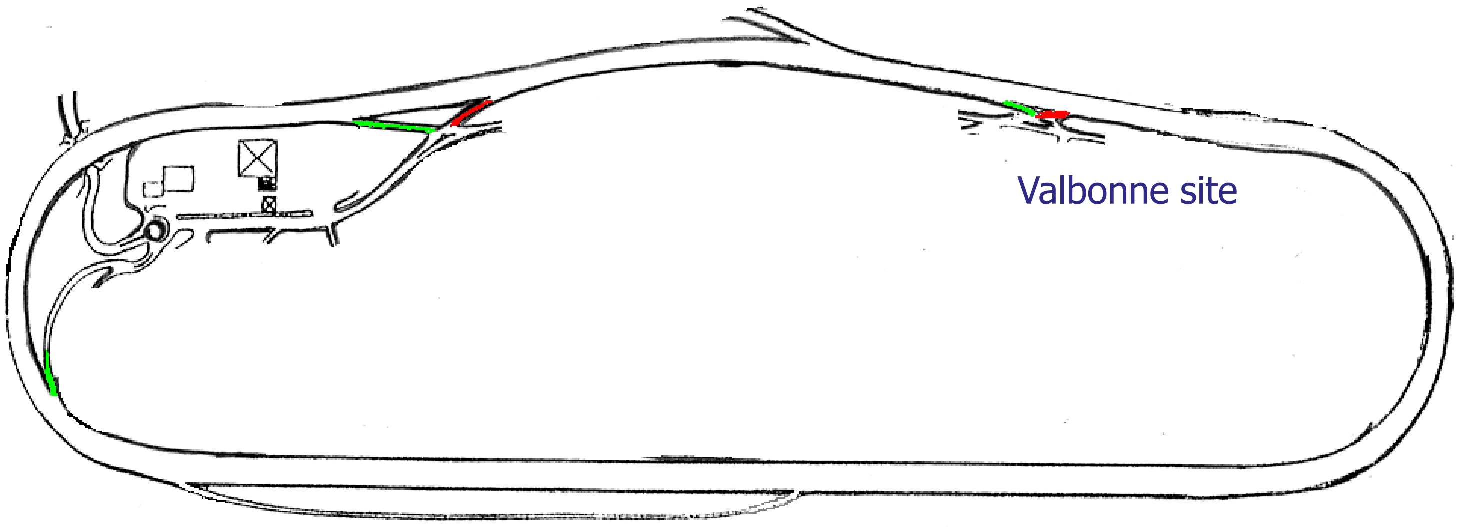
Many Tests:

- Straight line with constant speed of 50, 70 et 90km/h
- On all the site with constant speed of 50, 70 et 90km/h
- Braking in straight line
- Chicane Test



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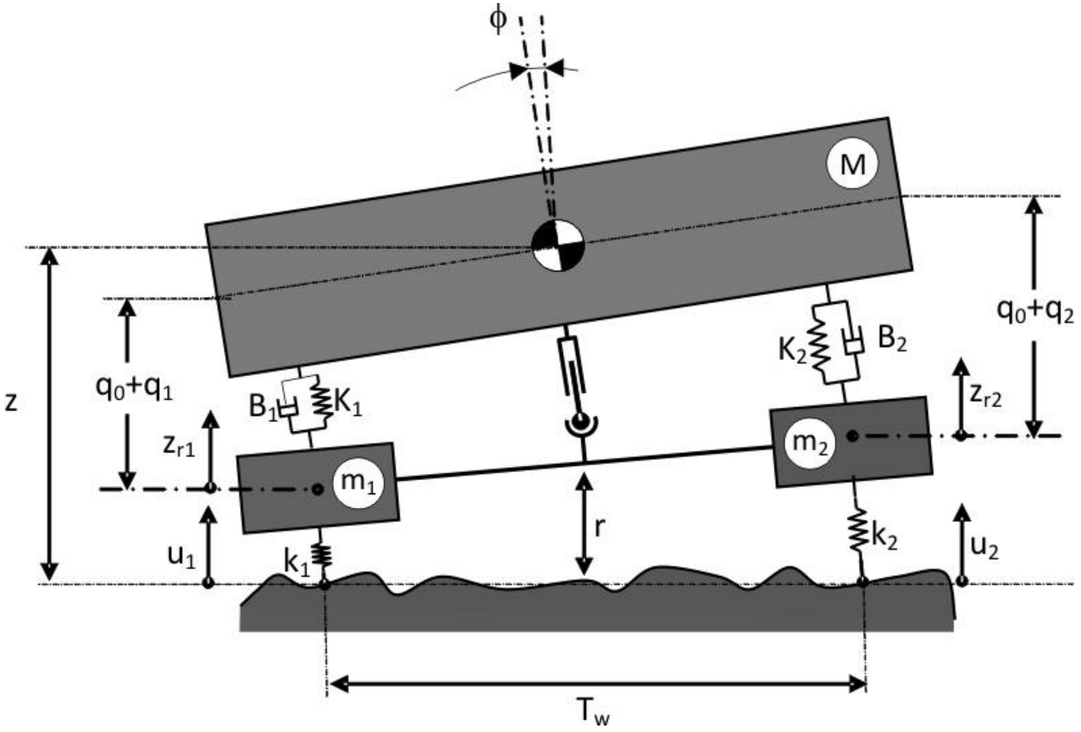
Chicane test



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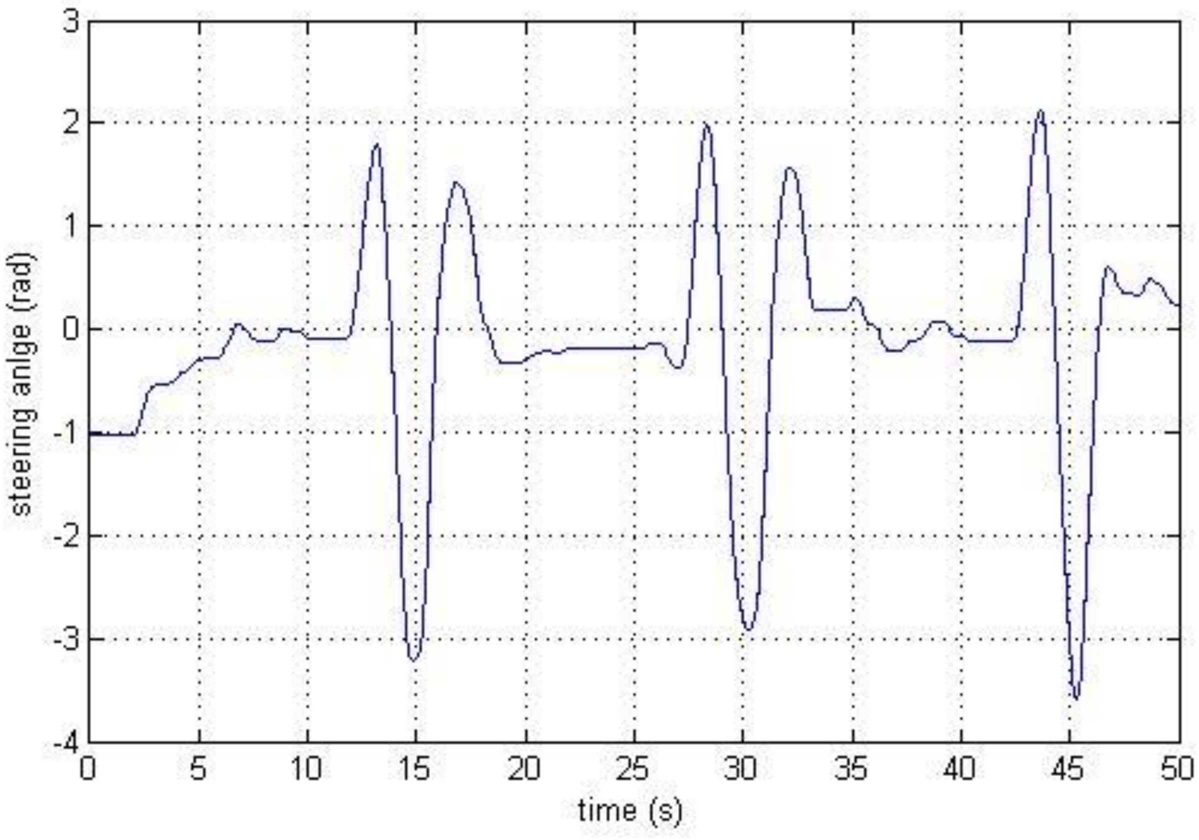
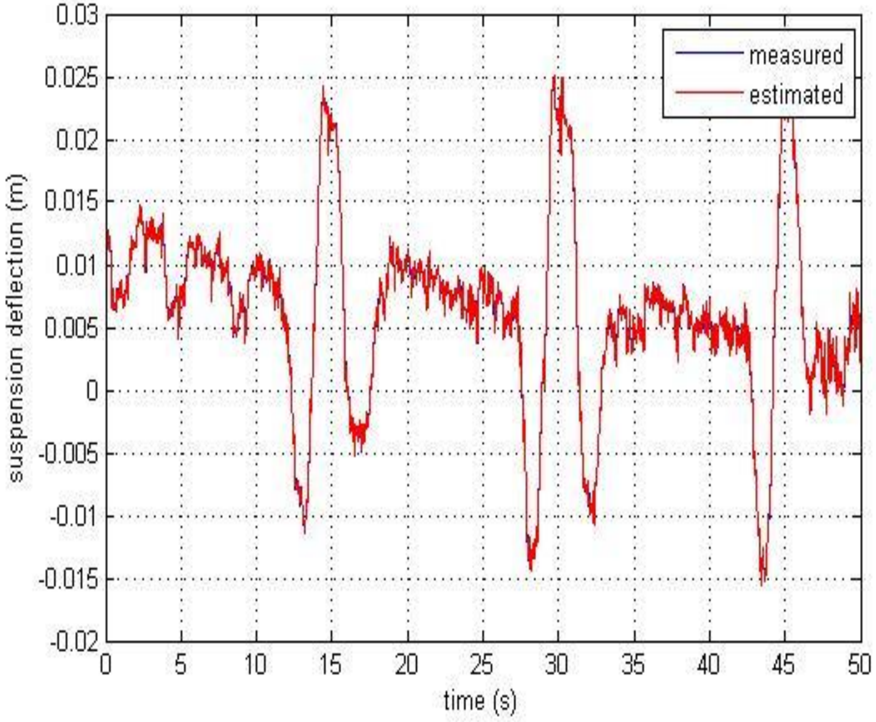
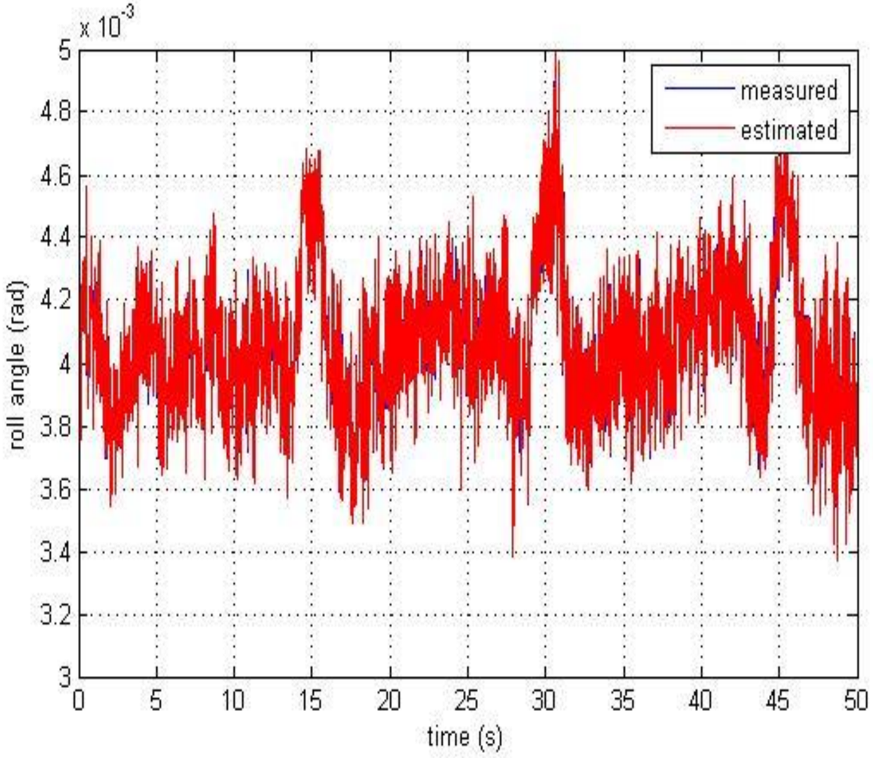


Steering angle

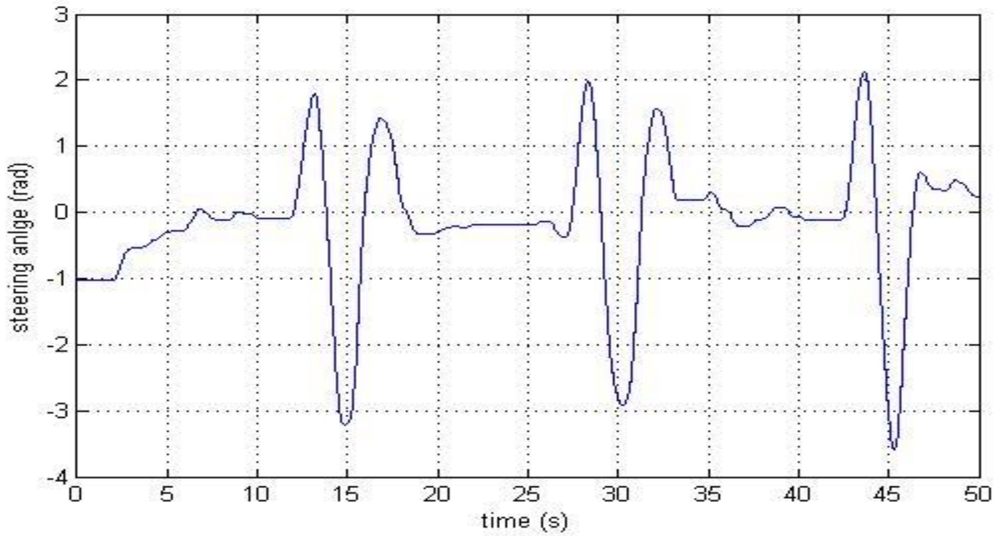


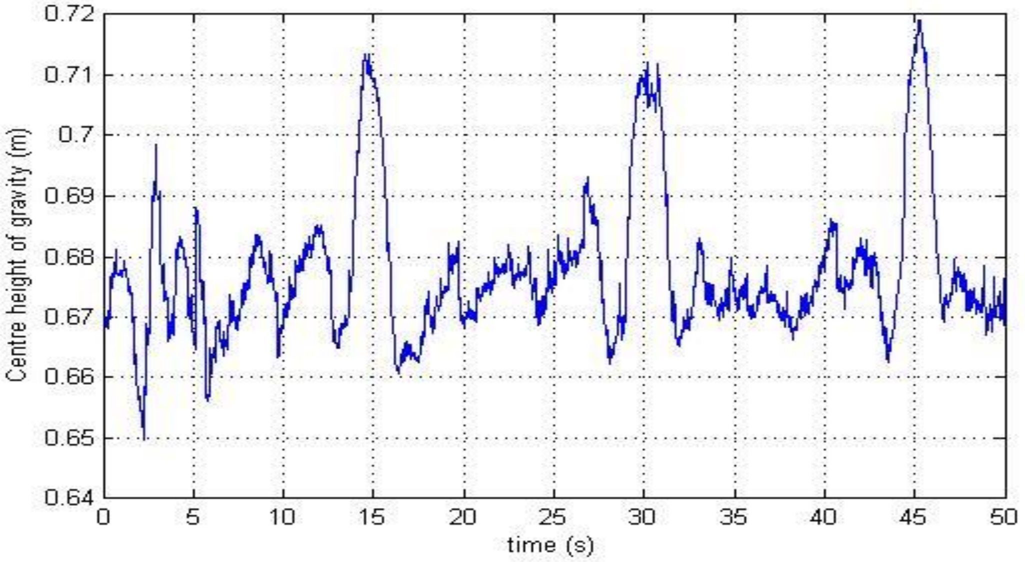
Suspension deflection



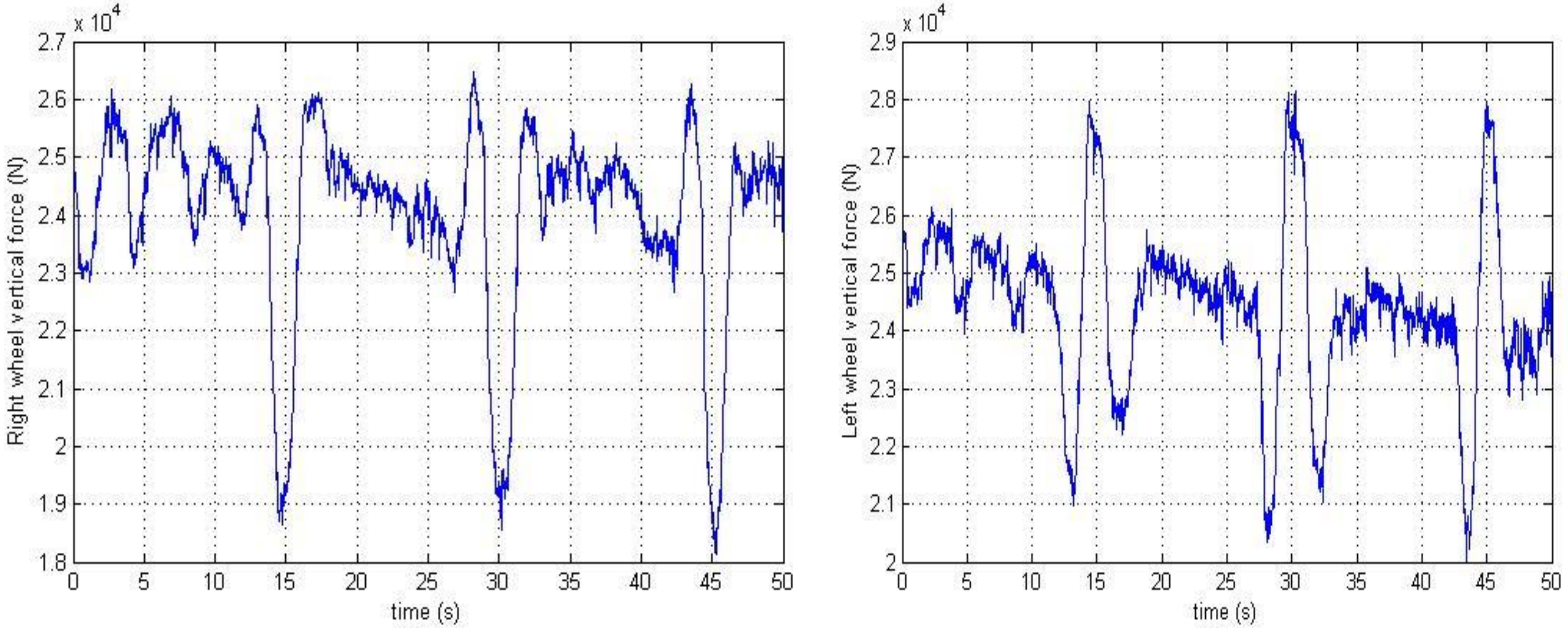
Roll angle

Steering angle

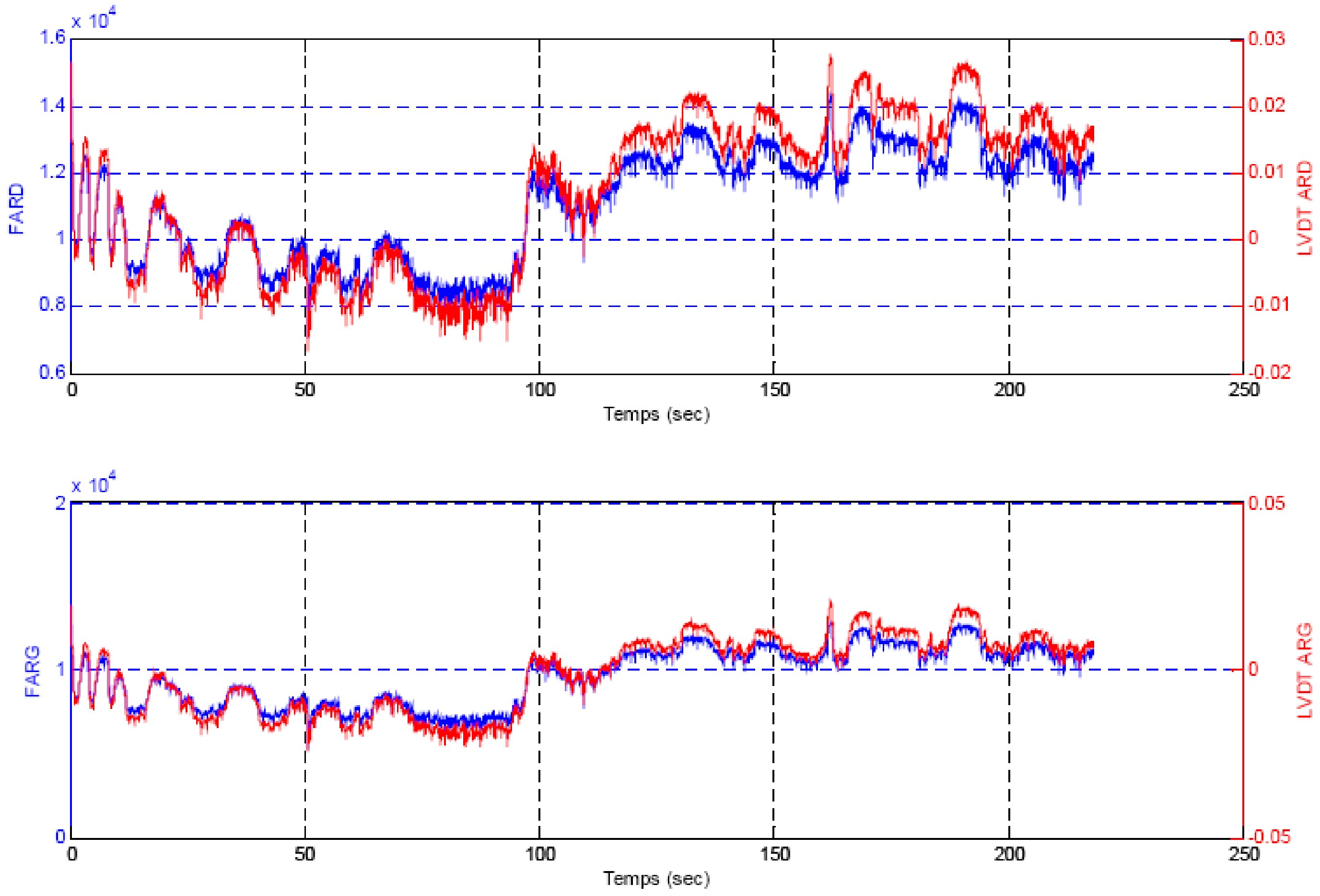




Centre height of gravity estimation

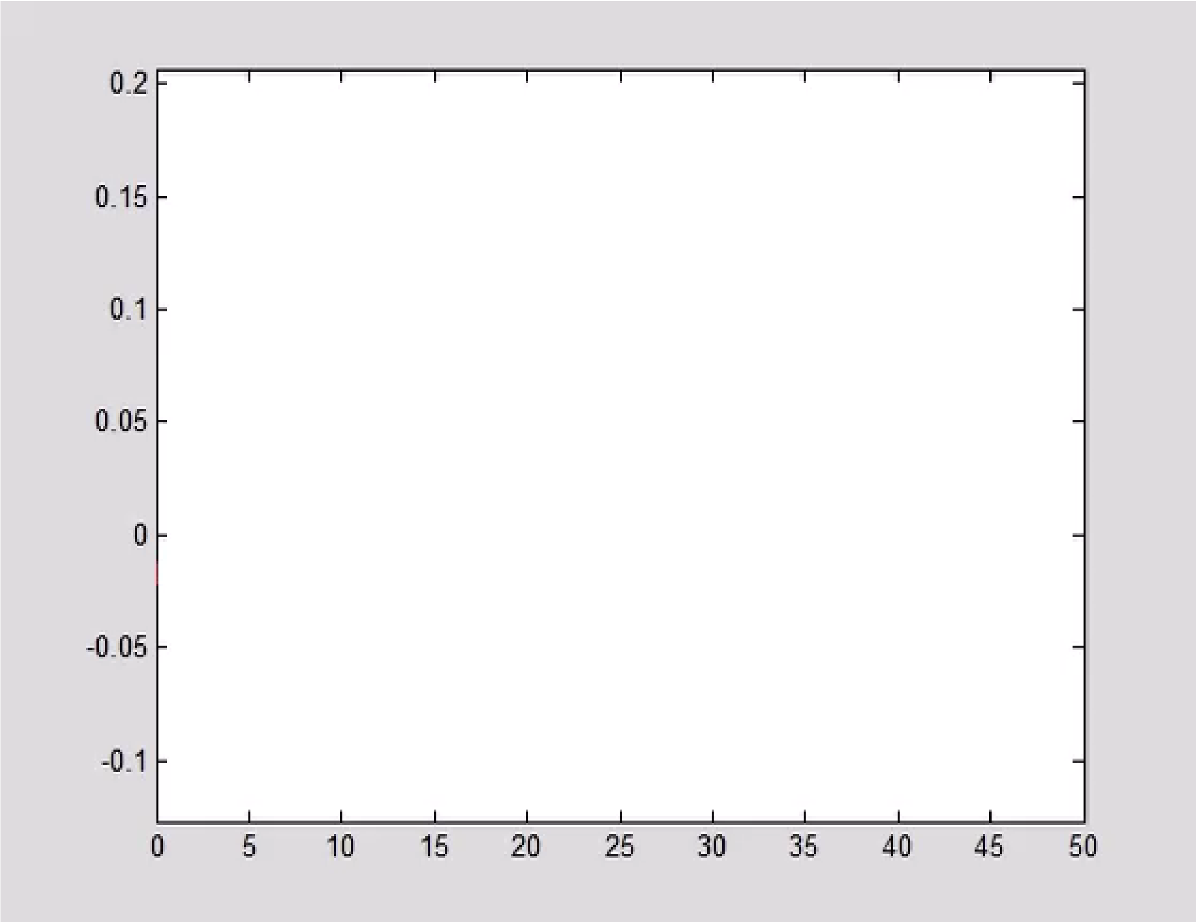


Impact forces estimation



Impact forces compared to LVDT measures

Load Transfer Ratio (LTR)



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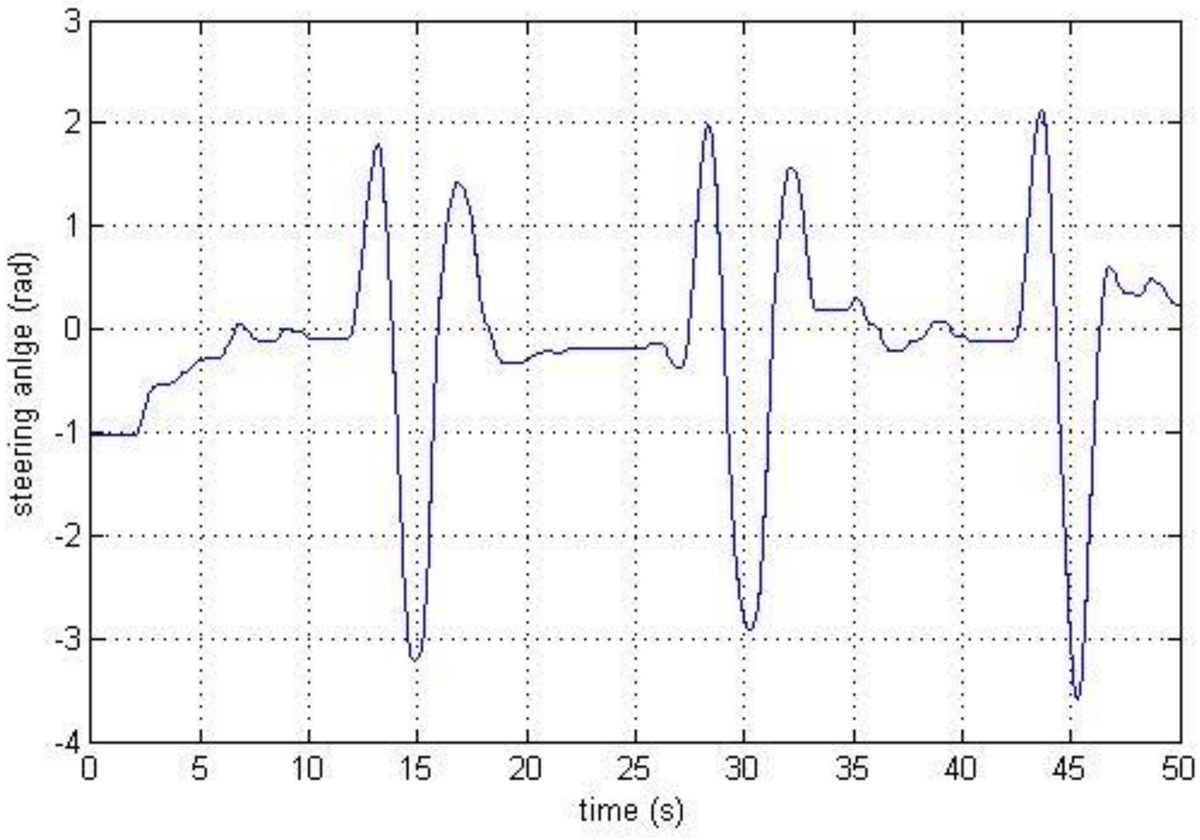
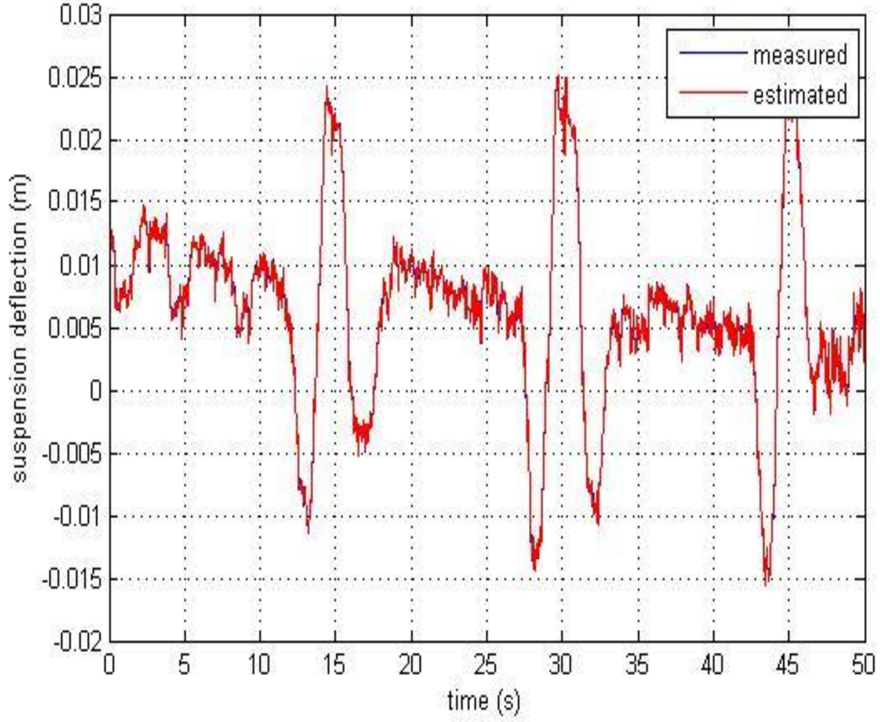
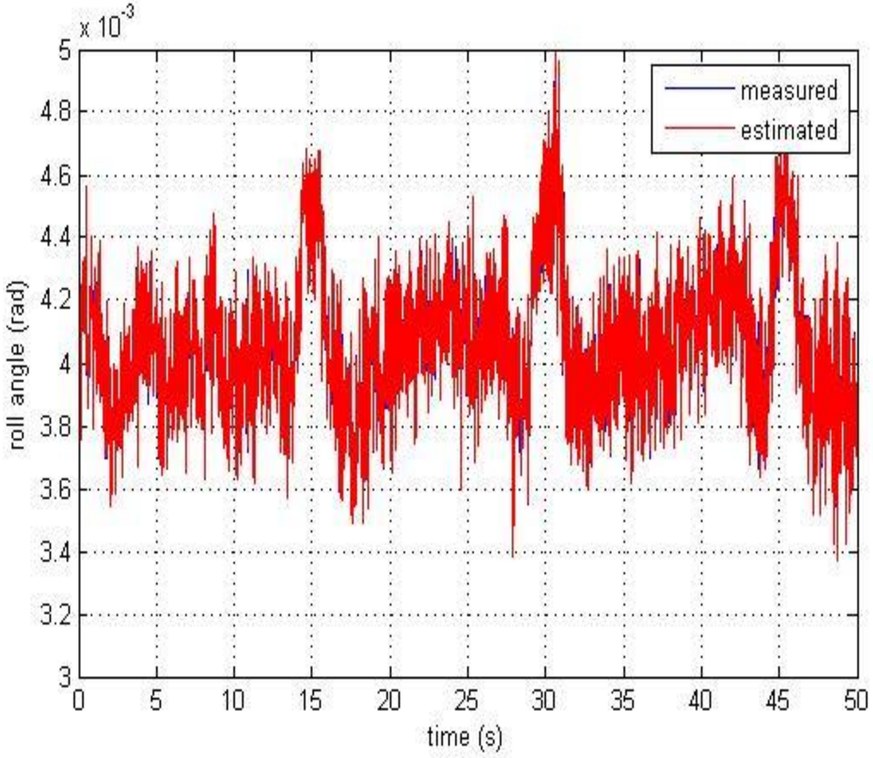


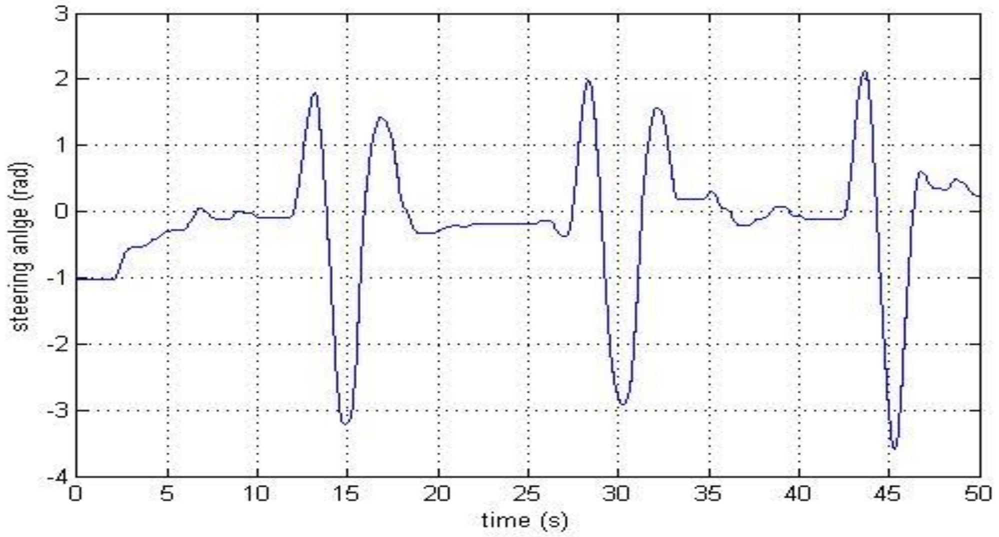
Steering angle



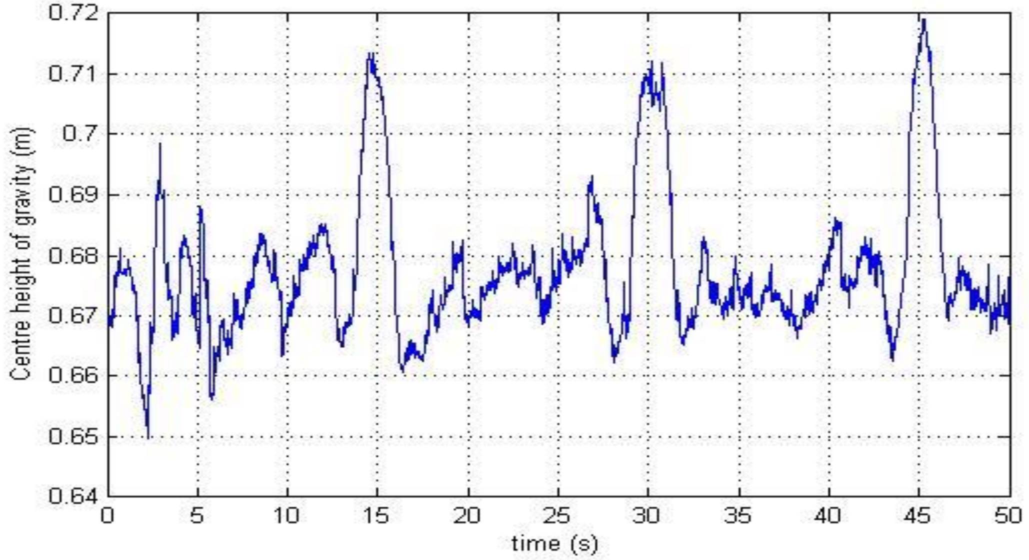


Suspension deflection

Roll angle



Steering angle



Centre height of gravity estimation

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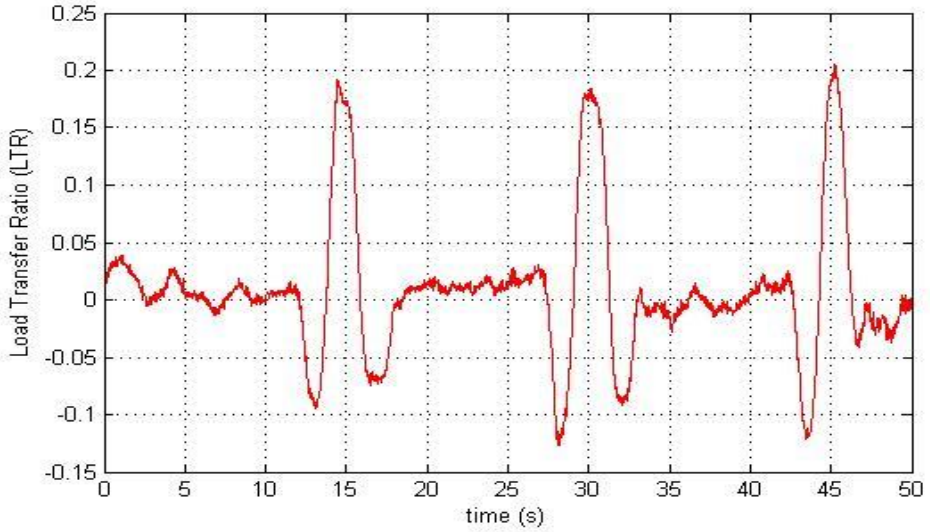
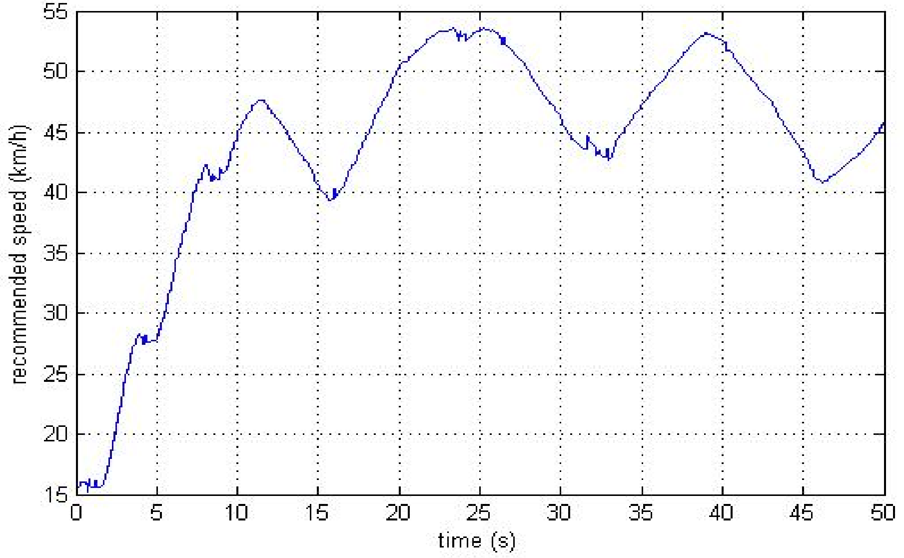
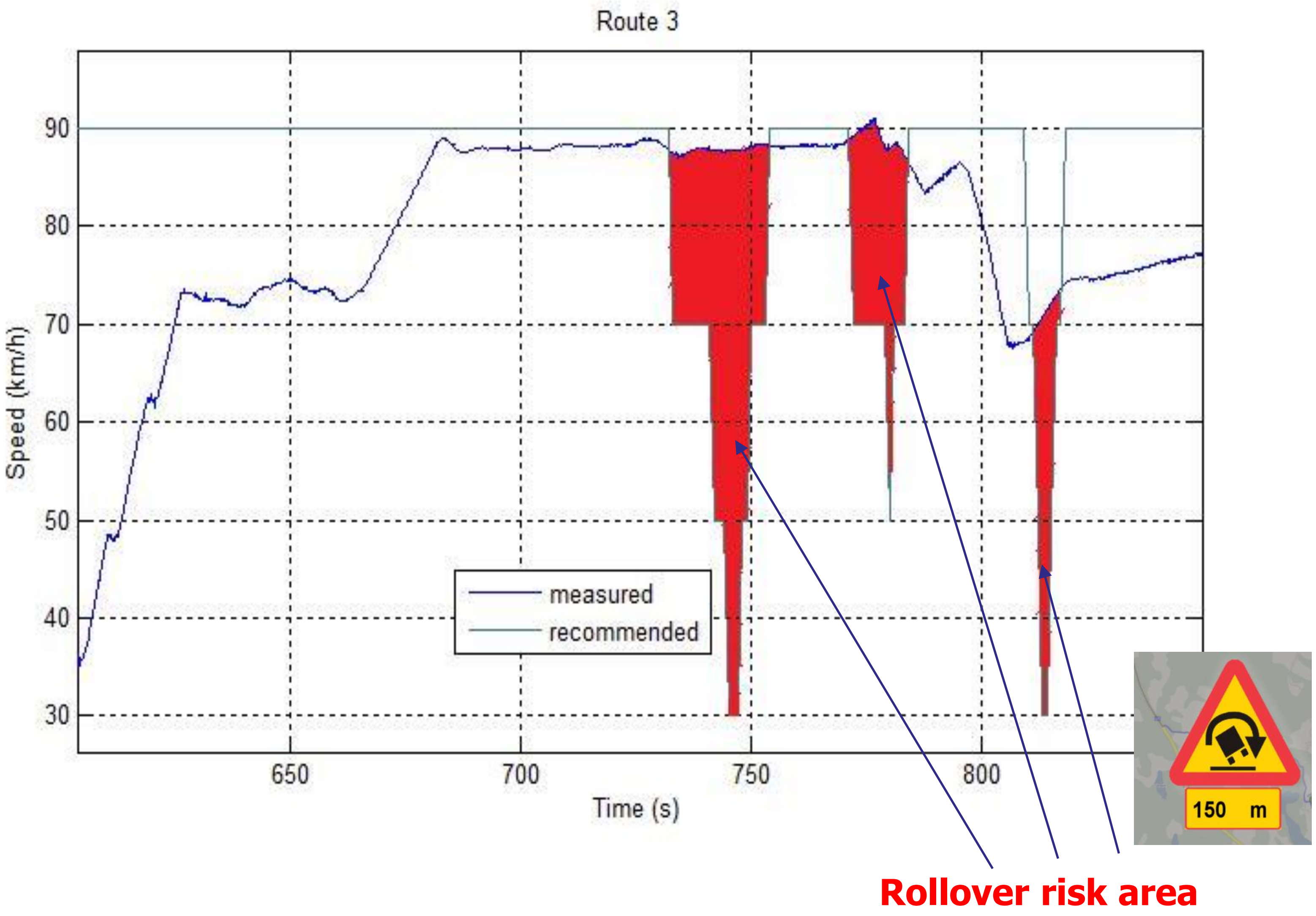


Load Transfer Ratio



Recommended speed



Route 3
90
80
70
60
50
40
30
Speed (km/h)
650
700
750
800
Time (s)
measured
recommended
150 m
Rollover risk area

Nonlinear control

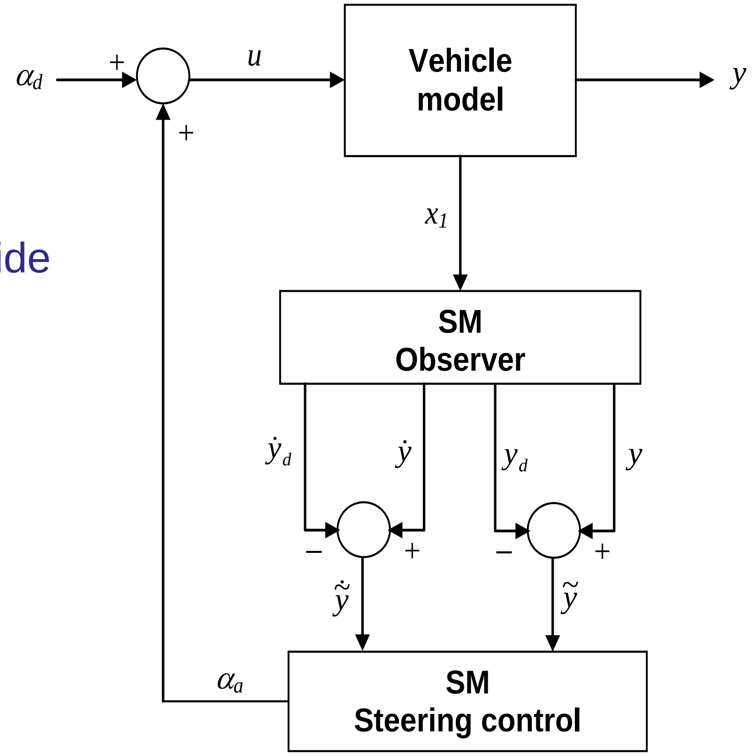
Advantages of the research :

- estimate the non measurable states of the HV.
- identify some unknown parameters of HV.
- robust control using super twisting algorithm

Rollover avoidance

The aim of the developed steering control is
to ensure the convergence of the lateral acceleration a_y
of HGV to its acceleration limit a_{ylim}.

➔ Bounded Load transfer between the right and the left side
of HGV to its limited value 0.9.



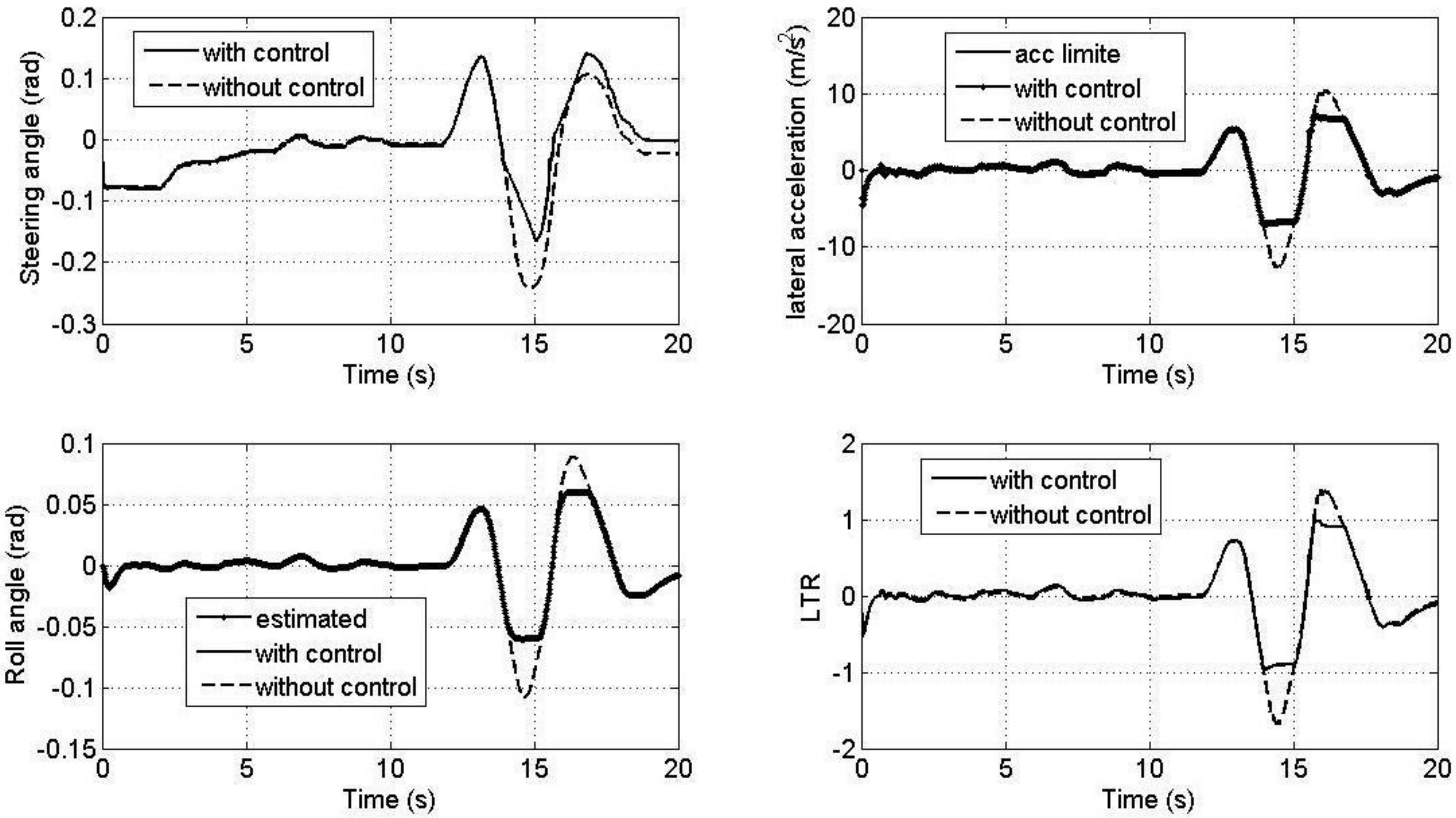
The control algorithm is defined as:

$$\begin{cases} \delta_a = u_{eq} - G_1 |S|^{1/2} sign(S) + u_1 \\ \dot{u}_1 = -G_2 sign(S) \end{cases}$$

$$S = \dot{\tilde{y}} + \lambda \tilde{y}$$

Simulation results

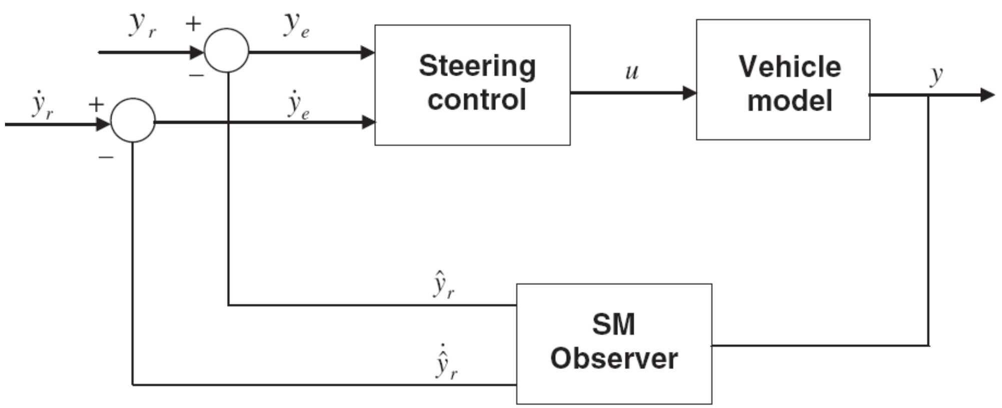
Simulation results for a driver steering input zigzag



Lane departure avoidance

Lane keeping assistance is based on the control of lateral position, yaw angle and their respective speed in order to keep the HGV in the centre of the line.

$$y_r = y_l + \psi$$

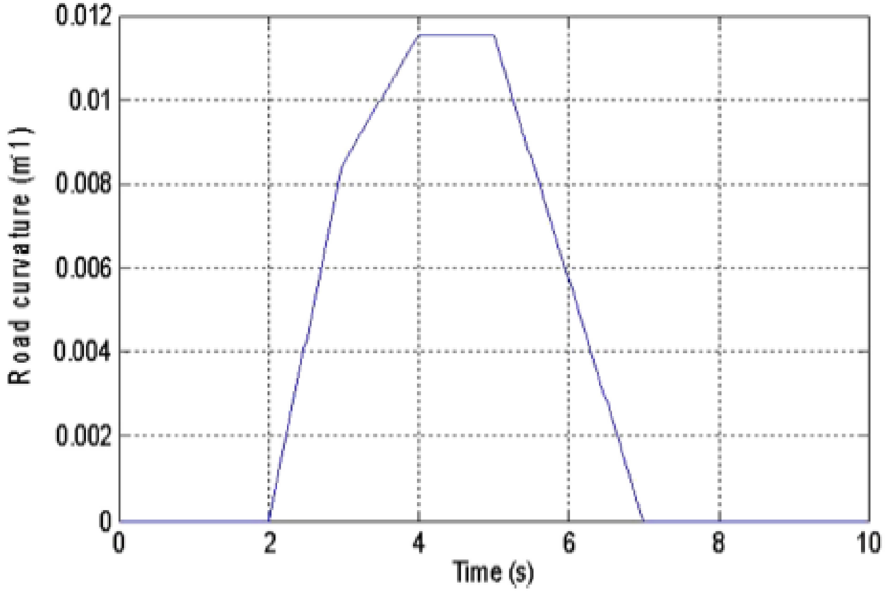


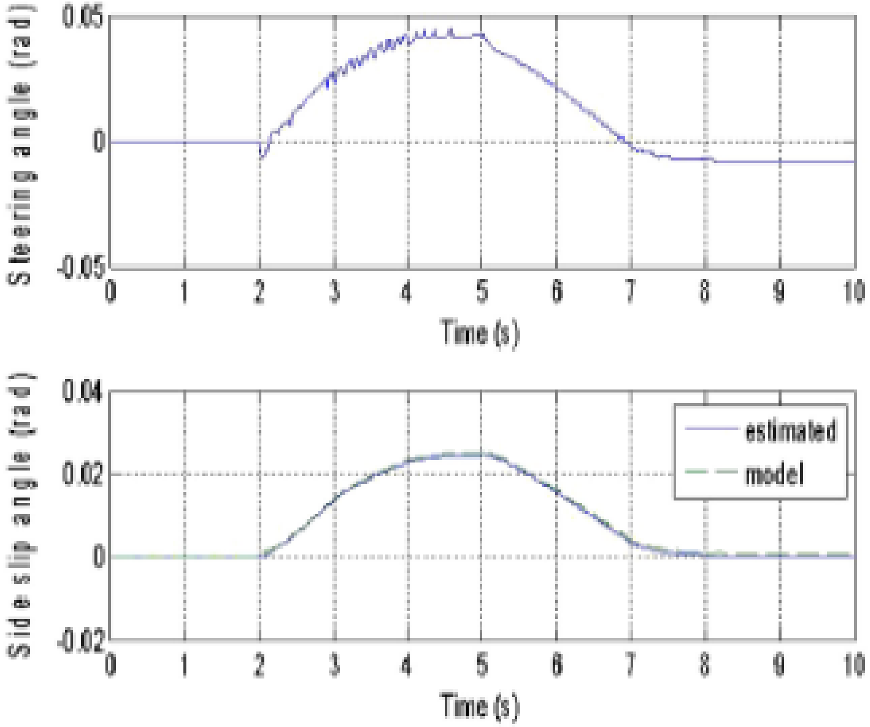
The control algorithm is defined by:

$$\begin{cases} u = u_{eq} - k_1 |S|^{1/2} \operatorname{sign}(S) + u_1 \\ \dot{u}_1 = -k_2 \operatorname{sign}(S) \end{cases}$$

$$S = \dot{y}_e + \lambda y_e$$

Simulation results





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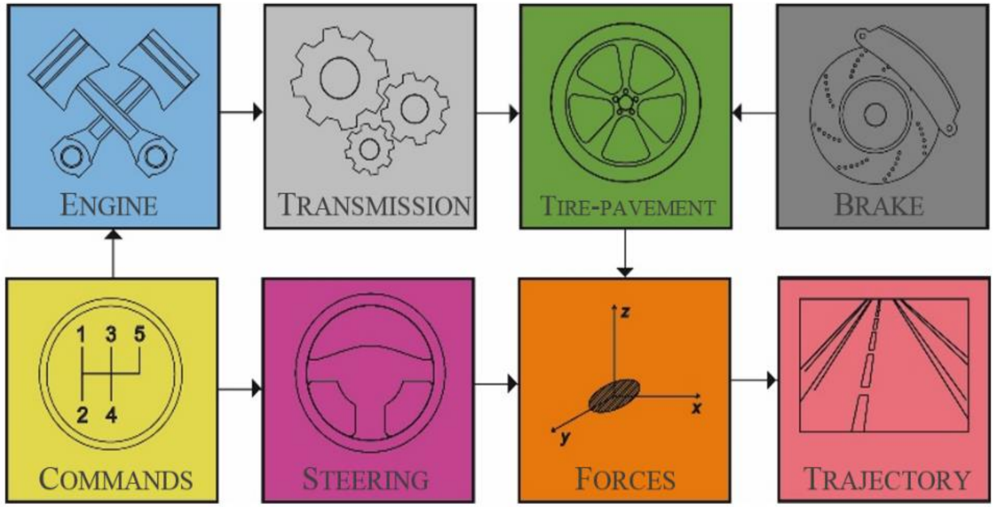
Actual and future works

Study the effects of road characteristics on simulators (Car and Bicycle)

In order to improve the safety and stability of this kind of vehicles, following tasks have been achieved:

- ✓ Develop new models of vehicles, taking into account the road characteristics.
- ✓ Simulate the driver's perception in vehicle control tasks.
- ✓ Tests on simulator and model validation
- ✓ Analyse the road characteristics and their influence on the safety.
- ✓ Define drivers and trajectories classes.
- ✓ Real tests with instrumented vehicles.

Car Simulator



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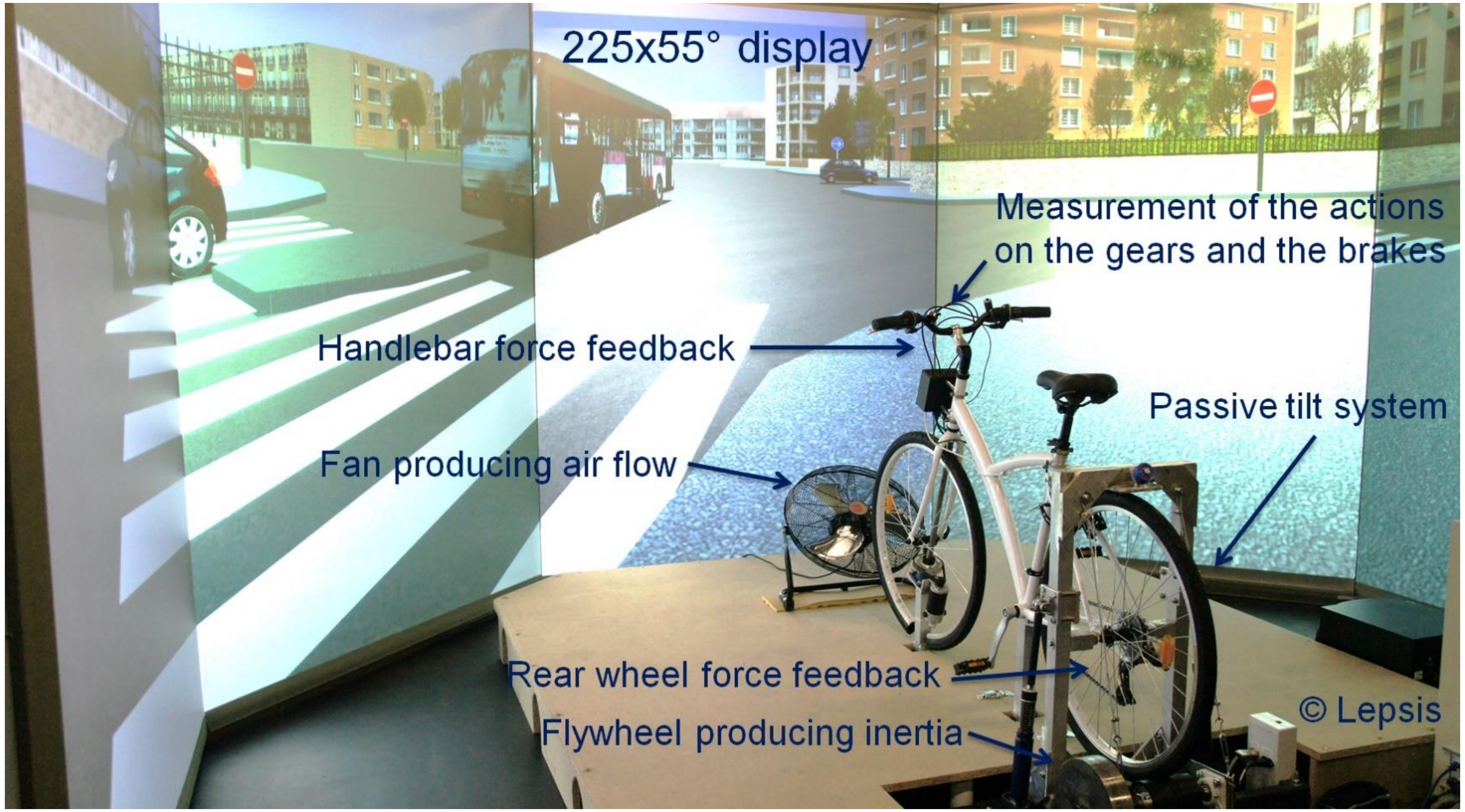
Bicycle simulator



* Caro, S., Chaurand, N., Dang, N.T., & Vienne, F. (2013). Conception d'un simulateur de vélo pour l'étude du comportement des cyclistes. Journées Transports & Déplacements du Réseau Scientifique et Technique du MEDDE. Bron, France, Juin 19-21.


Bicycle simulator
Ifsttar