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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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
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.

- 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
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,...
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
Road profile

Road Profile

Road Construction

- Qualify serviceability of road pavement

Vehicle safety

- Inputs (vehicle 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*)

Reconstruction by Inertial Method (GMR)

**APL measure**

The image shows a diagram of a vehicle with various components labeled, including:
- Laser sensor
- Vertical accelerometer
- Inertial pendulum
- Road profile
- Damper
- Wheel carrier arm
- Chassis

The transfer function is given by:

\[ H(z) = K \frac{(1 - z^{-1})(1 + z^{-1})^2}{(1 - p_0 z^{-1})(1 - p_1^2 z^{-1})(1 - p_2 z^{-1})(1 - p_3 z^{-1})} \]
Inertial Method

Profile = Z − U
Profile: APL and inertial method
Position of the plates on the track

Plate on the track

Environ 200m
39 m
10 mm
8 mm
1 m
1 m

Plate 1
Plate 2

Environ 200m
Reconstruction of the two plates
**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 ..)

\[ \mu \Rightarrow 0 \quad \text{The road is icy} \]

\[ \mu \Rightarrow 0.3 \quad \text{The road is sliding} \]

\[ \mu \Rightarrow 0.6 \quad \text{The road is wet} \]

\[ \mu \Rightarrow 1 \quad \text{The adhesion is maximum and the tire / ground contact is considered excellent} \]

*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

[Diagram of a vehicle with labeled parts: masses, springs, dampers, and forces.]
Vehicle model

Driver Inputs
- Steering wheel
- Engine speed
- Load
- Pressure

States
- Direction
- Engine
- Braking
- Aerodynamic
- Suspension
- Pneumatic

Components:
- Engine
- Transmission
- Tires-pavement
- Brakes
- Commands
- Steering
- Forces
- Trajectory
The angle at the steering wheel is usually measured
In order to obtain the engine torque, the engine field map is used.

**Engine Torque related to speed**

<table>
<thead>
<tr>
<th>Régime (tr/min)</th>
<th>Charge (%)</th>
<th>correc.</th>
<th>Servit.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.0</td>
<td>1.5</td>
<td>22.0</td>
</tr>
<tr>
<td>200</td>
<td>0.0</td>
<td>2.00</td>
<td>5.50</td>
</tr>
<tr>
<td>1000</td>
<td>0.0</td>
<td>1.30</td>
<td>5.00</td>
</tr>
<tr>
<td>1500</td>
<td>-1.50</td>
<td>1.30</td>
<td>4.60</td>
</tr>
<tr>
<td>2000</td>
<td>-3.50</td>
<td>2.00</td>
<td>4.00</td>
</tr>
<tr>
<td>3000</td>
<td>-4.00</td>
<td>1.00</td>
<td>4.00</td>
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<tr>
<td>4000</td>
<td>-4.50</td>
<td>0.0</td>
<td>3.00</td>
</tr>
<tr>
<td>5000</td>
<td>-5.00</td>
<td>-1.00</td>
<td>1.20</td>
</tr>
<tr>
<td>5500</td>
<td>-5.50</td>
<td>-2.00</td>
<td>0.0</td>
</tr>
<tr>
<td>5750</td>
<td>-6.00</td>
<td>-3.00</td>
<td>-2.00</td>
</tr>
<tr>
<td>correc.</td>
<td>1.20</td>
<td>1.00</td>
<td>0.99</td>
</tr>
</tbody>
</table>

Peugeot 406, type de moteur : Essence
Engine map
**Braking torque**

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

<table>
<thead>
<tr>
<th></th>
<th>Pression (bar)</th>
<th>0.0</th>
<th>15.00</th>
<th>30.00</th>
<th>45.00</th>
<th>60.00</th>
<th>75.00</th>
<th>90.00</th>
<th>105.00</th>
<th>120.00</th>
<th>1.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>Couple train 1 gauche (m.daN)</td>
<td>0.0</td>
<td>50.00</td>
<td>100.00</td>
<td>150.00</td>
<td>200.00</td>
<td>250.00</td>
<td>300.00</td>
<td>350.00</td>
<td>400.00</td>
<td>0.57</td>
<td></td>
</tr>
<tr>
<td>Couple train 1 droite (m.daN)</td>
<td>0.0</td>
<td>50.00</td>
<td>100.00</td>
<td>150.00</td>
<td>200.00</td>
<td>250.00</td>
<td>300.00</td>
<td>350.00</td>
<td>400.00</td>
<td>0.65</td>
<td></td>
</tr>
<tr>
<td>Couple train 2 gauche (m.daN)</td>
<td>0.0</td>
<td>10.00</td>
<td>20.00</td>
<td>30.00</td>
<td>40.00</td>
<td>50.00</td>
<td>60.00</td>
<td>70.00</td>
<td>80.00</td>
<td>0.70</td>
<td></td>
</tr>
<tr>
<td>Couple train 2 droite (m.daN)</td>
<td>0.0</td>
<td>10.00</td>
<td>20.00</td>
<td>30.00</td>
<td>40.00</td>
<td>50.00</td>
<td>60.00</td>
<td>70.00</td>
<td>80.00</td>
<td>0.70</td>
<td></td>
</tr>
</tbody>
</table>

**Braking torque related to pressure**
Dynamic chassis behavior

3 translation movements
- Longitudinal
- Transversal
- Vertical

3 rotational movements
- Roll
- Pitch
- Yaw
Roll

Pitch
\[
\begin{align*}
\mathbf{m} \begin{bmatrix}
\dot{v}_x \\
\dot{v}_y \\
\dot{v}_z
\end{bmatrix} &= \mathbf{T}_r \begin{bmatrix}
Fx_f1 + Fx_f2 + Fx_r1 + Fx_r2 \\
Fy_f1 + Fy_f2 + Fy_r1 + Fy_r2 \\
Fz_f1 + Fz_f2 + Fz_r1 + Fz_r2
\end{bmatrix} \\
\mathbf{T}_r &= \begin{bmatrix}
\cos \theta \cos \psi & \sin \theta \sin \phi \cos \psi & \cos \theta \sin \phi \cos \psi + \sin \theta \sin \phi \\
\cos \phi \cos \psi & \sin \theta \sin \phi \sin \psi + \cos \theta \cos \psi & \cos \theta \sin \theta \sin \phi - \sin \theta \cos \psi \\
-\sin \psi & \sin \theta \cos \phi & \cos \theta \cos \phi
\end{bmatrix}
\end{align*}
\]

\[
\mathbf{J} \begin{bmatrix}
\ddot{\theta} \\
\ddot{\phi} \\
\ddot{\psi}
\end{bmatrix} = \begin{bmatrix}
(F_z f_1 - F_z f_2)p_f + (F_z r_1 - F_z r_2)p_r \\
-(F_z f_1 + F_z f_2)r_1 + (F_z r_1 + F_z r_2)r_2 \\
[(F_y f_1 + F_y f_2)r_1 - (F_y r_1 + F_y r_2)r_2 + (F_x f_2 - F_x f_1)p_f + (F_x r_2 - F_x r_1)p_r]
\end{bmatrix}
\]
Suspension modeling

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

\[
\begin{align*}
F_{zri} &= k_{ri} (z_{ri} - u_i) + B_{ri} (\dot{z}_{ri} - \dot{u}_i) \quad ; \quad i = 1, 2 \\
F_{zfi} &= k_{fi} (z_{fi} - u_j) + B_{fi} (\dot{z}_{fi} - \dot{u}_j) \quad ; \quad j = 3, 4
\end{align*}
\]
Longitudinal modeling

\[ f_{xi} = \mu f_{ni}, \ i = 1..4 \]

\( f_{xi} \) Longitudinal force
\( f_{ni} \) Normal force
\( \mu \) Road adhesion coefficient

[Graph: Longitudinal Force in function of \( f_n \) at given Velocity]

\( f_n \) at 50 km/h
In the acceleration or braking phases, a driving or braking torque is applied to the tire $\Rightarrow$ a longitudinal force is generated at the contact surface.

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

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

$$\left\{ \begin{array}{ll}
\lambda = \frac{rw}{v_x} - 1 & \text{si } v_x > rw \Rightarrow \text{braking} \\
\lambda = 1 - \frac{rw}{v_x} & \text{si } v_x < rw \Rightarrow \text{acceleration} 
\end{array} \right.$$
Note: Forces in kg as per original reference. 400 kg load.
**Lateral modelling**

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

$F_y$ : Lateral force

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

$C_y$ : Stiffness coefficient

$\delta_f$ : Side slip angle

$\psi$ : Yaw speed
In the case of small slip angles (pseudo slip area) :

\[ \mu = C_1 (1 - e^{-C_2 \lambda}) - C_3 \lambda \]  

(Burckhardt Model*)

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

\[ Y(X) = y(x) + S_y \]

\[ y(x) = D \sin(C \arctan(Bx - E(Bx - \arctan(Bx)))) \]

\[ x = X + S_h \]

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

Wheel’s rotational movement

\[ J \dot{w} = \tau - r F_x \]

- \( w \): 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
• Vertical, transverse and longitudinal accelerometers
• Vertical wheels accelerometers
• Vertical, transverse and longitudinal gyroimeters (roll, pitch and yaw)
• Suspension displacements sensors
Accelerometers and gyrometers box
Laser
Accéléromètre
Validation

Driver commands → Vehicle model → Simulated results → Data acquisition → Analysed data → Comparison

Instrumented vehicle
Validation results

Vertical displacements of wheels

Wheels speeds
Vertical displacements of chassis

Vertical acceleration of chassis
Impact forces identification

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

[Diagram showing the flow of data and processes: Vehicle Model, SM Observer, Estimator, Infrastructure database, and Steering angle.]

1. Infrastructure database
2. Steering angle
3. Vehicle Model
4. SM Observer
5. Estimator
6. Methodology

Equations:
- $Y$
- $\hat{X}$
- $F_n$
System (S)\[\begin{align*}
\dot{x}_1 &= x_2 \\
\dot{x}_2 &= M^{-1}(F_g - C(x_1, x_2)x_2 - K(x_1)) \\
y &= x_1
\end{align*}\]

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

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

Vertical displacements
\[\begin{align*}
z_{r1} &= z - q_1 + \frac{T}{2} \sin(\theta) - r \\
z_{r2} &= z - q_2 - \frac{T}{2} \sin(\theta) - r
\end{align*}\]

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

Vertical forces
\[F_{ni} = F_{ci} + k_i (u_i - z_{ni}), i = 1..4\]
\[
\ddot{z}_{r1} = (B_1\dot{q}_1 + K_1 \frac{T_w}{2} \sin(\phi) + B_1 \frac{T_w}{2} \cos(\phi) \dot{\phi} \\
+ K_1 q_1 - k_1 z_{r1} + k_1 u_1)/m_1 \\
\ddot{z}_{r2} = (B_2\dot{q}_2 - K_2 \frac{T_w}{2} \sin(\phi) - B_2 \frac{T_w}{2} \cos(\phi) \dot{\phi} \\
+ K_2 q_2 - k_2 z_{r2} + k_2 u_2)/m_2
\]
Second order sliding mode observer

\[
\begin{aligned}
\dot{\hat{x}}_1 &= \hat{x}_2 + Z_1 \\
\dot{\hat{x}}_2 &= f(\hat{x}_1, \hat{x}_2, u) + Z_2
\end{aligned}
\]

\[
\begin{aligned}
Z_1 &= \lambda \left| \hat{x}_1 \right|^{1/2} \text{sign}(x_1 - \hat{x}_1) \\
Z_2 &= \alpha \text{sign}(\hat{x}_1)
\end{aligned}
\]

Dynamic states errors:

\[
\begin{aligned}
\dot{\tilde{x}}_1 &= \tilde{x}_2 - Z_1 \\
\dot{\tilde{x}}_2 &= F(x_1, x_2, \hat{x}_2) - Z_2
\end{aligned}
\]

\[
F(x_1, x_2, \hat{x}_2) = f(x_1, x_2, u) - f(\hat{x}_1, \hat{x}_2, u)
\]
Convergence analysis

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

\[ f^+ = 2\text{Max}|x_2| \]

\[ \alpha > f^+ \]

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

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

\[ \begin{align*}
\dot{x}_1 &= \dot{x}_2 - Z_1 \rightarrow 0 \\
\dot{x}_2 &= F(x_1, x_2, \hat{x}_2) - Z_2 \rightarrow 0
\end{align*} \]
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
Test bench
Vehicle inputs (road profile)

Vehicle inputs (road profile)

Vehicle inputs (road profile)

Vehicle inputs (road profile)
Roll angle estimation

Suspension deflection estimation
Impact force estimation
2. Experiments with ALF

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

Rollover simulation

Speed limit respected (30km/h)
Rollover simulation

Speed limit not respected (45km/h)
Rollover simulation

Load Transfer
Rollover risk prediction system

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

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

Recommended speed
Lateral acceleration limit
Rollover risk prediction
Load Transfer
Rollover simulation

Data Analysis

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

\[ \text{LTR (Load Transfer Ratio)} \]

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

\[ < R_{lim} = 1 \]

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

\[ \sum F_{z,r} = 0 \Rightarrow \text{Right wheel lift off the road} \Rightarrow \text{rollover risk} \Rightarrow \text{LTR} = -1. \]

\[ \sum F_{z,l} = 0 \Rightarrow \text{Left wheel lift off the road} \Rightarrow \text{rollover risk} \Rightarrow \text{LTR} = 1. \]

\[ \sum F_{z,r} = \sum F_{z,l} \Rightarrow \text{No rollover risk} \Rightarrow \text{LTR} = 0. \]
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

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

\[
\begin{align*}
\ddot{z}_{r1} &= (K_1q_1 - K_1 \frac{T}{2} \sin(\phi) + B_1\dot{q}_1 - B_1 \frac{T}{2} \cos(\phi)\dot{\phi} - k_1z_{r1} + k_1u_1) \frac{1}{m_1} \\
\ddot{z}_{r2} &= (K_2q_2 + K_2 \frac{T}{2} \sin(\phi) + B_2\dot{q}_2 + B_2 \frac{T}{2} \cos(\phi)\dot{\phi} - k_2z_{r2} + k_2u_2) \frac{1}{m_2} \\
\ddot{z} &= (K_1q_1 + K_2q_2 + (K_1 - K_2) \frac{T}{2} \sin(\phi) + B_1\dot{q}_1 + B_2\dot{q}_2 - (B_1 - B_2) \frac{T}{2} \cos(\phi)\dot{\phi}) \frac{1}{M}
\end{align*}
\]

\[
\begin{align*}
z_{r1} &= z - q_1 + \frac{T}{2} \sin(\phi) - r \\
z_{r2} &= z - q_2 - \frac{T}{2} \sin(\phi) - r
\end{align*}
\]

\(z\): Centre heigh of gravity  
\(r\): wheel 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

\[
\begin{align*}
\dot{x}_1 &= \hat{x}_2 - \lambda_0 |\hat{x}_1 - x_1|^{2/3} \text{sign}(\hat{x}_1 - x_1) \\
\dot{x}_2 &= \hat{x}_3 - \lambda_1 |\hat{x}_2 - \hat{x}_1|^{1/2} \text{sign}(\hat{x}_2 - \hat{x}_1) \\
\dot{x}_3 &= -\lambda_2 \text{sign}(\hat{x}_3 - \hat{x}_2)
\end{align*}
\]

\(\hat{x}_1, \hat{x}_2, \text{ and } \hat{x}_3\) are the estimated of \(x_1, x_2\) and \(\dot{x}_2\)

\(\lambda_0, \lambda_1, \text{ and } \lambda_2\) are the observer gains

Dynamics error:

\[
\begin{align*}
\ddot{x}_1 &= x_2 - \dot{x}_2 + \lambda_0 |\hat{x}_1 - x_1|^{2/3} \text{sign}(\hat{x}_1 - x_1) \\
\ddot{x}_2 &= \dot{x}_2 - \dot{x}_3 + \lambda_1 |\hat{x}_2 - \dot{x}_1|^{1/2} \text{sign}(\hat{x}_2 - \dot{x}_1) \\
\ddot{x}_3 &= \ddot{x}_2 + \lambda_2 \text{sign}(\hat{x}_3 - \dot{x}_2)
\end{align*}
\]
\[
\begin{align*}
\ddot{z}_r1 &= (-m_1 \ddot{z}_r1 + B_1 \dot{q}_1 + K_1 \frac{T_w}{2} \sin(\phi)) \\
&\quad + B_1 \frac{T_w}{2} \cos(\phi) \dot{\phi} + K_1 \dot{q}_1 + k_1 u_1)/k_1 \\
\ddot{z}_r2 &= (-m_2 \ddot{z}_r2 + B_2 \dot{q}_2 - K_2 \frac{T_w}{2} \sin(\phi)) \\
&\quad - B_2 \frac{T_w}{2} \cos(\phi) \dot{\phi} + K_2 \dot{q}_2 + k_2 u_2)/k_4
\end{align*}
\]

Suspension deflections and speeds estimated

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

Wheel’s vertical displacements estimated

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

Vertical forces estimated

Load Transfer Ratio calculated
Instrumented vehicle

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

Valbonne site
Chicane test
Suspension deflection

Roll angle
Steering angle

Centre height of gravity estimation
Impact forces estimation
Impact forces compared to LVDT measures
Load Transfer Ratio (LTR)
Steering angle
Suspension deflection

Roll angle
Centre height of gravity estimation

Steering angle
Load Transfer Ratio

Recommended speed
Advantages of the research:

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

$$\begin{align*}
\delta_a &= u_{eq} - G_1|S|^{1/2} \text{sign}(S) + u_i \\
\dot{u}_i &= -G_2 \text{sign}(S) \\
S &= \hat{\gamma} + \lambda \hat{\gamma}
\end{align*}$$

$\lambda$ is a parameter that is typically set to 1 for this case.
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.

\[ y_r = y_1 + \psi \]

The control algorithm is defined by:

\[
\begin{align*}
u &= u_{eq} - k_1 |S|^{1/2} \text{sign}(S) + u_1 \\
\dot{u}_1 &= -k_2 \text{sign}(S)
\end{align*}
\]

\[ S = \dot{y}_e + \lambda y_e \]
Simulation results
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
Bicycle simulator

225x55° display

Measurement of the actions on the gears and the brakes

Handlebar force feedback

Fan producing air flow

Passive tilt system

Rear wheel force feedback

Flywheel producing inertia

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