VEHICLE DYNAMICS CONTROL USING BOND GRAPH WITH SLIDING MODE OBSERVERS

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ABSTRACT

This paper deals with the design of a sliding mode observer using Bond graph for the control of the dynamics of a vehicle. The control objective is to define and develop effective procedures making it possible to observe dynamics correctly in a robust way and to detect certain situations sufficiently early. This method is shown to be robust with respect to perturbation and parametric uncertainties. Experimental results illustrate the efficiency of the proposed approach.

Keywords: Bond graphs, sliding mode observers, control, diagnosis workstation design, work measurement, ergonomics, decision support system

1. INTRODUCTION

During these last decades important studies (Hocine,2003),(Rill and,Zbiri 2005), were carried out to integrate driver assistance system with more and more control with a great number of methods of observation, and detection of critical situations. The goal consists to define and develop effective procedures making it possible to observe dynamics correctly in a robust way and to detect certain situations sufficiently early. The vehicles are a complex Dynamics System with unknown inputs (like contact forces, road profile, external perturbations…). Their behaviour is affected by several factors that may depend or not on its structure. The external influence depends mainly on the contact between the pneumatic tyre and the road and the aerodynamic forces introduced by the wind flowing around it. Tire forces affect the vehicle dynamic, performance and behavior properties.

Robust observer with unknown inputs is shown efficient for estimation of road profile and for estimation of the contact forces. Different dynamic controls on the vehicle like tracking, braking and cornering, reduce the friction coefficient. The traction and braking control reduces the wheel slip, and this can be done by the use of sliding mode approach for observation and control. For vehicles and road safety analysis, it is necessary to take into account the contact force characteristics. However, the friction coefficient and different force (like traction force) cannot be directly measured. They are complex to precisely represent by some deterministic model equations. Usually some experimentally fitted and approximated model are used to deduce their values.

In this work we develop a method to observe tire forces. The proposed estimation procedures have to be robust, and can then be used to improve the security detecting some critical driving situation. This estimation can be used in several vehicles control system such as Anti-lock Brake System (ABS), traction control system (TCS), diagnosis systems, etc... An observer is then proposed to estimate the forces and friction coefficient. The estimations are produced using only the angular wheel position and longitudinal velocity as measurement and they are the input to the specially designed robust observer based on the Second Order Sliding Modes (SOSM). (Imsland and al 2006) The method of estimation is verified through simulation with as contact model a “Pacejka Model” (Magic Formula). (Pacejka & al. 1997,2000),

2. OBSERVERS

The readers can find in (M’Sirdi & al. 2003,2007), (Rabhi 2004,2005) the different models of the whole vehicle. In this work, we focus on the use of the sliding mode technique with Bond Graph, to show, that this combination can replace advantageously the classical approaches. We use Second Order Sliding Modes to develop a second order differentiator in order to obtain the tire road friction estimation. (A. Levant,2003), (Fridman2004)

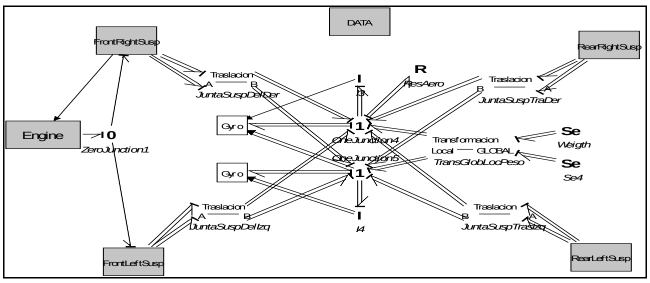


Fig 1: Complete Bond Graph Vehicle

2.1. High Order Sliding Mode Observer (HOSM)

Robust Differentiation Estimator (RDE) is used on this works to deduce our estimations. Consider a smooth dynamics function $s(x) \in \mathbb{R}$. The loop containing this variable may be closed by some possibly-dynamical discontinuous feedback where the control task may be to keep the output $s(x(t)) = 0$.

Then provided that successive total time derivatives $s, \dot{s}, \ddot{s}, \ldots, s^{(r-1)}$ are continuous functions of the state space variables, and the sliding point set is non-empty and consist locally of Filippov trajectories.

$$s = \dot{s} = \ddot{s} = \ldots = s^{(r-1)} \quad (1)$$

The motion on set is called r-sliding mode (rth-order sliding mode). The HOSM dynamics converge toward the origin of surface coordinates in finite time always that the order of the sliding controller is equal or bigger than the sum of a relative degree of the plant and the actuator. To estimate the derivatives s_1 and s_2 we will use the 2nd-order exact robust differentiator of the form.

$$\begin{aligned} \dot{z}_0 &= v_0 = z_1 - \lambda_0 \left|z_0 - s_w\right|^{\frac{2}{3}} sig\left(z_0 - s_w\right) \\ \dot{z}_1 &= v_1 = -\lambda_1 \left|z_1 - v_0\right|^{\frac{1}{2}} sig\left(z_1 - v_0\right) + z_2 \quad (2) \\ \dot{z}_2 &= -\lambda_2 sign\left(z_2 - v_1\right) \end{aligned}$$

where z_0, z_1 and z_2 are the estimate of s_w, s_1 and s_2, respectively, $\lambda_i > 0, i = 0,1,2$. Under condition $\lambda_0 > \lambda_1 > \lambda_2$ the third order sliding mode motion will be established in a finite time.

The obtained estimates are $z_1 = s_1 = \dot{s}_w$ and $z_2 = s_2 = \ddot{s}_w$ can be used in the estimation of the state variables and also in control.

2.2. Cascaded Observers and Estimator

This work uses the previous approach to build the observer and obtain an estimation scheme in 20-Sim.

We produce the estimation in steps using like input the wheel angular position and the longitudinal body speed. The inputs are considered available for measurements.

The robust differentiation observer is used for estimation of the velocities and acceleration of the four wheels.

1st Step: produces estimation of angular velocity of the wheel. The convergence of these estimates is guaranteed in finite time t_0.

$$\begin{aligned} \dot{\theta}_0 &= v = \hat{\omega} - \lambda_0 \left|\theta - \theta_0\right|^{2/3} sign(\theta - \theta_0) \\ \dot{\hat{\omega}} &= v_1 = \dot{\hat{\omega}} - \lambda_1 \left|\hat{\omega} - v_0\right|^{1/2} sign(\hat{\omega} - v_0) \quad (3) \\ \ddot{\hat{\omega}} &= -\lambda_2 sign(\dot{\hat{\omega}} - v_1) \end{aligned}$$

2nd Step: Estimation of the forces F_x (longitudinal) and F_z (vertical).

To estimate the F_x we used the following equation,

$$\hat{F}_x = \frac{(T - J.\dot{\hat{\omega}})}{R_{ef}} \quad (4)$$

The torque could be also estimated by means of use additional equation from engine behavior or measured.

To estimate the F_z we use the following equation,

$$\begin{aligned} \hat{F}_{zf} &= \frac{m}{2.(l_f + l_r)}.(g.l_r - h.\dot{\hat{v}}_x) \\ & \qquad\qquad\qquad\qquad (5) \\ \hat{F}_{zr} &= \frac{m}{2.(l_f + l_r)}.(g.l_f + h.\dot{\hat{v}}_x) \end{aligned}$$

where (21) is for the front axis, and (22) is for the rear axis. $\dot{\hat{v}}_x$ and $\dot{\hat{\omega}}_x$ are produced by the Robust Estimator (RE).

3rd Step: We estimated the friction coefficient or pneumatic adherence.

$$\hat{\mu}_x = \frac{\hat{F}_x}{\hat{F}_z} \quad (6)$$

4th Step: We estimated the Rolling Resistance and Aerodynamics Resistance Force.

$$\begin{aligned} \hat{R}_{rolling} &= 0.01.(1 + \frac{3.6.}{160}\hat{v}_x).\hat{F}_{zi} \\ i &= 1..4 \quad (7) \\ \hat{F}_x^{Aer} &= \frac{1}{2}\rho_{air} C_x A_f . \hat{v}_x^2 \end{aligned}$$

5th Step: We estimated the Slope Angle. (8)

$$\hat{\alpha} = \arcsin(\frac{\hat{F}_x - 1/2\rho_{air} A_{frontal} \hat{v}_{xprom} - \hat{R}_{rolling})}{M_v g}$$

where $\hat{F}_x = \hat{F}_{x1} + \hat{F}_{x2} + \hat{F}_{x3} + \hat{F}_{x4}$

$\hat{R}_{rolling} = \hat{R}_{rolling1} + \hat{R}_{rolling2} + \hat{R}_{rolling3} + \hat{R}_{rolling4}$

are the total traction forces and rolling resistance (each by tire-four wheels).

2.2 Implementation in 20-Sim

The observer is build in 20-Sim with blocks element. 20-Sim admits the interaction between bond graph and signal components (Getting Started with 20-Sim 3.6", *2005)*. We used the bond graph vehicle model to get the powers variables using sensors (flow and effort sensors), and are introduced in the observer and estimator modules like signal mode. The inputs in the observer module are the tire angle position and the measured longitudinal body velocity.

The observer module produces the estimated variables used in the estimator module to get the longitudinal and vertical forces. The friction coefficient is also estimated. Torque is measured with a sensor on the bond graph model, it is an input for the estimator module.

Figure 7 shows the general observer module where the inputs are the measured variables and the outputs are the first and the second derivative estimated. In our work the inputs are the angular position and the longitudinal body velocity, and the outputs are the angular acceleration estimated and longitudinal acceleration estimated. It is possible to get the angle velocity estimated and then the estimated angle acceleration.

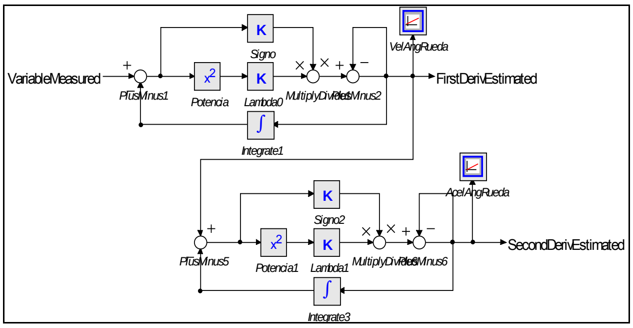


Figure 1: General Observer module with blocks diagram

Figure 8 shows the F_x estimated module, where the inputs are the estimated tire angular acceleration (estimated in the observer module) and the torque measured (or estimated). On this module other parameters are needed to estimate the longitudinal force (F_x) by the equations (18).

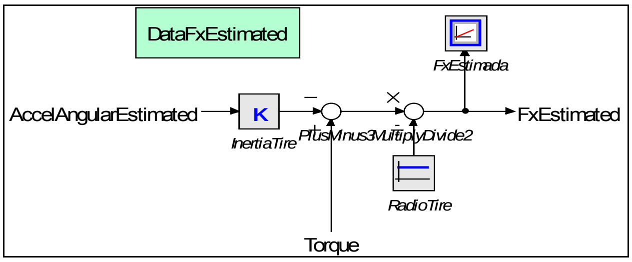


Figure 2: Fx Estimate Module

Figure 9 shows the F_z estimated module, where it has as input the longitudinal acceleration estimated (estimated in the observer module). On this module other parameters are needed to estimate the vertical force (F_z) by the equations (19) and (20).

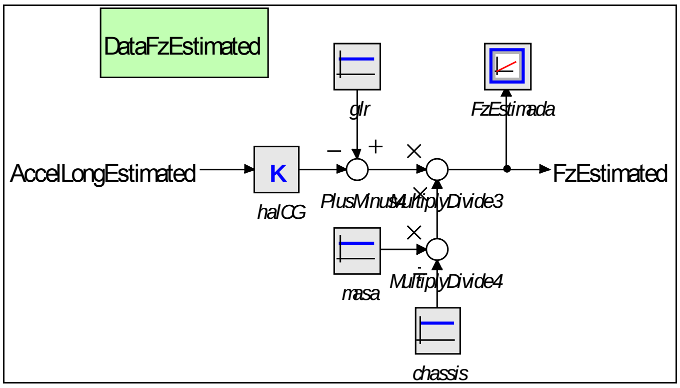


Figure 3: Fz Estimate Module

Figure 10 shows the μ estimated module, where it has as inputs the Longitudinal and Vertical Forces estimated ($\hat{F}_x, \hat{F}_z$) by the equation (21).

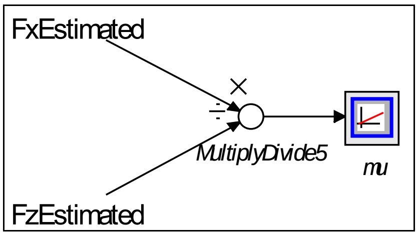


Figure 4: µ Estimate Module

Figure 11 shows the Rolling resistance estimated module, it has as inputs the Longitudinal Velocity measured and Vertical Forces estimated ($\hat{v}_x, \hat{F}_z$) by the equation (22).

This module is used in each wheel to estimate all different rolling resistance. These modes of use make an optimal estimated slope angle, so we can make individual estimation for each wheel.

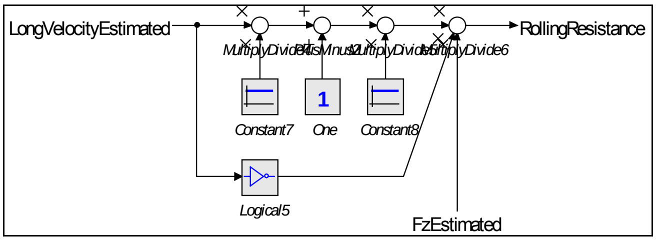


Figure 5: Rolling Resistance Estimate Module

Figure 12 shows the Aerodynamics Resistance estimated module, where it has as input the Longitudinal Velocity ($\hat{v}_x$) by the equation (23). Other coefficients like C_x, Area, ρ_{air} are inputs for the module.

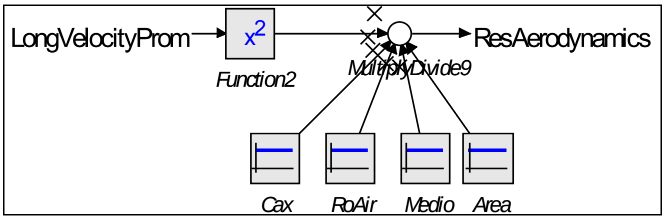


Figure 6: Aerodynamics Resistance Force Estimate Module

Figure 13 shows the complete estimated module for the slope angle, where the inputs are the estimated variables from each wheel. Then we estimate each rolling resistance, and the aerodynamics resistance force. Finally we can obtain the Slope angle estimated by the equation (24). Other coefficients are necessary like inputs for the estimated module.

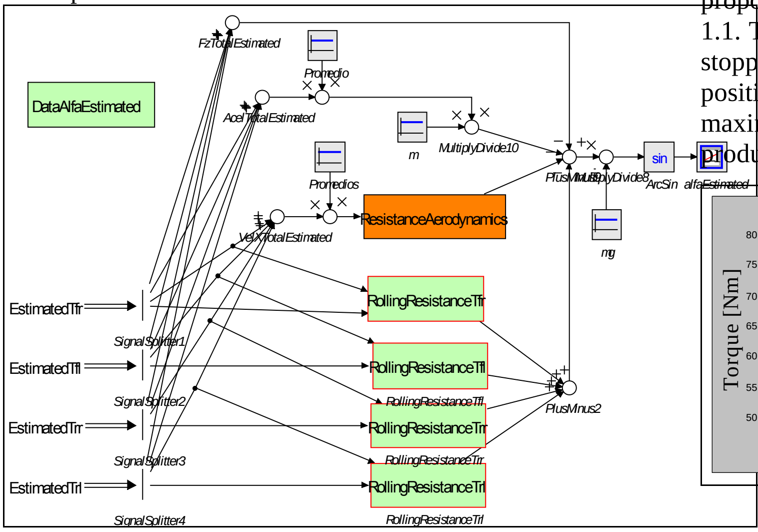


Figure 7: Complete Slope Angle Estimate Module

Figure 14 shows the complete bond graph model for the suspension system, where the mechanical suspension system is modeled with bond graph, sensor placed on the bond graph model and the observer and estimated modules with their signal inputs.

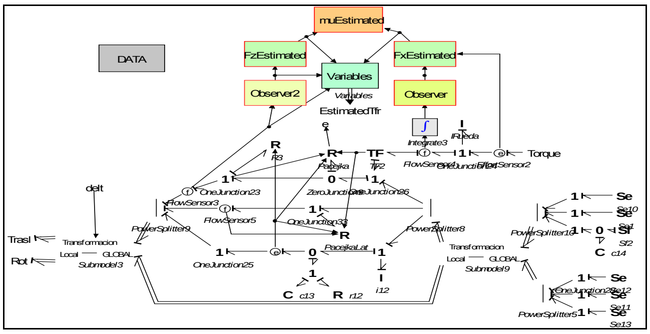


Figure 8: Suspension System with Observer and Estimate modules

Figure 15 shows the complete bond graph model for the vehicle, where we have the BG vehicle model and the Slope Angle Estimated Module.

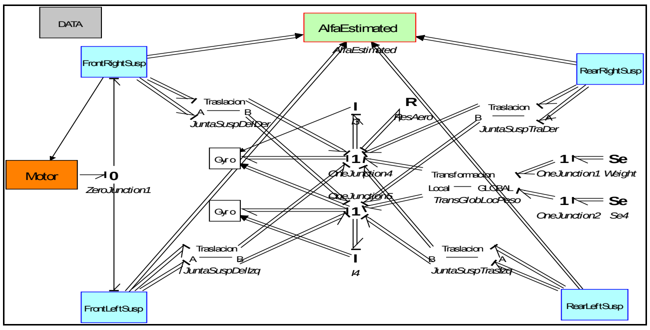


Figure 9: Vehicle BG Model and Slope Estimate Module

3. SIMULATION

In this part we show the results obtained with simulation on 20-Sim. The simulation shows us the behavior of vehicle dynamic and validates our approach and the proposed observers. The state and forces are generated by the Bond Graph Vehicle dynamics proposed. The data used are from a car Renault Clio RL 1.1. The simulation begins with zero velocity (vehicle stopped). On the second 8, the accelerator changes his position from 0 to 1 (the butterfly valve obtains maximum position) and begins the acceleration. It produces a torque from the engine to the traction tires.

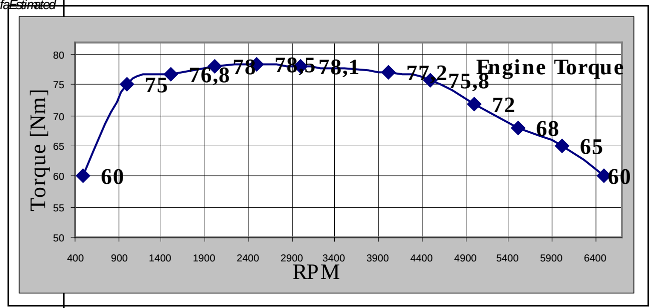


Figure 10: Engine Torque

At time=100 second, the accelerator passes from 1 to 0 causing the deceleration of the vehicle. Figure 17 shows the accelerator profile between 0 and 1 position. We propose a variable slope angle as it presented in table 1.

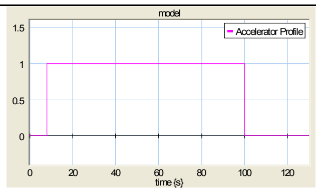


Figure 11: Accelerator Profile

Time	Slope Angle Proposed
0s-10s	0°
10s-20s	5°
20s-50s	10°
>50s	3°

Table 1: Slope Angle Proposed

Figure 18 shows the engine behavior, with the RPM, Torque and speed gearbox. Figure 19 shows the principal behavior of the vehicle, with Speed on axis 'X', Speed on axis 'Z', Pitch Angular Speed, Longitudinal and Vertical Position of the Centre Gravity. Figure 20 shows the Chassis Position on the Z global axis.

Figure 21 shows the tire angular velocity estimated and measured. The figure shows the good convergence to tire angular velocity.

Figure 22 shows the angular acceleration estimated and linear acceleration estimated. The 2^{dn} step on the observer model gives us the estimated longitudinal force F_x and the vertical estimated force F_z. Figure 23 shows the F_x estimated and real (vehicle simulation).

Figure 24 shows the F_z estimated and real (vehicle simulation).

The 3^{rd} step on the observer model gives us the friction coefficient estimated.

Figure 25 shows the friction coefficient tire estimated and the friction coefficient obtained with the Pacejka model.

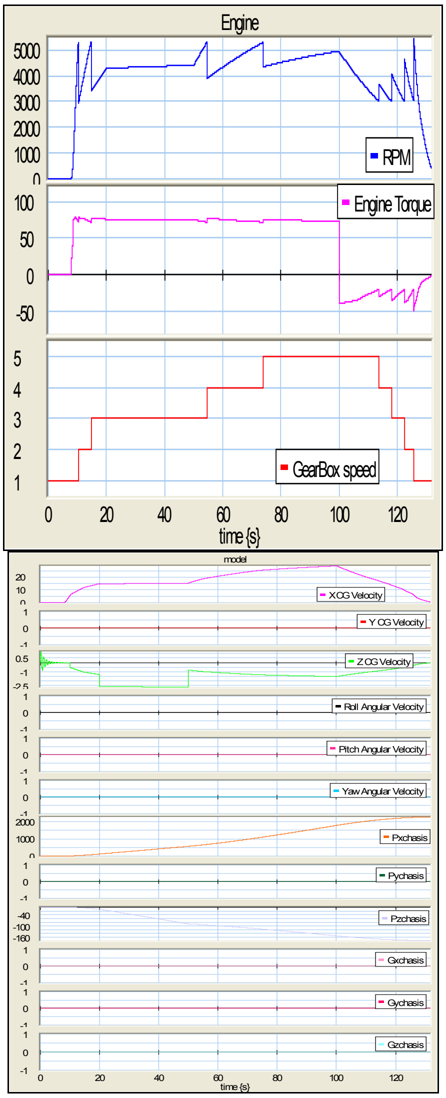


Figure 12: Principal behavior Centre of Gravity, Figure 13: Engine Behavior

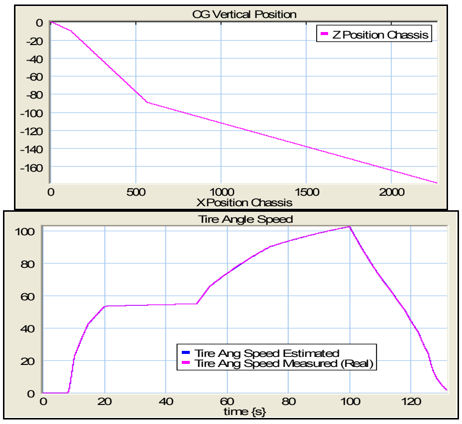


Figure 14: Z Chassis Position Figure 15: Tire Angular velocity Estimated and Measured

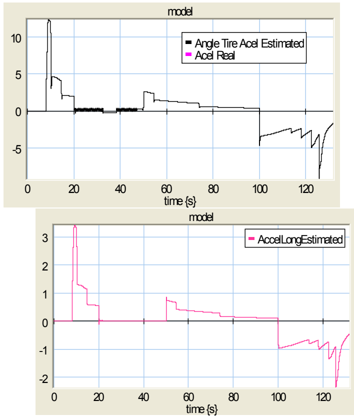


Figure 16: Angular Acceleration and Linear Acceleration Estimated

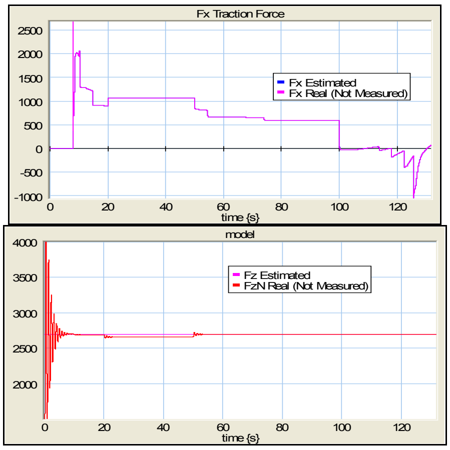


Figure 17: Longitudinal Force Estimated and Simulated; Figure 18: Vertical Force Estimated and Simulated

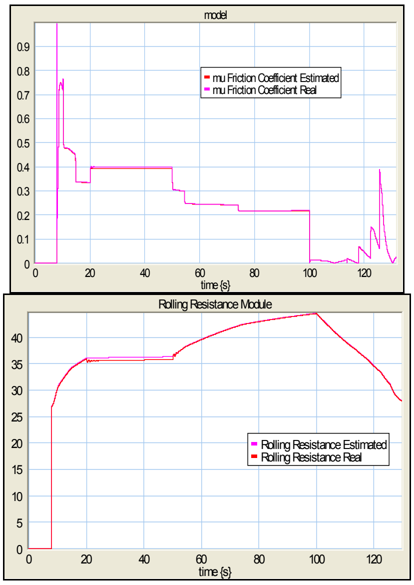
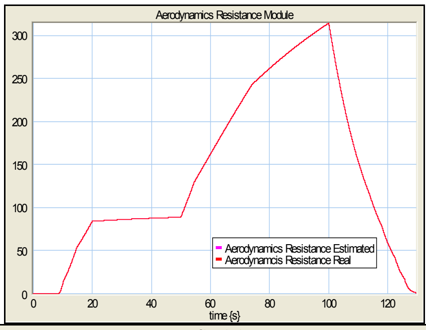


Figure 19: Friction Coefficient Estimated and with the Pacejka Model ; Figure 20: Rolling Resistance Estimated and Simulated

The 4th step on the observer model gives us the estimated rolling resistance and aerodynamics resistance force. Figure 26 shows the estimated and real Rolling resistance. Figure 27 shows the estimated and real Aerodynamics resistance force.



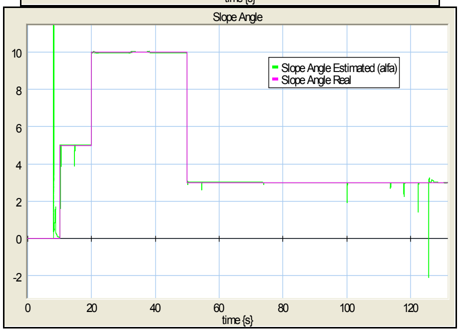


Figure 21: Aerodynamics Resistance Force Estimated and Real; Figure 22: Slope Angle Estimated and Real

The 5th step on the observer model gives us the estimated slope angle.

Figure 28 shows the Slope Angle Estimated and Real proposed by table (1) to the vehicle model.

CONCLUSION

In this work we have developed a method to observe tire forces. The proposed estimation procedures are robust, and can then be used to improve the security by detecting some critical driving situation. This estimation can be used in several vehicles control system such Anti-lock Brake System (ABS), traction control system (TCS), diagnosis systems, etc. An observer was proposed to estimate the forces and friction coefficient. The estimations are produced using only the angular wheel position and longitudinal velocity as measurement and they are the input to the specially designed robust observer based on the Second Order Sliding Modes (SOSM). The method of estimation is verified through simulations using a contact model ,the “Pacejka Model” (Magic Formula) (H.B. Pacejka 1973).

This work presents a vehicle model composed by different modules. We have the chassis like rigid body, the suspension system, the pneumatics tire (Pacejka), transmission and engine. This model was constructed and simulated with the bond graph model in 20-Sim. Then we used the proposed efficient robust estimator, based on the second order sliding mode differentiator, to build an estimation scheme to identify the longitudinal and vertical forces, the friction coefficient, the tire rolling resistance and the slope angle. The estimation converging finite time produced allows us to obtain virtual measurements of model inputs, in five steps by cascade observers and estimators. Using the vehicle model we can compare the estimation variables with real variables (not measurable). These robust estimations on line are necessary for use on vehicle control dynamics. The observer and estimators were constructed and simulated in 20-Sim with the vehicle model.

This form of construction of models allows obtaining more finished and complex models, making possible to improve the definition of variables. It is possible to obtain estimations for different components specifically and individually, achieving a major precision in the estimation of variables. All this is possible with the relative simple construction of models. The plots obtained on the simulation in 20-Sim verify the correct works of the proposed robust observer for the estimation of variables.

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