Estimation of longitudinal and lateral velocity of vehicle

Conference Paper · July 2009

DOI: 10.1109/MED.2009.5164605 · Source: IEEE Xplore

Estimation of Longitudinal and Lateral Velocity of Vehicle

B. JABALLAH, N. K. M'SIRDI, A. NAAMANE and H. MESSAOUD

***Abstract*— In this paper, we compare three observers and methods for estimation of the longitudinal and latéral velocity of the vehicle. These methods are based on the First Order Sliding Mode (FOSM), Second Order Sliding Mode (SOSM) and on the use of algebraic approach ALIEN. Their performance are studied using a 16 DoF dynamic simulator.**

***Index Terms*— Vehicle dynamics, Sliding Mode Observers, Algebraic Approach, Robust Observers, Estimation of vehicle velocities.**

I. INTRODUCTION

Vehicle dynamics is often represented by partial and approximate models which have, some times, a variable structure [**?**]. Vehicle dynamics can be seen composed with many passively coupled subsystems: wheels, motor and braking control system, suspensions, steering, more and more inboard and embedded electronics. Several non linear sub models are coupled [2]. These coupling may be time varying and non stationary [**?**]. Approximations have to be made carefully regarding to the desired application [4].

In previous works of our staff a good nominal vehicle model with 16 DOF have been developed and validated for a French vehicle type (P406), [A. El Hadri(2000)]. Several interesting applications was successful and have been evaluated by use of this model before actual results [5]. We have also considered this modeling for estimation of unknown inputs [7], interaction parameters and exchanges with environment [2]. This approach has been used successfully also for heavy vehicles [N. K. M"Sirdi(2006)]. The developed car simulator will be used here to compare observer performances.

In this paper the car model is shortly presented and then partial simple models are used to design observers. The corresponding subsystems and the overall system obey the passivity property [**?**]. This feature justifies the possibility to use sub-models and design robust observers for partial state estimation.

II. VEHICLE MODELING

A. Nominal Vehicle modeling

Consider a fixed reference frame R as in figure (1) and represent the vehicle by the scheme below [3] [8] [1]. The generalized coordinates $q \in R^{16}$ are defined as

$$q^T = [x, y, z, \theta, \phi, \psi, q_{31}, q_{32}, q_{33}, q_{34}, \delta_3, \delta_4, \varphi_1, \varphi_2, \varphi_3, \varphi_4]$$

B. JABALLAH, N.K. M'SIRDI and A. NAAMANE are with LSIS, CNRS UMR 6168, Domaine Univ. St Jerome, Av. Escadrille Normandie - Niemen. 13397, Marseille Cedex 20, France belgacem.jaballah@lsis.org ; nacer.msirdi@lsis.org

B. JABALLAH and H. MESSAOUD are with ATSI, Ecole Nationale d'Ingnieurs de Monastir, rue Ibn El Jazzar, 5019 Monastir, Tunisia

where x, y, and z represent displacements. Angles of roll, pitch and yaw are θ, ϕ et ψ respectively. The suspensions elongations are noted q_{3i}: $(i = 1..4)$. δ_i: stands for the steering angles$(i = 3, 4)$. φ_i: are angles of wheels rotations $(i = 1..4.)$. $\dot{q}, \ddot{q} \in R^{16}$ are respectively velocities and corresponding accelerations.

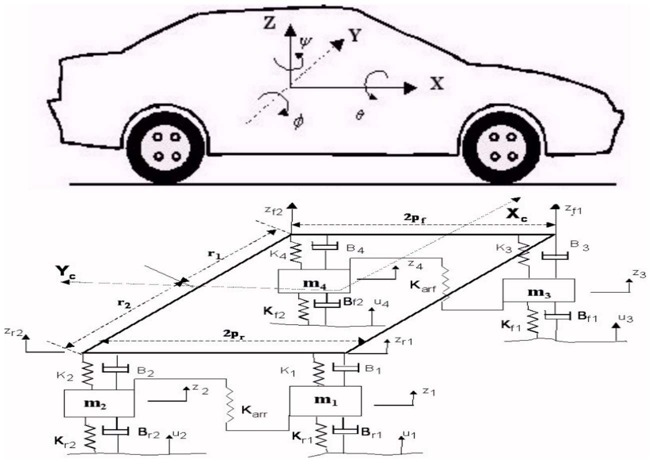

Fig. 1. Vehicle dynamics and reference frames

The Nominal model of the vehicle with uncertainties is developed in assuming the car body rigid and pneumatic contact permanent and reduced to one point for each wheel [2].The 16 Degrees of Freedom model is then equivalent to [9], [3]:

$$\tau = M(q)\ddot{q} + C(q,\dot{q})\dot{q} + V(q,\dot{q}) + \eta_o(t,q,\dot{q}) \quad (1)$$

$$\tau = \Gamma_e + \Gamma = \Gamma_e + J^T F \quad (2)$$

$$\dot{F} = f(\alpha, \lambda, q, F_N) + e(t) \quad (3)$$

$$F_N = h(l_f, l_r, h, g, \dot{v}_x, \dot{v}_y, q, x_{road}, \beta, \gamma) \quad (4)$$

Where

- $M(q)$ represent the matrix of inertia of the system, it is Symmetric Positive Definite (SPD) :

$$M = \begin{bmatrix} \overline{M}_{1,1} & \overline{M}_{1,2} & \overline{M}_{1,3} & 0 & 0 \\ \overline{M}_{2,1} & \overline{M}_{2,2} & \overline{M}_{2,3} & \overline{M}_{2,4} & \overline{M}_{2,5} \\ \overline{M}_{3,1} & \overline{M}_{3,2} & \overline{M}_{3,3} & 0 & 0 \\ 0 & \overline{M}_{4,2} & 0 & \overline{M}_{4,4} & 0 \\ 0 & \overline{M}_{5,2} & 0 & 0 & \overline{M}_{5,5} \end{bmatrix}$$

- $C(q,\dot{q})$ is coriolis and centrifugal forces

$$C = \begin{bmatrix} 0 & \overline{C}_{1,2} & \overline{C}_{1,3} & 0 & 0 \\ 0 & \overline{C}_{2,2} & \overline{C}_{2,3} & \overline{C}_{2,4} & \overline{C}_{2,5} \\ 0 & \overline{C}_{3,2} & \overline{C}_{3,3} & 0 & 0 \\ 0 & \overline{C}_{4,2} & 0 & 0 & 0 \\ 0 & \overline{C}_{5,2} & 0 & 0 & \overline{C}_{5,5} \end{bmatrix}$$

- $J(q) \in R^{16} \times R^{12}$ is the Jacobian matrix depending on the contact points and $R(q) \in R^{12} \times R^{12}$ is the square transformation matrix to convert the force vector from the local frame to the absolute fixed reference frame.

$$J^T = \begin{bmatrix} J_{1,1} & J_{1,2} & J_{1,3} & J_{1,4} \\ J_{2,1} & J_{2,2} & J_{2,3} & J_{2,4} \\ J_{3,1} & J_{3,2} & J_{3,3} & 0 \\ 0 & 0 & 0 & J_{4,4} \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

- F is the input forces vector acting on the wheels. It has 12 components (longitudinal, lateral and normal(F_{xi}, F_{yi}, F_{zi}) forces for each one of the 4 wheels). Forces applied to the wheel i are expressed in a frame attached to wheel i.

$$F = [F_{x1}, F_{y1}, F_{z1}, F_{x2}, F_{y2}, F_{z2}, F_{x3}, F_{y3}, F_{z3}, F_{x4}, F_{y4}, F_{z4}]$$

- Γ represent extra inputs for perturbations.
- $V(q,\dot{q}) = \xi(K_v\dot{q} + K_p q) + G(q)$ are the suspensions and gravitation forces with :
  - Respectively damping and stiffness matrices K_v, K_p
  - $G(q)$ is the gravity term
  - ξ is assumed equal to unity when the corresponding wheel is in contact with the ground and zero if not.

B. Longitudinal and Lateral Dynamics

As we saw previously the vehicle is a complex system. The model (1), despite retaining only nominal dynamics, is too complex and assuming good knowledge of its parameters is not realistic. To reduce complexity while guaranteeing a certain degree of realism and efficacy of modeling, the passive system nature is exploited using a partial model (retaining only the two first equations) [9]. This way, one takes into account, in simplified equations, the longitudinal and lateral dynamic effect on the vehicle model:

$$\dot{V}_x = \dot{\psi}V_y + [F_{x12}\cos(\delta) - F_{y12}\sin(\delta) + F_{x34}] \quad (5)$$
$$\dot{V}_y = -\dot{\psi}V_x + [F_{y12}\cos(\delta) + F_{x12}\sin(\delta) + F_{y34}] \quad (6)$$

with : $F_{x12} = F_{x1} + F_{x2}$ $\quad F_{y12} = F_{y1} + F_{y2}$
$F_{x34} = F_{x3} + F_{x4}$ $\quad F_{y34} = F_{y3} + F_{y4}$ $\quad \delta = \frac{1}{2}(\delta_3 + \delta_4)$

By choosing as components of the state vector $x_1 = (x_{11}, x_{12})^T = (V_x, V_y)^T$, we have $x_2 = (x_{21}, x_{22})^T = (\dot{V}_x, \dot{V}_y)^T$. The inputs of the considered subsystem are the steering angle δ and $\dot{\psi}$ the yaw velocity which can be measured by use of sensors placed in the vehicle. We assume that the vector of velocities x_1 can be measured or deduced by use of accelerometers.
By defining as new system input variables F_1 and Δ as follows:

$F_1 = \begin{pmatrix} F_{x12} & -F_{y12} & F_{x34} \\ F_{y12} & F_{x12} & F_{y34} \end{pmatrix}$ and
$\Delta = \begin{pmatrix} \cos(\delta) \\ \sin(\delta) \\ 1 \end{pmatrix}$,

we can then rewrite the systems equations (5), (6) in the following state space model:

$$\begin{cases} \dot{x}_1 = x_2 \\ \dot{x}_2 = \dot{\psi}\begin{pmatrix} x_{12} \\ -x_{11} \end{pmatrix} + \frac{1}{m}F_1\Delta \\ y = x_1 \end{cases} \quad (7)$$

This one will be used to build robust observers of which performance will be analyzed using the previously presented complete dynamics nominal model for realistic simulations.

III. SLIDING MODE OBSERVERS

As in our previous work cascaded observers are used to estimate partial states of the subsystems of the vehicle and exploiting the feature of the finite time converging estimates we will be able to deduce the unknown inputs and then avoid some technical problems encountered when considering the global model [9].

The Sliding mode technique is an attractive approach for robustness. The primary characteristic of SMC (Sliding Mode Control) is that the feedback signal is discontinuous, switching on one or several manifolds in the state-space. Consider a smooth dynamics function, $s(x) \in \mathbb{R}$. The system 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 $s, \dot{s}, \ddot{s} ... s^{(r-1)}$ are continuous functions of the closed system state space variables, and the r-sliding point set is non-empty and consist locally of Filippov trajectories.

$$s = \dot{s} = \ddot{s} = ... = s^{(r-1)} = 0 \quad (8)$$

In the following parts we will use a First Order Sliding Mode (r=1, $s = 0$) to design a estimate the longitudinal and lateral velocities (V_x,V_y) of the vehicle. Then we will use the Second Order Sliding Mode (r = 2, $s = \dot{s} = 0$) to estimate the same velocities.

A. First Order Sliding Mode Observer (FOSM)

1) The Observer design: To estimate both the longitudinal and lateral velocity (V_x,V_y), we propose in this section to develop an observer with unknown inputs based on the First Order Sliding Mode approach followed by an estimator. This approach is robust versus the model knowledge and the parameters uncertainties for state estimation and is able to reject perturbations and uncertainties effects.
The following First Order Sliding Mode Observer gives the estimates $\hat{x}_1$, $\hat{x}_2$:

$$\begin{cases} \dot{\hat{x}}_1 = \hat{x}_2 + \Lambda_1 sign(x_1 - \hat{x}_1) \\ \dot{\hat{x}}_2 = \hat{\dot{\psi}}\begin{pmatrix} \hat{x}_{12} \\ -\hat{x}_{11} \end{pmatrix} + \frac{1}{m}\hat{F}_1\hat{\Delta} + \Lambda_2 sign(x_1 - \hat{x}_1) \end{cases} \quad (9)$$

Where $\Lambda_1 = diag(\lambda_{11}, \lambda_{12})$ and $\Lambda_2 = diag(\lambda_{21}, \lambda_{22})$ are positive gain matrices, $\hat{F}_1$ and $\hat{\Delta}$ are respectively estimates of the unknown inputs: contact forces F_1 and the steering vector Δ.

The estimations will be produced in two steps as Robust Differentiation Estimators (RDE) and First Order Sliding Mode (FOSM) in order to reconstruct longitudinal and lateral velocity step by step. The figure (2) represent the general scheme of the estimation procedure using cascaded observers.

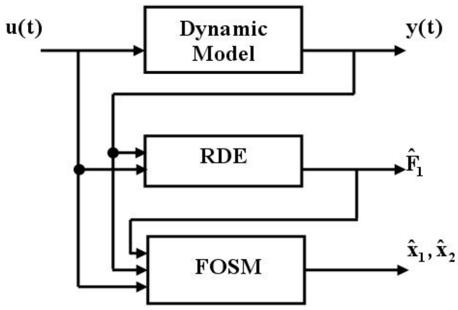

Fig. 2. General diagram of the observer FOSM

1[st] **Step**: Estimation of the forces F_1[9]
In this part we use Robust Differentiation Estimators (RDE) to build an estimation scheme allowing to identify the tire road friction.
2[nd] **Step**: Estimation of the longitudinal and lateral velocity V_x and V_y with the First Order Sliding Mode given by the equations (9).

2) Finite time convergence of the observer: For the convergence analysis, we have to express the state estimation error ($\tilde{x}_1 = \hat{x}_1 - x_1$ *and* $\tilde{x}_2 = \hat{x}_2 - x_2$) dynamics equation. We can study the behavior of the system :

$$\dot{\tilde{x}}_1 = \tilde{x}_2 + \Lambda_1 sign(\tilde{x}_1) \quad (10)$$

$$\dot{\tilde{x}}_2 = \tilde{\dot{\psi}} \begin{pmatrix} \tilde{x}_{12} \\ -\tilde{x}_{11} \end{pmatrix} + \frac{1}{m}\tilde{F}_1\tilde{\Delta} + \Lambda_2 sign(\tilde{x}_1) \quad (11)$$

with $\tilde{\dot{\psi}} = \hat{\dot{\psi}} - \dot{\psi}$, $\tilde{F}_1 = \hat{F}_1 - F_1$, $\tilde{\Delta} = \hat{\Delta} - \Delta$, $\tilde{x}_{11} = \hat{x}_{11} - x_{11}$ and $\tilde{x}_{12} = \hat{x}_{12} - x_{12}$.
The convergence of the 1[st] step is obtained in finite time t_0. For the 2[sd] step we use the technic of Lyapunov. Then the Lyapunov function $V_1 = \frac{1}{2}\tilde{x}_1^T\tilde{x}_1$, help to show that the sliding surface $\tilde{x}_1 = 0$ is attractive if $\dot{V}_1 < 0$ by means we choice of λ_i:

$$|\tilde{x}_{2i}| < \lambda_i \quad for \quad i = 1, 2 \quad (12)$$

The convergence, in finite time ($t_1 > t_0$) for the system state is obtained : $\hat{x}_1$ goes to x_1 in finite time t_1, so $\dot{\tilde{x}}_1 = 0 \ \forall t > t_1$. We can then deduce from equation (10) that $\tilde{x}_2 = -\Lambda_1 sign_{eq}(\tilde{x}_1)$ with $sign_{eq}$ the average value of function "*sign*" in the sliding surface. Then equations (10,11) becomes:

$$\dot{\tilde{x}}_2 = \tilde{\dot{\psi}} \begin{pmatrix} \tilde{x}_{12} \\ -\tilde{x}_{11} \end{pmatrix} + \frac{1}{m}\tilde{F}_1\tilde{\Delta} - \Lambda_2\Lambda_1^{-1}\tilde{x}_2 \quad (13)$$

For equation (13) we take as Lyapunov candidate function: $V_2 = \frac{1}{2}\tilde{x}_2^T\tilde{x}_2$. The derivative of this function is :

$$\dot{V}_2 = \tilde{x}_2^T\dot{\tilde{x}}_2 \quad for \quad t > t_1 \quad (14)$$

$$\dot{V}_2 = \tilde{x}_2^T[\tilde{\dot{\psi}} \begin{pmatrix} \tilde{x}_{12} \\ -\tilde{x}_{11} \end{pmatrix} + \frac{1}{m}\tilde{F}_1\tilde{\Delta} - \Lambda_2\Lambda_1^{-1}\tilde{x}_2] \quad (15)$$

Knowing that $\tilde{F}_1$ is converged in 1[st]**Step** at time t_0 and choosing Λ_2 with λ_{2j} $(j = 1, 2)$ large enough ($\lambda_{2j} > |\tilde{\dot{\psi}} \begin{pmatrix} \tilde{x}_{12} \\ -\tilde{x}_{11} \end{pmatrix} + \frac{1}{m}\tilde{F}_1\tilde{\Delta}|_{max}$), the convergence of $\tilde{x}_2$ to zero is guaranteed in a finite time $t_2 > t_1 > t_0$ then we will have $\dot{\tilde{x}}_2 = 0$, consequently.

B. Second Order Sliding Mode Observer (SOSM)

1) The Observer design: In this subsection we propose an observer based on Second Order Sliding Mode approach, to increase robustness versus parametric uncertainties, modeling errors and disturbances. We propose an observer following the same guidelines as in our previous work in [2][6][7] applying the approach of [11]. As in the previous observer $\hat{x}_1$ and $\hat{x}_2$ are the state estimations.
The proposed observer is the following :

$$\begin{cases} \dot{\hat{x}}_1 = \hat{x}_2 + \Lambda_3|x_1 - \hat{x}_1|^{\frac{1}{2}} sign(x_1 - \hat{x}_1) \\ \dot{\hat{x}}_2 = \hat{\dot{\psi}} \begin{pmatrix} \hat{x}_{12} \\ -\hat{x}_{11} \end{pmatrix} + \frac{1}{m}\hat{F}_1\hat{\Delta} + \alpha sign(x_1 - \hat{x}_1) \end{cases} \quad (16)$$

With $\Lambda_3 = diag(\lambda_{31}, \lambda_{32})$ is a positive gain matrice.

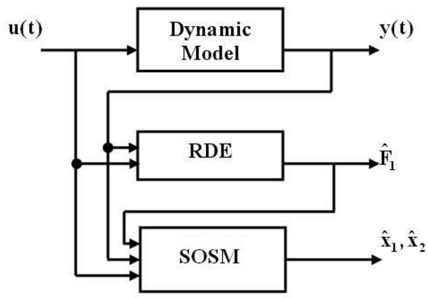

Fig. 3. General diagram of the observer SOSM

2) Finite time convergence of the observer: In order to ensure the stability of the observer, we must find Λ_3 and α. By writing $\tilde{x}_1 = x_1 - \hat{x}_1$ *and* $\tilde{x}_2 = x_2 - \hat{x}_2$, the observation error dynamics is then :

$$\begin{cases} \dot{\tilde{x}}_1 = \tilde{x}_2 + \Lambda_3|\tilde{x}_1|^{\frac{1}{2}} sign(\tilde{x}_1) \\ \dot{\tilde{x}}_2 = \tilde{\dot{\psi}} \begin{pmatrix} \tilde{x}_{12} \\ -\tilde{x}_{11} \end{pmatrix} + \frac{1}{m}\tilde{F}_1\tilde{\Delta} + \alpha sign(\tilde{x}_1) \end{cases} \quad (17)$$

By choosing $\zeta_1 = \tilde{\dot{\psi}} \begin{pmatrix} \tilde{x}_{12} \\ -\tilde{x}_{11} \end{pmatrix} + \frac{1}{m}\tilde{F}_1\tilde{\Delta}$, the preceding system becomes as follows :

$$\begin{cases} \dot{\tilde{x}}_1 = \tilde{x}_2 + \Lambda_3|\tilde{x}_1|^{\frac{1}{2}} sign(\tilde{x}_1) \\ \dot{\tilde{x}}_2 = \zeta_1 + \alpha sign(\tilde{x}_1) \end{cases} \quad (18)$$

As the system (7) has an explicit triangular form with Bounded Input and Bounded State (BIBS in finite time). We can easily see that there exist positive constant C such that $|\tilde{\zeta}_1| \leq C$. Then we can find α and Λ_3 satisfying the inequalities [10] :

$$\begin{aligned} &\alpha > C \\ &\Lambda_3 > \sqrt{\frac{2}{\alpha - C}} \frac{(\alpha+C)(1+q)}{(1-q)} \end{aligned} \tag{19}$$

Where q is some chosen constant, $0 < q < 1$. The observer (16) for the system (7)ensures then a finite time converging states estimations.

C. Simulation results

In this section, we give somme realistic simulation results in order to test and validate our approach proposed observer. In simulation, the state and forces are generated by use of a car simulator with Matlab-Simulink (fig.4). The model block

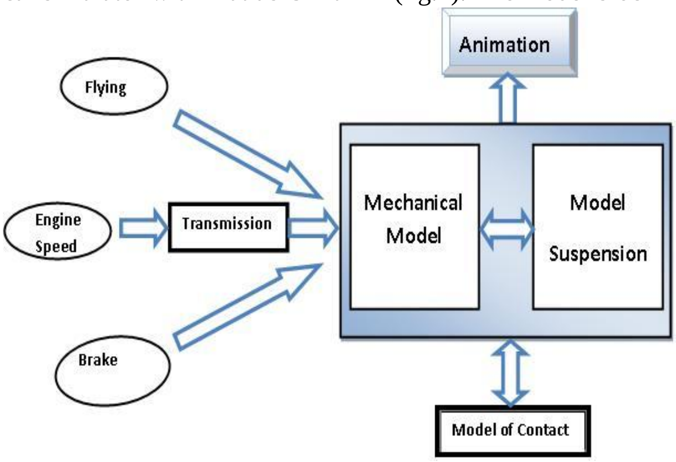

Fig. 4. Modular concept of the simulator

of the vehicle (fig.5) allows the resolution of the differential equation given by (1) and rewritten in following forme:

$$\ddot{q} = M^{-1}(q)(\Gamma + J^T F - C(q,\dot{q})\dot{q} - V(q,\dot{q}) - \eta_o(t,q,\dot{q})) \tag{20}$$

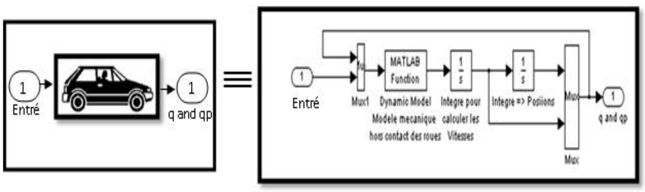

Fig. 5. Simulink block for the resolution of the equations of motion

The validation of this simulator was made for the laboratory LCPC of Nantes by an instrumented car (peugeot 406). The input (steering angle) of model applied is shown in (6a). The figure (6b) represents the variation of longitudinal displacement according to the lateral displacement. The figures (8a) and (8b) represents respectively the estimation of the longitudinal and lateral velocity of the vehicle with the First Order Sliding Mode ($\lambda_{11} = \lambda_{12} = 10$ and $\lambda_{21} = \lambda_{22} = 8$). These figures show the convergence of the estimated velocity to their actual value in finite time.
In figures (8c) and (8d) we show the convergence of respectively the longitudinal and lateral velocity (V_x and V_y) to actual values.

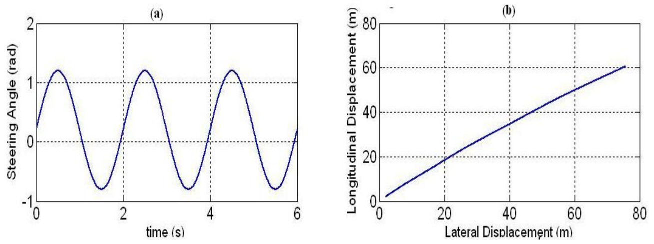

Fig. 6. (a) : Steering angle (b) : Displacements

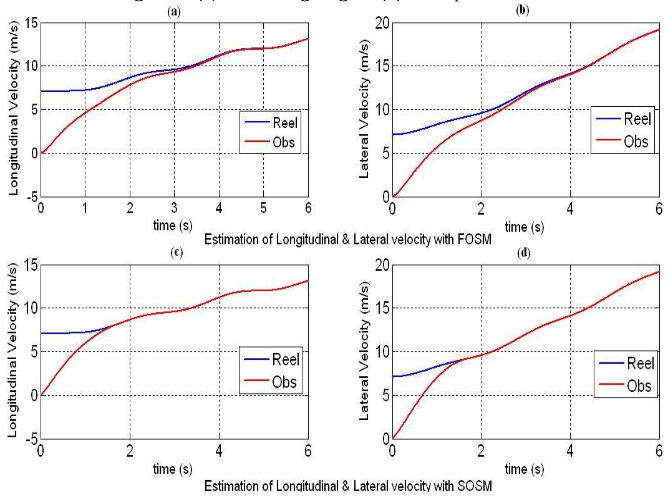

Fig. 7. Estimation of longitudinal and lateral velocity with Sliding Mode

IV. Algebraic Approach

A. Presentation of the Algebraic Approach

(ALIEN) In this part we propose a estimation approach for vehicle velocities at its center gravity [12][13]. It is based on algebraic estimation techniques and diagnosis tools. The considered strategy uses only acceleration equations with respect to a rotating frame:

$$\begin{cases} \gamma_x(t) = \dot{V}_x(t) + \dot{\psi}(t)V_y(t) \\ \gamma_y(t) = \dot{V}_y(t) - \dot{\psi}(t)V_x(t) \end{cases} \tag{21}$$

With V_y, $\dot{\psi}$, γ_x and γ_y are respectively the lateral velocity, the yaw velocity, the longitudinal acceleration, the lateral acceleration.
The longitudinal and lateral velocities (V_x,V_y) cannot be simultaneously estimated from equations (21) if values $V_{x_{t0}}$ and $V_{y_{t0}}$ at initial time t_0 are known. By means of diagnosis tools, the velocities (V_x,V_y) can be written ;

$$\begin{cases} V_x(t) = R_x(t) + G_x(t) \\ V_y(t) = R_y(t) + G_y(t) \end{cases} \tag{22}$$

Where (R_x,R_y) and (G_x,G_y) are respectively the ideal and the disturbing term:

- $R_x = r\omega_t$:
  - r is the static wheel radius,
  - $\omega_t = \frac{1}{4}\sum_{i=1}^{4}\omega_i$ is the mean rotation speed of the 4 wheels,
- $R_y = -L_1\dot{\psi}$:
  - L_1 is the Kart front wheelbase
  - $\dot{\psi}$ is the yaw velocity

By using the two equations, (21) and (22), we obtains the following expressions of $(\dot{R}_x, \dot{R}_y)$:

$$\begin{cases} \dot{R}_x = -\dot{\psi} R_y - \dot{G}_x - \dot{\psi} G_y + \gamma_x \\ \dot{R}_y = \dot{\psi} R_x - \dot{G}_y + \dot{\psi} G_x + \gamma_y \end{cases} \tag{23}$$

we can then write $\dot{G}_x$ and $\dot{G}_y$ by the following form :

$$\begin{cases} \dot{G}_x = -\dot{\psi} G_y - L_1 \dot{\psi}^2 - r\dot{\omega}_t + \gamma_x \\ \dot{G}_y = \dot{\psi} G_x - L_1 \ddot{\psi}^2 - \dot{\psi} r \dot{\omega}_t + \gamma_y \end{cases} \tag{24}$$

with

$$G_x(t_0) = 0 \ ; \ G_y(t_0) = 0 \tag{25}$$

B. Algebraic Approach

By using the equations from the (21) to (25), we propose two algorithms for the estimate of, these algorithms are applied in same time.

1) Algorithm 1: Estimation of V_x
To propose the algorithm of estimate the longitudinal velocity, we suppose that the yaw rate $\dot{\psi}(t)$, longitudinal and lateral acceleration ($\gamma_x(t)$ and $\gamma_y(t)$), 4 wheel's rotation speed $\omega_i(t)$ and lateral velocity estimator $\hat{V}_y(t)$ are measured.

if $|\dot{G}_x(t)| < \varepsilon_1$ **then**

$$\hat{V}_x(t_i) = r\omega_t(t)$$

else

$$\hat{V}_x(t_i) = \hat{V}_x(t_{i-1}) + (\int_{t_i}^{t} \gamma_x + \dot{\psi}\hat{V}_y(t))dt$$

End if

2) Algorithm 2: Estimation of V_y
To propose too the algorithm of estimate the lateral velocity, we suppose that the yaw rate $\dot{\psi}(t)$, longitudinal and lateral acceleration ($\gamma_x(t)$ and $\gamma_y(t)$), 4 wheel's rotation speed $\omega_i(t)$ and longitudinal velocity estimator $\hat{V}_x(t)$ are measured.

if $|\dot{G}_y(t)| < \varepsilon_2$ **then**

$$\hat{V}_y(t_i) = -L_1\dot{\psi}$$

else

$$\hat{V}_y(t_i) = \hat{V}_y(t_{i-1}) + (\int_{t_i}^{t} \gamma_y - \dot{\psi}\hat{V}_x(t))dt$$

End if

C. Simulation and experimental results

With the same steering angle (6a), the car simulator, figure (9), gives us the estimation, figures (7c) and (7d), of the longitudinal and lateral velocity ($V_x(t)$ and $V_y(t)$) found by the algebraic approach ($\varepsilon_1 = 0.15$ and $\varepsilon_2 = 0.8$). The figures (7a) and (7b) we show the evolution of $\dot{G}_x$ and $\dot{G}_y$ with the time.

V. CONCLUSIONS

In this paper, we compare 3 efficient and robust observers allowing to estimate longitudinal and lateral velocities and unknown inputs (forces and wheel steering). These observers obey to the first kind assuming that input forces and torques, which are not modeled for the observer design, are constant or slowly time varying ($\dot{F} \simeq 0$ and $\dot{\delta} \simeq 0$). The robustness of the sliding mode and algebraic observers versus uncertainties on model and parameters is an important feature. ALIEN, First and Second Order Sliding Mode Observers have been compared using a validated simulator and their performance evaluated. Simulation results show effectiveness of their performance.

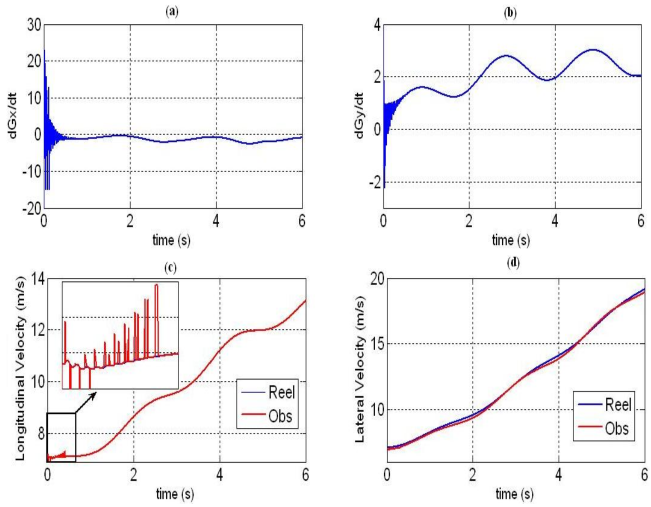

Fig. 8.

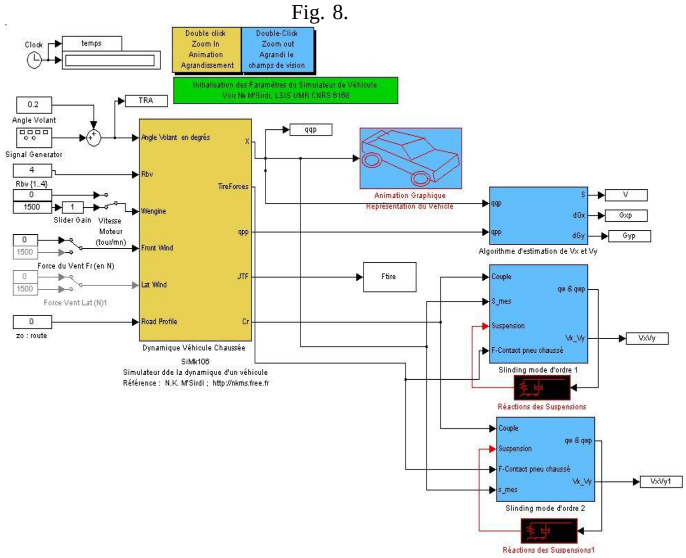

Fig. 9. Car simulator with the 3 methods of estimation

ACKNOWLEDGMENTS

This work has been done in the context of a the GTAA (Groupe Thématique Automatique et Automobile). The GTAA of the GdRMACS is a research group supported by the CNRS.

REFERENCES

[1] K. N. M'Sirdi, A. Rabhi, and A. Naamane. A nominal model for vehicle dynamics and etimation of input forces and tire friction. Conference on control systems, Proceedings of the CSC 07, Marrakech, Maroc, 16-18 mai 2007., 2007.

[2] N.K. M'sirdi, A. Rabhi, N. Zbiri and Y. Delanne. VRIM: Vehicle Road Interaction Modelling for Estimation of Contact Forces. Accepted for TMVDA 04. 3rd Int. Tyre Colloquium Tyre Models For Vehicle Dynamics Analysis August 30-31, 2004 University of Technology Vienna, Austria.

Methods	Measured	Observed	Conditions	Results
FOSM	$\dot{\psi}(t)$ $\delta_3(t)$ $\delta_4(t)$	$F(t)$ $V_x(t)$ $V_y(t)$	$V_{xt0}=0$ $V_{yt0}=0$	a good convergence
SOSM	$\dot{\psi}(t)$ $\delta_3(t)$ $\delta_4(t)$	$F(t)$ $V_x(t)$ $V_y(t)$	$V_{xt0}=0$ $V_{yt0}=0$	a good convergence
ALIEN	$\dot{\psi}(t)$ $\gamma_x(t)$ $\gamma_y(t)$ $\omega_i(t)$	$V_x(t)$ $V_y(t)$	$V_{xt0}=7.0711$ $V_{yt0}=7.0711$	a good convergence only with these conditions

TABLE I

COMPARATIVE TABLE BETWEEN THE THREE METHODS OF ESTIMATION

[3] K. N. M'sirdi, L. H. Rajaoarisoa, J.-F. Balmat, and J. Duplaix. Modelling for control and diagnosis for aclass of non linear complex switched systems. Advances in Vehicle Control and Safety AVCS 07, Buenos Aires, Argentine, February 8-10, 2007.

[4] B. Jaballah, N. K. M'Sirdi, A. Naamane, H. Messaoud. Model Splitting and Robust Observers for Estimation and Diagnosis in vehicles. Submitted to Safe Process 2009.

[A. El Hadri(2000)] N. K. M'Sirdi J.C. Cadiou et Y. Delanne A. El Hadri, G. Beurier. Simulation et observateurs pour l'estimation des performances dynamiques d'un vhicule. *CIFA*, 2000.

[5] A. Rabhi, H. Imine, N. M' Sirdi and Y. Delanne. Observers With Unknown Inputs to Estimate Contact Forces and Road Profile AVCS'04 International Conference on Advances in Vehicle Control and Safety Genova -Italy, October 28-31 2004

[6] N. M' Sirdi, A. Rabhi, L. Fridman, J. Davila and Y. Delanne. Second Order Sliding-Mode Observer for Estimation of Vehicle Parameters. Submitted to IEEE TCST, Octobre 2005, IEEE Transaction on Control Systems Technology.

[7] N. M' Sirdi, A. Rabhi, L. Fridman, J. Davila and Y. Delanne. Second Order Sliding Mode Observer for Estimation of Velocities, Wheel Sleep, Radius and Stiffness.Proceedings of the 2006 American Control Conference Minneapolis, Minnesota, USA, June 14-16, 2006

[N. K. M"Sirdi(2006)] A. Rabhi L. Fridman N. K. M"Sirdi, A. Boubezoul. Estimation of performance of heavy vehicles by sliding modes observers. ICINCO:pp360–365, 2006.

[8] N.K. M'Sirdi, A. Rabhi, and Aziz Naamane. Vehicle models and estimation of contact forces and tire road friction. ICINCO, Invited paper ICINCO:351-358, 2007.

[9] N. K. MSirdi, B. Jaballah, A. Naamane, and H. Messaoud. Robust observers and unknown input observers for estimation, diagnosis and control of vehicle dynamics. IEEE/RSJ International Conference on Intelligent RObots and Systems, Invited paper in the Workshop on Modeling, Estimation, Path Planning and Control of All Terrain Mobile Robots, IROS 08:September 22th 2008, Nice, France. http://wwwlasmea.univ-bpclermont.fr/MEPPC08/MEPPC08final.pdf

[10] Levant, A. Higher-order sliding modes, differentiation and output-feedback control, International Journal of Control, 2003, Vol.76, pp.924-941

[11] J. Davila and L. Fridman. Observation and Identification of Mechanical Systems via Second Order Sliding Modes, 8th. International Workshop on Variable Structure Systems,September 2004, Espana

[12] Jorge Villagra, Brigitte d'Andrea-Novel, Michel Fliess, Hugues Mounier. Estimation of longitudinal and lateral vehicle velocities: an algebraic approach

[13] M. Fliess, C. Join, H. Sira-Ramírez, "Non-linear estimation is easy", Int. J. Modelling Identification Control, vol. 3, 2008 (online http://hal.inria.fr/inria-00158855/en/).