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Vehicle State and Parameters Estimation Using Sliding Mode Observer

A. Rabhi[1], N.K. M'sirdi[2]

Abstract— **In this paper, we present a Robust Sliding Mode Observer for systems with unknown Inputs. The system considered is a vehicle model with unknown inputs that represent the attributes of the road (slope and banking of the road). This parameters affect the vehicle dynamic performance and behavior properties. Thus for vehicles and road safety analysis, it is necessary to take into account this parameters. However, slope and banking of road are difficult to measure directly. In this work we deal with a simple model of vehicle and we develop a method to observe slope and banking of the road.**

Keywords— **Nonlinear observer, Sliding Modes, vehicle dynamics, state estimation, slope and road profile.**

I. INTRODUCTION

Studies of accidentologies have shown an important role of the infrastructure in road accidents. Vehicle stability control systems and state estimators commonly use lateral acceleration measurements from accelerometers to calculate lateral acceleration and sideslip angle of the vehicle [1][2]. These acceleration measurements, however, are easily affected by disturbances such as road bank angle and suspension roll induced by suspension deflection. As a result, many researchers have pointed out that detection of the road bank angle and suspension roll is necessary to have satisfactory performance of such systems [3][1][2]. Two common techniques for estimating these values are proposed to integrate inertial sensors directly and to use a physical vehicle model [7][9]. Some methods use a combination or switching between these two methods appropriately based on vehicle states [7][8]. Direct integration methods can accumulate sensor errors and unwanted measurements from road grade and superelevation (side-slope). In addition, methods based on a physical vehicle model can be sensitive to changes in the vehicle parameters and are only reliable in the linear region.

The main objective of our work is therefore to use more available information on the environment, to drive better and to evaluate the behavior (nominal) of a vehicle in its environment. We develop in this paper a robust observers to estimate the attributes of the road (longitudinal and the transversal slopes) [4].

The paper is organized as follows: in section 2 we present the estimation of the slope of road and in section 3, the design of the observer for estimation of transversal slope of road is developed. Some results about the states observation, and road parameters are presented in section 4. Finally, some remarks and perspectives are given in a concluding section.

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II. ESTIMATION OF THE SLOPE OF ROAD

The slope represent an information useful for the systems of help to driving. It influences the longitudinal dynamics of the vehicle. When braking the normal loads of the wheels depend also on the slope.Among the parameters that largely influence a vehicle's performance, road slopes are the most important. It is therefore important to estimate on line the road slopes explicitly or implicity. In addition to the speed controller, many other controllers like the transmission control unit and the anti-lock brake system can benefit from these estimates.

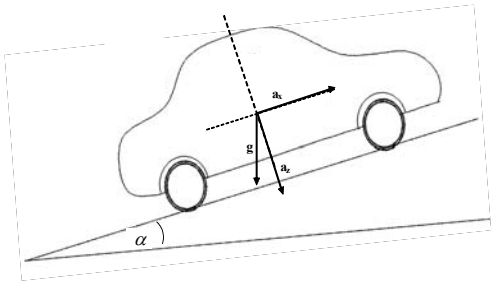

Fig. 1. Presentation of a vehicle in a slope

A. Modeling

We use here the simple longitudinal model, in the case of a longitudinal slope [5][6][4].

we have:

$$M_v\dot{v}_x = F_x - \frac{1}{2}C_{ax}\rho_x v_x^2 - M_v g\sin(\alpha) \quad (1)$$

$$J\dot{\omega} = T_f - R_e F_x \quad (2)$$

where M_v is the vehicle mass and v_x is the linear velocity of the vehicle.

ω is the angular velocity of the considered wheel.

T is the accelerating (or braking) torque, and F_x is the tire/road friction force.

$C_{ax}$is the drag coefficient and ρ_x is air density.

α is the slope (road grade).

B. Observer

In this section we develop a robust second order differentiator [12] to estimate the slope. The estimations will be produced in three steps as cascaded observers and estimator in order to reconstruct information and system states

step by step. For vehicle systems it is very hard to build up a complete and appropriate model for observation of all the system states. Thus in our work, we avoid this problem by means of use of simple and cascaded models suitable for robust observers design.

The first step produces estimations of velocities. The second one estimate the tire forces (longitudinal) and the last step reconstruct the slope.

The robust differentiation observer is used for estimation of the velocities and accelerations of the wheels. The wheels angular positions and the velocity of the vehicles body v_x, are assumed available for measurements. The previous Robust Differentiation Estimator is useful for retrieval of the velocities and accelerations.

1st Step:

$$\begin{aligned}
\dot{\widehat{\theta}} &= v_0 = \widehat{\omega} - \lambda_0 \left|\theta - \widehat{\theta}\right|^{\frac{2}{3}} sign(\theta - \widehat{\theta}) \\
\dot{\widehat{\omega}} &= v_1 = \dot{\widehat{\omega}} - \lambda_1 sign(\widehat{\omega} - v_0)^{\frac{1}{2}} sign(\widehat{\omega} - v_0) \\
\ddot{\widehat{\omega}} &= -\lambda_2 sign(\dot{\widehat{\omega}} - v_1)
\end{aligned}$$

The convergence of these estimates is garanteed in a finite time t_0.

2nd Step:

In the second step we can estimate the forces F_x. Then to estimate F_x we use the following equation,

$$J\dot{\widehat{\omega}} = T - R_{ef}\widehat{F}_x \tag{3}$$

In the simplest way, assuming the input torques known, we can reconstruct F_x as follows:

$$\widehat{F}_x = \frac{(T - J\dot{\widehat{\omega}})}{R_{ef}} \tag{4}$$

$\dot{\widehat{\omega}}$ is produced by the RDE. Note that any estimator with output error can also be used for $\widehat{F}_x$ to enhance robustness versus noise.

After those estimations, their use in the same time with the system equations allow us to retrieve de angle α as follows.

$$\alpha = \arcsin\left[\frac{(\widehat{F}_x - \frac{1}{2}C_{ax}\rho_x\widehat{v}_x^2 - M_v\dot{\widehat{v}}_x)}{M_v g}\right] \tag{5}$$

C. Simulation results

In order to validate our approach, we compared the obtained results with the results given by the Simulator Vedyna while introducing a slope sets up of 15 degrees.

The figure 2 show the estimation of the angular position and velocity. We note that the correct estimation since the values estimated confuse themselves practically with the measures.

The last step gives us the estimated longitudinal forces F_x wich are presented in figure 3.

The observer allows a good estimation of longitudinal forces F_x. The difference is due to the other friction forces that are not taken into account in this model. In a third

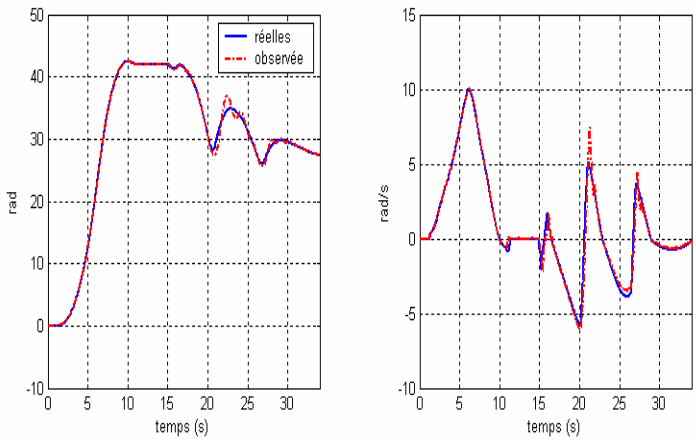

Fig. 2. Estimation of the angular positions and velocity

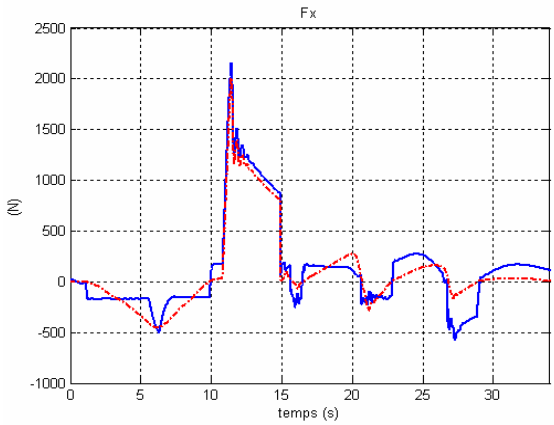

Fig. 3. Longitudinal force $\widehat{F}_x$

step, we apply the differential observer to estimate the longitudinal acceleration that is presented with the estimation of linear speed in figure 4.

We note a good convergence of the estimates in finished time. As consequence of this good estimation, we obtain the estimation of the slope as indicated by the equation 5.

In simulations we have used the simulator Vedyna involving a complete vehicle model. We then note that satisfactory reconstruction of the variables is obtained despite that we have used a very simple model and we neglected the forces of frictions. This emphasizes the robustness of the estimator.

III. ESTIMATION OF THE ROAD BANK ANGLE

Road bank angles have a direct influence on vehicle dynamics and lateral acceleration measurement. A vehicle stability control system that knows road bank angle will have an advantageous capability in achieving desired control sensitivities for maneuvers on ice and snow, among all surfaces, while avoiding false /nuisance activation on a banked road [4].

Figure 6 shows a schematic diagram for a vehicle roll model with road bank angle. It is assumed that the vehicle

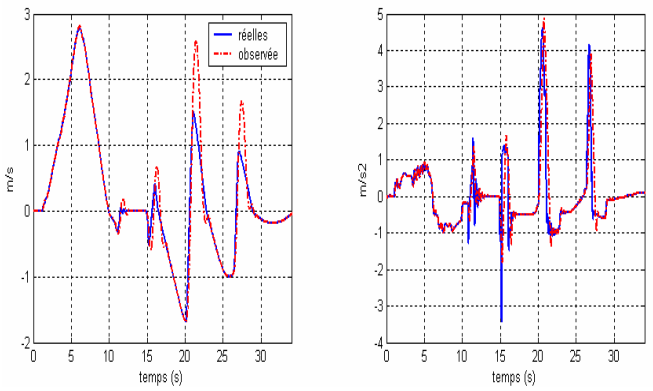

Fig. 4. Estimation of the linaire velocity and acceleration

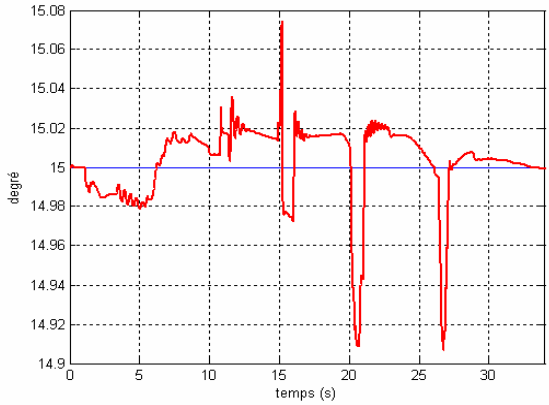

Fig. 5. Estimation of road slope

body rotates around the roll center of the vehicle.

We use in this application a simple model already used and presented in ([10][11]), where

ζ_r: represents the road bank angle

ϕ : is the roll angle

$$\phi = (\varphi - \zeta_r) \tag{6}$$

With an accelerometer we can measure the lateral acceleration a_{ys} :

$$a_{ys} = a_y + g\sin(\phi + \zeta_r) \tag{7}$$

The rotation movement following the x axis is expressed by:

$$J_{xx}\ddot{\phi} + C_r\dot{\phi} + K_r\phi = ma_y h + mg\sin(\phi + \zeta_r) \tag{8}$$

J_{xx}: represents the inertia moment around the x axis

C_r: rumble coefficient of the vehicle

K_r: reminder stiffness

a_{ys}, a_y = lateral accelerometre measurement and bias

Let us replace the equation 6 in 8 we are:

$$J_{xx}\ddot{\varphi} + C_r\dot{\varphi} + K_r\varphi = ma_{ys}h + J_{xx}\ddot{\zeta}_r + C_r\dot{\zeta}_r + K_r\zeta_r \tag{9}$$

we suppose that:

$$\ddot{\zeta}_r = \dot{\zeta}_r = 0 \tag{10}$$

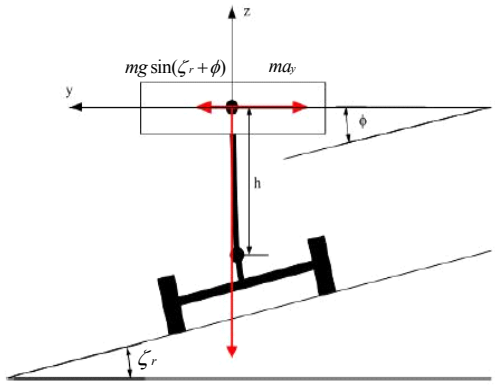

Fig. 6. Vehicle Roll Model

If we put $x_1 = \varphi$, the system can be written under the equation form of state:

$$\begin{cases} x_1 = \varphi \\ \dot{x}_1 = x_2 \\ \dot{x}_2 = \frac{1}{J_{xx}}(-K_r x_1 - C_r x_2 + ma_{ys}h) + K_r\zeta_r \end{cases} \tag{11}$$

We use the robust sliding mode observer:

$$\begin{aligned} \dot{\hat{x}}_1 &= \hat{x}_2 + z_1 \\ \dot{\hat{x}}_2 &= \frac{1}{J_{xx}}(-K_r\hat{x}_1 - C_r\hat{x}_2 + K_r\zeta_r + ma_{ys}h) + z_2 \end{aligned} \tag{12}$$

where $\hat{x}_1$ and $\hat{x}_2$ are estimations, and the variables z_1 and z_2 are corrections calculated by the super-twisting algorithm.

$$\begin{aligned} z_1 &= \lambda|x_1 - \hat{x}_1|^{1/2}\, sign(x_1 - \hat{x}_1) \\ z_2 &= \alpha\, sign(x_1 - \hat{x}_1). \end{aligned} \tag{13}$$

The observer considers the unknown input that represents here the banking as disruptions, to be restored after the convergence in finished time of the estimated states.

IV. Simulation results

We give in this section some results obtained in simulations while using the robust sliding mode observer. We suppose known the different parameters of the model. We did a simulation on VeDyna in which we took the simulated banking as a constant one. The figure 7 present the comparison between the roll angle estimated and the angle given by the Simulator Vedyna. We obtain a good observation.

The estimation of the roll velocity is presented in figure (8), we note a good convergence. Nevertheless, we remarque the appearance of a chattering that comes from to the sign functions.

After the convergence of the states of the system, we restore the unknown input that presents here banking after a low pass filtering. The figure 9 shows the comparison of the estimated road bank angle and the value that we introduced in the simulator VeDyna. We remark finally that the estimated value of the road bank angle converges towards the simulated value.

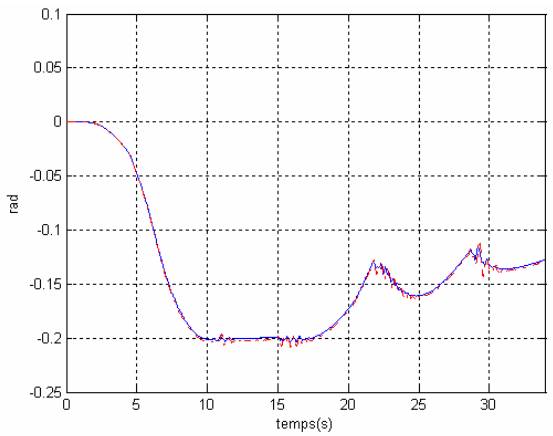

Fig. 7. Estimation of the angle of roulis

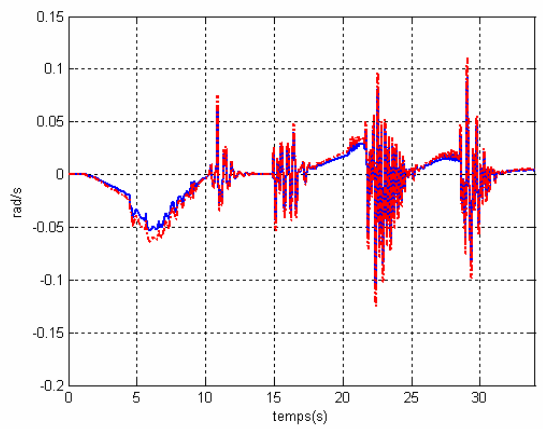

Fig. 8. Estimation of the speed of roulis

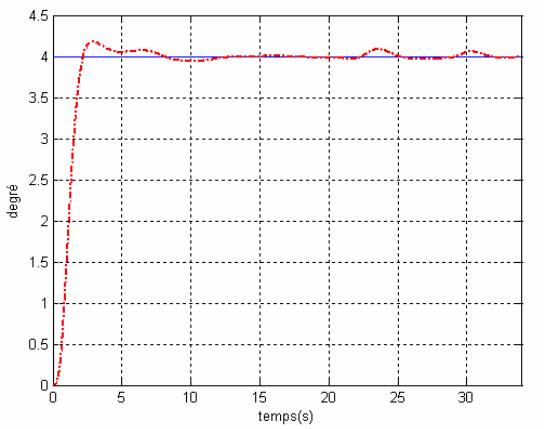

Fig. 9. Estimation of the road bank angle

V. Conclusion

In this paper, we have developed a robust observers with unknown inputs to estimate the attributes of the road (longitudinal and the transversal slopes). A Robust Sliding Mode Observer has been shown efficient for estimation of these unknown Inputs (slope and banking of the road). In this work simple models have been used to develop a robust method to observe slope and banking of the road. The Simulation results involve a complete vehicle model to emphasize performance of the method.

References

[1] H. E. Tseng et al. Development of vehicle stability control at Ford. IEEE/ASME Transactions on Mechatronics, 4(3):223–234, 1999.

[2] A. Y. Ungoren, H. Peng, and H. E. Tseng. Experimental verification of lateral speed estimation methods. In Proceedings of AVEC 2002 6th Int. Symposium on Advanced Vehicle Control, pages 361–366, Hiroshima, Japan, 2002.

[3] A. Nishio et al. Development of vehicle stability control system based on vehicle sideslip angle estimation, 2001. SAE Paper No. 2001-01-0137.

[4] A. Rabhi "Estimation de la dynamique d'un véhicule en interaction avec son environnement", Thèse de doctorat de l'Université de Versailles Décembre 2005.

[5] LINGMAN Peter ; SCHMIDTBAUER Bent "Road slope and vehicle mass estimation using Kalman filtering" Vehicle system dynamics (Veh. Syst. Dyn.) ISSN 0042-3114

[6] Ken Johansson "Road Slope Estimation with Standard Truck Sensors" Master Thesis Department of Signals, Sensors and Systems KTH 2005-04-25

[7] Akitaka Nishio, et. al., "Development of Vehicle Stability Control System Based on Vehicle Sideslip Angle Estimation," SAE Paper No. 2001-01-0137.

[8] Yoshiki Fukada, "Slip-Angle Estimation for Vehicle Stability Control", Vehicle System Dynamics, 1999, v.32, no.4, p.375-388.

[9] Jim Farrelly and Peter Wellstead, "Estimation of Vehicle Lateral Velocity", IEEE Conference on Control Applications – Proceedings, 1996, p.552-557.

[10] J. Ryu, J. Christian "Estimation of Vehicle Roll and Road Bank Angle" American Control Conference, Boston, 2004.

[11] D. Eve, T. Massel and M. Arndt "Fault Tolerant Roll Rate Sensor Monitoring" AVEC'2004.

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