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INTELLIGENT SYSTEMS FOR ELECTRIC VEHICLES

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ABSTRACT
Electrical vehicles are complex electromechanical systems with highly nonlinear dynamics. Hence the electromechanical transmission systems high-performance operation, require a nonlinear control design to fully exploit their capabilities. This paper develops a new approach to Fuzzy-Sliding Mode Control (FSMC), for the robust control in torque and speed within the dynamic model of a transmission system using induction motor propulsion. Are presented also, the elements to design an active vehicle suspension taking into account the influence of the induction motor torque and speed.
Keywords: electric vehicle, fuzzy-sliding mode control, active vehicle suspension.

1. INTRODUCTION
The new U.E. concept of metropolitan area can requests at the level of some cities, planning solutions including new vehicle types. In this aim, the electric vehicles may represent a suitable solution despite they are complex electromechanical systems (battery or fuel cells-electronic converter-induction motor, control and mechanical systems) with highly nonlinear dynamics. In this aim, it has been developed a new Fuzzy-Sliding Mode Control (FSMC), for the robust control in torque and speed of the induction motor and a unified controller structure which is able to work with all kinds of controlled suspensions. This controller requires measuring of five physical quantities (three vertical positions or vertical accelerations and two horizontal accelerations) in order to recover the whole state of the car (single wheel) and its control. Is used the term of *controlled suspension*, as a fully active suspension with hydraulic or electric systems able to deliver prescribed (vertical) forces acting on each wheel, to control the car attitude. A simplified model of the full three-dimensional car is then introduced showing how a single wheel controller may be used as a low-level loop. A high-level loop than distributes the necessary forces on the four wheels, to keep the car in the desired attitude.

2. STRUCTURE OF THE ELECTROMECHANICAL SYSTEM
The electromechanical transmission systems with high performance operation, suitable for the vehicle propulsion, require nonlinear control design to fully exploit their capabilities. Both electrical and mechanical systems are presented in a unified conception, as followings.

2.1. Structure of the electrical system
The structure of the electrical system consists in: supply source (battery or fuel cells), PWM voltage source inverter, induction propulsion motor and control loops for speed and torque. This system based on the variable-structure control has been designed and implemented in a FSMC mode control by using a dSpace digital signal processor TMS320C30. To have good performances in the speed/torque control, a combined sliding mode and fuzzy logic controllers are used, by means of an expert system based on the fuzzy reasoning [1,2,3,7,8]. The new structure embodies the advantages that both nonlinear controllers offer: sliding-mode controller which increases the system stability limits and the

PI - fuzzy logic one which reduces the chattering during the steady state. In accordance with [3], the scheme has been designed with the computer and implemented as an expert system which is used in order to weight the outputs issued from the both nonlinear controllers to get the control action [1,3]. With this system, a good global stability is provided, as experimental work results. The mathematical description related to the induction motor model, PWM inverter losses and control loops design, are presented in [3].

2.2. Structure of the mechanical system

Suspension control has recently become a challenging topic for the car manufacturers with the aim to improve the car comfort and security. This corresponds to the usual trend consisting in providing more control assistance to classical mechanic devices, such as those already present on usual vehicles, at minimum additional cost. We aim to improve the mastering of controlled suspensions and designing a product adaptable to several classes of vehicles.

The comfort aspects may be divided into two different categories: vibrations isolation and keeping the car horizontal as possible. Note that, in the latter category, security and comfort requirements go in synergy [6]. First, is presented a simplified dynamical model of a *quarter car* (single wheel), as seen in the Fig.1 and its control.

After, is introduced a simplified model of the full three-dimensional car, as shown in the Fig.3. We show how the single wheel controller may be used as low-level loop and how a high-level loop then distributes the necessary forces on the four wheels, to keep the car into desired attitude.

3. CAR SIMPLIFIED DYNAMICAL MODEL

We consider the vertical motion of a single wheel with a spring of stiffness k and a variable damper, supporting a mass m. The tyre dynamics (faster than the rest of the model) are neglected.

The road profile (already filtered by the tyre) is denoted by $t \rightarrow w(t)$ and is a perturbation, representing the relative height of the road at the time t. Is denoted by z the difference of height between the actual car position and its equilibrium position $\bar{z}$.

The control u is supposed to affect the characteristics of the damper: the force created by the damper is a function of the input and the velocity difference in the vertical direction between the car and the road.

This force equals $-G(u, \dot{z}-\dot{w})$, where the function G is of the form displayed on the right part, in the Fig.2, for u_{min} (soft) and u_{max} (hard).

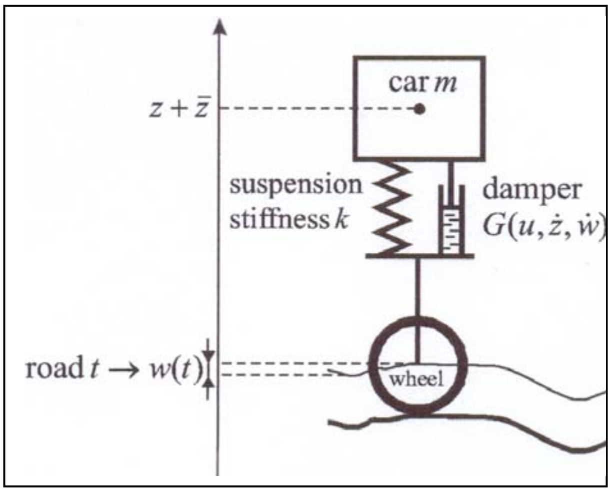

Figure 1. The simplified model of a quarter car.

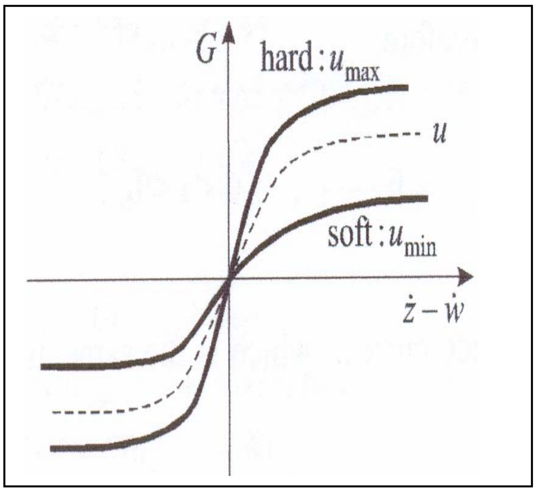

Figure 2. The damping curves.

The curves $\xi \rightarrow G(u, \xi,)$, depicted in the Fig.2, are non decreasing for every u and $G(u, 0)=0$, which reflects that, if $\dot{z}-\dot{w}=0$, the damper is useless for all u. Note that $\xi = \dot{z}-\dot{w}$.

Moreover, the curves of G show that the damper can only oppose itself to vertical motion by creating a positive force, if the car moves up with respect to the road, and a negative force in the opposite case. But it cannot create an arbitrary force, which justifies the name *semi-active suspension*.
The model of a quarter-car is thus:

$$m\ddot{z} = -k(z - w) - G(u, \dot{z} - \dot{w}). \tag{1}$$

Notice that, as a consequence of the properties of G, *the linear tangent model at an equilibrium point* $\left(i.e.\ \ \dot{z} = \dot{w} = 0, \ddot{z} = 0\right)$ *is uncontrollable*. A popular strategy to isolate the car from the ground consists in *hooking the car to the sky*, which represents an idealization of the fact that one wants to design the dumping controller such that the closed-loop system is equivalent to a filter with prescribed characteristics. This is a particular case of feedback linearization. The sky hook strategy and its linearizing control has been presented in [6].

4. FULL CAR SUSPENSION CONTROL

In the Fig.3, a full car in 3 dimensions is represented. It assumes that its chassis is rigid, that the 4 wheels are in the same plane, tangent to the road (as before filtered by the wheels and tyres), and that the tyre dynamics and wheel masses are negligible. The profile *w(t)* is supposed to be equal to the relative height of the wheels.

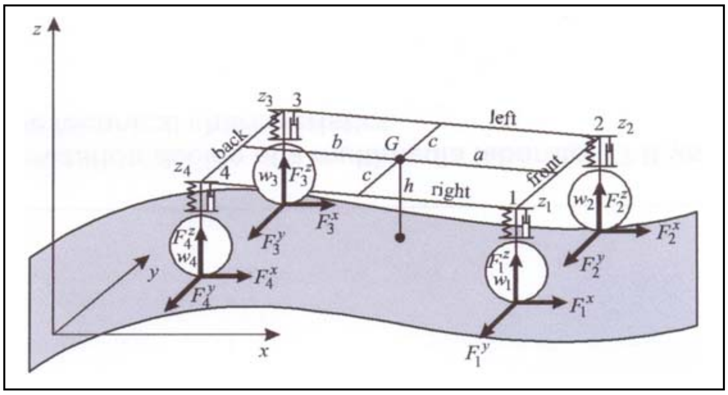

Figure 3.The full car vehicle.

The notations are those of the Fig.3, with θ the pitch angle (rotation around the y axis) and ψ the roll angle (rotation around the x axis). Since we are not interested in the dynamics in the direction of the car's velocity vector, we do not consider the angle of turn (around the z axis). Applying the Newton's second low, are obtained:

$$m\ddot{x}_G = \sum_{i=1}^{4} F_i^x, \quad m\ddot{y}_G = \sum_{i=1}^{4} F_i^y, \quad m\ddot{z}_G = \sum_{i=1}^{4} F_i^z,$$

$$I_y\ddot{\theta} = -h\left(\sum_{i=1}^{4} F_i^x\right) + b\left(F_3^z + F_4^z\right) - a\left(F_1^z + F_2^z\right), \tag{2}$$

$$I_x\ddot{\psi} = +h\left(\sum_{i=1}^{4} F_i^y\right) + c\left(F_2^z + F_3^z\right) - c\left(F_1^z + F_4^z\right),$$

the forces being given by:

$$F_1^z = -k_f\left(z_1 - w_1\right) - G_1\left(u_1, \dot{z}_1 - \dot{w}_1\right) - c_f\left[z_1 - z_2 - \left(w_1 - w_2\right)\right],$$

$$F_2^z = -k_f\left(z_2 - w_2\right) - G_2\left(u_2, \dot{z}_2 - \dot{w}_2\right) + c_f\left[z_1 - z_2 - \left(w_1 - w_2\right)\right], \tag{3}$$

$$F_3^z = -k_r(z_3 - w_3) - G_3(u_3, \dot{z}_3 - \dot{w}_3) - c_r[z_3 - z_4 - (w_3 - w_4)],$$

$$F_4^z = -k_r(z_4 - w_4) - G_4(u_4, \dot{z}_4 - \dot{w}_4) + c_r[z_3 - z_4 - (w_3 - w_4)],$$

with c_r and c_f the stiffness of the respective rear and front anti-roll bars. Assuming that $\ddot{x}_G$ and $\ddot{y}_G$, and the profile w are known functions of time, the system is flat with (z_G, θ, ψ, Γ) as a flat output, where Γ is an arbitrary combination of the damping forces G_1, G_2, G_3 and G_4; the components with respect to x and y of the forces can be eliminated in function of $\ddot{x}_G$ and $\ddot{y}_G$ respectively, and (2) becomes:

$$m\ddot{z}_G = \sum_{i=1}^{4} F_i^z,$$

$$I_y\ddot{\theta} = -hm\ddot{x}_G + b(F_3^z + F_4^z) - a(F_1^z + F_2^z), \tag{4}$$

$$I_x\ddot{\psi} = +hm\ddot{y}_G + c(F_2^z + F_3^z) - c(F_1^z + F_4^z),$$

that is a system of 3 equations with 4 unknowns F_1^z, F_2^z, F_3^z and F_4^z. Adding the afore-mentioned function Γ, the four vertical components of the forces applied to the chassis can thus be inverted in function of (z_G, θ, ψ, Γ) and their derivatives up to the second order. Moreover, note that, if the accelerations $\ddot{x}_G$ and $\ddot{y}_G$ and the vertical accelerations of three distinct points of the chassis are measured, a nonlinear observer may be constructed to compute the road profile and the attitude of the car.

5. CONCLUSIONS

For experiments, a test induction motor with V_N = 120V, I_N = 56A, P_N = 12kW, n_N = 2000rot/min and T_N = 56Nm was used. It was considered a transmission rate of 9,8. Some remarkable curves, as traction characteristics (torque and power) and the transmission total energetic balance, have been presented for the computer aided design of the drive system, in [3]. Results presented in this paper are important from a practical point of view since they provide the traction characteristics for the induction motor. The electrical system is join to the mechanical one combining time scaling considerations with flatness, and producing physically well understood controllers.

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