

CG behaviour analysis has a key role to play when investigating vehicle kinetic equilibrium [2].

The proposed system consists of some fuzzy analyzers: Driver consciousness (DC), data accuracy (DA), dynamic stability (DS) and crisis fuzzy analyzers. Sensor #1- 4 prepare information needed for external crisis analysis. The driving crisis signal is made with two crisis signals: 1) external crisis and 2) internal crisis. Figure 1 shows the whole concept of analysis of driving crisis and dynamic stability system.

THE SUSPENSION, BRAKE AND STEERING SYSTEM DYNAMICS

SUSPENSION SYSTEM MODEL, STATICS AND DYNAMICS

In dynamic analysis points of view the suspension system is an important part of vehicle. We use a simple full-car suspension model. In this section both statics and dynamics of the Spring Mass Damper (SMD) system for the simulation are briefly introduced. We consider both the spring K_p and the damper C_p in the passive mode. The actuator F_a is considered in the dynamics of the vehicle in this paper [3].

In the above full-car model the links between sprung masses are considered to be solid rods (see Figure 2). Then, we can formulate three mechanical equations for pitching, rolling and center of gravity (CG) motion, respectively [4]:

$$\begin{aligned}(F_{A_{fl}} + F_{A_{fr}})l_f - (F_{A_{rl}} + F_{A_{rr}})l_r &= J_p \dot{\omega} \\ (F_{A_{fl}} + F_{A_{rl}})l_l - (F_{A_{fr}} + F_{A_{rr}})d_r &= J_r \dot{\Omega} \\ F_{A_{fl}} + F_{A_{rl}} + F_{A_{fr}} + F_{A_{rr}} &= m_{body} \dot{v}_T\end{aligned}\quad (1)$$

where $m_{body} = m_{b_{fl}} + m_{b_{fr}} + m_{b_{rl}} + m_{b_{rr}}$. These equations lead to the quarter-car links. If some nonlinearities are neglected, a car model describing the impacts of actuators and road irregularities to the vehicle body through the suspension system becomes available.

The dynamics of the SMD system has two important parameters that completely define the dynamics of the SMD system: these are its *undamped natural frequency* and its *damping ratio*. The undamped natural frequency, ω , is given by the expression

$$\omega_n = \sqrt{k'/m}, \text{ in radians/sec.} \quad (2)$$

The un damped natural frequency is the frequency at which the mass will oscillate about the zero reference if the mass is pushed down (or pulled up) and then let go. The actuators cause these movements. Theoretically, the oscillation will go on indefinitely since there is nothing to dissipate the original energy stored in the spring at its initial deflection (the spring is assumed to dissipate no energy. Since $C=0$, the natural frequency is a function only of the mass and the spring rate. As damping is added, frequency (ω_n) tends to reduce with increased C (that is, If damping is light and oscillatory behavior is occurring) [5]. The method of CG position calculation in this paper is based on the height changes. Rectilinear system has been used for height demonstration in the simulation.

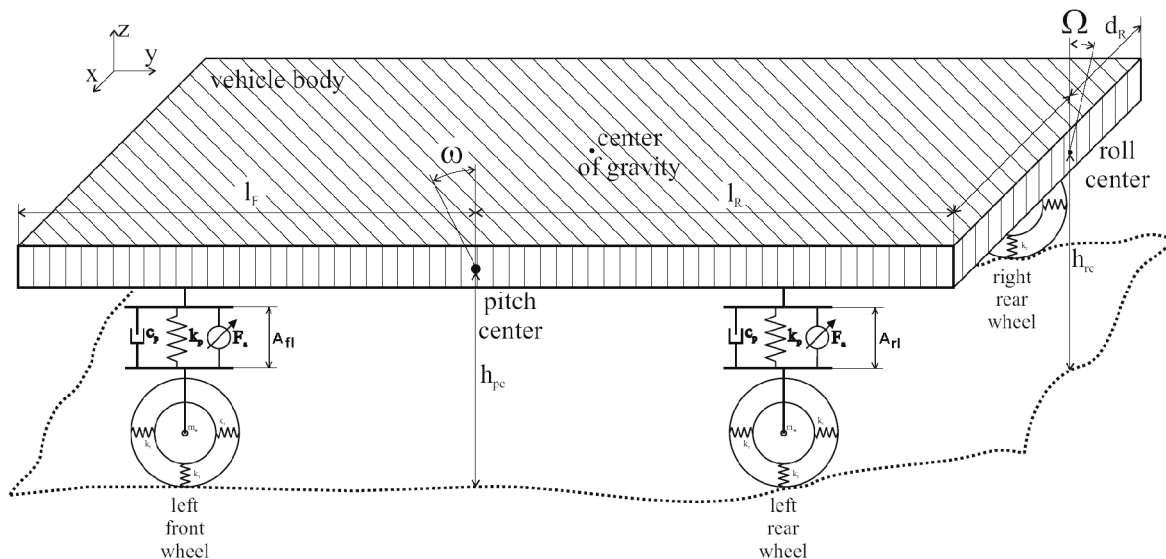


Fig.2. Full-car SMD model

BRAKING AND CORNERING

Now, we introduce the dynamic forces, which act directly on the car body. In the other words, this description is concerned with load changes during suddenly braking and cornering. To describe how the braking and cornering affect the dynamic load, both influences can be analyzed separately due to the superposition principle [6]. The equations for each wheel are similar; hence equations for the front-left wheel only will be introduced and the others will be easy to derive. The front-left force acting on the wheel is:

$$F_{load_{fl}} = F_{static_{fl}} + \Delta F_{roll_{front}} + \Delta F_{pitch_{left}} \quad (3)$$

In the equation (3):

$$\begin{aligned} F_{static_{fl}} &= m_{body} \cdot g \cdot \frac{l_r}{l} \cdot \frac{d_r}{d} \\ \Delta F_{roll} &= m_{body} \cdot a_y \cdot \frac{h_{rc}}{d} + K_{roll} \cdot \frac{\Phi_{roll}}{l} \\ \Delta F_{pitch} &= m_{body} \cdot \dot{\psi}_x \cdot \frac{h_{pc}}{l} + K_{pitch} \cdot \frac{\Phi_{pitch}}{l} \\ \Delta F_{roll_{front}} &= \Delta F_{roll} \cdot \frac{l_f}{l} \\ \Delta F_{pitch_{left}} &= \Delta F_{pitch} \cdot \frac{d_l}{d} \end{aligned} \quad (4)$$

For simplicity it is assumed that the body angle is proportional to horizontal forces. The symbol Φ indicates angle rate and the constants K_{roll} and K_{pitch} are the roll and pitch body stiffness, respectively [6]. The following assumptions are made for the angles:

$$\begin{aligned} \Phi_{roll} &= \frac{m_{body} \cdot h_{rc} \cdot a_y}{K_{roll} - m_{body} \cdot h_{rc} \cdot g} \\ \Phi_{pitch} &= \frac{m_{body} \cdot h_{pc} \cdot \dot{\psi}_x}{K_{pitch} - m_{body} \cdot h_{pc} \cdot g} \end{aligned} \quad (5)$$

where $g = 9.8 \text{ m/sec}^2$ is the gravitation force. If these equations are included into the model, a full car model, which is able to simulate car driving with braking and cornering, will be obtained.

The model developed above implies the question of how driver commands impact car motion through the Brake and steering wheel, in the lateral direction especially, so that this effect can be included in the model. The main problem is to determine the force acting on each wheel from the road, which impacts the spring and changes the height of the spring. In fact, this force depends mainly on the tire characteristics, which are strongly nonlinear, in particular during skidding.

Moreover, even nonlinear tire models are very complicated and, therefore, in most applications a simple linear model is used. The side force acting on the wheels depends not only on the tires and road, but on the car

speed too, because a real car must over- or under steer and therefore slip on the front and rear wheels is different and the radius of the curve varies for fixed front wheel angles. Fortunately, if some of these nonlinearities and dependencies are neglected, a relatively simple model of driver's impact to the lateral behavior of the car can be observed [7].

If the car is cornering at high speed, we should consider over- or under steering behavior of the car. How the car behaves depends on the location of the center of gravity. Consequently, if the wheel angle is fixed, the radius of the curve increases with increasing speed of the car. Then, the radius is:

$$R = \frac{L - K v^2}{\delta} \quad (6)$$

where K is the under steer gradient defined as:

$$K = F_N \left(\frac{l_r}{l} \frac{1}{c_{fT}} - \frac{l_f}{l} \frac{1}{c_{rT}} \right) \quad (7)$$

where c_{xT} is the tire coefficient. These coefficients depend on the load and the slip of the wheels is nonlinear. If K is positive, then car is under steering and if K is negative, it is over steering, i.e., the CG is toward the front or toward the rear of the car, respectively. For K equal to zero, the car has neutral steering and the radius is the same as for low speed turning [8].

It is obvious that to obtain an accurate lateral model of the car responding to the driver's commands is a very complicated task for the purpose aimed in this paper. Therefore, we use fuzzy logic analysis to cover the imprecision of vehicle dynamics nonlinearities. The simplistic model of vehicle dynamics is introduced only to organize our imagination in order to extract the fuzzy rules correctly.

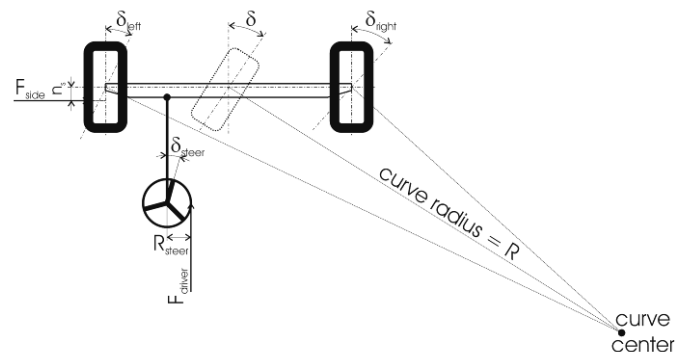


Fig.3. Steering mechanism

From the vehicle dynamics point of view, acceleration in each direction causes CG movement and change in Φ_{roll} , Φ_{pitch} . Also dynamic forces on the vehicle influence the suspension system, with resulting spring height change. Excluding small road irregularities that have no effect on the vehicle's mass, we can suppose