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Four Quarters of Vehicle Model

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ABSTRACT

In the market are several complex vehicle models, models so efficient that are not easy to use outside of author-predefined vehicles. This paper is an effort to return to the basics, starting from the well know quart of vehicle model, connected with other three ones by a rigid structure, as result is presented a simple model easily adjustable for any 4 wheels vehicle. By Instrumentation of the vehicle and performing some road maneuvers, the system adjust the model parameters, resulting in a model capable of imitate the vehicle dynamic behavior.

INTRODUCTION

For years, engineers have take the advantage of use vehicle simulators to represent the dynamic behavior of vehicles and solve a wide range of problems or applications. Also these simulators have evolved in time to complex systems, highly precise results, in elaborated graphical environments.

Figure 1 . Carsim example.

In Figure 1, can be noticed the representation of the forces exercised by the car against the pavement during a zigzag type maneuver. But there is a few things not considered. The software focuses in the vehicle and his reactions to the environment, this could not always be correct.

For example when a truck perform a 90° turn, in the simulator, the vehicle fix the steering to perform a perfect turn (Figure 2.a), but the real deal could be different, because in real life, the driver do not follow precise trajectories, usually he makes a initial turn, and continuously make adjustments, due his perception on obstacles or restrictions, vehicle characteristics, and driver expertise (Figure 2.b).

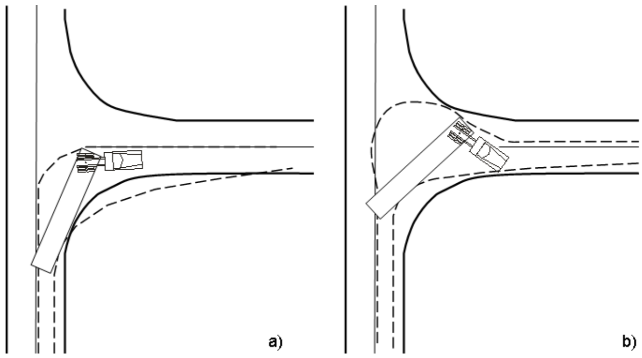

Figure 2. Hypothetical comparison of a 90° turn in simulator and a real life situation.

Another significant difference is to see the problem upside down. Commonly simulators measure forces to the road, whereas the proposed model uses road information to evaluate vehicular comfort and safety.

Besides road bumps and banking, in Mexico as well many other countries is common to find wear roads, and those irregularities have effect on both, vehicular safety and comfort.

Even more, what about an old car, or a custom made vehicle modification. In published simulators, there is no-way to incorporate this information.

MODEL CONSTRUCTION

A quarter-of-vehicle model usually employed to solve most of the problems related to suspension analysis, modeling suspension and tire elasticity, who-ever for specific dynamic problems considering rotational inertia, vehicle's mass specially when study in motions of pitch and yaw angles. In this case, the selected configuration was made up of four quarters of vehicle attached to a rigid body, this produces a 3-degree-of-freedom mechanical system model and thus a sixth order state space.

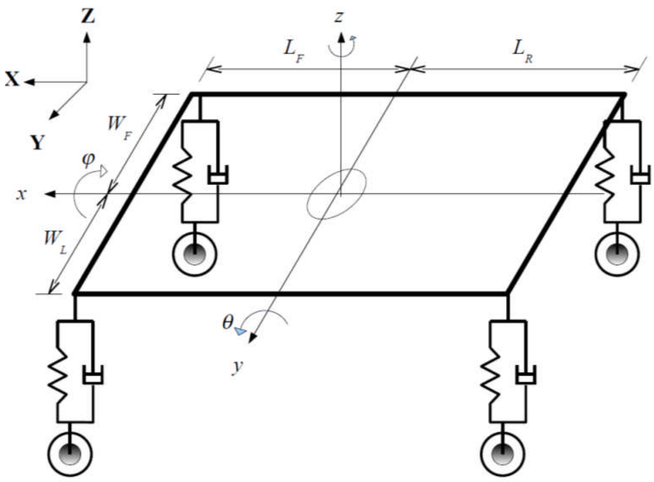

Figure 3. Sketch of the car.

Identifying the equivalent parameters of the four-wheeled vehicle. In order to simplify our model, we assume that the car motion takes place on a horizontal plane, and the road profileis considered to be a vector input with four components: the heights of the centers of rotation of the four wheels, ξ_i, for i =1,2,3,4. As a result of the motion Each of the vertical forces F_i, i =1,2,3,4, causes a torque with two components: The torque component τ_i^x, measured around the x axis, contributes directly to the second derivative of the roll angle, i.e. $\ddot{\varphi}$. Likewise the component τ_i^y , measured around the y axis contributes to the second derivative of the pitch angle: $\ddot{\theta}$. The torque components may be calculated as follows

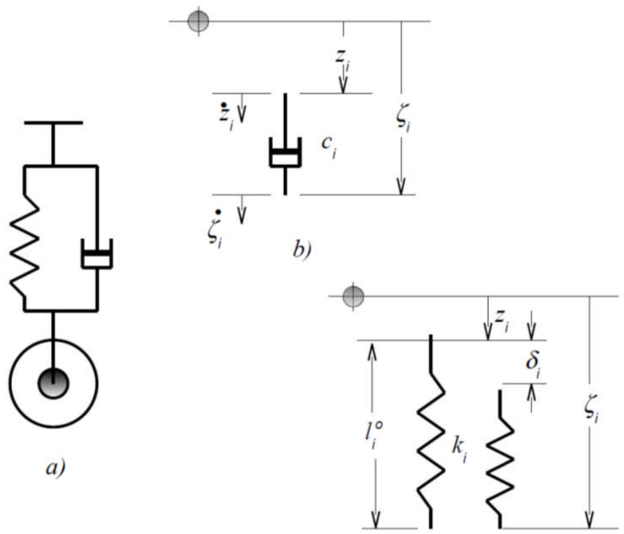

Figure 4. Idealized components of the car suspension

$$\tau_1^x = W_L F_1, \quad \tau_2^x = W_L F_2, \quad \tau_3^x = -W_R F_3, \quad \tau_4^x = -W_R F_4,$$
$$\tau_1^y = -L_F F_1, \quad \tau_2^y = L_R F_2, \quad \tau_3^y = L_R F_3, \quad \tau_4^y = -L_F F_4.$$

In the expressions for computing the moments, W_R is the portion of the car's width measured from the x-axis to the right of the mass center, W_L is the portion of the width measured to the left, L_F is the car length measured from the mass center along the x-axis in the positive direction, L_R is the car length measured along the x-axis along towards the rear. Each of the forces F_i is in turn, the sum of two effects: the spring's restoring force and the damper's mechanical resistance.

$$F_i = F_i^k + F_i^c \tag{1}$$

The deformation of the i-th elastic element is

$$\delta_i = l_i - l_i^0 = (\xi_i - z_i) - l_i^0,$$

thus, the force applied by the i-th elastic element on the respective corners of the car is

$$F_i^k = k_i \delta_i = k_i[(\xi_i - Z_i) - l_i^0].$$

Likewise, the damping force is given by

$$\begin{aligned} F_i^c &= -c_i(\dot{Z}_i - \dot{\xi}_i) \\ &= c_i(\xi_i - \dot{Z}_i). \end{aligned}$$

By application of Newton's second law to the mass center (2)

$$\begin{aligned} M\ddot{Z} = \sum F &= -Mg + F_1 + F_2 + F_3 + F_4 \\ &= -Mg + \{k_1[(\xi_1 - Z_1) - l_1^0] - c_1(\dot{Z}_1 - \dot{\xi}_1)\} \\ &+ \{k_2[(\xi_2 - Z_2) - l_2^0] - c_2(\dot{Z}_2 - \dot{\xi}_2)\} \\ &+ \{k_3[(\xi_3 - Z_3) - l_3^0] - c_3(\dot{Z}_3 - \dot{\xi}_3)\} \\ &+ \{k_4[(\xi_4 - Z_4) - l_4^0] - c_4(\dot{Z}_4 - \dot{\xi}_4)\}. \end{aligned}$$

The equation of motion around the x-axis is (3)

$$\begin{aligned} J_{xx}\ddot{\varphi} &= \tau_1^x + \tau_2^x + \tau_3^x + \tau_4^x \\ &= W_L F_1 + W_L F_2 - W_R F_3 - W_R F_4 \\ &= W_L\{k_1[(\xi_1 - Z_1) - l_1^0] - c_1(\dot{Z}_1 - \dot{\xi}_1)\} \\ &+ W_L\{k_2[(\xi_2 - Z_2) - l_2^0] - c_2(\dot{Z}_2 - \dot{\xi}_2)\} \\ &- W_R\{k_3[(\xi_3 - Z_3) - l_3^0] - c_3(\dot{Z}_3 - \dot{\xi}_3)\} \\ &- W_R\{k_4[(\xi_4 - Z_4) - l_4^0] - c_4(\dot{Z}_4 - \dot{\xi}_4)\}. \end{aligned}$$

Likewise, the equations of motion around the *y* axis (pitch moment) are

$$J_{yy}\ddot{\theta} = \tau_1^y + \tau_2^y + \tau_3^y + \tau_4^y \tag{4}$$
$$= -L_F F_1 + L_R F_2 + L_R F_3 - L_F F_4$$
$$= -L_F\{k_1[(\xi_1 - Z_1) - c_1(\dot{Z}_1 - \dot{\xi}_1)]\}$$
$$- L_R\{k_2[(\xi_2 - Z_2) - c_2(\dot{Z}_2 - \dot{\xi}_2)]\}$$
$$- L_F\{k_3[(\xi_3 - Z_3) - c_3(\dot{Z}_3 - \dot{\xi}_3)]\}$$
$$- L_F\{k_4[(\xi_4 - Z_4) - c_4(\dot{Z}_4 - \dot{\xi}_4)]\}.$$

The equations(2), (3) and (4) express the derivatives of the roll, pitch and yaw angle sin terms of the heights Z_1, Z_2, Z_3, Z_4 but these variables are not generalized coordinates and velocities. Thus, we need to replace them in terms of the generalized coordinates φ, θ and Z.

We assume that motion is composed of two consecutive rotations with respect to the local axes: an angle θ with respect the local y axes (pitch) and then the angle φ with respect the local x-axis (roll).

$$\mathbf{r}_{global} = [R_{x,\varphi} R_{y,\theta}]^{-1} \mathbf{r}_{local},$$

given the orthogonality of the rotation matrices, the following holds

$$[R_{x,\varphi} R_{y,\theta}]^{-1} = R_{y,\theta}^{-1} R_{x,\varphi}^{-1}$$
$$= R_{y,\theta}^{T} R_{x,\varphi}^{T}$$

That means

$$R_{y,\theta}^{T} R_{x,\varphi}^{T} = \begin{pmatrix} \cos\theta & 0 & -\sin\theta \\ 0 & 1 & 0 \\ \sin\theta & 0 & \cos\theta \end{pmatrix}^T \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\varphi & \sin\varphi \\ 0 & -\sin\varphi & \cos\varphi \end{pmatrix}^T$$
$$= \begin{pmatrix} \cos\theta & \sin\theta\sin\varphi & \sin\theta\cos\varphi \\ 0 & \cos\varphi & -\sin\varphi \\ -\sin\theta & \cos\theta\sin\varphi & \cos\theta\cos\varphi \end{pmatrix}$$

The coordinates of the position vector with respect to a moving coordinate frame located at the mass center of the vehicle and its coordinates with respect to the inertial frame,

$$\begin{pmatrix} X_i \\ Y_i \\ Z_i \end{pmatrix} = \begin{pmatrix} \cos\theta & \sin\theta\sin\varphi & \sin\theta\cos\varphi \\ 0 & \cos\varphi & -\sin\varphi \\ -\sin\theta & \cos\theta\sin\varphi & \cos\theta\cos\varphi \end{pmatrix} \begin{pmatrix} x_i \\ y_i \\ z_i \end{pmatrix}$$

The four points, where the sensors are located have the local coordinates

$$\text{Front left} \begin{pmatrix} x_1 \\ y_1 \\ z_1 \end{pmatrix} = \begin{pmatrix} L_F \\ W_L \\ -h \end{pmatrix}, \quad \text{Rear left} \begin{pmatrix} x_2 \\ y_2 \\ z_2 \end{pmatrix} = \begin{pmatrix} -L_R \\ W_L \\ -h \end{pmatrix},$$
$$\text{Rear right} \begin{pmatrix} x_3 \\ y_3 \\ z_3 \end{pmatrix} = \begin{pmatrix} -L_R \\ -W_R \\ -h \end{pmatrix}, \quad \text{Front right} \begin{pmatrix} x_4 \\ y_4 \\ z_4 \end{pmatrix} = \begin{pmatrix} L_F \\ -W_R \\ -h \end{pmatrix}$$

Later these parameters will be substituted by the vehicular values.

ROAD SCANNER

In order to collect the road characteristics, a mobile scanner was developed. Based on Micro-Electro-Mechanical System (MEMS) inclinometers, a GPS receiver and a web-cam, the tow device, register all road alterations near the tire track, principally any alteration than could result in a vertical excitation to the vehicle.

Figure 5. Road scanner.

Ones defined the road to study, the device is towed over the selected vehicle trajectory, drawing a virtual dynamic map referenced by the GPS system.

Then, when the instrumented vehicle performs the maneuver guided by the web-cam and the GPS signal, is easy to identify resulting excitations as they are from the road, or if those are inherent of the vehicle suspension characteristics.

VEHICLE INSTRUMENTATION

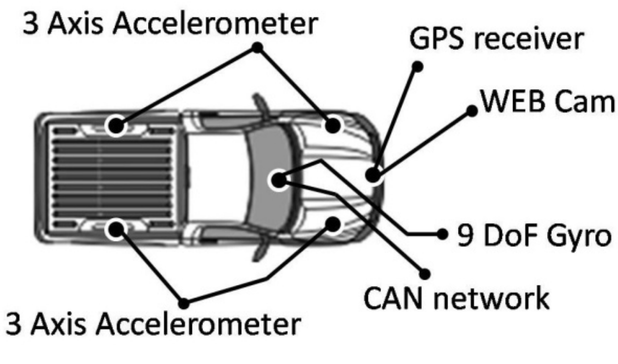

Figure 6. Instrumentation location map.

By our own experience [1] looking for reliability, simple set up process, and durability, we have collected a set of sensors that give acceptable results (Figure 6).

CAN NETWORK. Everything what happens inside the vehicle is in the network, excellent to synchronize maneuverability events to changes in the steering wheel, engine RPM´s, even all lights and sounds can be monitored or some even controlled.

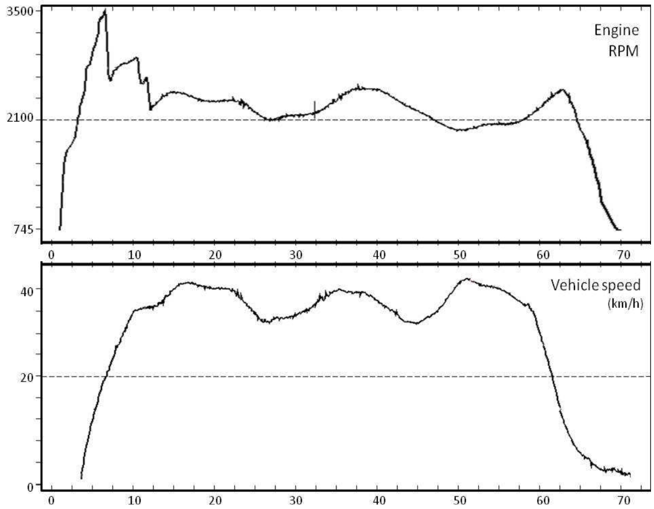

Figure 7. Example of information from the vehicle CAN-network during an up-hill maneuver.

9 DOF GYRO. A MEM-GYRO is used to record any cabin movement, these movements are important because they are the ones perceived by the crew, and also they testify important effects in the suspension.

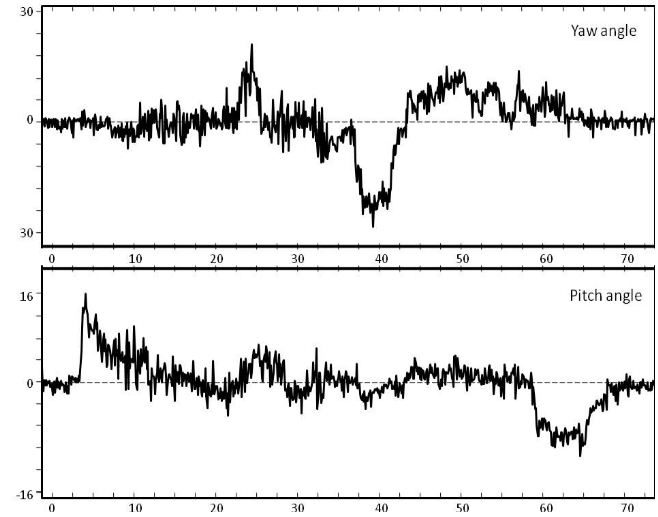

Figure 8. Example of information from the vehicle Gyroscope during an up-hill maneuver.

WEB-CAM. Located in the frontal center of the vehicle to have maneuver repeatability (acceptable results than could be improved if located a better camera just over the center of frontal axle).

GPS RECEIVER. After the elimination of the error induced to the system, this device has been very useful. By calibrating starting points, it is possible to synchronize trajectories in order to have a splendid repeatability.

ACELEROMETERS. In the suspension structure, next to each wheel is locater an accelerometer, to record vibrations in the wheel, be these from the vehicle to the soil or from the soil to the vehicle.

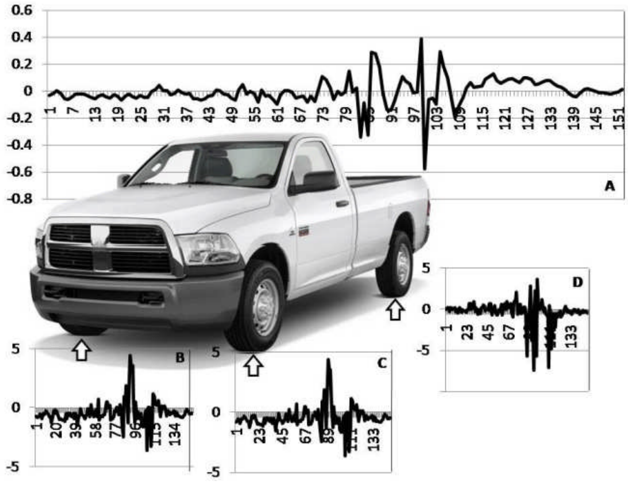

Figure 9. Effect of wheel accelerations from the soil to the cabin dealing with a double street bump.

Another important thing, every sensor or device is USB compatible, so all is connected to a single laptop computer, facilitating the synchrony between all the readings.

PARAMETER IDENTIFICATION

One important issue to consider for control purposes and also for verifying the practical results with those obtained in simulation is the process of parameter identification. In this case, it will be important to consider the parameter identification of all the transfer functions involved in the process because, it will be necessary to consider some inputs and see how the system does behaves before it actually is tested in a real experiment for security reasons. Furthermore, there can be considered some inputs such that the system is tested at its performance limits before the inputs are actually injected to the real system, which makes possible to gain information about security levels, possible control actions, just to mention a few.

There exist several methodologies for parameter identification and among them one possible classification is [3]: open loop and closed based methodologies. Because the linearized system developed above is open loop stable, it is possible to consider an open loop identification technique such as the Gradient or Least Squares (LS) Algorithms [7]. In this work it will be implemented the LS algorithm with forgetting factor [7].

In order to implement the identification algorithm, it is necessary to consider each output and parametrize it as described in the following.

Let us consider the known values W_L =0.98, W_R =0.90, L_F =1, L_R =1.07 and that all the k_i have the same value and so do c_i, i =1, 2, 3, 4. Let also consider the system matrices $A \in \mathbb{R}^{6\times 6}$, $B \in \mathbb{R}^{6\times 8}$ and $C \in \mathbb{R}^{3\times 6}$ and its state-space representation

$$\begin{aligned} \dot{\mathbf{x}} &= A\mathbf{x} + Bu \\ \mathbf{y} &= C\mathbf{x} \end{aligned} \tag{5}$$

The matrix transfer function, $\mathbf{G}(s) \in \mathbb{R}^{3\times 8}$, for(5) is given by

$$\mathbf{G}(s) = C\left(sI - A\right)^{-1} D \tag{6}$$

where each element g_{ij}(s) of (6)has the form

$$g_{ij}(s) = \frac{a_1 s^4 + a_2 s^3 + a_3 s^2 + a_4 s + a_5}{s^6 + b_1 s^5 + b_2 s^4 + b_3 s^3 + b_4 s^2 + b_5 s + b_6}$$

with g_{ij} (s) relating the effect of the input u_j on the output y_i. Thus, the output equation can be stated as

$$y(s) = \frac{a_1 s^4 + a_2 s^3 + a_3 s^2 + a_4 s + a_5}{s^6 + b_1 s^5 + b_2 s^4 + b_3 s^3 + b_4 s^2 + b_5 s + b_6} u(s) = \frac{n(s)}{d(s)} u(s)$$

CONCLUSION

In the real life there is no perfect maneuver, the driver perception, his response-time and his driver expertise will affect the resultant vehicle turn. Even more, usually every road has wear, cracks and bumpers that will affect the vehicle dynamics.

There is no doubt on the value for engineering of the published simulators, but they are victims of their own grow, they are heavy, complex and limited to very specialized functions. And something may has left behind in the process.

Going back to the basics is useful to solve different problems, like in this example, focused in the vehicle comfort and safety dealing with several field maneuvers.

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