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Road safety contribution by evaluation of tire crushing using a measuring hub

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Abstract

The aim of this study is to improve road safety by analyzing road influence on vehicle stability. Nowadays, vehicle stability is enhanced by electronic systems. It can be expected that, in a near future, stability systems will rely on complete vehicle dynamics models. This means measuring, on each axle, the forces and deformations of -especially- tires and suspensions. In that perspective, the contact forces can be obtained by using dynamometrical wheels or load bearing sensors (SKF-TNO), which are likely to become available at a sufficiently low cost. For the deformation concern, we can think of lots of possibilities to gauge the suspension parts, but, at the present time, the tire vertical deformation remains difficult to acquire. Although different techniques exist to determine the tire crushing, the most popular consists in measuring the distance between a laser sensor fitted on a wheel and the corresponding local road surface. Nevertheless, this kind of sensor is expensive, difficult to adapt on standard cars and its measurements are highly influenced by the road texture state (water depth, markings ...). The whole new idea is that, assuming the availability of bearing load sensors on a vehicle for force measurement, tire height could be evaluated without any additional equipment by measuring torques and forces applicated to this wheel. So, we propose to evaluate the effectiveness of equivalence between the tensor components and optical crushing measurements. Experiments have been worked out at various speeds and curves. These experiments tend to show that the longitudinal torque and lateral force at the wheel center can be used to determine the wheel radius in the maximum loaded phases. Dynamometrical measurements present the possibility to be used under extreme weather conditions, for particular road texture contrary to optic techniques and at an expected affordable cost in a near future. More deepened studies will be launched to estimate the influence of tire structure, road curvature, evenness and texture on the proposed methodology.

1. Introduction

In France, 20% of the 80 000 road accidents involve traffic-free vehicles in a curve. These accidents are often due to the driver behaviour but most of these may be attributed to infrastructure defects. Our work is to qualify the road serviceability level and to find why some trajectories are dangerous. A possibility to bring to fruition these objectives is to define criteria describing the road dangerousness. A first criterion could be the tire crushing. In fact, tire deformation can inform if the stability limit of the system Vehicle-Infrastructure-Driver is near or

not. So, it is important for the driver or inboard stability systems to evaluate precisely the vehicle stability limits. Short-term perspectives are expected to be achieved such evaluation by using advanced dynamic models what means knowing the forces and deformations states of a given vehicle (Glaser, 2004), (Brossard, 2005) and (Stephant, 2004). The forces needed are the contact forces, which can be measured with dynamometrical wheels or with load bearing sensors (Van Leeuwen, 2007). The latter have been designed to be generalized at low cost to mass-produced vehicles. On the other hand, deformations to be estimated are the suspension and tire deformations. For the suspension deformations, potentiometrical measurements represent a good solution already used by many laboratories. Vertical tire deformation is commonly measured using laser sensors calculating the wheel centre to ground distance. However, this measurement is highly influenced by the texture state and much more by the presence of water on the pavement (Weakness of optical technologies). The aim of this work is to find a workaround for this problem and for that we propose to use a dynamometrical wheel to calculate the vertical tire deflection. Moreover, another use of this method could be about the tire pressure, for example, if the tire deformation is abnormal compared to the steering wheel angle. If the tire is under pressured, the deformation will be higher and if the tire is over pressured, the deformation will be lower. Dangerous situations could then be foreseen and accidents avoided.

2. Theoretical background

The dynamic wheel radius estimation is based on a simple mechanical wheel equilibrium. The taken hypotheses are:

- The torque on the \bar{x} axle at the contact point C is negligible,
- In a first approach, the camber angle θ is the only deformation taken into account. There is neither eccentricity of the contact point nor tire dangling: (Martin, 2003) and (Michelin, 2001),
- The laser distance sensor is set at the point S at a distance d from the wheel rotation centre.

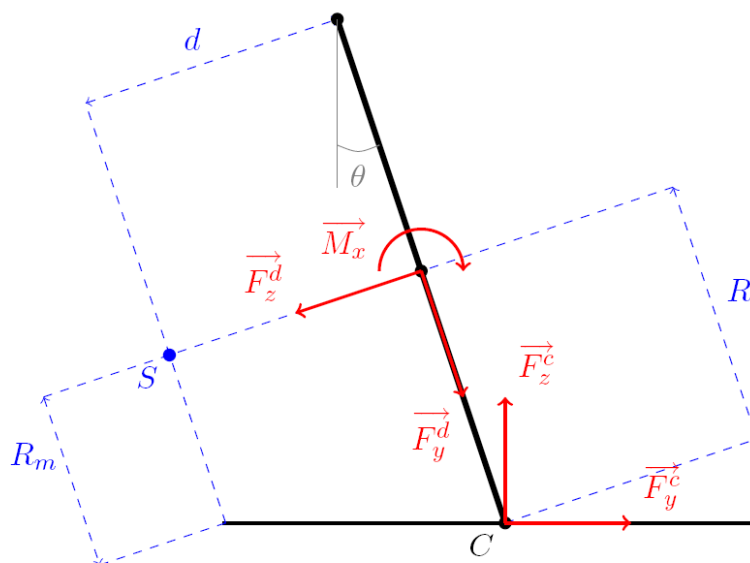


Figure 1. Wheel equilibrium: front view

In the case of the Figure 1,

$$R_m = R - d \cdot \tan(\theta) \quad (\text{Eq. 1})$$

$$F_y^c = F_y^d \cdot \cos(\theta) - F_z^d \cdot \sin(\theta) \quad (\text{Eq. 2})$$

$$F_z^c = F_y^d \cdot \sin(\theta) + F_z^d \cdot \cos(\theta) \quad (\text{Eq. 3})$$

Then, the torque equilibrium can be expressed:

$$-M_x + F_y^c \cdot R \cdot \cos(\theta) + F_z^c \cdot R \cdot \sin(\theta) = 0 \quad (\text{Eq. 4})$$

Now, if the equations 2 and 3 are used in the equation 4, we have,

$$R = \frac{M_x}{F_y^d} \quad (\text{Eq. 5})$$

Latest equation provides a simple order relation between the tire deflection and the forces transmit by the wheel. The equation 1 underline the fact that the laser measured radius is affected by non null camber angles.

3. Experiments

On the LCPC test track (Figure 2) located near Nantes (France), three circular trajectories of different radii (90m, 110m and 130m) have been plotted using a centimetrical GPS. These trajectories have been followed by a fully instrumented vehicle (406 Peugeot) at various speeds (from 60 to 100 km/h). The sensors used were a Kistler dynamometrical wheel, a Keyence laser crushing sensor, a Correvit speedometer and a Crossbow inertial measurement unit to check the effectively travelled paths.



Figure 2. LCPC test track

As it can be seen on Figure 2, the test track comprise an entry clothoid, a constant radius curve and an exit clothoid. On Figure 3 are represented the measured radius (Keyence laser sensor

measurement) and the deduced radius (Equation 5), for the 90 km/h and 90 m curvature radius case.

The radius R_m and R are very similar during the stabilized phase when the road curvature is constant ($60 < d < 140$ m). In a first approach this result tend to validate the proposed method, although camber angle effects have not yet been taken into account (as appearing in Equation 1).

For the transitional phases ($d < 20$ and $d > 150$), differences between R_m and R are due to both instationary forces and tyre crush. Curves representing wheel radii evolution with the vehicle speed have been plotted on Figure 4, 5 and 6 for the 90, 110 and 130 m road curvature radii. The radii equality comes about 80 km/h for the 90 m and about 90 km/h for the 110 and 130 m. Also, it can be seen on Figure 4 that the radii stabilized when they become equal. This phenomenon is not observed on Figure 5 and 6 because speed is not high enough relatively to the higher curvature radii. However, the tendency seems to be the same. This radius stabilization could mean that the system vehicle-infrastructure-driver was close to the physical stability limit (Nguyen, 2005). This information is really important and allow for example to warn the driver of the risky situation.

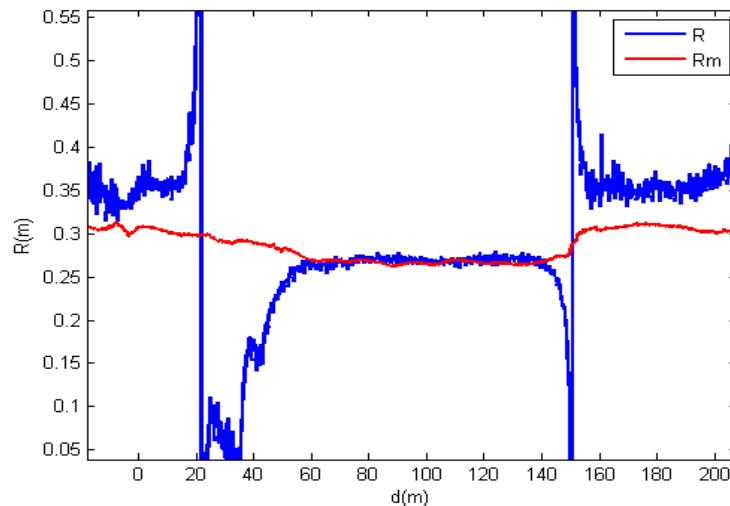


Figure 3. Measured (R_m) and deduced (R) radii for a road radius of 90 m at 90 km/h.

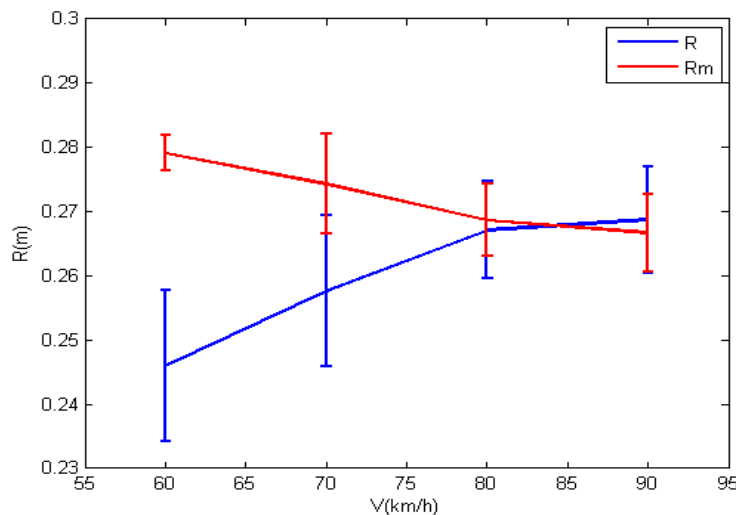


Figure 4. Radius evolution with vehicle speed in the 90 m curvature corner

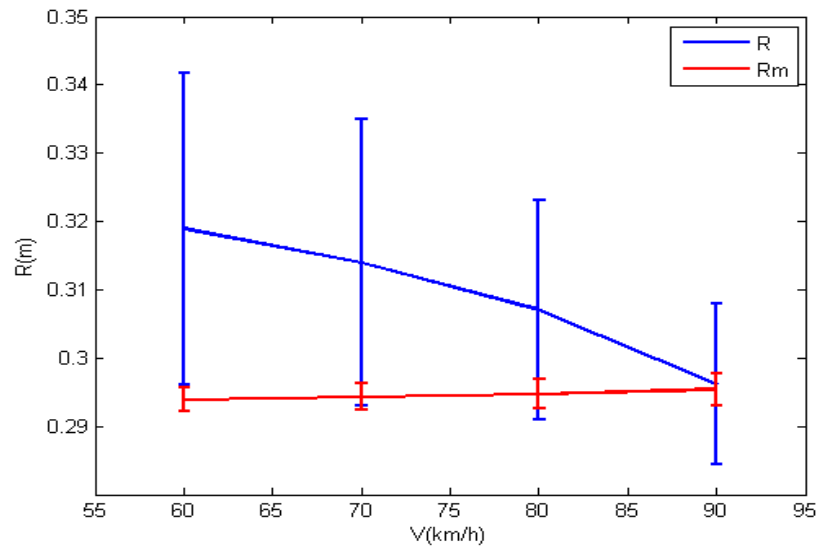


Figure 5. Radius evolution with vehicle speed in the 110 m curvature corner

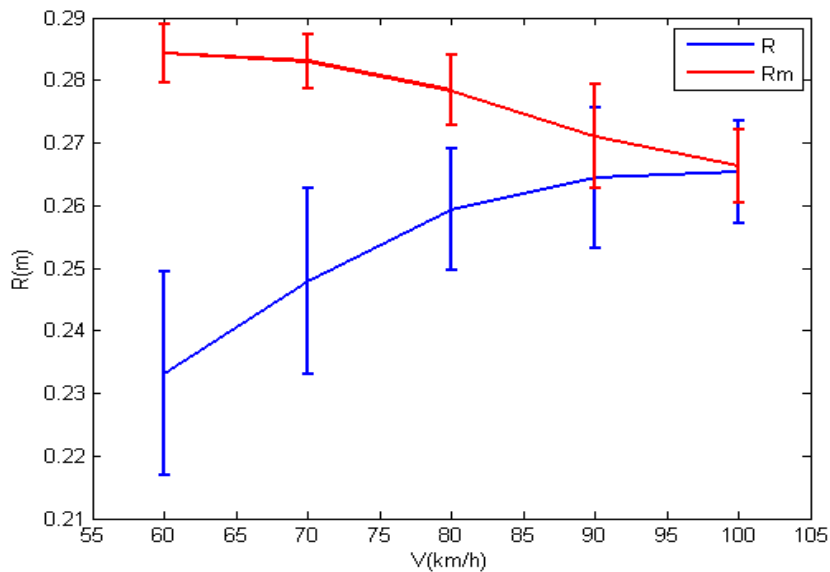


Figure 6. Radius evolution with vehicle speed in the 130 m curvature corner

The error range for on Figure 4, 5 and 6 are represented as more or less two standards deviations for each data set.

4. Conclusions

The aim of this study was to give solutions in order to improve road safety. The evaluation of tire crushing using a measuring hub allowed us to present to exploratives ways:

- The consideration of tire crushing in precise vehicle models can improve the evaluation of the vehicle state and so, improve stabilization systems.

- Using directly the tire crushing as a stability criterion allowing to warn the driver in real time of the stability limit approach can reduce the number of accidents.

Of course, the measurement method presented in this article permits to evaluate the tire crushing in wet conditions, what could not be done with optical technologies. Our results show that the wheel radii can be precisely estimated in the case of high solicitations of transversal grip for corners from 90 to 130m on the LCPC test track texture. To extend this method to all kind of road layouts, more deepened studies will be launched to estimate the influence of tire structure, road curvature, evenness and texture. Also, we need to compare the tire deformation stabilization effect to the lateral consumed grip and to the side slip angle to know if we can estimate the stability limit using the wheel radius measurement. A camber angle sensor should improve the determination of the position of the mean contact point and therefore help us to generalize this calculus to all situations.

5. References

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