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

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Abstract

This study takes part of a research program about the 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: (Glaser, 2004), (Brossard, 2005) and (Stephant, 2004). 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 sensing (SKF-TNO), which is 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 local road surface. Nevertheless, this kind of sensor is expensive, difficult to adapt on standard cars and its measures are highly influenced by the road texture state (water depth, paintings ...). The whole new idea is that, assuming the availability of bearing load sensing on a vehicle for the force measurement needs of enhanced stability systems, 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 lateral tensor components and optical crushing measurements. Experiments have been worked out at various speeds and curves. These experiments tend to show that the lateral torque and 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, under particular 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 implicate a lonely vehicle in a curve. These accidents are often due to the driver behaviour but most of these may be attributed to infrastructure defects. So, it is important for the driver or inboard stability systems to evaluate precisely the vehicle stability limits. Short-term perspectives are expected to achieved such evaluation by using advanced dynamic models what means knowing the forces and deformations states of a given vehicle. The forces needed are the contact forces, which can be measured with dynamometric 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 dynamometric wheel to calculate the vertical tire deflection.

2. Theoretical background

To estimate the dynamic wheel radius, the mechanical wheel equilibrium has been established. The hypotheses for this calculus are:

- The torque on the $\vec{x}$ 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 deformation sensor is set at the point S at a distance d from the wheel rotation centre.

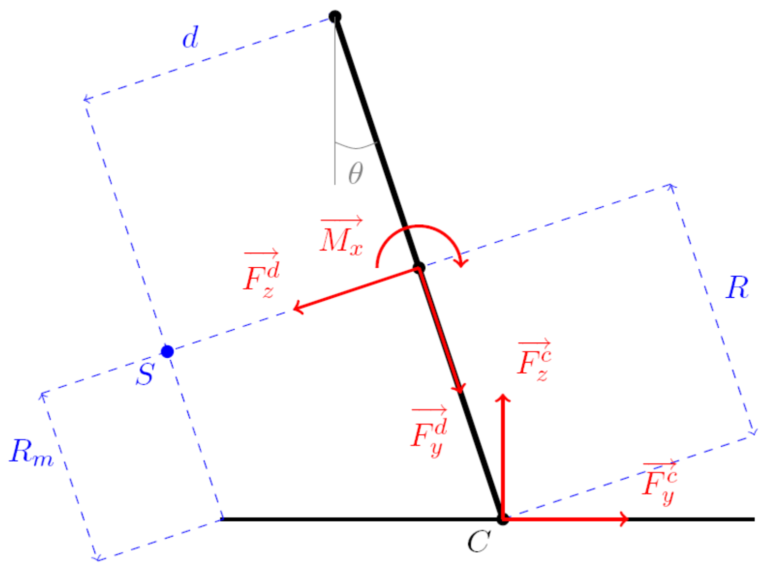

Figure 1. Wheel equilibrium: front view

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 has been written,

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

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

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

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 trajectory is made of an entry clothoïd, a constant radius curve and an exit clothoïd. On Figure 3 are represented the measured radius (Keyence laser sensor measurement) and the deduced radius (Equation 5) at 90 km/h on the 90 m curvature radius. The radius Rm and R are very similar during the stabilized phase when the road curvature is constant. This equality can be attributed to the tire lateral deformation which modify the lateral position of the force centre and therefore modify the wheel radius. For lower solicitations, the estimated radius differs from the measured one because there is nearly no tire lateral deformation and this difference, due to the camber angle, appears in Equation 1. 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 can not be observed on Figure 5 and 6 because speed is not high enough. 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).

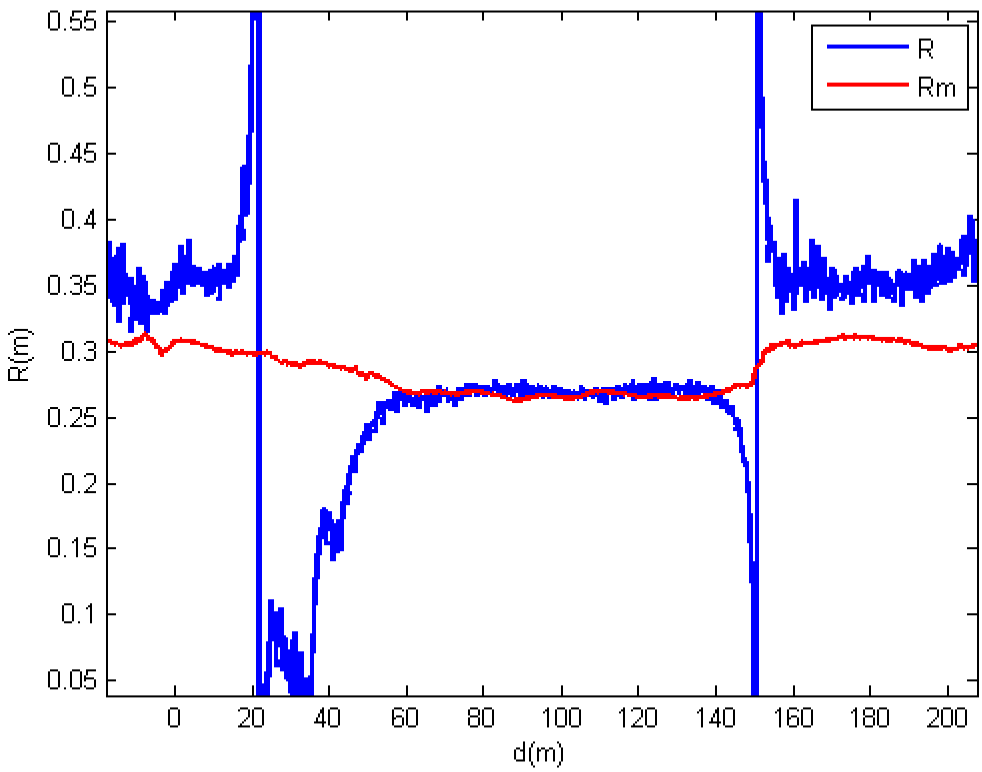

Figure 3. Measured (Rm) and deduced (R) radii for a road radius of 90 m at 90 km/h.

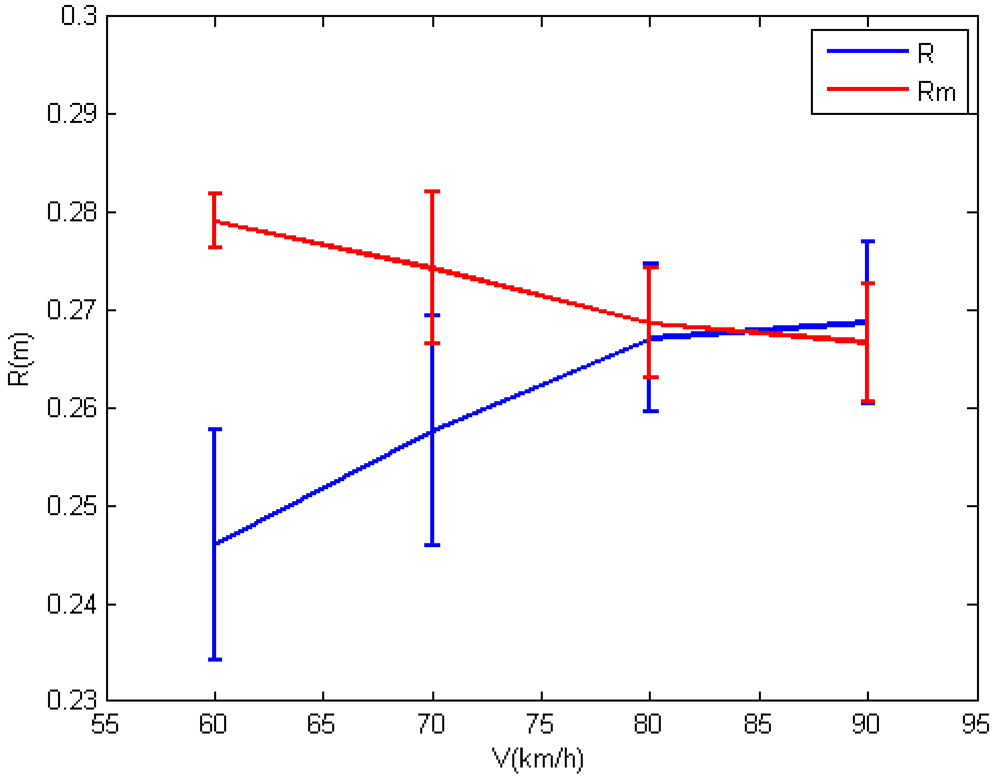

Figure 4. Radius evolution with vehicle speed in the 90 m curvature corner

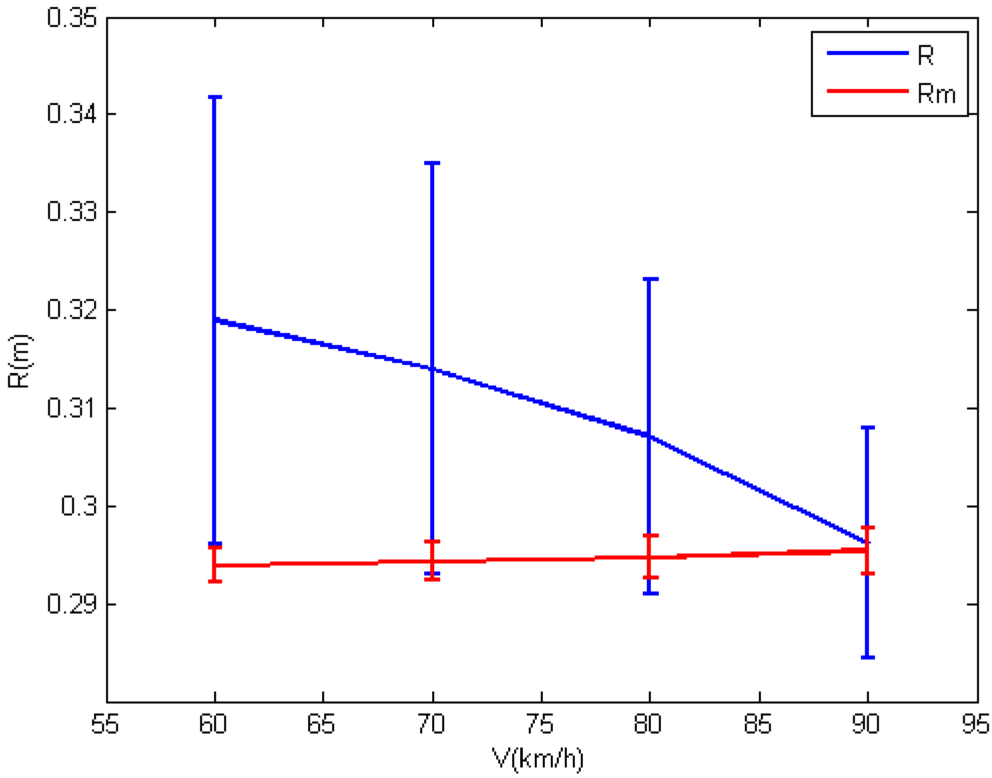

Figure 5. Radius evolution with vehicle speed in the 110 m curvature corner

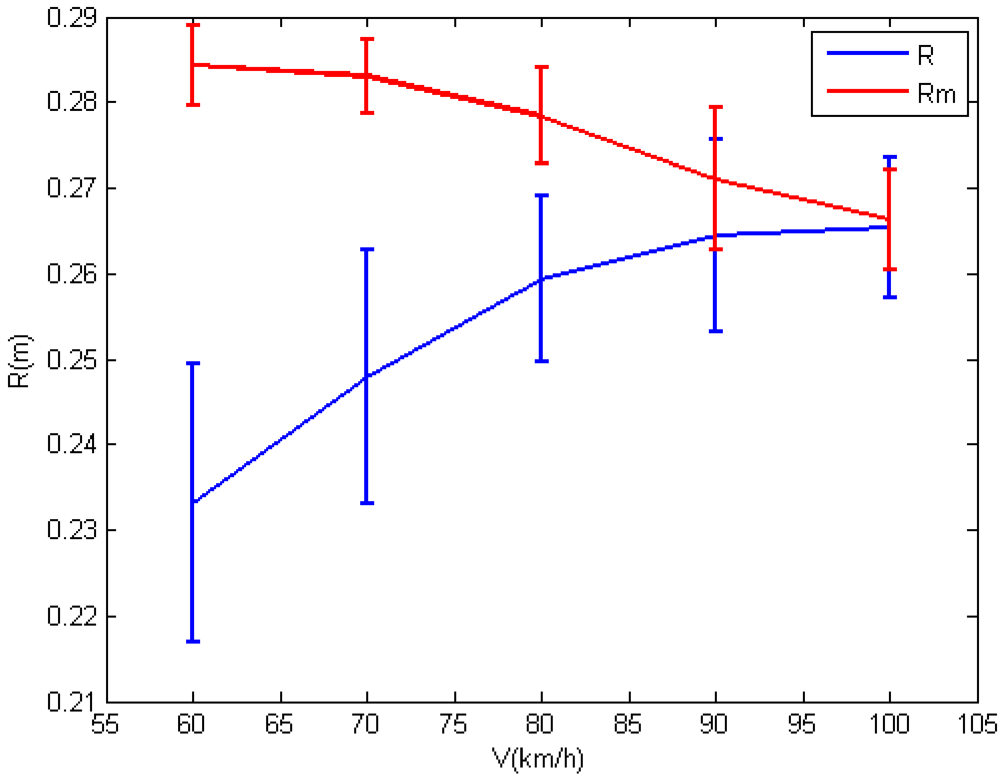

Figure 6. Radius evolution with vehicle speed in the 130 m curvature corner

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 know if it is possible to estimate the wheel radius with a dynamometric wheel or a load bearing sensor in order to furnish precious information concerning the tire deformation state. This data could be used, indirectly, in dynamics models as, directly, like a stability limit criteria. Another use of this information 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. It has been shown, in this work, 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, 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 exact position of the contact point and therefore help us to generalize this calculus to all situations.

5. References

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