Estimation of the Safety Vehicle Speed in Curve Using Inertial Sensors

Emil Iv. Iontchev[1] and Rosen G. Miletiev[2]

Abstract - **This paper presents a method for calculation of the maximum authorized vehicle speed in the curve using inertial sensors to accomplish an active safety tracking system. The curve radius and road tilt are calculated by the roll and pitch vehicle axis accelerations. The system performance and the method functionality is tested and analyzed.**

Keywords - **land vehicle rollover, inertial sensors, tilt**

I. Introduction

MEMS sensors allow the implementation of lots of different functions, as free-fall detection, car navigation, map browsing, gaming, menu scrolling, motion control, vibration monitoring, antitheft and many others. With the introduction of the low-cost controllers and low-cost MEMS technology, much more economical inertial sensors can now be targeted toward automotive steering/traction control. Steering/traction control systems require a three variable inertial sensor system. In this example, the system must detect motion in the X- and Y-axis and rotation on the Z-axis (yaw) [1]. This system is able to detect the direction of actual vehicle movement in comparison to the desired movement and provide feedback to the overall system controller [2]. Incidents with vehicles as a result driving with a high speed and consequence turnover are a serious problem for the transportation companies [3].

Therefore, developing systems of warning of the driver of decrease to the speed accordingly the geometry a route, the state of the vehicle and the atmospheric conditions is particularly actual question.

As an example for such system witch warning the driver ahead is explain in [4]. The Estimation of the safety curve speed is based on the information for the lateral acceleration. The term that is being used for estimation the hazard of rollover is:

$$RSA_{score} = \frac{a_n(actual)}{a_n(critical)} 100\% \tag{1}$$

where a_n is the vehicle lateral acceleration.

The critical lateral acceleration is inversely proportional to the mass of the vehicle and was determined experimentally with a tilt table.

[1]Emil Iv. Iontchev is with the Departament of Material Handling and Construction Machines, Higher Scool Of Transport "T. Kableshko**v"** Sofia, Bulgaria E-mail: e_iontchev@yahoo.com

[2]Rosen G. Miletiev is with the The Faculty of Communications and Communications Technologies, Technical University of Sofia Bulgaria E-mail: miletiev@tu-sofia.bg

The system computes the RSA score every half second, and once it generates a high score, it delivers a warning message to the driver. This system require combination of precise placement, digital maps with the accuracy data about the road, accurate calculate the dynamic parameters to the vehicle, as well as predict it the speed. They would be able to deliver a warning signal to the driver some seconds before the dangerous section of the road.

The other kind of systems are these that calculate the current state, they are registering and can be exploited for subsequent analysis on the causes that had led the incident.

In the last years the MEMS sensors are integrated with GPS receivers, with which the measured parameters are increased, as well as the accuracy of measurement. There are developed methods of measurement of some of the above parameters in [5, 6].

This paper explains a method of estimation the critical vehicle speed according to the inertial sensors data to accomplish an active safety tracking system.

II. Road and Vehicle Kinematics

The high safe speed in a curve depends on the geometry of the curve, the state of road surface, the stability of the vehicle against rollover and an experience of the driver.

A vehicle roll model with road bank angle is shown on Fig. 1.

The highest speed which a vehicle can pass in a curve without a side-slip can be estimated by the expression [7]:

$$V_{\max} = \sqrt{gR\mu_{lat}}\,, \tag{2}$$

and the highest vehicle speed in a curve without a rollover can be estimated by the expression [7]:

$$V_{\max} = \sqrt{gR\tan\phi_{\lim}}\,. \tag{3}$$

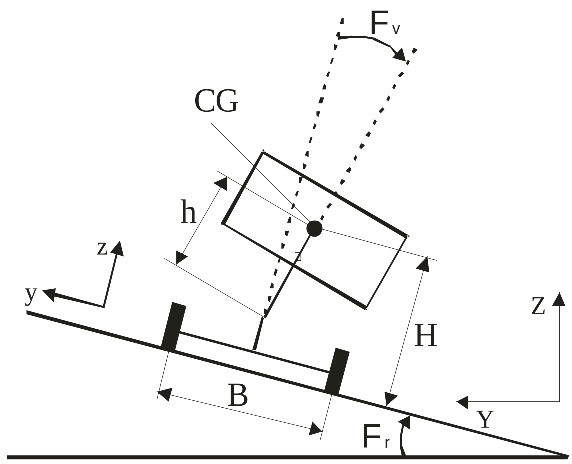


Fig.1 Vehicle kinematics

It is seen that V_{max} value is determined by the curve radius R, Earth gravity acceleration g, lateral coefficient of coherence μ_{lat}, which is function of the state of the surface on the road, the vehicle tires, atmospheric conditions and the static stability angle $\tan\phi_{\lim}$. The last parameter is determined by the base of the vehicle B and the position of vehicle gravity center H according to the equation [7]:

$$\tan\phi_{\lim} = \frac{B}{2h} \tag{4}$$

When the curve there is a bank as a whole the stability against rollover and side-slip is increased. The expression (2) in this case is transformed to the following equation:

$$V_{\max} = \sqrt{gR\left(\frac{\mu_{lat} + \tan\phi}{1 - \mu_{lat}\tan\phi}\right)}, \tag{5}$$

and the expression (3) is transformed to the next equation:

$$V_{\max} = \sqrt{gR\tan\left(\phi_{\lim} + \phi_p\right)} \tag{6}$$

The total tilt of the vehicle in a curve is a sum from the route bank ϕ_r and the suspension tilt ϕ_v in dependence of the parameters μ_{lat} and $\tan\phi_{\lim}$ on a side-slip before rollover and vice versa.

All parameters needed for calculation of the speeds can be measured carefully by the inertial sensors. Their values are measured with respect to a vehicle frame that is shown of Fig.2.

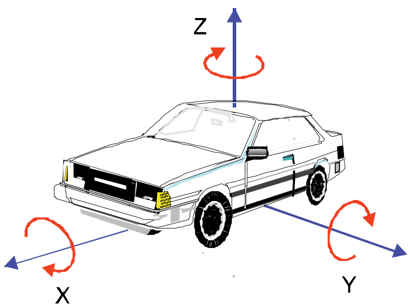


Fig.2 Vehicle frame

III. INERTIAL MEASURED SYSTEM

The acceleration data for calculation of the critical vehicle speed are obtained from a system, which block diagram is shown on Fig.3. The inertial sensor measures the linear accelerations on the three axes. The tilt of vehicle measures by the same accelerometer, whose axis's x and y match the same axis's of co-ordinate system of the vehicle.

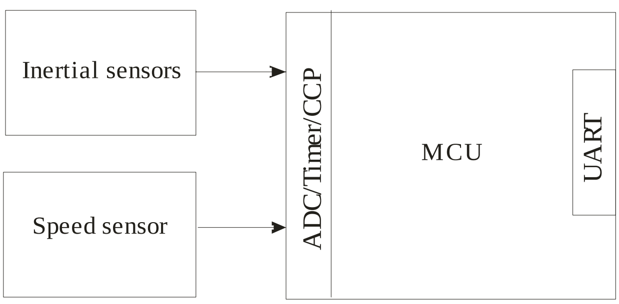


Fig.3 Block diagram of the measured system

The block for gaining the speed can use the sensors rigged with the gear, a GPS receiver or it can be calculated by mean of the data of accelerometer about the x axle.

A very precise analog to digital converter AD7739 [8] was used in this design to minimize the errors from conversion of analog outputs of the sensors to digital data. The MCU takes care of the synchronization of measurements and transfer of gathered inertial data to the other block. The inertial block algorithm has been developed to make measurements with frequency of 10Hz which is quite enough for land-vehicle applications.

IV. PERFORMANCE OF THE SYSTEM

The ingredient in the signal which is being changed from bank is changing more slowly that ingredient is being changed from tilt of vehicle therefore is made filtration to take more reality data. In our case it is thought that the tilt of vehicle due to the suspension is little, therefore the received data is mainly from the bank of route. The relationship between the measured values from accelerometer about y and x axes and the angles are:

In case that the vehicle is laterally tilted:

$$\phi = \arcsin\frac{a_y}{1g}, \tag{7}$$

and when it is longitude tilted:

$$\theta = \arcsin\frac{a_x}{1g}. \tag{8}$$

The radius of curve is estimated from the linear vehicle speed v and the normal acceleration a_y:

$$R = \frac{v^2}{a_y} \tag{9}$$

The estimation of the vehicle speed in a real time experiments have been carried out. The circular shape of trajectory is known. Thus a stadium (Fig.4) is selected as reference trajectory because its shape is very close to the circular one. The selected place for experiments has very low level of slope.

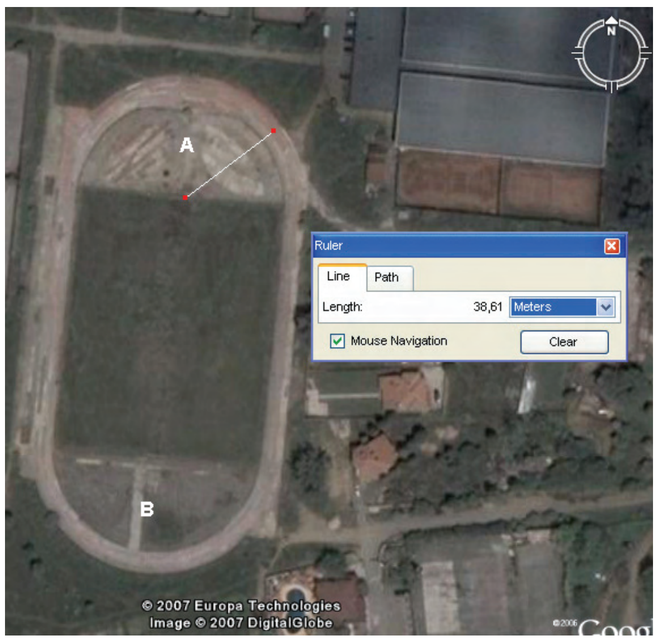
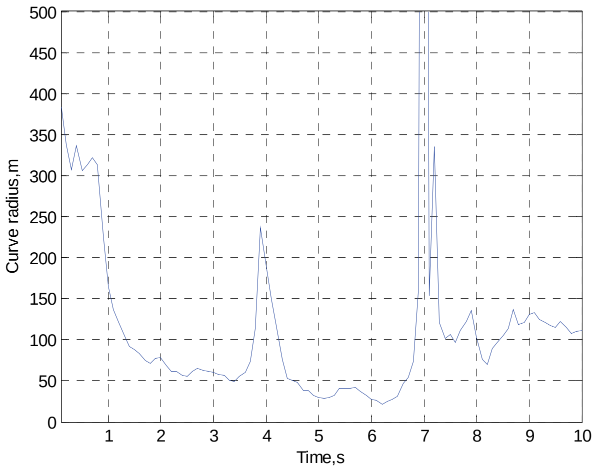
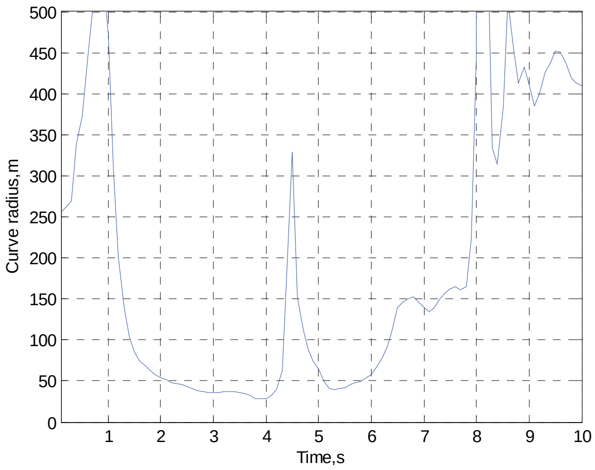


Fig.4. Google Earth's image of the reference trajectory

The results of the system performance experiments are shown at Fig.5.



(a)

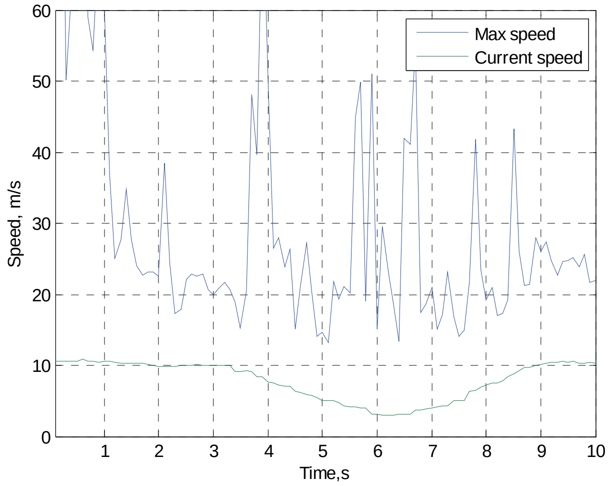


(b)
Fig.5. Estimated curve radius *R*

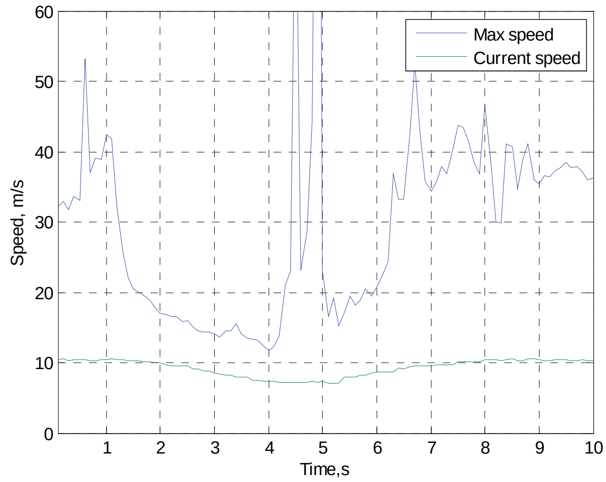
Figure 5a and Figure 5b represents the estimated curve radius *R* for A and B area (Fig.4) respectively according to the equation (9). The estimated radius value is close to the real curve radius. The both figures contain a time period (approximately 0,5s) when the estimated curve radius is much higher then the real one. This time period corresponds to the middle curve point when the driver restores the wheel angle and put out to the next curve.

The safety curve speed is also calculated according to the equation (6). It is compared with the driving speed and the estimated results are represented at Figure 6. Figure 6a and Figure 6b represents the estimated safety curve speed and the current driving speed for A and B area (Fig.4) respectively.

The represented results show that the driving speed is lower than the safety curve speed. If the estimated maximum curve speed is exceeded, then the traction control system reduces the driving speed and retains the car stability.



(a)



(b)
Fig.6. Estimated safety curve speed

The system performance can be improved if the low-cost angular rate sensor (gyroscope) is added. In this case the car rotation rate can be estimated directly from the gyroscope data.

V. CONCLUSION

The represented method allows determining the curve radius and maximum safety speed by using only one three dimensional linear accelerometer. This system is able to detect the direction of actual vehicle movement in comparison to the desired movement and provide feedback to the overall system controller to prevent the road accidents. It also accomplishes the real-time calculations of the critical speed and is able to deliver a warning signal to the driver up to few seconds before the road dangerous section or can directly access to the car traction control systems to reduce the current speed to the safety one.

VI. REFERENCES

[1] Inertial Sensor for Steering/Traction Control, www.freescale.com

[2] Richard Dixon, Prospects for MST sensors in automotive applications, WTC document, 2006

[3] Ryu, J. and Gerdes, J. C., “Estimation of vehicle roll and road bank angle”. American control conference, 2004, Boston, US

[4] Seth Rogers, Wenbing Zhang, “Development and Evaluation of a Curve Rollover Warning System for Trucks”, DaimlerChrysler Research & Technology North America

[5] Rumen Arnaudov, Yordan Hristov, Yasen Angelov, „Application of inertial navigation systems in control of military subdivisions”, National Millitary Forum, V. Tyrnovo, 2004

[6] Dr.-Ing. Edgar von Hinüber, “Inertial Measuring Systems with Fiber-Optic Gyroscopes”, ATZ magazine, 2002, vol.6

[7] Jordan Dimitrov, “Theory of the automobile, tractor and the forklift trucks”. TU, 1991, Sofia

[8] Analog Devices, AD7739 8-Channel, High Throughput, 24-Bit ∑-Δ ADC, product datasheet, www.analog.com