Development of V2V and GPS Based Collision Warning Algorithm for Uncontrolled Intersections

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***Abstract*—The present article proposes a vehicle collision warning algorithm on an uncontrolled road intersection in a situation when a vehicle enters an intersection from a side road starting from a full stop position. A decision about potential collision is made by analysing information received from the Global Positioning System (GPS) navigation system and the V2V (vehicle-to-vehicle) communications.**

***Index Terms*—Collision avoidance, road accidents, vehicle safety, global positioning system, advanced driver assistance systems.**

I. Introduction

Dynamic proliferation of the global motor vehicle fleet has created a serious problem in the context of road traffic safety. Creation of new collision prevention systems and upgrading of the existing ones using the Intelligent Transport Systems (ITS) significantly reduce the likelihood of motor vehicle collisions.

One of the ways to solve the collision prevention objectives is to use special road infrastructure such as video monitoring systems, infrared barriers, and the V2I (vehicle-to-infrastructure) communications [1]. In the algorithm described in [2], the decision on a possible collision is made by the Intelligent Control Unit (ICU), which is the part of the road infrastructure. The solution offered in [3] requires the use of information received by on-board car units only, i.e. without the involvement of special road infrastructure. Implementation of the proposed algorithm in real road conditions is described in [4].

According to the statistics, uncontrolled intersections are the most dangerous sections of a motor road. Entering an intersection from a side road is a difficult task for a driver. Poor visibility due to unfavourable weather conditions and roadside structures situated close to a road intersection, misestimation of the speed of oncoming vehicles and the distance to them, especially, during hours of darkness, and misassessment of one's car possibilities significantly increase the risk of a road accident.

This article reviews scenarios of passage of an uncontrolled intersection by a motor vehicle from the full stop position, going straight ahead and turning to the left.

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II. Information Receipt and Exchange

Handling the task of collision prevention requires information about the location and motion parameters of all the cars within a certain limited area. Additional information may include data about the vehicle's external dimensions and weight, brake lights status, etc.

The task of determining the location, speed and heading of a car is handled by using the GPS satellite navigation system. However, the use of a GPS receiver in an off-line mode cannot ensure the required accuracy. In such a mode, the positioning error range is 10 metres–15 metres, and in some cases even 100 m. When using a differential GPS, one can achieve a nearly acceptable accuracy of about 1 metre. The DGPS method provides for the transmission of pseudo-range corrections from the base-end station to users of mobile receivers for receipt of adjusted pseudo-range values.

Data transmission by carrier phase has made available real-time high-accuracy positioning for users of GPS receivers even when the mobile receiver is on the move. The method is known as RTK (Real Time Kinematic). In the RTK mode, a radio channel is also used for transmission of corrections, whereas the 'age' of such corrections, as a rule, must not exceed 0.5 seconds to 2 seconds, unlike the code differential mode, where corrections may be updated every 10 seconds. The use of the RTK solution ensures centimetre-level accuracy.

Additionally, the use of the satellite (GPS) and Inertial Navigation System (INS) has shown good results in improving the accuracy, reliability and plausibility of data received.

The received information exchange is carried out by the DSRC (Dedicated Short Range Communication) intervehicle communication, which operates on the basis of Standard IEEE802.11p. In view of the small range (up to 1 km) of the V2V communications, information will only be available from vehicles located within the said zone.

The given algorithm is based on the so-called BSM (Basic Safe Message), which is transmitted by each vehicle at intervals of 100 ms in a broadcast mode. The structure of

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such a message is regulated by the SAE1975 Standard [5].

III. Collision Warning Algorithm

To determine a safety criterion, it is worthwhile to present a car not as a point of location of its GPS-antenna but as a certain rectangle that will display not just the external dimensions of a car but also the determined safety zone.

Knowing the car orientation in the X-Y plane, which is determined by course angle φ, and the car's exterior dimensions, one can easily determine the projections of the end points on the X- and Y-axes.

That brings us to a unique geometrical model of a car on a plane, which is sufficient to solve the task of collision prevention as shown in Fig. 1.

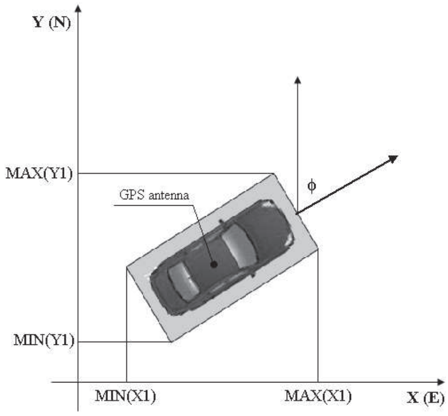

Fig. 1. Geometrical model of a car.

The main prerequisite for a 'no collision' situation at any moment is the absence of simultaneous superimposition of the two cars' projections on the X- and Y-axes as shown in Fig. 2.

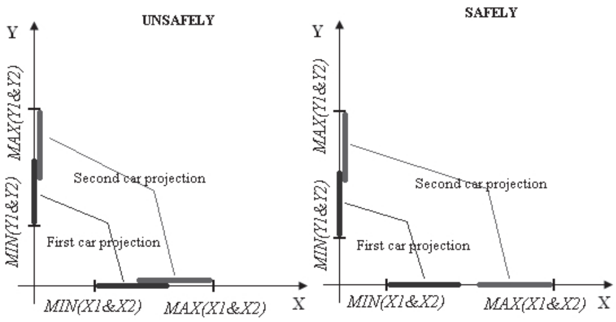

Fig. 2. Safetiy criterion.

The mathematical formulation of the given condition is as follows

$$S_X(t) > 0, \tag{1}$$

or

$$S_Y(t) > 0, \tag{2}$$

here:

$$\begin{cases} S_X(t) = \left[MAX(X1\,\&\,X2) - MIN(X1\,\&\,X2)\right] - \\ -\left[(MAX(X1) - MIN(X1)) + (MAX(X2) - MIN(X2))\right], \\ S_Y(t) = \left[MAX(Y1\,\&\,Y2) - MIN(Y1\,\&\,Y2)\right] - \\ -\left[(MAX(Y1) - MIN(Y1)) + (MAX(Y2) - MIN(Y2))\right], \end{cases} \tag{3}$$

where *X1*, *Y1*, *X2*, and *Y2* are the coordinates of the vehicles' projections on the X- and Y-axes respectively.

Thus, having reviewed the reciprocal time-dependent behavior of the S_x and S_y functions, we can now estimate the safety of passage of a road intersection.

IV. Simulation of Driving Situations

As shown above, this article reviews situations of entering an intersection from a side road and going straight ahead or turning to the left after full stop at a stop line.

For the 1st scenario, as shown in Fig. 3.

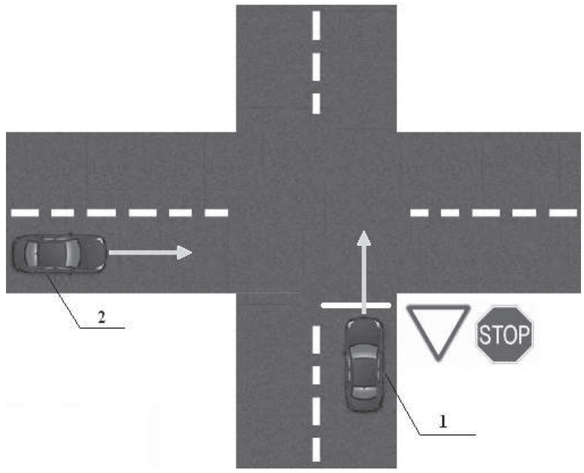

Fig. 3. Car movement through the intersection straight ahead.

The cars' motion equations are as follows:

$$\begin{cases} X_1 = v_{1x}t + \dfrac{a_{1x}t^2}{2}, \\ Y_1 = v_{1y}t + \dfrac{a_{1y}t^2}{2}, \end{cases} \tag{4}$$

where v_{1x}, v_{1y}, a_{1x}, a_{1y} – the projections of the 1st car's speed and acceleration on the X- and Y-axes.

$$\begin{cases} X_2 = X_{20} + v_{2x}t + \dfrac{a_{2x}t^2}{2}, \\ Y_2 = Y_{20} + v_{2y}t + \dfrac{a_{2y}t^2}{2}, \end{cases} \tag{5}$$

where X_{20}, Y_{20} are the initial coordinates of the 2nd car, and v_{2x}, v_{2y}, a_{2x}, a_{2y} – the projections of the 2nd car's speed and acceleration on the X- and Y-axes.

For the purposes of further analysis, the 2nd car's acceleration may be presented as equal to zero, assuming the car is moving along the main road towards an intersection at cruise. To estimate the acceleration of the 1st (one's own) car when starting from rest, one must take into account not just the vehicle's potential but also the road surface condition and the driver's psychophysical qualities.

The simulation was based on the data gained as a result of the experiments described in [6].

In 45 % of cases the average acceleration when starting from rest to go straight was 1.9 m/s^2. The S_x and S_y functions' time dependency graph for the acceleration value

a = 1.9 m/s^2 is shown in Fig. 4.

The parameters of the cars participating in the simulation are shown in Table I.

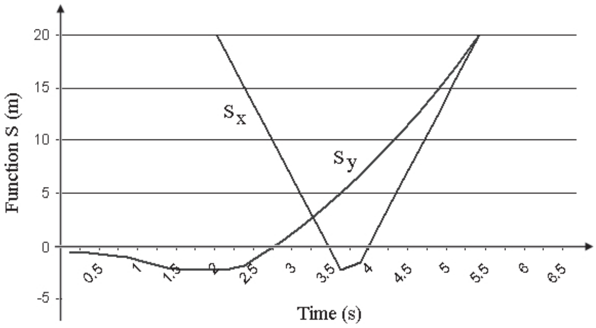

Fig. 4. Dependence of the $S_X(t)$ and $S_Y(t)$ with a_1 = 1.9 m/s^2.

TABLE I. VEHICLES' PARAMETERS.

Car No	Width, m	Length, m	X_0, m	Y_0, m	Speed, km/h	Acceleration, m/s^2
1	2.30	5.0	0	0	0	1.9
2	2.30	5.0	-50	3	50	0

The graphs show that, given the data of the initial conditions, the passage of an uncontrolled intersection in straight direction is safe.

When the 1st car's starting acceleration is reduced to the level of 1 m/s^2, a collision becomes possible as seen in the graphs in Fig. 5. In the time interval of 3.5 seconds to 3.75 seconds, the S_x and S_y functions have negative values, which is in conflict with the above-mentioned safety criterion.

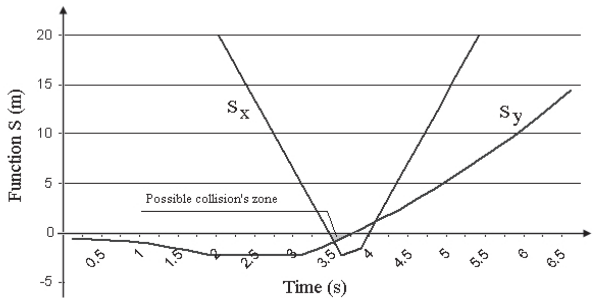

Fig. 5. Dependence of the $S_X(t)$ and $S_Y(t)$ with a_1 = 1.0 m/s^2.

For the scenario shown in Fig. 6, one must estimate the change in the car's path when turning to the left.

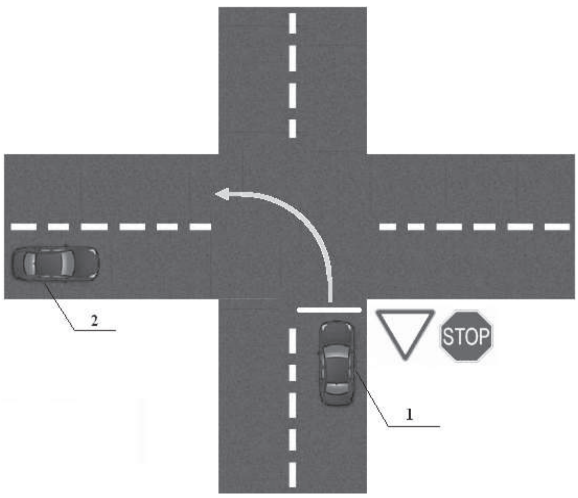

Fig. 6. Car movement through the intersection with turning to the left.

According to the road traffic rules, a left-turning path must form an arc passing through an imaginary centre of the intersection. In such a case, the car may not drive in the oncoming lane – it may only cross it. The turning process is accompanied by a change in the course angle and, consequently, the car's orientation as shown in Fig. 7.

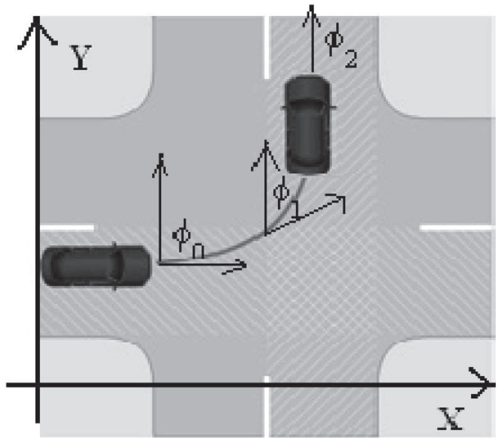

Fig. 7. The trajectory of movement of the car through the intersection with turning to the left.

The angle change in a turn to the left may be described as follows (5)

$$\phi(t) = \phi_0 - \frac{v}{R}t, \tag{6}$$

where v – linear speed, R – intersection arc radius.

It should be noted that a manoeuvring car's linear speed is changing according to

$$v(t) = v_0 + at, \tag{6}$$

where v_0 and a are the car's initial speed and acceleration respectively.

A manoeuvre is deemed to be accomplished when the turning angle becomes equal to the intersection angle. It should be noted that information about the arc radius and the road intersection angle must be made available, e.g. on an electronic map.

The result of the simulation for the same cars is shown in Fig. 8.

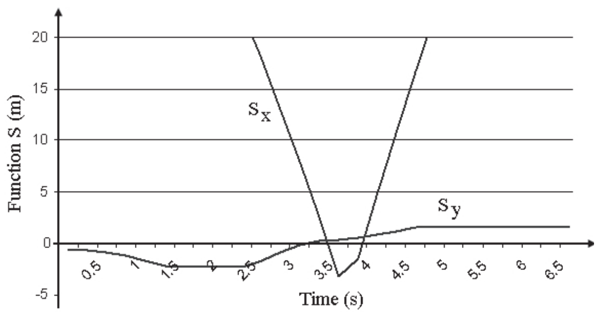

Fig. 8. Dependence of the $S_X(t)$ and $S_Y(t)$ with a_1 = 1.9 m/s^2.

As can be seen in the graphs of the S_x and S_y functions, a left turn is safe for the 1st car at the acceleration value of 1.5 m/s^2.

A reduction of the starting acceleration to 1.0 m/s^2 results in a situation when a road accident is possible as shown in Fig. 9.

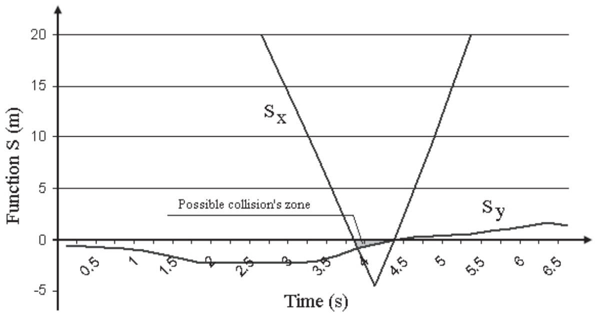

Fig. 9. Dependence of the $S_X(t)$ and $S_Y(t)$ with a_1 = 1.0 m/s^2.

The simulation process reviewed the data from two cars only. Provided that a BSM message is received from several participating cars, one must make up reciprocal functions S1-2, S1-3…S1-N for all the participants and analyse their time-dependent behaviour.

So, the safety criterion for many participants will be as follows

$$\begin{aligned} &\left\{S_{X(1-2)}(t) > 0 \text{ OR } S_{Y(1-2)}(t) > 0\right\} \& \\ &\& \left\{S_{X(1-3)}(t) > 0 \text{ OR } S_{Y(1-3)}(t) > 0\right\} \& \ldots \\ &\ldots \& \left\{S_{X(1-N)}(t) > 0 \text{ OR } S_{Y(1-N)}(t) > 0\right\}. \end{aligned} \tag{7}$$

V. Conclusions

The present paper offers a potential collision warning algorithm for vehicles passing an uncontrolled intersection based on the data received from the GPS navigation system and the V2V (vehicle-to-vehicle) communication. A conclusion about a possible collision was made as a result of mathematical modelling of the movement of cars for various scenarios. In this case, the movement through the intersection from the position of a full stop directly and with a turn to the left were considered. Results were obtained for various acceleration values of a starting vehicle.

It should be noted that the algorithm operation results in a warning signal only. In any event, the ultimate decision on the safety of the imminent manoeuvre lies with the driver.

Further work with this algorithm provides for an experiment in real road conditions.

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