Warning of Potential Collision for Vehicles

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Abstract: A moving vehicle may very likely run into accidents. The occurrence rate of accidents would be largely reduced if the driver is warned in advance, even only 0.5 s earlier. For a running vehicle, the driving route within short time before collision has the characteristic of Markov. In this case, the coordinates of position only have to be considered within a short range, rather than the running status during the past long period. Within short period before collision, the driving route can be basically divided into two states: a straight line and a binomial curve. In this paper, a mechanism is proposed for sending collision warning messages to running vehicles.

Keywords: Curve fitting, collision, dissemination, emergency warning, VANET.

1. INTRODUCTION

Vehicular Ad-hoc NETwork (VANET) is an open mobile Ad-hoc network composed of intercommunications between vehicles and fixed access point on roads. VANET is a self-organized between-vehicle communication network with open structure [1].

VANET is widely used in road traffic safety, information service, traffic query, and assistant driving. In particular, research on road traffic safety focuses on anti-collision warning. The research on various traffic accidents conducted by German Benz Automobile Corporation shows that at least 60% of rear-end accidents would be prevented if the drivers could promptly recognize the risks and take measures only 0.5 s earlier. About 90% of traffic accidents can be avoided if measures are taken 1 s earlier. The National Highway Traffic Safety Administration sponsors developed an Integrated Vehicle-Based Safety System to monitor traffic environment with an aim to reducing crashes. A similar project sponsored by the European Union develops a pre-crash sensorial system [2-5].

Sengupta *et al*. [6] first proposed a cooperative driver assistance system, which considers varying emergency warning grades. This system has been applied in many aspects, such as intersection collision emergency warning or forward collision warning, with parameters such as collision time as the condition for sending Emergency warning messages (EWMs). The positioning error can be reduced below 50 cm by integrating GPS, yaw rate gyro, and steering angle sensor.

Tang *et al*. [7] investigated timings for collision avoidance systems assuming DSRC transmission delays of 25 ms and 300 ms in normal and poorer channel conditions, respectively. They concentrated on the events such as DSRC communication latency, detection range, road condition, driver reaction and deceleration rate. With these events, they defined two collision avoidance timings: critical time to avoid collision and preferred time to avoid collision.

The work reported in Mitropoulos *et al*. [8] also presents a driver assistant system (WILLWARN– wireless local danger warning) designed to timely warn the driver about a dangerous situation ahead by decentralized distribution of warnings and incident messages *via* ad hoc inter-vehicle communications.

The study reported in Ibanez-Guzman *et al*. [9] presents the implementation and basic test in an intersection scenario of an instance of the architecture developed for cooperative vehicle applications. The study highlighted the relevant impact of obstructions on the communications performance, the importance of positioning technologies, the difficulty in creating hazardous situations in testing scenarios, and the need to adequately quantify and log results.

An approach to the study of the positioning impact is that reported by Santa *et al*. [10]. The authors show that the most appropriate navigation sub-system is based on a combination of motion and GNS sensors. The studies evaluated the positioning error and proposed advanced positioning solutions to support cooperative V2X active safety applications, without addressing the design and implementation of complete functional driver assistant system prototypes.

Lefèvre *et al*. [11] pointed out that risk assessment at intersections is possible by comparing intention and expectation. Liebner *et al*. [12] also used drivers' intent inference at intersections.

In addition, from the aspect of data distribution, T. Nadeem *et al*. [13] discussed dissemination techniques for the exchange of messages containing either traffic conditions or vehicles' current status information (e.g. speed and direction).

Dornbush *et al*. [14] focused on the application of informing vehicles about traffic conditions in their surroundings. They proposed a mechanism for vehicles to

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estimate traffic conditions and, through a clustering approach, disseminated the obtained information to vehicles in the network.

In this paper, a EWM transmission mechanism is built. The driving route has the characteristics of Markov: when risks occur, it is independent of the history of driving. Thus, to send emergency warning, it only depends on the driving state within short time. VANET can be used to obtain the position information of vehicles, thereby predicting the driving route, estimating the point of two-vehicle collision, and obtaining the time difference [15, 16]. In this way, the vehicles in neighbouring queues are sorted out by emergency condition, and involve those reaching the alarm threshold in the queue to receive EWMs. Only vehicles entering this queue are regarded as the network nodes of EWM in VANET, which largely reduces load compared with the flooding type network.

2. MODELING MECHANISM

2.1. Fitting of Driving Route

The driving route of a vehicle can be divided into subsections depending on the condition of roads. Within a short time, the driving route may be classified into two types: straight line or polynomial curve.

1) The straight route can be expressed as y=ax+b. During the travelling, a vehicle periodically sends messages to other vehicles and promptly updates the position information in the neighbour list. The system continually corrects and fits the route accordingly. Because of the errors contained in the data, the least square method is used to fit the straight line. According to the measured historical data, $(x_i, y_i)(i=0,2\ldots n)$, a running vehicle follows the Markov rule that the possibility of braking-caused collision is independent of the previous driving route, and thus the value of n should be within the effective time limit, expressed as n'. Least square method is used to build the following equation:

$$\sum_{i=0}^{n'} \varepsilon_i^2 = \sum_{i=0}^{n'} (ax_i + b - y_i)^2 \tag{1}$$

This is a function of a and b, namely:

$$f(a,b) = \sum_{i=0}^{n'} (ax_i + b - y_i)^2 \tag{2}$$

This problem is now equal to finding the minimum of f(a, b) under the following condition:

$$\begin{cases} \dfrac{\partial f(a,b)}{\partial b} = 0 \\ \dfrac{\partial f(a,b)}{\partial a} = 0 \end{cases} \tag{3}$$

Then

$$\begin{cases} 2\sum_{i=0}^{n'} (ax_i + b - y_i) = 0 \\ 2\sum_{i=0}^{n'} (ax_i + b - y_i)\cdot x_i = 0 \end{cases} \tag{4}$$

After unfolding and reorganization, then

$$\begin{cases} a\sum_{i=0}^{n'} x_i + b\cdot n' = \sum_{i=0}^{n'} y_i \\ a\sum_{i=0}^{n'} x_i^2 + b\sum_{i=0}^{n'} x_i = \sum_{i=0}^{n'} x_i y_i \end{cases} \tag{5}$$

The matrix form is:

$$\begin{bmatrix} \sum_{i=0}^{n'} x_i & n' \\ \sum_{i=0}^{n'} x_i^2 & \sum_{i=0}^{n'} x_i \end{bmatrix} \begin{bmatrix} a \\ b \end{bmatrix} = \begin{bmatrix} \sum_{i=0}^{n'} y_i \\ \sum_{i=0}^{n'} x_i y_i \end{bmatrix} \tag{6}$$

Then the values of a and b are found of this equation set. When a new point (x_{new}, y_{new}) is obtained, xnew is substituted; if $y= y_{new}$ or $y= y_{new}+\varepsilon$ (ε is the permissible error), the driving route can be judged as a straight line. Otherwise, the route is a curve.

2) The polynomial curve can be expressed as $y = \sum_{k=0}^{m} a_k X^k$: This is function of driving route.

From the historical data, the vehicle's coordinates can be obtained as set A = $\{(x_0,y_0), (x_1,y_1)\ldots\ldots(x_m,y_m)\}$. The value of m should be within the effective time limit, expressed as m'. Then solving the fitting curve of y as equal to minimizing the sum of squared deviations of y and $y_{m'}$, namely:

$$\Phi(X) = \sum_{i=0}^{m'} [\sum_{k=0}^{n} a_k x_i^k - y_i]^2 = Min \tag{7}$$

Then solving $\Phi(X)$ is transformed to finding the extremums, then:

$$\frac{\partial \Phi(X)}{\partial a_j} = 2\sum_{i=0}^{m'} (\sum_{k=0}^{n} a_k x_i^k - y_i) x_i^j = 0 \quad j=0,1,2,3\ldots n \tag{8}$$

Unfolding Eq. (8), then

$$\sum_{i=0}^{m'} \sum_{k=0}^{n} a_k x_i^k = \sum_{k=0}^{n} (\sum_{i=0}^{m'} x_i^{k+j}) a_k = \sum_{i=0}^{m'} y_i x_i^j \tag{9}$$

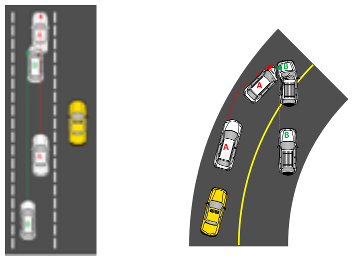
The above equation is equivalent to a linear equation set related to a_0-a_n:

$$\begin{bmatrix} m' & \sum_{i=0}^{m'} x_i & \ldots & \sum_{i=0}^{m'} x_i^n \\ \sum_{i=0}^{m'} x_i & \sum_{i=0}^{m'} x_i^2 & \ldots & \sum_{i=0}^{m'} x_i^{n+1} \\ \vdots & \vdots & \vdots & \vdots \\ \sum_{i=0}^{m'} x_i^n & \sum_{i=0}^{m'} x_i^{n+1} & \ldots & \sum_{i=0}^{m'} x_i^{2n} \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ \vdots \\ a_n \end{bmatrix} = \begin{bmatrix} \sum_{i=0}^{m'} y_i \\ \sum_{i=0}^{m'} x_i y_i \\ \vdots \\ \sum_{i=0}^{m'} x_i^n y_i \end{bmatrix} \tag{10}$$

According to the properties of symmetric positive definite matrix, there is one and only solution to a_0-a_n, which can determine the fitted nonlinear polynomial equation of driving vehicles.

2.2. EWM Sending Mechanism

Based on the above route analysis, the collision point can be located. The route of collision may be a combination of straight line and curve. According to the travelling characteristics, beforehand, when collision occurs, if the curve route is adopted within short time, the route can be fitted using a quadratic polynomial curve, as shown in the Fig. (**1**) below:



(**a**) Straight (**b**) Curve

Fig. (1). Driving conditions.

Then the two-vehicle intersection is equal to combinatorial solving $y=ax+b$ and $y=a_0+a_1x+a_2x^2$, while their parameters are known before fitting.

If the equation set has no solution, the two vehicles will not collide; if it has two solutions, let (x_1,y_1), (x_2,y_2); if it has one solution, then $x_1= x_2$, $y_1=y_2$. The nearest point of intersection ahead of the driving direction is a potential collision point, expressed as (x_{cross}, y_{cross}). If there is no point of intersection, the two vehicles will not collide.

With the intersection between a straight line and a curve as an example, vehicle A is supposed to be located at (x_A, y_A), running at a speed of v_A along a straight line. Vehicle B located at (x_B, y_B), running at a speed of v_B along a curve. A and B are at distance of s_A and s_B respectively away from the cross point. Then

$$s_A = \left|x_{cross} - x_A\right| / \left|\cos\left(\arctan(\alpha)\right)\right| \tag{11}$$

$$s_B = \int_{x_B}^{x_{cross}} \sqrt{1+\left(a_1+2a_2x\right)^2}\, dx \tag{12}$$

The time difference when A and B arrive at the cross point is $t_\Delta = \left|s_A/v_A - s_B/v_B\right| \le \zeta$, where ζ is the warning threshold, and then EWM is sent.

3. MESSAGE SENDING MECHANISM

When two vehicles intercommunicate, the originating node S_0 periodically sends a message package “Hello” to the neighbor nodes within its transmission range. The message “Hello” contains the information about the position of this sender node and relevant information collected from the newest neighbor nodes. By exchanging the message “Hello”, each node can build a newest information list for its neighbor nodes, and understand the distribution of neighbor nodes within its transmission range. Then S_0 can maintain the network topology with these neighbor nodes. Supposing A-H are the neighbor vehicles within a two-hop range of S_0. If a message is sent out in the flooding way, there will be redundant information in the network. Therefore, to reduce the redundant EWM, the following method is proposed to send EWM. When S_0 to send a warning of braking, at the first hop, S_0 selects the nodes with which the collision possibility is within a certain threshold; however, these nodes may become the nodes at the second hop. Transmission is not necessary if no node is within the threshold. After the above computation, A, B, C, D, E and F are supposed to be neighbor nodes of S_0, and G, H as neighbor nodes of B. In the flooding mode, these nodes will retransmit the message extensively (as shown in Fig. **2**). Then the above threshold computation is introduced to avoid such circumstance. If among all neighbor nodes of S_0, only B is within the threshold, then B becomes a re-transmitting node. B will compute its transmission queue with the same method. If G is within the threshold, G becomes the second-hop node. Transmission will be stopped if no node in G's transmission queue is within the threshold (as shown in Fig. **3**).

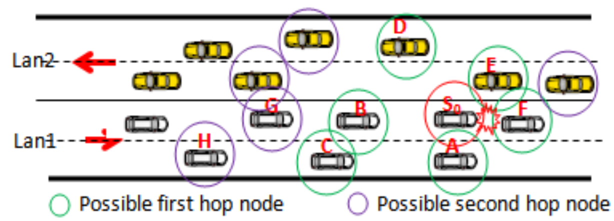


Fig. (2). Flooding mode.

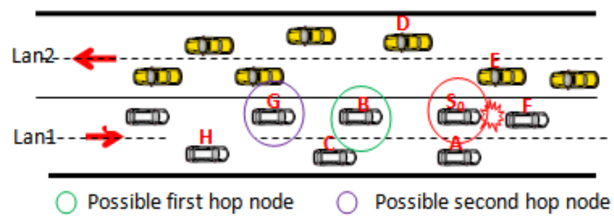


Fig. (3). EWM mode.

Obviously, the amount of transmitted data will be reduced largely. The nodes within the emergency warning range can be calculated as **Algorithm 1**.

The steps are as follows: based on the function fitting method in Section 1.2, the records of travelling are transferred to generate a neighbor queue travelling route including the originating node and fit a function. The transmitting queue is selected with the between-vehicle distance as threshold, and involves the vehicles within the warning vehicle-distance into the computation. First, the fitting function is computed for the neighbor vehicles with the smallest space in between, and the collision time is estimated; if it is within the threshold, then EWM is sent, and moving on to the next neighbor node, the above computation is repeated. The originating node searches its transmission queue L, sends the EWM to the neighbor node S’ within the time threshold; when S’ receives the EWM, it searches its own sending queue L; if there is no node in L, no node is within the warning range, then sending of EWM is stopped to the next node.

4. SIMULATION

The Vanet simulation system is composed of two modules: network communication module and vehicle motion module.

Algorithm 1. Algorithm for the choice of the warning range nodes.

Warning_options_algorithm( )

1 Traverse _Neighbor (s_0) // Search the whole neighbor queue of node s

2 If d≤ε

3 L←s;// select the neighbor nodes with between-vehicle distance within the threshold, and form a queue L; Sort in the ascending order

4 while S'← L do // Find the first node of queue L, obtain n-step historical position information (x_1,y_1), (x_2,y_2),…

5 d1←(x1,y1);

6 d2←(x_2,y_2);…

7 Function_fitting(d_1,d_2,…);// Transfer the fitting algorithm to produce a function set

8 Time_calculation(s');// Compute the time difference

9 if tΔ(s',s_0) ≤ // The time difference between the originating node s_0' and other vehicles is within the threshold.

10 send(message);

11 delete(s');

12 next;

13 end while;

4.1. Simulation Environment of Network and Road Traffic

The network simulation module simulates the communication between vehicle nodes. In this paper, this module is realized *via* OMNET++. At present, VANET vehicle-targeted electronic wireless communication accords to 802.11p communication agreement. Veins possess complete and detailed IEEE 802.11p and IEEE 1609.4 DSRC / WAVE network layer models and creditable vehicle fluidity model. Therefore, the whole simulation model is based on OMNet++, and with the introduction of Veins frame, the road traffic is simulation displayed on SUMO.

Fig. (4). Traveling simulation scene.

4.2. Performance Assessment

The Jilin University campus map, double-channel road is introduced which induces probability of random collision. Vehicle speed changes randomly at 20- 40 m/h. Two types of messages including periodical message and EWM are sent. The periodical messages are generated at 10 pkts/s; EWM is generated when the traveling speed reaches the above threshold. The traveling simulation scene is as follows:

The simulation experiments accord to EWM sent by DCF competition mechanism in IEEE 802.11MAC agreement. The simulation time is 600 s and the size of EWM is 1024 Byte (Fig. **4**).

The average delay of EWM transmission increases along with the elevated vehicle density, and the amplitude is more obvious (as shown in Fig. **5**). When the number of vehicles is smaller than 20, the average delay of EWM transmission is intensified very smoothly, but when the number is larger than 20, the average delay is intensified at a higher amplitude.

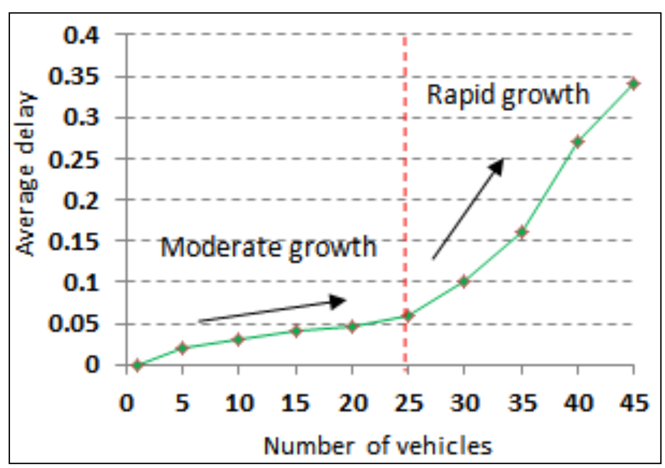


Fig. (5). The relationship of the traffic density and the average delay(s).

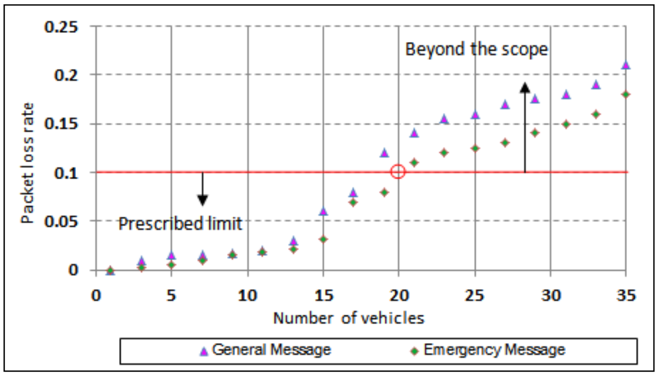


Fig. (6). The drop rate variation with the number of vehicles.

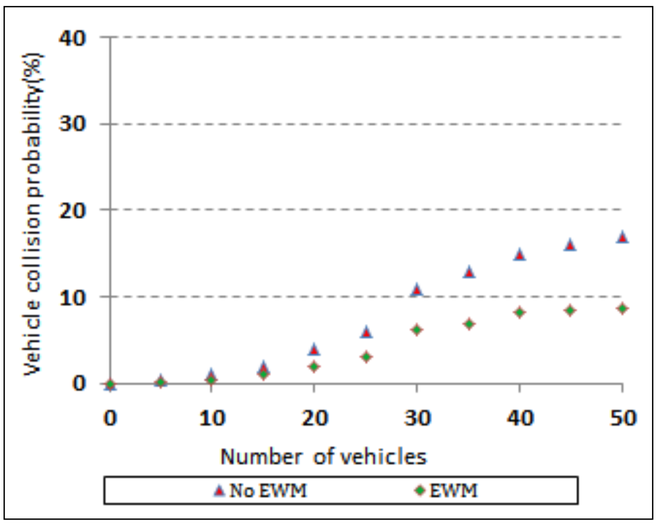


Fig. (7). Vehicle collision probability comparison.

Fig. (**6**) shows the package drop rate along with the number of vehicles. The drop rate increases with the increased number of vehicles; when there is only 1 vehicle in the communication extent, the drop rate of emergency message is 0, the drop rate of common message is 0.5% which is due to internal collision of messages. Along with the increased number of vehicles in the communication range, the message collision is intensified, leading to a greater number of message retransmission and higher package drop rate. The demand of package drop rate does not exceed 10%, and the maximum vehicle number within the emergency message communication time limit is no greater than 20.

Fig. (**7**) compares the variations of vehicle number along with the vehicle collision probability under two situations: EWM and No EWM. Generally, the vehicle collision probability becomes higher with the increased number of vehicles under both situations, but the amplitude becomes gradually smaller. When the number of vehicles reaches 30, the probability of vehicle collision gradually stabilizes.

CONCLUSION AND PROSPECTS

First the background and meaning of research on development and technology of VANET warning data are introduced and a warning model mechanism is built. Targeted at the distributing speed and credibility of warning data, a warning data distributing mechanism suitable for VANET is proposed. This mechanism mainly considers single-hop transmission of warning data and its role in emergency warning to avoid traffic accidents.

Many meaningful findings are achieved but further improvement and perfection are needed.

1) The newly built system is limited and restricted to simplify the simulation scene. Actual measurements will be conducted to validate the effects of this mechanism.

2) It is very important to apply VANET in other aspects, such as assisting vehicles to understand position information of relevant service network points, improving the comfort of drivers, and providing services of mobile office and on-line entertainment. These aspects will be studied in the future.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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