A VANET-based Real-time Rear-End Collision Warning Algorithm

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***Abstract* — Rear-end traffic collision has been a crucial problem due to numerous injury even death and corresponding economic and social damage. In order to eliminate these threats, a large number of researchers have paid effort on this area, with time-consuming artificial intelligence-inspired methods or mathematical method in strict assumptions. In this paper, we propose a VANET-based real-time rear-end collision warning algorithm (VERCWA), to carry on real-time traffic risk assessment and inform drivers collision warning message in appropriate time. Traffic risk is evaluated with the consideration of space headway of the preceding vehicle and following vehicle, current speed of the relevant vehicles, drivers' behavior characteristics (i.e. perception-reaction time) in a real-time way. Experiments conducted show that our VERCWA can obtain better performance, compared with HONDA algorithm with the utilization of a public dataset in California.**

Keywords - collision warning system (CWS), vehicular ad hoc networks (VANET), rear-end collision warning

I. INTRODUCTION

Traffic accidents has played an increasingly important part in people's daily life due to numerous injury even death and corresponding economic and social damage. Within all kinds of traffic accidents, rear-end traffic collision catch the first role when occur in freeways, which caused mainly by drivers' incorrect judgement in distance or speed [1]. A statistical survey of 2012 shows that almost 30% traffic accidents are rear-end traffic collision in China [2]. In order to cover this problem, a tool called as Advanced Driver Assistance System (ADAS) has been developed, which contains Forward Collision Warning (FCW), Rear-end Collision Avoidance, Adaptive Cruise Control (ACC) and Stop-Go Control [2]. Rear-end collision warning system is a subsystem to push warning message to drivers for possible and potential traffic risk situation. In the warning notice generation process, abundant useful information, i.e. relevant vehicle's speed and position, should be collected to be processed for the decision making of traffic risk situation.

There has numerous efforts been paid on rear-end collision warning methods in the past decades. The existing work reviewed in this field can be classified from two aspects: mathematical methods and Artificial Intelligence-inspired methods. ·

- A large amount of mathematical methods have been developed and improved for rear-end collision warning algorithm. The most emblematic methods are Minimum Safety Distance-based methods and Minimum Safety Time-based methods. The main idea of Minimum Safety Distance-based methods is to compute and determine a distance between the preceding vehicle and the following vehicle as a threshold to put forward warning notice, with the consideration of some relevant influential factors, including space headway of the two vehicles and perception reaction time of drivers [3-8]. Some well-developed and typical minimum safety distance-based methods include MAZDA Algorithm [9, 10], Honda Algorithm [11], and so forth. In the distance decision making process, the perception reaction time of drivers contains perception time and decision making duration when facing emergent situation and need to take the brake [12, 13]. Generally, the value of perception reaction time usually ranges from 0.5 seconds to 2.5 seconds [13, 14]. On the other hand, the critical thought of Minimum Safety Time-based methods is to provide drivers collision warning message when the traffic risk is in emergency with a minimum predictable time computed, which has included perception reaction time of drivers [15, 16]. These methods assume that all the vehicles will remain in the current velocity, which is unsuitable for the dynamic traffic situation.
- There are as well some Artificial Intelligent-inspired studies applied in this area. A number of researchers have paid effort on drivers' behavior to help put forward traffic collision warning message [17-18]. Artificial neural networks are used for online-learning for drivers' behavior models to adapt to warning notice for drivers,

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and the parameters are optimized by genetic algorithm in [17]. In [18], the authors have developed a driving-assistance system, which can put forward collision warning information. The drivers' behavior can be identified and transformed into the model and the parameters can be adjusted through the recursive least square methods. Furthermore, many studies using artificial intelligence-inspired approaches have developed some improvements in perception reaction time-related traffic collision warning problems [16, 19-21]. The authors in [16] have proposed a fuzzy-based approach for traffic pre-crash reminder with heterogeneous data fusion by quantum-tuned-BPNN which are sensed and transmitted through V2V communication. The minimum safety distance between the preceding vehicles and following vehicles also can be solved through the artificial intelligence-inspired way. As in [19], a Multi-layer Perception NN-based approach has been proposed to compute the minimum safety distance with the utilization of traffic data from probe vehicles. MLPNN and fuzzy logic have been combined together and applied into this problem to provide warning notice for multi-directional collision situation and automobiles in the highway respectively in [20] and [21].

All the computation methods would take traffic data into consideration, either traffic data form probe vehicles or experimental data. For the traffic data collection, the general way is the utilization of sensors, to detect the presence of preceding vehicles or other traffic characteristics. The information is usually transmitted through vehicle-to-vehicle communication (V2V) and vehicle-to-infrastructure communication (V2I), to achieve a real-time transmission for the real-time traffic risk assessment.

In order to cover the aforementioned drawbacks, we propose a VANET-based real-time rear-end collision warning algorithm (VERCWA), which can put forward real-time traffic risk assessment and inform the drivers the collision warning message in critical moments. VERCWA is working based on some related traffic data collection, including position of preceding vehicles and following vehicles, speed of preceding vehicles and following vehicles, and so forth. The traffic risk would be evaluated with the consideration of space headway of the preceding vehicle and following vehicle, current speed of the relevant vehicles, some drivers' behavior characteristics (i.e. perception-reaction time) in a real-time way. Some experiments have been conducted and compared with HONDA algorithm with the utilization of a public dataset in California. The experimental results depict that our VERCWA obtain better performance, to achieve higher true positive rate.

The remainder of this paper is organized as follows. We take the literature review on some representative studies in Section II and formulate the traffic collision warning problem in Section III. Our algorithm VERCWA is proposed and illustrated in Section IV. The experiments designed and conducted are described in Section V, with results analysis compared with HONDA algorithm. At last, this paper is concluded and some future possible directions are outlined in Section VI.

II. PROBLEM FORMULATION

The rear-end collision warning problem is to provide drivers the necessary and critical warning suggestions under some certain traffic risk situation that remind them to take some measures to keep a safe distance with the preceding vehicles proactively and improve the driving assistance.

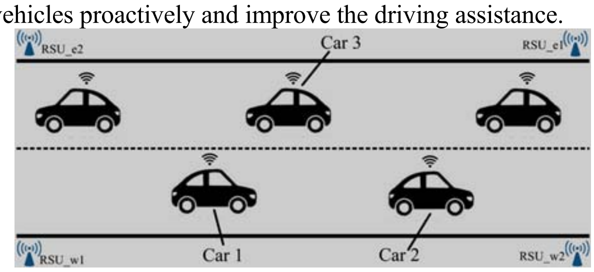

Fig.1 A Typical Traffic Scenario

In order to model this problem, we will consider a typical traffic scenario as shown in Fig.1. In this scenario, a two-direction road segment is illustrated with four roadside unit (RSU) equipped next to the intersection, and all the vehicles are equipped with sensors which can detect the traffic environment and transmit traffic information collected from outsides and from itself. All the vehicles enter into this road segment can be detected by the corresponding RSUs. For example, when the vehicles enter into the road from the approach west, it can be identified by RSU_w1 and then RSU_w2 will receive the message through unicast to be informed this car is in this road segment currently.

In the rear-end collision warning problem, Car 1 is treated as the following car and the main car. Our problem is to confirm the preceding car in the same lane same direction, and then assess the traffic risk levels at present. If the traffic risk level is higher than a threshold, this traffic situation should be considered as in slight-danger, and become tougher step by step with the traffic risk levels increased, until it reach the emergent situation when the driver must take the brake to keep itself safety. Here, we define $TR(V)$ as the current traffic risk of vehicle V. Our objective is to compute $TR(V)$ and confirm a maximum threshold value $Thresh(V)$ to decide in which case the driver must take brake, as shown in formula (1).

$$Max \quad Thresh(V) \tag{1}$$

There are some related characteristics for this output. Obviously, the distance between the preceding vehicle and the following vehicle is very important. In this way, the distance between vehicles to RSU can be an effective way.

We define $Dst(V, RSU_{i1})$ and $Dst(V, RSU_{i2})$ as the distance between the candidate vehicle V to the two RSU RSU_{i1} and RSU_{i2} in the same direction of the same road segment respectively, $i \in \{east, west\}$. We also define vehicle V' velocity as $vlc(V)$, and the related road segment vehicle V belong to as $rs(V)$.

III. OUR VANET-BASED REAL-TIME REAR-END COLLISION WARNING ALGORITHM

In this section, we would propose a VANET-based rEal-time Rear-end Collision Warning Algorithm (VERCWA) to solve the aforementioned problem as presented in Fig.2. This algorithm includes three stages: identification of the preceding vehicle, computation of traffic risk of the following vehicle, and assessment of traffic risk of the following vehicle. The identification of the preceding vehicle stage is to clarify which car is the preceding car of the following car, with the help of so much sensed traffic information and transmitted through V2V and V2I communication. The computation of traffic risk of the following vehicle stage is to compute the following car' s traffic risk and confirm the maximum and minimum value of the threshold of common traffic risk. The assessment of traffic risk of the following vehicle stage is to compare the current traffic risk of the following car with the maximum and minimum value of the threshold, and determine the final assessment of the traffic risk of the following vehicle.

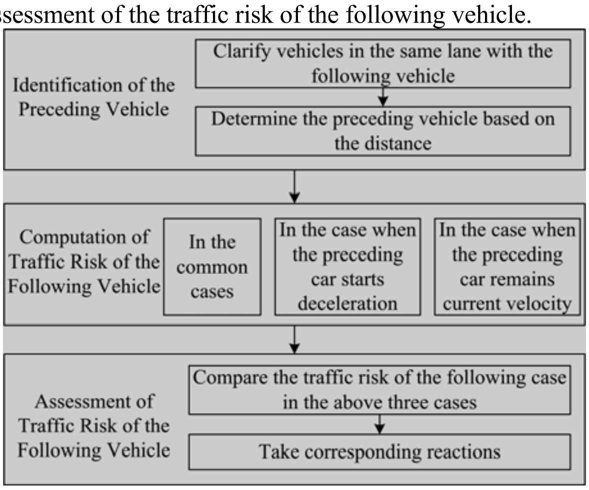

Fig.2 the Process of VERCWA

A. *Identification of the Preceding Vehicle*

This stage is to determine the specific preceding car V_P once a following car V_F targeted, within the so many vehicles around. For example, as in Fig.1, the preceding car of Car 1 is the Car 2 obviously, not the car indexed as Car 3 which is nearest to Car 1 in geomatics. Hence, the preceding car can not always be recognized as the car with nearest distance with the following car. The process of identification of the preceding vehicle is presented in Fig.3.

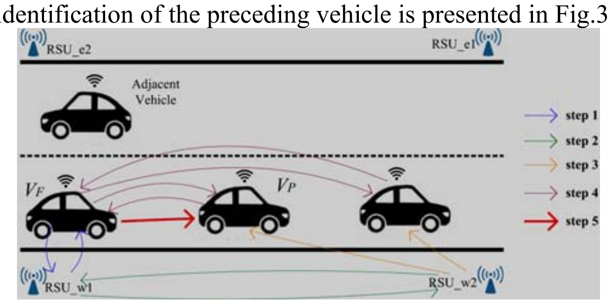

Fig.3 the Process of Identification of the Preceding Vehicle

Firstly, the two vehicles V_P and V_F should in the same lane which are covered by the RSUs in the same roadside.

Once a vehicle V_F comes into a road from the direction west, it will broadcast itself message and communicate with the nearest RSU as RSU_w1 through V2I communication. And then, RSU_w1 will inform RSU_w2 that a new car's event once RSU_w1 itself notice through the I2I communication. At that moment, the two RSUs all clear the existence of this vehicle, and store this car's unique ID in its list.

Secondly, the RSU_w1 and RSU_w2 will broadcast message to the vehicles in this same lane to notify them the arrival of V_F. And then, all the cars in front of V_F will communicate with V_F and V_F compute the distance between them and itself. The distance would be determined based on their location data in the format of GPS data with a little bit error.

Finally, V_F would compare all the distance between itself and a car in front of itself, and select the car with smallest distance as the preceding car.

B. *Computation of Traffic Risk of the Following Vehicle*

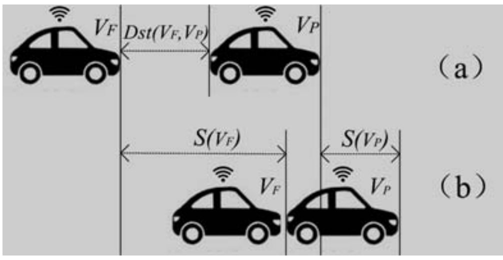

Fig.4 An Example Scenario of Traffic Collision

Then, traffic risk of V_F, which defined as $TR(V_F)$, should be computed based on the minimum safety distance. As shown in Fig.4-(a), there are two vehicles V_P and V_F running in the same road with velocity $vlc(V_P)$ and $vlc(V_F)$ respectively, and $Dst(V_F,V_P)$ defined as the distance between the two vehicles is what we want to know, and calculated in formula (2). After a certain time T, as shown in Fig.4-(b), V_F catches V_P after a running distance of $s(V_F)$ and $s(V_P)$ respectively. With the consideration of perception reaction time, 1.5 seconds is employed in our method due to the previous work suggesting that 60% rear-end collision can be eliminated with 0.5 second earlier warning and 90% rear-end collision can be prevented with 1.5 seconds earlier warning [22]. Here, $a(V_F)$ and $a(V_P)$ are defined as the acceleration rate. $sh(V_F,V_P)$ is defined as the space headway of V_P and V_F.

$$\begin{aligned} Dst(V_F,V_P) &\geq s(V_F) - s(V_P) \\ &= (vlc(V_F) - vlc(V_P)) \times (T+1.5) \\ &\quad + \frac{1}{2}(a(V_F) - a(V_P)) \times (T+1.5)^2 \end{aligned} \tag{2}$$

We also consider two typical traffic scenarios. From that moment on, V_P starts to decelerate until it stops running with a distance of $s(V_P)$ after time T. Once V_P stops, V_F just catches V_P with the same velocity $vlc(V_F)$ and a running distance of $s(V_F)$. In this scenario, $Dst(V_F,V_P)$ would be calculated in formula (4), and we define this $Dst(V_F,V_P)$ as $Thresh\_min(V_F)$ which refers to the minimum value of $Thresh(V_F)$.

$$T = \frac{vlc(V_P)}{a(V_P)} \tag{3}$$

$$\begin{aligned} Thresh\_min(V_F) &= (vlc(V_F) - vlc(V_P)) \\ &\quad \times \left(\frac{vlc(V_P)}{a(V_P)} + 1.5\right) \\ &\quad + \frac{1}{2}(a(V_F) - a(V_P)) \\ &\quad \times \left(\frac{vlc(V_P)}{a(V_P)} + 1.5\right)^2 \end{aligned} \tag{4}$$

As in another typical traffic scenario, V_P keeps running in the same velocity of $vlc(V_P)$ with a running distance of $s(V_P)$, and V_F just catches V_P with the same velocity $vlc(V_F)$ and a running distance of $s(V_F)$. Under this case, the $Dst(V_F,V_P)$ would be calculated in formula (5), and we define this $Dst(V_F,V_P)$ as $Thresh\_max(V_F)$ which refers to the maximum value of $Thresh(V_F)$.

$$\begin{aligned} Thresh\_max(V_F) &= (vlc(V_F) - vlc(V_P)) \\ &\quad \times (T+1.5) \end{aligned} \tag{5}$$

C. Assessment of Traffic Risk of the Following Vehicle

After the computation of $Dst(V_F,V_P)$, $Thresh\_min(V_F)$ and $Thresh\_max(V_F)$, we would compare their value, and take actions as show in formula (5). If $Dst(V_F,V_P)$ is larger than $Thresh\_max(V_F)$, which means it's a safe traffic situation and there is enough long distance between V_P and V_F, there is not any warning message or suggestion message should sent. If $Dst(V_F,V_P)$ is larger than $Thresh\_min(V_F)$ and smaller than $Thresh\_max(V_F)$, which means it is in somehow a traffic risk situation with a certain safe degree although. Hence, a warning suggestion message should be put forward. If $Dst(V_F,V_P)$ is equal to

$Thresh\_min(V_F)$, which means it is an urgent traffic situation, a collision warning message should be sent immediately. Due to the three steps are running cyclical, the case that $Dst(V_F, V_P)$ greater than $Thresh\_min(V_F)$ would not happen.

$$Dst_{(V_F,V_P)} \begin{cases} = Thresh\_min(V_F), \\ \quad \text{put forward warning messages} \\ \quad \text{and take brake;} \\ \in (Thresh\_min(V_F), Thresh\_max(V_F)), \\ \quad \text{put forward suggestion messages;} \\ > Thresh\_max(V_F), \\ \quad \text{nothing to do;} \end{cases} \quad (6)$$

IV. EXPERIMENTS AND ANALYSIS

Due to the difficulties in the access of large amount of traffic data by ourselves, we employ a publicly available database known as the Next Generation Simulation (NGSIM) trajectory data to evaluate the algorithm's performance. The trajectory data are collected from 12:50 p.m. to 1:00 p.m. in Peachtree Street in Atlanta, Georgia on November 8, 2006. These data includes vehicle's velocity, acceleration, location and so forth. In order to evaluate our VERCWA's performance, we select a well-acknowledged and common algorithm HONDA.

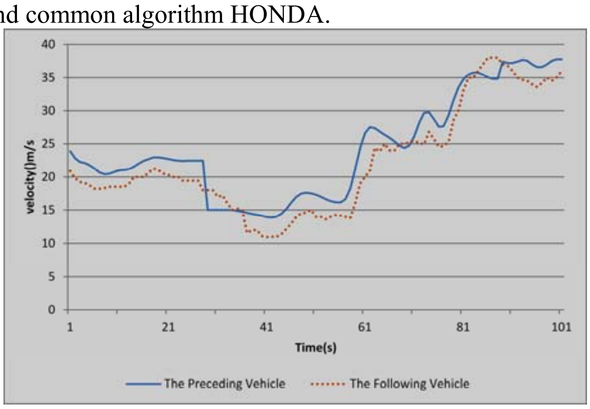

Fig.5 Velocity Trend of the Two Vehicles

We compare the velocity changing of the preceding vehicle and the following vehicle based on the trajectory data with every 0.1 second in Fig.5. On the other hand, we also depict the changing of acceleration of the preceding vehicle and following vehicle in Fig.6. From the two figures, we can find that the velocity and acceleration of the following car has some relationship with the preceding car. In some cases, with the preceding car in sharp deceleration, the following car would take some responsive reactions.

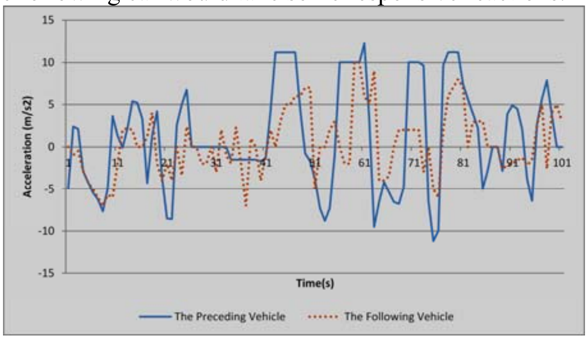

Fig.6 Acceleration Trend of the Two Vehicles

Fig.7 depicts the performance of HONDA algorithm, in which we can observe that HONDA algorithm can assess traffic risk in many important moments, such as in acceleration higher than almost 5m/s2 or deceleration higher than 5m/s2 approximately. However, there also exist some cases that the HONDA algorithm did not find out and put forward collision warning message, especially when the acceleration or deceleration is not high.

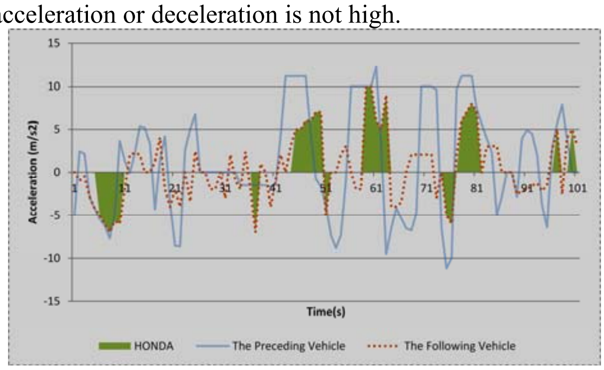

Fig.7 Performance of HONDA Algorithm

In Fig.8, we present the performance of our VERCWA algorithm. From this figure, we can find that most of the traffic cases in risk can be detected and the collision warning message would be put forward consequently. When the acceleration or deceleration of the following vehicle increased sharply, VERCWA is able to identify and assess the traffic risk of the following vehicle, and then provide real-time final decision, even the acceleration value almost reach to 3 m/s2.

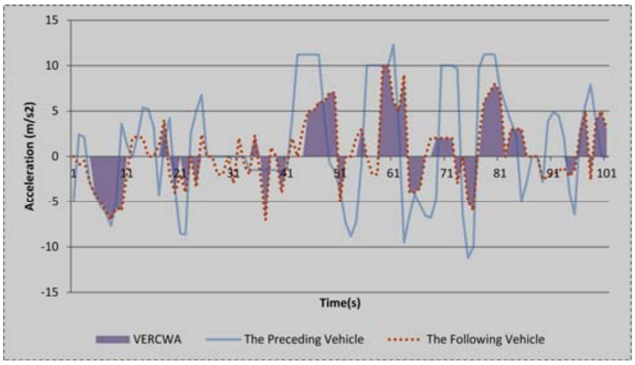

Fig.8 Performance of VERCWA Algorithm

V. CONCLUSION

Nowadays, the rear-end traffic collision have become an increasingly severe problem. In order to relieve the rear-end collision, we have proposed a VANET-based real-time rear-end collision warning algorithm (VERCWA), to remind drivers when in the risk of traffic collision, based on the real-time traffic data collected by sensors and transmitted through V2V and V2I. With the utilization of real-time obtained traffic data, e.g. position of preceding vehicles and following vehicles, speed of preceding vehicles and following vehicles, VERCWA can identify the preceding vehicle for each following vehicle, and compute the traffic risk and assess them. The traffic risk can be evaluated with the consideration of space headway, current speed of the two vehicles, drivers' behavior characteristics (i.e. perception-reaction time). Finally, we evaluate VERCWA's performance by using the public available traffic dataset NGSIM, and compared with HONDA algorithm. The experimental results present that our VERCWA is able to get better performance.

CONFLICT OF INTEREST

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

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