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Research Article

Safety Distance Calculation for Collision Avoidance in Vehicular Ad hoc Networks

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Abstract: A Vehicular Ad-Hoc Network (VANET) is a special form of Mobile ad-hoc network used for the communication between nearby vehicles and between vehicles and fixed roadside equipment. VANETs are an important component of Intelligent Transport System (ITS) that combines computer and communication technologies for traffic management to reduce traffic congestion, improve traffic efficiency, avoid accidents and improve road safety. Vehicular safety is an important application of VANET and these include vehicle collision warning, brake warning from a preceding car, obstacle warning and other emergency notifications. In this paper, we focus on accident prevention and propose a Safety Distance Calculation methodology that is based on the relative velocity and distance between the vehicles. The driver is warned, when the safety distance to another vehicle is reached so that the driver can take appropriate steps for collision avoidance. The proposed system is based on the positional information provided by GPS receivers. As most cars, today, are equipped with GPS receivers, our proposed system provides a simple and feasible solution for accident prevention. Since, the relative distance between the vehicles is used for computation; the safety distance can be accurately estimated.
Keywords: VANET, Accident Prevention, Safety Application, GPS, Safety Distance, Safety Distance Calculation, Collision Avoidance.

INTRODUCTION

Intelligent Transport System (ITS) covers the new trend of computer and communication technologies and applications used for traffic management that aims to improve passenger safety and increase the efficiency of the transportation systems [19]. It includes a wide range of technology for vehicular information such as vehicle communication system, Global Positioning System (GPS), digital mapping, video cameras, sensor and technologies together with advanced information processing to provide relevant and timely information to users and traffic management systems to reduce traffic congestion, improve traffic efficiency, avoid accidents and improve road safety.

Vehicular Ad Hoc Network (VANET) is a special purpose Mobile Ad-Hoc Network (MANET) that is an important component of ITS. VANET is used for exchange of messages between vehicle to vehicle (V2V) and also between vehicles and fixed roadside equipment (V2R) used for traffic management. Vehicles communicate using on-board sensors and communication equipment using Dedicated Short Range Communications (DSRC) [6, 11, 14] that includes wireless technologies like WIFI, IEEE 802.11, WIMAX, IEEE 802.15 and Bluetooth.

There are a number of significant differences between VANET and MANET [17]. VANETs like MANETs allow vehicles to form a self-organized network without the requirement of permanent infrastructures. However, VANETs have a highly dynamic topology as compared to MANET, due to the high mobility of vehicles and the movement of the vehicles can be from both directions. On the other hand, unlike MANET, vehicular movements are restricted to a geographical pattern, such as a network of streets or highways. Unlike MANET, vehicles support substantial power resources for V2R and V2V communication. Another important aspect of VANET is that, a good portion of the messages exchanged are both delay-critical and safety-critical.

VANET applications can be classified under two categories [3, 10]; Comfort applications and Safety applications. Comfort Applications provide driver assistance by supplying the driver with information regarding navigation, traffic congestion, weather, location of nearest gas station, petrol station and restaurant. Safety applications [16] are intended for lane changing, vehicle collision warning, brake warning from a preceding car, obstacle warning and other emergency notifications.

In this paper, we propose a safety distance warning system which alerts the driver when a minimum distance to another vehicle is reached. This would enable the driver to take emergency measures, like braking, to avoid vehicle collision. The rest of the paper is organized as follows. Section II describes the safety applications and related work. In Section III, we explain the safety distance calculation and the collision-avoidance alarm system. In Section IV, we discuss the simulation results and Section V concludes with observations on future research.

SAFETY APPLICATIONS AND RELATED WORK

Vehicle safety systems can be classified as passive safety system and active safety system. Passive safety relate to safety equipment on board the vehicle, like blowing the airbag or warning to fasten the safety belt. These help to minimize or reduce passenger injuries. Active systems try to prevent vehicle collision by providing the driver with suitable warning to take the necessary emergency actions. This information could also be propagated to other nearby vehicles to avoid major accidents. In our proposed system, an active safety system is used to avoid accidents. Inter-Vehicle Communication Systems (IVCs) provides communication between vehicles [20].

The driver's capability is affected by the physical and mental abilities to quickly assess the situation and respond immediately. Several techniques have been proposed by many researchers. The already developed Collision Avoidance/Warning Systems [15] are: the sensors are installed in the vehicle at the front. It constantly senses the road ahead for vehicles or obstacles. If any vehicle or obstacle is on the way, then this sensor raises peep sound to the driver. The REduce Speed of Collision Under Emergency (RESCUE) collision-mitigation system [7] is introduced to decrease the kinetic energy dissipated during a collision through automatic emergency braking.

Adaptive (Intelligent, Smart) Cruise Control [15] is a combination of collision warning technology and existing cruise control. This system maintains the distance between its vehicle and the vehicle behind a followed vehicle using an adjustable range control feature. The Lane Tracking or Lane Departure Warning [15] system provides an audible alarm in the vehicle sounds to alert the driver if a vehicle moves to the edge of the roadway. The GPSenseCar a Collision Avoidance Support System [1] will start to horn with different tones according to the estimated degree of danger as calculating from the pedestrian's smart phone. This system requires every user to have a WiFi enabled cell phone.

Vehicular – Collision Avoidance Support System (VCASS) [12] is a GPS based collision avoidance system that employs 802.11b for inter-vehicle communication. VCASS demonstrates that by combining a high precision GPS receiver and IEEE 802.11 network, the obstacle beyond a building at a distance of 1.2km can be detected.

The Driving Safety Support System (DSSS) [13] is used to avoid collisions at intersections and warns the driver to avoid collision. It also developed an Accident Prevention System for motorcycle when drivers make a left turn. Driver Warning Provision System for Pedestrian prevents accidents caused by drivers trying to make a right/ left turn and failing to notice pedestrians or bicycles at crossing.

The design of Automobile Collision Avoidance Warning System Based on LabVIEW [11] monitors the distance and velocity of forward vehicle. This system uses a sensor and data acquisition card to calculate safety distance

The GPS based Vehicular Collision Warning System using IEEE 802.15.4 MAC/ PHY Standard [4] looks at collision warning system for dumpers in an open cast mine by calculating vehicle safety distance co-ordinates.

SAFETY DISTANCE CALCULATION AND COLLISION WARNING

In this paper we propose a Safety Distance Calculation methodology that is based on the relative velocity and distance between the vehicles. The driver is warned, by raising an alarm, when the safety distance to another vehicle is reached so that the driver can take appropriate steps for Collision Avoidance.

Vanita Lonkar *et al.* has been proposed a Secure, Pre Warning Collision Avoidance Algorithm (SPWCA) to broadcast secure warding messages if the distance between two vehicles are less [21].The authors have also shown the simulation results to ensure low delay, high throughput and high trustworthiness of secured messages.

Receiving positional information of nearby vehicles

We assume that each vehicle is equipped with a GPS receiver that provides positional information (latitude, longitude) and direction.

GPS receivers are known to have a localization error of ± 10 to 30m [5]**.** Hence the computed position of the vehicle may not be absolutely accurate. Since, we calculate and use the relative distance between the vehicles, this distance can be accurately estimated.

We also assume that the vehicles are capable of communication using 802.11; to transmit their GPS position to other nearby vehicles traveling on the highway.

Distance calculation between two vehicles:

Every vehicle on the highway can receive the GPS information of the other vehicles and calculate the distance (D) between its vehicle and the other vehicles using Haversine formula [18] as given below:

dlat = lat2 - lat1
dlon = lon2 - lon1
A = (sin (dlat/2)) ^2 + cos (lat1) * cos (lat2) * sin (dlon/2)) ^2
C = 2* atan2 (sqrt (A), sqrt (1-A))
D = R * C

Where (lat1, lon1) are the latitude and longitude of one vehicle and lat2, lon2 are the latitude and longitude of the second vehicle and R is the earth radius in kilo meter. The latitude and longitude values are given by GPS receiver in the form of degrees, minutes and seconds. The distance D is obtained in kilometer.

For example, let us assume two vehicles A and B who transmit their GPS positions to each other. If A's latitude and longitude are (13º 0.1′ 0″, 80º 0′ 0″) and B's are (13º 0′ 0″, 80º 0′ 0″), then the distance is calculated as 0.2 km or 200 m.

Safety Distance Calculation

We have taken the following into consideration for calculation of safety distance (SD):

- The time (t_h) taken for the vehicle driver to react after receiving the alarm
- The braking distance ($dist_{brake}$), which is the distance the vehicle travels while slowing to a complete stop
- Minimum distance ($dist_{min}$) to be maintained between the two vehicles even after they come to a stop

The braking distance is a function of several variables [8]. First, the slope (grade) of the roadway will affect the braking distance. If the vehicle is traveling uphill, gravity assists in the attempts to stop and reduces the braking distance. Similarly, gravity works against when the vehicle is descending and will increase the braking distance. Next, the frictional resistance between the roadway and the tires can influence the braking distance. The last parameter is the initial velocity of the vehicle; higher the velocity, the longer it will take the vehicle to stop, given a constant deceleration.

Collision Warning

We have considered two scenarios and applied the safety distance calculation to raise the alarm for collision warning. We have considered a highway which allows vehicular traffic in both directions.

Scenario 1: (Vehicles traveling in the same direction)

When two vehicles are traveling in the same direction, the possibilities can be considered as follows:

- Both vehicles are traveling with the same velocity
- The vehicle in front is traveling at a higher velocity than the rear vehicle
- The vehicle in front is traveling at a slower velocity than the rear vehicle

In the first two instances, the vehicles will not collide, but in the third instance, the vehicles can collide and collision warning would apply.

Consider two vehicles A and B where A is the vehicle in front and B is the vehicle behind traveling at a higher velocity than A as shown in Figure 1.

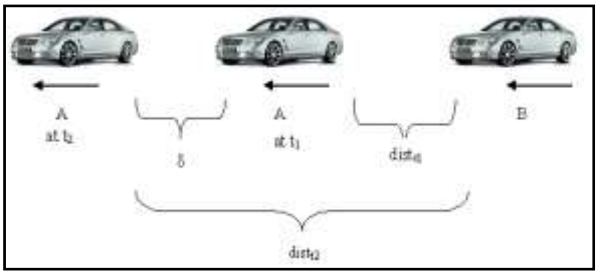

Fig-1: Vehicles traveling in the same direction

Vehicle B obtains the GPS coordinates of vehicle A at instance $\mathbf{t_1}$ and $\mathbf{t_2}$ and calculates distance $\boldsymbol{dist_{t1}}$ and $\boldsymbol{dist_{t2}}$ at time $\mathbf{t_1}$ and $\mathbf{t_2}$ respectively. The distance $\boldsymbol{\delta}$ traveled by vehicle A in the time $\mathbf{(t_2 - t_1)}$ is :

$$\delta = dist_{t2} - dist_{t1}$$

The velocity of A, $\mathbf{V_A}$ is calculated as :

$$V_A = \delta / (t_2 - t_1)$$

Given $\mathbf{V_B}$ is the velocity of B, the relative velocity $\mathbf{V_{rel}}$ between A and B is calculated as :

$$V_{rel} = V_B - V_A$$

If the two vehicles continue to travel at the same velocity, then the two vehicles are likely to collide at time $\mathbf{t_c}$, calculated as:

$$t_c = dist_{t2} / V_{rel}$$

Given the acceleration of B is '**a**', the distance $\mathbf{dist_{hr}}$ traveled by B during the human reaction time t_h, is given as:

$dist_{hr} = V_B\ t_h + ½\ a\ t_h^{\ 2}$

The formula for calculating the braking distance, $\mathbf{dist_{brake}}$ assuming there is no gradient in the road is [8]:

$dist_{brake} = V_B^{\ 2}/(2gf\ )$

Where '**f**' is the coefficient of friction between the tires and the roadway and '**g**' is the acceleration due to gravity (9.8 m/sec^2). The value of the coefficient of friction for different vehicle velocities is assumed as given in Table 1.

Table-1: Coefficient of Friction values

Design Speed (kmph)	Coefficient of Friction (f)
30	0.40
40	0.38
50	0.37
60	0.36

The stopping distance, $\mathbf{dist_{stop}}$ of B can be calculated as:

$dist_{stop} = dist_{hr} + dist_{brake}$

The length of the vehicle has not been considered in the above calculations. Hence, we add a minimum distance, $\mathbf{dist_{min}}$ to the stopping distance for calculating the safety distance SD. The minimum distance can be suitably varied to accommodate different vehicle lengths.

$SD = dist_{stop} + dist_{min}$

To travel SD, the time taken, $\mathbf{t_{sd}}$ based on the relative velocity $\mathbf{V_{rel}}$ would be:

$t_{sd} = SD / V_{rel}$

The collision alarm must be raised in vehicle B, such that B has time t_{sd} to avoid collision and allows vehicle B to brake and come to a stop without hitting the vehicle A.

Vehicle B would continuously re-calculate the velocity and the relative distance with A and accordingly an alarm would be raised when the vehicle distance becomes equal to the safety distance. Similarly vehicle A can also monitor the movement of B and accordingly increase its speed to avoid collision.

The safety distance would have to be calculated for all the nearby vehicles in the same manner and must also be monitored continuously.

Scenario 2: (Vehicles traveling in opposite direction)

When two vehicles are traveling in the opposite direction as shown in Figure 2, there is a distinct possibility of collision between the two vehicles, irrespective of the speed with which they are traveling.

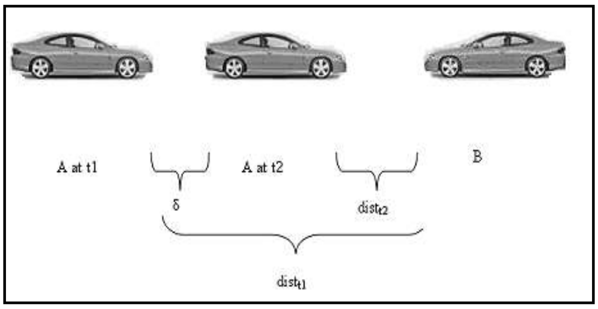

Fig-2: Vehicles traveling in opposite direction

Vehicle B obtains the GPS coordinates of vehicle A at instance $\mathbf{t_1}$ and $\mathbf{t_2}$ and calculates distance $\boldsymbol{dist_{t1}}$ and $\boldsymbol{dist_{t2}}$ at time $\mathbf{t_1}$ and $\mathbf{t_2}$ respectively. The distance **δ** traveled by vehicle A in the time $\mathbf{(t_2 - t_1)}$ is :

$\delta = \boldsymbol{dist_{t1} - dist_{t2}}$

The velocity of A, $\mathbf{V_A}$ is calculated as :

$V_A = \delta / (t_2 - t_1)$

Given V_B is the velocity of B, the relative velocity $\mathbf{V_{rel}}$ between A and B is calculated as :

$V_{rel} = V_B + V_A$

The two vehicles are likely to collide at time $\mathbf{t_c}$, calculated as :

$t_c = \boldsymbol{dist_{t2}} / V_{rel}$

The braking distance of A $\mathbf{dist_{ba}}$ and B $\mathbf{dist_{bb}}$ are calculated as :

$\mathbf{dist_{ba}} = V_A^{\ 2}/(2gf\ )$

$\mathbf{dist_{bb}} = V_B^{\ 2}/(2gf\ )$

Vehicle B can calculate the acceleration '**a**' of vehicle A by calculating the velocity of A at two instance of time and then calculating the acceleration using the formula:

$v = u + a\ t_h$

where v is the final velocity and u is the initial velocity of vehicle B.

The human reaction time for vehicle A and B can be calculated as:

$dist_{hra} = V_A\ t_h + ½\ a\ t_h^{\ 2}$

$dist_{hrb} = V_B\ t_h + ½\ a\ t_h^{\ 2}$

The safety distance SD when A and B are traveling in the opposite direction is given as :

$$SD = (dist_{ba} + dist_{hra}) + (dist_{bb} + dist_{hrb}) + dist_{min}$$

To travel SD, the time taken, $\mathbf{t_{sd}}$ based on the relative velocity $\mathbf{V_{rel}}$ would be :

$$t_{sd} = SD / V_{rel}$$

The collision alarm must be raised in the vehicles A and B, such that the vehicles have time $\mathbf{t_{sd}}$ to avoid collision. The vehicles would have to continuously re-calculate the velocity and the relative distance and accordingly an alarm would be raised when the vehicle distance becomes equal to the safety distance. The safety distance would have to be calculated for all the nearby vehicles in the same manner and must also be monitored continuously.

SIMULATION RESULTS

The safety distance calculation and collision warning was implemented and tested using NS-2 simulator. The transmission range was set to 500m. The simulation has been done with multiple nodes ranging from 2 to 10 nodes. Figure 3 shows the simulation carried out in NS2 for 10 nodes.

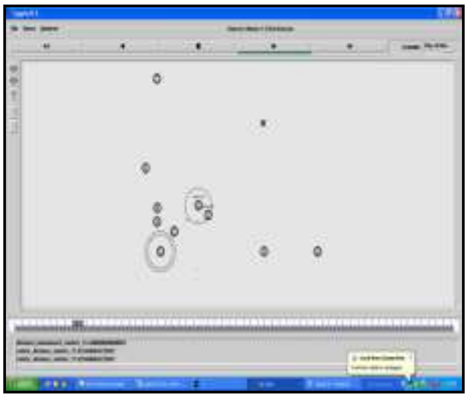

Fig-3: NS2 Simulation with 10 nodes

Keeping the speed of one vehicle constant, the safety distance was calculated for different speeds of the other vehicle for speeds varying from 30 km /hr to 120 km/hr. The simulation was also done for different human reaction times of between 1.5 to 3 seconds. The minimum distance was varied from 3m to 10m to accommodate varying vehicle lengths.

For example, keeping the speed of one vehicle A as 50 km/hr, human reaction time as 2 seconds and minimum distance as 3m, the safety distance and alarm time for varying speeds of a second vehicle is given in Table 2, for vehicles traveling in the same direction.

V_B (km/hr)	V_B (m/sec)	V_{rel} (V_B- V_A)	f	$dist_{brake}$ (m)	SD (m)
30	8.33	-20.0	0.40	8.8	$dist_{min}$
40	11.11	-10.0	0.38	16.5	$dist_{min}$
50	13.8	0.0	0.37	26.2	$dist_{min}$
60	16.6	10.0	0.36	39.05	58.65
70	19.44	20.0	0.35	55.08	77.52
80	22.22	30.0	0.34	74.08	99.3
90	25.0	40.0	0.33	96.6	124.6
100	27.7	50.0	0.32	122.33	153.03
110	30.05	60.0	0.31	153.10	186.6
120	33.3	70.0	0.30	188.58	225.08

Table 2: Safety distance value (vehicles moving in same direction)

Table 3 gives the safety distance calculation for vehicles traveling in opposite directions

Table 3: Safety distance value (vehicles moving in opposite directions)

V_B (km/hr)	V_B (m/sec)	V_{rel} (V_B+ V_A)	f	$dist_{ba}$ (m)	$dist_{bb}$ (m)	SD (m)
30	8.33	80.0	0.40	26.2	8.8	60.16
40	11.11	90.0	0.38	26.2	16.5	70.22
50	13.8	100.0	0.37	26.2	26.2	83
60	16.6	110.0	0.36	26.2	39.05	98.65
70	19.44	120.0	0.35	26.2	55.08	117.52
80	22.22	130.0	0.34	26.2	74.08	139.3
90	25.0	140.0	0.33	26.2	96.6	164.6
100	27.7	150.0	0.32	26.2	122.33	193.3
110	30.05	160.0	0.31	26.2	153.10	226.6
120	33.3	170.0	0.30	26.2	188.58	264.88

As seen from the tables, the safety distance increases proportionate to the relative velocity of the vehicles. Figure 3 and 4 gives the graph of relative velocity versus safety distance plotted for different human reaction times for vehicles traveling in the same direction and opposite direction.

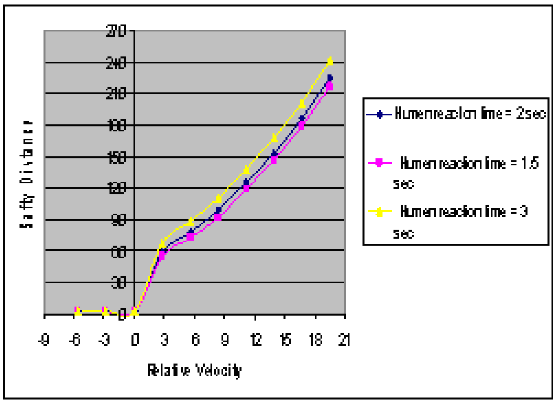

Fig-3: Relative velocity vs safety distance for vehicles in same direction.

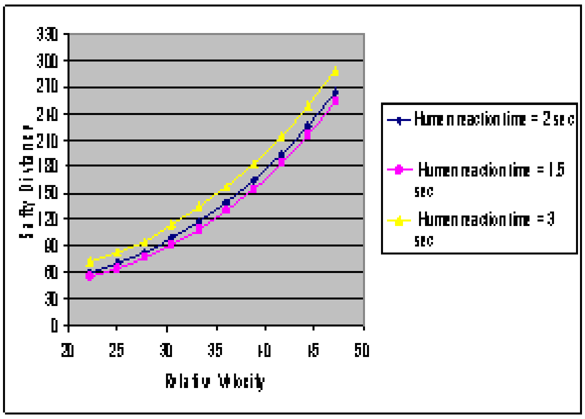

Fig-4: Relative velocity vs safety distance for vehicles in opposite direction.

CONCLUSION AND FUTURE WORK

In this paper, we have proposed a collision warning system, wherein the safety distance between vehicles is calculated based on the relative velocity between two vehicles. As most cars, today, are equipped with GPS receivers, our proposed system provides a simple and feasible solution for accident prevention**.** Since, the relative distance between the vehicles is used for computation; the safety distance can be accurately estimated.

As future work, we propose to carry out more rigorous testing with multiple nodes simulating traffic at different times of day to depict real-life vehicular traffic movement and traffic congestion. We also plan to consider the time taken for computation and its impact on computation of minimum distance to provide for computational delay and vehicle length. Further, we also propose to test using clusters of vehicles and communication of positional information within the cluster.

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