2013 IEEE 27th International Conference on Advanced Information Networking and Applications

An Advanced Vehicle Collision Warning algorithm over the DSRC Communication Environment*

An Advanced Vehicle Collision Warning algorithm

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Abstract—**Although many kinds of collision pre-warning algorithms and systems for vehicles were proposed in order to prevent accidents in past years, two problems have to be resolve in order to enhance the accuracy of collision detection. First, a vehicle does not always keep the same velocity when it is moving. Second, the curve road condition should be considered. In this paper, we proposed an Advanced Cooperative Collision Warning algorithm named ACCW to deal with these two problems. Basically, ACCW uses the acceleration parameter to correct some errors that are caused by velocity and direction changing. The simulation results show that that the proposed ACCW algorithm has high accuracy's warning rates in both intersection and curve situations.**

Keywords- Telematics; Driving Safety; Cooperative Collision Warning

I. INTRODUCTION

Telematics, which is an emerging technique of wireless network, brings a new marketplace not only for the automobile industry but also for the information technology industry. Telematics combine informatics, communication, and electronics on vehicles to provide applications and services for enhanced comfort and safety requirements. For the safety issue, some researches tried to provide powerful mechanisms or methods to prevent accidents [1][2]. In order to enhance driving safety, collision warnings before crash help drivers to avoid it.

For driving safety enhancement, more road conditions such as curve road should be considered in the collision warning system. A collision warning system based on sensors built on roads was proposed in [5] to overcome the problem of curve situation. Although the system can be applied on curve roads, cost of the system is expensive if most curve roads are built with sensors.

The basic idea about the cooperative collision warning (CCW) system is broadcasting the location information to neighboring vehicles using wireless communication such as Dedicated Short-Range Communications (DSRC). After the location information is received at the receiver vehicle, oncoming collisions can be predicted.

Although many collision warning algorithms and systems were proposed in past years, two problems should be considered in a collision warning system. First, factors about a moving vehicle such as acceleration and deceleration should be considered in the calculation of collision prediction to enhance the warning accuracy. Second, a curve road should be considered in the collision warning system. A curve road is the main factor affects the accuracy of the collision warning system.

In this paper, an Advanced Cooperative Collision Warning (ACCW) algorithm is proposed and addressed to resolve the aforementioned two problems. In the ACCW algorithm, vehicles broadcast Relationship Information (RI) messages to neighboring vehicles periodically through DSRC communication. When a RI message is received by vehicles, these vehicles calculate whether potential collisions between two vehicles (sender and itself) may happen or not. In the ACCW algorithm, the host vehicle (receiver) uses its RI message and target vehicle's (sender) RI message to calculate the closest point of these two approaching vehicles. In order to tackle some errors caused by velocity and direction changing when calculating the closest point of two vehicles, acceleration information of a vehicle is used. After calculation, if the distance between the closest point and the host vehicle is less than a threshold, it is concluded that the collision between these two vehicles is oncoming. Next, The ACCW algorithm sent a warning message *k* seconds before on coming collision, in which *k* depends on the users' setting. Finally, some related information is recorded in the ACCW algorithm, which can be used for accident identification.

The rest of this paper is organized as follows: Section II introduces others' cooperative collision warning researches. Section III describes the proposed of ACCW algorithm. Section IV presents the performance analysis of ACCW. Finally, Section V has conclusion remarks.

*This research is supported by the National Science Council of the Republic of China Taiwan under the contract number NSC 100-2219-E-006 -002 and Institute for Information Industry (III).

1550-445X/13 $26.00 © 2013 IEEE
DOI 10.1109/AINA.2013.72

IEEE computer society

II. RELATED WORKS

The phrase of Cooperative Collision Warning system (CCW) was proposed by GM automobile research group in 2005 [6]. CCW is a novel collision warning structure for vehicles. The CCW system exchanges information to neighboring vehicles using wireless communication. The information contains some parameters such as time, longitude, latitude, course, velocity, etc., which can be obtained from the Global Positioning System (GPS) device. The CCW system calculates whether the collision of vehicles may occur or not depending on the received information. The proposed CCW system was implemented in 2007 [7].

Some CCW systems rely on the DSRC communication technique. A DSRC-based cooperative collision prediction and warning mechanism was proposed in [8][9]. The Safety Headway, which is based on the received location and velocity information, is to assist the driver to obtain the dynamic relationships and to keep a reasonable distance for maintaining adequate response time to emergent situations. In addition, four warning levels were defined in these researches and were determined by (1) the distance between a host and its neighboring vehicles and (2) driving patterns. However, the cooperative collision warning scheme based on distance in the research may only be able to be applied to the highway environment only. Some situations are not considered, e.g. intersection and curve.

In [10], the authors proposed a cooperative collision warning scheme based on distance between two vehicles for ommi-direction (360-degree). The basic idea of the research is to exchange some information between vehicles through wireless communication. After that, calculating the time on which vehicles reach the intersection. Two vehicles will collide if the time is equal or smaller than a threshold. Nevertheless, it is unsuitable to be used in the curve environment. Another cooperative collision warning scheme was proposed in [11], in which the authors proposed a warning system that employs sensors, sink nodes, and base stations for avoiding collision on the curved road. However, the system needs to deploy some infrastructures. The cost of such infrastructure system is expensive. It costs a lot to build sensors at all curves. Furthermore, it is unsuitable to be used in the intersection environment because a large number of information exchanging at the intersection results in packets collision and loss.

In our previous works [12][13], a Collision Pre-Warning Algorithm (CPWA) was proposed. Referring to the simulation results in [12], warning massages were sent before collisions occur in different velocities' situations, and the curve environment was simply simulated in [13]. Hence the warning algorithm can be applied to both city and high way situations. Although our previous work has high accuracy of collision pre-warning detection, two problems that are described in aforementioned Section should be considered at the same time.

III. ADVANCED COOPERATIVE COLLISION WARNING (ACCW) ALGORITHM

ACCW algorithm contains three parts: (1) Information Exchanging, (2) Collision Calculation, and (3) Storage and Alerting. Let each vehicle be equipped with a GPS device, an accelerometer, and a Wireless Access in the Vehicular Environments (WAVE) communication module, which provide the GPS position information, acceleration information of the vehicle, and capability of wireless communication, respectively. These parts are explained as follows.

i. Information Exchanging

In this part, host vehicles' Information (My RI), which includes GPS position information and acceleration information, is delivered to the WAVE communication device at anytime. Let accelerometers be equipped on vehicles and thus it can provide the acceleration information to the ACCW algorithm. Three moving patterns (acceleration, deceleration, and keeping the same velocity) can be measured from the accelerometer. As a result, My RI and Target RI messages can contain the acceleration information. Next, MyRI information is encapsulated into the RI packet and broadcasted by the WAVE communication device, periodically. Any vehicle in the communication range will receive the RI packet. When RI (Target RI) packets that come from neighboring vehicles are received, the WAVE communication module decapsulated the packet. Next, two RI messages, including My RI and Target RI, were sent to next part in order to trigger the procedure of collision calculation.

ii. Collision Calculation

The ACCW algorithm computes whether the collision between target and host vehicles will occur or not based on the concept of Closest Point of Approach (CPA). If the collision does not occur, the system returns to the waiting state for the next oncoming RI message. Otherwise, the warning message is given to the driver depending on the predefined warning levels, e.g., 3 or 6 seconds before the oncoming collision occurs. The predefined warning level provides three selections for user, High, Middle, and Low. If the collision is oncoming, in the third part, the warning message can be sent through voice, lights, or image, etc.

Symbols' Definitions of those symbols used in the ACCW algorithm are as follows. $D_{A,B}$ means a distance between vehicle A and B. V_A denotes the vector of vehicle A. Symbols $TCPA_{A,B}$ and $DCPA_{A,B}$ are time and distance to the closest point of approach between vehicle A and B, respectively. Symbols t means timing, and ACC_B denotes the acceleration of vehicle B. Symbols TP_i and VP_{Bi} denote the temporary point at the ith round and the vector point at the ith round of vehicle B, respectively. Symbols θ_B and Δ denote a steering angle of vehicle B and vector calculation, respectively.

$$
TCPA_{A,B} = (\text{Distance}_{CPA,TP_{i-1}} / \text{Distance}_{TP_i,TP_{i-1}}) + i - 1
$$

$$
\text{where} \begin{cases} i = \text{Times to repeat} \\ \text{Distance}_{CPA,TP_{i-1}} = \text{Distance between point CPA and the temp point } (\text{TP}_{\text{i-1}}) \\ \text{Distance}_{TP_i,TP_{i-1}} = \text{Distance between temporary point } \text{TP}_{\text{i}} \text{ and temporary point } \text{TP}_{\text{i-1}} \\ \text{TCPA}_{\text{A,B}} = \text{Time to CPA of Vehicle A and B} \end{cases} \tag{1}
$$

● Velocity changing

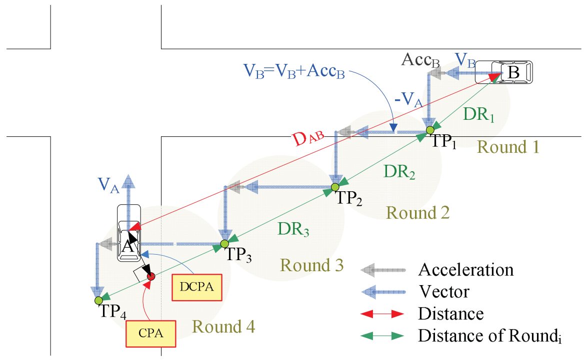


Figure 1 Closer Point to Approach calculation with acceleration changing.

Referring to Figure 1, assuming vehicle A is the host vehicle and vehicle B is the target vehicle. Let V_A and V_B denote the vector of vehicle A and vehicle B, respectively, and Acc_B denote the acceleration of vehicle B. The acceleration can be a positive or negative number. It is a positive number if the vehicle is to speed up, and the acceleration is negative if the vehicle is deceleration. If the vehicle keeps the same velocity, the acceleration should be 0. When the collision calculation is started, it adds acceleration Acc_i to vector V_i first, such as Acc_B to V_B and Acc_A to V_A. After that, adding the reversed vector V_A to find the first temporary point called TP_1. If the distance between vehicle A and vehicle B (D_{AB}) is larger than the distance between point TP_i and vehicle B, let V_B be equal to $V_B + Acc_B$ and repeat the same procedure again. Note that *i* has to plus 1 at each repeated round.

After that we can find a point called Closest Point of Approach (CPA), which is an intersection between a line passes vehicle A and is perpendicular to a line between last two temporary points, e.g., TP_3 and TP_4. The temporary point is defined as a point with the temporary property, which is only used in this calculation. CPA is the closest point between host vehicle and target vehicle after several time units (e.g. seconds). Distance between the host vehicle and point CPA is called DCPA (Distance to CPA), which also denotes the shortest distance between the host vehicle and the target vehicle after several time units. After CPA and DCPA are found, Time to CPA (TCPA) can be obtained using Equation (1). TCPA is a time interval, which denotes how much time the host vehicle and the target vehicle reach the shortest distance (DCPA). If the shortest distance DCPA is smaller than a threshold or equal to zero, the collision may happen. In addition, we can say that the host vehicle and the target vehicle will collide after TCPA time units if DCPA is equal to zero. Table 1 gives a pseudo code of this situation.

TABLE 1 PSEUDO CODE OF THE ACCW ALGORITHM.

Receive (MyRI and Target RI) /* Calculate the CPA */

{

Do{

$V_B = V_B + Acc_B$

$V_A = V_A + Acc_A$

$\alpha = \dfrac{\arccos(\Delta^2 + D_{A,B}{}^2 - D_{A,B}{}^2 \cdot \Delta)}{2 \cdot \Delta \cdot D_{A,B}}$

$\rho TP_i = D_{A,B} \cdot \sin(\alpha)$

$if\,(D_{A,B} > D_{TP_i,B})$

$\{\, V_B = V_B + Acc_B, V_A = V_A + Acc_A, i = i + 1 \}$

$\}\ While(D_{A,B} > D_{TP_i,B})$

$\Delta = -V_A + V_B + Acc_B$

$\alpha = \dfrac{\arccos(\Delta^2 + D_{A,B}{}^2 - D_{A,B}{}^2 \cdot \Delta)}{2 \cdot \Delta \cdot D_{A,B}}$

$\rho_{CPA} = D_{A,B} \cdot \sin(\alpha)$

$DCPA_{A,B} = D_{A,B} \cdot \cos(\alpha)$

$TCPA_{A,B} = (\text{Distance}_{CPA,TP_{i-1}} / \text{Distance}_{TP_i,TP_{i-1}}) + i - 1$

If DCPA $\leq$ Warning Distance & & TCPA $\leq$ Warning Level

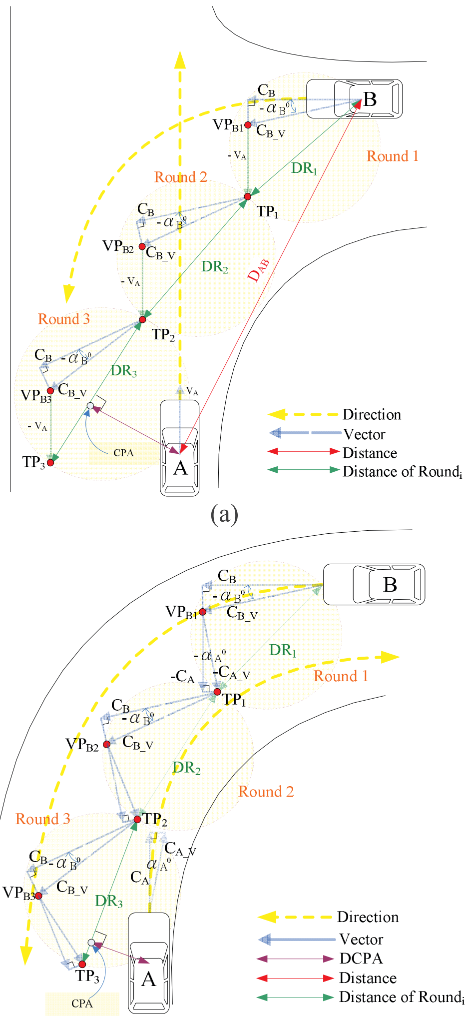
Send (Warning Message)

}

● Curve Environment

The second challenge in the CCW system is the curve environment. The curve environment such as mountain road and interchange, should be considered in the CCW system. Two cases depicted in Figure 2-(a) and Figure 2-(b) for the curve environment should be handled. The first case is that only one vehicle changes its coursing, and the second case is that both vehicles change their coursing.

Let the Steering Angle be obtained from the accelerometer and be denoted as α. The value of α is positive if the Steering Angle is clockwise, otherwise α is negative. Referring to Figure 2-(a) and Figure 2-(b), assuming host vehicle A is to go straight and the steering angle of the target vehicle B is $-\alpha_B$ degree. In order to find the closest point of two approaching vehicles, three steps should be executed. These steps are (1) finding the Vector Point (denotes as VP_{Bn}) of the target vehicle B at the *n*th round, (2) finding the Temporary Point at the *n*th (denotes as TP_n) round, and (3) repeating n rounds. Details of these three steps are as follows.



(a)

(b)

Figure 2 Course changing for (a) a vehicle change its coursing, and (b) two vehicles change their coursing.

◆ *Step 1: Find the Vector Point of target vehicle B.*

When the collision detection algorithm is triggered, the first step is to find the Vector Point (VP_{Bn}) of the target vehicle B at the nth round. Referring to Equation (2), let GPS location of vehicle B be a start point and b_x and b_y be the coordinates of vehicle B. The coordinates of Vector Point VP_{Bn} at the nth round can be obtained using Equation (2), which is dependent on vehicle B's coursing C_{Bn}. For example, assuming coursing of vehicle B is 60 degree (C_{Bn}=60) and velocity of vehicle B is 15 meter/second, the coordinates of X axis for Vector Point (VP_{Bn}) is equal to b_x + sin(60)*15. Using Equation (2), the Vector Point VP_{Bn} can be obtained. Next, the course of vehicle B should be changed from C_B to C_{B_V} for the calculation at the next round.

$$\left.\begin{array}{ll}
\text{If } 0 <= C_{Bn} < 90, & \text{(First Quardant)} \\
\quad VP_{Bn}(x) = b_x + \sin(C_{Bn}) \bullet \text{Velocity} & \\
\quad VP_{Bn}(y) = b_y + \cos(C_{Bn}) \bullet \text{Velocity} & \\
\text{If } 90 <= C_{Bn} < 180, & \text{(Fourth Quardant)} \\
\quad VP_{Bn}(x) = b_x + \sin(C_{Bn}) \bullet \text{Velocity} & \\
\quad VP_{Bn}(y) = b_y - \cos(C_{Bn}) \bullet \text{Velocity} & \\
\text{If } 180 <= C_{Bn} < 270, & \text{(Third Quardant)} \\
\quad VP_{Bn}(x) = b_x - \sin(C_{Bn}) \bullet \text{Velocity} & \\
\quad VP_{Bn}(y) = b_y - \cos(C_{Bn}) \bullet \text{Velocity} & \\
\text{If } 270 <= C_{Bn} < 360, & \text{(Second Quardant)} \\
\quad VP_{Bn}(x) = b_x - \sin(C_{Bn}) \bullet \text{Velocity} & \\
\quad VP_{Bn}(y) = b_y + \cos(C_{Bn}) \bullet \text{Velocity} &
\end{array}\right\} \quad (2)$$

◆ *Step 2: Finding the Temporary Point of each round.*

Through Equation (2), we can get the coordinates of point VP_{Bn}. Next, reversing vector V_A and then adding it to VP_{Bn} to get a Temporary Point called TP_n. An example is depicted in Figure 2-(a). Since vehicle A in Figure 2-(a) does not change its coursing, the steering angle of vehicle A is equal to 0. On the other scenario that is depicted in Figure 2-(b), both vehicles are changing their coursing. In this scenario, let the steering angle of vehicle A be denoted as α_A. It should be changed to -α_A if we reverse the vector of vehicle A. Since the vector is reversed, the steering angle should be reversed, too. In addition, the distance between point VP_{Bn} and TP_n is the velocity of vehicle A.

After we reversing the vector of vehicle A and adding it to point VP_{Bn}, we can get a Temporary Point TP_n. Next, how many rounds should be executed is decided at Step 3.

◆ *Step 3: Repeating n rounds.*

Let point TP_n be the start point of the next round, and the course of vehicle B be changed from C_B to C_{B_V}. Then, using the same steps depicted in the first round until the point of CPA is found. How many rounds should be calculated is still a problem to be tackled. The next round is always continued unless the distance between vehicle A and B (denote as D_{AB}) is smaller than the total distance between two points at each round (denote as DR_i). Please note that it must let C_B be equal to C_{B_V} before the next round is enabled. After point CPA is found, TCPA can be obtained using Equation (1).

● Collision judgment rule

The collision judgment rule defines which calculation results will result in collision. Two parameters should be introduced in this Section. The first one is warning distance, which is a radius of a circular coverage around a car.; the second one is warning level. Three defined warning levels are high, middle, and low. Drivers and users can choose the warning level depending on their demands. In our design, the high warning level means the collision warning message should be passed to drivers 9 seconds before the collision will occur. The middle and low warning levels were designed to be 6 and 3 seconds, respectively. Finally, the collision judgment rule is expressed as Equation (3).

$$\begin{aligned}&\text{If DCPA} \leq \text{Warning Distance} \,\&\&\, \text{TCPA} \leq \text{Warning Level}\\&\quad \text{Send(Warning Message)}\end{aligned} \tag{3}$$

iii. Storage and Alerting

After collision calculation, the potential collision can be detected several seconds before the collision occurs. In this phase, the collision warning system has to store the results of the collision calculation. The reason is that it can provide some information for accident arbitration if the collision really occurs. For example, some information about velocity, acceleration, and positioning information of a vehicle can be stored. On the other hands, the warning message is passed to the driver if the collision is oncoming. The warning message includes the target ID and TCPA. Finally, the drivers, hopefully, brake their vehicles to avoid the accident because the warning message is passed just in time.

IV. PERFORMANCE ANALYSIS

In order to evaluate the accuracy of the ACCW algorithm, we utilized the network simulation tool NS-2 to simulate the communication and motion of vehicles. For the accuracy of collision warning enhancement, two scenarios were tested: analysis of velocity being changed, and analysis of the curve environment. In order to evaluate the accuracy of the ACCW algorithm, we compared the Collision Pre-Warning Algorithm (CPWA) with the proposed ACCW algorithm. The CPWA was proposed in our previous work [12], which can only be operated well when velocity and course are fixed.

- Analysis of Velocity being Changed

In order to understand the accuracy of the ACCW algorithm in various environments, we focused on two vehicles being moving on different lanes. These two vehicles will collide at an intersection. Four different conditions are considered in this subsection.

1. Only one vehicle has acceleration

Table 2 shows the results of comparing ACCW and CPWA algorithms. In this simulation, the warning level is set to low. Therefore, the collision warning algorithm has three warning messages before two vehicles collide. The first warning message should be passed 3 seconds before, and second warning message should be passed 2 seconds before, etc. In addition, the acceleration is set to 1 m/s. In CPWA, the first warning message is missed because it is believed that the collision will not happen after calculation. Next, the second warning message is passed in the CPWA algorithm. However, the error of DCPA is 1.845 meter, and the error of TCPA is 0.15 second. In the third warning message, the error of DCPA is 0.61 meter and the error of TCPA is 0.05 second. Errors of both DCPA and TCPA are decreased in the second and third warning messages. It is because two vehicles were more and more approaching. On the other hand, lower errors of both DCPA and TCPA in the ACCW algorithm in each warning message are depicted in Table 2.

TABLE 2 ACCURACY COMPARISON (ONE VEHICLE HAS ACCELERATION).

Algorithm	Parameter	Warning message			Average
		1st	2nd	3rd	
ACCW	DCPA Error	0.02	0.02	0.02	0.02
	TCPA Error	0	0	0	0
CPWA	DCPA Error	-	1.845	0.61	1.2275
	TCPA Error	-	0.15	0.05	0.1

2. Two vehicles with the same acceleration

The simulation results of two vehicles with the same acceleration are given in Table 3. DCPA errors of the two algorithms are little and almost the same. Since two vehicles use the same acceleration, CPA and DCPA errors are similar. However, TCPA error in the CPWA algorithm is larger than that of the ACCW algorithm.

TABLE 3 ACCURACY COMPARISON (TWO VEHICLES HAVE THE SAME ACCELERATION).

Algorithm	Parameter	Warning message			Average
		1st	2nd	3rd	
ACCW	DCPA Error	0.01	0.01	0.01	0.01
	TCPA Error	0.02	0.02	0.02	0.02
CPWA	DCPA Error	0.01	0.01	0.01	0.01
	TCPA Error	0.33	0.11	0	0.147

3. Two vehicles with different velocities

In this simulation, let two vehicles use different velocities and accelerations to reach the intersection. Referring to Table 4, either DCPA error or TCPA error in the CPWA algorithm is higher than that of the ACCW algorithm.

TABLE 4 ACCURACY COMPARISON (TWO VEHICLES USE DIFFERENT VELOCITIES).

Algorithm	Parameter	Warning message			Average
		1st	2nd	3rd	
ACCW	DCPA Error	0.01	0.01	0.01	0.01
	TCPA Error	0	0	0	0
CPWA	DCPA Error	0.18	0.05	0.01	0.08
	TCPA Error	0.26	0.08	0.0	0.113

4. Only one vehicle has deceleration

TABLE 5 ACCURACY COMPARISON (ONLY ONE VEHICLE HAS DECELERATION).

Algorithm	Parameter	Warning message			Average
		1st	2nd	3rd	
ACCW	DCPA Error	0.025	0.02	0.025	0.023
	TCPA Error	0	0	0	0
CPWA	DCPA Error	-	2.305	0.805	1.5625
	TCPA Error	-	0.08	0.03	0.055

Deceleration is considered in order to evaluate the brake condition. The simulation result is similar to the first scenario and is depicted in Table 5. CPWA missed the first warning message in this situation. In the CPWA algorithm, errors of DCPA and TCPA are higher than that of the ACCW algorithm in the second and third warning messages.

● Analysis of the curve environment

Two scenarios are presented in this part: (1) only one vehicle changes its direction and (2) two vehicles change their directions.

1. Only one vehicle changes its direction

TABLE 6 DCPA ERROR COMPARISON.

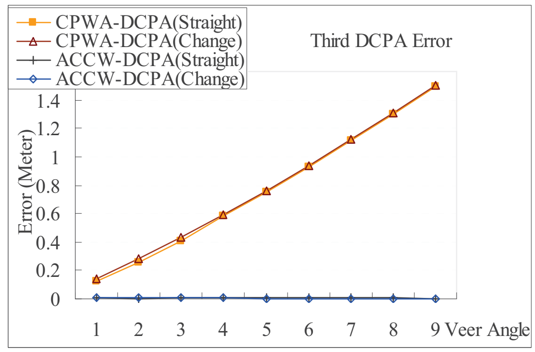
Algorithm	Vehicle	DCPA	Veer Angle								
			1	2	3	4	5	6	7	8	9
CPWA	A (Straight)	DCPA-1st	-	-	-	-	-	-	-	-	-
		DCPA-2nd	-	-	-	-	-	-	-	-	-
		DCPA-3rd	0.12	0.26	0.41	0.58	0.75	0.93	1.11	1.3	1.49
	B (Change direction)	DCPA-1st	0.78	1.62	-	-	-	-	-	-	-
		DCPA-2nd	0.4	0.82	1.27	1.75	2.25	2.78	-	-	-
		DCPA-3rd	0.14	0.28	0.43	0.59	0.76	0.94	1.12	1.31	1.5
ACCW	A (Straight)	DCPA-1st	0	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08
		DCPA-2nd	0.01	0	0	0	0	0	0	0	0
		DCPA-3rd	0.01	0	0.01	0.01	0.01	0.01	0.01	0.01	0
	B (Change direction)	DCPA-1st	0.02	0.03	0.03	0.04	0.05	0.06	0.07	0.08	0.09
		DCPA-2nd	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
		DCPA-3rd	0.01	0.01	0.01	0.01	0	0	0	0	0

TABLE 7 TCPA ERROR COMPARISON.

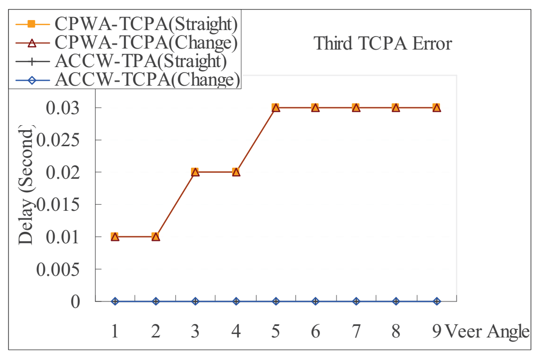
Algorithm	Vehicle	TCPA	Veer Angle								
			1	2	3	4	5	6	7	8	9
CPWA	A (Straight)	TCPA-1st	-	-	-	-	-	-	-	-	-
		TCPA-2nd	-	-	-	-	-	-	-	-	-
		TCPA-3rd	0.01	0.01	0.02	0.02	0.03	0.03	0.03	0.03	0.03
	B (Change direction)	TCPA-1st	0.05	0.09	-	-	-	-	-	-	-
		TCPA-2nd	0.02	0.04	0.06	0.07	0.08	0.09	-	-	-
		TCPA-3rd	0.01	0.01	0.02	0.02	0.03	0.03	0.03	0.03	0.03
ACCW	A (Straight)	TCPA-1st	0	0	0	0	0	0	0	0	0
		TCPA-2nd	0	0	0	0	0	0	0	0	0
		TCPA-3rd	0	0	0	0	0	0	0	0	0
	B (Change direction)	TCPA-1st	0	0	0	0	0	0	0	0	0
		TCPA-2nd	0	0	0	0	0	0	0	0	0
		TCPA-3rd	0	0	0	0	0	0	0	0	0

Table 6 shows the DCPA error comparison between CPWA and ACCW algorithms. In this scenario, the Warning Level is set to Low (3 seconds before). Therefore, three warning messages (first, second, and third) should be passed to drivers. Table 6 shows the error of DCPA for each warning message. Referring to Table 6, CPWA misses first two warning messages for vehicle A on different veer angle situations. The miss rate is increased at vehicle B when the veer angle is increased in the CPWA algorithm. In addition, although the third warning message is not missed for both vehicles A and B in the CPWA algorithm, the DCPA error is increased when the veer angle is increased. On the other hand, the ACCW algorithm has a high accuracy rate of DCPA. Although the error of DCPA in the CCEW is increased a little when the veer angle is increased, the range is small.

Table 7 depicts CPA error comparison between CPWA and ACCW algorithms, which is similar to Table 6. Therefore, some resemble descriptions are omitted. Figure 3 depicts the third error of DCPA and TCPA, respectively. Only the final warning message (third) is considered here because CPWA has the final warning message only. Referring to Figure 3-(a) and (b), both average errors of DCPA and TCPA in the CPWA scheme are grown when the veer angle is increased, but CCEW does not.



(a)



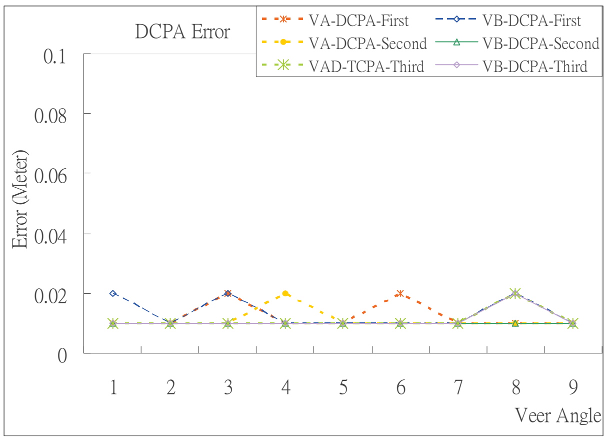
(b)

Figure 3 Average errors of CPWA and ACCW (only one vehicle changes its direction).

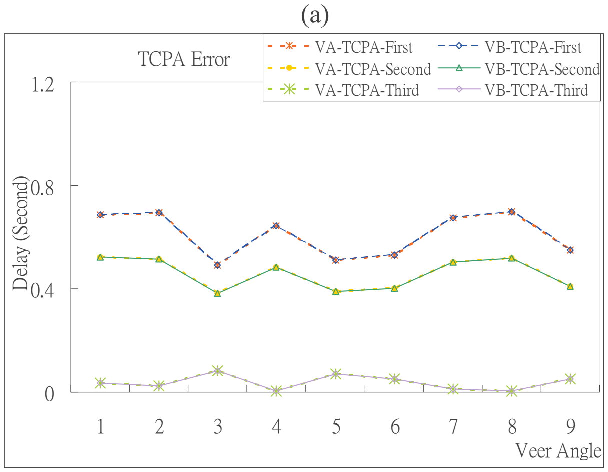
2. Both vehicles change their directions

Errors of collision warning may be large if both vehicles changed their directions. Simulation result shows that ACCW has higher accuracy at such environment. The velocity of both vehicles is set to 10 m/s. Various veer angles are tested from 1 degree to 9 degree.

Figure 4 depicts the simulation results of the ACCW algorithm. Since the CPWA algorithm is failed in this simulation, it is ignored. In our testing, three warning messages should be passed in both target vehicle and host vehicle. Since the veer angle is considered in ACCW, the DCPA error is very low. Figure 4-(a) shows the DCPA error is between 0.01 and 0.02 meter at each test. Although the veer angle is increased, the DCPA error is very low. In Figure 4-(b), the TCPA error of (1) the first warning messages in both vehicles A and B is between 0.7 and 0.5 second, and (2) the second warning messages is between 0.38 to 0.5 second. Although the TCPA has some errors, the warning message is still passed to drivers. The error of TCPA affects the time to warning. For example, let two vehicles collide at t1, the time that the first warning message is passed to drivers should be before $t_1 + 3 \pm \mathrm{TCPA}_{\mathrm{Error}} = t_1 + 3 \pm 0.7$ seconds, when the veer angle is equal to 2 degree. The third TCPA error for warning message is very low, which is between 0 to 0.1 second.



(a)



(b)

Figure 4 Average errors of CPWA and ACCW (both vehicles change their directions).

V. CONCLUSION

One of the goals for active driving safety is to prevent oncoming accidents. Many kinds of systems, algorithms, methodologies were proposed to achieve the same purpose. Some collision warning algorithms did not cope with these three challenges, i.e., velocity changing, course changing, etc., that are identified in this paper.

The goal of our ACCW is to handle aforementioned problems. Since the collision calculation in the ACCW algorithm considers the acceleration of vehicles, it keeps high accuracy of collision warning calculation. According to the simulation results, accuracy of the ACCW algorithm always outperforms that of the CPWA algorithm. Although the ACCW algorithm using acceleration information can correct the potential calculation error of collision, acceleration information obtained from an accelerator may have some vibration even if it is placed on the disk or ground. Hence, the main future work is how to deal with the problem of accelerator vibration.

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