An Inter-Vehicle Geocasting Algorithm for Vehicular Cooperative Collision Warning System using DSRC

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ABSTRACT

This paper presents an inter-vehicle geocasting and collision warning algorithm to accomplish multihop and collision avoidance in cooperative driving and data exchanged based on GPS positioning and dedicated short range communication (DSRC). The concept of cooperative collision warning (CCW) system provides warning or situation awareness to drivers based on broadcast messaging the motions of neighboring vehicles obtained by one-way communication from other vehicles. The proposed system has the advantage of omnidirectional transmitting/receiving functions of DSRC module that provides 360-degree coverage in own surveillance region. The scenario of CCW system is mainly applied on group trips; moreover, the developed algorithm has the ability of message broadcasting and collision point estimation. This article concerns message geocasting and collision warning in inter-vehicle communication. Indeed, each CCW system can show other vehicles on the geographical map, and furthermore the developed inter-vehicle geocasting algorithm is the key point in remote surveillance, while some vehicles move away or turn into the roadway or intersection. The development system integrates DSRC and GPS with embedded system into CCW system. From the positioning data and vehicular information, this paper provides a conflict detection algorithm to do time separation and remote warning with error bubble consideration. The proposed system is carried out with theoretical application and hardware integration, and the result shows cooperative driving approach applicability using vector geocasting method. Some experiments are

also scheduled about packet loss and latency by static tests, in which vehicles stop in fixed position away from 0 to 200 m.

INTRODUCTION

Every year in Taiwan, about two thousands deaths within 24 hours in traffic accidents, there are about 2539 deaths per hundred thousands of people and the statistical number is very serious in the world [1]. While many different factors contribute to vehicle incidents or accidents, such as rainy day or blind spot area, driver behavior is considered as the main cause of more than 95 percent. Traffic safety, in terms of infrastructure or injuries, has been discussed and improved by government's policy. However, the numbers of deaths or injuries have remained relatively flat due to the increasing number of vehicles or fatigued driving with low attention.

In the recent years, more and more people like to have a travel in the weekend. People usually take a portable navigation device with them. It provides high accuracy position, any weather condition and has the advantage in faster positioning. Although it is easier to know own location mapped onto GIS, groups trip cannot be aware of others position. In the context of ITS, wireless communication plays a fundamental role in the recent two decades. The CCW concept, a vehicle can broadcast its driving parameters to others over Wi-Fi technologies like DSRC [2]. The choice of ad hoc network, contrary to cellular network, is more rigorous and justified by the fact that the network is organized without an infrastructure which avoids data blocking or unavailability of the network as in 2.0 to 3.5G mobile communication. To meet a higher vehicle safety, DSRC which has a wireless communication protocol in the 5.9 GHz frequency band plays an important role of vehicular system. Indeed, by communicating information in remote surveillance on possible emergencies, dangerous events can be avoided. Thus, exchanged data can be used to improve the safety and become aware of neighboring vehicles location, including speed, location and heading. In addition, IEEE has taken up the standardization of DSRC by creating IEEE 802.11p. In the proposed system, 802.11p protocol had been porting into embedded system for DSRC data link layer.

In order to realize efficient message broadcasting, geocasting is becoming popular in sensor network. The geocsting is a mechanism to multicast information to the network nodes whose location locates within a given geographical area, named as the target area. Furthermore, the scope of the applications that are well suited for multicasting is growing. In inter-vehicle geocasting, some recent solutions have been proposed [3-4]. In Ref. [3], the proposed solution called inter-vehicle geocast (IVG), present a new technique for efficient alarm message dissemination based on defer time algorithm and fully distributed dynamic relay designation. In Ref. [4], this article presents a time-stable and abiding geocast method to alarm message in a warning area. Hence, the message broadcasting problem will be concerned and discussed in later section.

This paper proposed a CCW system using an embedded system to operate as a control system to manipulate DSRC unit, vehicular unit and GPS unit for cooperative driving and collision warning. GPS module can provide accurate positioning and heading solution per second with independence of time, all weather and location for long period performance. DSRC module, whose characteristic has short range radio and high data rate, is the bridge among all the vehicles. To transmit the vehicular information and broadcast vehicle position; DSRC technology is adopt as the bridge, in which the IEEE 802.11p standard is installed in MAC layer.

Vehicular unit, whose speed is autonomous from hall sensor sensing wheel motion, has higher stable than GPS speed. The positioning unit is used to provide the position and heading information from GPS module, and furthermore the vehicular unit is used to receive the odometry, break, and throttle signals via controller area network (CAN) interface. The broadcast and multihop will be finished by inter-vehicle geocasting method, and the collision warning is estimated and warned by developed algorithm.

CONCEPT OF CCW SYSTEM

The system technology for CCW system is designed with an integration of GPS receiver and data transmitting through DSRC module. The GPS module could provide a good positioning solution, and then the positioning information may display on the screen to monitor other neighboring vehicles in remote operation. The vehicular data of vehicle will be routed by CAN module and broadcast to neighboring vehicles by UDP protocol onto the internet via DSRC communication. The concept of proposed system architecture is shown in Figure 1. The test information is debugged and showed in the screen of laptop using well defined format, and the total lengths which follow CAN 2.0A is about 8 bytes with its id in different devices.

A general vehicular communication which depends on its coverage area can be classified into four categories: inter-vehicle, outer-vehicle, vehicle-to-infrastructure (V2I) and

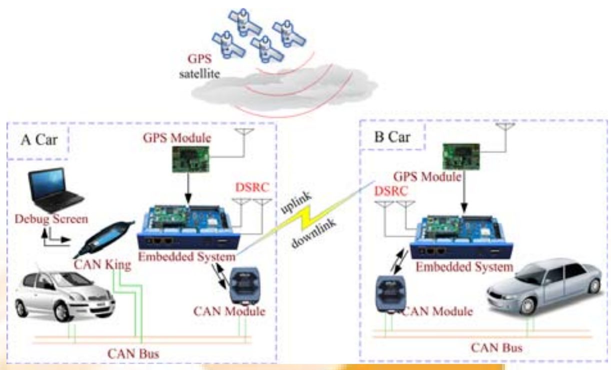


Figure 1 CCW System Architecture

vehicle-to-vehicle (V2V). A common solution, Bluetooth, its coverage is too low to do vehicular communication as a precaution. In outer-communication, mobile communication has presented its wide coverage, high reliability of data transmission in surveillance applications. However, mobile communication has a drawback in time delay about 1.0 sec in TCP mode or 0.8 sec in UDP mode [5]. To meet a high converge, data rate and low time latency. DSRC is a good choice, and its theoretically provides up to a 1 km range and allows communications between vehicles moving up to 160 km/h [6]. It also has low latency about 50 millisecond and 8 priority levels. In DSRC software, the network protocol is based on IEEE 802.11p standard under open system interconnection (OSI) model. This layer is ported from revising 802.11a, and other layers are followed UDP/IP mode.

In GPS module, the output adopts the NMEA-0183 standards as a format for interfacing marine electronic devices. The default communication parameters for NMEA output rate support fixed baud rate at 9600 bits/sec with 8 data bits, 1 stop bit, and no parity. The GPS fixed data is processed in one second period, including the acquisition of position and heading. In the conflict detection design, this system experienced that GPS module with high performance, high sensitivity, low power consumption, small size and fast TTFF (Time To First Fix) at low signal levels. The G-Sat BU-353 GPS module is based on SiRF Star III chipset with the well-verified technology. Its far reaching capability meets the sensitivity requirement by the remote surveillance application.

In vehicular information, the wheel speed, break and throttle condition are transmitted to other vehicles by CAN acquisition. CAN is a serial, asynchronous, multi-master communication protocol for connecting electronic control modules, sensors and actuators in automotive and industrial applications. The CAN-based system is based on the broadcast communication mechanism which is achieved by using a message oriented transmission protocol and different id number. The key role from vehicular unit is vehicular speed, and the node identification code is 0x61. Its length is one byte (available from 0 kph to 255kph) and the refresh time is 80 msec. These vehicular signals are held and processed by CAN circuit board in supervisor node. This circuit board adopts PIC18F4585 as CAN controller and PCA82C251 as the transceiver. The CAN transceiver is the interface between the CAN protocol controller and the physical transmission line and it is one of the key factors influencing the capability of network system. It is fully compatible with the "ISO 11898".

SYSTEM ALGORITHM

The collision warning algorithm is designed to process broadcast messages from neighboring vehicles, and furthermore it continuously operates on the premise that neighboring vehicles broadcast its own messages and multihop messages adjacent to the edge of its surveillance by inter-vehicle geocasting algorithm. After each vehicle receives data from other vehicles, the mathematical model of conflict detection will build a geometry model [7-9]. The vehicular data is received and processed for calculating collision time. The frame of geometry model is geographic ellipsoidal coordinate, called World Geodetic System 1984 (WGS-84). For collision analysis in vehicle utilization, it needs to transform the coordinate frame from WGS-84 to north-east-down (NED) local navigation coordinate.

COLLISION WARNING

The first step is geometry analysis. Although GPS receiver supplies precision position under dependent performance, the output data of GPS receiver provides lower bandwidth and risks under interference and error. The error factor is considered by reason of GPS error uncertainty. As shown in Figure 2, B is the ownership so it has an error bubble around it [10]. A is the intruder which drives near the vehicle B in any intersection. Their extrapolation lines have an intersection in the near future. A is positioned at (Λ_1, λ_1) in WGS-84 and travels with its speed V_A. B is positioned at (Λ_0, λ_0) and travels with its speed V_B.

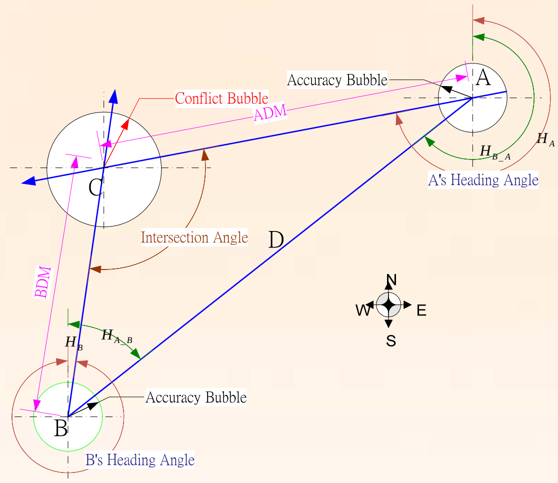


Figure 2 Geometry Model of Two Conflicting Objects.

L_A and L_B are two line segments which predict future driving trajectory, and the driving distance is decided by initial position and heading. Through two forecasted extrapolation lines, any two vehicles on a planar motion can possibly extrapolate to an intersecting point C and can respectively decide the collision time which two vehicles arrive in point C. The predicted time (t) is an index which decides them whether approaching in the future. Generally speaking, two vehicles will cause conflict or collision when (Λ, λ, t) are all the same, as long as one of them is different, the dangerous condition can be avoided. The time must be observed whether being equal or not.

In conflict analysis, the rough calculation could give the relative distance using (1). If the relative distance is calculated under safe separation and maybe resulted of conflict collision, that needs delicate calculation and does three procedures which includes coordinate transform, geometry distance and collision time. Before the collision avoidance algorithm operates the related calculation, there is an important thing to concern. The position of GPS output show the previous moment position, hence it need to estimate the current location using (2). M is the radius of curvature in Merdian, and N is the radius of curvature in prime vertical. The first procedure is transformed from WGS-84 to ECEF and ECEF to NED frame using (3)-(4). The altitude (h) is given by GPGGA format from GPS receiver and the other parameters are eccentric (e) and semi-major axis (a). Equation (3) is result from the shape of the Earth which is an ellipsoid, not a true sphere. The following procedure is to take ownership as center and calculate relative position using (4).

$$D=\sqrt{[110946.2573\times(\Lambda_1-\Lambda_0)]^2+[111319.4907\times\cos(\lambda_0)\times(\lambda_1-\lambda_0)]^2} \quad (1)$$

$$\begin{bmatrix}\Lambda_k\\ \lambda_k\end{bmatrix}=\begin{bmatrix}\Lambda_{k-1}\\ \lambda_{k-1}\end{bmatrix}+\begin{bmatrix}\dfrac{1}{M+h} & 0\\ 0 & \dfrac{1}{(N+h)\cos(\Lambda_{k-1})}\end{bmatrix}\begin{bmatrix}v_N\\ v_E\end{bmatrix}\Delta t \quad (2)$$

$$\begin{bmatrix}x^E\\ y^E\\ z^E\end{bmatrix}=\begin{bmatrix}(N+h)\cos\Lambda\cos\lambda\\ (N+h)\cos\Lambda\sin\lambda\\ [N(1-e^2)+h]\sin\Lambda\end{bmatrix} \qquad N=\frac{a}{\sqrt{1-e^2\sin^2\Lambda}} \quad (3)$$

$$\begin{bmatrix}x^N\\ y^E\\ z^D\end{bmatrix}=\begin{bmatrix}-C(\lambda_0)\cdot S(\Lambda_0) & -S(\lambda_0)\cdot S(\Lambda_0) & C(\Lambda_0)\\ -\sin(\lambda_0) & \sin(\lambda_0) & 0\\ -C(\lambda_0)C(\Lambda_0) & -S(\lambda_0)C(\Lambda_0) & -S(\Lambda_0)\end{bmatrix}\times\begin{bmatrix}x_1^E-x_0^E\\ y_1^E-y_0^E\\ z_1^E-z_0^E\end{bmatrix} \quad (4)$$

Although the mathematical model usually adopts Cartesian coordinate, all of the angles are still referenced to NED coordinate. Fig. 2 only shows one kind of collision condition, but vehicle A maybe locates at different quadrant and has different heading angle result from geometry relationship. The collision conditions are discussed and suitable at any conflict area, and each possible case is listed in the following Table I & II. In Table I, the global heading angle is (H_A,H_B) and local relative heading is (H_{AB},H_{BA}). The local relative heading (H_{AB}) takes B as center and could be given relative to North direction. The first two figures of Fig. 3 shows that A locates at I or IV, and both quadrant conditions has four collision relationships from Case I to IV area. The relationship meant the possible collision in each case area. The last two figures of Fig. 3 shows the other relationships with vehicle A in Quad II or III and the possible collision also has four cases in different color indication. From Table 1 & 2, the system can give the relative distances and then use sine law to calculate A distance margin (ADM) and B distance margin (BDM). The key features of ADM and BDM are depending on the heading, relative heading angles and triangular angles.

Table 1. Relative Heading Angle in Quad I&IV

	Case I	Case II	Case III	Case IV
∠A	2π-H_{BA}+H_A	H_{BA}-H_A	H_A-H_{BA}	H_A-H_{BA}
∠B	H_{AB}-H_B	H_B-H_{AB}	H_{AB}-H_B	2π+H_{AB}-H_B

Table 2. Relative Heading Angle in Quad II&III

	Case V	Case VI	Case VII	Case VIII
∠A	H_{BA}-H_A	H_A-H_{BA}	H_{BA}-H_A	2π-H_A+H_{BA}
∠B	2π-H_{AB}+H_B	H_{AB}-H_B	H_B-H_{AB}	H_B-H_{AB}

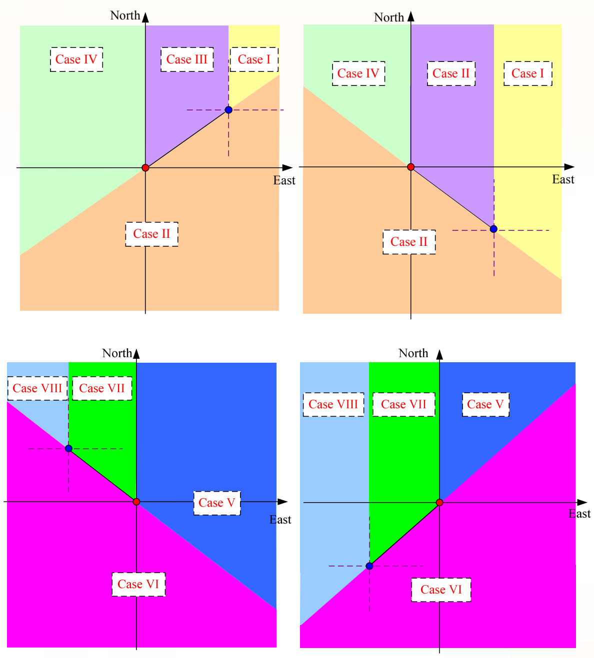


Fig. 3 Collision Conditions with Vehicle A in Quad I to Quad IV.

The second step is collision decision and warning display.

According to the pervious segment, the possible intersection is calculated and needs to forecast in time by considering the possible errors. The error is caused by GPS drift which includes multipath, ionosphere effect, troposphere effect and clock error. This paper proposes a simplified computation that the possible ADM does plus and subtraction operations using Eq.(5) in vehicle A, moreover, the same concern is considered in own vehicle. The error is distributed over the circle whose magnitude of radius is changed by different GPS. One sigma error of commercial GPS is about 6 meters. In this paper, the circle error is known as the error intersecting bubble as shown in Fig. 2. After the embedded processor calculates the ADM and BDM, both of regional collision times (t_{A1}, t_{A2}, t_{B1}, t_{B2}) are given by using (5). If the temporal separation between two vehicles is larger than zero, the time is no overlapping, it represents there is no significant intersection between them. It predicts there is no dangerous conflict in the near future, as shown in left Fig. 4. If $t_{A1\text{-}A2}$ occurs between the start of t_{B1} and the end of t_{B2}, their times are overlapping in right Fig. 4. This represents a conflict or intersection. This condition can estimate that there will be an approaching incident in the near future, and then the collision time will be showed in the screen and given some sound by collision avoidance system. The lateral separation is also considered except the direct driving. This is probably happened in the same direction or opposite approach. The lateral time margin is calculated by the projection of A and B motion using Eq.(6), and it is distributed over the driver response time whose magnitude is about 0.5 to 0.75 sec [11]. After the coordinate is located in navigation frame in Eq.(4), the screen display needed to transform into vehicle coordinate. And the transform matrix is Eq.(7). The right vector is NED position and H is the vehicular heading relative to earth pole. After the matrix multiplication, the left term which uses to show vehicle in screen in Eq.(7) is presented in vehicle coordinate.

$$t_{A1} = (ADM + error\ \ range)/V_A,\ \ t_{A2} = (ADM - error\ \ range)/V_A \qquad (5)$$

$$t_{LSM} = D/(V_A \cdot \cos(\angle A) + V_B \cdot \cos(\angle B)) \qquad (6)$$

$$\begin{bmatrix} B_x \\ B_y \end{bmatrix} = \begin{bmatrix} \cos(H) & -\sin(H) \\ \sin(H) & \cos(H) \end{bmatrix} \begin{bmatrix} E \\ N \end{bmatrix} \qquad (7)$$

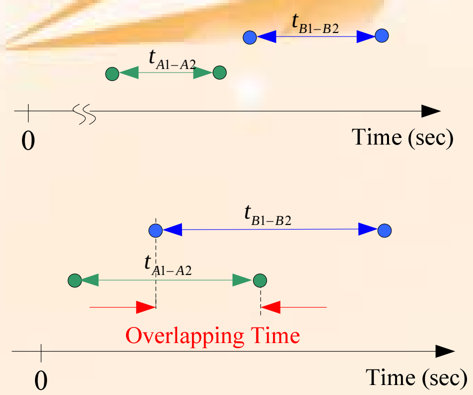


Fig. 4 No Overlapping Time and A Span Overlapping Time.

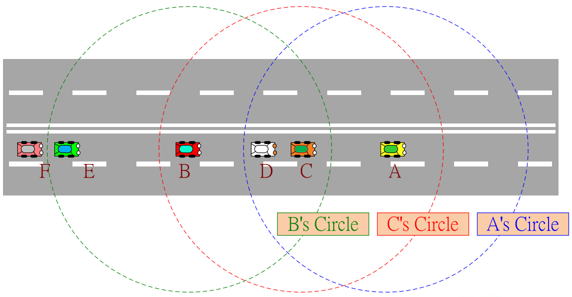
INTER-VEHICLE GEOCASTING

The previous section can give a clear algorithm to estimate where the possible collision point is. However, it needs to depend on broadcasting messages. Geocast, i.e. the transmission of a message to some or all nodes within a geographical area, allows promising new services or application [12]. In inter-vehicle geocasting, each vehicle can broadcast own vehicular message and receive messages from neighboring vehicles [13]. In real application, each DSRC module has about 300 m of transmitting ability in this paper. This is active surveillance area, and there is another surveillance area which is about 500 m. Moreover, the outer area is relied on inter-vehicle geocasting. To meet a good geocasting, there are two key points to concern: relative distance and heading difference between prior vehicles and following ones. CCW is sent in the form of sentences; each starts with a dollar sign "#" and terminates with a carriage return <CR> and line feed <LF>. There are 9 parameters setting for CCW including group id, source node, repeater node, UTC time, latitude, longitude, height, heading, and vehicle speed. If the message is original one, the repeater node will be null string. The parameters are arranged as the sentence as follow:

#ARTC,E,,082714,24.059958,120.383784,8.6,310.62,63.1

In Fig. 5, the left figure shows straight driving in highway or expressway and the right one is intersection case. Taking left Fig. 5 as the distance example, B node transmits its message periodically and receives other messages from neighboring vehicles. In B's area, it only receives messages from C, D and E. At this moment, it will determine which vehicle is located in the edge of its transmitting area. In the logical decision, B will repeat C and E message in its region if the communication time is small than 2 seconds. The communication time is calculated using Eq.(8) which is from Eq.(4) and its projection in relative coordinate. From relative position (x and y), speed (V_x and V_y) and transmitting range (R), the communication time (C_t) is obtained. For C node, it can receive A, B D and E messages from B. The previous segment is only available in straight or low curve roadway, but it cannot communicate with turned vehicle, such as right Fig. 5. In order to avoid this kind of case, the turning vehicle will broadcast vehicles message which have large heading difference relatively. Owing to non-synchronous GPS time, the message parameters include time stamp. The time stamp also uses to check the time difference and update the message by checking the effective messages. In Fig. 6, the pseudo code for messages processing is shown below.

$$C_t = (-(V_x \cdot x + V_y \cdot y) + \sqrt{(V_x^2 + V_y^2)R^2 - (V_x \cdot y + V_y \cdot x)^2}) / (V_x^2 + V_y^2) \quad (8)$$



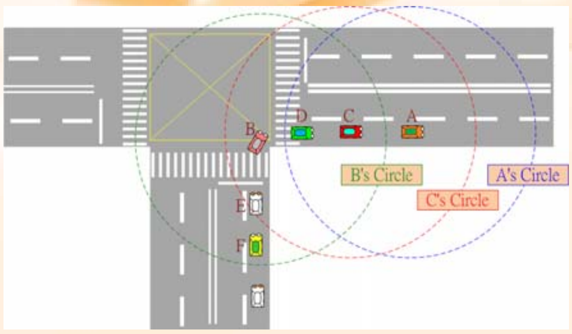


Figure 5 Inter-Vehicle Geocasting in Straight Roadway and Intersection

```
// Location: B
// group: ARTC
// node: B
// time: B' s time

    // Receiving Interrupt
    if( (group==ARTC) & (group!=B) )
        put (packet+B' s time) into memory stack.
    else
        discard

// Transmitting Interrupt
if( ||Distance of Node_X || >R1)
    put Node_X into possible transmitting cases.

for (possible transmitting cases_X){
    if (X is the most outer edging point)
        put X into transmitting schedule
}

for( || Heading difference for X|| > H_threshhold )
    put X into transmitting schedule

Transmitting X through DSRC module
```

Figure 6 Pseudocode for inter-vehicle geocasting

VERIFICATION TESTS

Under system implementation, the platform static tests include packet loss and latency. The environment noise was measured before static test in Fig. 7. The power of environment noise was -115 to -95 dbm, and it was too small to affect the packet tests. Each result would minus 20 because of probe decay. The range test showed in Table 3, and the packet loss rate rule is to get 95% successful receiving at 1000 times packet transmitting.

Table 3 Static test about packet loss rate and latency

Position (m)	Packet Loss Rate (%)	Latency (msec)
+200	76	654.8
+100	70	461.7
0	55	19.6
–100	66	668.6
–200	54	361.3

Figure 7 Background measurement using frequency spectrum

After the static tests were finished, the dynamic test of cooperative driving was operated. The test platform, as shown in Fig. 8, was used to implement the proposed CCW system. Three vehicles were used to run on the ARTC roadway to verify the geocasting and collision warning function; while three vehicles were followed on roadway or driven into intersection in order to easily verify system design in the verification. Under system design and implementation, vehicular data which connected to CAN interface was collected for scheduled tests. For test operations, DSRC module was used to exchange data. The GPS receiver also outputted positioning data, and the positioning performance was well processed and mapped to demonstrated map. Fig. 9 showed the inter-vehicle geocasting tests, where two cases showed that three vehicles were individually running on ARTC roadway. Two tests demonstrated the CCW system away from other vehicles, and the driver drove far away from preceding vehicle or following the other vehicle. Fig. 10 showed another test, where the driver drove into an intersection. These cases offered an important awareness to the driver under test. The map reported neighboring vehicles position periodically, and broadcasted to other vehicles via DSRC communication. In these tests, the actual position of the vehicle was monitored and displayed on the screen. The CCW system provided a cooperative driving that the operator could be fully aware of 360-degree situation under proposed system concept.

Figure 8 System Hardware and Implementation.

Figure 9 Inter-Vehicle Geocasting Result in intersection

Figure 10 Collision Warning in blind intersection

CONCLUSION

In this paper, the proposed concept demonstrates a cooperative collision warning system for remote surveillance applications. The system design simplified using embedded microprocessor with DSRC module to activate UDP and port 802.11p protocol into data link, continuously vehicular speed using CAN network and high sensitivity GPS positioning. The proposed warning system assists drivers to know current relationship to other vehicles through intersection and following tests with the situation awareness capability. The proposed CCW system assists drivers to know current relationship to other vehicles through an intersection or following tests with the situation awareness capability. Although the result of DSRC packet loss rate and latency are not very good, this drawback will be improved in progress concern. The demonstrated tests have been verified the availability of collision estimation and inter-vehicle geocasting algorithm.

ACKNOWLEDGMENT

This work was supported by Department of Industrial Technology, Ministry of Economic Affairs, Taiwan, R.O.C.

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