Verification of On-Line Vehicle Collision Avoidance Warning System using DSRC

C. W. Hsu, C. N. Liang, L. Y. Ke, F. Y. Huang

***Abstract*—**Many accidents were happened because of fast driving, habitual working overtime or tired spirit. This paper presents a solution of remote warning for vehicles collision avoidance using vehicular communication. The development system integrates dedicated short range communication (DSRC) and global position system (GPS) with embedded system into a powerful remote warning system. To transmit the vehicular information and broadcast vehicle position; DSRC communication technology is adopt as the bridge. The proposed system is divided into two parts of the positioning and vehicular units in a vehicle. 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 break, throttle, and other signals via controller area network (CAN) interface connected to each mechanism. The mobile hardware are built with an embedded system using X86 processor in Linux system. A vehicle is communicated with other vehicles via DSRC in non-addressed protocol with wireless access in vehicular environments (WAVE) short message protocol. From the position data and vehicular information, this paper provided a conflict detection algorithm to do time separation and remote warning with error bubble consideration. And the warning information is on-line displayed in the screen. This system is able to enhance driver assistance service and realize critical safety by using vehicular information from the neighbor vehicles.

***Keywords*—**Dedicated short range communication, GPS, Control area network, Collision avoidance warning system.

I. INTRODUCTION

IN recent years, the number of fatalities in traffic injuries is about nearly 43 thousands according to U.S. department of transportation (DoT) statistic data and the incapacity for work of over 3 consecutive days is about 3.2 million. The wasting social cost is over 1.5 hundred million in addition. To solve this kind of problem, the solution for vehicle collision avoidance, such as intelligent transportation Systems (ITS) and smart car, is the most popular method to implement at present. The concept of ITS is incorporated artificial intelligence, navigation information, communication, other emerging technologies into transportation systems to improve efficiency and advanced safety vehicle (ASV) of such systems, including reducing environmental impact. Although ITS is a fully scheme, it is hard to build completely infrastructure in short duration. In other thinking, a smart car could be rapidly implement in transition stage of ITS. A smart car belongs to one of the application of ASV, which uses advanced technologies to bring about markedly improved safety.

C. W. Hsu is now with the Research & Development Division, Automotive Research & Testing Center, Changhua, Taiwan.(phone: +886-4-7811222 # 2351; fax: +886-4-7811333; e-mail: winsonhsu@artc.org.tw).
C. N. Liang is now with the Research& Development Division, Automotive Research & Testing Center, Changhua, Taiwan. (e-mail: cnl@artc.org.tw).
Liang-Yu Ke is now with the Research & Development Division, Automotive Research & Testing Center, Changhua, Taiwan. (e-mail: anndymaktub@artc.org.tw).
Fu-Yan Huang is now with the Research & Development Division, Automotive Research & Testing Center, Changhua, Taiwan. (e-mail: kikivans@artc.org.tw).

To meet a higher vehicle safety, DSRC which is a wireless communication protocol in the 5.9 GHz frequency band plays an important role of vehicular system [1]. All vehicular information should always on-line for remote warning application. In the on-line warning solution, the most concern appears to be the DSRC basis QoS being applied based on transportation communication system [2], [3]. A high-reliability communication interface usually transmits by client-server model communication and packets are addressed to or from IP protocol. For real time control, a common communication can reversely be implemented to switch into User Datagram Protocol (UDP) to receive packets and forward self-information to other cars. A DSRC is designed to active WAVE protocol to another one and it also has the ability of broadcast in remote operation in addition. DSRC communication unit as well as vehicular equipment is designed to offer a complete solution for mobile data broadcast and establishing conflict relationship.

When GPS were mature and available in 1990s, long term navigation gets easy today. GPS is a worldwide radio-navigation system formed from constellation of 24 satellites and ground stations [4]. It provides high accuracy position, any weather condition and has the advantage in faster positioning. Positioning accuracy and reliability is great concern to many users, and becomes a good engineering topic for study in depth. GPS receiver has been miniaturized to just a few integrated circuits and becoming very economical in different areas. Simple and economical GPS combinations can offer positioning information in many varieties of applications. In implementation, GPS module is taken to receive positioning data under driving.

This paper proposed a system configuration using an embedded system to operate as a control system to manipulate DSRC unit, vehicular unit and GPS unit for collision avoidance. GPS module could provide accurate positioning, speed 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.

II. Concept of Collision Avoidance Warning System

The system technology for collision avoidance warning system is designed with an integration of GPS and data transmitting through DSRC. The information may display on the screen to monitor other neighbor vehicles in real time operation. The vehicular data of vehicle will be routed and broadcast to neighbor vehicles by short message protocol onto the internet via DSRC communication. The concept of the proposed system technology is shown in Fig. 1.

A. *The Proposed System Architecture*

A data fusion of collision avoidance warning system platform is built of the basic three parts, including GPS receiver, DSRC communication unit and CAN transceiver. A X86 processor is the mainly adopted controller, where the embedded kernel to access data input and output is programmed. To fulfill the proposed anti-collision application, GPS data as well as vehicular data are processed in specific logic, digital formats and sent through DSRC module in controlled intervals. The data packet is formed up in X86 processor from the peripheral sensors as well as GPS. Each data packet is collected and sent to DSRC module within each cycle of data surveillance. Meanwhile, the processor is activated by embedded Linux system. The USB of embedded system interface is simulated as a serial port that is used as COM1 port for GPS module to capture positioning data, and two mini-PCI slots for DSRC modules to transmit data or receive data from other vehicles.

B. *Communication Unit*

In the recent two decades, wireless communication had a tremendous growth in many applications. Cellular systems, infrared, Bluetooth and DSRC in wide area or local area communication have rapidly increased. 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 vehicle-to-vehicle (V2V).

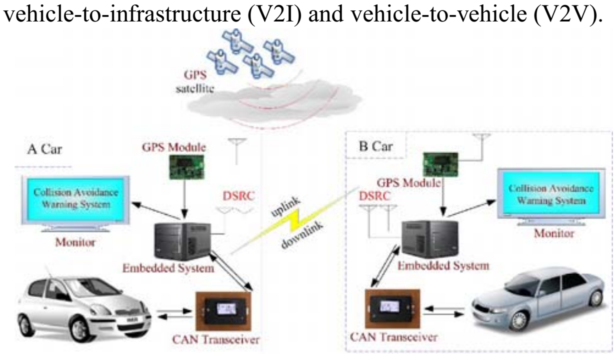

Fig. 1 The proposed system architecture

A common solution, Bluetooth, is applied to microphone, audio and media control system in inter-vehicle communication. The coverage distance of Bluetooth is up to 10 meter, but this kind of 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 [5]. It is a good means for any moving individual to send or receive message from anywhere within base station coverage. The application of data reporting for surveillance or real time control is a rising demand where either GSM or GPRS services are available. However, mobile communication has a drawback in time delay about 1.0 sec in TCP mode or 0.8 sec in UDP mode. In 1999, the USA Federal Communications Commission defined DSRC whose frequency is located in 5.9 GHz band to be used exclusively for V2V and V2I communications. DSRC 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.

TABLE I
REQUIREMENTS AND SPECIFICATIONS

Criterion	Required	Desirable	DSRC
Coverage	Enough to cover within a radius of 300 m area	Transmit/ Receive vehicular data.	Up to 300-1000 m
Data Rate	Enough to process vehicular data within 10 msec	Enough to process moving data of vehicles.	3□27 Mbps
Working Mode	Support non-IP mode and high reliability	For data broadcast and direct access	Point-to-point / bidirectional data exchange
Timeliness ability	Time delay within 100 msec	Enough to do real time operation	Latency about 50 msec

A communication module plays a potential auxiliary support to derive packages of vehicular data to implement the remote surveillance and do warning signals. Each of the communication modes has own applied conditions, and the specification and requirement of DSRC communication are listed in the following Table I. As shown in Fig. 2, the frequency spectrum of DSRC is divided into seven wide channels (10MHz). Channel 178 is the control channel (CCH), which is restricted to safety communications only. CCH is a unique channel shared with all WAVE devices and used for control communication. The two channels at the edges of the spectrum are reserved for future advanced accident avoidance applications and high powered public safety usages. The remainder is service channels (SCH) which are available for both safety and non-safety usage, and SCH is used for normal data communication.

Fig. 3 illustrates the adopted DSRC protocol under open system interconnection (OSI) model, and the system architecture of DSRC is based on IEEE 802.11p standard to WAVE protocol in. From bottom to up, the physical and data link layer is defined by 802.11p. The rest layers are defined by WAVE protocol or IEEE 1609.1 to 1609.4 in resource management, security services, network services and medium access control. In the network interface layer, the DSRC adopts the non-IP or IP base protocol to establish network connection. In the application layer, each vehicle is programmed to process the communication data between them.

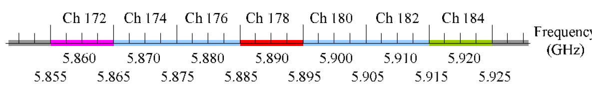

Fig. 2 DSRC frequency allocation

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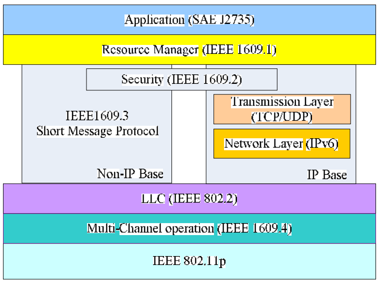

Fig. 3 DSRC system architecture

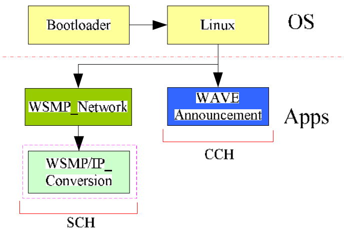

Fig. 4 The flow chart for DSRC communication

Though the DSRC standards were incomplete, it was feasible to use and modify existing 802.11a equipment to simulate performance in the DSRC band. The hardware of collision avoidance warning system established the operation system software and the application system software in Fig. 4. The operation system software is inherently a Linux operating system under X86 infrastructure, and contained “Bootloader” and “Linux” programs. The application system software are developed with “WAVE_Announcement”, “WSMP_socket”, “WSMP/IP_Conversion” for use as shown in Fig. 4, where (1) “WAVE_Announcement” carried out registration of user service information, completed service acquisition on CCH and adjusted appropriate SCH according to the received information; (2) “WSMP_Network” provided a socket interface to send/receive WAVE short message on SCH; (3) “WSMP/IP_Conversion” provided UDP/IP communication and converted UDP packets to a certain UDP port, in next generation, this function is finished by “WSMP_Network”.

C. *Positioning Unit*

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. The key features of the GPS module are Low power: 80mA(avg.) @4.5~5.5V full power; acquisition rate: hot start - 1 sec for remote operation and interface in USB.

GPS adopts the NMEA-0183 standards as a format for interfacing marine electronic devices [7]. The default communication parameters for NMEA output are set as 4800 baud, 8 data bits, stop bit, and no parity. One of the NMEA message format, GPRMC, is employed to provide the precise positioning in the proposed system. The GPS fixed data is processed in one second period, including the acquisition of position, ground speed and course.

D. *Vehicular Unit*

In the warning system, the break and throttle condition is transmitted to other vehicles by vehicular data acquisition. The amount of electronic devices in vehicles is connected and diagnosed by CAN bus in recent years. 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. The bit rate of CAN bus is up to 1 Mbps and is possibly operated at network lengths below 40 meter. Fig 5 shows that the supervisor node gets throttle, break and other signals from CAN bus. The supervisor node is implemented by CAN circuit board.

These vehicular signals are held and processed by CAN circuit board in supervisor node, as shown in Fig. 6. 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”.

III. Collision Avoidance Algorithm

After each vehicle receives data from other vehicles, the mathematical model of conflict detection will build a geometry model [8]-[10]. Fig. 7 shows that 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.

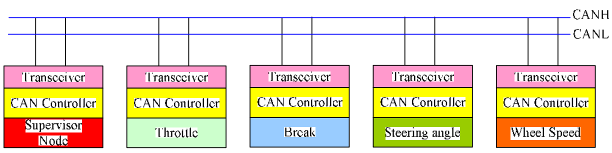

Fig. 5 Block diagram of CAN bus in vehicle

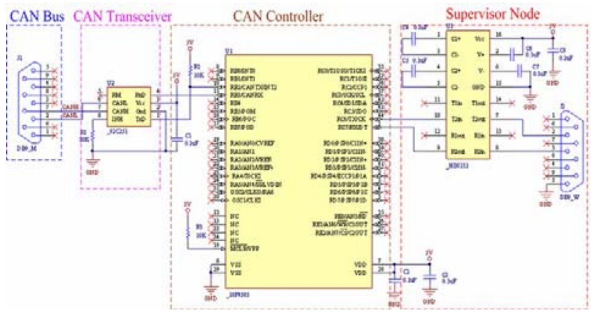

Fig. 6 CAN circuit board in supervisor node

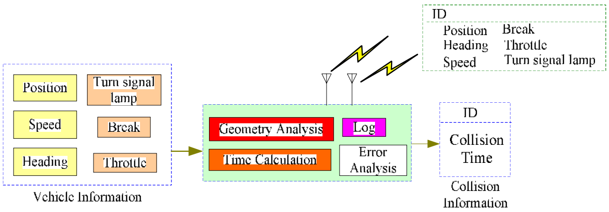

Fig. 7 Block diagram of vehicular information.

A. Conflict Detection

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 Fig. 8, B is the ownership so it has an error bubble around it [11]. 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.

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.

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

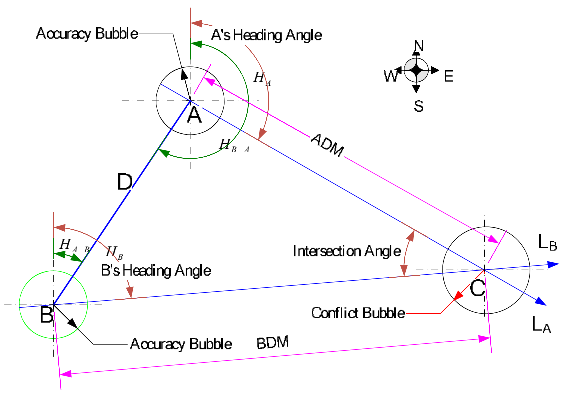

Fig. 8 Geometry model of two conflicting moving objects

The first procedure is transformed from WGS-84 to ECEF and ECEF to NED frame using (2)-(3). The altitude (h) is given by GPGGA format from GPS receiver and the other parameters are eccentric (e) and semi-major axis (a). Equation (2) 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 (3).

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

$$\begin{bmatrix} x^N \\ y^E \\ z^D \end{bmatrix} = \begin{bmatrix} -\cos(\lambda_0)\cdot\sin(\Lambda_0) & -\sin(\lambda_0)\cdot\sin(\Lambda_0) & \cos(\Lambda_0) \\ -\sin(\lambda_0) & \sin(\lambda_0) & 0 \\ -\cos(\lambda_0)\cos(\Lambda_0) & -\sin(\lambda_0)\cos(\Lambda_0) & -\sin(\Lambda_0) \end{bmatrix} \times \begin{bmatrix} x_1^E - x_0^E \\ y_1^E - y_0^E \\ z_1^E - z_0^E \end{bmatrix} \quad (3)$$

Although the mathematical model usually adopts Cartesian coordinate, all of the angles are still referenced to NED coordinate. Fig. 8 only shows one kind of collision condition, but vehicle A maybe locates at different quadrant and has different heading angle result from geometry relationship. Fig. 9 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. Fig. 10 shows the other relationships with vehicle A in Quad II or III and the possible collision also has four cases.

The collision conditions are discussed and suitable at any conflict area, and each possible case is listed in the following Table II(A) & II(B). In Table II, 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.

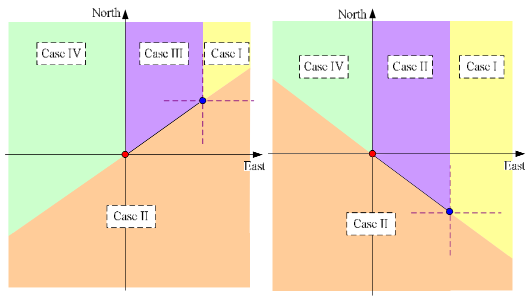

Fig. 9 Collision conditions with vehicle A in Quad I or IV.

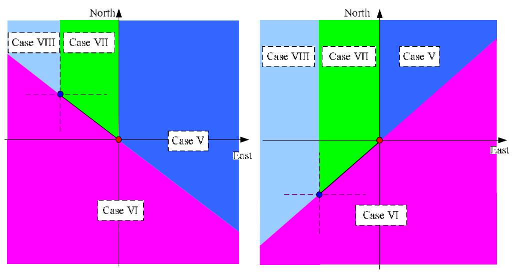

Fig. 10 Collision conditions with vehicle A in Quad II or III

TABLE II(A)
RELATIVE HEADING ANGLE OF COLLISION POINT IN QUAD. I OR IV

Angle	Collision cases			
	Case I	Case II	Case III	Case IV
$\angle A$	$2.-H_{BA}+H_A$	$H_{BA}-H_A$	H_A-H_{BA}	H_A-H_{BA}
$\angle B$	$H_{AB}-H_B$	H_B-H_{AB}	$H_{AB}-H_B$	$2.+H_{AB}-H_B$

TABLE II(B)
RELATIVE HEADING ANGLE OF COLLISION POINT IN QUAD. II OR III

Angle	Collision cases			
	Case V	Case VI	Case VII	Case VIII
$\angle A$	$H_{BA}-H_A$	H_A-H_{BA}	$H_{BA}-H_A$	$2.-H_A+H_{BA}$
$\angle B$	$2.-H_{AB}+H_B$	$H_{AB}-H_B$	H_B-H_{AB}	H_B-H_{AB}

From (3), the system could give the relative distances and then use sine law to calculate A distance margin (ADM) and B distance margin (BDM) [12]. The key features of ADM and BDM are depend on the heading, relative heading angles and triangular angles $(\angle A, \angle B)$.

B. Overlapping Time

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 (4) in vehicle A, moreover, the same concern is considered in ownership 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 10 meters and differential GPS is within 3 meters. In this paper, the circle error is known as the error intersecting bubble as shown in Fig. 8.

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 (4). 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 Fig. 11. If $t_{A1\text{-}A2}$ occurs between the start of t_{B1} and the end of t_{B2}, their times are overlapping in Fig. 12. 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.

$$t_{A1} = \frac{ADM + error \quad range}{V_A}, \quad t_{A2} = \frac{ADM - error \quad range}{V_A} \tag{4}$$

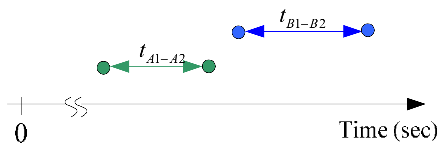

Fig. 11 No overlapping time between the two vehicles

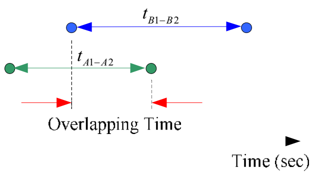

Fig. 12 A span overlapping time between the two vehicles

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 (5), and it is distributed over the driver response time whose magnitude is about 0.5 to 0.75 sec [13].

$$t_{LSM} = \frac{D}{V_A \cdot \cos(\angle A) + V_B \cdot \cos(\angle B)} \tag{5}$$

IV. VERIFICATION TESTS

The test platform, as shown in Fig. 13, is used to implement the proposed remote collision avoidance warning system. A vehicle is used to run on the roadway to verify the proposed function capability; while two vehicles are driven on the same roadway in order to easily verify system design in the verification. Under system design and implementation, vehicular data acquisition circuit is fabricated and installed on the vehicle for tests as follows in Fig. 14.

For test operations, DSRC module is used to do two-way data link communication. The embedded system used two DSRC modules to do data communication in control channel and service channel individually. When the DSRC module has initial operation, the module emits warning messages and safety status messages on the control channel. In normal condition, the control channel is used to execute safety application, and then it switches to service channels. DSRC module executes non-safety applications and listens again on the control channel. Meeting a more rapidly communication, two modules are adopted to handle control and service channels individually.

Fig. 15 shows the remote warning test, where two vehicles were running on ARTC roadway. This test demonstrated the warning system in a longer distance (53.4 m) within visual range, and the green point presented a safe condition. This form also showed other information which had break, throttle and turning signal on the screen.

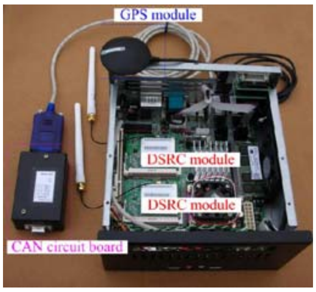

Fig. 13: Test platform, including DSRC, GPS and CAN board.

Fig. 14: CAN circuit board.

The vehicle warning system offered important awareness to the driver under test. Each vehicle reported GPS positioning data and vehicular information once every 1 second periodically, and broadcast to other vehicle through non-IP based protocol via DSRC. Although the protocol adopted non-IP based protocol, the data exchange was operated by hardware address. In the warning test, the actual position of the vehicle was monitored and displayed on the screen. GPS error is inevitable, but it is not a problem in this paper. The GPS error was considered and the collision was calculated during an interval (4.6~6.5 sec) in Fig. 15. The driver could easily see how other vehicle was presented in remote performance of collision time and several motion conditions. In the test to the near range, the vehicular information as well as remote collision time was also verified on the screen, as shown in Fig. 16. The opposite direction showed a vehicle that broadcast data through DSRC module to own vehicle in this test. The embedded processor predicted that there was possible danger or conflict in the near future. The display shows the break signal, turning signal and throttle signal of the vehicle that the operator could be fully aware of other vehicle situation.

V. Conclusions

In this paper, the capability of a remote vehicle collision avoidance warning system using DSRC communication is verified. The proposed system designed and implemented an integrated technology using CAN microcontroller to accomplish vehicular data access and DSRC module to allow remote data exchange through embedded processor. The implementation presented the capability of the vehicular information into remote warning applications in many intersections.

The verification tests have proven that the advantages of DSRC and GPS integration between vehicles may satisfy most remote warning applications using direct collision time and lateral collision time. The proposed warning system offers drivers to know current relationship to other vehicles through a roadway test or intersections with the situation awareness capability. The advantage of the vehicle collision avoidance warning system has presented with exact awareness of possible collision time, and the demonstration provides a feasible solution for intersection warning to enhance driving safety.

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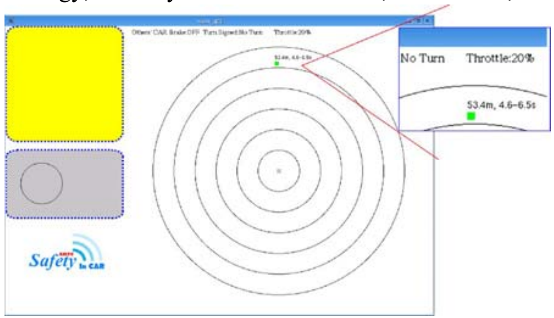

Fig. 15: Remote warning test in a longer distance.

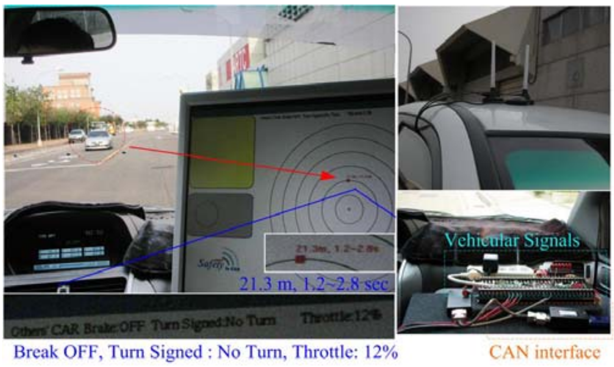

Fig. 16: Remote warning test in short range.

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Chan Wei Hsu was born in Changhua, Taiwan in 1976. He received his B.S., M.E., and D.E. degrees in institute of Astronautics and Aeronautics from National Cheng Kung University, Taiwan, in 1999, 2001, and 2008, respectively.

He joined the Automotive Research & Testing Center in 2008. Since then, he has been engaged in the research and development of DSRC application and vehicle collision avoidance system for vehicle safety. His current interests are intelligent car following control, 2D driving map by Radar/Lidar processing, advanced parking guidance system and adaptive cruise control for vehicle development.

Chih Neng Liang was born in Changhua, Taiwan in 1970. He received his M.E. degree in institute of Computer Science and Information Engineering from National Cheng Kung University, Taiwan, in 1995.

He joined the Automotive Research & Testing Center in 2006. Since then, he has been engaged in the research and development of DSRC application and vehicle network for vehicle safety.

Liang Yu Ke was born in Kaohsiung , Taiwan in 1983. He received his M.E. degrees in Computer Science and Engineering Department of Yuan Ze University at 2007.

He joined the Automotive Research & Testing Center in 2008. Since then, he has been engaged in the research and development of DSRC application and vehicle network for vehicle safety.

Fu Yan Huang was born in Chiayi Taiwan in 1982. He received his B.S.degrees in Department of Vehicle Engineering from National Taipei University of Technology, Taiwan, in 2002.

He joined the Automotive Research & Testing Center in 2008. Since then, he has been engaged in testing and verification of system functionality for V2V and EPB system.