DDAS: Distance and Direction Awareness System for Intelligent Vehicles

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Wireless technology has been widely used for applications of wireless Internet access. With the matured wireless transmission technology, the new demand on wireless applications is toward the concept of deploying wireless devices on transportation systems such as buses, trains and vehicles. Statistics of car accident cases show that car accidents are often caused from drivers unnoticing other approaching cars during driving. Without the assistants of automotive personal computer system (also called as Auto PC), during high-speed moving, driver always counts on himself/herself to look for all vehicles around him/her via limited vision and acoustic recognition. In case that the Auto PC is able to provide useful surrounding information, such as the directions and distances to nearby vehicles, to drivers, unnecessary collisions could be obviously avoided, especially in cases of changing lane, crossing intersection and making a turn. In this paper, we will introduce the concept of automatic distance and direction awareness system (DDAS) and describe the designed embedded DDAS integrated with three-wheel and four-wheel robot cars.

Keywords: embedded, smart antenna, vehicle, wireless, Zigbee

1. INTRODUCTION

As the growing the wireless applications, the concept of intelligent vehicles with wireless devices becomes more practical and doable. Applications for vehicles with wireless system can be classified into two categories: vehicle-to-vehicle and vehicle-to-road applications. Wireless devices used in vehicle side and road side are named as the on-board-unit (OBU) and road-side-unit (RSU) respectively. The cooperation between OBU and RSU can provide the useful services such as vehicle positioning, electrical toll collection (ETC), parking lot payment, cargo tracking, road condition warning, traffic information, intersection collision warning, and so on. On the other hand, the communications among OBUs can provide the fantasy services of approaching emergency vehicle warning, vehicle safety inspection, cooperative adaptive cruise control (ACC), and so on.

To make sure the interoperability among vehicular and roadside wireless devices, the dedicated short range communications (DSRC) [3] technology has been defined by ASTM association formally several years ago. The DSRC is a short to medium range communications service that supports both public safety and private operations in road-side to vehicle and vehicle to vehicle communication environments. Besides, DSRC is
proposed to provide very high data transfer rates in circumstances where minimizing latency in the communication link and isolating relatively small communication zones. At this stage, the DSRC standardization process has been smoothly transferred to the IEEE 802.11p [6] working group for the consideration of world-wide market. From the released documents, the technique of wireless communications among vehicles and roadside system mainly inherits from the IEEE 802.11a physical layer (PHY) and IEEE 802.11 medium access control (MAC) protocol [5].

Statistics of car accident cases show that accidents are often caused from drivers unnoticing the other approaching cars. Without the assistants of automotive personal computer system (also called as Auto PC, which is plays the role of OBU), during high-speed moving, driver always counts on himself/herself to look for all nearby vehicles around him/her via limited vision and acoustic recognition. In case that the Auto PC is able to provide drivers the useful surrounding information, such as the directions and distances to nearby vehicles, unnecessary collisions could be avoided, especially in cases of changing lane, crossing intersection and making a turn. Therefore, it is worth designing an automatic distance and direction awareness system (DDAS) for intelligent vehicles in order to provide precise positioning, safe driving, automatic driving, and so on.

In this paper, we utilize both the standard IEEE 802.11 wireless local area network (WLAN) network interface cards (NICs) and the IEEE 802.15.4 Zigbee [7] modules as the wireless transmission modules to be equipped on OBU(s) and RSU(s). In our designs, the proposed direction and distance awareness system (DDAS) does not require any settings by users. This designed system is plug-and-play (PnP) system. When the embedded DDAS system is powered on, it will automatically detect and display the surrounding vehicles on the LCD panel. Besides, it can timely alert driver to the danger of any potential collision. Warning messages could be represented in any kind of formation such as voice, beep tones, flash, and so on. Here, we just simply display the positions of other moving vehicles around the driver and make beep tones (i.e. warning signals) in case that distance between the other vehicle and itself is less than a predefined threshold. As the driver falls into sleep during driving, once the vehicle diverges from original lane and approaches the other vehicle, the DDAS will also make the alarms to drivers automatically. This implies that the designed system is proactive system, not passive system.

The rest of paper is organized as follows. Section 2 describes the origin concept of DDAS. The implementation details of DDAS prototype is described in section 3. Section 4 demonstrates the designed system and describes the potential applications of DDAS. Section 5 gives some conclusion remarks.

2. AUTOMATIC DISTANCE AND AWARENESS SYSTEM (DDAS)

In the literature of distance/direction measurement, there are a few low-cost conventional solutions. Conventional techniques such as ‘infrared’ and ‘ultra-sonic’ can be used to measure the distance as well as direction. However, both of them suffer from the restrictions of line of sight (LOS) and the distance. Technique used in our proposed DDAS is the radio signal (RF), which can penetrate through obstacles between source and receiver. This implies that wireless devices could be equipped inside vehicles. With the RF technique, the distance measurement method is based on the received signal strength
indicator (RSSI) at the recipient side. In other words, the path loss of RF signal can be used as the major factor in measuring the distance between sender and receiver. One benefit is that the distance measurement in either sender or receiver can be done during data exchanges between them. On the contrary, the direction measurement method of RF-based technique could be accomplished by using contemporary smart antenna which has the ability to quickly form the radio beam with a particular direction and angle for data transmission. Without the beam-forming control command, the smart antenna becomes the standard omni-directional antenna.

Notably, if the smart antenna supports 60° angle of beam, the process of wireless device scanning the neighbor devices need send the probe_request broadcast messages six times (each with different angle) in order to probe the devices in different directions related to the sender. Fig. 1 shows the six-direction smart antenna used for direction detection. Wireless devices receiving probe_request message have to asynchronously reply a probe_response message to the sender following the standard contention-based MAC protocol. This reply message is sent with the omni-directional antenna mode. Due to the property of carrier sense multiple access (CSMA) protocol, when the device stays in receiving mode, the antenna is set as omni-directional mode in order to receive messages from all directions. In a word, the smart antenna is set as directional antenna mode only when the device sends probe_request broadcast message and the smart antenna is set as omni-directional antenna mode when the device stays in receiving mode or the device replies the probe_response unicast message.

Fig. 1. Six-direction smart antenna is used to detect the direction of the other vehicles.

Fig. 2 illustrates the 2-way handshaking of vehicle A finding the neighboring vehicle B and measuring the direction and distance between them. Since the smart antenna and standard MAC contention protocol are not the contributions of this paper, we put our focuses on the concept and the implementation details of embedded system designed for DDAS.

For avoiding false alarms and missing critical alarm, the proposed DDAS should take the robustness and reliability issues into considerations. In our designs, the alarm will be issued only if a number of consecutively measured distances from a vehicle are all shorter than a predefined threshold. Assume the moving speed of a vehicle approaching our vehicle be 100km/hour and the scanning/conformance process take 50ms long. We can easily calculate the moving distance D of the approaching vehicle during the
Fig. 2. The way of vehicle A finding the neighboring vehicle B and measuring the direction and distance between them.

(a) Vehicle A detects vehicle B but failing in detecting vehicle C.

(b) Vehicle B detects that vehicle C approaches vehicle A according to the measured direction.

(c) Vehicle B informs vehicle A about the approaching of vehicle C.

Fig. 3. Collaborative DDAS among vehicles on roadway.
scanning/conformance process. We have $D = 100 \text{km/hr} \times 50 \text{ms} = 0.138 \text{m}$. Since the process with smart antenna is very fast with respect to the vehicle moving speed, the confirmation process is acceptable in terms of response time. For the issue of missing critical alarms, we need further extend the DDAS to have the ability of exchanging neighborhood information among vehicles. For instance, assume that vehicle A has detected a neighbor vehicle, say B. Once vehicle B detects another vehicle, say C, which direction is the same as the direction of vehicle A to vehicle B, vehicle B will immediately inform vehicle A about this situation. For some wireless interference reasons, if vehicle A does not detect any information about vehicle C, our DDAS will automatically issue critical alarm to driver about this situation. Excepting above erroneous cases from wireless interferences, we also add the watchdog in the embedded system to make the DDAS work well. Fig. 3 illustrates the critical alarm operations that can resolve missing critical events.

3. IMPLEMENTATIONS OF DDAS

In this development, we use the wireless protocol analyzer to validate the wireless transmissions, designed protocol and coded software. To speedup the development process, we also use open source programs to help us debugging and managing our source codes. Open source program such as trace utility is used to print out the trace of all system calls made by process or program. Linux Trace Toolkit (LTT) is used for tracing and debugging Linux kernel. We also use KGDB to do source level kernel debugging which is similar to the debugging technique often used on user applications. Standard ARM-Linux kernel is ported on the platform we chosen. GNU GCC and GNU tools are used to compile Linux kernel and user applications.

The implementation includes three stages. In the first stage, we setup the embedded system with embedded Linux OS. Meanwhile, we attach the selected wireless module onto the hardware platform. In the second stage, we develop the core of direction and distance awareness system (DDAS) on the platform. The protocols performed between vehicles, the device driver of controlling the smart antenna and the direction/distance measurement method are completely designed and developed in this stage. In the last stage, we build our 3-wheel and 4-wheel robot cars and then integrate the embedded system of DDAS and robot cars. Moreover, we also develop the GUI for PC/NB to remotely control the robot car as well as display the positions of neighboring vehicles returned from the controlled robot car. That is, in addition to display the measurement results on the LCD panel, which is mounted on robot cars, we can also directly observe the measurement results in the remote control site. This system is first tested in our laboratory environment, after that, it is tested in the open field. The quality assurance plans of the designed DDAS with robot cars are partitioned into three parts: the module testing, the integration testing and field testing. By using CVS server, we organize and maintain our developed source codes.

3.1 Introduction of Embedded OS

In general, the embedded system does not allow developer to directly compile programs on the target board. Instead of, the OS kernel, drivers, and file system programs
are compiled on powerful and friendly host PCs. Therefore, the related tool chain with target board is required, and is known as cross-compiler process. Fig. 4 shows the standard process of developing embedded Linux.

The Linux kernel separates the hardware part from the user-level tasks. The kernel uses scheduling algorithm to assign priority for each task in order to provide good performance and memory management. Moreover, kernel has the ability to suspend any user-level task once that task has run out the time-slice allotted to it. The scheduling algorithms along with device drivers, uninterruptible system calls, and virtual memory operations are sources of unpredictability. Fig. 5 shows the kernel architecture of the embedded operation systems.

### 3.2 Platform of the DDAS

The auto PC, which is mounted on vehicle, consists of the embedded system with Linux O.S., the optional display panel and the IEEE 802.11a/b/g NIC and/or IEEE 802.15.4 modules with smart antenna. Recall that the multi-direction smart antenna is used to control the range and angle of wireless signals. We also design the embedded software not only to measure the direction and distance to individually nearby vehicle but also to control the movement of our vehicles. The aim that we measure the distances/
directions to all surrounding vehicles is to precisely notify driver which direction may encounter collision. By controlling the smart antenna, the wireless handshaking messages between two vehicles are sufficient for Auto PC to retrieve the information of direction and distance between them. The direction and distance are derived from the assigned angle of smart antenna and the received signal strength indicator (RSSI) respectively. Distance between vehicles is retrieved from the RSSI value by referring the database of path loss we measured in the open field. Fig. 6 illustrates the relationships between distance and RSSI value.

![Fig. 6. Relationship between RSSI and distance.](image)

Without loss of generality, the DDAS is developed by integrating the embedded hardware platform, embedded software and optional graphic user interface (GUI). The hardware platform is similar to conventional ARM-based embedded system. The embedded software includes the embedded Linux O.S. and the entities of DDAS. In this project, we display the positions of neighboring vehicles on either user PC (or notebook) and/or the LCD panel connected on the hardware platform. Data exchanges between embedded system (Auto PC) and user PC/NB are also accomplished by the IEEE 802.11 NIC and 802.15.4 module. To demonstrate the collision warning system, we also develop the control interface (on user PC) with game pad (of PS2) for users to freely and remotely control their robot cars. While driving robot cars, DDAS will help players to drive safely as mentioned before.

### 3.3 Hardware Architecture

This subsection introduces the selected x86-like platform. This CPU core is a high performance 32-bit RISC processor which operated at 166MHz with the compatibility of windows O.S., Linux and most popular real-time OS (RTOS). It also integrates 16KB write direct map L1 cache, PCI rev. 2.1 32-bit bus interface at 33 MHz, SDRAM/ROM/memory controller, IPC (Internal Peripheral Controllers with DMA and interrupt timer/counter included), Fast Ethernet MAC, FIFO UART, 10/100M MAC and USB2.0 Host. Regarding to the system memory, X-bus connects 8MB flash, which is used to store Linux O.S. and program files, and 64MB PC133 SDRAM for executing programs. The IEEE 802.3 Ether-switch chipset with respect to network communication goes through IEEE 802.3u 100BASE-T Media-Independent-Interface (MII). The Universal Asyn-
chronous Receiver/Transmitter (UART) is a simple transmission interface. In the development project, the UART is not only used to debug, but also used to control display panel. Fig. 7 shows the system blocks of DDAS hardware platform. Fig. 8 shows the picture of embedded system hardware platform. Fig. 9 shows the designed system blocks of DDAS hardware platform.

In this project, excepting the pervasive IEEE 802.11 WLAN NICs, we particularly choose the low-power, low-cost and short-distance IEEE 802.15.4 Zigbee wireless as the alternative wireless transceiver in DDAS. To do this, we not only develop our IEEE 802.15.4 Zigbee module but also develop the MAC and NWK (multi-hopping protocol) firmware following Zigbee standard. In the designed modules, the 16-bit TI MSP430 is used as the microcontroller and the Chipcon CC2420 is used as the IEEE 802.15.4...
BB/RF transceiver. Notice that this module is also used to control LCD panel to display information. Fig. 10 shows the main block diagram of ZigBee module and shows the developed hardware of the ZigBee module for this project.

In order to build the DDAS notification system on vehicle, the GG1206N1SKY1S (LM6321SGL) module is adopted as the LCD panel in DDAS. The number of dots in such LCD panel is 128 (W) times 64 (H) dots. The module size is about 93mm times 70mm and the viewable area is about 70mm times 39mm as shown in Fig. 11.

For the sake of demonstrations, we built the 3-wheel robot cars which have the attractive capability of omni-directional movement. Fig. 12 shows the 3D graphic and real hardware of 3-wheel robot car. Furthermore, we also built the 4-wheel mini robot cars for demonstrating the nearby vehicles moving around the 3-wheel robot car. The 4-wheel
mini robot cars equipped with the designed Zigbee module and omni-directional antenna are shown in Fig. 13. The 3-wheel robot car uses smart antenna to position the other 4-wheel mini robot cars with omni-directional antenna. As mentioned before, the system has the ability to remotely and smoothly control the 3-wheel and 4-wheel robot cars by using PS2 gamepad.

3.4 Software Architecture

In this project, we choose an x86-based platform with embedded Linux OS (from open source). The flash on hardware platform should have at least 4MBytes and the embedded Linux OS and file systems we build are stored on it. Peripherals such as wireless NIC, Zigbee module, smart antenna, buzzer, battery container, PWM controller, and motors of robot cars are connected onto this platform. The software architecture is illustrated in Fig. 14. Note that there is a protocol designed for connecting the 802.11/802.15.4 MAC and smart antenna in the DDAS system. Beside, the driver of LCD panel is optional in our software system.

4. DEMONSTRATIONS AND FUTURE WORKS

Figs. 15 and 16 shows how the DDAS provides driver the information of directions/distances to nearby vehicles, and the reason it can help avoiding car accident.

There are some other attractive applications if one extends the usage model of proposed DDAS. One important application is the guiding system. Taking parking car for example, assume that the road-side-units (RSUs) are installed in every parking space of
parking lot as shown in Fig. 17. The RSU of a parking space will keep broadcasting wireless signals if its space is available. On the other hand, the on-board-unit (OBU) on vehicle, which is looking for parking space, can easily find out the direction and distance to any free parking space via tracking the signals sent from RSUs. One more interesting application is to guide the plug-in Hybrid Electric Vehicle (HEV) in order to find the charging place while parking in an unfamiliar parking lot. We believe that, in the near future, the automatic charging could be done by vehicles themselves.
In summary, the novel features and technical innovations of proposed DDAS are highlighted as followings:

1. Smart antenna is used for DDAS. It does not need any complicated installation.
2. The DDAS is plug-and-play system.
3. The DDAS can detect all the vehicles within the wireless coverage area no matter whether vehicles hiding behind some obstacles.
4. The detection range of DDAS is wider and longer than traditional methods.
5. The scanning and updating latency of DDAS is very fast.
6. The DDAS uses the ubiquitous IEEE 802.11/802.15.4 wireless NICs. The proposed DDAS not only provides low hardware cost solution but also guarantee the interoperability among OBUs and RSUs.

5. CONCLUSIONS

The novelty of proposed DDAS is to integrate the smart antenna and IEEE 802.11/802.15.4 MAC/Baseband to achieve the goal of neighborhood detection and positioning. The DDAS keeps its eyes on monitoring its neighboring vehicles all the time. It controls the angle and range of smart antenna to find out the direction and distance to the other vehicles which have the same system. The scanning process in wireless network is very fast and the position update latency is much shorter than humans’ response time. Moreover, the proposed method is quite difference from the traditional positioning approach such as ultrasonic and infra-red that are restricted by the light-of-sight constrain. Our method using IEEE 802.11 OFDM or IEEE 802.15.4 DSSS technique can easily recognize all the information from vehicles including the hard detectable vehicles behind the neighboring vehicles. So, we name our system as the omni-detector DDAS.

REFERENCES

1. S. Biswas, R. Tatchikou, and F. Dion, “Vehicle-to-vehicle wireless communication

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