Design of Vehicle Control System Based on Bluetooth Low Energy Smartphone Platform

Xia Kun, Xu Xinyue, Wang Nan
School of Optical-Electrical and Computer Engineering,
University of Shanghai for Science and Technology, Shanghai, China
E-mail: xiakun@usst.edu.cn

Abstract — A vehicle control system based on Bluetooth 4.0 on smartphone platform is designed in this paper. The system uses Apple iPhone4s and TI CC2540 which supports BLE (Bluetooth Low Energy) specification to realize short-range communications. On the one hand, vehicle BCM (Body Control Module) with CC2540 collects the car information by CAN in real-time. On the other hand, the smartphone connects CC2540 to control the vehicle and to display the information on smartphone interface using BLE technology. The Apple iPhone4s' application is on the base of X-code4.5 development platform with iOS6. The experiments show that the control system has a good performance and a broad prospect of application in short-range communication.

I. INTRODUCTION

With the development of information technology and the popularity of smartphone, people put forward a higher request for more convenient living style. There is no doubt that lower power consumption and faster transmission speed are the future development direction in the field of wireless communication.

In June 30, 2010, Bluetooth Core Specification Version 4.0 was announced by the Bluetooth SIG, which has the key features of ultra-low peak, average and idle mode power consumption, low cost and enhanced communication range [1]. Bluetooth low energy consumption is far less than the traditional Bluetooth, and as a result, the device can run several years with a button cell. Bluetooth 4.0 technology will be used further in the fields of health care, sports and fitness, vehicle and home entertainment [2].

The CC2540 is a cost-effective, low-power, and true system-on-chip solution for Bluetooth low-energy applications. The CC2540 combines an excellent RF transceiver with an industry-standard enhanced 8051 MCU, in-system programmable flash memory, 8-KB RAM, and many other powerful supporting features and peripherals. The CC2540 is suitable for systems where very low power consumption is required [3].

IPhone 4s, one of the most popular mobile phone, supports for Bluetooth 4.0 wireless technology. According to a built-in Bluetooth chip, IPhone4s can act as a master or slave node in the communication net [4] [5].

This paper demonstrates a project about how to control a car through an IPhone4s running on an Apple application conveniently. The system embedded Bluetooth 4.0 achieves the purpose that users can use Iphone4s to complete the operation of starting the car and the acquisition of vehicle information without using a traditional key.

II. SYSTEM STRUCTURE

A. System structure design

As shown in figure 1, the intelligent control system is composed of three parts which are Apple iphone4s, BCM with a Bluetooth chip and vehicle simulated system.

BCM can transmit data to iphone4s by Bluetooth4.0, and at the same time, it monitors the vehicle parameters and gets the information back via CAN transmission. The Bluetooth chip, Texas Instruments CC2540, supports the version 4.0 of the Bluetooth and passes the Apple's MFI (made for iPhone) verification. IOS5 embedded with CoreBluetooth.Framework provides BLE API interfaces and protocols [6]. Through a visual interface, users can be convenient to know about the vehicle working states and control it without any traditional keys.

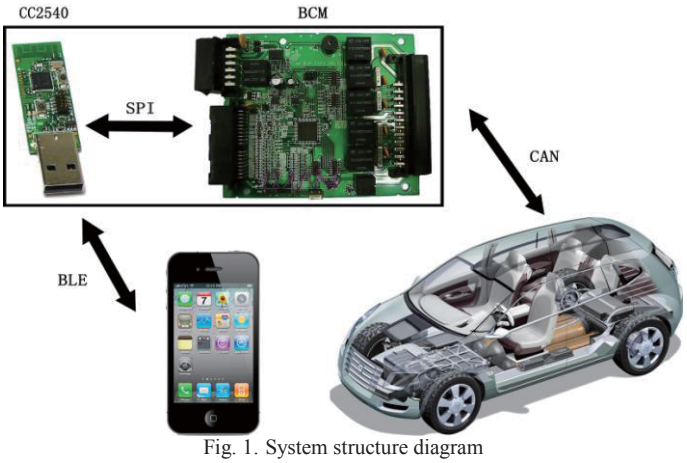

Fig. 1. System structure diagram

B. Bluetooth low energy

Bluetooth wireless technology is a wireless communication system which intended to replace the cables connecting electronic devices. The key features of the technology are robustness, low power consumption and low cost [1].

Version 4.0 of the Bluetooth standard allows for two systems of wireless technology which are Basic Rate (BR) and Bluetooth low energy. A "dual-mode" device can support BR and BLE at the same time such as a mobile phone or computer. Correspondingly, devices that only support BLE are referred to as "single-mode" devices. These single-mode devices are used for application in which low power consumption is a primary cost such as key or headset.

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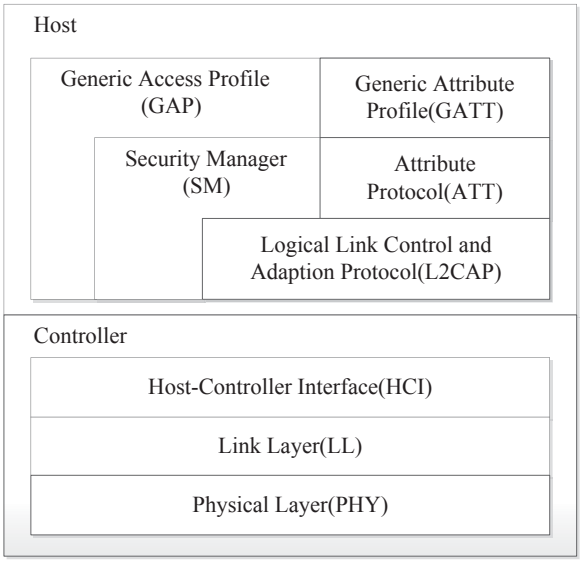

Fig. 2. BLE Protocol Stack

As shown in figure 2, the protocol stack is composed of two sections which are the controller and the host. This separation of controller and host goes back to standard Bluetooth BR/EDR (Enhanced data rate) devices, in which the two sections were often implemented separately. Any profiles and applications that are being used sit on the top of the GAP and GATT layers of the stack [7].

The physical layer is a 1Mbps adaptive frequency-hopping GFSK (Gaussian Frequency-Shift Keying) radio operating in the unlicensed 2.4 GHz band. It had 3 fixed advertising channels for broadcasting and 37 adaptively frequency hopped dynamic data channels.

The link layer controls the Radio Frequency (RF) states of the device. The device has five possible states: standby, advertising, scanning, initiating and connected. Advertisers transmit data without being in a connection, while scanners listen for advertisers. An initiator can scan the advertisers nearby and respond them with a connection request. If the advertiser accepts, both the advertiser and initiator will enter a connected state. One device can also act as multiple roles at the same time.

The HCI layer provides the communication between the host and controller via a standardized interface. This layer can be implemented through a software API or a hardware interface such as UART, SPI, or USB.

The L2CAP layer provides data encapsulation services to the upper layers, allowing for logical end-to-end communication of data.

The SM layer defines the law for pairing and key distribution, and provides functions for other layers of the stack to securely connect and exchange data with another device.

The GAP layer directly controls the application and profiles, handles device discovery and connection-related services for the device. The initialization and status control of the device can also be done by GAP layer's commands.

The ATT protocol allows a device to expose certain pieces of data to another device. In the context of ATT, the device exposing attributes is referred to as the "server", and the peer device is referred to as the "client". The LL state of the device is independent of the ATT role of the device. So, a master device may either be an ATT server or an ATT client, and a slave device also may be one of ATT server or client. It is also possible to be both an ATT server and an ATT client for a device simultaneously.

The GATT layer is a service framework that defines the sub-procedures for using ATT. GATT specifies the structure of profiles. All pieces of data that are being used by a profile or service are called "characteristics". A characteristic can be set by his properties, value and descriptor. All data communications occur between two devices in a BLE connection are handled through GATT.

C. Design of Hardware

Freescale Mc9s12xs128 is used to control the vehicle on BCM as main control chip, which delivers 32-bit performance with all the advantages and efficiencies of a 16-bit MCU while retaining the current advantages of low cost, low power consumption, EMC and code-size efficiency [8]. The chip transmits data to PC via CAN and to CC2540 via SCI.

The CC2540 combines an excellent RF transceiver with an industry standard-8051 MCU, enhanced the programmable flash-memory, 8 KB RAM, and many other powerful supporting the features and peripherals. It is embedded an OSAL (Operating System Abstraction Layer) systems internally, which adopts an events chain to manage the corresponding task of each protocol stack. Each event in the list is a structure and is used to record the basic information of the task in the list. The list is set up according to the task priority, and a higher priority task will be inserted into the front of low priority tasks. According to the API function on HCI layer, on the one hand, CC2540 can control the physical layer to perform a variety of Bluetooth communication, such as initialization of master or slave, devices discovery, broadcast and so on; on the other hand, the feedback of the physical layer will be sent to Host by different events. Through analyzing these different events, we can know the working status of Bluetooth chip and make corresponding actions.

D. Design of Software

Since November 2011, Apple Inc. has released the iOS5.0.1, added the CoreBluetooth.Framework, to support BLE interface and protocols. The device can complete the functions including searching and connecting another BLE device, reading or writing the messages. Then in November 2012, Apple Inc. released iOS6.0, the device can become a master or slave, advertising or updating the UUID and local data according to different situation.

Program is designed on Xcode4.5.2 development platform. As shown in figure 3, the interface can be edit via Storyboard much more conveniently. The user constraints make the program compatible with 3.5 inch and 4 inch screen. The final program includes five parts which are entrance, vehicle control, vehicle detection, information display and map.

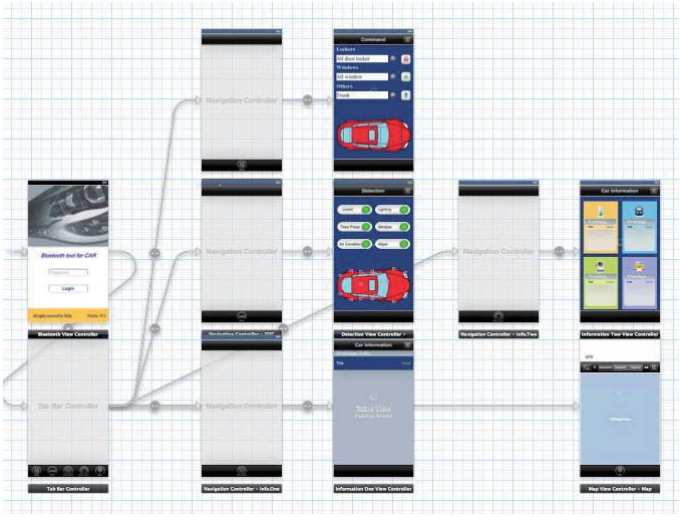

Fig. 3. Storyboard

Its function can be concluded as follows:

1) The data is stored with AES-128 encryption algorithms. IPhone will update the data when connecting. User is not allowed to enter the main program until inputting the right passwords. Otherwise the error message will appear.

2) IPhone 4s can scan and set a connection with CC2540 automatically, and then the mobile may control the car doors, windows, trunk, lights and other parts.

3) If some faults occur, the program will be alert, and the interface will show a warning sign in according position.

4) After refreshing the data, users can immediately get the vehicle information, including vehicle distance, battery level of car and the key, tire pressure, fuel capacity, temperatures, engine speed, etc.

5) On the map, the current phone location and the latest parking location can be shown on the screen.

6) When the program comes into sleep mode, the program will save the current vehicle information. So the program can be inquired next time conveniently.

The Bluetooth communication program flow diagram is shown in figure 4.

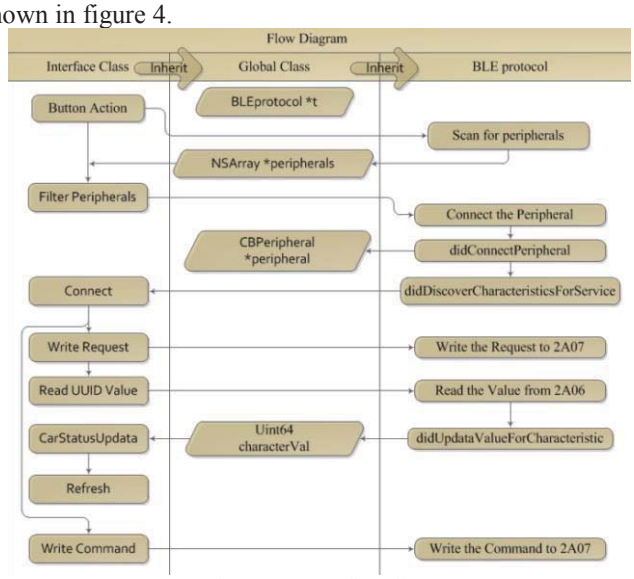

Fig. 4. Program flow diagram

III. RESULT

As the Bluetooth master, the iphone4s can scan surrounding BLE peripherals and record their UUID so that the peripherals can be connected next time automatically. If the connection were established, the mobile phone would begin to update current vehicle information and send command or request bases on the transfer protocol.

According to the command or request, CC2540 will take corresponding measures. In the entire process of request, the data will be transferred for five to ten times in order to ensure its reliability. The time of command response is within 2s, while its request response is within 4s. Finally, both sides will execute the disconnect operation so that the CC2540 runs into low power consumption mode and other equipment can take communication with it.

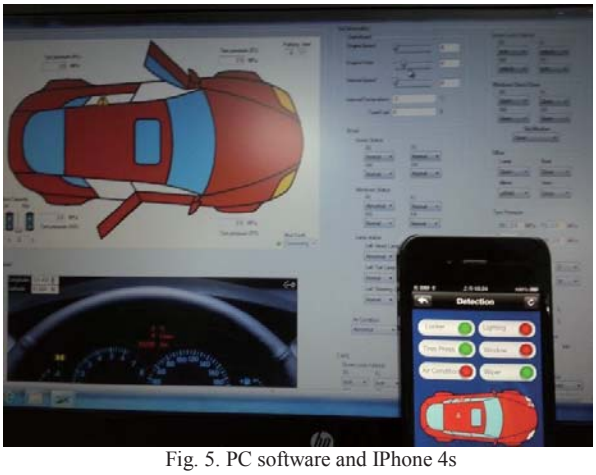

Fig. 5. PC software and IPhone 4s

As shown in figure 5, the vector CANoe PC software can simulate and send information to the BCM via CAN, including the parameters about vehicle doors, windows, trunk, mirrors and some switches, as well as vehicle fuel, tire pressure, etc. At the same time, the software also can be used to simulate every device's failure state, and then send the information to the IPhone.

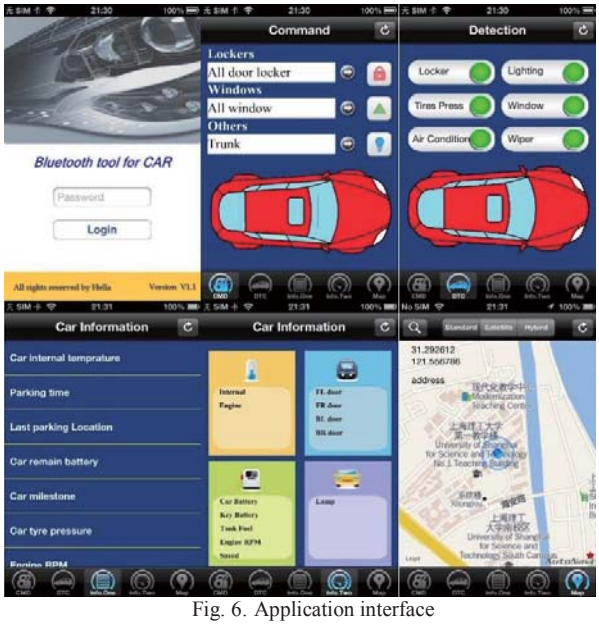

Fig. 6. Application interface

The application interface is shown in figure 6. In the outdoor space, the farthest distance of communication is 15 meters. Communication distance could be increased by optimization of the Bluetooth antenna and setting a high-power level.

IV. CONCLUSION

This paper proposed the design of vehicle control system based on Bluetooth 4.0 in smartphone platform. The system embedded Bluetooth 4.0 achieves the purpose that user can use iphone4s to complete the operation of starting the car and the acquisition of vehicle information without key. The system has the advantage of the low power consumption and can be used in many applications in short-range communication.

V. REFERENCES

[1] Specification of the Bluetooth System, Covered Core Package Version: 4.0, Bluetooth SIG, July 2010.

[2] Elke Mackensen, Matthias Lai, Thomas M. Wendt, "Performance Analysis of a Bluetooth Low Energy Sensor System", Wireless Systems (IDAACS-SWS), 2012 IEEE 1st International, Page(s): 62 - 66, 2012.

[3] Texas Instrument (Pub.): Texas Instruments CC2540 Bluetooth Low Energy Texas Instruments Inc., "2.4-GHz Bluetooth low energy System-on-Chip, CC2540", October 2010.

[4] Chandra Fernandes, Kok Yew Ng, Boon How Khoo, "Development of A Convenient Wireless Control of An Autonomous Vehicle Using Apple iOS SDK", TENCON 2011 - 2011 IEEE Region 10 Conference, Page(s): 1025 - 1029, 2011.

[5] Bin Yu, Lisheng Xu, Yongxu Li, "Bluetooth Low Energy (BLE) Based Mobile Electrocardiogram Monitoring System", Information and Automation (ICIA), 2012 International Conference, Page: 763 - 767, 2012.

[6] Core Bluetooth Framework Reference, Apple .USA, 2010.

[7] Texas Instruments CC2540/41 Bluetooth Low Energy Software Developer´s Guide. V1.0, Texas Instrument (Pub.), 2010.

[8] MC9S12XS256 Reference Manual, Freescale Semiconductor Japan Ltd., 2009.