Cannon: A Pocket Laboratory for the Experiment of Short-Range Wireless Communication Course

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Abstract. The widespread use of short-range wireless communication technology in many areas requires students who major in electronic engineering to have a basic understanding of the technology. Therefore, there is a necessity to strengthen experimental teaching in short-range wireless communication course. This paper presents a pocket laboratory named Cannon for the above course, which will be taught at the second or third semester of the department of electronic engineering in Changzhou Institute of Information Technology. Cannon is used to introduce to students the basic application implementation methods of Bluetooth Low Energy (BLE) communication practically. Cannon not only contains a complete Bluetooth intelligent hardware system, but also has its own JUMA SDK, a BLE application development framework developed by JUMA Technology. The feedback from students shows that Cannon can make their learning process faster and encourage them to acquire the skills necessary to accomplish the BLE application.

Keywords. Short-range wireless communication course; experimental teaching; bluetooth low energy; JUMA SDK.

1. Introduction
Experimental teaching plays a more and more important role in engineering course. With experiments, students can put theoretical knowledge into practice. The practical ability, innovation awareness, critical thinking can be cultivated through the experiment training.

The concept of the pocket laboratory [1-3] was introduced into China by Texas Instruments and Xilinx China University projects in recent years, and with reference to various powerful small development boards, it advocates a new experimental teaching mode with limited time and space. It provides students with a mini experiment box, which shrinks the original experimental equipment [4]. Thus it is convenient for students to carry and can even be put into their pockets. The box size also minimizes the limitation of experimental space. Even more, the pocket laboratory also has rich software and hardware resources. Many universities have cited and promoted pocket laboratories for teaching [5]. Pocket laboratory has been highly recognized by teachers and students.

At present, many universities have used pocket laboratory for their teaching. The course “The use of MCU to expand ARM Cortex-M4 MCU” [6] in Tsinghua university provides lots of hardware boards which are the prototype of pocket laboratory. In Xi’an Jiaotong University, the digital electronic technology course [7] is equipped with one pocket experiment board per student. The operating method of all above courses is to provide students with pocket laboratory during the course time, and the equipment is returned before the end of the course. This leads to low resource utilization because only...
students participating in the course can take advantage of pocket experimental resources, while others cannot.

To solve above-mentioned problems, Changzhou Institute of Information Technology (CCIT) has teamed up with JUMA Technology to jointly develop a pocket laboratory named Cannon for experimental teaching. The experimental course of short-range wireless communication is learned by second-year students at the department of electronic engineering, CCIT. We choose BLE [8] as the representation of short-range wireless communication technology in that course. To develop students’ abilities to understand theoretical knowledge and master basic skills in development of BLE applications, we provide not only free samples, integrated SDKs, but also free workshops and technical support from JUMA Technology. All of the experimental resources have been integrated into Cannon, thus students can get Cannon at any time in campus.

2. System Design
In order to make preparation for the experimental teaching resources, the first question we face is that what BLE is used for. As the development of smart home and intelligent systems, more and more sensors are widely used. We know that the amount of data from sensors is usually small, requiring low communication speed which is exactly the advantage of BLE communication. Therefore, we combine BLE and environmental sensors together for experiment [9].

2.1. Hardware
Cannon is a compact, power-optimized, multi-sensor device designed for collecting environmental data of various types. It is an easy-to-use learning platform, designed to help students master the development of application based on BLE, with the understanding of short-range wireless communication from a practical point of view. This part focuses on the hardware components of Cannon with detailed descriptions of the various hardware blocks.

As a complete Bluetooth intelligent hardware system, STM32F401 [10] functions as the brain of Cannon. STM32F401 SoC consists of a 32-bit ARM Cortex-M4F MCU, 96KB RAM, 512KB non-volatile flash memory. Figure 1 shows a number of devices especially suitable for IOT are arranged: BLE network processor BLUENRG-MS [11], gyroscope and accelerometer 2-in-1 chip LSM6DS3, atmospheric pressure sensor LPS25HB, temperature and humidity sensor HTS221, magnetic force and acceleration 2-in-1 sensor LSM303AGR. It should be noted that all of above sensors are interfaced over I2C (Inter-Integrated Circuit), to the STM32f401 core.

BlueNRG-MS, a single-mode BLE network processor, is based on Bluetooth Specification v4.2 from STMicroelectronics. In order to communicate with Bluetooth-enabled devices, it is connected to the STM32f401 core over SPI (Serial Peripheral Interface).

Figure 1. Top view of the circuit board.
As for input and output interface, Cannon has two LEDs and one reset button. One LED is controlled by STM32F401 for the application use. The other LED is linked to the power supply to indicate when the power is on. Instead of JTAG, SWD interface is preferred for programming and debugging because only two pins are needed. The system uses an LDK130M33R DCDC (DC to DC) converter that converts any voltage source from 2.5V to 5.5V to the required 3.3V efficiently. Therefore, the converter supports multiple options, including a 3V coin cell battery (e.g. CR2032), a 3.7V rechargeable lithium polymer battery (Li-Po) and super capacitors. The SD card slot is used for the storage of filesystem or numerous data form different sensors.

Figure 2 shows the printed circuit board (PCB) of Cannon, with dimensions of 60mm × 40mm, which is the same size as a credit card. It is really convenient for students to carry and can even be put into their pockets.

2.2. Framework

In the actual development process, some uncertain factors will make the development cycle difficult to estimate. For example, for key technologies such as how to extend the battery life of Bluetooth products, how to establish a highly reliable Bluetooth connection, and Bluetooth compatibility of mobile terminals are usually annoying.

Moreover, we find that it often takes students too much time to learn the BLE technology itself, such as reading the datasheet or reference manual of a new Bluetooth chip, or being familiar with the Bluetooth API documentation for Android or iOS.

For above reasons, the original invention of the SDK called JUMA SDK is designed for Cannon to solve these problems. We manage to create the most simple and easy-to-use BLE application development framework, freeing students from Bluetooth Specifications. The JUMA SDK is divided into two parts: an embedded SDK and a mobile SDK.

As shown in table 1, the embedded SDK consists of JUMA Embedded Platform and JUMA PRC Profile. JUMA Embedded Platform layer is aim to use programming interface provided by the chip manufacturer, such as ST SDK and its register programming interface. It also modulates the common functions required by a large number of intelligent hardware, covering peripherals such as UARTs, ADCs, buzzers, LEDs, OLEDs, G-Sensors, etc. It also supports customized applications in a range of scenarios, such as iBeacon [12], thermometer, pedometer, sphygmomanometer, etc. Students can quickly complete solution verification and flexibly customize application requirements. Table 1 shows the hierarchical relationships in internal implementation architecture of the embedded SDK.

In addition to peripheral driver and application configuration support, our embedded SDK also has some functions and features such as: more embedded task scheduling, low power management, cloud message forwarding, algorithm aggregation, etc. All of these characteristics are more suitable for the development of Internet of Things.

Table 2 shows the hierarchical relationships in internal implementation architecture of the mobile SDK. The mobile SDK has API interfaces for Android and iOS. It is used in conjunction with the above-mentioned embedded SDK. Compared with the native BLE interface of Android or iOS, it can
ensure more stable and effective Bluetooth interconnection and interoperability operations. Students no longer need to consider BLE-specific concepts such as service, characteristic, and notification.

### Table 1. Internal implementation architecture of the embedded SDK.

| Embedded ROM                  | JUMA PRC profile  |
|-------------------------------|-------------------|
| JUMA embedded platform       |                   |
| Application components        | Power management  |
| Hardware abstraction layer    |                   |
| Bluetooth API                 | Embedded device driver |
| Embedded bluetooth stack      | Peripherals       |
| SOC                           |                   |

### Table 2. Internal implementation architecture of the mobile SDK.

| Embedded ROM |
|--------------|
| Android API  |
| IOS API      |
| Javascript API|
| Web interface|
| Middleware   |
| Local data store|
| OS bluetooth API|
| Bluetooth stack|
| Bluetooth adaptor|
| GPRS/3G/WiFi network|

In addition, the Javascript API interface of the mobile SDK is being implemented and can be directly called by HTML5 mobile applications in the future. This is a cross-platform BLE encoding method. We will also support APICloud, Cordova, CrossAPP and other plug-ins in order to provide richer cross-platform development support.

### 3. Experimental Arrangement

The experimental course is sophisticatedly organized and performed with one Cannon per student. The students are encouraged to work in groups to discuss problems about hardware or software while they do their exercises. However, each student should answer the teacher’s different questions individually to earn his or her own score.

#### 3.1. Overall Scheme

Beginning with the JUMA SDK, peripheral device drivers and sample applications have been merged into one. As shown in figure 3, through the documentation overview, the SDK provides quick start guides, porting and migration guides. Students can take advantage of entry-level applications such as peripherals, central devices, broadcasters, observers. These foundation projects are templates for students to start developing and customizing their own BLE applications [13].

The workflow in figure 3 can be divided into four stages. The first stage “Demo” is helping students rapidly establish link between Cannon and a phone, blinking LED, etc. Thus, students can get the intuitive comprehension of BLE communication and see what happened. The second one “Learn” provides ready-to-use training materials for students who are new to BLE. Learning interest can be further prized in this stage. The third one “Develop” describes how to use the development platform to create fantastic and reliable applications. The last one “Enhance” is additional information/sample apps not contained in SDK. More advanced projects are also supported, such as multi-role, wireless
download (OAD) [14] and Eddystone [15], an open Bluetooth low energy beacon format provided by Google. The concrete projects designed for the Cannon are listed as following:

- Bluetooth Low Energy Fundamentals: Setting up the development environment, running Project Fisrt using PC tool such as Sniffer, changing the advertisement name or characteristic data.
- Scanning and Advertising: topic on how to use the advertising and scanning features of the ST BLE-Stack with example code.
- Connections: An overview of how to set up Bluetooth low energy connections suited to developers’ needs. Explanation of key concepts such as master-slave and connection parameters.
- BLE Enhanced OAD: Learn about the fundamentals of ST's Over the Air Download (OAD) solution. Topics include performing an OAD, factory images, adding OAD to existing projects, and advanced OAD debugging techniques.
- BLE Security Fundamentals: Learn about the fundamentals of BLE security such as pairing, bonding and privacy.

3.2. Key Point

Students can take advantage of the Bluetooth Developer Studio [16] ST plug-in. In addition to the existing applications included in the SDK and sample packages, Cannon also supports the Bluetooth Developer Studio of SIG. That is a GUI-based environment that helps developers quickly build any BLE profile. For example, if you are generating a scalable profile, you can take advantage of the ST plug-in in Bluetooth Developer Studio to generate source code to reduce development time. Figure 4 shows the actual interface with three accomplished profiles in Bluetooth Developer Studio.
4. Questionnaire Feedback
In the final of the course, an online survey about teaching and learning assessment was conducted. Table 3 shows the students’ feedback on the five questions was really positive. Most students (83%) agree that they are motivated by Cannon to learn these skills and theories. The feedback also shows that students were happy to have joined the project and written their own codes.

Table 3. Students’ feedback on the questionnaire.

| Questions                                                                 | Average   |
|---------------------------------------------------------------------------|-----------|
| The pocket laboratory can effectively change the previous way of my learning. | 4.15 (1-5) |
| The project is sophisticatedly designed and interesting enough for me to understand difficult theories. | 4.02 (1-5) |
| It is more helpful for me to make the hands-on project, because each step can be performed and acquired in the learning process. | 4.31 (1-5) |
| I would like to buy Cannon for further learning.                           | 3.32 (1-5) |
| The project-based pocket laboratory makes my learning efficiently.        | 4.30 (1-5) |

5. Conclusion
A low cost but versatile educational pocket laboratory named Cannon jointly devised by Changzhou Institute of Information Technology and JUMA Technology is presented in this paper. Cannon is a project oriented learning platform for the experimental course of short-range wireless communication. Several important components about Cannon are devised to help students learn the development of BLE application. They include (1) hardware analysis, (2) JUMA SDK framework overview, (3) workflow design for the course, (4) concrete projects. Because the schematic of Cannon is open source, it is strongly recommended that every student can have his/her own pocket laboratory and quickly learn the techniques in accomplishing the application of BLE. The students’ feedback shows that Cannon stimulate students’ interest effectively, and therefore encourage them to learn related theory and skills more actively.

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