Demonstration Abstract: An 8×8 mm^2 Bluetooth Low Energy Wireless Motion-Sensing Platform

Tong Kun Lai[†], Anping Wang[†], Chun-Min Chang[†], Hua-Min Tseng[†],
Kailing Huang[†], Jo-Ping Li[†], Wen-Chan Shih[‡], Pai H. Chou[*†], Wen-Tsuen Chen[‡]
[†]Department of Computer Science, National Tsing Hua University, Taiwan
[‡]Institute of Information Science, Academia Sinica, Taiwan
[*]Center for Embedded Computer Systems, University of California, Irvine, USA
Email: {tongkunlai, csiewap, tangent7787, thm822, gugigugi323, zeroping.tw, teddyshihau, pai.chou}@gmail.com
chenwt@iis.sinica.edu.tw

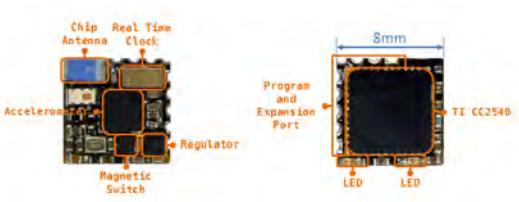
***Abstract*—This demo presents the world's smallest wireless motion-sensing platform based on Bluetooth 4.0 Low Energy (BLE) Technology. It is merely 8×8 mm^2 in area but is complete with a user-programmable microcontroller and integrated RF, a digital triaxial accelerometer with programmable threshold detection, and a real-time clock and calendar chip, and a magnetic sensor/switch. This system has been used in a number of applications, including a proximity tag, a pedometer, an air mouse with gesture recognition, and a BLE-to-IR remote controller.**

I. Introduction

Bluetooth 4.0 Low Energy (BLE) Technology is a new RF protocol that has gained significant momentum in the past year. Its low average current consumption of 15 μA and low peak current of 15 mA enable it to last for one year on a CR2032 coin cell battery. Moreover, it has the advantage of being directly compatible with smartphones and tablets, collectively called smartmobiles, without requiring a dongle or a gateway. This makes possible a new generation of wireless sensor networks (WSN) that interact directly with the user instead of operating in their isolated, bridged networks.

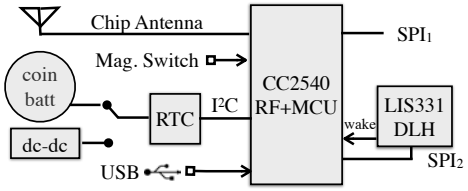
There are not many BLE platforms available to date. Two that come closest are RFduino [1] and Bluegiga's BLE 113 [2]. The former is is based on the Nordic nRF51822 single-chip Cortex M0-based MCU with integrated RF. As an Arduino board, this means it can take advantage of the programming tools, source code, and expansion modules called Arduino shield. While RFduino is good for functional prototyping, it is still too large as a deployment platform for many wearable applications. The latter is based on the TI CC2541 and measures 16 $\times$ 8 mm^2, which is twice our area but without any sensors built in.

Our contribution is that we are the first to bring a truly miniature BLE-based mote to the community. It is part of a development kit that includes software tools, libraries, and template code for smartmobiles and PCs. The whole kit is expected to enable the rapid development of a wide range of WSN applications that work closely with smartmobiles, without having to re-invent yet another hardware board with all the sensing features.

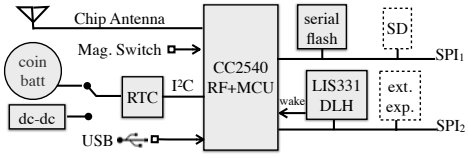


(a) Mini node

(b) Full-sized Top (c) Full-sized Bottom



(d) Mini node block diagram



(e) Full-sized node block diagram

Fig. 1: Mini node and Full-sized node

II. System Overview

A. Node Hardware

The mini node is shown in Fig. 1a. Measuring 8×8mm^2, whose block diagram is shown in Fig. 1d, it contains not only a BLE-enabled MCU but also a triaxial accelerometer, DC-DC converter, magnetic switch, and an RTC. The miniature form factor is made possible by using newly available miniature components and 4-layer PCB design.

The full-sized node is shown in Fig. 1b, with the block

(a) Proximity Tag (b) BLE pedometer worn on the user's waist (c) BLE node as an air mouse (d) IR-Remote

Fig. 2: Applications of our BLE motion-sensing platform.

diagram in Fig. 1e. It is built to be primarily a development platform. It uses the identical MCU, accelerometer, and RTC as the mini mode, making it possible to develop code on full-sized node more conveniently and then port code easily over to the mini node. In addition, it contains the expansion ports necessary for a wide variety of applications that are not stringently size-constrained. It includes on-board sensors and nonvolatile storage so that it is a self-contained unit that is usable even without adding any expansion modules.

B. Expansion Port

The expansion port based on the Molex SlimStack board-to-board connector. The connector contains the following: SPI, I^2C, USB, GPIO, UART, power supply to the expansion module, firmware programming interface and analog inputs. The mini node also provides expansion ports in the form of PCB edge connector with the following: GPIO (the same pins as UART), SPI, programming pins, and USB D+ and D−. The full-sized node also includes a 2MB on-board serial flash plus a MicroSD slot for data logging.

C. Software: Library, BLE Service, and Runtime

We implement BLE services and interfaces as C-based libraries for the triaxial accelerometer, RTC, SPI, I^2C, USB, GPIO, and UART. Specially for the RTC and digital accelerometer, we provide their BLE profiles so that any BLE device that implements the standard profiles can readily connect to the node to get RTC or accelerometer services without having to install any extra hardware or driver.

To take advantage of the BLE stack, currently one must use the IAR C/C++ compiler to link in the stack (binary) and compile it with the OS abstraction layer (OSAL, available in source) by TI.

III. Demo Applications

We propose to demo the following real-world applications that were built using our mini and full-sized nodes.

A. Proximity Tag

The 8×8 mm^2 size of the mini mode makes it particularly suitable as a proximity tag as shown Fig. 2a. It not only is the smallest tag to date but also can sense triaxial acceleration and has an RTC-calendar chip. A proximity tag works by first pairing the tag with a smartmobile, and both sample each other's RSSI value. When the RSSI drops below a threshold, the tag or the smartmobile (or both) can generate an alert.

B. Pedometer

BLE is now the RF protocol of choice for health and fitness applications, including heart-rate monitors, pedometers, and blood pressure meters. The same proximity tag can also work as a pedometer, but we have chosen to implement it on the full-sized node to enable data logging to flash memory, as shown in Fig. 2b. The pedometer takes advantage of the accelerometer's built-in threshold detection and the BLE connection parameter to saving power. The MCU can enter sleep mode and be waken on an external interrupt, enabling it to save over 80% of energy while keeping the sensitivity and specificity above 95%.

C. Air Mouse with Gesture Recognition

Our BLE node can be worn on a finger to work as an air mouse with gesture recognition. As shown in Fig. 2c, it has a button that, when held, causes the MCU to recognize gestures, and when released, indicates tracking the gravity vector such that tilting the finger moves the mouse cursor on the computer's screen. Thanks to the direct compatibility with computers using BLE's HID profile, it does not require driver installation.

D. IR-Remote Controller

Using the expansion port connector, we can make our BLE node work as an IR-remote controller for smartmobiles that cannot emit IR signals directly. The smartmobile would pair with the BLE node, which is augmented with an IR transmitter to emit remote-control code. By adding an IR photo diode, our BLE node can also learn remote-control code emitted by any conventional IR remte control. Fig. 2d shows a smartphone app controlling a karaoke machine via our BLE node. In addition to providing a software version of the remote, it also provides a phonebook-like interface to allow the user to choose songs without having to lookup and dial the song code each time.

Acknowledgment

This work is sponsored in part by Ministry of Economic Affairs (Taiwan) 98-EC-17-A-04-S1-044 and National Science Council (Taiwan).

References

[1] "RFduino," http://www.rfduino.com/.

[2] Bluegiga Technologies, "BLE113 Bluetooth Smart Module - Bluegiga," https://www.bluegiga.com/en-US/products/bluetooth-4.0-modules/ble113-bluetooth--smart-module/.