The Use of Bluetooth Low Energy Smart Sensor for Mobile Devices Yields an Efficient Level of Power Consumption

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***Abstract*—Mobile devices, such as smartphones and tablets have already become an integral part of our lives. For example, they are widely used throughout society with several applications in various business sectors which include smart houses, irrigation systems, healthcare and many more. This paper proposes a method to improve the use of smartphones with a smart wireless sensor network acquisition system through Bluetooth Low Energy (BLE). A new BLE Smart Sensor, which acquires environmental data was designed. This can be used with normal android devices (Smartphones, Tablets) to collect information from a smart sensor. Moreover, a BLE acquisition algorithm was successfully implemented on the firmware of the device.**

Keywords-Bluetooth Low Energy; Wireless Sensor Networks; Smartphone applications.

I. INTRODUCTION

The Internet has become an integral part of everyday life and this is expected to herald a new era of Internet expansion known as the Internet of Things (IoT). Instead of being controlled by human beings, sensors, actuators and appliances will work directly to measure and respond to a wide variety of data such as temperature, how much power is consumed, or body functions such as blood pressure or heart rate [1][2].

Wireless sensor networks (WSN) are a relatively new and fast developing area of IoT applications, which can provide processed real time data acquisition from sensors distributed in remote areas. The sensor nodes deployed on the specific places measure various environmental parameters. These measurements can help in making decisions on irrigation (automating, semi automating), fertilizer and pesticide applications, intruder detection, pest detection, yield prediction, plant disease prediction [3][4][5][6]. Hardware is currently an active research area carried out in universities around the world and in private companies. The possibilities in this field are endless due to the increasing demand to look for new sensors for different applications, the advances in miniaturization, components to be integrated, or new features to save energy. In this sense, WSN technology is clearly the most promising candidate to significantly improve automation systems of specific areas or places. In combination with low-cost communication modules and Bluetooth Low Energy (BLE) sensor motes, the new lower overall costs of WSN for smartphone applications are driving the possibility for more cost-effective applications than previously reported [7].

BLE is expected to appear in billions of devices and sensors in the next few years. The issue of power consumption of the remote devices is one of the main issues of today's IoT applications; therefore, in December 2009 it was introduced by the Bluetooth Special Interest Group to address this. The main feature of BLE is the Bluetooth specification v4.0. It is a new protocol which allows for long-term operation of Bluetooth devices that transmit low volumes of data. It enables smaller form factors, better power optimization, and the ability to operate on a small power cell for several years [8].

A different approach was used in [9], where several sensors used with different structures. In fact, increasing the number of distributed sensors maximizes the lifetime of the network, since more failures can be tolerated; this tackles the power consumption challenge. Another advantage of applying more sensors at the same time is an increased reliability of the network. The smartphone application manages the sampling frequency and the method of connection between sensors using an independent communication with each sensor, without the need for multi-hop routing to gather environmental information. The data is gathered and analyzed directly by the smartphone application. A new device was developed for data acquisition and improved android application [9] with the possibility of acquiring data from several sensors at the same time. However, hardware design and power consumption was far from optimal.

In this paper, the authors designed a completely new device which has the benefits of low cost and low power consumption using BLE technology. Moreover, we developed a new android application with the ability to communicate with BLE devices (see Fig. 1.).

The rest of this paper is organized as follows. Section II describes the hardware design and algorithm of the android application. In Section III we present the cover box of temperature and humidity acquisition system. Section IV discusses the future work and new ideas. We close the article with acknowledgements.

II. METHODS

A. Bluetooth Low Energy Smart Sensor

The authors of [9] presented Classic Bluetooth based temperature and humidity acquisition system. They used low power components but most of the power consumption was due to the classic Bluetooth module. The power consumption of the classic Bluetooth is 26 mW while it is waiting connection and 90mW during the transmission [9]. Concerning the power consumption of the device a new BLE based temperature and humidity device was designed.

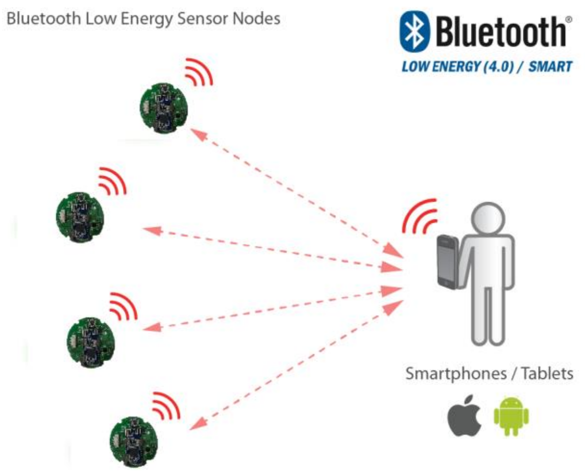

Figure 1. BLE-based wireless sensor network to collect environmental data for smartphones.

In order to reduce power consumption on the hardware part, we used a low power temperature and humidity sensor (SHT21 from Sensirion, temperature range from -40 to +125°C and accuracy of 0.3°C, humidity range from 0 to 100% and accuracy of 2%) [18]. The I2C protocol is used to communicate between sensor and microcontroller. For this system, a MSP430G2553 microcontroller from Texas Instrument MSP430 family has been selected. It is an ultra-low-power microcontroller. The architecture, combined with five low-power modes, is optimized to achieve extended battery life in portable measurement applications. The device features a powerful 16-bit RISC CPU, 16-bit registers, and constant generators that contribute to maximum code efficiency. The digitally controlled oscillator (DCO) allows wake-up from low-power modes to active mode in less than 1 µs. In addition, it has a 10-bit analog-to-digital (A/D) converter. In order to avoid power consumption, the microcontroller switches on the temperature and humidity sensor only during the acquisition of the environmental parameters; after this it switches for 15 seconds off. In addition, the microcontroller puts itself in a low power mode between two consecutive measurements in order to save power. The reasons for choosing BLE are that it consumes less power and costs less compared to the Classic Bluetooth. In addition, its simplicity, wide range of users, the capability to work in the absence of Wi-Fi and, most importantly, the fact that the new models of smartphones support BLE [10] [11] [12] are very important factors.

The BLE module HM-10 from JNHuaMao Technology Company was used to design the device. It is compatible with the new standard Bluetooth 4.0. BLE is a new short range radio technology, optimized for ultra-low power applications. It is different from Bluetooth classic (BR/EDR), but with same benefits like robustness, interoperability, royalty free or connectivity with smartphones and PCs. BLE module consumes 0.01 to 0.5 W while transmitting. The BLE module receives data from the Universal Asynchronous Receiver/Transmitter (UART) interface of the microcontroller, and forwards it to a receiver using the Generic Access Profile (GAP). GAP is the cornerstone that allows Bluetooth Low Energy devices to interoperate with each other. It provides a framework that any BLE implementation must follow to allow devices to discover each other, broadcast data, establish secure connections, and perform many other fundamental operations in a standard, universally understood manner. There is a button on the device which switches the BLE module on only during transmission of the data and turns it off after transmission. The designed hardware is powered by a 3V lithium coin battery (Energizer CR2032). Typical capacity of the battery is 240mAh (to 2.0 volts). 3D version and final prototype board of the BLE-based Temperature and Humidity acquisition system are shown in Fig. 2.

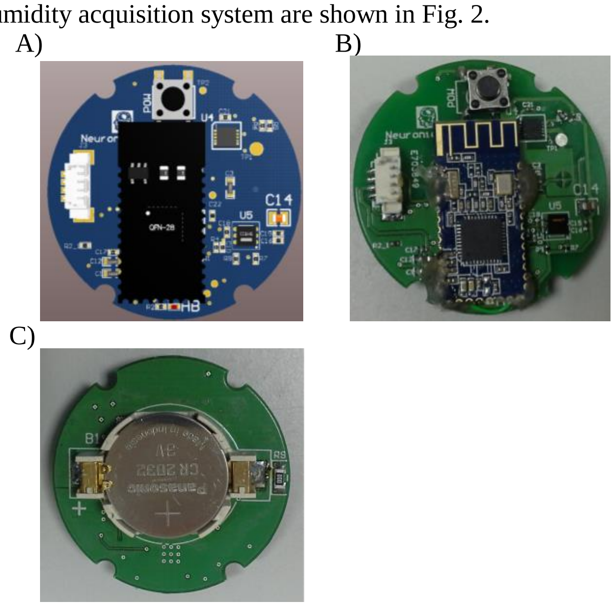

Figure 2. (A) 3D version of the electronic circuit BLE-based temperature and humidity acquisition system. (B) Prototype Board: Top view temperature and humidity sensor, microcontroller and BLE module. (C) Bottom view of the device.

B. Android Application of Bluetooth Low Energy Smart Sensor

An android application for the BLESensor was developed on an updated version of Android Studio.

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BLE communication settings and algorithms are implemented in application. The software model of BLE is described below:

Client

A device that initiates Generic Attribute Profile (GATT) commands and requests, and accepts responses, for example a computer or smartphone.

Server

A device that receives GATT commands and requests, and returns responses, for example a temperature sensor.

Characteristic

A data value transferred between client and server, for example the current battery voltage.

Service

A collection of related characteristics, which operate together to perform a particular function. For instance, the temperature and humidity acquisition services include characteristics for a temperature measurement value, and a time interval between measurements.

Descriptor

A descriptor provides additional information about a characteristic. For instance, a temperature value characteristic may have an indication of its units (e.g., Celsius), and the maximum and minimum values which the sensor can measure. Descriptors are optional - each characteristic can have any number of descriptors.

Some service and characteristic values are used for administrative purposes - for instance, the model name and serial number can be read as standard characteristics within the Generic Access service. Services may also include other services as sub-functions; the main functions of the device are so-called primary services, and the auxiliary functions they refer to are secondary services.

Identifiers

Services, characteristics, and descriptors are collectively referred to as attributes, and identified by UUIDs. Any implementer may pick a random or pseudorandom UUID for proprietary uses, but the Bluetooth SIG have reserved a range of UUIDs (of the form xxxxxxxx-0000-1000-8000-00805F9B34FB [10]) for standard attributes. For efficiency, these identifiers are represented as 16-bit or 32-bit values in the protocol, rather than the 128 bits required for a full UUID. For example, the Device Information service has the short code 0x180A, rather than 0000180A-1000-.... The full list is kept in the Bluetooth Assigned Numbers document online.

C. Algorithm of the BLESensor

The Algorithm of the application: BluetoothLeService class provides a service for managing connection and data communication with a GATT server hosted on a given BLE device. DeviceControlActivity class checks whether there is Bluetooth LE communication or not and if yes display data. Moreover, this activity provides GATT services and characteristics supported by the device. The software continuously checks for the availability of the sensor and after communication it remembers the last connection [13].

The BLESensor application has a menu for discovering and selecting the desired BLE-based sensor to get characteristics. This part of the application is called Discover UUIDs, and, for all primary services, after running the application, it tries to find service with a given UUID. The software discovers all characteristics for a given service. The next step is to find a characteristic matching with a given UUID where after application reads all descriptors for particular characteristics.

Finally, GATT offers notifications and indications. The client may request a notification for a particular characteristic from the server. The server can then send the value to the client whenever it becomes available. For instance, a sensor (SHT21) server may notify its client every time it takes a measurement. This avoids the need for the client to poll the server, which would require the server's radio circuitry to be constantly operational.

An indication is similar to a notification, except that it requires a response from the client, as confirmation that it has received the message.

The next part of the application is called discovery. BLESensor can distinguish between a Bluetooth classic based device and a BLE-based device. Sensors will be saved as Pair-Sensors after each communication. After selecting sensor/s, the process of connecting starts. In some cases, two attempts are needed to connect to the sensor. If the standard method of connecting fails, the reflection method starts.

The obtained data stream needs to follow the process of tokenization to break desired values of temperature and humidity from several lines of data that are read from the sensor [10]. Acquired data is computed with the formula of the SHT21 sensor from the datasheet. Additionally, all sensor data is stored in a text file in the data storage of the mobile phone. The application has a setting to select the number of available sensors to follow and the mentioned processes will happen automatically. The main interface of the BLESensor application is shown in Fig. 3. It illustrates how two sensors send indoor and outdoor environmental data to the BLESensor mobile application.

Figure 3. Main Interface of the BLE-based android application for acquiring environmental data.

III. COVER BOX FOR TEMPERATURE AND HUMIDITY DEVICE

One of the issues of the device was protection from environmental impacts. Moreover, esthetically it requires being attractive and easy to use for users. For that reason, we designed a cover box for the device. The cover box is designed in SOLIDWORKS 2015 x64 Edition and used STL file to print in 3D printer of Neuronica Laboratory [15]. The size of cover box is reduced as much as possible. 3D dimension of the cover box is provided in Fig. 4.

A)

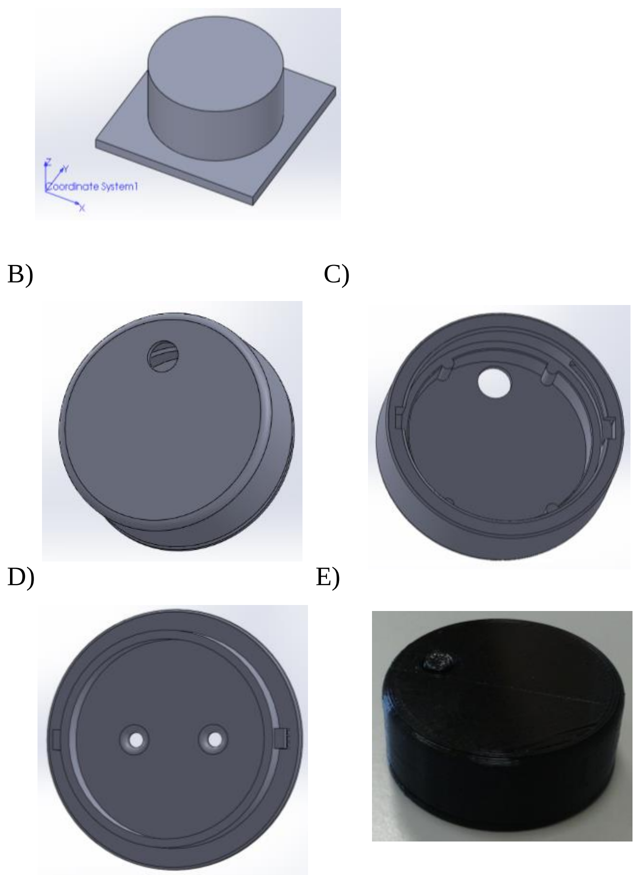

Figure 4. (A) Cover box for BLESensor: Button to switch electronic device, (B) Assembled parts of box, (C) Case of the box, (D) Cover of the case, (E) Final printed product with sensor inside.

IV. Discussion/Conclusion

This paper introduces a device designed with low power components which acquires environmental data through BLE technology and sends it to an android application developed on Android Studio [14].

Future work will focus on experiments using a climate chamber with various environmental conditions, to determine the accuracy of the sensor within it. At the same time, we will test the power consumption of the device during each condition to determine if the changes in environmental conditions alter the power consumption in any way. The amount of power which will be consumed has only been theorized at this point in time so physical data to coincide with this would confirm our original hypothesized consumption levels.

Another area of our work will focus on Network topology for BLE. This is an area of interest because billions of sensors and actuators will be deployed in the next few years and an emerging trend is to connect sensors with Internet of Things (IoT). The low-power radio technology has perhaps the highest potential for IoT use. The application which is still lacking IP capability is BLE which is expected to be incorporated in billions of consumer electronics devices around the globe (e.g., smartphones, tablets, Google glass, etc.,) [17]. Accordingly, the capability to run IPv6 over BLE opens new doors to the IoT and promotes BLE towards new application areas. The most important of these areas would be to exploit the smartphone as a gateway for providing Internet connectivity to surrounding BLE-enabled sensors. For instance, this approach allows one to remotely and ubiquitously monitor medical parameters from body sensors. Another example of the use of this application is with vehicle health messages, which can be sent by vehicular sensors through the smartphone of the driver to remote Intelligent Transportation System (ITS) control centers in order to prevent accidents. Similar applications can be found in other domains including home, urban and industrial automation. Furthermore, enabling IPv6 over BLE contributes to interoperability between IoT devices that utilize different low-power radio technologies. This is particularly important since Internet Engineering Task Force (IETF) standardization work is currently progressing towards extending the family of low-power technologies with IPv6 support [16]. Other experiments have been proposed with the goal of implementing different learning machine tools in Wireless Sensor Networks in order to predict a sensor data will also be investigated. In conclusion, the use of BLE technology with our Android system can reduce power consumption on the whole system [17].

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