# Development of a Smart Wearable Device for Human Activity and Biometric Data Measurement

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## Abstract

*This paper presents a smart wearable device cooperating with smartphones to measure and utilize human activity and biometric data such as motion tracking, photoplethysmography (PPG), skin temperature (SKT), and galvanic skin response (GSR). It is comfortably designed and implemented as a wristband-type device and provides wireless Bluetooth Low Energy (BLE) connection to smartphones based on the Android operating system. According to the predefined packet format and control commands, the proposed smart wearable device can transmit measured sensing data and update its firmware. Implemention results verify the feasibility and usability of the proposed smart wearable device. It can be applied to various healthcare and wellness services or even emotional game applications.*

*Keywords: Wearable, Device, Android, Human Activity, Biometric Data*

## 1. Introduction

Recently, many researchers have developed a lot of healthcare and wellness technologies for the realization of the ambient assistant living through human-to-machine interactions in digital home environments [1-3]. Moreover, Internet of Things (IoT) as a promising solution for human-to-machine and machine-to-machine interactions has been actively investigated in the areas of healthcare and wellness industry, since it allows many researchers to easily create various applications specific to these industries based on the interconnection between physical objects and the Internet [4-6].

In addition, IoT-related wearable devices are considered as a newly emerging technology to acquire and manage personalized data such as user location, health information, [7-8]. Since these devices seamlessly track people, they are also expected to bring excellent experiences to make life healthy and more convenient, and to provide personalized health and wellness data such as human activity and biometric data impacting quality of daily life. Practically, these human motion and location parameters as well as biometric physiological parameters such as blood pressure, heart rate, and skin temperature can be utilized for some differentiated healthcare and wellness services or emotional game applications.

In this paper, therefore, a smart wearable device comfortably designed for portability and conveniently communicated to Android-based smartphones is proposed. It is implemented as a wristband-type device supporting two sensing parts: human activity and biometric data parts. It also supports a Bluetooth Low Energy (BLE) module for connecting to smartphones and a Global Positioning System (GPS) module for obtaining user location and time information. More importantly, new data format and control commands are defined for the BLE communication. The rest of the paper is organized as follows. Section 2 describes the proposed smart wearable device in detail, and Section 3

presents some implementation results to verify its feasibility and usability. This paper is concluded in Section 4.

## 2. Description of the Proposed Smart Wearable Device

In Figure 1, the block diagram of the proposed smart wearable device is illustrated. It consists of two functional parts where a biometric sensing part with photoplethysmography (PPG), skin temperature (SKT), and galvanic skin response (GSR) modules is presented on the left side, and a human activity sensing and wireless connection part with GPS, BLE, and motion tracking modules is presented on the right side.
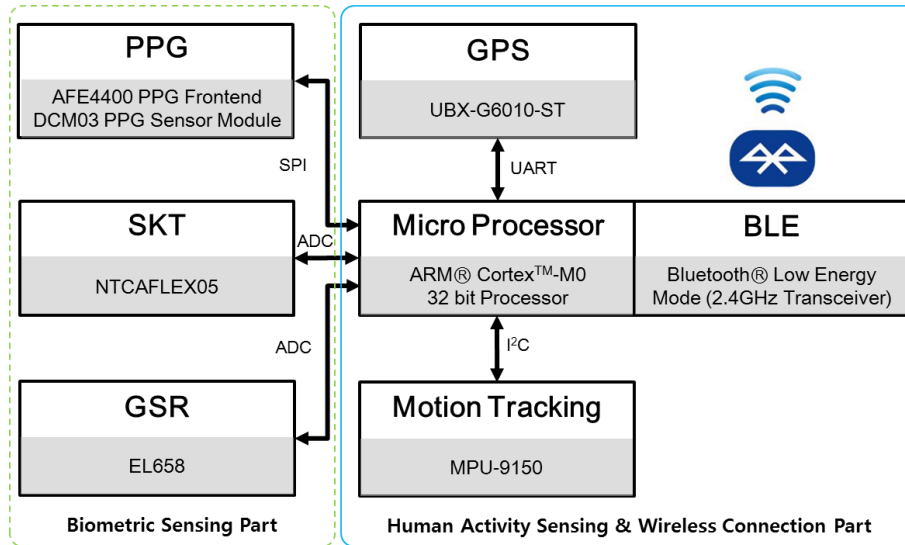


**Figure 1. Block Diagram of the Proposed Smart Wearable Device for Measuring Human Activity and Biometric Data**

In the biometric sensing part, the PPG module uses a light-based technology to sense the rate of blood flow as controlled by the pumping action of the heart. It is composed of an AFE4400 PPG frontend IC and a DCM03 PPG sensor. It is connected to the microprocessor via the serial peripheral interface (SPI) interface. The AFE4400 performs light emitting diode (LED) control and photodiode signal measurement for measuring the pulse in the DCM03 sensor. Basically, it amplifies the magnitude of the received signal, and then reads its analog-to-digital convert (ADC) values and sends them to the microprocessor through the SPI interface. The SKT module uses an NTCAFLEX05 sensor for measuring the temperature of the skin. The NTCAFLEX05 is a negative temperature coefficient (NTC) type sensor whose impedance varies depending on temperature. This variation is read by the ADC to measure the current temperature. The GSR module uses an EL658 sensor for measuring the electrical skin conductance as an indication of psychological or physiological arousal. Interestingly, the PPG, SKT, and GSR can be utilized for estimating and evaluating human emotion. Strong emotion will cause a stimulus to the sympathetic nervous system and result in more sweat related to the electrical conductivity. Also, happiness can be characterized by decreased heart rate, anger by increased heart rate and increased skin temperature, and fear by increased heart rate and decreased skin temperature.

In Figure 2, the prototype modules of Mainboard, GSR and PPG/SKT and the software for their device drivers and measurement are presented. Based on these prototype modules and software, the biometric sensing part was designed and its normal operation was tested.
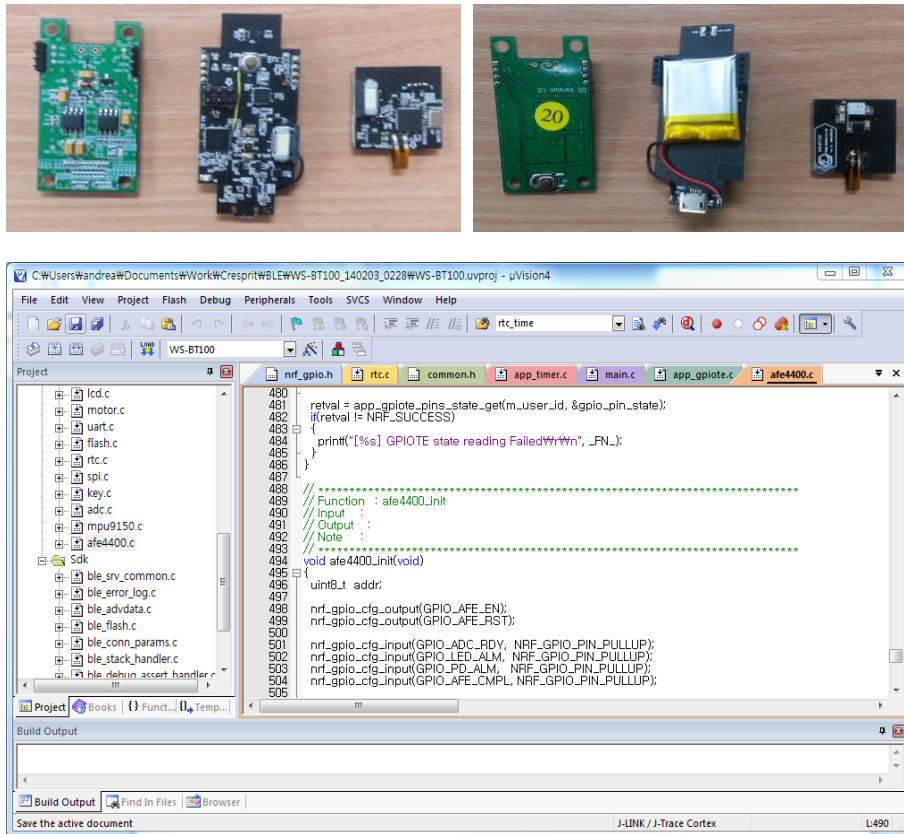
**Figure 2. Prototype Modules and Software for the Design and Operation Test of Mainboard, GSR And PPG/SKT**

In the human activity sensing and wireless connection part, nRF51822 BLE System-on-Chip (SoC) is exploited for the microprocessor and the BLE communication. More precisely, the microprocessor is ARMⓇ Cortex™-M0 32 bit processor supporting 256 kB embedded flash program memory, 16 kB RAM, 8/9/10 bit ADC (8 configurable channels), 31 general purpose I/O pins, Serial Peripheral Interface (SPI) master, two-wire master (I2C compatible), Universal Asynchronous Receiver/Transmitter (UART). Also, the BLE is the 2.4GHz transceiver with -93 dBm sensitivity in Bluetooth low energy mode and supports 250 kbps, 1Mbps, 2Mbps data rates. Next, the MPU9150 module is used for 9-axis motion tracking with an accelerometer, gyroscope, and geo-magnetic sensors. Its measurement range is as follows. Digital-output X/Y/Z-Axis angular rate gyroscopes provide a user-programmable full scale range of ±250, ±500, ±1000, and ±2000°/sec. Digital-output X/Y/Z-Axis accelerometers provide a programmable full scale range of ±2g, ±4g, ±8g and ±16g. Digital-output X/Y/Z-Axis magnetometer (compass) provides a full-scale range of ±1200μT. The GPS uses the UBX-G6010-ST module featuring high performance with low power consumption and low cost, which can be connected to the microprocessor via the UART.

Through wireless BLE connection to Android-based smartphones and motion tracking and GPS, a lot of health and wellness services and emotional game applications can be conveniently developed.

In order to communicate with Android-based smartphones, the BLE UART protocol based on Google's Android 4.3 is used for developing the application related to the proposed smart wearable device. In Figure 3, an Android application software is illustrated to establish the BLE bidirectional communication.
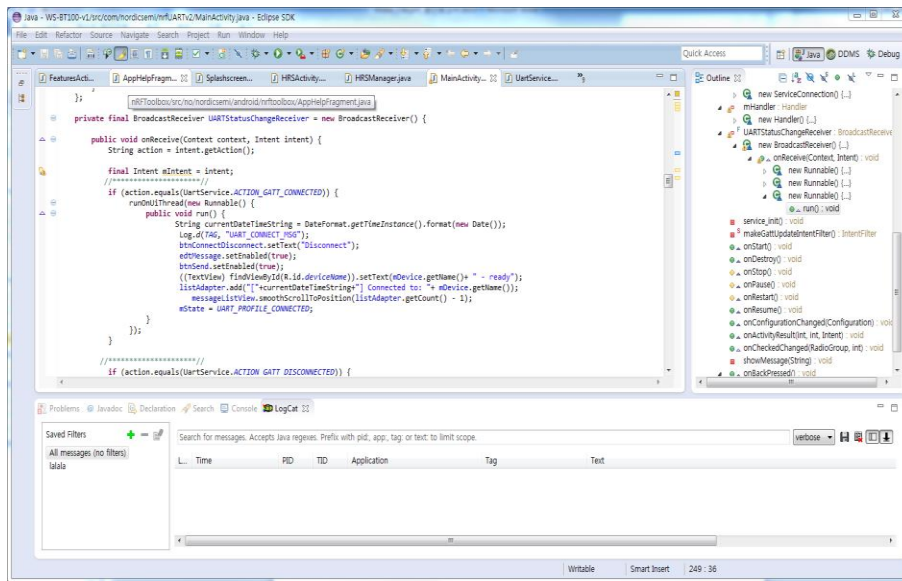
**Figure 3. Android Application Software Cooperating with the BLE**

The new packet format transmitted by the BLE UART protocol between the proposed smart wearable device and Android-based smartphones is defined as shown in Figure 4. Here, "Time Index" indicates packet generation point in time. "Time Index" of the most recent PGG peak value is called to as "PPG Peak Index". The basic unit for "Time Index" and "Peak Index" is 10 msec. "Heart Rate" denotes the most recent heart rate value. "PPG Peak Value" denotes the ADC output of the PPG peak value. "GSR" and "SKT" denote average skin conductivity and temperature measured for 0.5 sec before packet generation, respectively. "Motion Index" indicates the variation in movement in 5 different levels (0~5 level).

| Field | ID | Time Index | PPG Peak Index | Heat Rate | PPG Peak Value | PPG Average | GSR | SKT | Motion Index | Checksum |
|-------|----|-----------|----------------|-----------|----------------|-------------|-----|-----|--------------|----------|
| 20 Bytes | 1 | 4 | 4 | 1 | 2 | 2 | 2 | 2 | 1 | 1 |

**Figure 4. Packet Format Working with the BLE UART Protocol**

The control commands are also defined in Table 1 in order to transmit measured sensing data and update its firmware. "Command 1" means that smartphones request the transmission of the data measured in 0.5 second intervals for 5 seconds and the data measured for 35 seconds in 0.5 second intervals from the proposed smart wearable device. "Command 2", "Command 3" and "Command 7" denote the transmission of SKT, GSR, and PPG data, respectively. Also, "Command 4" to "Command 6" denote accelerometer, geomagnetic, and gyro data related to human motion and location, respectively. "Command 8" denotes the end of measured data transmission, and "Command 9" denotes update firmware of the proposed device.

**Table 1. Control Commands between the Proposed and Smartphones**

| Command | Operation |
|---------|-----------|
| 1 | Transmit the data measured in 0.5 second intervals for 5 seconds<br>Transmit the data measured for 35 seconds in 0.5 second intervals |
| 2 | Transmit measured SKT data |

| 3 | Transmit measured GSR data |
| 4 | Transmit measured accelerometer data |
| 5 | Transmit measured geomagnetic data |
| 6 | Transmit measured gyro data |
| 7 | Transmit measured PPG data |
| 8 | End of measured data transmission |
| 9 | Update firmware |

## 3. Implementation Results and Discussion

In Figure 5, the implementation results of the proposed smart wearable device are illustrated. The implemented smart wearable device can monitor its power, BLE operation, and biometric measurement status by three light-emitting diodes (LEDs). In addition, it measures PPG, SKT, and GSR sensing data and transmits them to Android-based smartphones by using a predefined packet format and control commands through the BLE communication.



**Figure 5. Implementation Results of the Proposed Smart Wearable Device**

In Table 2, the functional description of the implemented smart wearable device is given. "Number 1" denotes the Power LED, the LBE operation LED, and the Biometric Data Measuring LED. "Number 2" is the Power Button, "Number 3" is the GSR sensor connector, "Number 4" is the USB charging connector, "Number 5" is the SKT sensor, and "Number 6" is the PPG sensor.

**Table 2. Function Description of the Proposed Smart Wearable Device**

| Number | Type | | Description |
|--------|------|--|-------------|
| ① | LED | ⏻▢ | Power LED |
| | | ✳▢ | BLE Operation LED |
| | | 📈▢ | Biometric Data Measuring LED |
| ② | Power | | Power Button |

| ③ | GSR | GSR Sensor Connector |
|---|---|---|
| ④ | USB | USB Charging Connector |
| ⑤ | SKT | SKT Sensor |
| ⑥ | PPG | PPG Sensor |

Application software of Android-based smartphones cooperating with the implemented smart wearable device is shown in Figure 6. Pressing the "Connect" button on the application brings up the "BLE Device List", and the smart wearable device is listed as WS-BT100. When WS-BT100 is selected, the BLE connection is established. After that, we can enter the desired transmission command in the application input window and press the "Send" button for data transmission. If the smartphone sends a command in Table 1 to the smart wearable device, the smart wearable device will send back the corresponding response.
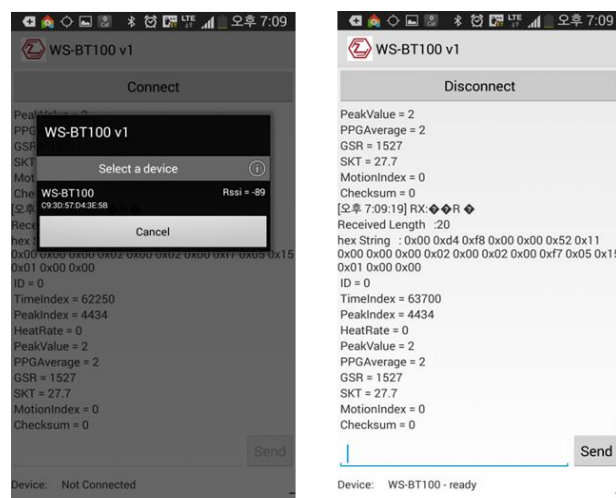


**Figure 6. Android Application for the Verification of the Proposed Smart Wearable Device**

## 4. Conclusions

In this paper, a smart wearable device, such as a comfortable wristband in cooperation with Android-based smartphones, was developed in order to measure and utilize human activity and biometric data such as motion tracking, PPG, SKT, and GSR. The BLE bidirectional communication was exploited for the connection between the proposed smart wearable device and the smartphones. The proposed smart wearable device could transmit measured sensing data and update its firmware by using the predefined packet format and control commands. Some implementation results verified its feasibility and usability. It is expected to be applied to various healthcare and wellness services or emotional game applications.

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