Design and Implementation of a Wristband-style Biomedical Signal Measurement Device using Zigbee for u-Healthcare Systems

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Abstract
Most of existing biomedical signal measurement devices measure and evaluate biomedical signals only in a single device. Also, even if the device shows multi-functional characteristics, those biomedical signals can be measured by the selection of users. In this paper, a wristband-style biomedical signal measurement device for u-healthcare systems is implemented to solve the problem mentioned above. The device used in this implementation uses four infrared sensors, two electrodes, and a 3-axis accelerometer in order to measure pulse, skin conductivity, and momentum, respectively. Also, we propose a communication packet frame for transmitting biomedical signal data to PCs or mobile devices using Zigbee. In the results of the actual test using the wristband-style device, the implemented device represents an error less than twice in its pulse measurement. Also, the reliability of momentum shows about 85.6% and 84.7%, and the skin conductivity has changed according to the physical condition of users.

Key words:
U-Healthcare System, PPG, GSR, quantity of motion, Zigbee

1. Introduction

The society in which the portion of people aged over 65 shows more than 7% in a country is called aging society. The rate of aged people in the world was 9.6% in 2006 and will be increased up to 30% in 2030. In this circumstance, it is necessary to provide quality services based on the total verification of the factors of medical safety and validity for medical consumers and a u-healthcare system that can provide the medical information technology, which shows improvements in the prediction capability and applicability of the information, to medical service providers [1]. The u-healthcare system provides timely high quality medical services whenever and wherever and that leads to provide the medical service by extending the conventional medical system, which is limited in hospitals as a single treatment or management, as space and time in order to provide the service to actual daily life through a lifetime. This system can be classified according to the subject of medical services and the type of measurement devices such as a very small mobile device focused on "Home & Mobile Healthcare" for aged people and chronic disease patients, a high quality device focused on "u-Hospital" for general patients, a home device focused on "Well-being" for maintaining health and for improving the quality of life, and a future device that shows biomedical signal based emotion recognition and can control feedbacks. For implementing these devices, a sensing technology that measures biomedical signals, a signal processing technology that processes the measured data, and wire and wireless transmission technologies that transmit the processed data to a u-healthcare server are required [1].

Most of the existing devices in u-healthcare systems measure a single biomedical signal and transmit the signal to a server [2], and the medical signal can be measured by the selection of a specific device. Thus, in this study, a biomedical signal measurement device that can measure biomedical signals (pulse, skin conductivity, and momentum), which can be used in a u-healthcare system, and transmit them to a server is proposed. The proposed device is a wristband-style that measures biomedical signals as a real-time manner and can transmit the signal to a home health server or mobile device using Zigbee.

This study consists of four sections. Section 2 shows the medical signal in u-healthcare systems and the diagram of a device system. Section 3 describes the experiment for measuring biomedical signals and the device implemented in this study. Section 4 represents the conclusion of this study.

2. Ubiquitous Healthcare System

2.1 Background studies

For implementing a healthcare system, Yoon proposed an art therapy service as a method of curing physical and mental diseases in users [3]. This service detects physical and mental diseases in users using a device fabricated by

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using various sensors and then provides information for music or painting to users. Ali proposed a ubiquitous kitchen environment for implementing a home network system [4]. Choi proposed an environment monitoring system for monitoring ECG, weight, snoring, writhing, and surrounding temperature in a sleeping condition [5]. Also, Kim proposed a sensor network based ubiquitous healthcare system [6]. These studies are usually focused on “u-Hospital” or “u-Home”, and these systems can only be applied to a specific space by installing several sensors on the user’s body or specific spaces.
For presenting a healthcare device, Baek implemented a sensing device using a pulse sensor and a processing device using Bluetooth [7]. Jang measured momentum, SPO2, blood pressure, and body fat for applying them to a healthcare integration model and implemented a device using Zigbee [2]. These studies apply a wireless communication process in data communication using individual sensor devices in which the devices represent a disadvantage that biomedical information can only be measured using a device for each specific function.
For solving such a problem, in this study, a wristband-style biomedical signal measurement device that can measure biomedical signals in users, such as pulse, skin conductivity, and momentum, whenever and wherever in a single device and then transmits such data to a home gateway or mobile device using Zigbee, which shows a low power consumption, in order to manage the data in a home server is proposed.

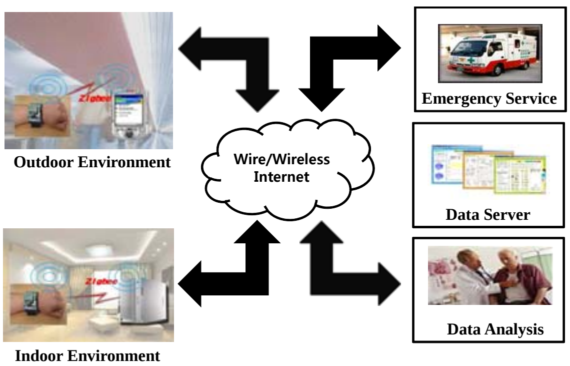


Fig. 1 Architecture of the Healthcare System

Fig. 1 illustrates the architecture of the healthcare system proposed in this study. This system measure biomedical signals using a wristband-style device and transmits the measured data to a data managing server using a wireless Internet network in a mobile device as it is used at an outdoor condition or a PC Internet network as it is used at an indoor condition for connecting them to emergency services and medical centers.

2.2 Wristband-style Biomedical Signal Measurement Device

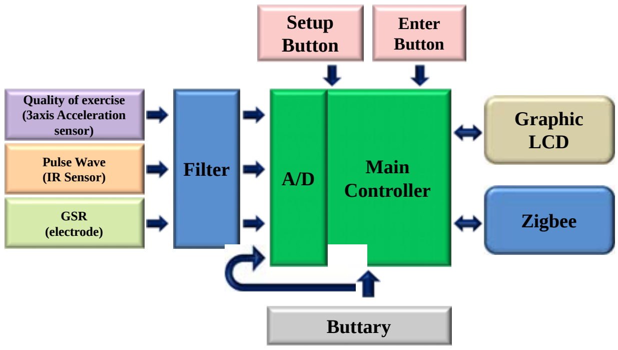
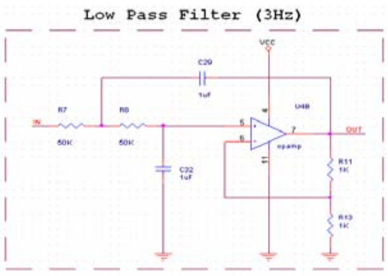


Fig. 2 Structure of the Wristband-style Biomedical Signal Measurement Device

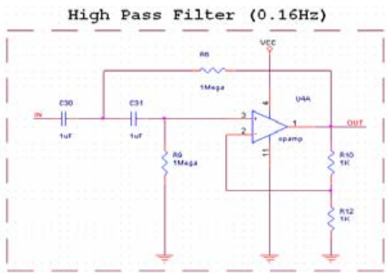
Fig. 2 shows the structure of the wristband-style biomedical signal measurement device. This device uses a 3-axis accelerometer for measuring momentum, four infrared sensors for measuring pulse, and two electrodes for measuring skin conductivity. Also, it includes buttons for initializing user information and data, a graphic LCD for presenting the measured data, and a Zigbee module for transmitting the measured biomedical data to a mobile device or a PC through a wireless manner. In the measurement of biomedical signals, filters are configured to remove unnecessary noises in the analog data collected from sensors, and the data will be processed in the main controller by converting the collected analog data to digital data. The main controller plays a role in outputting the processed data to the LCD and transmitting the data to the device through the Zigbee module.

2.3 Measurement of pulse

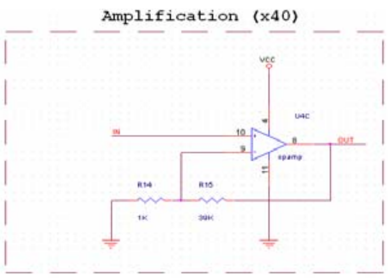
Pulse is a motion in a blood vessel that regularly contracts and relaxes the atrium and ventricle muscles of the heart to circulate blood. The pulse can be used to measure the stroke of the pulse in which the pulse range determined by 100 times to over 160 times per minute is called sinus tachycardia, which can occur in daily life due to high fever, reduction of blood volume, bleeding, anemia, cardic insufficiency, thyroid glands, and stress. Also, the pulse range determined by less than 60 times per minute is called sinus bradycardia. It can occur due to the excessive increase in the activity of the parasympathetic nervous system in daily life or the excessive decrease in the activity of the sympathetic nervous system. Although such sinus tachycardia and sinus bradycardia will not cause serious diseases, these become a type of important information that should be checked because they may cause some complications if they exceed a certain level.



(a) Low Pass Filter



(b) High Pass Filter



(c) Non-Inverting Amplifier

Fig. 3 Pulse measurement filter and amplification circuits

For detecting pulse signals, it is necessary to install an infrared sensor on the radial artery of the wrist in order to measure the amount of reflected infrared according to the amount of the blood flow in the radial artery. However, a filter for removing external noises is required to practically measure the amount of infrared. Fig. 3 represents the pulse measurement filter and amplification circuits by using infrared sensors. The low pass filter presented in Fig. 3 (a) was designed to pass low frequencies below 3Hz because the stroke of the pulse in people cannot exceed 200 times maximum. The high pass filter presented in Fig. 3 (b) was designed to pass high frequencies more than 0.16Hz in order to remove low frequency noises, which are determined as a DC component. The non-inverting amplifier presented in Fig. 3 (c) amplifies several tens of mV signals to 0-2V by about 40 times.

As shown in Fig. 4, the stroke of the pulse can be calculated using the phase of the pulse. That is, it can be calculated by dividing the time between the peak (P1) of the increasing section of the pulse and the next peak (P2) of the pulse by one minute (60 seconds). It can also be denoted as Eq. (1).

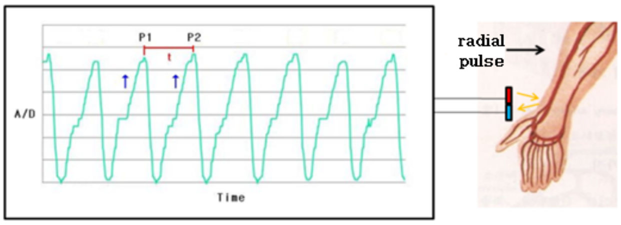
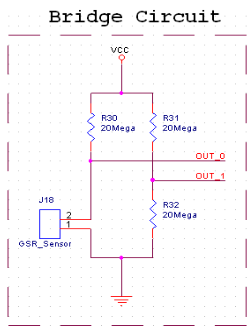


Fig. 4 Measurements of the pulse and the stroke of pulses

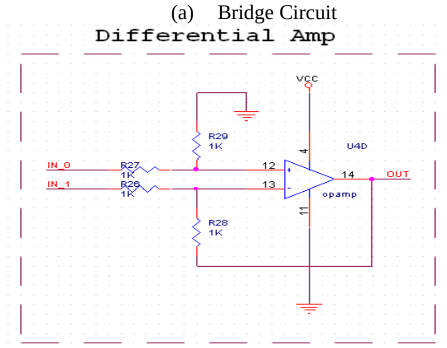
$$NumberofPulse = \frac{60}{Intervals\ with\ P1P2} \qquad \text{Eq. (1)}$$

2.4 Measurement of skin conductivity

As a stressed or surprising moment of people the sympathetic nervous system secrets sweat from the skin cleavage line. Then, it leads to change the human body as the muscle is strained, the breath and heart rate are increased, the digestive and reproductive systems are slowdown, and the circulation and muscle systems are strained. In addition, such changes also change the electric characteristics of the skin. The excitation of the sympathetic nervous system decreases the skin resistance instantaneously and that causes an electric response in the skin.



(a) Bridge Circuit



(b) Differential Amp Circuit

Fig. 5 GSR Measurement Circuits

The skin resistance of people can be measured as a range of about 2MΩ~5MΩ through measuring the resistance at fingers or the skin of the palm. In this study, however, the resistance was measured at the wrist to avoid the inconvenience in daily life as a range of about 15MΩ~20MΩ because the measurement at these parts may represent some inconveniences in daily life.

The skin resistance can be measured by attaching two electrodes, which show electric conductivity, on the wrist. The measured skin resistance is to be converted to voltage values using a bridge circuit (Fig. 5 (a)) through amplifying it using a differential amplification circuit (Fig. 5 (b)). Then, the voltage converted from the skin resistance will be compared with the reference fixed voltage using such a differential amplification circuit. Because the skin resistance can be varied according to people, the reference value is to be determined by averaging measured values, which are measured for about 3 seconds after wearing the medical signal measurement device. It can be measured that the lower skin resistance for the reference value represents the higher strain level.

2.5 Measurement of momentum

People need a specific amount of exercises usually for maintaining their health. However, it is not easy to keep such essential exercises for maintaining usual daily life as an excuse of their busy daily routine. Although the movement patterns of legs during working with a constant speed show up and down movements, it usually represents back and forth movements due to the natural movement of arms.

The momentum can be measured using the stroke of the pulse, oxygen intakes, and an accelerometer [8]. In the study, the number of steps can be calculated by measuring the acceleration of the movement of arms as people work using a 3-axis accelerometer. Fig. 6 shows the directions of the acceleration of 3 different axes presented by the wristband-style device.

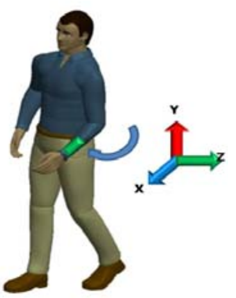


Fig. 6 Directions of the acceleration for three axes

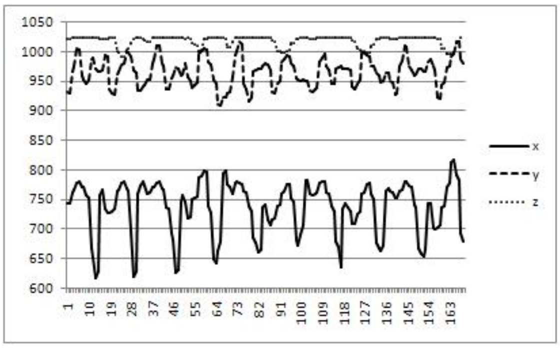


Fig. 7 Output waveforms of the acceleration for three axes

In the measurement of the movement of arms using a 3-axis accelerometer, the acceleration in the x axis shows a large change in its value as presented in Fig. 7. However, there are no changes in the y and z axes. Therefore, in this study, for extracting the maximum value (Feature) from the change in the x axis, an IIR (Infinite Impulse Response) filter, which is a type of low pass filters, was applied to remove the high frequency component in the input data (n). Also, a first order differentiation (z(n)) was applied to remove the low frequency component after applying a FIR (Finite Impulse Response) filter (p(n)), which is a type of high pass filters. It can be denoted as Eq. (2).

$$Z(n) = \sum_{n=0}^{\infty} (2p(n) + p(n-1) - p(n-3) - 2p(n-4)$$
$$p(n-1) = \begin{cases} 0 & n-1<0 \\ p(n-1) & otherwise \end{cases} \qquad \text{Eq. (2)}$$
$$p(n-3) = \begin{cases} 0 & n-1<0 \\ p(n-3) & otherwise \end{cases}$$
$$2p(n-4) = \begin{cases} 0 & n-1<0 \\ 2p(n-4) & otherwise \end{cases}$$

Then, as shown in Eq. (3), a square was applied and the figure was converted to remove the negative value.

$$\omega(n) = \sum_{n=0}^{\infty} z(n)^2 \times 0.001 \qquad \text{Eq. (3)}$$

Also, the maximum value was extracted using a moving average filter based on five data as presented in Eq. (4).

$$m(n) = \sum_{n=4}^{\infty} \frac{1}{5}(\omega(n) + \omega(n-1) + \omega(n-2) + \omega(n-3) + \omega(n-4)) \qquad \text{Eq. (4)}$$

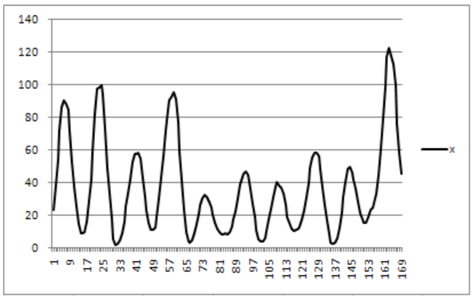


Fig. 8 Waveform of the maximum value extracted from the x axis data

By applying Eq. (4) for the x acceleration axis data, the waveform can be obtained as shown in Fig. 8 in which the number of steps can be obtained by extracting the maximum value.
As mentioned above, the measurement of the momentum for the measured steps can be determined as Eq. (5) [2].

$$CC = MC \times M \times 0.00006213$$
$$MC = 3.7103 + 0.2678 \times W$$
$$+ [0.0359 \times (P \times 60 \times 0.0006213)^2] \times W \quad \text{Eq. (5)}$$
$$M = \frac{(H - 100) \times P}{100}$$
$$JC = \frac{33.3 + 0.178 \times (JP - 150) \times W}{1000}$$

where M is the moving distance, MC is the calorie per mile, CC is the consumption of the calorie, W is the weight, H is the height, JC is the consumption of the calorie during jogging, and JP is the number of jogging steps.

2.6 Wireless communication

The wireless network in a healthcare system is a core technology for providing quality services, such as customized services and remote diagnoses, for each user by reducing the cost including post inspection and duplicated inspection through easy measurement of the health condition of users. In this study, a Zigbee wireless sensor network system was implemented for presenting this system.
The Zigbee presents the IEEE 802.15.4 MAC Layer and PHY Layer, and the Networking Layer uses an Ad-Hoc method that performs network connection and routing detection by itself. Also, the Application Layer provides a message exchanging function and specific industrial profiles. In the security, it uses MAC and Network, and AES-128 (Advanced Encryption Standard) and Key Management are used in the Application Lay [10].

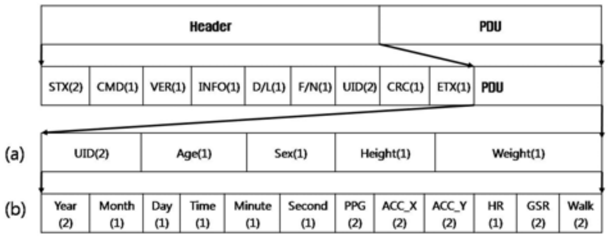
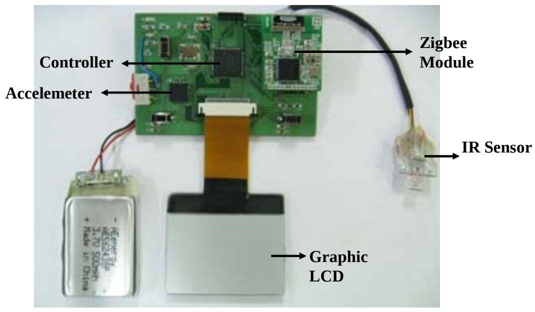


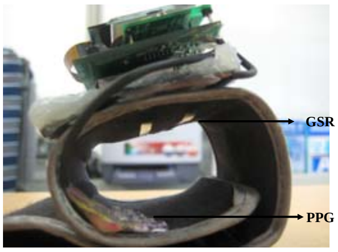
Fig. 9 Zigbee communication packet (numbers in ( ) are the size of byte)

The Zigbee communication used in this study can be performed based on the Profile of the Zigbee Alliance. Fig. 9 shows the user data packet in the Zigbee communication. The communication packet can be divided into the Header section that represents packet information and the PDU section that shows user information. In the Header section, STX shows the start of packet frames, CMD represents the PDU data that is either the personal information of users or the measured biomedical information, VER shows the version, INFOR shows the validation of data, error code, and etc., D/D shows the size of the PDU (bytes), F/N is the packet frame number, UID shows the unique ID of users, CRC is the checksum, and ETX represents the end of packet frames. Also, the PDU is varied according to the state of the CMD of the Header. If the CMD represents personal information, it shows the state presented in Fig. 9 (a) in which UID is the unique ID of users, Age shows the age of users, Sex shows male or female, Height is the height of users, and Weight of the weight of users. This information can only be transmitted as the start of the communication and the change in users. If the CMD represents biomedical information, it shows the state presented in Fig. 9 (b) in which Year, Mon, Day, Time, Min, and Sec represent the year, month, day, hour, minute, and second of obtaining biomedical signals, PPG shows pulse data, ACC_X, ACC_Y, and ACC_Z represent x-, y-, and z-axis data in the 3-axis accelerometer, HR is the heart rate, GSR shows the skin conductivity, and Walk shows the number of steps.

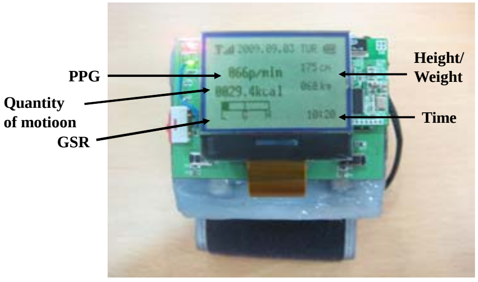
3. Test and implementation



(a) Device module



(b) Sensor location



(c) LCD presentation


(d) Measurement of biomedical signals

Fig. 10 Wristband-style biomedical signal measurement device

The wristband-style biomedical signal measurement device for the u-healthcare system implemented in this study is presented in Fig. 10. Fig. 10 (a) and (b) show the device module, (c) shows the LCD presentation for checking the measured data. The LCD represents the physical information (weight and height), heart rate, momentum, and skin conductivity of users including the present time. Also, (d) shows the actual wearing of this device.

Table 1 Specification of the wristband-style biomedical signal measurement device

Device Module	Specification
Dim. (W×D×H)	60×40×12(mm)
Weight(g)	100g
Power consumption	61.19mAH
Main controller	ATmega128L
Accelerometer	MMA7260QT by FreeScale
IR sensor	One ST-23G(Detector), Four EL-23G(Emitter)
Electrode	Two Ni coated electrodes
Graphic LCD	CGG128064Q00-FHY(128×64)
Battery	Li-Polymer 3.7v-500mAH
Wireless communication	2.4GHz based Zigbee

Table 1 shows the specification of the wristband-style biomedical signal measurement device. ATmega128, which is a 8-bit micro-controller, by Atmel was used as the main controller [11], and MMA7260QT by FreeScale was used as the 3-axis accelerometer for measuring the momentum [12]. The IR sensors for measuring the pulse were configured as a cross shape where one detector was installed at the center of the cross and four emitters were installed at each end of the cross in order to easily detect the radial artery. The electrodes were fabricated using Ni coated electrodes that have excellent electric conductivity. In addition, the wireless communication module showed the size of 24×19mm and was configured using a 2.4GHz based Zigbee module, which shows the power consumptions of 8.78mA and 1uA for the general communication and the slip mode, respectively, with the SPI interface. Although the entire power consumption of the device shows a higher level than the rated capacity of the used battery, the battery can be used for 7-8 hours continuously in the test. It can be seen that this duration is enough to measure the data in usual daily life, and the battery can be recharged if it is required.

In the test of the pulse, as illustrated in Fig. 11, the pulse and biomedical signals measured in the device based on the phase determined in Eq. (1) were observed using an oscilloscope. Then, the changes in output waves were also investigated for comparing them with the results of the observation using an oscilloscope. The errors between the measured data using the device and the phase determined by using an oscilloscope were usually presented by within twice.

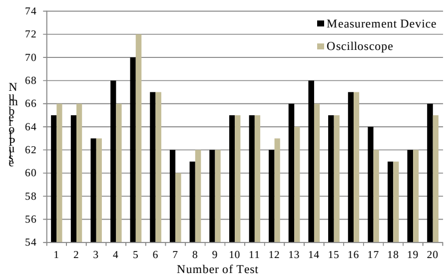


Fig. 11 Errors of the measured pulse

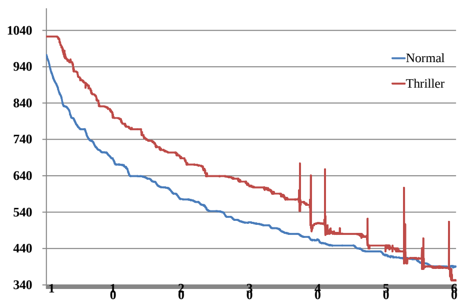


Fig. 12 Results of the measurement of GSR

Fig. 12 shows the results of the measurement of GSR with an interval of one second for one hour. Regarding the initial GSR data, because a metal is attached on the body, the values of the GSR continuously are decreased according to the passage of time. In addition, in the case of the data that is measured under watching a thriller or horror movie for presenting strain, it can be seen that the instant peak data of the GSR is significantly increased.
In the measurement of momentum, the test was applied by varying the walking speed in a running machine based on the average walking speed of people (4km/h) [9]. As noted in Table 2 and Table 3, the results of the test showed the reliabilities of about 85.6% and 84.7% respectively.

Table 2 Results of the measurement of steps (Tester 1)

Walking Speed	Actual Steps	Device Display	Recognition Rate
3km/h	100	82	82%
4km/h	100	85	85%
6km/h	100	90	90%

Table 3 Results of the measurement of steps (Tester 2)

Walking Speed	Actual Steps	Device Display	Recognition Rate
3km/h	100	84	84%
4km/h	100	91	91%
6km/h	100	79	79%

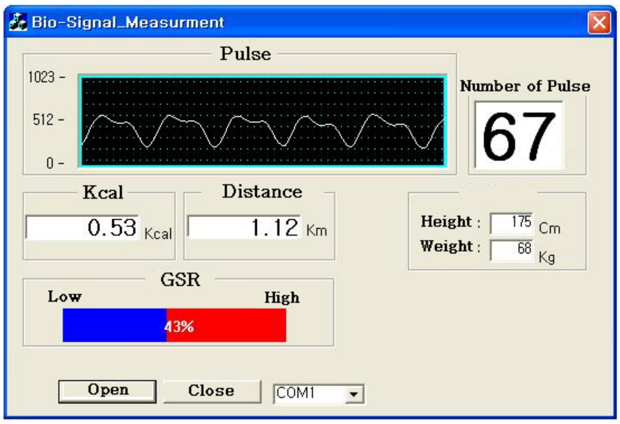


Fig. 13 User Program in a PC

Fig. 13 shows the user program for verifying the data measured in the wristband-style device in which the data was transmitted using the Zigbee wireless communication module. The user program uses the Zigbee module as a coordinator and converts the data transmitted from the Zigbee module into the format for the RS232 in a PC. This program measures the biomedical signals for the physical information of users and then outputs the pulse as a form of waves. Also, it outputs the values of pulse, momentum, and skin conductivity as a real-time manner.

4. Conclusion

In this study, a wristband-style biomedical signal measurement device was implemented for achieving a u-healthcare system. The implemented device can measure the pulse, skin conductivity, and momentum of users. The measured pulse showed an error of about 2~3 times compared with the phase measured by using an oscilloscope. In the skin conductivity, the skin resistance decreased according to the increase in the secretion of sweat at the wrist. In the measurement of the number of steps using an accelerometer, the error was about 1~2 steps. Although there were some errors in the results of each biomedical signal, it can be regarded as a reasonable range for measuring the health condition of users in a u-healthcare system device. In addition, the device implemented in this study was able to transmit the measured data to a user's PC through the Zigbee wireless communication module and that made possible to check the data as a real-time manner. In future studies, it is necessary to reduce the errors presented in this study through additional studies and the power consumption in this wristband-style device. Moreover, it is necessary to apply wireless Internet in order to use this device for outdoor purposes [2]. Also, a ubiquitous healthcare system is to be achieved by implementing a home healthcare server.

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