東海大學資訊工程研究所

碩士論文

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無線生理感測器區域網路與應用

A Wireless Physiological Sensor Area Network and its Applications

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中文摘要

台灣已經逐漸進入高齡化的社會，老年人口逐漸增加，這些銀髮族老人無論能行動自如或臥床而需要長期照護的人數皆逐年增加，而健康狀況是老人生活滿意程度的決定因素之一，在影響健康的許多因素中，生理訊號又是最重要的一環，但目前市面上可以買到的生理感測系統均以一電腦設備或電子儀器轉接所感測之生理訊號到遠端之照護中心或醫療院所。但這一些電腦設備或電子儀器體積常很大，且須接有線以外傳生理訊號，不利於攜帶外出，因而受照護者難以自由活動。其實，近年來智慧型手機已能透過藍牙收取生理感測器送出之訊號，又能將該訊號透過 WiFi 或 3G/4G 送到遠端，且可隨身攜帶，因此，本研究提出一個以智慧型手機取代電腦設備或電子儀器之醫療照護生理感測系統，稱為行動生理感測網路(Mobile Physiological Sensor Network, MoPSN for short)。這是一個以無線生理感測器區域網路 (Wireless Physiological Sensor Area Network, WPSAN)為基礎，透過生理感測器(Bio-sensor)監控銀髮族生理數據的行動感測系統，同時檢測許多受照護者，為免智慧型手機遺失任何生理數據，該數據傳送至資料蒐集與分類系統，以剖析分類至生理資訊資料庫，亦可以定時或不定時地傳送到照護雲。本研究亦設定各監控因子之回報基準，並將各項生理感測器資料經過醫療照護雲傳送到終端監控平台，讓醫護人員得以即時地監控受照護者之生理資訊，俾提供受照護者適時地照護。

關鍵字：無線人體感測網路;藍牙;智慧型手機;照護監控系統;照護雲。

Abstract

Taiwan has gradually entered its aging society. Her elderly population, including those who can freely move and those who require long healthcare in bed, is still increasing on a yearly basis. Generally, physiological data as the health indicators of an elderly can effectively reflect his/her health status which in turn shows whether he/she has fully satisfied with his/her everyday life or not. A healthcare sensor system for elderly is a sensing system that serves elderly people with a wireless physiological sensor area network (WPSAN for short) and physiological sensors (Bio-sensors) to monitor their healthy conditions. The sensed physiological data is transmitted to an interface server which in turn sends the data to a remote healthcare server or a healthcare cloud. Currently, the volume and weight of the interface server is often far beyond conveniently portable and is consequently inconvenient for an elderly to handily carry it. Therefore, in this study, we develop a wireless physiological sensor architecture which integrates a Wireless Body Sensor Network (WBSN for short) and sensors to sense physiological data for an elderly, and then transmits the data to a remote healthcare cloud through a smartphone. The system also classifies the receiving data based on individual's personal ID and types of sensors, and stores the classified data in a healthcare cloud, from which healthcare givers can monitor the physiological data of an elderly via a healthcare monitoring system, and then timely give suitable healthcare to the elderly when necessary. We also set up personal physiological thresholds for individuals since physiological thresholds for different people vary. Once an elderly's physiological data is out of its normal range, an alarm will be triggered and an email or a short message will be sent to healthcare givers to attract their attention.

Keywords: Wireless Body Sensor Network, Bluetooth, Smartphone, Healthcare Monitor Subsystems, Healthcare Cloud

Acknowledgements

「無線生理感測器區域網路與應用」係研究生何季倫先生之研究論文，由其獨立完成理論撰寫與實作，論文研究期間感謝呂芳懌博士的建議、指導與提攜，提供資工系資料庫實驗室軟硬體設施，並指示出席多次相關研討會，俾不斷地修正研究方向與內容，同時邀請參與東海大學全球環境暨永續社會發展計畫(Global Research & Education on Environment and Society, GREEnS)專案計畫。本論文為其銀髮族優質行動照護生物感測與環境感測系統之研究的一部分。在研究初期，這些生理感測器的攜帶對銀髮族是一個問題,為減輕銀髮老人的負荷,乃將穿戴式微型生理感測器構想納入本系統的研究範圍，因而，可作為未來製定穿戴式醫療照護服裝標準之參考。此外，為研究如何從各項感測器取得生理訊號，並傳送至後端伺服器或醫療雲之資料庫，本研究進行生理感測資料之採集、過濾、分析和整彙等流程之研究，並逐一解決所遭遇的問題，以致獲得良好的研究結果與成效。亦感謝本校資訊工程學系楊朝棟老師傳授雲端運算的基礎環境與虛擬化技術，最終建立一套醫療監控照護雲管理系統，讓個人獲益良多。

經過兩年多的長期累積且專注於研究工作，感謝內人的耐心打理家庭事務和子女，並協助美工圖案設計及給予本人撰寫論文的支持。一切盡在不言中，由衷心地說出謝謝。

Table of Contents

List of Tables

List of Figures

Chapter 1. Introduction

Physiology signals are healthy indicators showing whether a person's organs operate normally or not. When an elderly's physiology data is abnormal, some of his/her organs often have a problem or trouble and need to be medically treated. If we do not treat them timely, it may threaten the elderly's life, or trigger some events that we do not like to see, e.g., paralysis due to his/her high blood pressure, etc. In fact, if we can effectively utilize high-tech products to monitor an elderly person's physiological functions at any moment, it would be able to reduce unnecessary tragedy. Table 1 lists three diseases with the corresponding physiological data, from which we can see that a disease is often accompanied by some abnormal physiological indexes.

Table 1. Relationship between physiological measurements and three diseases [1]

Physiological measurements	Congestive heart disease	Diabetes	Asthma/chronic obstructive pulmonary disease
Weight	○	○	
Blood pressure	○	○	
Heart rate	○		
Body temperature	○		
Blood sugar		○	
Blood oxygen concentration			○
Lung function			○

In a traditional healthcare procedure, for knowing the health condition of a healthcare receiver, healthcare staffs first measure his/her basic life indexes, including body temperature, blood pressure, etc. But when necessary, they will further measure his/her blood oxygen, pulse and heart beat rate, etc. But, in a hospital, to monitor elderly people's physiological signals, healthcare staffs may often go back and forth frequently between the elderly people's patient rooms and the nursing stations. This often consumes a lot of labour and operating costs. The Wireless Body Area Network (WBAN) is then developed based on a wireless network system to meet the requirement of long-term healthcare. The development not only enables healthcare receiver to move and act freely without being limited to the location where the measurement equipments are placed, but also allows healthcare staffs to remotely monitor and interprets the healthcare receivers' physiological conditions. If the physiological data is abnormal or even some people's critical situations have been serious, healthcare staffs can know that immediately, and process the urgencies real time.

Therefore, in this study, we purpose a Wireless Physiological Sensor Area Network (WPSAN), called Mobile Physiological Sensor Network (MoPSN for short), which consisting of a body sensor network, a wireless network and a healthcare cloud is developed to detect the physiological data of healthcare receivers through a variety of physiological sensors. The data is then transmitted to the remote healthcare cloud. Due to employing a wireless system, the healthcare receiver can move and act freely without being tied to the location where the physiological sensors is placed and healthcare staffs can monitor the physiological information of healthcare receiver directly from the healthcare cloud so as to provide the required care or medical treatment when necessary to improve the healthcare quality for elderly people, and reduce the efforts and labors required for measuring physiological indices by healthcare staffs. Of course, it can also mitigate the chance for healthcare staffs to constantly round-trip between nursing stations and patient’s rooms where the healthcare receiver lives in. This system assumes that elderly people are put on a tight T-shirt with micro-biosensors, which will regularly or irregularly measure the healthcare receivers’ physiological data and transmit the data to a smart phone, which will simply show the data and then deliver the data to the healthcare cloud.

The rest of this paper is organized as follows. Chapter 2 describes the background of the research and reviews related literature. Chapter 3 introduces the MoPSN. The simulations and their results are presented and discussed in Chapter 4. Chapter 5 concludes this paper and outlines our future studies.

Chapter 2. Research Background and Related Literature

In recent years, developing a system which integrates various physiological sensors and the wireless body sensor network (WBSN) to measure a patient's physiological indexes is one of the hottest research topics in information domain. These physiological sensors include ECG sensor, blood glucose sensor, blood pressure sensor, heart rate/pulse sensor, body temperature sensor and oximetry sensor, which together in this study are called six key physiological sensors. Of course, the volumes of these sensors are not small. How to hide them in a wearable clothes in fact is an engineering challenge.

2.1. Wireless Protocols

Currently, many physiological sensors and receivers on market provide wireless transmission with ZigBee or Bluetooth protocol. The common advantages of them are low power, low electromagnetic wave strength and low cost. Since smartphones currently are only built-in Bluetooth without providing ZigBee protocol [2]. Therefore, the study chooses Bluetooth, meaning the MoPSN consists of the six key physiological sensors mentioned above with Bluetooth as their wireless protocol. In addition, a brain-wave sensor (EEG sensor) is also employed to detect healthcare receiver's EEG signal [3]. The brain-wave sensors and the six key physiological sensors together are called the seven key physiological sensors.

Bluetooth is transmitted in the 2.4 GHz band with transmission speed of 1MB per second, it can be set to encryption mode to encrypt transmitted messages. Compared to other wireless network protocols, it is not subject to electromagnetic interference. Due to low-power transmission, it is less harmful to human bodies [4].

Currently, Bluetooth has its own problems. First, its low power transmission can be easily interfered by other electronic devices of the same wireless band; Second, the brands of Bluetooth specifications are not fully compatible in the world [5].

2.2. Wearable Sensors

In the middle of 2000, the wearable products and technology have been successfully integrated. Lee [1,6] applied the wearable electrodes to detect ECG signal and the heartbeat pulse in 2010, and then transmitted the physiological data to a remote receiver through a wireless network. The healthcare staffs can read the data through a web browser.

In April 2014, the Industrial Technology Research Institute (ITRI) published a mobile health device, the physiological monitoring part of which provides the ECG technology developed by the ambulatory ECG's patch. The ECG continuously monitors heartbeat and breathing condition of a healthcare receiver in a real time and contactless manner. The ECG is attached to the place between chest and abdomen on body to measure ECG, body temperature and other physiological signals. During the measurement, it allows users to walk, go up and down stairs, stand up and crouch, chest or perform other daily activities. When the heartbeat rhythms are abnormal, the system issues a warning message to healthcare staffs via a phone or computer, aiming to reach the stage of portable care [7].

Currently, many wireless body sensor systems have been released to the market. Aziz et al. [8] and Lo et al. [9] proposed a BSN to match the clinically required physiological sensors of small size and low-power consumption fixed inside a clothes. The sensed data can be transmitted to a remote site for remote monitoring, alerting and control [10,11,12] through wireless communication. After that, this category of systems gradually is evolved into a wearable sensor system. [13] developed a wearable body sensing platform, called MIThril, which contains many sensing and transmitting components. These components sense physiological signals, enforce machine learning, utilize intelligent technology and integrate hardware/software applications to build a system which provides users with a platform that offers health information, and real-time communication. Pantelopoulos [14] in 2010 introduced a health monitoring system which has many wearable sensors, as a multi-purpose physiological monitor smart suit [15,16]. Healthcare receiver can use it to measure their physiological parameters, including temperature, breathing rate, ECG, heartbeat rate and pulse, etc., without requiring traditional electric conductive patch. The suit can be used to measure elderly people's and healthcare receiver's physiological data. Adnan et al. [17] proposed an evolution of wearable which has motivated various applications of Body Area Sensor Networks (BASN). The major requirements include human safety compatibility in terms of interoperability of nodes in a BASN compatible communication protocol, huge data storage, security and ease of use. But, some of these wearable sensors are designed for developing products for single healthcare receiver. Some are produced by a research institution, only suitable for those devices developed by the same institute. Also the physiological data collected by some of the sensors is transmitted from wearable sensors to the data collector through wired conducting lines, and cannot be easily integrated with the wireless physiological sensors.

Yeh [18] in 2013 proposed a method which transmits physiological signals through a wireless network. The signals are then converted to a series of data which is then transmitted to computer terminal via the Bluetooth protocol. After classification, the classified data is sent to drawing packages to display the data on the screen so as to facilitate the interpretation by healthcare staffs. But this system only sends the data to computer terminal, rather than to a mobile phone. This is not suitable for a freely moving elderly person who would like to go out.

But if we can substitute the computer with a smart phone and send the signals to back-end systems in real-time, then he/she can move freely.

In 2013, Maxim Integrated Corporation had made a Fit shirt with multiple embedded sensors, capable of measuring vital signs. The Fit shirt with embedded sensors can measured ECG, body temperature and the amount of user activity, providing healthcare institutions with a method to monitor the patient's vital sign continuously [19].

Lee et al. [20] also proposed a smart shirt which measures ECG and other physiological signals for continuous and real time health monitoring is designed and developed. The shirt mainly consists of sensors for continuous monitoring health data of a healthcare receiver via also wired conductive fabrics to access the physiological signals.

That is why in this study, we develop our own physiological sensor wireless area network. In fact, the wearable physiological sensors tailored in clothes can be made with the clothes together as an integrated one. In other words, they are hidden in the clothes. This can effectively increase their usage convenience, and is suitable for the elderly people. The system practically collects signals with different micro-chips, and transfers them to numeric data, so that the healthcare staffs can judge whether the healthcare receiver requires to enter his/her medical treatment procedure or not. Especially after integrating physiological sensors with WPSAN, we can contribute a high quality mobile care and a high reliable healthcare system to current healthcare society.

Chapter 3. WPSAN System Architecture

The MoPSN has three facets: sensing, communication and management. Sensing is to measure an elderly's physiological conditions with physiological sensors hidden in the wearable suit without influencing the elderly's movement and conformability. Communication is referred to the activities of delivering the physiological data and controlling instructions to an backend server through wireless networks, including wireless Bluetooth, WiFi, LAN and 3G/4G. Management represents that server-side is responsible for collecting, classifying and monitoring physiological data and warning healthcare staffs when the physiological data is abnormal.

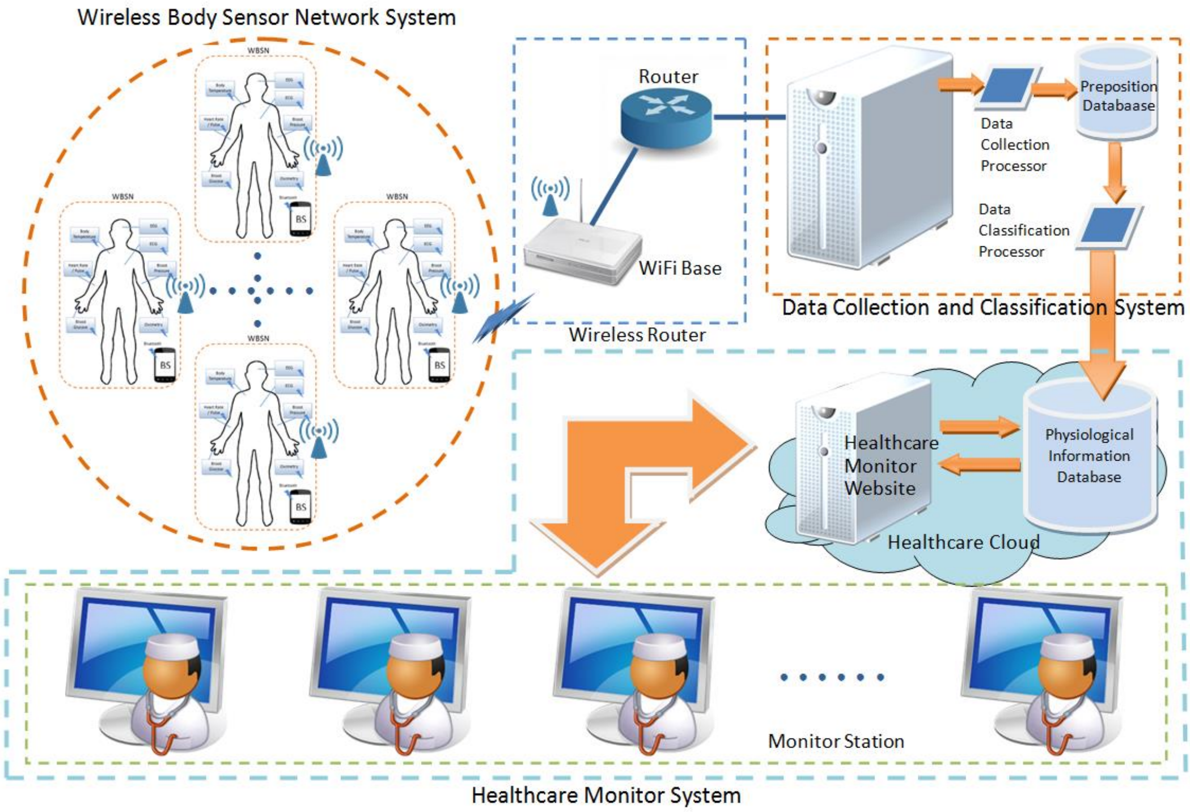


Figure 1. The MoPSN system architecture.

The MoPSN system architecture as shown in Figure 1 consists of a wireless body sensor network system (WBSNS), wireless network, data collection and classification system (DCCS), healthcare cloud and healthcare monitor system. The WBSNS senses the physiological data for healthcare receivers and sends it through the wireless network to the DCCS which collects the data and classifies the data according to individual healthcare receiver and sensors. At last, the classified results are stored in the healthcare cloud. The healthcare staffs can retrieve the physiological data of the healthcare receivers from the remote healthcare cloud and check their healthy conditions. The operating procedure of MoPSN system is shown in Figure 2, in which the left-hand side from top to down is elderly people, wireless body sensor network system, DCCS, healthcare monitor system and healthcare staffs. The wireless body sensor network system has three subsystems, including wearable physiological sensors, Bluetooth smartphone and LAN. DCCS contains Data collection server and data classification server. Healthcare monitor system has two subsystems, i.e., the healthcare cloud and healthcare monitor website.

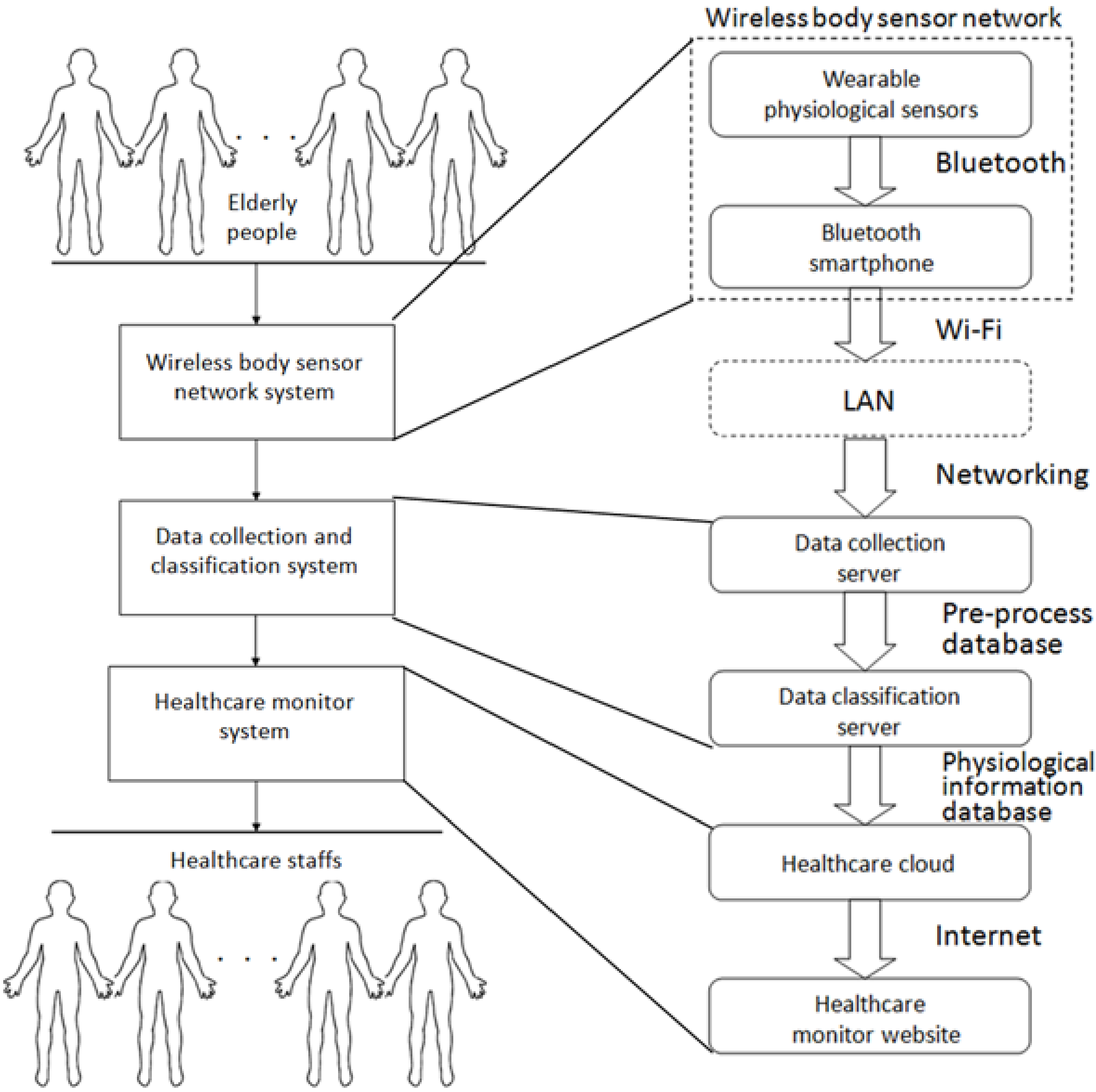


Figure 2. Subsystems of the MoPSN.

3.1. Wireless Body Sensor Network System

The wireless physiological sensors used to collect elderly people's physiological data can be divided into two categories, i.e., intrusiveness and non-intrusiveness. Non-intrusiveness is the sensors that sense the elderly people's physiological data from outside of their bodies. Sensors for monitoring body temperature and EEG are two typical examples. Intrusiveness sensors need to intrude into the elderly's body. Blood glucose sensor is an example.

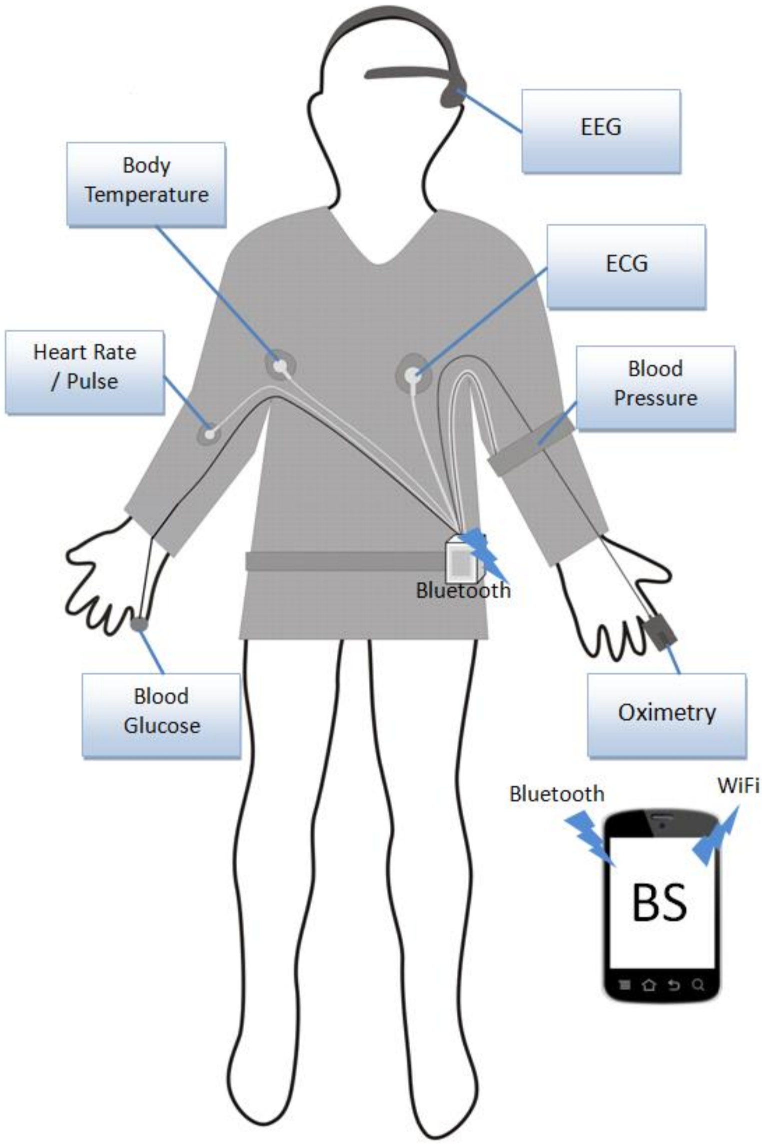


Figure 3. The wearable physiological sensors system architecture of the WBSN.

Our wearable physiological sensor system is a specific WBSN which as shown in Figure 3 is composed of different micro-physiological sensors, including body temperature, heart rate/pulse,…and oximetry sensors and Base Station (BS), in which BS is a smartphone with a built-in Bluetooth and a WiFi/3G/4G wireless protocol.

All micro-physiological sensors (or simply physiological sensors) are fixed and hidden at their own suitable locations in a tight T-shirt, in order to accurately measure physiological data. For example, the blood pressure sensor is placed in a hollow rubber cuff which is put around the upper arm or wrist of the healthcare receiver. The blood glucose sensor uses an intrusive way to prick a finger for a drop of blood, and put the drop of blood to blood glucose sensor. The temperature sensor is attached to either side of trunk or put under the armpit. The oximetry sensor and heart rate sensor is a small bag covering the forefinger or middle finger to measure blood transparency and the breath and pulse signals. The ECG sensor is attached to the body near the heart to obtain ECG waveform, the details of which are listed in Appendix A of this paper. The EEG sensor is contained in a headband and is touched to the healthcare receiver's forehead with a ear clip clipping on ear (grounding), to access four brain wave signals (i.e., β, α, θ, δ). The attributes of the four signals are shown in Appendix B.

3.1.1. The working flow of the WBSN

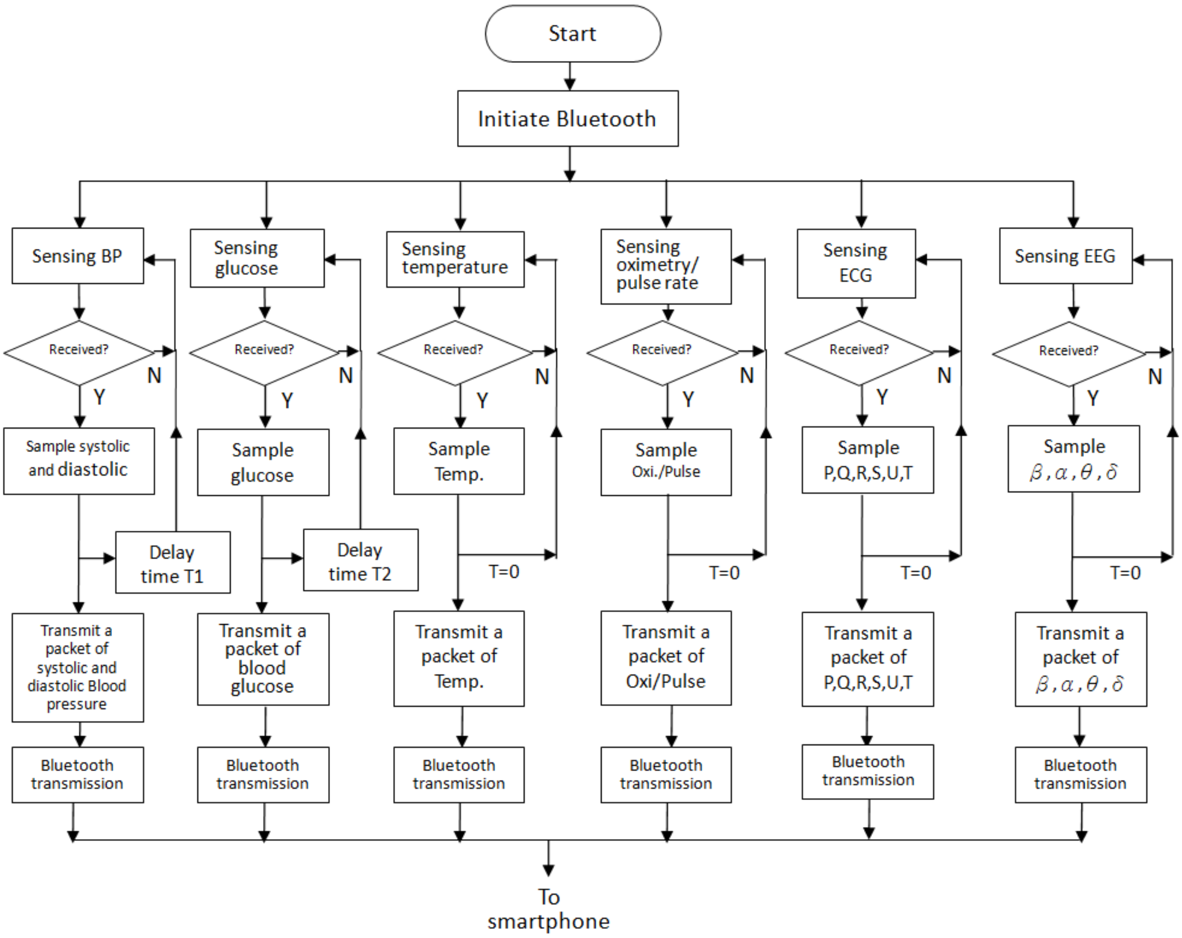


Figure 4. The working flow of the WBSN.

The initialization task of the WBSN is as follows. When a micro physiological sensor is started up, it initially connects itself to the BS to obtain BS's Media Access Control (MAC) address and password. After that, each time when the sensors are employed, no more initialization on the sensors is required. The working process of the WBSN is shown in Figure 4, in which when switching on, a sensor turns on its Bluetooth mechanism, starts sensing healthcare receiver's physiology signals, samples the signals to generate a packet and passes the packet to BS through Bluetooth.

The working processes of all sensors are similar. The only difference is the delay time (t) between two consecutive sampling. The delay times of blood pressure sensor and the blood glucose monitor are T1 and T2, respectively, T1,T2>0. The lengths of these delays are different based on their working characteristics. For example, blood pressure measurement interval is 12 or 24 hours. But the frequency of measuring blood glucose given a little drop of blood is measured twice or three times a day. Generally it is measured before and after a meal. Basically, other physiological sensors continuously measure and sample signals, i.e., T=0.

3.1.2. The working flow of the BS

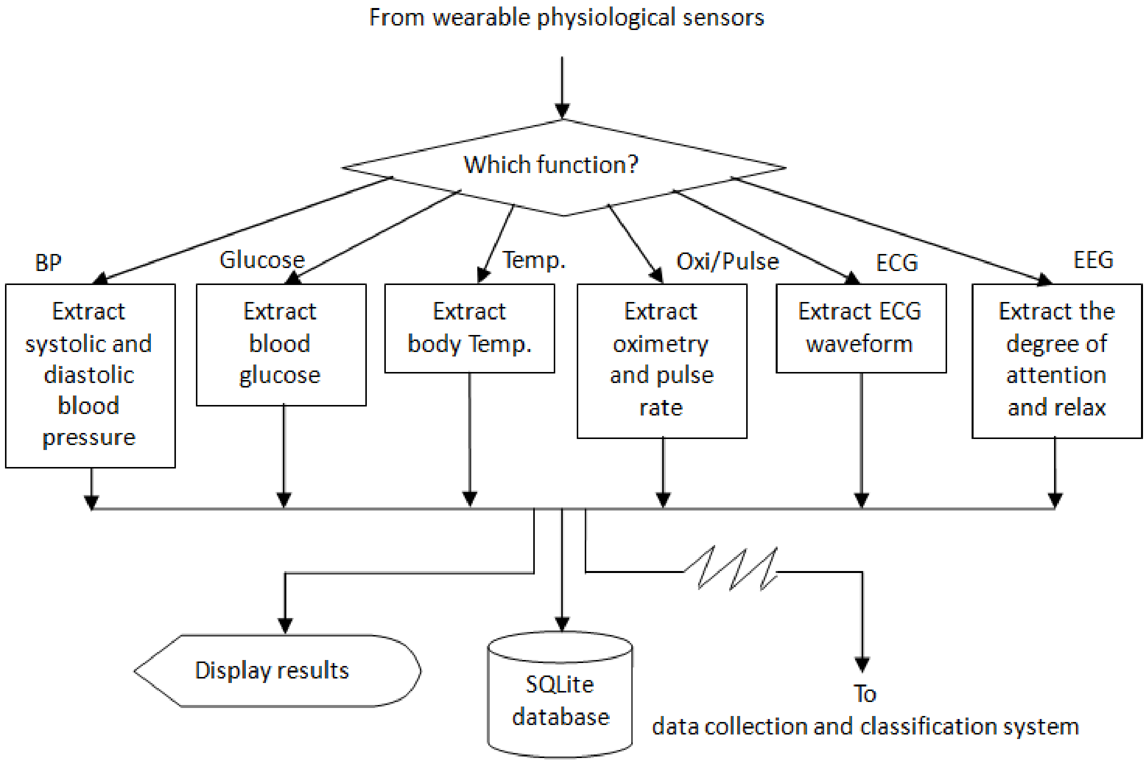


Figure 5. The working flow of the BS.

Figure 5 shows the working flow of the BS. After receiving all physiological packets, BS extracts required data from these packets, displays the results on its screen, saves the data in its local SQLite database and sends the data to the DCCS. Basically, each packet sent to BS by a sensor contains sensor device number and physiological information. The latter includes sensor type (ECG, EEG, BP, BT ...), and the date in which the physiological data is collected. The schema of the SQLite is shown in Appendix C of this paper. On the other hand, the BS has a built-in WiFi network interface card (NIC), through which the BS sends physiological packets to the DCCS via TCP/IP communication protocol.

3.2. The Data Collection and Classification System

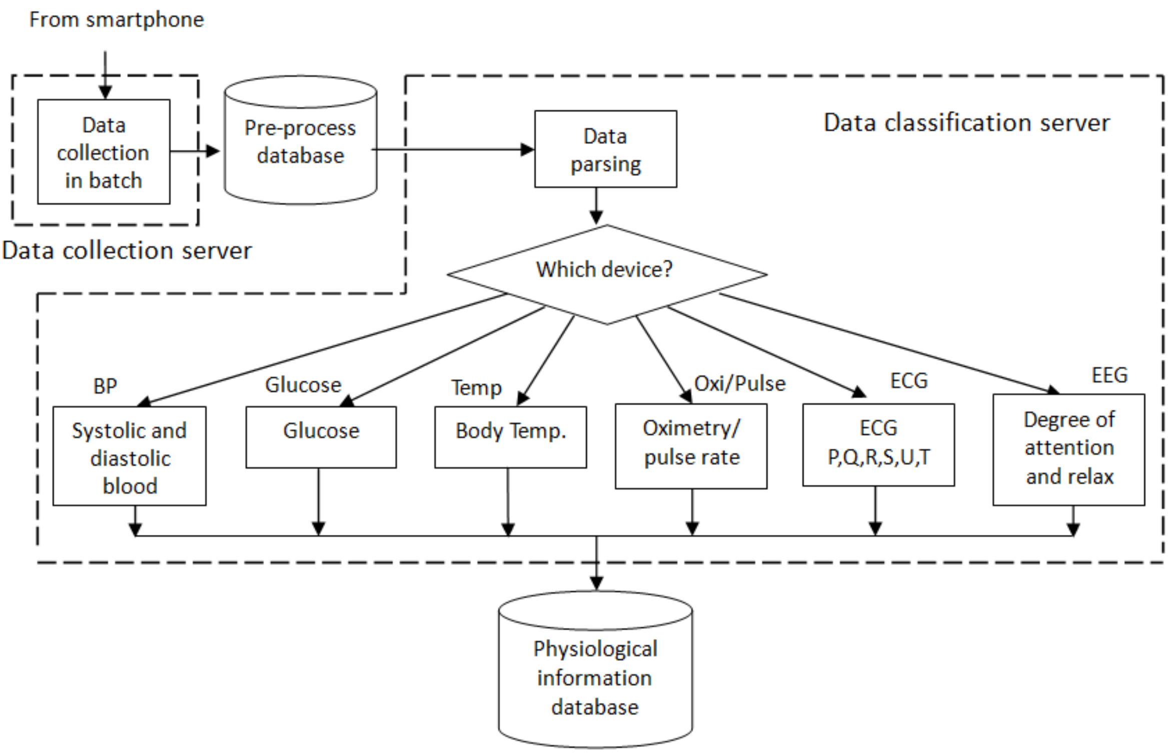


Figure 6. Data Collection and Classification System Flow.

The DCCS as shown in Figure 6 consists of a data collection server and data classification server. The former creates a pre-process database to store physiological data sent by the BS. The latter then retrieves the data from the pre-process database, parses and classifies the data and stores the classified data into a physiological information database.

In this study, parsing physiological data is to locate the required physiological data carried in a physiological packet and remove abnormal data, for example, incomplete data, or data values far out of their normal ranges. Further, data is classified based on sensor's device number, and sensor type (ECG, EEG, BP, BT ...). The former is used to identify who the healthcare receiver is, while the latter shows what physiological data it is. Of course, the data will be also recorded. For a person, different relation schemas for his/her different physiological data are listed in Appendix D: "SQL Server relation schemas" of this paper.

3.3. Healthcare Monitor System

As mentioned above, the healthcare monitor system consists of healthcare monitor Web site and healthcare cloud. Healthcare staffs can log in to the former anytime and anywhere to access and monitor the data stored in the latter so that they can timely provide the healthcare receiver with appropriate care or medical treatment when necessary.

3.3.1. Healthcare Monitor Website

Figure 7 shows the working flow of the healthcare monitor system, in which the webpage interface provides five basic query options, including real-time dynamics, status overview, device distribution, patient-healthcare-record and statistics graphs. Each option has seven sub-options, i.e., the seven key physiological signals. When users submit a part or all of the sub-options to the interface, the queried physiological information is displayed on the screen and refreshed every 5 seconds. Status overview lists all healthcare receivers' names and the corresponding seven key physiological data for each of them. Device distribution keeps the information, showing which device identified by its device ID is distributed to which healthcare receiver. Patient-healthcare-record shows healthcare receivers' healthcare records. The data shown includes sex, blood type, height, weight, blood pressure, heart rate range, blood glucose range, the date and time of the latest update, and note.

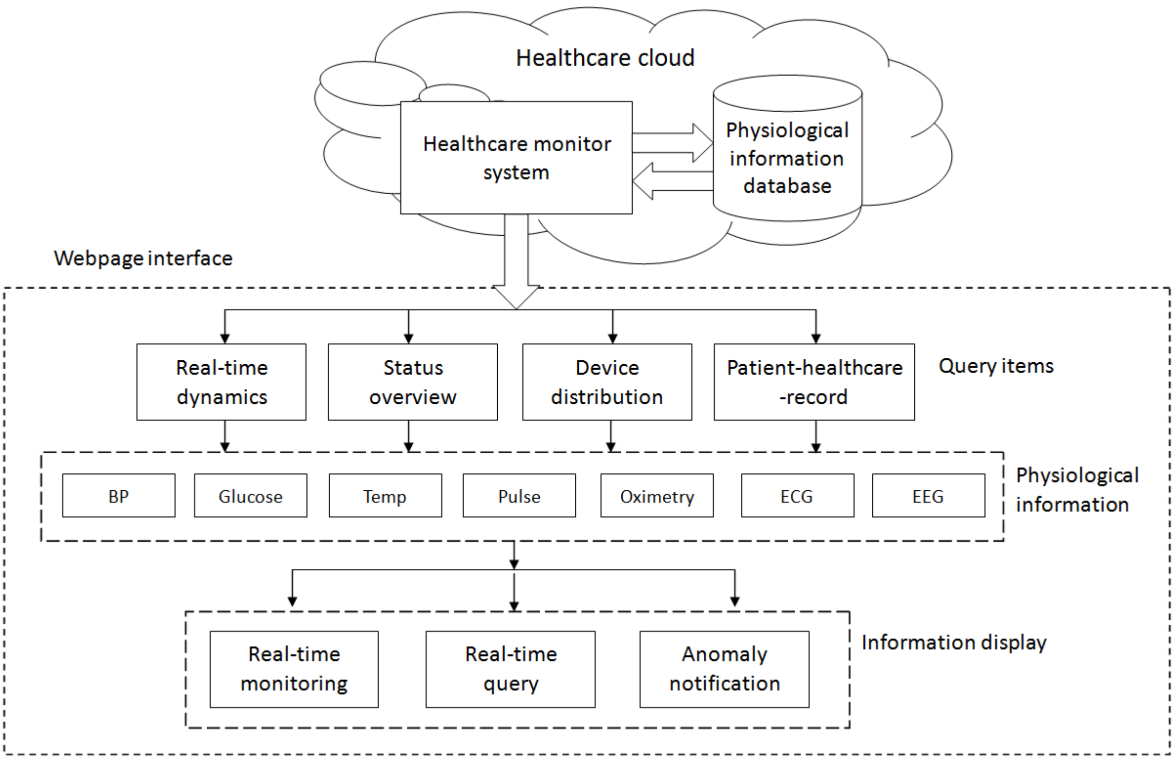


Figure 7. The Healthcare Monitor system's working flow.

In addition, the information display contains Real-time monitoring, Real-time query and anomaly notification. Real-time monitor shows the real-time physiological data which can be only a part or all of the seven key physiological data, for example, only monitoring blood pressure or heart rate. Real-time query retrieves physiological data that the monitored healthcare receiver has ever measured. Anomaly notification is the function which sends a warning message to healthcare staffs, telling them the emergent cases if the physiological data of the healthcare receiver is abnormally serious.

3.3.2. Healthcare Cloud

Cloud computing as an application of distributed computing connects a huge number of computation resources and storage space together through the Internet. It also divides a computation process into many smaller sub-processes, assigns them to servers for searching, operations and analysis, receives results from the servers and then sends the results to the user. Through this technology, the network service providers can process a large amounts of information in a short time period to make performance of the cloud to achieve the stage of a super-computer. Generally, cloud computing is a shared IT infrastructure, offering a large number of virtual servers, which link many computer systems together as a large resource pool to provide users with IT services. Since virtual servers are "virtual" resources. No matter whether the real computers are located locally or remotely, all can offer computing power and a large storage space with high portability, reliability and scalability. All services provided by a cloud are called cloud services which will be the applications for the next generation network services. Currently, many users share applications with others at the endpoints of a cloud. With these endpoints, users can access the services through browsers or other web techniques available in the cloud.

A healthcare cloud is a SaaS (Software as Service) cloud computing. Although we do not know the infrastructure and corresponding knowledge of a cloud, and do not know how to control its virtual machines, if we can migrate our websites and databases to a cloud, we can then enjoy cloud services, i.e., sharing its computing power and storage capabilities, to finish our tasks and achieve our goals.

We have built our healthcare cloud with Windows Azure [21], which as an open and flexible cloud platform can be deployed to manage applications across global data centers, integrate existing cloud platforms and IT environments, and set up their own service mechanisms, including virtual machines, cloud services, websites, mobile services, and SQL databases.

3.4. Application Development

All the sensors utilized by the MoPSN are manufactured by different manufacturing factories with different versions of Bluetooth protocols. Their hardware specifications are listed in the Appendix E of this paper. But only the minimum hardware requirements of memory and hard disk capacity for the Data Collection and Classification system are shown. But currently, the capacity of a hard drive is very huge. It would be able to meet the demand. But we need to pay to Microsoft monthly for establishing the healthcare cloud with Windows Azure. The payment includes the use of websites and databases.

The interface for transmitting physiological data from sensors to smartphone is developed by using the Eclipse development toolkit and JAVA for Android. The wireless protocol used is Bluetooth. The physiology data received is stored in the SQLite DB built in the smartphone.

The employed physiological sensors were manufactured by different factories and given different wireless brands. The firmware programs were developed with different program structures. The versions of the Android operating systems range from 2.0 to 5.0. To solve these problems, we design an Android framework based on MVC (Model View Control) mode [22,23]. Figure 8 shows the working flow of the WBSN service program in which the physiological data services are implemented with multithread to achieve multitasking, allowing them to carry out their own tasks synchronously so as to synchronize the tasks of receiving physiological data, display them on the BS screen simultaneously and update then in real-time.

On the left-hand side of Figure 8, the Service activation is used to activate the classes of services (Service classes), such as BO/HR class, BT class, BG class, etc., for all physiological sensors. In the following, XX represents one of the six class names. For example, XX may be BO/HR or BT. The purpose is to establish threads (namely Thread XX) to pair Bluetooth (namely Bluetooth XX) connection, and sense physiology data (i.e., Get XX Data) with a loop. After that, it notifies data receiver (Data Receiver, DR) by broadcasting these sensed data (namely Broadcast XX). The DR function is to update the sensed data with newly sensed value or waveform content and synchronize the data shown on the BS screen. At last, the onDestory() on the left-hand side of Figure 8 is utilized to call for onDestory() XX, which is on the right-hand side of this figure, for its thread to release the occupied memory, turn off its Bluetooth mechanism and stop sensing physiological data.

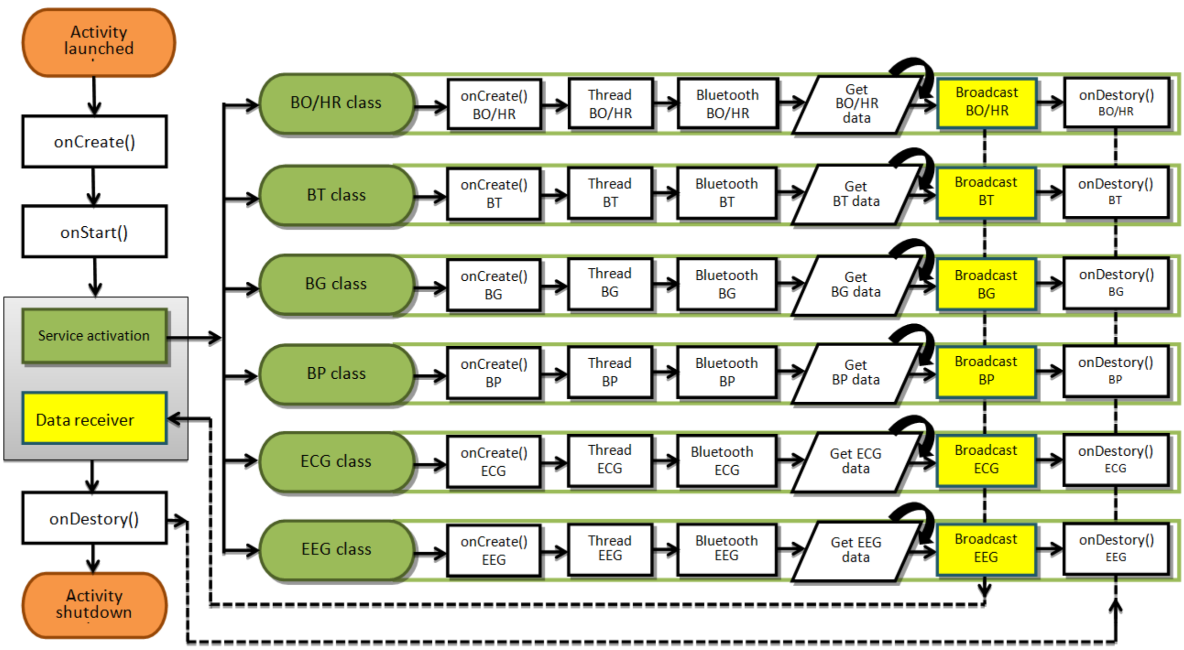


Figure 8. The working flow of the WBSN Service Program.

BS sends physiological data received to the Data Collection and Classification Subsystem which is implemented by using C# for Windows programming through the wireless TCP/IP protocol. The Healthcare monitor system is designed with ASP.NET MVC web.

Chapter 4. Experimental and Results

In this study, three experiments were performed to evaluate the MoPSN. The attributes of physiological sensors are listed in Table 2.

Table 2. Attributes of physiological sensors

Sensor name	Signal	Data packet	Connection method
ECG micro wireless heartbeat sensor and temperature sensor	ECG, and Body temperature	data	Wireless Bluetooth
Watch-style Oximetry monitor	Concentration of blood oxygen and Heart rate	data	Wireless Bluetooth
Blood pressure sensor	Diastolic pressure and Systolic pressure	data	Wireless Bluetooth
Blood glucose sensor	Blood glucose	data	Wireless Bluetooth
Head wearable EEG sensor	Degree of paying attention and degree of relax	data	Wireless Bluetooth

Our implementation integrates all components of the MoPSN and establishes personal physiological data's reference values [24,25,26]. When the data is out of its reference values, the monitor system will send an alert to healthcare staffs and show the message on screen of the healthcare monitor system so that when the staffs are sitting in front of the screen, they can see the message immediately. The purpose is to inform healthcare staffs to quickly response.

4.1. The Wireless Body Sensor Networks System

4.1.1. The experimental system

In the WBSN, all sensors are attached to their designated locations on a human body. Each sensor transmits sensed data to BS fastened on the belt at the healthcare receiver's left-hand side of body through Bluetooth. The BS is responsible for transmitting commands to sensors and receiving the data fed back from these sensors. The feedback data can be divided into two types, one-time feedback and continuous feedback. The former is applied to the sensors, whose time interval between two adjacent measurements is longer, such as 12-hour or 24-hour. Blood pressure and blood glucose are typical examples. The latter is suitable for those with very short measurement time interval, or even continuous measurements. The heart rate and blood oxygen monitors are of this category.

The interaction between BS and sensors is shown in Figure 9. BS first triggers sensors by sending commands to them and receives physiological data from sensors. The commands can be divided into two types, initiative commands and passive commands. Initiative commands are submitted when users need sensors to continuously sense data within a specified time interval and receive the data immediately, e.g., querying ECG data. Passive commands are delivered to sensors when users want the designated sensors to send physiological data to BS only once, e.g., requesting BP data.

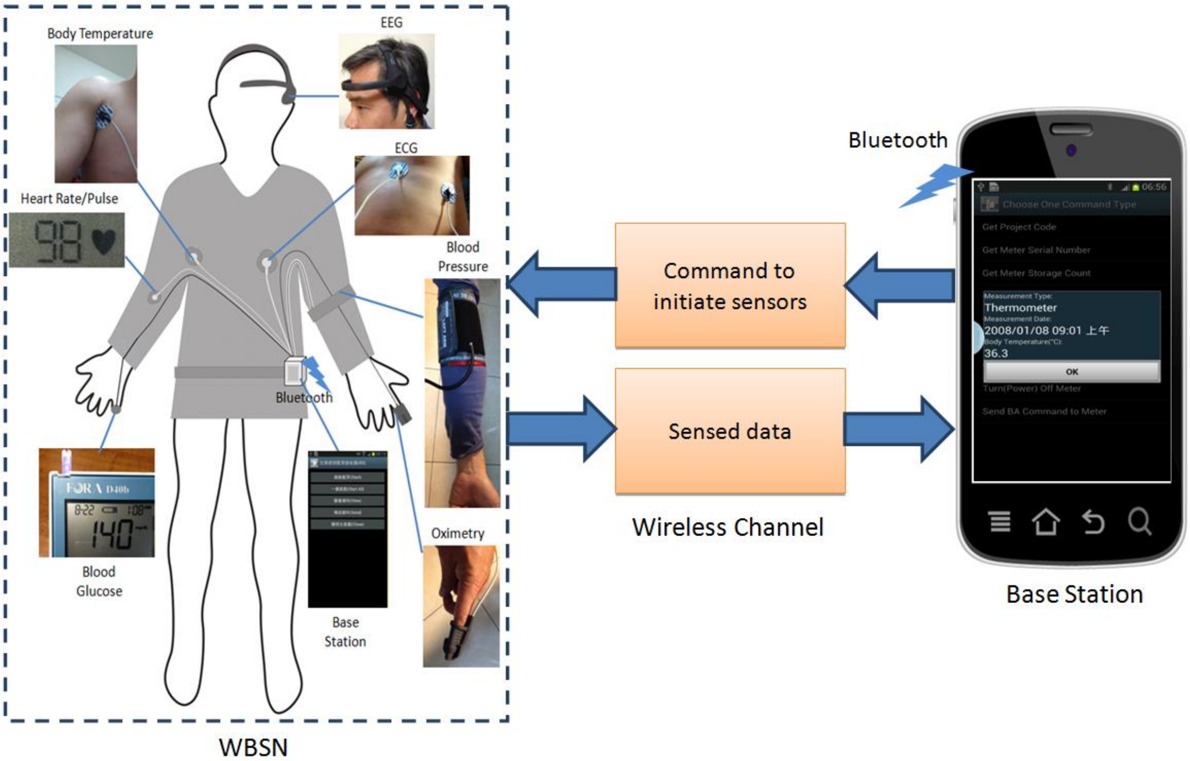


Figure 9. The interaction on which BS sends an execution command to sensors and receive sensed data from sensors.

In fact, some data conveyed in the messages transmitted by sensors to BS is not what we want. Therefore, we only retrieve the required information. We use the oximetry and heart rate sensor as an example. Figure 10 shows the transmitted messages in which the required physiological data is marked. Each received message has a total of 5 frames. Each contains 31 rows. So the total length of a message is 155 (=5 frames x 31 rows) bytes. Figure 11 illustrates the physiological data table provided by Nonin Healthcare manufacturer, showing users that the length of useful data carried in a message is 125 (=5 frames x 25 rows) bytes. Therefore, we need to find out the exact positions of the 125 bytes from the 155 bytes. The data analysis table of physiological data is shown in Figure 12. We first identify STAT2, the value of which is 20 in Byte4 field as the start point. According to the technical document provided by sensor manufactures, the 6th bit of the STAT2 byte is High Quality Smart Point Measurement, which is the pointer of high-quality measurements, and the remaining bits are all 0. That is why the status value is 20_{16}. Next, we retrieve the SpO2-D which as the concentration of blood oxygen follows STAT2. In Figure 12, the value is 62_{16}(=98_{10}). Also at the seventh byte from STAT2, E-HR MSB high byte and E-HR LSB low byte can be found (see Figure 11) and in Figure 12. Their values are 00_{16} and $4B_{16}$(=75_{10}), respectively. They together are the heart rates. Figure 13 illustrating our data analysis and retrieval process shows how the oximetry and the heartbeat rate values are correctly accessed.

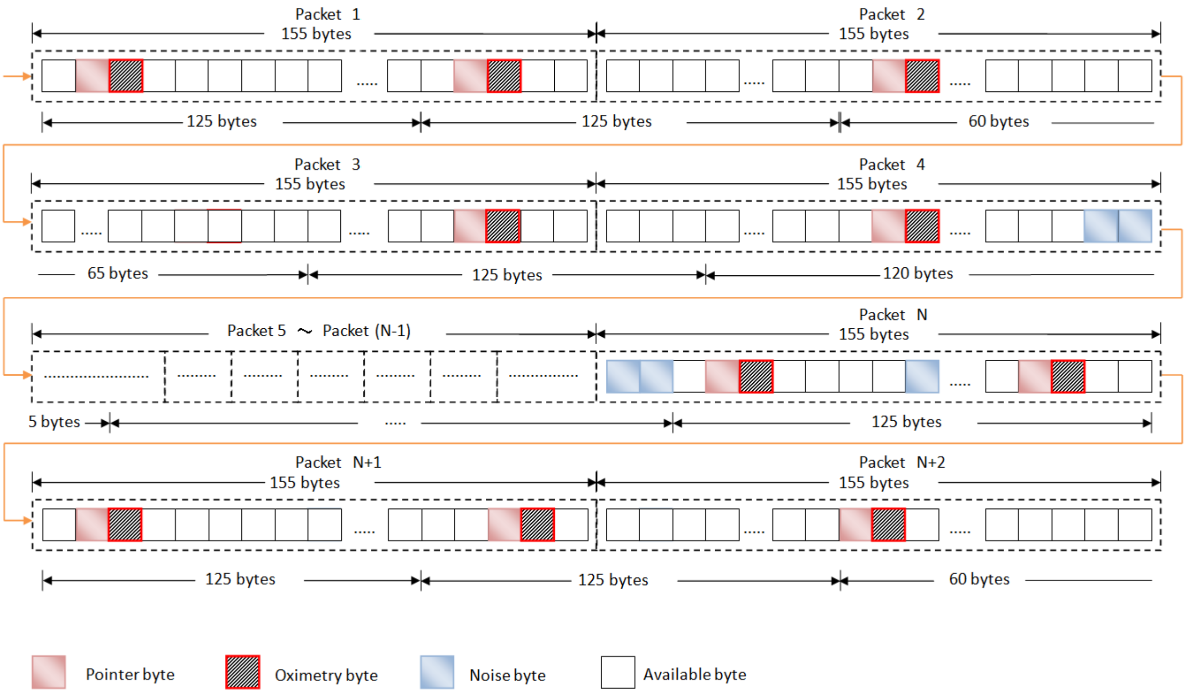


Figure 10. The transmitted messages from the oximetry and heart rate sensor to BS. The required data is marked.

Packet	Frame				
	Byte 1	Byte 2	Byte 3	Byte 4	Byte 5
1	STATUS	PLETH MSB	PLETH LSB	HR MSB	CHK
2	STATUS	PLETH MSB	PLETH LSB	HR LSB	CHK
3	STATUS	PLETH MSB	PLETH LSB	SpO_2	CHK
4	STATUS	PLETH MSB	PLETH LSB	SREV	CHK
5	STATUS	PLETH MSB	PLETH LSB	reserved	CHK
6	STATUS	PLETH MSB	PLETH LSB	TMR MSB	CHK
7	STATUS	PLETH MSB	PLETH LSB	TMR LSB	CHK
8	STATUS	PLETH MSB	PLETH LSB	STAT2	CHK
9	STATUS	PLETH MSB	PLETH LSB	SpO_2-D	CHK
10	STATUS	PLETH MSB	PLETH LSB	SpO_2 Fast	CHK
11	STATUS	PLETH MSB	PLETH LSB	SpO_2 B-B	CHK
12	STATUS	PLETH MSB	PLETH LSB	reserved	CHK
13	STATUS	PLETH MSB	PLETH LSB	reserved	CHK
14	STATUS	PLETH MSB	PLETH LSB	E-HR MSB	CHK
15	STATUS	PLETH MSB	PLETH LSB	E-HR LSB	CHK
16	STATUS	PLETH MSB	PLETH LSB	E-SpO_2	CHK
17	STATUS	PLETH MSB	PLETH LSB	E-SpO_2-D	CHK
18	STATUS	PLETH MSB	PLETH LSB	reserved	CHK
19	STATUS	PLETH MSB	PLETH LSB	reserved	CHK
20	STATUS	PLETH MSB	PLETH LSB	HR-D MSB	CHK
21	STATUS	PLETH MSB	PLETH LSB	HR-D LSB	CHK
22	STATUS	PLETH MSB	PLETH LSB	E-HR-D MSB	CHK
23	STATUS	PLETH MSB	PLETH LSB	E-HR-D LSB	CHK
24	STATUS	PLETH MSB	PLETH LSB	reserved	CHK
25	STATUS	PLETH MSB	PLETH LSB	reserved	CHK

Figure 11. The physioloigcal data table provided by Nonin Healthcare manufacturer.

Packet	Frame					Frame					Frame					Frame				
	Byte1	Byte2	Byte3	Byte4	Byte5	Byte1	Byte2	Byte3	Byte4	Byte5	Byte1	Byte2	Byte3	Byte4	Byte5	Byte1	Byte2	Byte3	Byte4	Byte5
1	01	81	5D	00	DF	01	81	64	00	E6	01	80	5B	70	4C	01	80	5C	00	DD
2	01	80	5D	4C	2A	01	80	64	4C	31	01	80	5A	20	FB	01	80	5B	00	DC
3	01	80	5F	62	42	01	80	64	62	47	01	80	5A	62	3D	01	80	5B	4C	28
4	01	80	60	18	F9	01	80	64	18	FD	01	80	5A	62	3D	01	80	5B	62	3E
5	01	80	63	00	E4	01	80	63	00	E4	01	80	5A	61	3C	01	80	5B	62	3E
6	01	80	66	72	59	01	80	63	72	56	01	80	5A	00	DB	01	80	5B	00	DC
7	01	80	6A	39	44	01	80	62	5A	3D	01	80	5A	00	DB	01	80	5B	00	DC
8	01	80	6D	20	0E	01	80	61	20	02	01	80	5A	00	DB	01	80	5B	00	DC
9	01	80	70	62	53	01	80	60	62	43	01	80	62	4D	30	01	80	5B	4C	28
10	01	80	71	62	54	01	80	60	62	43	01	80	61	00	E2	01	80	5B	00	DC
11	01	80	72	62	55	01	80	5F	62	42	01	80	60	4C	2D	01	80	5C	4C	29
12	01	80	72	00	F3	01	80	5F	00	E0	01	80	5F	00	E0	01	80	5D	00	DE
13	01	80	71	00	F2	01	80	5E	00	DF	01	80	5F	00	E0	01	80	5E	00	DF
14	01	82	70	00	F1	01	80	5E	00	DF	01	80	5E	00	E0	01	81	61	00	E3
15	01	82	6F	4B	3D	01	80	5E	4B	2A	01	80	5D	4C	2A	01	80	64	4C	31
16	01	82	6E	62	53	01	80	5E	62	41	01	80	5D	62	40	01	80	68	62	4B
17	01	82	6D	62	52	01	80	5E	62	41	01	80	5D	18	F6	01	80	6C	18	05
18	01	82	6C	00	EF	01	80	5E	00	DF	01	80	5D	00	DE	01	80	6F	00	F0
19	01	82	6B	00	EE	01	80	5E	00	DF	01	80	5D	72	50	01	80	71	72	64
20	01	82	6A	00	ED	01	80	5D	00	DE	01	80	5D	71	50	01	80	72	73	66
21	01	82	68	4B	36	01	80	5D	4B	29	01	80	5C	20	FD	01	80	73	20	14
22	01	82	67	00	EA	01	80	5D	00	DE	01	80	5C	62	3F	01	80	72	62	55
23	01	82	66	4B	34	01	80	5D	4B	29	01	80	5C	62	3F	01	80	72	62	55
24	01	82	65	00	E8	01	80	5D	00	DE	01	80	5C	62	3F	01	80	71	62	54
25	01	80	65	00	E6	01	80	5D	00	DE	01	80	5C	00	DD	01	82	70	00	F3

Figure 12. The data analysis table of physiological data from the oximetry and heart rate sensor.

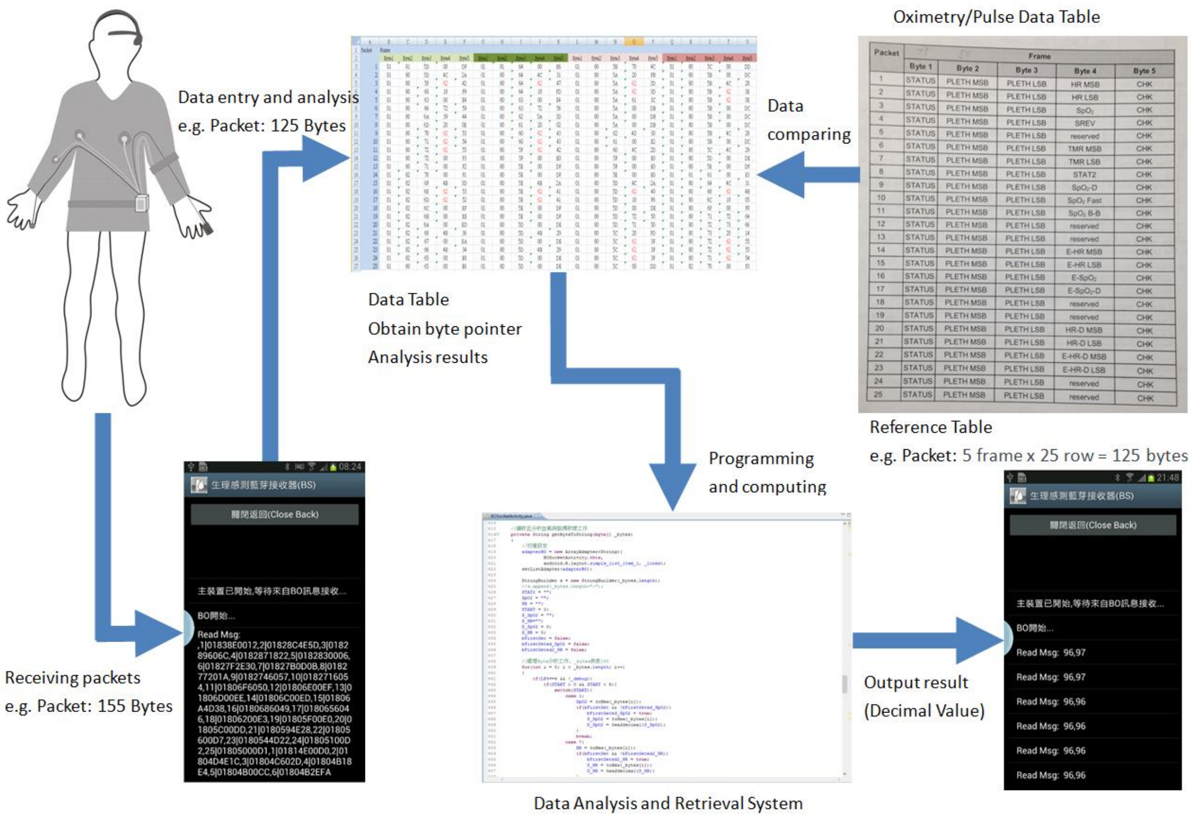


Figure 13. The working flow of our data analysis and retrieval process.

Because sensor manufacturers develop their own sensor control programs and build in the programming firmware, which is often their own intellectual properties, patents, or business secrets. So they do not provide source codes. We initially are unable to control and operate these systems. What we can do is receiving physiology data from sensors. Among the sensors, the blood pressure monitor transmits an one-time data, while the oximetry sensor sends continuous data after they are triggered due to the one-time and continuously measuring characteristics of their physiological data. Further, different sensors transmit data messages of different formats. In other words, how to unify the sensing activities for the sensors is one of the challenges.

Figure 14. BS screen shows sensing results of a person's physiological data.

In addition, as mentioned above, different sensors employ different Bluetooth versions. The firmware of different physiological sensors released by different sensor manufacturers is also different, and the Android versions on which these sensors' control systems were developed vary, thus increasing the difficulty of our system implementation, especially to synchronize the received messages on the BS for different physiological sensors. To synchronously display the data on the BS, we follow the service flow of WBSN shown in Figure 8 to implement the MoPSN. Each Android program developed for a physiological sensor is packed in a class, i.e., implementing them with service programs. Figure 14 shows a snapshot of the screen on the BS. The display is implemented by using a front-end program (Activity), while other services are implemented as background programs. In fact, a service is implemented by a thread so that various physiological data can be received and displayed synchronously, and Figure 15 shows seven participants whose physiological signals are measured by using the MoPSN.

4.1.2. The power consumption and RSSI strengths

Considering power consumption, these physiological sensors are connected to BS most of the time, while BS needs to receive and transmit packets through Bluetooth and WiFi. Therefore, the lifetimes of all there batteries have to be strengthened. Currently, their lifetimes can be enhanced by using mobile power. In the future, we would like to employ new green technology, such as solar energy cells, solar energy charger, wireless charger, dynamic energy generation, etc. We can also extend their time intervals between two physiological signal collection. This can further save more power.


(a) A schoolmate


(b) B schoolmate


(c) C schoolmate


(g) A participant are measured by using the MoPSN


(d) D schoolmate


(e) E schoolmate


(f) F schoolmate

Figure 15. Seven participants whose physiological signals were bing measured by the MoPSN.

On the other hand, these physiological sensors are attached to the bodies of elderly people. The strength of Bluetooth radio radiation around the radiation sources is about 1/800 of the strength of radio radiation radiated by a smartphone. To make sure the strength of radio radiation radiated by Bluetooth, we use the APP for RSSI measurement developed by Tamkang University at Taiwan [27] where RSSI stands for Received Signal Strength Indicator which tranfers the strength of received radio signal to the corresponding percentage, ranging from 1 to 100 with dbm as its unit. This measurement results are shown in Figure 16. When dbm value is smaller, the output power of this Bluetooth physiological sensor is lower.

Figure 16. The measurement results on Bluetooth radio radiation of different physiological sensors by using the tool for Bluetooth RSSI measurement which is an APP developed by Tamkang University, Taiwan.

Table 3 shows the RSSI strengths radiated by all sensors and WiFi router. We measured them at the distance of 10M or longer away from the tested sensors. When the distance exceeds 50M, the RSSIs from all sensors are zero. When the distance is zero, the RSSI strength is about -30 dbm. The lower the dbm value, the poor the RSSI strengths. Generally, when the value ranges between -20 and -60, the signal quality is good. If the value is between -60 and -80, the quality is sound. When the value is over -80, the signal quality is poor.

From the data shown in Table 3, our conclusion is that using Bluetooth for a long time, the elderly people's health is slightly influenced. But it would be better to stay far away from WiFi router since when the distance is 0, the RSSI strength is -10 dbm.

Table 3. The Bluetooth and WiFi radio radiations radiated by different physiological sensors. They are measured by using the tool for RSSI measurement provided by BS (- : no RSSI signal).

Distance (M)	BO,HR Sensor (dbm)	BP,BG Sensor (dbm)	ECG,BT Sensor (dbm)	EEG (dbm)	WiFi Router (dbm)
0	-30	-48	-47	-39	-10
1	-55	-63	-59	-57	-21
2	-65	-70	-71	-65	-33
3	-68	-75	-79	-71	-39
4	-71	-79	-82	-75	-45
5	-73	-82	-84	-77	-52
6	-73	-83	-87	-77	-55
7	-74	-83	-87	-77	-59
8	-76	-84	-88	-78	-62
9	-77	-84	-88	-79	-65
10	-80	-85	-88	-85	-68
15	-85	-86	-89	-87	-72
20	-85	-86	-89	-89	-76
30	-87	-87	-89	-89	-79
40	-	-90	-90	-90	-83
50	-	-91	-90	-90	-87
60	-	-	-	-	-91
70	-	-	-	-	-93
80	-	-	-	-	-95
90	-	-	-	-	-
100	-	-	-	-	-

4.2. The Data Collection and Classification System

Figure 17. A snapshot of the data collected by the data collection server of the DCCS.

Due to producing packets of different formats by different physiological sensors, on receiving packets from different sensors, BS needs to analyze the packets and retrieve the required data from different positions. Basically, a packet transmitted from a sensors to the BS includes device ID, physiological sensor type (BP, BG, BT, OX, HR, ECG, EEG), physiological values, sensed time and date, etc. from which BS can perform this analysis and corresponding data retrieval.

After showing physiological data received from sensors on the screen, BS sends the data to the data collection server of the DCCS, and stores the data in the pre-process database. Figure 17 shows the snapshot of the data collected by the data collection server. During data transmission, due to using a wireless network, the elderly people who are receiving healthcare can move freely. But, packets sent through a wireless access point and routers to the data collection server may be lost. Packet Loss Rate (PLR) is defined as follows.

$$PLR = (TPS - RPS) / TPS$$

where TPS and RPS, respectively, represent the number of transmitted packets and the number of received packets

This experiment has two parts, sending Ping packets and real data packets (messages) individually to the data collection server by BS through the wireless network with packet size = 1024 bytes. The amounts of packets delivered are 100, 1,000, 10,000 and 100,000. Table 4 shows the results, from which we can see that when the total number of transmitted packets is larger, the packet loss rates of real data packets are greater than those when ping packets are sent. The reason is that Ping packet is an ICMP packet. The probabilities with which they are blocked by firewalls and intrusion detection systems are low. Even they go through several routers, the probability is still low. The packet loss rates of physiological data sent to the data collection server is clearly higher than 0.5%, which is our tolerable packet loss rate. The packet loss rate is due to the fact that when a physiological data arrives, BS needs to take some time to store the data previously received in its SQLite database and transmits the data to the data collection server. During which, the receiving activities of the threads responsible for receiving physiological data from sensors may be affected. Newly arriving packets may be lost when the receiving queue is full, implying the programs for BS to receive physiological data through a socket need to be enhanced.

Table 4. Packet loss rates for sending Ping and physiological data packets to the data collection server by BS.

Amount of packets sent	Ping packet			Physiological data packet		
	Number of received packets	Number of lost packets	Packet loss rate	Number of received packet	Number of lost packets	Packet loss rate
100	100	0	0%	98	2	2%
1000	998	2	0.2%	974	26	2.6%
10000	9996	4	0.4%	9721	279	2.79%
100000	99953	47	0.47%	96900	3100	3.1%

4.3. The Healthcare Monitor System

The MoPSN is able to receive physiological data from different healthcare receivers simultaneously. It then classifies and sorts the physiological data, and stores the data in the healthcare cloud developed by using Windows Azure. This system also sets up the reference values for physiological signal. If the data is out of its normal range, the monitor system will issue a message to alert healthcare staffs. On the other hand, the dashboard of the MoPSN also provides administrators with the function of monitoring its web site operation. The healthcare monitor system also provides functions with which healthcare staffs can timely monitor healthcare receivers' physiological data.

Figure 18 shows an example of the six key physiological data of a healthcare receiver on the healthcare monitoring system in a real-time manner. The data shown is retrieved from healthcare cloud every 5 seconds, and displayed it on the screen. Figure 19 illustrates the real-time heart rate plots on healthcare monitoring system.

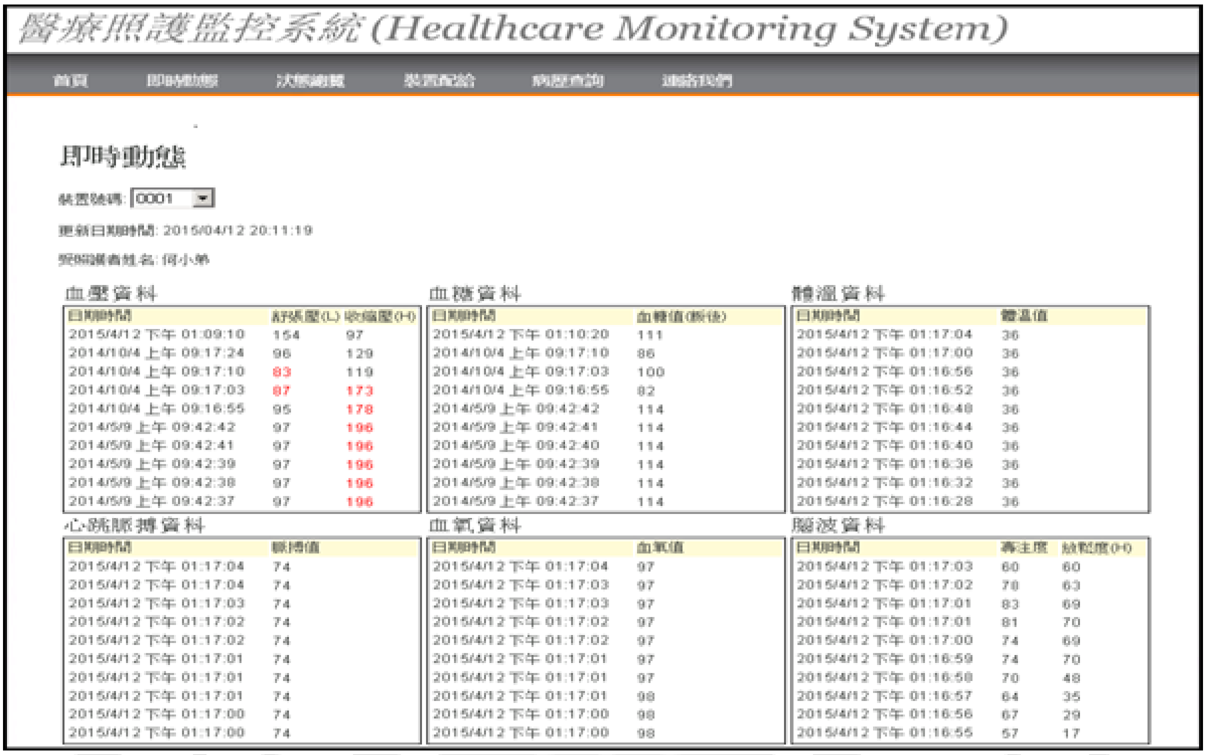


Figure 18. The six key physiological data of a healthcare receiver shown on healthcare monitoring system.

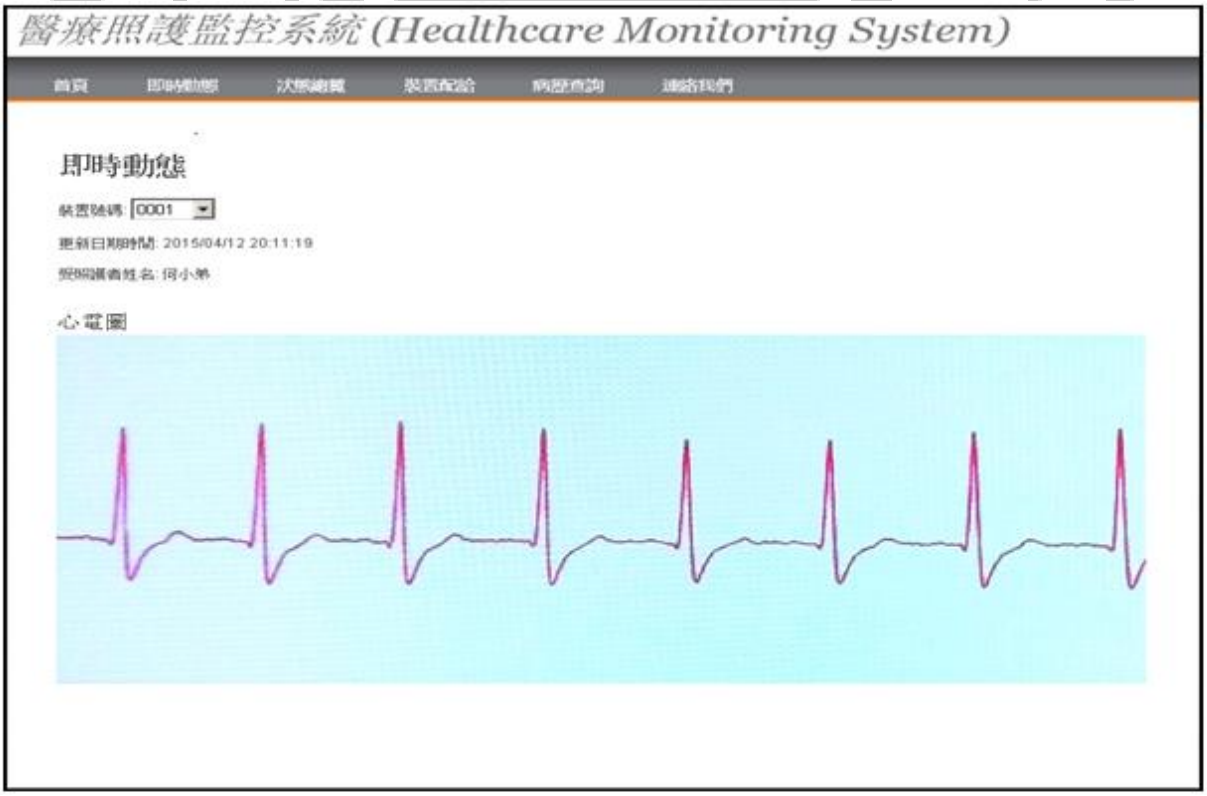
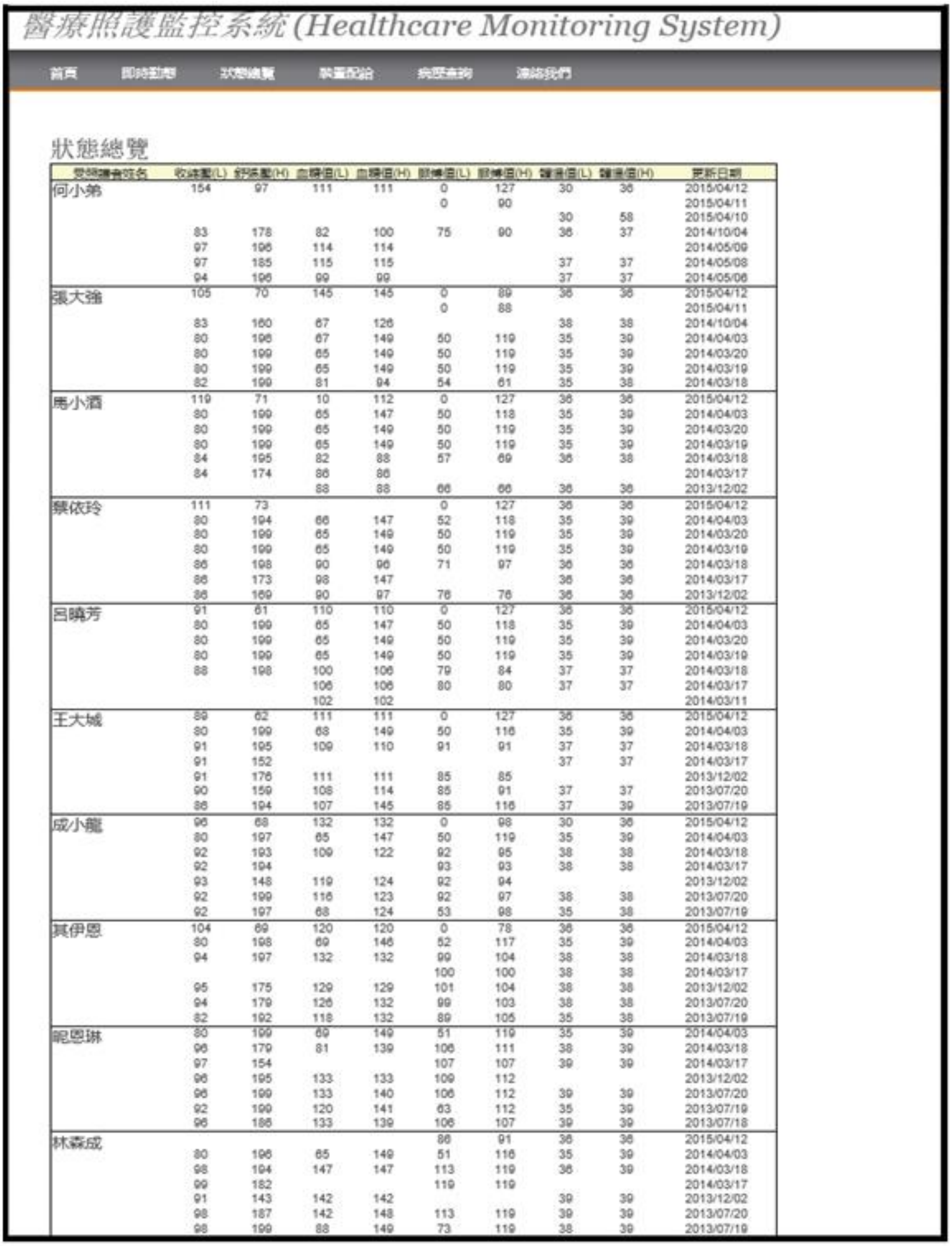


Figure 19. The heart rate plots of a healthcare receiver shown on healthcare monitoring system.

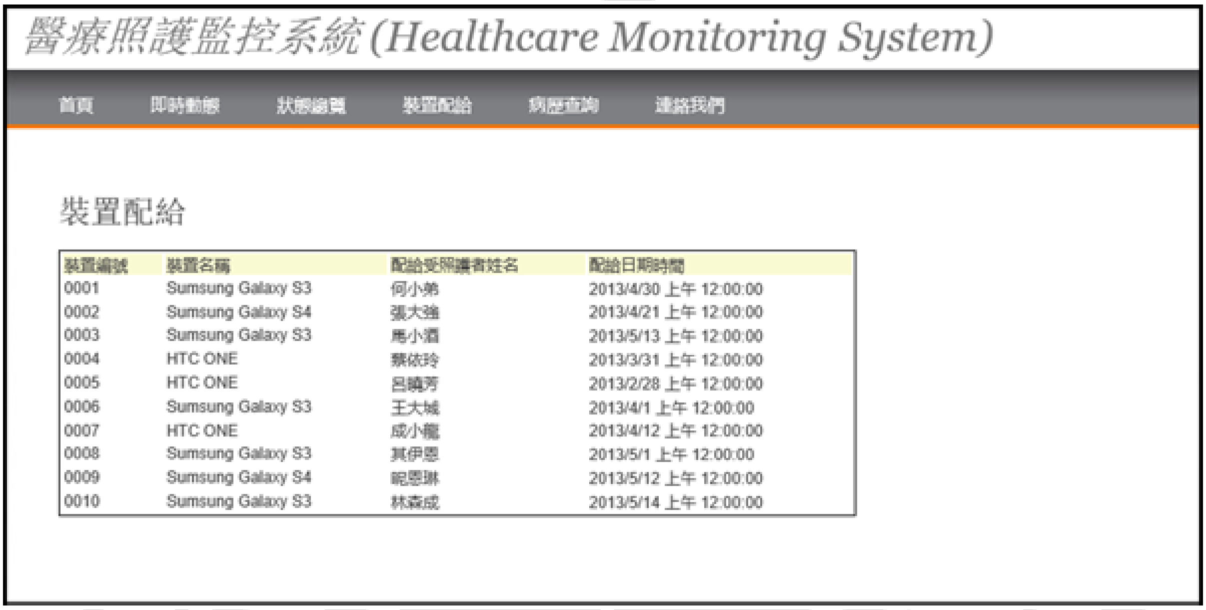
Figures 20 shows the overview of the physiological conditions of all healthcare receivers.



受照護者姓名	收縮壓(L)	舒張壓(H)	血糖值(L)	血糖值(H)	脈搏值(L)	脈搏值(H)	體溫值(L)	體溫值(H)	更新日期
何小弟	154	97	111	111	0	127	30	36	2015/04/12
					0	90			2015/04/11
							30	58	2015/04/10
	83	178	82	100	75	90	36	37	2014/10/04
	97	196	114	114					2014/05/09
	97	185	115	115			37	37	2014/05/08
	94	196	99	99			37	37	2014/05/06
張大強	105	70	145	145	0	89	36	36	2015/04/12
					0	88			2015/04/11
	83	160	67	126			38	38	2014/10/04
	80	196	67	149	50	119	35	39	2014/04/03
	80	199	65	149	50	119	35	39	2014/03/20
	80	199	65	149	50	119	35	39	2014/03/19
	82	199	81	94	54	61	35	38	2014/03/18
馬小酒	119	71	10	112	0	127	36	36	2015/04/12
	80	199	65	147	50	118	35	39	2014/04/03
	80	199	65	149	50	119	35	39	2014/03/20
	80	199	65	149	50	119	35	39	2014/03/19
	84	195	82	88	57	69	36	38	2014/03/18
	84	174	86	86					2014/03/17
			88	88	66	66	36	36	2013/12/02
蔡依玲	111	73			0	127	36	36	2015/04/12
	80	194	66	147	52	118	35	39	2014/04/03
	80	199	65	149	50	119	35	39	2014/03/20
	80	199	65	149	50	119	35	39	2014/03/19
	86	198	90	96	71	97	36	36	2014/03/18
	86	173	98	147			36	36	2014/03/17
	86	169	90	97	76	76	36	36	2013/12/02
呂曉芳	91	61	110	110	0	127	36	36	2015/04/12
	80	199	65	147	50	118	35	39	2014/04/03
	80	199	65	149	50	119	35	39	2014/03/20
	80	199	65	149	50	119	35	39	2014/03/19
	88	198	100	106	79	84	37	37	2014/03/18
			106	106	80	80	37	37	2014/03/17
			102	102					2014/03/11
王大城	89	62	111	111	0	127	36	36	2015/04/12
	80	199	68	149	50	116	35	39	2014/04/03
	91	195	109	110	91	91	37	37	2014/03/18
	91	152					37	37	2014/03/17
	91	176	111	111	85	85			2013/12/02
	90	159	108	114	85	91	37	37	2013/07/20
	86	194	107	145	85	116	37	39	2013/07/19
成小龍	96	68	132	132	0	98	30	36	2015/04/12
	80	197	65	147	50	119	35	39	2014/04/03
	92	193	109	122	92	95	38	38	2014/03/18
	92	194			93	93	38	38	2014/03/17
	93	148	119	124	92	94			2013/12/02
	92	199	116	123	92	97	38	38	2013/07/20
	92	197	68	124	53	98	35	38	2013/07/19
其伊恩	104	69	120	120	0	78	36	36	2015/04/12
	80	198	69	146	52	117	35	39	2014/04/03
	94	197	132	132	99	104	38	38	2014/03/18
					100	100	38	38	2014/03/17
	95	175	129	129	101	104	38	38	2013/12/02
	94	179	126	132	99	103	38	38	2013/07/20
	82	192	118	132	89	105	35	38	2013/07/19
昵恩琳	80	199	69	149	51	119	35	39	2014/04/03
	96	179	81	139	106	111	38	39	2014/03/18
	97	154			107	107	39	39	2014/03/17
	96	195	133	133	109	112			2013/12/02
	96	199	133	140	106	112	39	39	2013/07/20
	92	199	120	141	63	112	35	39	2013/07/19
	96	186	133	139	106	107	39	39	2013/07/18
林森成					86	91	36	36	2015/04/12
	80	196	65	149	51	116	35	39	2014/04/03
	98	194	147	147	113	119	36	39	2014/03/18
	99	182			119	119			2014/03/17
	91	143	142	142			39	39	2013/12/02
	98	187	142	148	113	119	39	39	2013/07/20
	98	199	88	149	73	119	38	39	2013/07/19

Figure 20. The overview of the physiological conditions of all healthcare receivers.

Figure 21 shows the device-allocation list for healthcare receivers. In this list, a device is a unit, telling us which wearable device is allocated to which healthcare receiver. The schema of the list includes device number, device name, user (the healthcare receiver) and the date the device is allocated the this user.

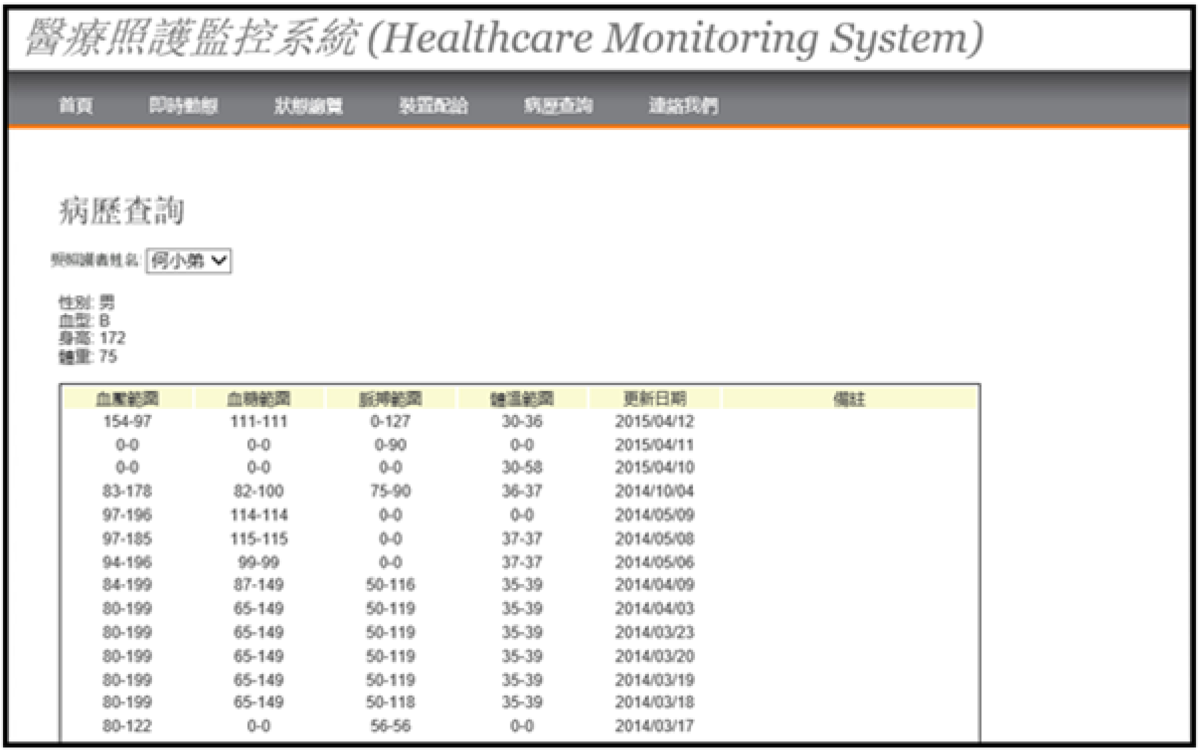


裝置編號	裝置名稱	配給受照護者姓名	配給日期時間
0001	Sumsung Galaxy S3	何小弟	2013/4/30 上午 12:00:00
0002	Sumsung Galaxy S4	張大強	2013/4/21 上午 12:00:00
0003	Sumsung Galaxy S3	馬小酒	2013/5/13 上午 12:00:00
0004	HTC ONE	蔡依玲	2013/3/31 上午 12:00:00
0005	HTC ONE	呂曉芳	2013/2/28 上午 12:00:00
0006	Sumsung Galaxy S3	王大城	2013/4/1 上午 12:00:00
0007	HTC ONE	成小龍	2013/4/12 上午 12:00:00
0008	Sumsung Galaxy S3	其伊恩	2013/5/1 上午 12:00:00
0009	Sumsung Galaxy S4	昵恩琳	2013/5/12 上午 12:00:00
0010	Sumsung Galaxy S3	林森成	2013/5/14 上午 12:00:00

Figure 21. Device allocation list for healthcare receivers.

Figure 22 illustrates an example of healthcare-record query for a healthcare receiver. The results include the healthcare receiver's sex, blood type, height, weight, blood pressure range, heart rate/pulse range, blood glucose range, updated date, note, etc.

When the healthcare receiver has an emergent condition, the monitoring system besides continuously collecting the receiver's physiological data, also checks the emergent message to see what happens to this healthcare receiver. For example, his/her oxygen concentration is lower than its low limit, i.e., 80, the body temperature is higher than 38 degrees centigrade, or the electrocardiogram ST surge is abnormal. The purpose is to give a help to and rescue the healthcare receiver appropriately and timely.



血壓範圍	血糖範圍	脈搏範圍	體溫範圍	更新日期	備註
154-97	111-111	0-127	30-36	2015/04/12	
0-0	0-0	0-90	0-0	2015/04/11	
0-0	0-0	0-0	30-58	2015/04/10	
83-178	82-100	75-90	36-37	2014/10/04	
97-196	114-114	0-0	0-0	2014/05/09	
97-185	115-115	0-0	37-37	2014/05/08	
94-196	99-99	0-0	37-37	2014/05/06	
84-199	87-149	50-116	35-39	2014/04/09	
80-199	65-149	50-119	35-39	2014/04/03	
80-199	65-149	50-119	35-39	2014/03/23	
80-199	65-149	50-119	35-39	2014/03/20	
80-199	65-149	50-119	35-39	2014/03/19	
80-199	65-149	50-118	35-39	2014/03/18	
80-122	0-0	56-56	0-0	2014/03/17	

Figure 22. A healthcare-record query of a healthcare receiver.

Figure 23 shows the Healthcare Cloud's management center implemented by the Windows Azure. It was built at a website called healthcare-web for healthcare cloud, providing Azure system managers with a dashboard to monitor the service capacity, and performance bottlenecks of the cloud, and check to see whether it can expand its service capacity when necessary. With which, system managers can also observe status of the web site operation on healthcare cloud, e.g., CPU usage time, HTTP server errors, data input, data output, and so on. Figure 24 illustrates an example of the monitoring system's operational statuses which display the resource usage status of healthcare-web site server, indicators, including CPU usage (%), disk read speed (bytes/sec), disk write speed (bytes/sec), network receiving (k bps) and network transmitting (k bps) in the past and present. The x-axis is time. If they are high, representing that the resources cannot sufficiently support further website activities.

Figure 23. The Windows Azure management center of the healthcare cloud.

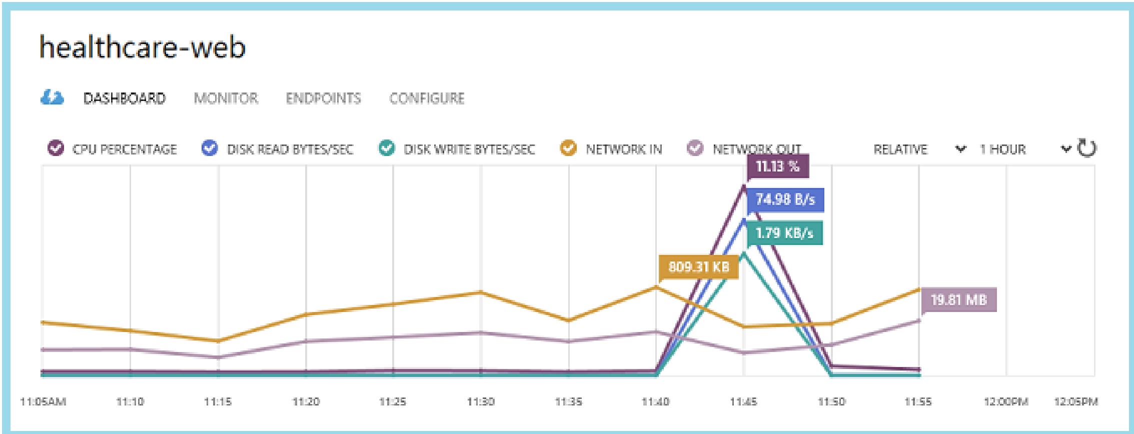


Figure 24. Monitoring system operational status of the healthcare cloud.

Chapter 5. Conclusions and Future Work

In recent years, with the trend of an aging society, we can see that in the near future, substantial human and material resources need to be invested to take care of aging population. On the other hand, due to the quick development of electronic technology, if our high technology products can substitute for the healthcare manpower, the demand for social care workforce will be significantly reduced. Traditionally healthcare staffs need to regularly monitor the physiological signals of elderly people. They often rush between the elderly people setting rooms and the healthcare room (or nursing station). In this study, a body area network is utilized to remotely monitor the physiological data for healthcare receivers. The healthcare staffs can analyze the data on server side. When an abnormal physiological condition occurs, the staffs can reach the elderly and give him/her an appropriate care when necessary. This study also constructs a wireless physiological sensor area network. Currently medical equipments are developed towards highly integrated ones with the characteristics of easy to use, highly secure, small size and low power consumption to reduce the burden of wearing these wearable physiological devices.

Currently, Healthcare systems are not popularly used in the world, due to the reasons, including the costs of the required equipments are high, healthcare receivers' historical data may be stolen easily, after being measured, the input and operation of the data collection server is not an easy task, and the healthcare system is often not compatible with hospital information systems and is hard to integrate. But the MoPSN combines the portability of smart phones, the convenience of using WiFi/wireless LAN, and the advantages of wireless sensor systems and cloud system, aiming to improve the functions and remove the drawbacks of traditional healthcare service systems. Our healthcare monitor system has the following characteristics:

(1) Real-time:

This system can continuously monitor healthcare receivers' physiological data and work for a long time, thus letting healthcare receivers' physiological data be continuously collected and stored in the healthcare cloud. When the health condition of the healthcare receiver is poor, the MoPSN can real-time send out a warning message to notify healthcare staffs to immediately respond, so as to avoid the delay and the deterioration of healthcare services.

(2) Reducing the direct manpower:

Because the healthcare staff does not spend a lot of time around healthcare receivers, and they reach the healthcare receivers only when they need help. So this can significantly reduce the required manpower labour and other healthcare resources.

(3) Connecting to the MoPSN anytime and anywhere:

The wireless networks have been developed rapidly in recent years. A lot of people have their own smart phones. The information of the MoPSN is sent to the healthcare cloud through wireless networks. Therefore, as long as there is a device that can be connected to the Internet (smart phone via WiFi), the user can then connect himself/herself to the MoPSN and access the information stored the healthcare cloud, of course, ought to be under the condition of legal authorization.

At present, the cloud computing technology has been significantly improved and developed. In this study, the healthcare service is monitoring elderly people's physiological statuses through the cloud. This brings information technology into healthcare services to strengthen the information flow and analysis and provide exception monitoring to effectively improve the quality of healthcare and increase the health level of elderly people. Meanwhile, the wearable monitor system can also provide elderly people with more than the freedom and space of their own lives and enhance the levels of their living.

Taking a comprehensive view of the healthcare institutes and the development of physiological sensors' manufacturers, the related technology and services of remote healthcare can be used as healthcare advice, both from the viewpoints of physiological signal monitoring, and multiple physiological-parameter collection, saving, analysis and exchange. Basically, from the viewpoint of hospital, institution, community and home, the MoPSN integrates all of them together as a novel healthcare system to effectively monitor the elderly people's physiological status. We expect that this study can attract private businesses and/or government to continuously invest or conduct other healthcare and medical services, and integrate information services and healthcare services to create a new healthcare service environment. Healthcare has been recognized as a future star industry. We study this innovative information application of healthcare service, wishing to enlarge the economic scale and the efficiency of our healthcare society so as to improve the elderly people's everyday lives.

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Appendix A. The attributes of ECG waveforms

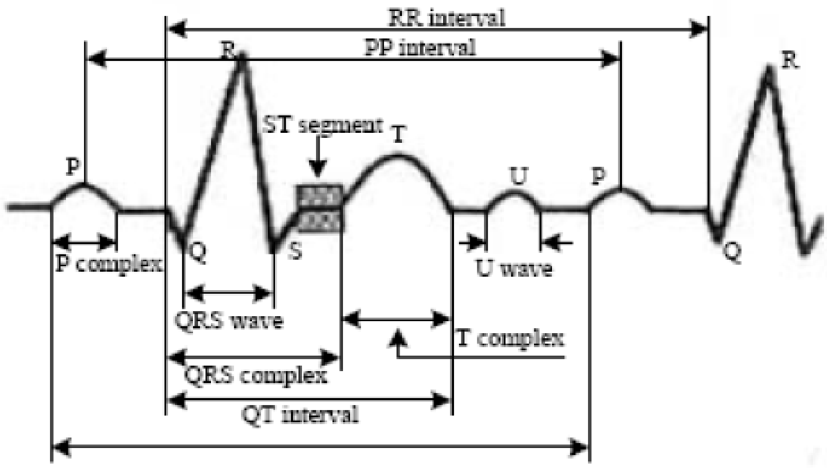


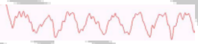
Figure A-1. ECG Signals[28,29]

Table A-1. Attribute of ECG[28,29]

Name	Wave description	Out of range
P wave	Results of atrial contraction, normally less than 0.12 seconds	Thickening of the atrial hypertrophy
QRS complex wave	Ventricular depolarization, normally no more than 0.11 seconds	Atrioventricular block
Q-T interval	1. left and right ventricular depolarization and Repolarization time 2. normal values of approximately 0.41 seconds	
U wave	Intraventricular Purkinje fiber polarized	
R-R interval or P-P interval	1. assessment of atrial to ventricular conduction velocity 2. normal values of around 0.12-0.20 seconds	
ST segment	1. early Repolarization of the heart 2. ST segment positions (high or low) are important than in length 3. normally between ± 1 mm	Assessment of myocardial infarction, myocardial ischemia or hypoxia and myocardial necrosis
Q-T interval	1. on behalf of the systolic phase 2 of potential. associated with heart rate 3. normally 0.35-0.43 seconds	Clinic for drugs and the effect of ions on the myocardial one pointer

Appendix B. The attributes table of the four waveforms for EEG

Table B-1. The attributes of the four basic waveforms of brainwave [30,31]

	α wave (Alpha)	β wave (Beta)	θ wave (Delta)	δ wave (Theta)
Frequency	8～14 Hz 8～12 Hz 8～13 Hz	14 Hz over 12～30 Hz 13～40 Hz	4～8 Hz 4～7 Hz	0.4～4 Hz 0.5～4 Hz 0～4 Hz
Amplitude	10～100μV	5～30/μV	20～40μV	10～20μV
Waveform				
Property	The consciousness level	Bridge between the conscious and subconscious levels	The subconscious level	The unconscious
Awakening	Daydream	Sober	Interrupt	None
Cause	Imagination	Intelligence	Creativity and inspiration	Intuition and sixth senses
Body status	Relaxation	Tension	Deep relaxation	Deep sleep
Physical and mental energy consumed	At least	More drama		
Brain energy	Higher	In addition to maintaining the operation of the system itself, yet to prepare command external defence system, thus reducing the body's immune system		
Wide awake		Have wave form		
Half asleep half awake	Have wave form			
Light sleep				Have wave form
Deep sleep			Have wave form	
Want to sleep insomnia			Haven't wave form	Haven't wave form
Tension and		Have wave form		

anxiety				
Excited		Have wave form		
Fear		Have wave form		
Anger		Have wave form		
Caffeine	Suppression	Improved	Suppression	
Overall condition	Body relax, distracted, open heart	A lot of pressure, psychological discomfort, tension, anxiety, uneasiness	Deep sleep to dream, deep meditation, spiritual awareness, personal experience is strong, personalities is strong	Restorative sleep needs, radar network of awareness

Appendix C. SQLite database schema

Basic physiological signal data

1.Table name: BTTable

2.Function description: Basic physiological signal data access

3.Fields definition:

Table C-1. Basic physiological signal data table

Field Name	Type	Description	PK	FK	Remark
_ID	INTEGER	Healthcare receiver ID	Yes	No	Automatic numbering
_UUID	VARCHAR	Sensor device ID	No	No	Pure uuid
_DATA	VARCHAR	Physiological data	No	No	Physiological data
_DATATIME	VARCHAR	Sensing date and time	No	No	Sensed date/time
_ISGET	VARCHAR	Is geted?	No	No	When to be compared? Select "Yes" or "No"

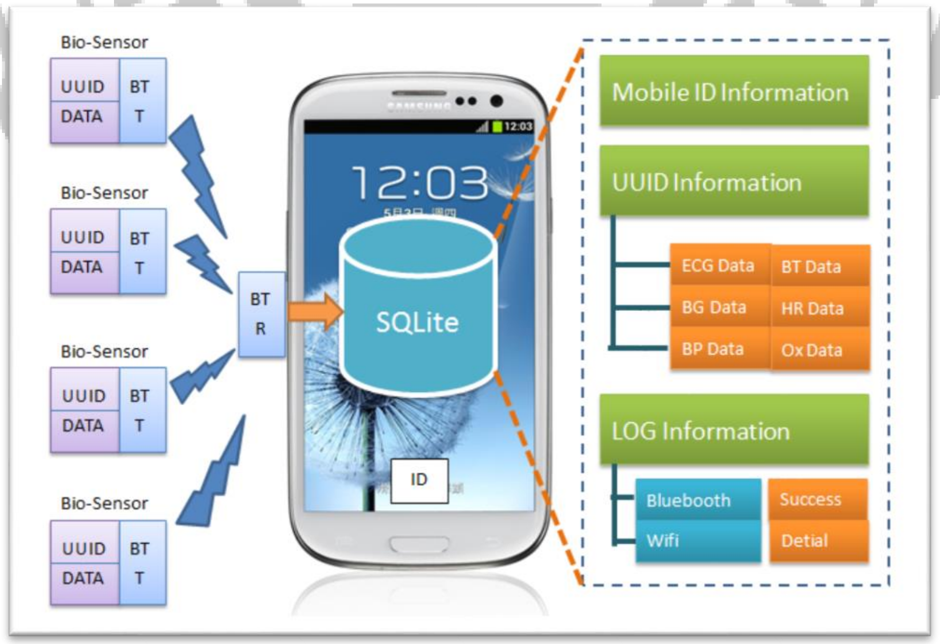


Figure C-1. SQLite database configuration

Appendix D. SQL Server relation schemas

D1. Database schema on pre-database

1. Table name: PreData

2.Function description: Pre-data collection

3.Field definition:

Table D-1. Pre-data table

Field Name	Type	Description	PK	FK	Remark
preId	Bigint	Pre-id	Yes	No	Automatic numbering
Dstring	nvarchar(MAX)	Collected data	No	No	Series of physiological data
dTime	DateTime	Collection date and time	No	No	Collection date/time
isGet	nchar(1)	Is geted?	No	No	When to be compared? Select "Yes" or "No"

D2. Receiving device allocation data

1. Table name: Um

2.Function description: Receiving device allocation data

3.Field definition:

Table D-2. Receiving device allocation table

Field Name	Type	Description	PK	FK	Remark
tId	Bigint	Allocation id	Yes	No	Automatic numbering
mId	nchar(10)	Device id	No	Yes	The receiving device (BS) ID
uId	Bigint	Receiver id	No	Yes	The ID of healthcare receiver
dT	DateTime	Date and time	No	No	The device is allocated to the

					healthcare receiver date and time

D3. Patient historical data

1. Table name: VLog

2.Function description: Healthcare receiver's physiological records

3.Field definition:

Table D-3. Patient history table

Field Name	Type	Description	PK	FK	Remark
lId	Bigint	Record ID	Yes	No	Automatic numbering
uId	Bigint	Receiver ID	No	Yes	The receiver ID
bp_l	float	Systolic blood pressure (low)	No	No	Lowest systolic blood pressure of a day
bp_h	float	Diastolic blood pressure (high)	No	No	Highest diastolic blood pressure of a day
bg_l	float	Blood sugar (low)	No	No	Lowest blood sugar value of a day
bg_h	float	Blood sugar (high)	No	No	Highest blood sugar value of a day
hr_l	float	Heartbeat pulse (low)	No	No	Lowest heart pulse rate of a day
hr_h	float	Heartbeat pulse (high)	No	No	Hightest heart pulse rate of a day
bt_l	float	Temperature (low)	No	No	Lowest temperature of a day
bt_h	float	Temperature (high)	No	No	Highest temperature of a day
uDT	DateTime	Date and time	No	No	Date and time of a day
St	nchar(10)	Status	No	No	Whether the status is normal or not

D4. Basic data of healthcare receiver

1. Table name: MH

2.Function description: Basic data of healthcare receiver

3.Field definition:

Table D-4. Healthcare receiver table

Field Name	Type	Description	PK	FK	Remark
uId	Bigint	Receiver ID	Yes	No	Automatic numbering
Vname	nvarchar(50)	Receiver name	No	No	The name of healthcare receiver
Sex	nchar(10)	Sex	No	No	The sex of healthcare receiver
Bh	nchar(10)	Height	No	No	The height of healthcare receiver
Bw	nchar(10)	Weight	No	No	The weight of healthcare receiver
Mm	nvarchar(MAX)	Notes	No	No	Other explain

D5. Blood glucose data

1. Table name: BG

2.Function description: Blood glucose records

3.Field definition:

Table D-5. Blood glucose table

Field Name	Type	Description	PK	FK	Remark
tId	Bigint	BG ID	Yes	No	Automatic numbering
mId	nchar(10)	Device ID	No	Yes	The receiving device (BS) ID
Val	float	Number	No	No	BG value
dT	DateTime	Date and time	No	No	BG's recording date and time

D6. Blood pressure data

1. Table name: BP

2.Function description: Blood pressure records

3.Field definition:

Table D-6. Blood pressure table

Field Name	Type	Description	PK	FK	Remark
tId	Bigint	BP ID	Yes	No	Automatic numbering
mId	nchar(10)	Device ID	No	Yes	The receiving device (BS) ID
val_l	float	Number	No	No	The value of systolic blood pressure
val_h	float	Number	No	No	The value of diastolic blood pressure
dT	DateTime	Date and time	No	No	BP's recording date and time

D7. Temperature data

1. Table name: BT

2.Function description: Temperature records

3.Field definition:

Table D-7. Temperature table

Field Name	Type	Description	PK	FK	Remark
tId	Bigint	BT ID	Yes	No	Automatic numbering
mId	nchar(10)	Device ID	No	Yes	The receiving device (BS) ID
Val	float	Number	No	No	Temperature value
dT	DateTime	Date and time	No	No	BT's recording date and time

D8. ECG data

1. Table name: ECG

2.Function description: ECG records

3.Field definition:

Table D-8. ECG table

Field Name	Type	Description	PK	FK	Remark
tId	Bigint	ECG ID	Yes	No	Automatic numbering
mId	nchar(10)	Device ID	No	Yes	The receiving device (BS) ID
Type	nchar(10)	HR pattern	No	No	P,Q,R,S,ST,T,U (ECG signal)
Val	float	Number	No	No	ECG value
dT	DateTime	Date and time	No	No	ECG's recording date and time

D9. Heartbeat pulse data

1. Table name: HR

2.Function description: Heartbeat pulse records

3.Field definition:

Table D-9. Heartbeat pulse table

Field Name	Type	Description	PK	FK	Remark
tId	Bigint	HR ID	Yes	No	Automatic numbering
mId	nchar(10)	Device ID	No	Yes	The receiving device (BS) ID
Val	float	Number	No	No	Heart pulse rate value
dT	DateTime	Date and time	No	No	HR's recording date and time

D10. Blood oxygen data

1. Table name: OX

2.Function description: Blood oxygen records

3.Field definition:

Table D-10. Blood oxygen table

Field Name	Type	Description	PK	FK	Remark
tId	Bigint	OX ID	Yes	No	Automatic numbering
mId	nchar(10)	Device ID	No	Yes	The receiving device (BS) ID
Val	float	Number	No	No	Blood oxygen value
dT	DateTime	Date and time	No	No	OX's recording date and time

D11. BS device data

1. Table name: MS

2.Function description: Physiological sensor device data

3.Field definition:

Table D-11. BS device table

Field Name	Type	Description	PK	FK	Remark
mId	nchar(10)	Device ID	Yes	No	BS’s ID
Mn	nvarchar(MAX)	Device name	No	No	BS’s name
Mm	nvarchar(MAX)	Device information	No	No	BS’s explaination

D12. Standard value

1. Table name: SV

2.Function description: Standard setting values

3.Field definition:

Table D-12. Standard value table

Field Name	Type	Description	PK	FK	Remark
tId	Bigint	SV ID	Yes	No	Automatic numbering
Type	nchar(10)	Measure type	No	No	Physiological type: BT,BP,OX,HR...
val_l	float	Number(low)	No	No	the lower limit of physiological value
val_h	float	Number(high)	No	No	the upper limit of physiological value

Appendix E. Sensor hardware and specifications

Table E-1. Sensor hardware and the specifications table (Provided by the manufacturers)

Sensor name	Specification description
Bluetooth ECG sensor (Built-in temperature sensor) BTECG tiny radio transmitters 	◎The HRV parameter of real time transmission once every 30 seconds. ◎Display real-time heart rate and body temperature. ◎Lithium battery 750mAH can continue to use 20 hours ◎Bluetooth：V2.1+EDR ◎Frequency band: 2.402 ~ 2.480 GHz ◎Power and distance: Class II, in 10 meters Manufacturer: Leadtek Research Inc.
Bluetooth oxygen sensor (Built-in pulse sensor) NONIN 3150 Wrist OX2 	◎Bluetooth 2.0 + EDR wireless technology ◎Enhanced Memory and Selectable Storage Rates:1080 hours with four second storage rate ◎SmartPoint Technology: The guesswork of determining measurement quality for data collection. Using a sophisticated algorithm to provide a fast and accurate snapshot of the patient's SpO_2. ◎Power Save: Automatically adjusts transmitted power based on the distance away from the main unit of this system. Manufacturer: Nonin Medical,Inc.
Blood pressure and blood sugar machine FORA D40 2-in-1 blood glucose and blood pressure monitor	◎Data transfer: Bluetooth wireless transmission. ◎Blood sugar measurement range: 20 - 600mg/dL （mg/100ml） ◎Blood glucose measurement accuracy: BG< 75 mg/dL, within ± 15 mg/dl, BG≧75 mg/dL, within ± 20%.

	◎Systolic blood pressure measuring range: 55 - 255 mmHg. ◎Diastolic blood pressure measuring range: 25 - 195 mmHg. ◎Static pressure measuring range: 0 - 300 mmHg. ◎Static pressure measurement accuracy: ±3mmHg. ◎Heart rate measuring range: 40 - 199 times/minute. ◎Heart rate measurement accuracy: within ±4%. Manufacturer: TaiDoc Technology Corporation.
Bluetooth EEG sensor MindWave Mobile 	◎ThinkGearAM chip, reading frequency of the original brain wave signals in real time: 512 per second, 6-8 hours of continuous measurement. ◎Using Bluetooth transmission interface, able to be used with Bluetooth online e-machines like, the PC/NB/PAD. ◎The original brain wave. ◎Processing and outputting the EEG power spectrum of EEG (alpha, beta, etc). ◎Processing and outputting focus, relax, blink detection, and other indexes. ◎Quality analysis of EEG (can be used to detect exposure to indecent or whether the device is worn on the head). Manufacturer: NeuroSky Technology Corporation.