

國立交通大學

生醫工程研究所

碩士論文

以短訊息為基礎的可移動心電監測系統

A SMS-based Mobile Electrocardiogram Monitoring System



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中華民國九十八年七月

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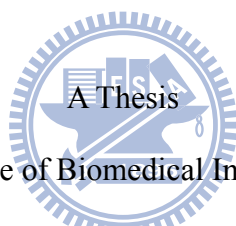
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生醫工程研究所

碩士論文



Submitted to Institute of Biomedical Image and Engineering

College of Computer Science

National Chiao Tung University

in partial Fulfillment of the Requirements

for the Degree of

Master

in

Computer Science

July 2008

Hsinchu, Taiwan, Republic of China

中華民國九十八年七月

A SMS-based Mobile Electrocardiogram Monitoring System

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Abstract

According to the report of Department of Health, Executive Yuan, Taiwan in 2008, in the ten leading causes of death in Taiwan, Malignant neoplasm (28.9%) and heart disease (9.3 %) ranked second and third respectively. Some of these lives can often be saved if prompt emergency care and cardiac surgery are provided within golden hour. Thus, patients with a risk of sudden heart failure need to monitor their cardiac health frequently whether they are indoors or outdoors, so that emergency treatment can be given if problems arise. In this study, a short message service (SMS)-based mobile electrocardiogram (ECG) monitoring system was proposed. The proposed system includes two major components: a personal mobility monitoring device, which contains an ECG acquisition module and an ECG monitoring mobile phone, and a health care server. The personal monitoring device and health care server can be located anywhere in the globe if they are under the coverage of Global System for Mobile Communications (GSM) cellular network. When the abnormal variation of heart rate (HR) was detected, not only the ECG monitoring program in the mobile phone would play an alert sound, but also the abnormal ECG data with global

positioning system (GPS) information would be combined into the alert message and be transmitted via SMS of GSM network to health care server. Then the rescue team can know the patient location and physical status and to provide healthcare and treatment on time. In daily upload, the monitor program can store the HR every minute, and then send to health care server every two hour. It makes physician to trace the patient status according to history of heart rate. In long-term store-and-forward mode, raw ECG data with location information could also be stored into extended secure digital (SD) memory plugged in mobile phone or the built-in memory of mobile phone. In the health care server, SMS which contains ECG raw data with location of latitude and longitude could be extracted and received by a GSM modem or commercial mobile phone which could be read by physicians. Finally, analysis of message transmission performance using different telecoms and different base stations, and reliability of R peak detection algorithm were performed. The experimental results showed that our proposed system architecture can indeed provide better tele- and mobile healthcare services in practice.

KEYWORD : GSM · ECG · SMS · GSM Modem · GPS · HR · SD card · mobile phone ·

R peak

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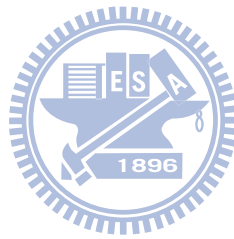
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中文摘要

根據 2008 年台灣行政院公佈的十大死因中，惡性腫瘤(28.9%)和心血管疾病(9.3%)分別排名第二和第三。這些心血管疾病的患者在有緊急情況發生時，如果能給予適當的治療和照護，其實可以減低其喪失性命的可能。因此，這些心血管疾病的患者不論他們在那裡都需要隨時監看他們的健康狀況，如此才能在問題發生時給予最適當的治療。在本篇論文中，提出一套以短訊息為基礎的可移動心電監測系統。該系統包含兩個主要部分：一套可移動個人監測裝置，其中包括心電訊號擷取模組和心電訊號監測手機，和一個健康看護伺服器。這套系統可以在全球移動通訊系統網路底下使用。當心電訊號監測手機偵測到異常的心律時，該手機不僅會發出一個警示音，而且會將異常的心律資料和患者的全球定位系統位置透過簡訊息傳送到健康看護伺服器上，如此緊急救護人員就可以即時知道患者的位置和生理狀態，以提供緊急照護和醫療。在日常生活的資料上傳中，心電訊號監測手機可以儲存每分鐘內的心律變化資料，並且每兩個小時利用短訊息將心律變化歷史資料上傳到健康看護伺服器中。如此可以讓醫生依據心律的歷史資料去追蹤患者的狀況。在長期監測模式下，患者的心電訊號和經緯度位置可以儲存到手機的記憶卡或者內建的記憶體中。在健康看護伺服器上，夾帶著心電訊號和全球定位系統位置的短訊息，醫生可以透過全球移動通訊系統數據機或手機接收及讀取。在論文的最後，測試及分析了使用不同的電信業者和基地台的時間，以及

R 波演算法的驗證。測試的結果顯示出本系統確實可以提供一套遠端照護機制。

關鍵字： 全球移動通訊系統、短訊息、心電圖、藍芽、全球定位系統、全球移動通訊系統數據機、R 波、心律變化



誌 謝

本論文的完成，首先要感謝指導教授林進燈博士，讓我學習到許多寶貴的知識，在學業及研究方法上也受益良多。另外也要感謝口試委員：台灣大學陳永耀博士、國衛院陳聖夫博士、交通大學林伯昱博士、加州大學聖地牙哥分校鐘子平博士的建議與指教，使得本論文更為完整。

其次，感謝我的父親王棋山先生與母親張雪惠女士對我的教育與栽培，並給予我精神及物質上的一切支援，使我能安心地致力於學業。此外也感謝姊姊王馨怡和哥哥王有為對我不斷的關心與鼓勵。

最後，感謝交通大學腦中心的學長立偉、紹航、智峰、尚文、得正，學姐玉潔的指導，同學哲睿、家欣、介恩、昕展的相互砥礪，以及學弟妹育航、智賢、聖翔、璽文、佩瑄、智綸、晉澤、婉茹在研究過程中所給我的協助，朋友建緯、智元、柏勳、柏全、芷芸在我最難過失意時給我最大的鼓勵。

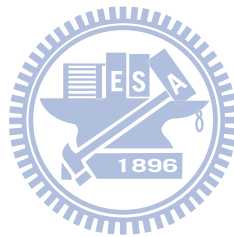
謹以本論文獻給我的家人及所有關心我的師長與朋友們。



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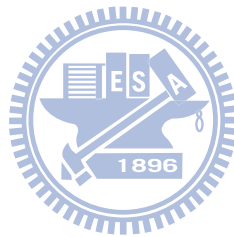
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Chapter 1 Introduction

There are many diseases caused by the aging. In this chapter, we will briefly describe the problems that were happened in Taiwan, and what the expert and scholar have done so far. The motivation of this thesis will be described in the end of this chapter.

1.1 Aging Problems In Taiwan

(A) Aging of the population structure

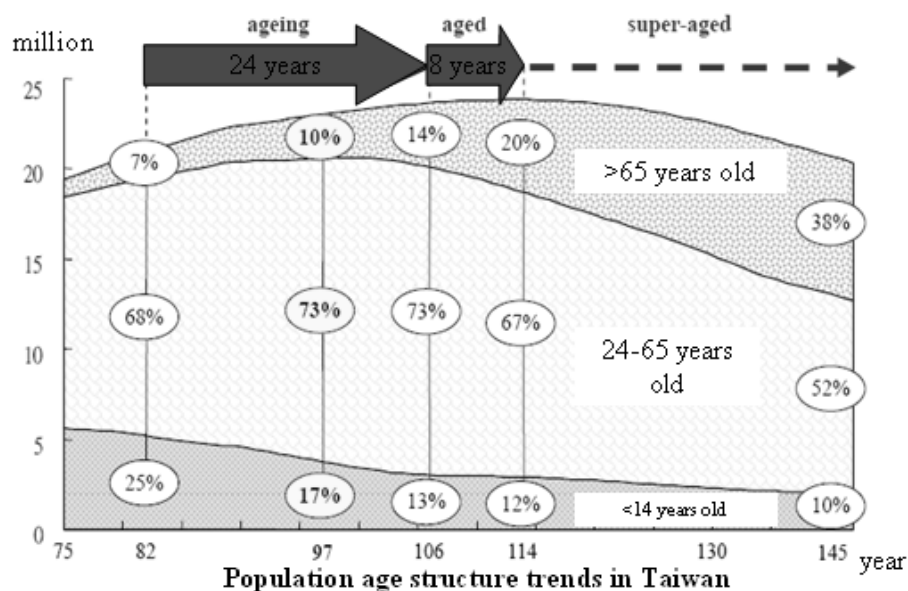


Fig.1- 1 Population age structure trends in Taiwan [1]

With the leap of living standard, medical and health advances, people gradually extend the average life expectancy, and the proportion of elderly population continues to grow. According to the information of CEPD, as shown in Fig.1- 1, in 1993, over 65 years of age in Taiwan has reached 7% of the population that means Taiwan has began entering into the aging society. It was estimated that, from 1993 to 2017 years, the ratio of total population of annual average increase of future elderly population

(people aged over 65) will reach to 14%; and from 2017 to 2056 years, the annual average increase for elder will reach to 240,000 people and the ratio of the total population will be over 38%.

(B) Diseases associated with the elderly

According to the report of Department of Health, Executive Yuan, Taiwan in 2008 [2], in the ten leading causes of death in Taiwan, Malignant neoplasm's (28.9%) and heart disease (9.3 %) ranked second and third respectively. The largest increase of death number occurred at 80 years of age. Therefore, in Taiwan, the aging population has become a major factor in the death. According to an estimate of World Health Organization, cardiovascular disease kills almost seventeen million people around the globe each year, and about twenty million people are at a risk of sudden heart failure [3]. Some of these lives can often be saved if prompt emergency care and cardiac surgery are provided within golden hour. Thus, patients with a risk of sudden heart failure need to monitor their cardiac health frequently whether they are indoors or outdoors, so that emergency treatment can be given if problems arise.

(C) Other problems

According to the study of the Organization for Economic Cooperation and Development (OECD) [4], the medical expenditure of over 65 years of age was over than four times average medical expenditure. According to the study of the American Association of Retired Persons, it showed that when elderly people faced the demand of medical care, 80 percent of people preferred to seek medical care at home services. This indicated that home health has become an important global trend.

Hypertension and arrhythmia are chronic diseases, which can be effectively prevented and controlled only if physiological parameters of patients are constantly monitored, along with the full support of health education and professional medical care. Therefore, professional medical person or care staff round-the-clock care is

required to avoid the occurrence of some danger for high blood pressure, arrhythmia and chronic patients. The general concept of home care for elder citizens would not be the emphasis on the occurrence of body pain and loss of function, and on emergency medical service in an accident. It would be the emphasis on the long-term, continuous, and non-conscious monitoring for elder in day life to establish the transfer, storage, processing, exploration, assessment of data. If the statuses of life quality in their home environment and health deteriorate, it can detect and alert before the occurrence of body pain and loss of function. This practice can reduce the cost of medical care of elder citizens effectively. Moreover, it also maintains the independence, health, and life quality of elder citizens.

1.2 Previous Works And Motivation

For the modern practice of medicine, telemedicine is widely considered to be a part of inevitable future. It was defined as “use of advanced telecommunication technologies to exchange health information and provide health care services across geographic, time, social, and cultural barriers” [5]. Recently, telemedicine is currently being used by physicians, hospitals, and other health care providers around the world, and many successful telemedicine monitor systems based on ubiquitous computing and communication technologies have been developed.

Up to now, outpatient service is still the major approach of healthcare for the common chronic diseases, such as hypertension and arrhythmia. But the feasibility of home care has been highly raised with the development of computing and communication technologies. In previous studies, PSTN and ISDN were widely applied to transmit bio-signals from patient to hospital [6] - [10]. Lee et al. used a cable television network to transmit electrocardiogram data to healthcare center and

to provide function of video conversation between healthcare providers and patients [11]. With the fast development and popularity of Internet, telecare medical applications, that provide long-term monitoring and healthcare by transmitting physiological information via Internet, have become highly feasible [12]. Guill'en et al. proposed a telehomecare multimedia platform utilizing videoconferencing standards H.320 and H.323, and a standard TV set based on ISDN and Internet protocol to upload patients' physiological information to a healthcare center, and to provide home telecare services, such as teleconsultations [13]. In order to provide a safer and more comfortable healthcare environment for inpatient and resident, and to achieve the purpose of illness prevention, the development of home care system has another trend: various miniature flexible noninvasive bio-signal sensors are integrated inside patients' clothing for ease of daily dressing and for long-term monitoring of the patients [14]. However, medical services with mobile communication could be delivered in any location if they are under the coverage of cellular networks. The above-mentioned healthcare systems have to be restricted within some specific activity areas, such as the medical healthcare institute or the residence area. To provide more freedom to patients, it is important to integrate wireless communication technology into modern healthcare systems [15] – [21]. Lin et al. [15] used a PDA to monitor and collect physiological parameters extracted by a physiological signal module attached to patients. The physiological information was then immediately transmitted to a remote central management unit via wireless local area network (WLAN), and was analyzed by medical personnel.

Recently, home telecare service has been further extended to become mobile care service [16] – [21] due to the ubiquity of GSM and general packet radio service (GPRS). Anliker et al. [16] proposed a wearable multi-parameter medical monitoring and alert system called advanced care and alert portable tele-medical

MONitor. In their system, front-end wrist-worn monitoring device was connected to back-end telemedicine center via GSM mobile network such that healthcare service would not be restricted within specific areas. The utility of emergency alert messages via GSM/GPRS mobile network has also been broadly applied to the design of a healthcare system [16], [18] – [21]. However, all of the above-mentioned GSM/GPRS communication modules were designed and implemented by using commercial modules that increased power consumption, volume and weight of user-end healthcare devices. The volume and weight factor of user-end healthcare devices subsequently reduced the using intention of patients.

The popularity of mobile phones has highly increased recently. For example, in 2002, the popularity of mobile phones in Taiwan was already almost 100% [33]. Thus, using commercial mobile phones as platforms for physiological signals processing becomes feasible. Moreover, many mobile phones provide a Java programming design environment and Bluetooth interface. The maturity of mobile-phone technology overcomes problems for user-end healthcare devices' volume, weight, and power saving to increase the using intention of patients. The utility and implement of the function of emergency alert messages via GSM/GPRS mobile network for healthcare service also becomes more and more convenient. The utility of mobile phones for healthcare will increase the feasibility of mobile care services and the using intention of patients. Rasid and Woodward [17] designed a Bluetooth telemedicine processor to pre-process and transmit physiological signals wirelessly to a Bluetooth mobile phone, which uploaded physiological information to a back-end medical healthcare institute via a GPRS mobile network. Although newer mobile communication technologies, such as 3G, Worldwide Interoperability for Microwave Access (WiMax), GPRS, and Enhanced Data rates for GSM Evolution (EDGE), can provide higher data transmission speeds (rates) than 2G GSM cellular

system, the newer technologies are usually deployed mostly in or around crowded high income metropolitan areas. Thus, the majority (80.5%) of the 3.7 billion cellular phone users in the world are still 2G GSM users [34]. R.G. Lee [23] proposed a monitor system which utilized Bluetooth commercial mobile phones as physiological signal processing platforms to construct a ubiquitous mobile care system to increase the feasibility of mobile care services and to increase the desire of users. In their system, ECG can be monitored on mobile phone and send the warning message to healthy provider. Although above-mentioned systems used SMS as interface to transmit alert messages to notify home members or physicians, the alert message contained only warning information in text form send an alert message, rather than the raw ECG data. Therefore, when the physician received this alert message, he would only be notified that the patient may be in the dangerous status caused by heart diseases, but didn't have other detail information. This alert message may be caused by detection of heart diseases, but it also may be caused by the judgment fault of detecting diseases. The judgment fault of detecting diseases will increase the cost of healthcare and the workload of physicians. Moreover, the patient position was not recognized. Locating the current positions of patients outside the hospitals is one important requirement in the health care system design.

In this study, we proposed a SMS-based mobile electrocardiogram monitoring system to service healthcare. Here, an ECG acquisition module was designed for long-term ECG measurement. And an ECG monitoring program in mobile phone was developed to monitor ECG signal and the variation of HR. The program also integrated GPS information to locate the position of patient, if abnormal variation of HR was detected, then this ECG monitoring program would send a SMS alert message with raw ECG data and GPS information to back-end server and physicians via GSM network. Then physicians can identify the detail of the abnormal condition

by raw ECG data and real-time position by GPS information, and service emergency treatment.

1.3 Organization of Thesis

The organization of this thesis goes as follows. In chapter 2, we described the background of physiological signal and ECG. In chapter 3, we briefly described the basic architecture of this system and address the following issues: 1) Hardware specification: The hardware specification of the ECG acquisition module was described here. Hardware specification includes ECG amplification, wireless transmitting unit, a micro controller and the mobile phone used in personal mobility monitoring device. 2) Software specification: Software specification includes the software architecture, procedure and data structure used in either ECG monitoring mobile phone or health care server. 3) Algorithm: The algorithm for this system was described here. In chapter 4, we described the testing and result. The testing contains three parts: MIT database, simulated ECG data, and SMS transmission time. The testing result will be shown and discussed here. Finally, we concluded our work in Chapter 5.

Chapter 2 Background

2.1 Human Physiological Signals

Fig.2- 1 showed some physiological electronic signals. These signals are useful to the diagnosis of diseases by proper interpretation in clinical reference. Here, physiological signals obtained via noninvasive measurement, include ECG, EEG, EOG, EMG, blood pressure, temperature and etc, are most frequently carried out in hospitals. Table 2- 1 listed the characteristics of various physiological signals on amplitude and frequency domains. In this study, we focus on the processing and analysis of cardiac-electric signals.

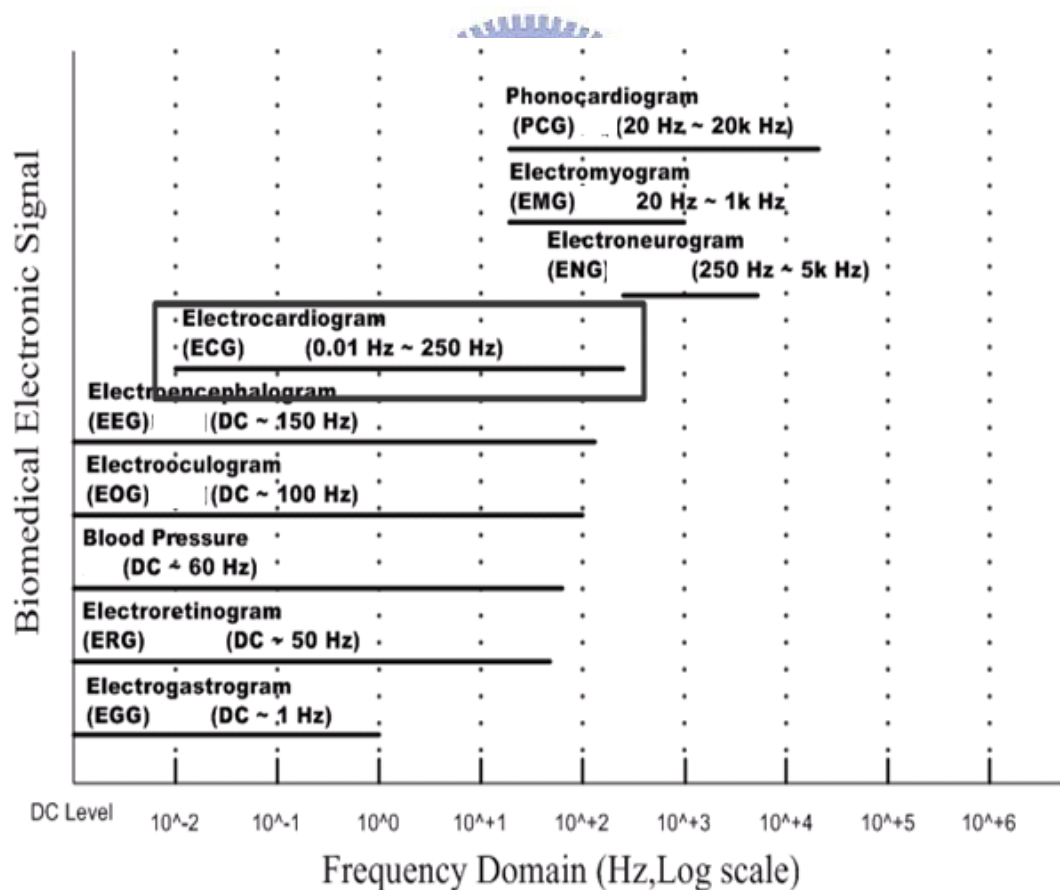


Fig.2- 1 Frequency distribution of physiological electronic signals [24]

Table 2- 1 Characteristics for various physiological electronic signals

Type of bio-signals	Amplitude (mV)	Frequency (Hz)
ECG	0.01 ~ 4	0.05 ~ 150
EEG	0.01 ~ 0.3	0.5 ~ 100
EOG	0.050 ~ 3.5	0 ~ 50
EMG	0.1 ~ 5	5 ~ 2000

2.2 Electrocardiogram

ECG is a graphical representation of electrical activities of the heart. Many studies investigated the characteristics of cardiac anomalies. The normal rate of heartbeat is composed by ECG waves depended on the mechanical action of the heart. In general, 12-lead ECG is most frequently used to provide precise and useful information. In the measurement of 12-lead ECG, 10 electrodes are placed and twelve ECG signals are derived from these 10 electrodes. The electrodes positions of 12-lead ECG are described as follows:

- (1) V1 - V6 are 6 points on the chest from the right of the breast bone extending sideways towards the left hand border of the rib cage. The location of electrode V3 should be placed on the middle between electrodes V2 and V4. The locations of electrodes V4, V5 and V6 should be placed at the same horizontal height as V4, as shown in Fig.2- 2.
- (2) Right arm lead (RA), left arm lead (LA), right leg lead (RL) and left leg lead (LL) are on the right and left arm below the shoulder and on right and left legs below the groin respectively. RA, LA, RL, and LL are usually used to measure lead-I, II, and III ECG, as shown in Fig.2- 3. Here, lead-I ECG is the measurement from RA to LA. Lead-II ECG is the measurement from RA to

LL, and lead-III ECG is from LA to LL.

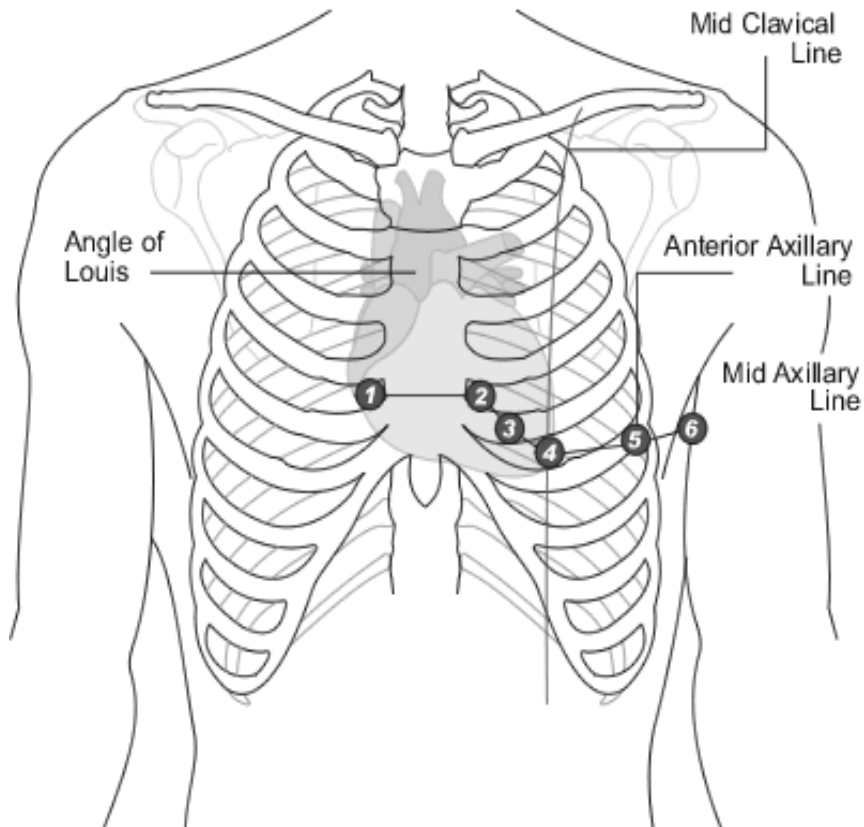


Fig.2- 2 Electrode positions for 6-lead ECG [26]

Although 12-lead ECG provides more precise and useful information in clinical diagnosis, it is not conveniently and easily used at home. Moreover, the attachment of 10 electrodes on the patient will cause the inconvenience of movement. In this study, we monitored long-term lead-II ECG, and focused on R-Wave detection. In general, the waveform of ECG consists of three principal components: P-wave, QRS complex and T-wave, as shown in Fig.2- 4.

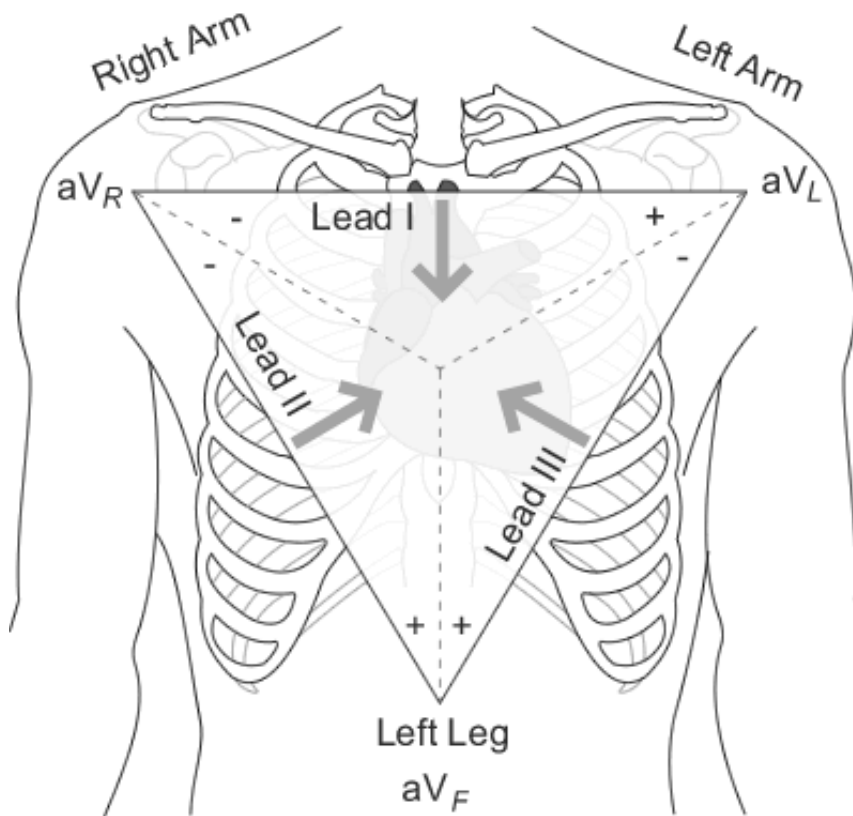


Fig.2- 3 ECG lead positions of limb [26]

The waveform of P-wave represents auricular depolarization. The complex QRS corresponds to ventricular depolarization preceding the mechanical effect of contraction, the wave R is of a great amplitude because the mass of the ventricles is higher than that of the auricles. The T wave represents the repolarization of the ventricles. Lastly, the wave U, not constant, translates the repolarization of the network of Purkinje [25]. These ECG components are listed as below:

- (1) P wave: This deflection is due to the atria depolarization
- (3) Q wave: This first negative deflection is caused by the ventricle depolarization.
The first positive deflection (R) follows.
- (4) R wave: This first positive deflection caused by the ventricle depolarization.
- (5) S wave: This first negative deflection follows the first positive deflection (R) during the period of ventricle depolarization.

- (6) T wave: This deflection is due to the ventricle repolarization.
- (7) U wave: The deflection succeeds the T wave and leads the next P wave. (A positive wave in usual) The mechanism generating this wave forms is unclear yet. One proposal referred this phenomenon to the slower repolarization of the conducting system among ventricles (Purkinje fibers).

The characteristic of ECG intervals are introduced briefly as follows:

- (1) RR interval: RR interval stands for the time interval between two successive R waves. The BPM (beat per minute) can be derived by $60/RR$ interval (60 divided by RR interval).
- (2) PR interval: This is the period of AV conduction mainly. The period consists of some processes as follows: (i) atria depolarization (ii) normal conduction delay in AV node (about 0.07 sec) (iii) the period of depolarization waves passing Bundle of His and its branches until the beginning of ventricle depolarization. The normal value of PR interval is usually from 0.12sec to 0.2sec.
- (3) QRS interval: This period represents the whole time that ventricle depolarization takes. The normal value of QRS interval is usually from 0.04sec to 0.11sec.
- (4) QT interval: The period is from the starting point of Q wave to the ending of T wave. It stands for the period of electric power contracting of heart.
- (5) ST interval: The period is from the ending of QRS complexes to the starting point of T wave. The point connecting the QRS complexes and ST interval is called junction J.

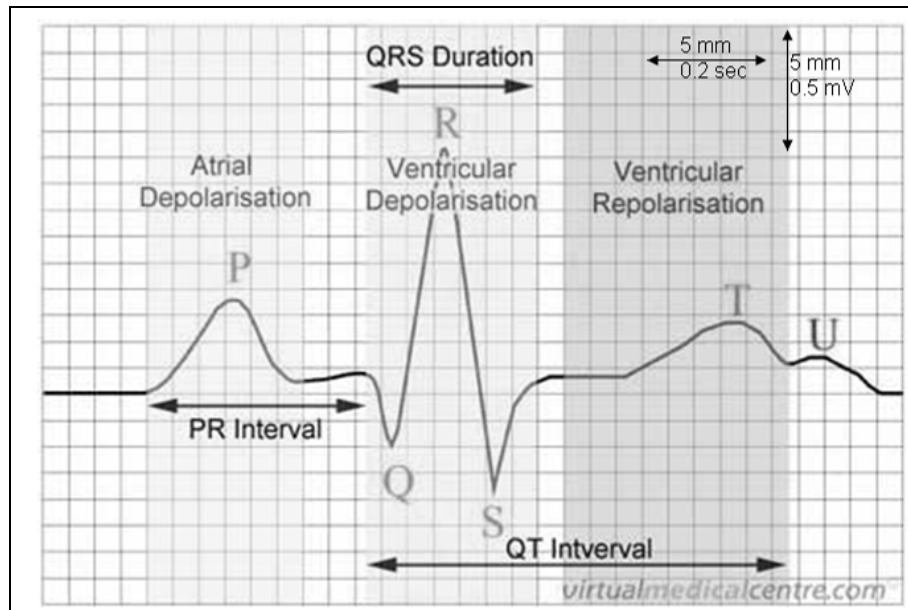


Fig.2- 4 Typical ECG with actions [43]

In general, the traces of cardiac anomalies are appeared in one or more parameters related to ECG waveform. These waves are related to the activity of the auricles and the ventricles in the form of activation or recuperation. The contraction of the heart muscles (of the heart) produces a visible wave of depolarization in the layout of the ECG and the return to the state of the rest constitutes a wave of repolarization represented by an iso-electric voltage constituting the line base.

The slowly heart beats are the Bradycardia and the accelerated rhythm corresponds to the Tachycardia. The Ventricular Tachycardia is marked following a scar of a former heart attack. Auricular Fibrillation describes completely chaotic activation in the auricles. In this case, the production of the fluctuations is irregular in the line base whereas complex QRS remains normal.

The frequencies of each wave present some variations according to the rate of heartbeat. The change of the rhythm of the beat is called Arrhythmia. The frequency band of the ECG signal is approximately 60 Hz for a normal subject and can go up to 130 Hz for an abnormal patient. Table 2- 2 showed the actions of membranes of the heart in the Normal case and the associated waves like their temporal and frequencies

characteristics.

Table 2- 2 Heart actions and electrical characteristics of a normal arrhythmia

Heart Actions	Wave name	Amplitude (mV)	Duration (ms)	Frequency (Hz)
Auricular depolarization	P	≤ 0.3	80-120	10
Depolarization of the ventricle	QRS complex	Q<0 R:0.5-2 S>0	85-120	20-50
Repolarization of the ventricles	T	0.2	200	5



Chapter 3 System Architecture

3.1 System Overview

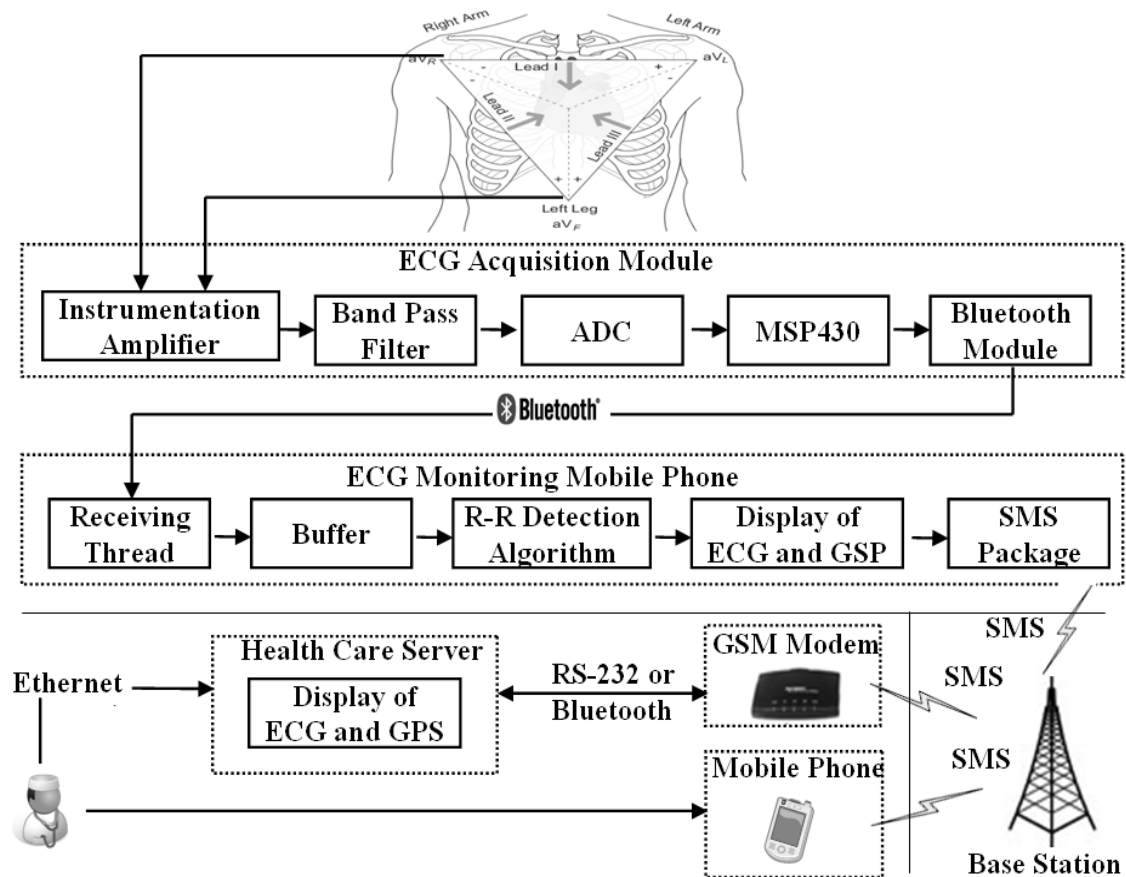


Fig.3- 1 Overview of SMS-based mobile electrocardiogram monitoring system

The basic scheme of the proposed SMS-based mobile ECG monitoring system is shown in Fig.3- 1. The hardware of this system consists mainly of three major components: ECG acquisition module, ECG monitoring mobile phone, and health care server.

The ECG acquisition module is a bio-signal acquisition module which can measure and process one channel of ECG signal. ECG signal was obtained by attaching three ECG electrodes to the patient’s body, and then was amplified (x 100) by instrumentation amplifier, filtered (frequency band of the filter: 0.1 – 100 Hz) by

band pass filter, and digitized by analog-to-digital converter (ADC). Next, TI MSP430 was used as the controller in this ECG acquisition module. The digitized ECG signal would be transmitted to a mobile phone via wireless Bluetooth module. Here, in this study, the sampling rate of ECG acquisition module was set to 512 Hz.

A J2ME program developed on Borland JBuilder2005 conjunction with wireless development kit 2.5 was installed on the ECG monitoring mobile phone to plot received ECG signal. The raw ECG data will first be received by receiving thread. Second, put the raw data in to the buffer. Third, the R-R interval [29] and QRS detection algorithm [31] were implemented in this program. Forth, the waveform of ECG was plotted in mobile phone's window whose resolution was 320×240 pixels. Fifth, when the abnormal variation of heart rate (HR) was detected, the program would perform an alert sound. If the estimated variation of heart rate (HR) was lower or higher than the threshold set by physicians, the abnormal ECG data with the GPS information would be transmitted via SMS of GSM network to provide further healthcare and treatment. In long-term store-and-forward mode, raw ECG data with the longitude and latitude could also be stored into extended secure digital (SD) memory plugged in the mobile phone or build-in memory in mobile phone.

In the health care server, SMS which contains ECG raw data with GPS information will be extracted and received by a GSM modem or commercial mobile phone which could be read by physician. The AT-command is used to communicate between health care server and GSM modem. Health care server was designed and developed by ASP.NET and J2SE program, it can display: 1) the raw ECG data and location on the map; 2) personal information with the physician suggestions; 3) and daily heart rate history.

3.2 Personal Mobility Monitoring Device

The front-end personal mobility monitoring device comprises an ECG acquisition module and an ECG monitoring mobile phone of model Nokia N85. The ECG acquisition module consists of amplifier, ADC, microcontroller, and wireless Bluetooth module. The ECG monitoring mobile phone needs to receive ECG and GPS data, and provide communication link between ECG acquisition module and health care server. The ECG monitoring mobile phone supports J2ME in software, Bluetooth and GSM/GPS. The whole personal mobility monitoring device is shown in Fig.3- 2.



Fig.3- 2 Whole personal mobility monitoring device

3.2.1 ECG Acquisition Module

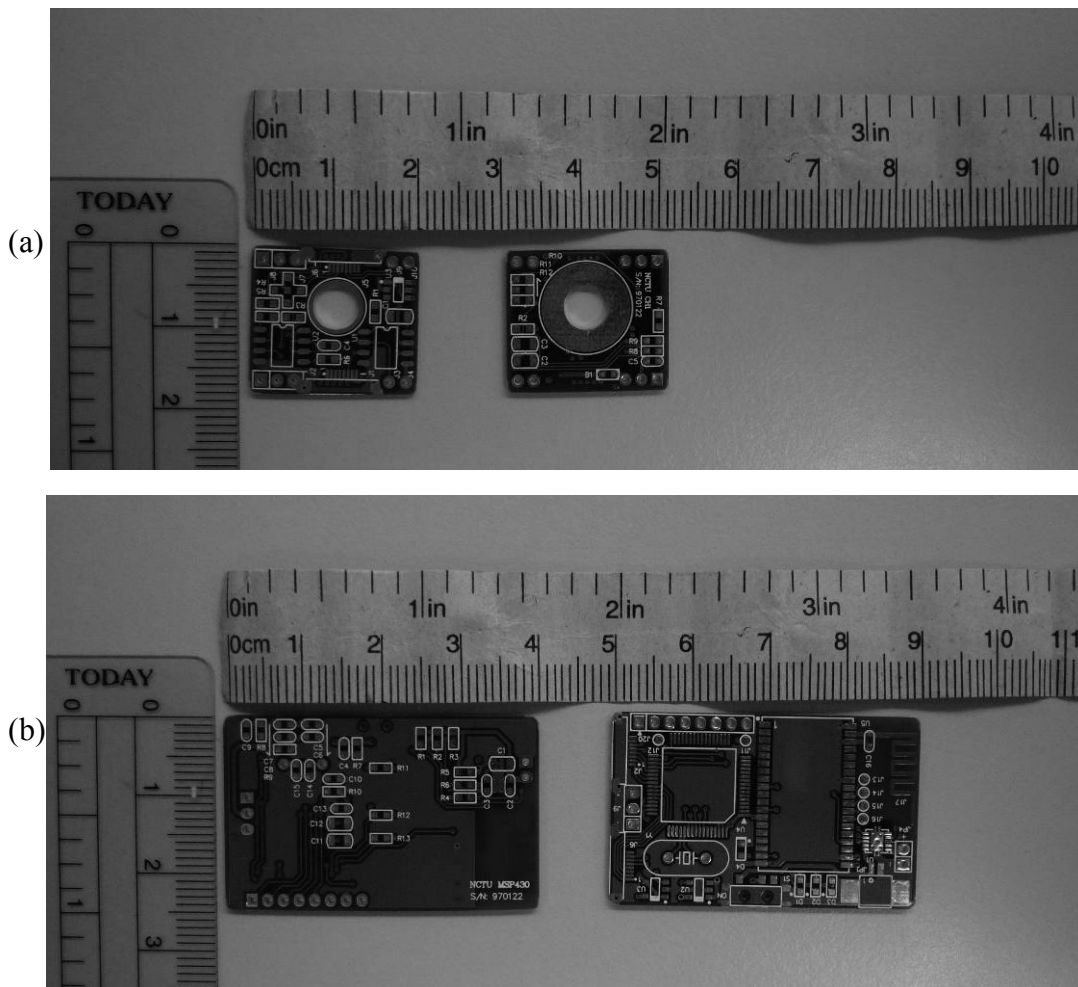


Fig.3- 3 ECG acquisition module of: (a) analog circuit, and (b) digital control circuit

Fig.3- 3 shows the ECG acquisition module. It contains five parts: 1) instrumentation amplifier, 2) band pass filter, 3) analog digital converter, 4) microcontroller, and 5) Bluetooth module. The data flow is shown in Fig.3- 4.

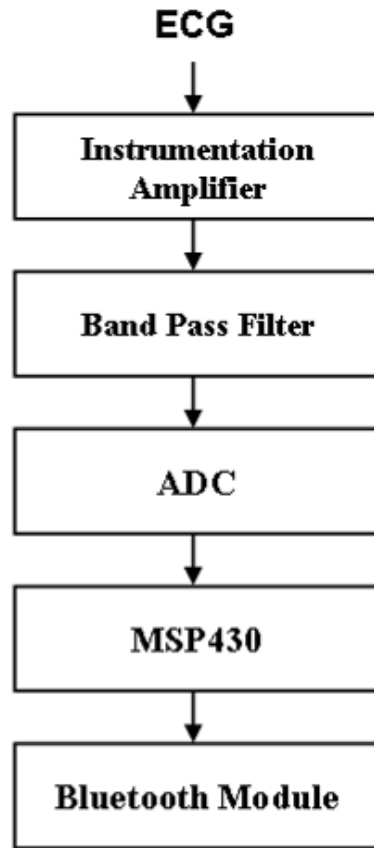


Fig.3- 4 Data flow chart of ECG acquisition module

(A) Instrumentation Amplifier

Here, instrumental amplifier LT1789-1 was used as the first stage of analog amplifier. LT1789-1 owns an ultra low input current and a high common-mode rejection ratio (CMRR) about 90dB. A high CMRR is important in applications that the signal of interest is represented by a small voltage fluctuation superimposed on a (possibly large) voltage offset, or when relevant information is contained in the voltage difference between two signals. Here, instrumental amplifier LT1789-1 provided not only the function of gain, but also that of one stage high pass filter by adding a capacitor. The corner frequency was set at 0.1Hz, and the gain was set to 2.25 times.

$$f_0 = \frac{1}{2 * \pi * R * C} = 0.099 \quad (3-1)$$

$$gain = 1 + \frac{200k}{R_G} = 2.25 \quad (3-2)$$

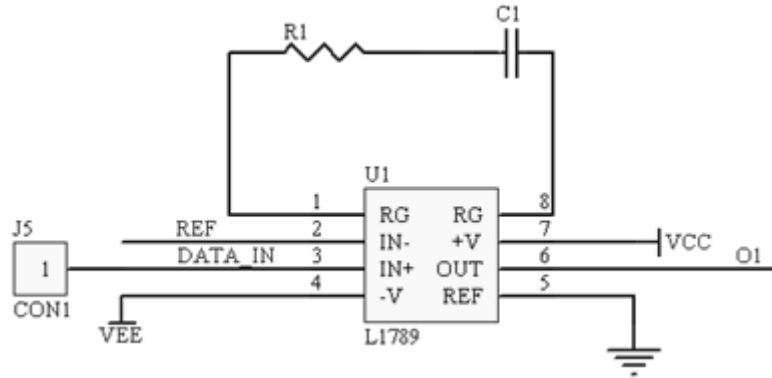


Fig.3- 5 Circuit of instrumentation amplifier

(B) Band Pass Filter

In order to more precisely reserve relevant ECG signal, a band pass filter with frequency band of 0.1Hz ~ 100Hz and with gain of 100 times was designed. The band-pass filter consisted of a 2nd-order high-pass filter and a 2nd-order low-pass filter. Here, OP-AMP AD8607 was used to construct the band-pass filter. AD8607 also owns high CMRR (about 100dB), low input current, low distortion, and no phase reversal.

$$f_0 = \frac{1}{2\pi\sqrt{R1 * C1 * R2 * C2}} = 0.099 \quad (\text{High-pass corner frequency}) \quad (3-3)$$

$$f_0 = \frac{1}{2\pi\sqrt{R3 * C2 * R4 * C5}} = 97.93 \quad (\text{Low-pass corner frequency}) \quad (3-4)$$

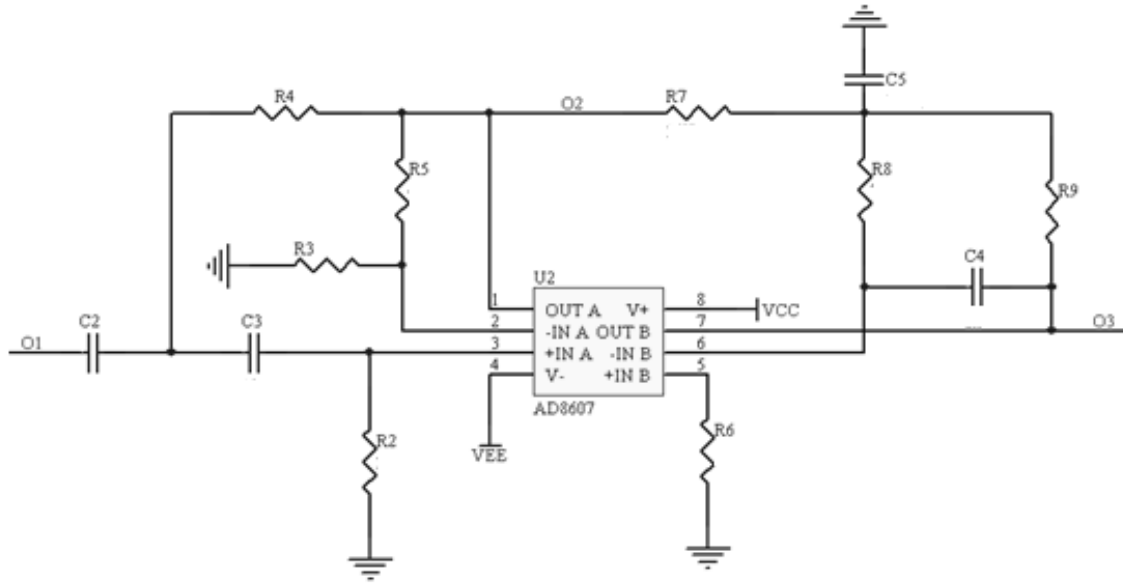


Fig.3- 6 Circuit of band pass filter

(C) Analog Digital Converter

The analog amplifier circuit and digital control circuit of ECG extraction device were placed individually in two different PCB boards. There are some leading wires to connect both. A 12-bits analog-to-digital converter (ADC) AD7466 was used to convert continuous ECG signal of analog amplifier circuit to digitized ECG signal. Here, the micro-controller (MSP430F1611) was used to control ADC AD7466. The command signals and serial digitized ECG signal were transmitted via the serial peripheral interface (SPI) of MSP430F1611. The micro-controller MSP430F1611 outputs SCLK and CS signals in specific sampling rate 512Hz, and then digitized ECG signal would deliver into MSP430F1611. Each converting interval needed 16 cycles to complete transmission of digitized data, here, the data in first 4 cycles were zero, and the others were real 12-bit digitized data based on MSB. Moreover, according to equation (3-1), the conversion time is about 4.7 μ s, and 8-bit digitized data were transmitted every transmission cycle. And the maximum frequency of input signal of ADC was 100Hz. After calculating in equation (3-2) and (3-3), the result

conforms to the equation (3-3). Thus, this system needn't a sample and hold amplifier to hold analog voltage.

$$\left(\frac{dV_{in}}{dt} \times t_a \right) \leq 1LSB \quad (3-5)$$

$$LSB = \frac{3V}{2^8} = 0.0117 \quad (3-6)$$

$$\frac{dV_{in}}{dt} \times t_a = \hat{V} \times 2\pi f \times t_a = 3 \times 2\pi \times 100 \times 4.7\mu = 0.00886 \quad (3-7)$$

(D) Microcontroller

The TI micro-controller MSP430F1611 was utilized to control other parts of circuits in ECG extraction device. It owns many advantages for medical application, includes ultra-low power consumption, 16-bit RISC architecture, 125 ns instruction cycle time, five power saving modes, and diversification of peripheral communication interface. The functional block diagram of MSP430F1611 was shown in Fig.3- 7.

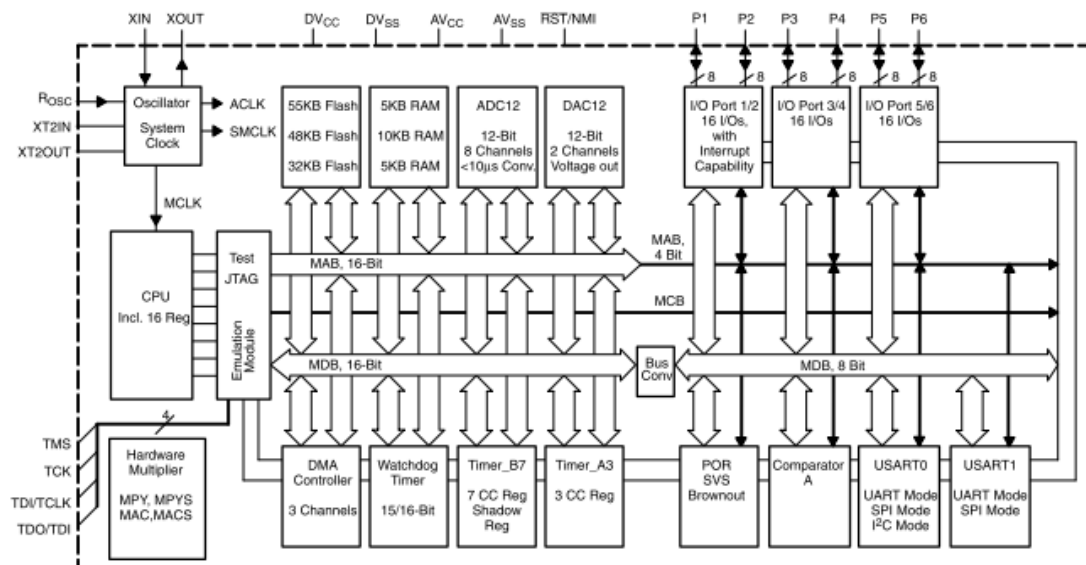


Fig.3- 7 Functional block diagram of MSP430F1611

MSP430F1611 catch digitized ECG signal from ADC AD7466 via serial peripheral interface with sampling rate 512Hz, and then digitized ECG data were stored into memory of MSP430F1611. Next, a moving average filter was used to remove 60-Hz power line interference before wireless transmission.

(E) Bluetooth Module

Bluetooth is a wireless protocol utilizing short-range communication technology to facilitate data transmission over short distances from fixed and/or mobile devices. The intent behind the development of Bluetooth was the creation of a single digital wireless protocol, capable of connecting multiple devices and overcoming issues arising from synchronization of these devices. In this study, Bluetooth module BM0203 was used. BM0203 is an integrated Bluetooth module to ease the design gap and uses CSR BlueCore4-External as the major Bluetooth chip. CSR BlueCore4-External is a single chip radio and baseband IC for Bluetooth 2.4GHz systems including enhanced data rates (EDR) to 3Mbps. It interfaces to 8Mbit of external Flash memory. When used with the CSR Bluetooth software stack, it provides a fully compliant Bluetooth system to v2.0 of the specification for data and voice communications. All hardware and device firmware of BM0203 is fully compliant with the Bluetooth v2.0 + EDR specification. Bluetooth operates at high frequency band to transmit wireless data, so it can be perfect worked by using a PCB antenna, as shown in Fig.3- 8.

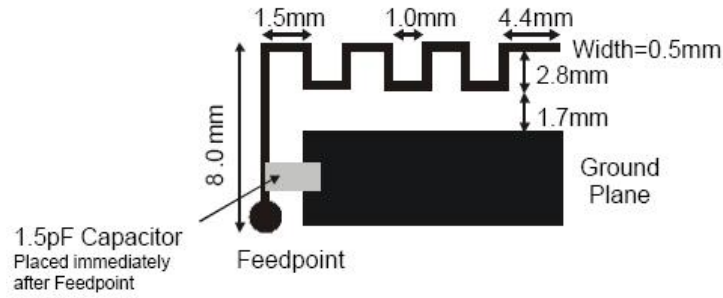


Fig.3- 8 PCB Blue Tooth antenna [41]

The amplitude of QRS-complex is typically about 0.01~4 mV. Three ECG electrodes (KENDALL, MEDITRACE™ 200, ECG Conductive Adhesive Electrodes, 31050522) were placed on Left Arm (AR), Right Arm (AR), and Left Leg (LL) to measure ECG signal. The specification of ECG extraction device is listed in Table 3- 1.

Table 3- 1 Specification of ECG acquisition module

Type	Portable ECG Acquisition Module	
Channel Number	1	
System Voltage Range	1.7~3V	
Gain	100	
Bandwidth	0.1~100Hz	
ADC Resolution	12bits	
Output Current	29.5mA	
Battery	Lithium 3.7V 450mAh	15~33hr
Full Scale Input Range	577 μ V	
Sampling	512Hz	
Input Impedance	greater than 10M Ω	
Common Mode Rejection Ratio	77dB	
Power Supply Rejection Ratio	88dB	
Size	18mm x 20mm and 25mm x 40mm	

3.2.2 R-R Interval Detection Algorithm

Previously, Friesen et al. [30] have tested nine QRS detection algorithms. They found that methods based on digital filtering and first derivative gave good results even though the ECG signal was corrupted by high level of composite noise. In this study, we followed the ECG detection algorithm proposed by Friesen et al. Since the QRS detection method may be implemented on different platforms, the computational requirement must be kept at a reasonable level while without compromising its accuracy. Therefore, the first derivative approach (FDI) for QRS detection was selected in this study, and was described as below.

Let $X(n)$ represent the received discrete ECG data at iteration n . The slope at $X(n)$ can be obtained by

$$\text{slope}(n) = -2X(n-2) - X(n-1) + X(n+1) + 2X(n+2) \quad (3-8)$$

The slope threshold is defined by

$$\text{Slope_threshold} = 0.70 \times \max(\text{slope}(n)) \quad n = 0 \dots 5119 \quad (3-9)$$

The onset of QRS wave can be detected by using either of the following two criteria: $\text{slope}(n) > \text{slope_threshold}$ or $\text{slope}^2(n) > \text{slope_threshold}^2$.

In general, the waveform of interference is high and sharp. Therefore, the slope of a single noise point usually exceeds the slope threshold and will produce a false detection in the algorithm. However, for consecutive two-point ECG data, if both of their slopes are larger than the slope threshold or both of the square of slopes are larger than the square of slope threshold, these two-point data maybe not noise and can be used as the onset of QRS wave.

Friesen et al. used maximum value of $\text{slope}(n)$ which was found by comparing all the values of $\text{slope}(n)$. However, the ECG data received from front-end is sequentially. Therefore, the maximum value has to be varied adaptively. So and Chan

[29] modified the algorithm and it was described as below.

After detecting the onset of QRS complex, the height on this onset is then set as the minimum. The maximum point following the onset is taken as the R point. The maximum (maxi) is then updated by equation (3-10) as shown below.

$$\text{maxi} = [((\text{height of R point} - \text{height at onset}) - \text{maxi}) / \text{filter parameter}] + \text{maxi} \quad (3-10)$$

This is an one-pole filter which can smooth out the effect of any abrupt change. If the slope is negative at the onset, the R point is detected by finding the minimum point following the onset because the polarity of the QRS complex is inverted and the equation becomes

$$\text{maxi} = [((\text{height at onset} - \text{height of R point}) - \text{maxi}) / \text{filter parameter}] + \text{maxi} \quad (3-11)$$

Moreover, equation (3-9) is modified such that the factor of 0.70 is replaced by a variable parameter.

$$\text{Slope_threshold} = (\text{parameter} / 16) \times \text{maxi} \quad (3-12)$$

The condition of detection of the onset is also changed to

$$\text{absolute value of slope} > \text{slope threshold} \quad (3-13)$$

to accommodate for positive and negative QRS complex waveforms. The maximum slope detection method alters the equation of the slope threshold to

$$\text{slope threshold} = (\text{parameter} / 16) \times \text{maximum slope} \quad (3-14)$$

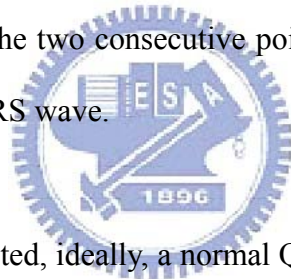
The maximum slope is obtained in a similar way as in the previous method by getting the height of R point. The maximum slope is updated by putting the first maximum (or minimum) slope after the detection of the onset of the QRS complex into the following equation.

$$\text{maxi} = [(\text{first max} - \text{maxi}) / \text{filter parameter}] + \text{maxi} \quad (3-15)$$

According to the algorithm described above, the operation procedure of R-R

interval detection algorithm used in this system was shown in Fig.3- 9. The process is listed below :

1. In the beginning, the program will create a new thread to receive ECG data into the buffer in the ECG monitoring mobile phone from ECG acquisition module.
2. The sample rate in this system is 512 samples/second, the moving window size is 10 seconds, so it will continue receive until 5120 points.
3. When 5120 points of ECG data were received, the slope of each point will be calculated by equation (3-8).
4. After calculated the slope of every points, the slope threshold is calculated by equation (3-12).
5. Because of a single noise point usually exceeds the slope threshold and will produce a false detection, the two consecutive points which are bigger than slope threshold as the onset of QRS wave.
6. Get the Q point.
7. After the Q point was detected, ideally, a normal QRS complex wave is not longer than 120 ms, for our sample rate of 512 samples/second, the R point is in the maximum amplitude within 62 points from onset of QRS complex wave.
8. The procedure will next continue search the R point within 5120 points.
9. After finish scan 5120 points, the R-R interval could be calculated and the heart rate could be also calculated and displayed on the screen on the mobile phone.
10. It will continue receive ECG data.
11. The thread will receive ECG data until achieve 2560 points, that is, 5 seconds data.
12. The moving window will overlap 5 second ECG data and go to step 2.



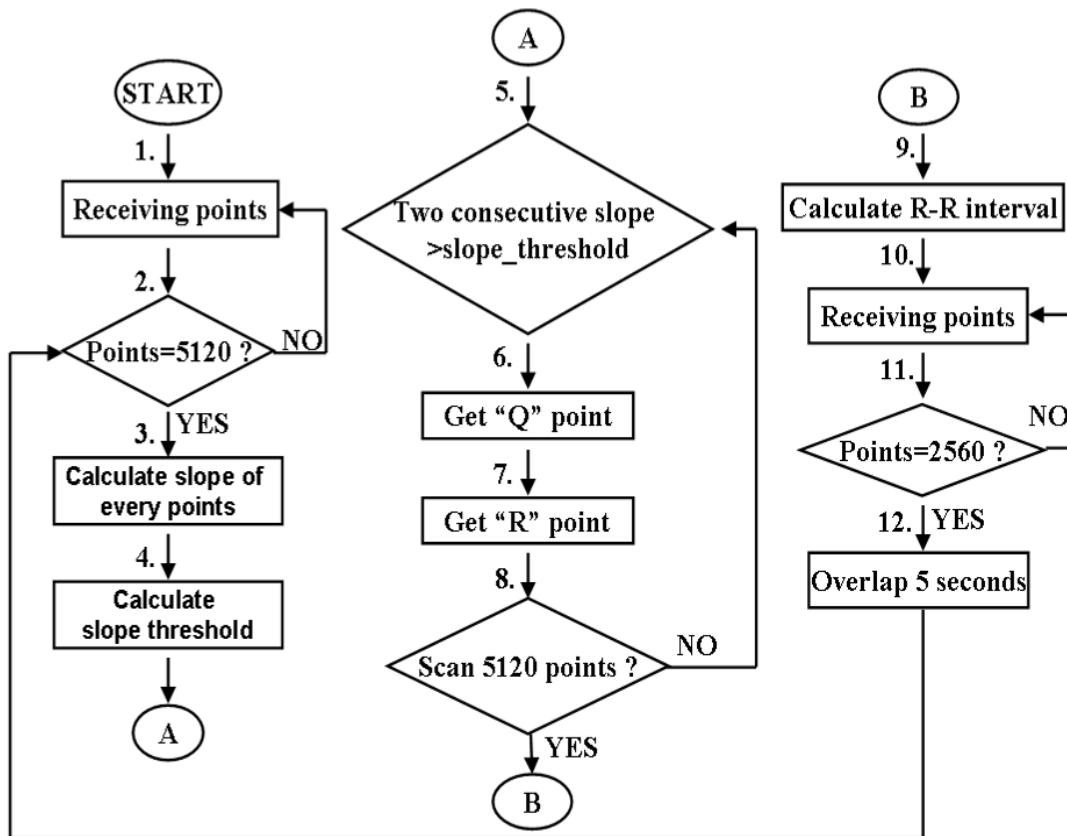


Fig.3- 9 Procedure of R-R interval detection algorithm



3.2.3 SMS-based Transmission

SMS stands for Short Message Service. The major capability is to send message between mobile phones. SMS first appeared in Europe in 1992. It was included in the GSM standards right at the beginning. Later it was ported to wireless technologies like CDMA and TDMA. The GSM and SMS standards were originally developed by ETSI. ETSI is the abbreviation for European Telecommunications Standards Institute. Now the 3GPP (Third Generation Partnership Project) is responsible for the development and maintenance of the GSM and SMS standards. Moreover, the advantages of SMS are:

- (1) SMS can be sent and read at any time. Because of the popularization of mobile phone in the world, every one now can type and receive the message

any time and anywhere.

- (2) No interrupt while receiving the message. Imagine someone who is in a meeting, when s/he received a message, s/he needn't to interrupt the meeting to answer the message. The message will be received by cell phone automatically. S/he can read the message after meeting.
- (3) SMS can be sent anytime no matter the recipient phone is on-line or off-line. The base station of carrier can store the message when the signal of recipient phone is temporarily unavailable or turn-off, and can deliver the message when the recipient phone is in the signal coverage or turn-on the phone.
- (4) No limitation if sending to different wireless carriers.

There are two ways of sending and receiving SMS messages: by Text mode and by Protocol Description Unit (PDU) mode. The text mode is just an encoding of the bit stream represented by the PDU mode. The PDU mode offers to send binary information in 7 bit, 8 bit, 16 bit format. When using the default 7 bit characters, the SMS message, as specified by the ETSI organization documents GSM 03.40 and GSM 03.38, can be up to 160 characters long, while when using 8 bit characters, messages can contain a maximum of 140 characters. Table 3- 2 listed the coding length of SMS. Messages that use 8-bit characters are not usually viewable by the phones as text messages; instead they are used for data in smart messaging. Unicode (UCS2) text messages use 16-bit characters, and the maximum length of the message is reduced to 70 characters only. In order to overcome the drawback of limitation of character length in a message, one solution has developed. When the length of message is over the limitation, also known as long message, the phone of sender will break the message into segments that can fit the length of one message depends on the coding method. If using 8 bit coding method, for example, when the message contains

200 characters, the phone of sender will break the message into two segments, one contains 140 characters, and another contains 60 characters. Once the message was received by the phone of receiver, the phone will automatically concatenate two messages into one message so that the user can easily to read. The sender phone number, message sent time and data can also be extracted from message header. The ECG monitoring mobile phone packs the ECG raw data with GPS information into message. Because the sample rate is 512 Hz, that is, 512 samples in one second, it will need four messages segments if we used 8 bit coding, moreover, the amplitude of ECG acquisition module is between 0~255, so, we use 8 bit data coding when constructing the SMS. However, sometimes we may not need high resolution of ECG. If we down sample from 512 Hz to 128 Hz, then each SMS, which contains 128 bytes, is capable of displaying one ECG segment of 1.12s and containing location of longitude and latitude. If the location uses two bytes, this will leave 10 bytes for other vital signs if desired. In principle, the GSM standard allows for 255 messages to be concatenated and received as one long SMS message. In our case, this will allow us to transmit up to 285.6 seconds of ECG at a time.

Table 3- 2 SMS coding description

Coding	Characters (Bytes)	Description
7 bit	160	It is suitable for encoding Latin characters like English alphabets.
8 bit	140	Coding as binary data, so it can send pictures, operator logos, wallpapers, etc
16 bit	70	Non-Latin characters like Chinese characters

3.2.4 Software Design of ECG Monitoring Mobile Phone

(A) Architecture

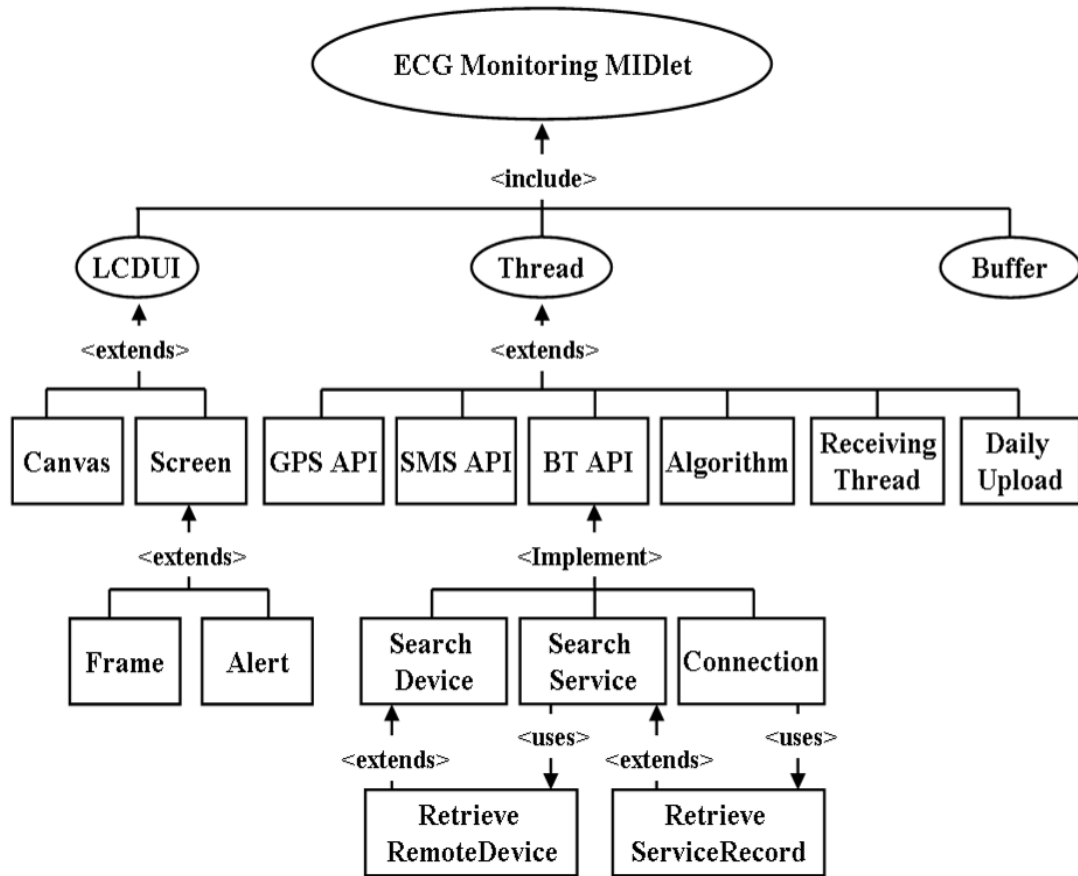


Fig.3- 10 Software architecture of ECG monitoring mobile phone

Fig.3- 10 specified the software architecture of ECG monitoring program in mobile phone. The detail description is listed below:

1. LCDUI is the base of any GUI application packages created in J2ME. It has a similar role to the abstract windowing toolkit and swing APIs, which are used in Java SE and Java EE but offers a more restricted and resource-efficient approach to UI development. LCDUI has a simple screen-based approach where a single Displayable is always active at a time in the display area of the application user interface. This Displayable can contain predefined screen elements, or be manipulated in more specific ways. On a logical level, the MIDP UI is divided

into two levels: the high-level and the low-level, as shown in Fig.3- 11.

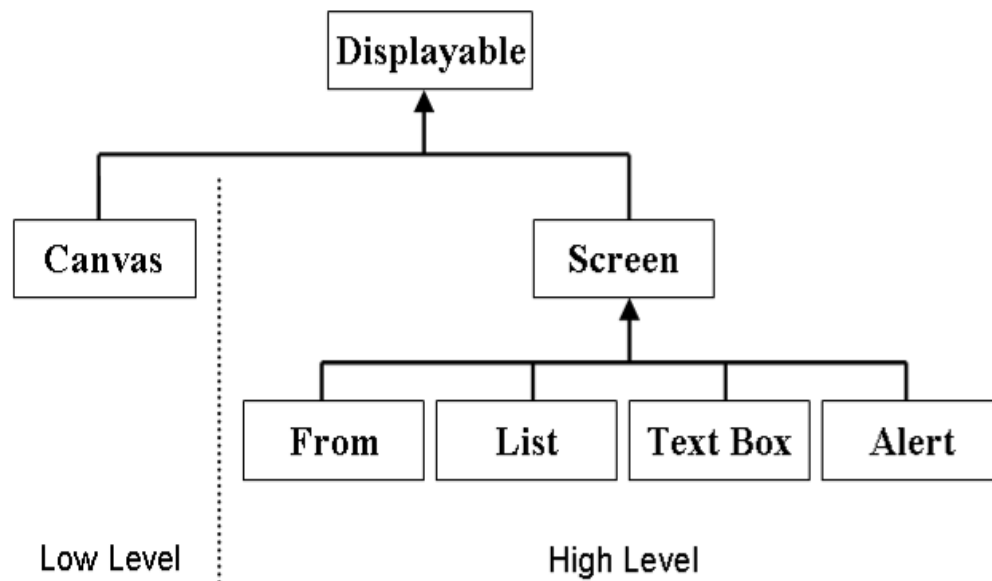


Fig.3- 11 Class hierarchy of javax.microedition.lcdui

In general, the choice is made between the easy, quick and portable high-level APIs and the more customizable low-level APIs. In ECG monitoring MIDlet architecture, Frame is used to display text string, such as the status of Bluetooth searching, error message when the program occurred a runtime error. Canvas is used to plot ECG waveform, GPS information, HR variable values when the link is established between ECG acquisition module and ECG monitoring mobile phone. Alert in this proposed system is used to perform a warning sound that remind the patient something is wrong, such as heart rate is too fast.

2. A thread is a light weight process in a program. The Java Virtual Machine (JVM) allows an application to have multiple threads of execution running concurrently. Every thread has a priority. Threads with higher priority are executed in preference to threads with lower priority. Each thread may or may not also be marked as a daemon. When code running in some thread creates a new thread object, the new thread has its priority initially set equal to the priority of the creating thread, and is a daemon thread if and only if the creating thread is a

daemon. When a JVM starts up, there is usually a single non-daemon thread (which typically calls the method named main of some designated class). The JVM continues to execute threads until either of the following occurs: 1) The exit method of class runtime has been called and the security manager has permitted the exit operation to take place. 2) All threads that are not daemon threads have died, either by returning from the call to the run method or by throwing an exception that propagate beyond the run method.

The life cycle of thread is illustrated in Fig.3- 12. In ECG monitoring MIDlet architecture, GPS API, SMS API, BT API, Algorithm, Receiving Thread, and Daily Upload are all independent threads. GPS API is used to get GPS information, such as latitude and longitude. SMS API is one of the packages of the Wireless Messaging API (WMA) which is an optional package for the J2ME that provides platform-independent access to wireless communication resources. The package in this system is used to let program transmit short message containing ECG raw data and GPS information and transmit it to health care server. BT API is used to establish the link between ECG acquisition module and ECG monitoring mobile phone. It is used JSR 082 package [35] so that application programs utilize Bluetooth functions in the mobile phone.

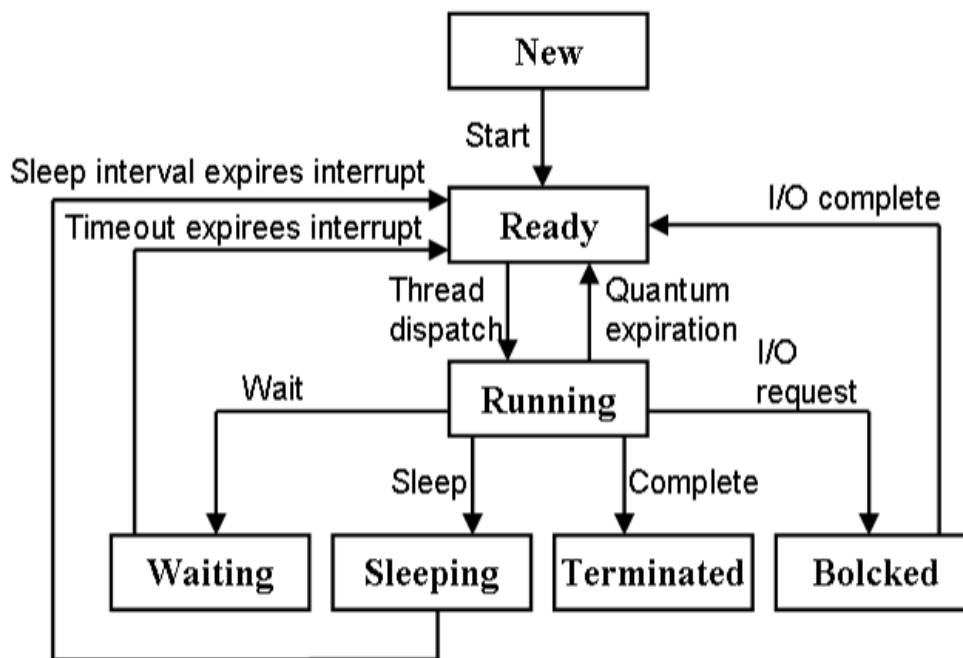


Fig.3- 12 Life cycle of thread

To extract the physiological parameters measured from front-end ECG acquisition module, this system uses Bluetooth mobile phone with JAVA APIs for Bluetooth Wireless Technology (JABWT) to develop client application program MIDlet to control and use ECG acquisition module to realize the physiological parameter extraction function on personal mobile device. The methods for interface DiscoveryListener in javax.bluetooth API have to be implemented in programs to let MIDlet receive RemoteDevice and ServiceRecord found by DiscoveryAgent. Connection address attributes in remote device service records are used to setup connection to utilize services provided by remote devices. Since the Bluetooth module is in the ECG acquisition module, the API of Javax.microedition.io's StreamConnection interface can be used to set up connection. After the connection has been set up, application program of ECG monitoring mobile phone can easily use SPP transmission protocol to communicate with ECG acquisition module to receive

physiological parameter measurement data. Finally, the data can be transmitted to physicians or health care server with short messages. Algorithm is used to get the R-peak wave and calculate the R-R interval which is described in section 0. Receiving Thread is used to receive the ECG raw data which is from ECG acquisition module. Daily Upload is used to collect the history of heart rate in every minute and send it to health care server every two hour.

Using separate thread can make sure mobile phone continues working without blocking. Table 3- 3 listed the thread files used in the ECG monitoring MIDlet. The active time means when the thread will be dispatched, that is, get the usage of professor. For example, Daily upload will go to running state every two hour to send the average HR of every minute

Table 3- 3 Summarized of thread file

Thread Name	Active Time	Job Description
SMS API	Any time	Send abnormal data to server
GPS API	All time	Continuous to receive GPS information
BT API	Beginning	To establish the Bluetooth link
Receiving thread	All time	To receive ECG data from device
Algorithm	5 second	To calculate the variation of HR
Daily upload	2 hour	To upload the average of HR every minute

3. Buffer is a container that is used to store the ECG raw data from ECG acquisition module. The basic data structure in Buffer of ECG monitoring MIDlet is linked list. Normally, linked list is as Fig.3- 13:

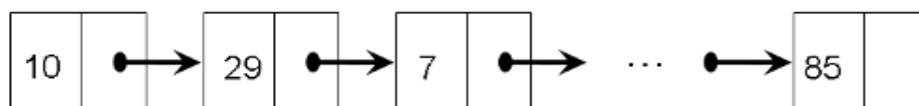


Fig.3- 13 A linked list whose nodes contain two fields: integer and a link to next node

The reason of using this data structure is that linked lists allow insertion and removal of data at any point in the list, with a constant number of operations and we can't declare the size of an array because we have no idea about how many data will be sent from ECG acquisition module. Fig.3- 14 is modified linked list that is used in Buffer of ECG monitoring program. A node contains two fields: an integer array and a link. The integer array contains one second data, which is 512 samples, and the link is a pointer which is directed to next node. So, if we want to review the received data, we can sequential search the data we need and easily to insert or remove node.

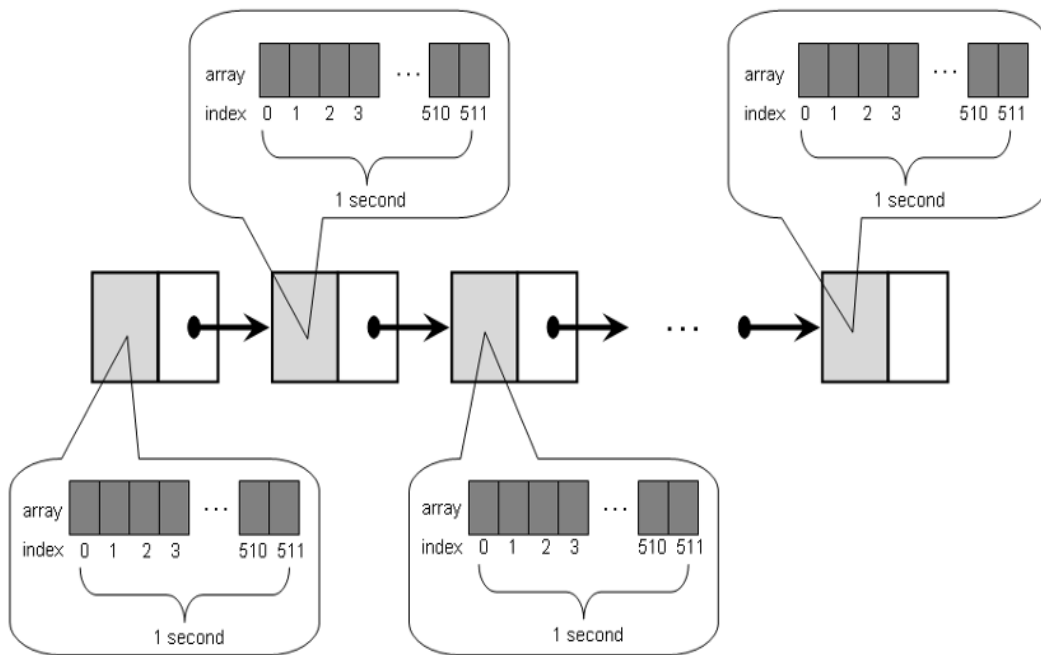


Fig.3- 14 Modified linked list

(B) Procedure

There are three major states in ECG monitoring mobile phone: 1) Normal ECG monitoring procedure; 2) Abnormal heart rate detected procedure; 3) Daily heart rate history upload procedure. The state transition diagram of three procedures is shown in Fig.3- 15. In the beginning, the normal ECG monitoring procedure is performed.

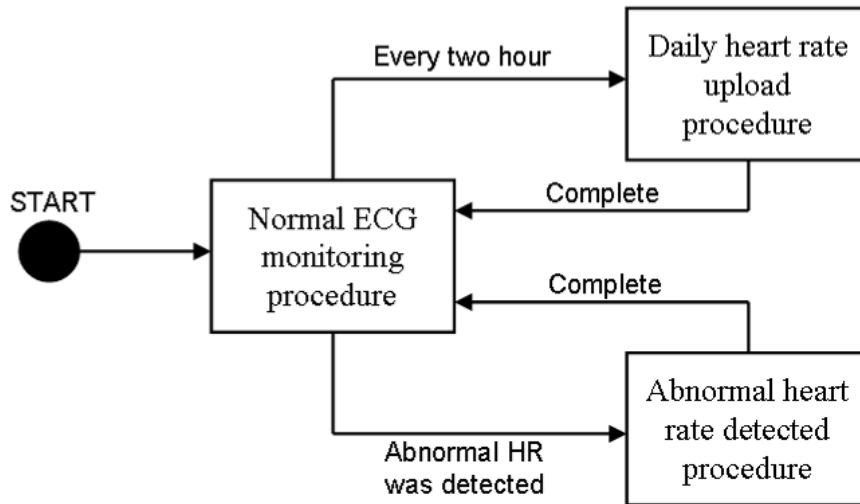


Fig.3- 15 State transition diagram for ECG monitoring procedures

When this procedure has performed for two hour, it will change to daily heart rate upload procedure and go back when finished. If, in anytime, abnormal heart rate was detected during normal ECG monitoring procedure, the procedure will change to abnormal heart detected procedure and go back when finished.

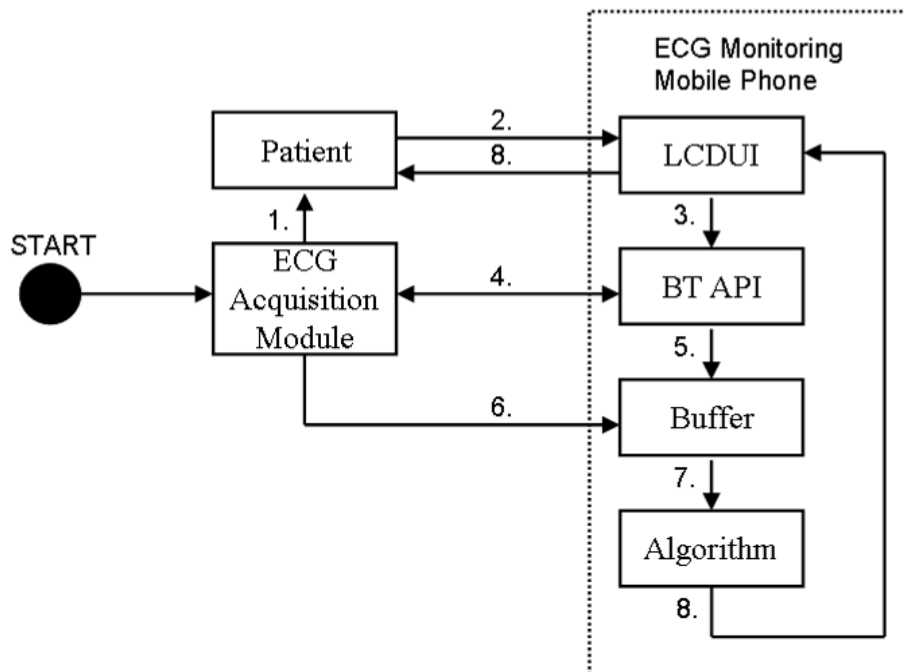


Fig.3- 16 Normal ECG monitoring procedure

The detail steps of normal ECG monitoring procedure is shown in Fig.3- 16 and

described below:

1. The ECG acquisition module is first attached in patient body, as shown in Fig.3-17.
2. Patient press the beginning bottom on ECG monitoring mobile phone to start measuring, as shown in Fig.3- 18.
3. The BT API is called to establish the connection between ECG acquisition module and ECG monitoring mobile phone.

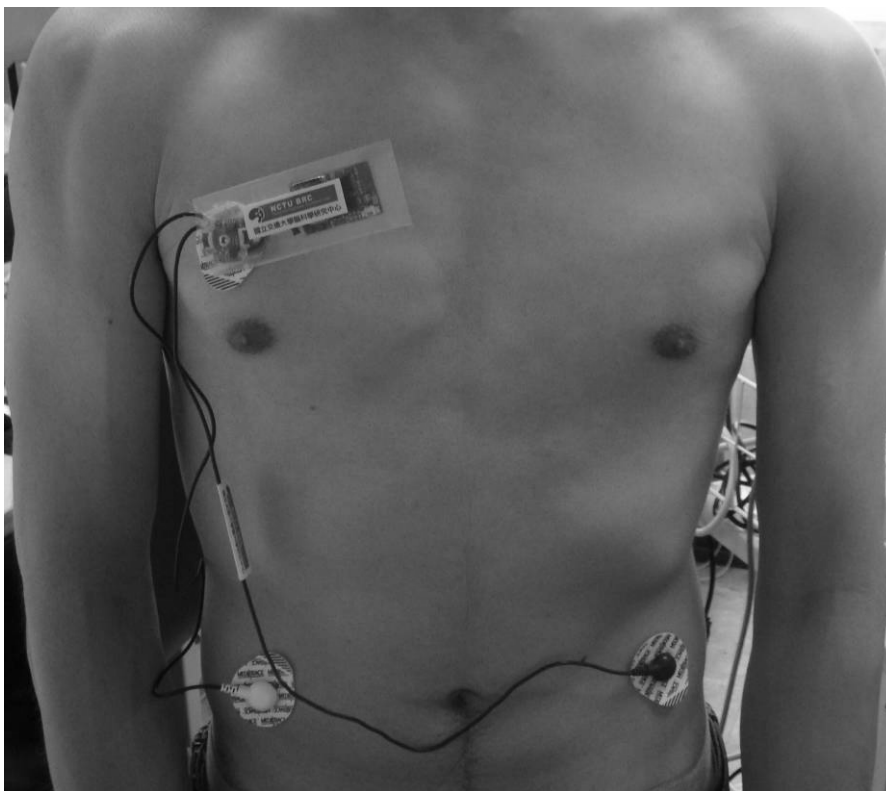


Fig.3- 17 Snapshot of ECG acquisition module attached on the body



Fig.3- 18 Snapshot of searching ECG acquisition module process: (a) start to inquiry the Bluetooth device around, (b) lists the device found around, (c) found the ECG acquisition module, and try to search the SPP service, and (d) found SPP service and try to create the connection.

4. BT API successfully establishes the connection.
5. ECG monitoring mobile phone will create a Buffer to store the ECG data.
6. The ECG raw data will be received and stored in to the Buffer.
7. The Algorithm will be called to calculate the HR.
8. The HR will be calculated and displayed on the screen of mobile phone to patient, as shown in Fig.3- 19. Due to the overlap is five second, the output time of

calculated HR is shown in Fig.3- 20.

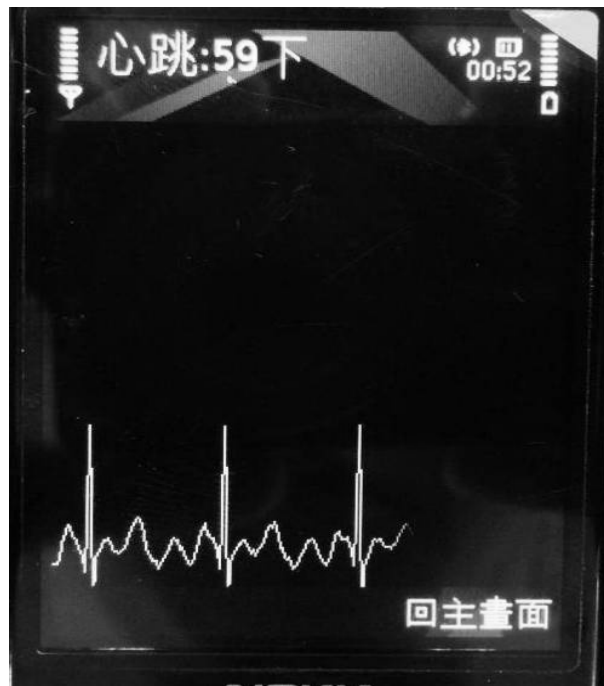


Fig.3- 19 ECG and HR displayed on the screen

Steps 1-8 above are also called initial steps. These steps are used to setup the GUI and connection. The initial steps should be only called one time until the program exit. Once the initial steps are run, the normal steps 9- 11 will be executed repeated.

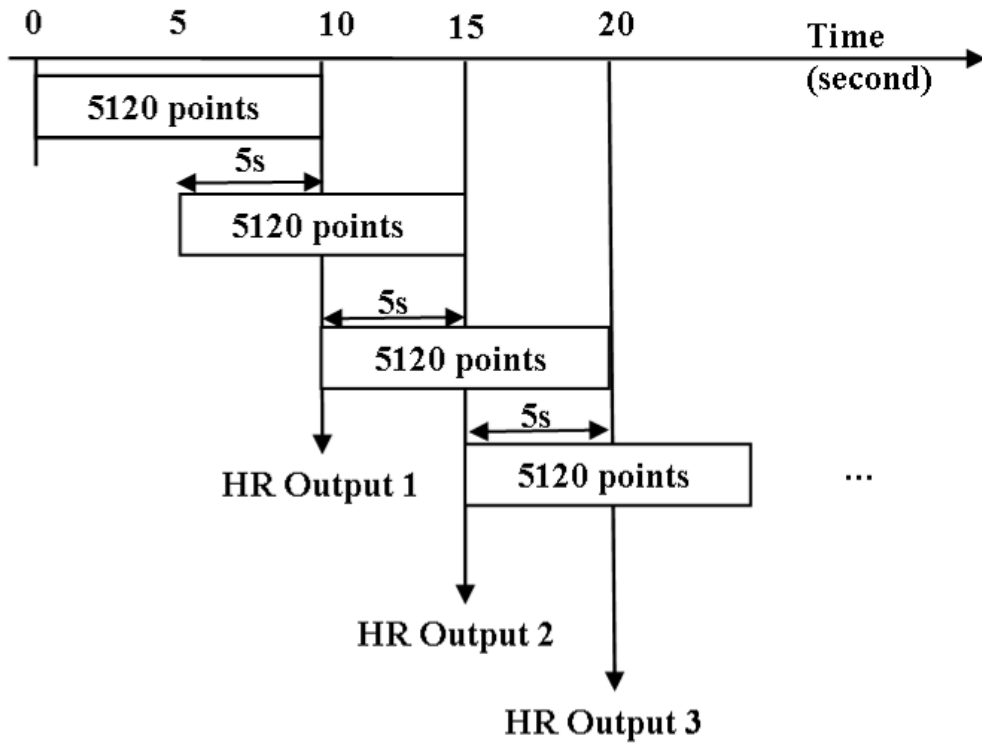


Fig.3- 20 Time procedure for calculating HR

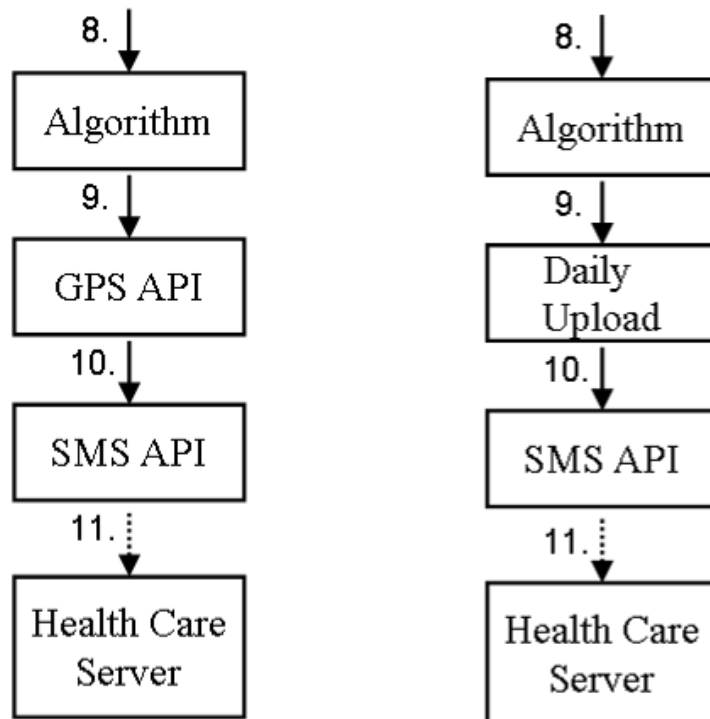


Fig.3- 21 (a) abnormal heart rate detected procedure; (b) daily heart rate history upload procedure

According to the different usage, the abnormal heart rate detected procedure and daily heart rate history upload procedure has more steps which is shown in Fig.3- 21 and described below:

9. In abnormal heart rate detected procedure, when the abnormal HR was detected, as shown in Fig.3- 22, the program will get the GPS information by using GPS API; in daily heart rate history upload procedure, the daily upload will collect the history of HR.
10. In abnormal heart rate detected procedure, the SMS API will set the ECG raw data and GPS information as payload of message; in daily heart rate history upload procedure, the SMS API will set the history of HR as payload of message, as shown in Fig.3- 23.
11. In both of two procedures, SMS API will send the message to health care server.

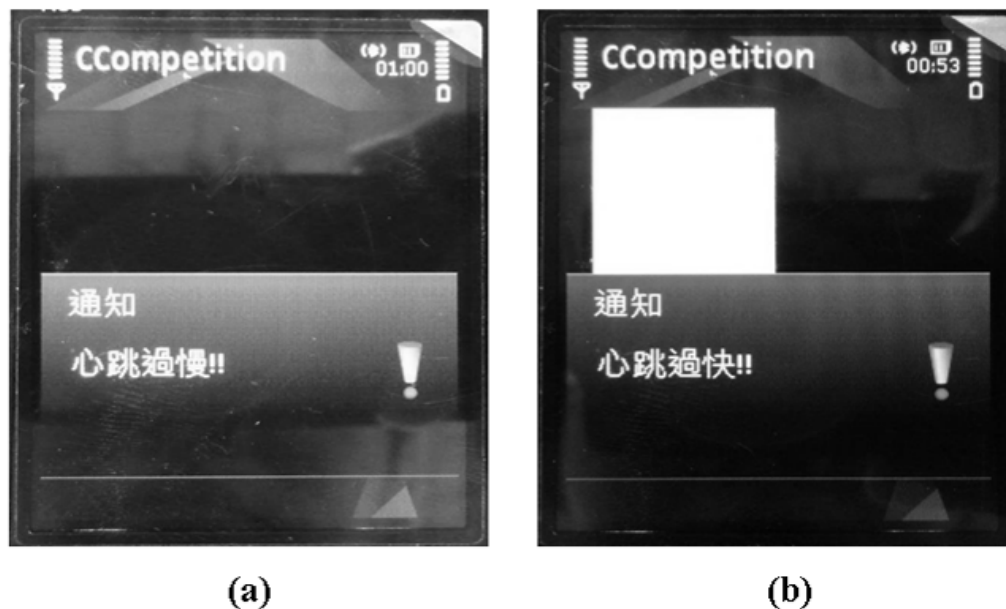


Fig.3- 22 Abnormal HR was detected and warning when (a) HR is too slow, and (b) HR is too fast



Fig.3- 23 Permission of sending SMS

3.3 Health Care Server



The health care server included a GSM modem and a server. Here, the GSM modem was used to receive SMS transmitted from patient's mobile phone and then passed the message to the server. SonyEricsson m600i is a PDA mobile phone which supports GSM modem and Bluetooth function. So, health care server uses this PDA as GSM modem due to the mobility. The connection between mobile phone SonyEricsson m600i and the server was by using either RS-232 serial cable or Bluetooth. The PDA is shown in Fig.3- 24.



Fig.3- 24 GSM modem used in health care server

3.3.1 AT Command

The AT commands are standard control tools based on GSM (07.07) to establish communication with the mobile GSM phone or modem. AT is the abbreviation of “Attention”. Every command line starts with "AT" or "at". That's why modem commands are called AT commands. Table 3- 4 listed commands used in our system.

Table 3- 4 Description of AT-commands

Command name	Parameter	Description
AT	none	Answer Command
AT&F	none	Reset to stored profile
ATE0	none	Deactivate command echo
AT+CMGF	0	Report Mobile Equipment Error in PDU mode
AT+CNMI	2,1,0,1,0	Indication new incoming SMS

As shown in Table 3- 4, these commands were used to communicate between GSM modem and PC. As an example: “AT+CNMI=2,1,0,1,0”, is a command for indicating

that there is a new incoming SMS, where “AT” is a prefix used for all commands, “CNMI” is a description to the kind of task to be performed, and “2,1,0,1,0” is the parameter.

3.3.2 Software Design of Health Care Server

(A) Architecture

Fig.3- 25 illustrates the component of the server. The link between GSM modem and server could be either RS-232 serial cable or Bluetooth, and use AT command to communicate with each other.

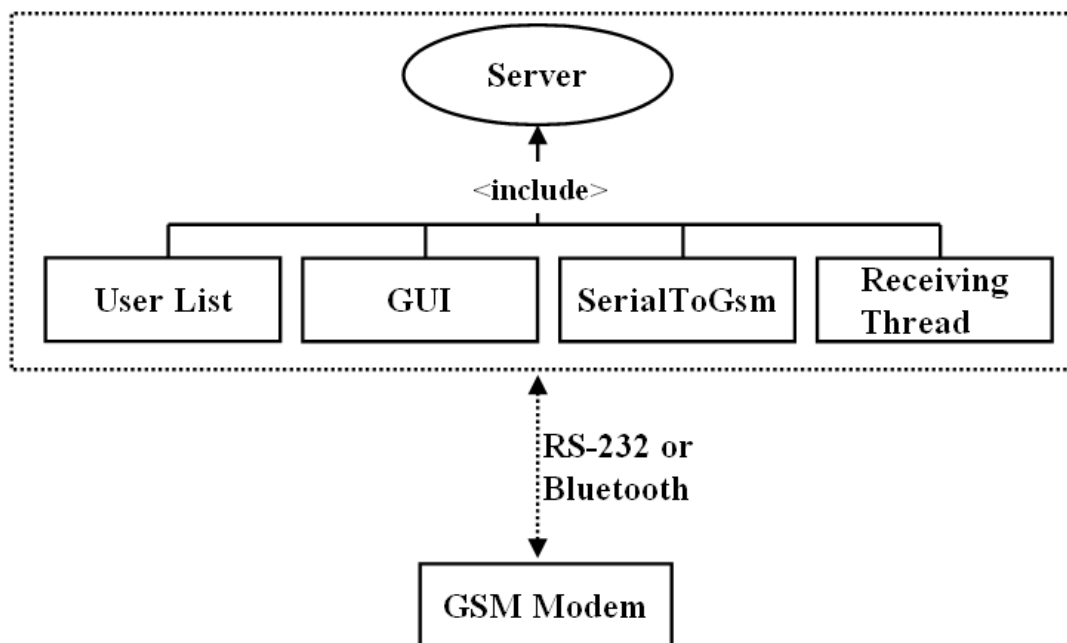


Fig.3- 25 Architecture of health care server

The program in server is designed and developed by ASP.NET and J2SE. The major capability of health care server is used as a database to extract SMS of ECG raw data with GPS information from patient and let physician to query the patient status. Due to the GPS information is contained in the message, the rescue team can also go to the right location to offer emergency rescue.

(B) Data Structure

Fig.3- 26 illustrates the data structure in server. The usage of server is monitoring the patients' status, so we used a modified linked list, as described in section 0, to store patients' information. The data structure is an array of type linked list, first node stores the patient identify information, such as mobile phone number. In personal mobility monitoring device, the ECG monitoring mobile phone will automatically upload his or her ECG raw data every two hour via SMS, so, from second node, the normally ECG raw data will be inserted behind. Initially, for example, user2 is the one subject that this system monitored, after two hour, user2 upload the daily ECG raw data via SMS by ECG monitoring mobile phone, and then the data (Msg1) will be inserted in the list of User1. Two hour later, Msg2 will be inserted to the list behind Msg1 and so on.

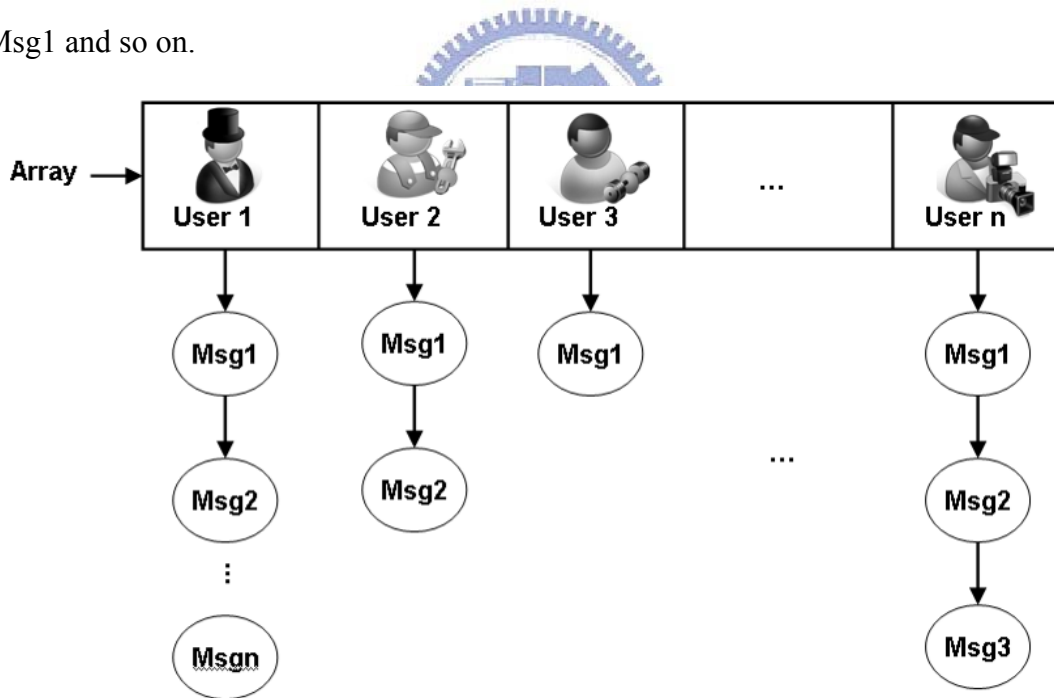


Fig.3- 26 Data structure in server

(C) Procedure

There are three main states in health care server: 1) initial, 2) listening, and 3) update GUI. The relation among the states is shown in Fig.3- 27.

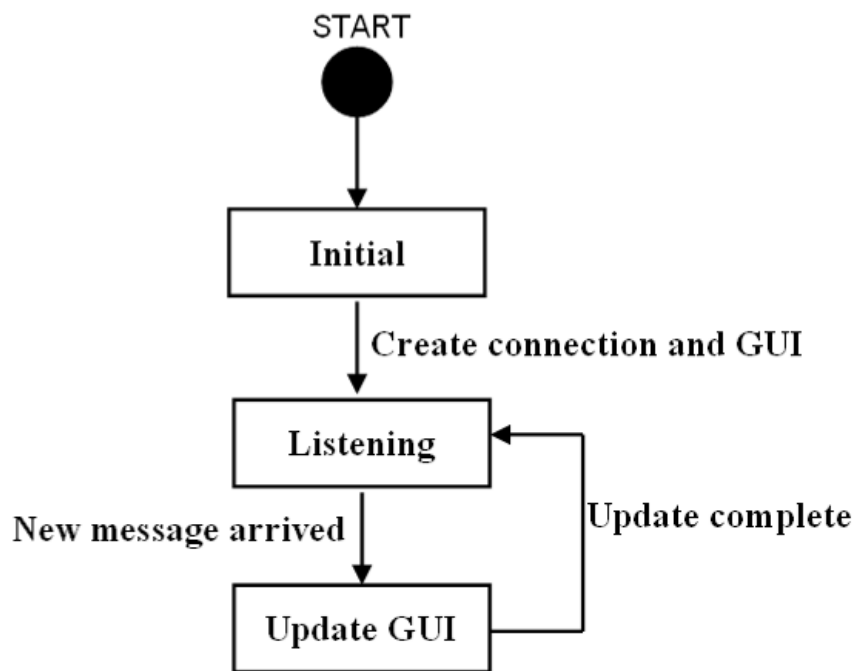


Fig.3- 27 Relation of states in health care server

In the beginning, the program will enter in initial state. In this state, the GUI and the connection between the GSM modem and server will be created. After initial state, it will enter in listening state. This state is used to listen whether the new message is received or not. Once the new message is received by GSM modem, as shown in Fig.3- 28, it will enter to update GUI state. The update GUI state is used to update the patient list which is monitoring in health care server.



Fig.3- 28 Notice of new message received

The detail process of initial state is described below and shown in Fig.3- 29:

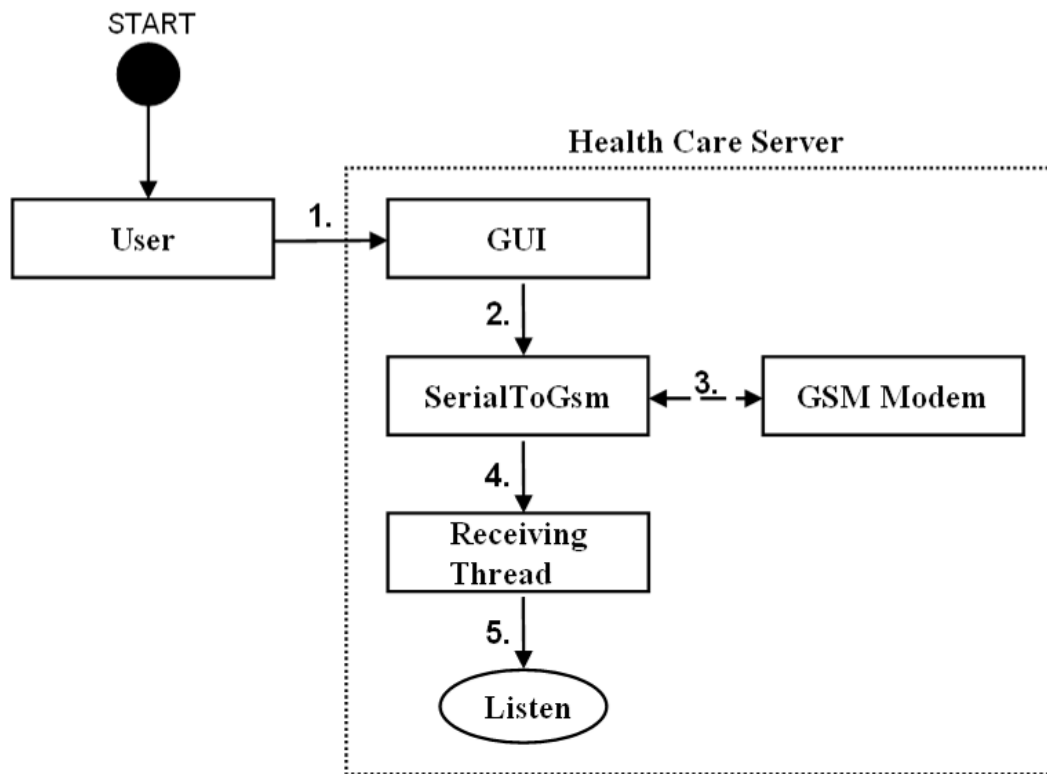


Fig.3- 29 Procedure of initial steps in health case server

1. Users, such as physician or health care nurse, start the program. Then the GUI of this program was shown on the screen.
2. After the GUI was created, the program will create a stream name as SerialToGSM, this stream is used to receive the response command and send the command to GSM modem.
3. After the SerialToGSM stream was created, the program will send a “at” AT-command to test whether the link between server and GSM modem is established. If GSM modem responses an “OK”, then the link is fine. Otherwise, this link is not established.
4. If the GSM modem response an “OK” after “at” AT-command sent, the program will create a thread name as ReceivingThread to listen the event of new message coming.
5. Go to the listening state.

After finish the initial procedure, the program will enter in listening state which is shown in Fig.3- 30 and described below:

1. The new message is received by GSM modem.
2. GSM modem will notify the ReceivingThread that there is a new message coming.
3. The ReceivingThread will then forward the message to SerialToGsm.
4. Go to update GUI procedure.

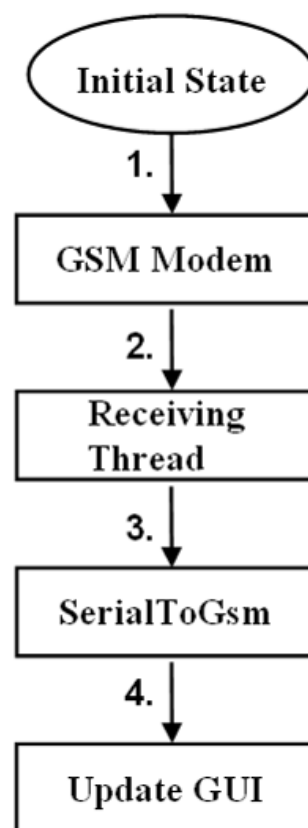


Fig.3- 30 Procedure of listening state in health care server

After finish the listening procedure, the program will enter in update GUI state which is shown in Fig.3- 31 and described as follow. In the beginning, the program will search the user whether on the list or not depend on the mobile phone number, if so, it will find out the user location and check if it is a multi-message or not. If the user is not in the list, the program will check whether the list is full or not. The prototype of

this system is set to monitor ten users. If the user list is not full and the user is not on the user list, either, the program will allocate a new location to store the user.

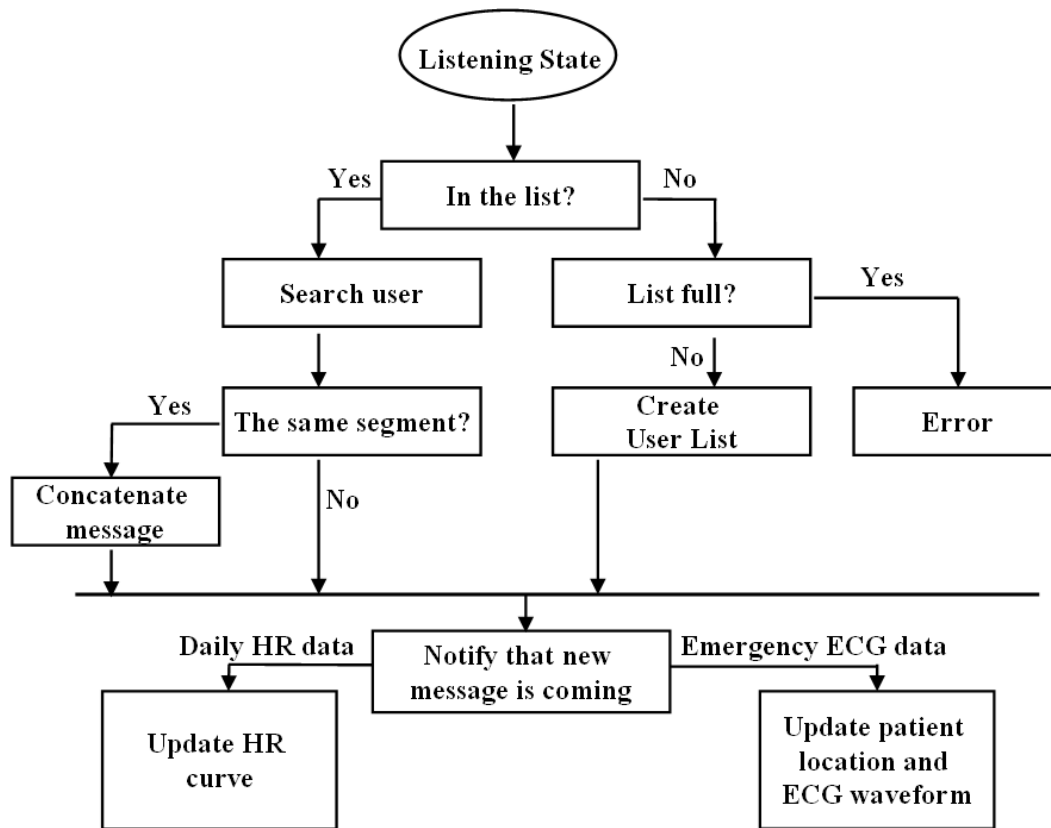


Fig.3- 31 GUI update procedure

In the GUI, as shown in Fig.3- 32, there five borders: personal information area, function area, message area, ECG waveform area, and daily HR curve area. Personal information area, which is in left up corner, is used to display user information such as name, sex, and the notice wrote by physician. Function area contains some buttons which are used to adjust the ECG waveform such as zoom in or zoom out. Message area is used to display the SMS received form patient, and, there are two blocks in the message area. Up block is the user mobile phone number and down block is the message received. In this example, there are two users on it, which is 886955492063 and 886912568574. Once we press the user number, the ECG waveform will be plotted one the ECG waveform area. ECG waveform area and daily HR curve area are

used to display the ECG waveform and daily HR, and, are plotted in window with an area of 512×234 pixels.

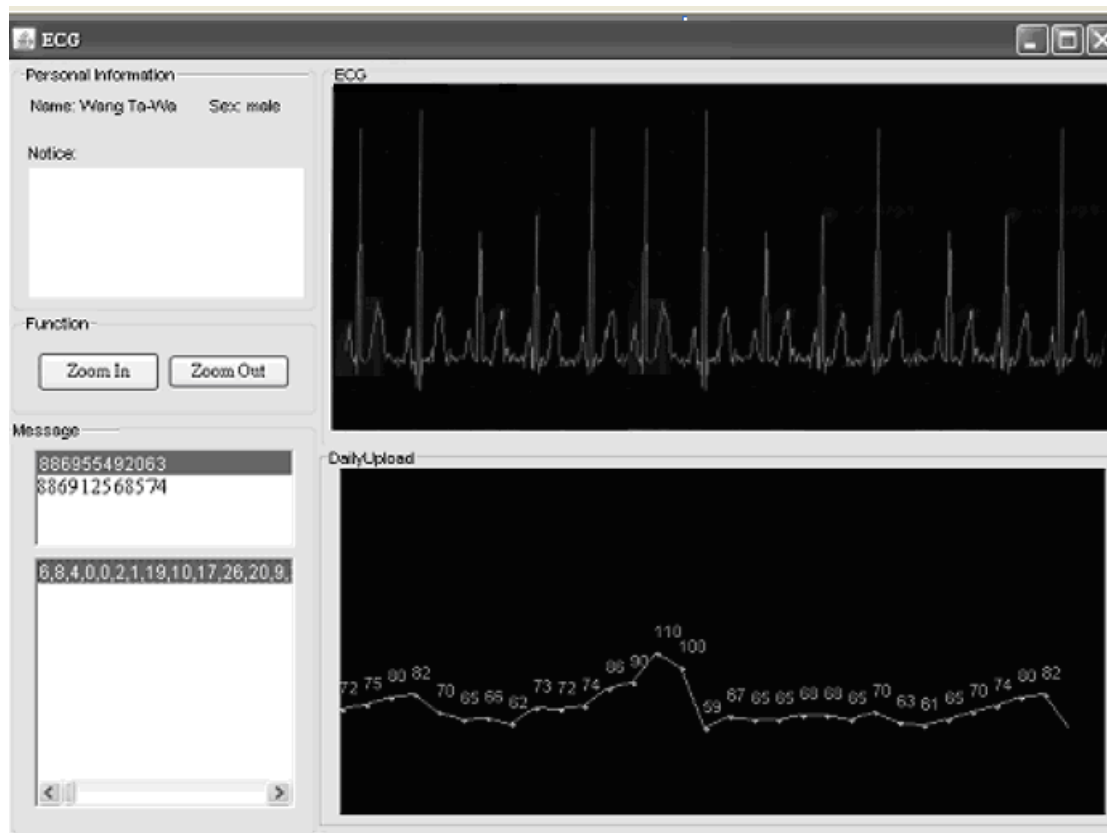
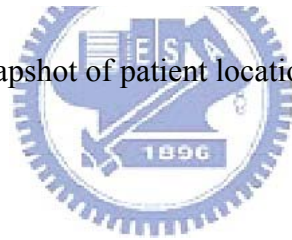


Fig.3- 32 GUI of health care server

Because of the SMS sent from ECG monitoring mobile phone does not only contains the ECG raw data but also the GPS information, that is, latitude and longitude. Therefore, we can use this information to locate the patient location, as shown in Fig.3- 33. This program is using YAHOO map API [42]. The patient location is located on the map by using the latitude and longitude.



Fig.3- 33 Snapshot of patient location on map



Chapter 4 Results and Discussion

In this proposed system, the SMS transmission time from patient to health care server and the accuracy of R peak detection in ECG monitoring mobile phone are both important issues. Therefore, we tested and discussed these issues in this chapter.

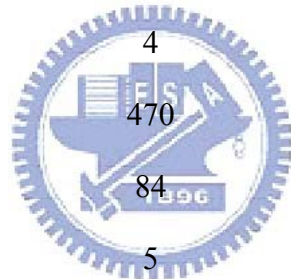
4.1 Evaluation of R-R Interval Detection Algorithm for MIT Database

MIT-BIH database is the source of the examined data [40]. The studied anomalies are Arrhythmia (AFA) and Tachycardia (TFA) Atria Fibrillation. The normal cases will be arranged in a third class. The arrhythmia database has been used to verify the accuracy of MSC algorithm. We have also used 30 sets of the ECG record files in MIT-BIH database to test the accuracy of our system and the result is showed in Table 4- 1. We can see that the average accuracy for the 30 sets of data is 95% which is acceptable. That is, our proposed algorithm can effectively detect the locations of R-waves, and by monitoring the intervals between R-waves, and in can also effectively detect abnormal HRV conditions.

Table 4- 1 Results of testing by using 30 sets of ECG record files in MIT-BIH database

Records	Total Beats	FN	FP	Accuracy
100	2272	0	0	100%
103	2083	1	0	100%
104	2322	42	135	92%
106	1927	120	20	93%
107	2135	41	39	96%

111	2123	7	6	99%
113	1794	0	0	100%
114	1878	3	2	100%
116	2390	35	13	98%
117	1537	2	4	100%
121	1862	4	3	100%
123	1518	0	0	100%
124	1605	28	14	97%
200	2593	30	22	98%
201	1933	240	173	79%
203	2839	425	284	75%
205	2652	4	0	100%
207	2072	470	210	67%
208	2919	84	48	95%
209	3008	5	9	100%
212	2749	1	2	100%
213	3243	39	32	98%
215	3365	4	6	100%
220	2048	0	0	100%
222	2486	46	49	96%
223	2563	79	37	95%
228	2034	101	82	91%
230	2256	1	1	100%
231	1571	2	0	100%
232	1806	9	35	98%



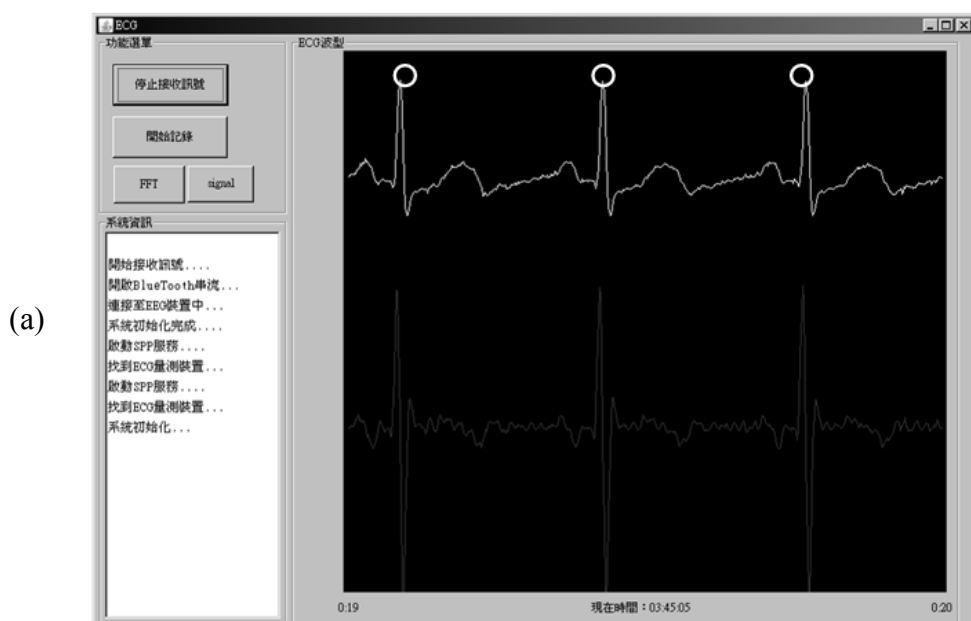
FN: When there exist beats but detected as beats does not exist

FP: When there exist no beats but detected as beats exist

Accuracy: $1 - (FP + FN) / (\text{Total Beats})$

4.2 Evaluation of R-R Interval Detection Algorithm for Simulated ECG

Fig.4- 1 shows the results of the maximum slope detection obtained from a segment of ECG data. It is a JAVA testing program implemented from the MSC algorithm. An ECG function generator (Agilent 33220A) was used to produce simulated ECG signal. Fig.4- 1 (a) and Fig.4- 1 (b) showed the results of simulated 3-Hz and 2-Hz ECG (up line) obtained from our ECG acquisition module respectively, and their first derivative (down line). The results showed that the peaks of R waves (white circle) could be successfully detected, and then the heart rate could be calculated from R-R interval.



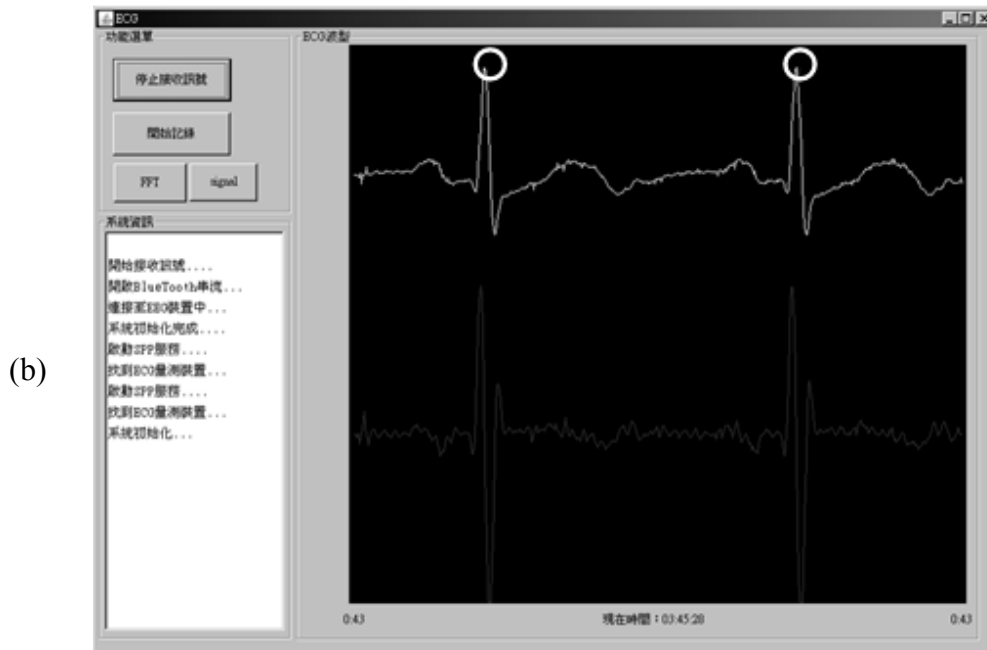


Fig.4- 1 Results of simulated 3-Hz and 2-Hz ECG (up line) obtained from our ECG acquisition module respectively, their first derivative (down line), and peaks of R waves (white circle).



4. 3 Evaluation of SMS Transmission Rate

Due to the message sent in this system is a long message, that is, the message body is cut to many segments. In our system, that is four segments. In order to make sure that the ECG raw data will be sent within golden hour, we tested the long message transmission time. The experiments were performed on twelve different times (0:00 A.M., 2:00 A.M., 4:00 A.M., 6:00 A.M., 8:00 A.M., 10:00 A.M., 12:00 P.M., 2:00 P.M., 4:00 P.M., 6:00 P.M., 8:00 P.M., 10:00 P.M.) and four situations: A) The same telecom company (Chunghwa Telecom) with the same base station, B) The same telecom company (Far Eastone) with the same base station, C) Different telecom company with the same base station, and D) Different telecom company with different base station. The results of average time of A, B, C, and D are in the last row

in Table 4- 2. As we can see, the final average time is about 25.075 s, 25.4 s, 25.94 s, and 45.2 s respectively. In D, because of the distance and number of base stations is more than others, it is about 20 s longer than A, B and C. Compares to [23], the average time is about 20 s longer than one SMS transmitted.

Table 4- 2 Results of experiments for performance analysis

Time	Condition A	Condition B	Condition C	Condition D
0 A.M.	24.2	24.5	24.3	44.5
2 A.M.	24.5	26.5	25.5	44.9
4 A.M.	24.5	24.6	26.2	45.8
6 A.M.	25.6	25.1	26.3	44.6
8 A.M.	24.1	25.8	25.2	45.2
10 A.M.	25.6	26.1	25.9	44.6
12 P.M.	25.5	25.5	26.1	46.2
2 P.M.	25.6	25.4	26.4	46.7
4 P.M.	25.5	25.9	26.4	44.9
6 P.M.	26.1	24.8	26.8	44.8
8 P.M.	24.8	24.9	26.4	45.2
10 P.M.	24.9	25.8	25.8	45.1
Average	25.075	25.4	25.94	45.2

Condition A: The same telecom company (Chunghwa Telecom) with the same base station

Condition B: The same telecom company (Far Eastone) with the same base station

Condition C: Different telecom company with the same base station

Condition D: Different telecom company with different base station (Hsinchu to Taipei)

Average transmission time of 10 times experiments.

Chapter 5 Conclusions and Future Works

In this study, we presented the design and implementation of a SMS-based mobile ECG monitoring system which consists of the ECG acquisition module, mobile phone with ECG monitoring, and the health care server. The modular approach applied in hardware and software design enables this system to be configurable for different application scenarios. For example, in the future, the ECG acquisition module can be used to connect several optional physiological sensors in addition to the built-in one, and it doesn't affect the whole system architecture. This system is feasible for further extension. Moreover, our ECG acquisition module is small, light, and wearable, therefore, it is suitable for long-term ECG monitoring in patients' daily life. In this system, a commercial mobile phone was used as development platform for ECG monitoring. By using commercial mobile phones, it not only provided powerful and flexible functions, but also substantially reduced both the time and cost for system development. The R-R interval and QRS detection algorithms were implemented in the mobile phone to detect abnormal HR conditions. After testing the accuracy of our algorithms by using MIT-BIH database, the results showed that the accuracy of our algorithm for AFA and TFA detection can reach to 95%. Therefore, the mobile phone with ECG monitoring can effectively monitor ECG and detect abnormal HR conditions.

By using SMS via GSM network, patients can monitor their HR anywhere in the globe if they are under the coverage of GSM cellular network. Different from long-term physiological signal transmission via GSM/ GPRS, the alert mechanism can effectively reach the goal of power saving because the alert message was only sent for abnormal conditions. According to the raw ECG signal data in the alert message, physicians can know the alert message caused by the abnormal HR

condition or by judgment fault of recognition algorithms, and then decide whether emergency treatment is required. Moreover, the GPS information in the alert message can rapidly provide the location of patients. Besides the alert mechanism, this SMS-based ECG monitoring system also provided the complete daily HR records of patients. The daily HR records of patients can completely be recorded in the database of healthcare server. Physicians, family members, and other related staffs then could look the daily HR records of patients via Internet. After testing the transmission time of alert messages, the results showed that the average transmission time of alert messages which contained raw ECG data and GPS information required about only 25 sec to be sent to physicians. Therefore, physicians can service emergency treatment within the golden hour when abnormal HR condition occurred. The SMS-based ECG monitoring system really provides a better solution for telecare medical applications, in comparison with other productions.



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