Reduction of Mobile Phone Interference in Tele-ECG Monitoring

By

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Abstract

Heart disease has been ranked the second leading cause of death in Hong Kong in the past 30 years, and it is expected that up to 40% of all deaths in the world will be related to heart diseases by 2020. Therefore, there is an increasing need for heart monitoring, enabling early treatment and minimizing the chance of fatality.

ECG (Electrocardiogram), the recording of the biopotential generated from the heart, provides significant information related to the condition of the heart. Holter units are commonly used for long duration recording and storage of ECG; however, the data cannot be accessed in real-time. As already demonstrated by several parties, a solution is the application of telemetry in ambulatory monitoring.

The design of the ECG acquisition circuit has significant effect on the quality of the acquired signal. Since the patient is mobile in ambulatory monitoring, the signal is often contaminated by 1.) motion artifact, which is due to skin-stretch potential and disturbance of the electrode-electrolyte interface; and 2.) EMI (electromagnetic interference), which is emitted from nearby electronics, power lines, lights, and radio-frequency communication devices. Various designs of the preamplifier stage and driven-right-leg circuit have proven to be successful in the reduction of these noises at frequency up to the kHz range. However, these techniques are no longer effective when the unit is exposed to EMI that is in the MHz and GHz range, which causes demodulation effects in the preamplifier and the following filtering circuits, thus introducing noise in the ECG. In the worst case the preamplifier saturates, and the signal would be totally unrecoverable.

A solution proposed is the integration of EMI filters into the driven-right-leg circuit. The modified circuit is built, and evaluated. Results show that the inclusion of the EMI filters improves the circuit's immunity to high-frequency EMI. In addition, the least-mean square (LMS) adaptive filtering technique is applied to the acquisition circuit's output to further reduce any remaining noise in the ECG. Results show that it is successful in removing most of the noise.

Also covered is an investigation of a telemedicine system based on WAP (Wireless Application Protocol), which has been developed for browsing various physiological data including ECG, blood pressure, and heart rate. The application was developed with WML (Wireless Markup Language) and Perl programming, and a database, managed by MySQL.

Demonstrations with emulation software and with a WAP phone show that such a system is feasible and is potentially applicable in many fields in telemedicine.

摘要

在過往三十年,心臟病一直是香港「第二號殺手」。統計顯示在二零三零年,全世界死亡人數中,高達四成的死亡原因將和心臟病有關。所以,爲了及早治療和減低因心臟病所引起的死亡率,對心臟監護的工具及研究有很大的需求。

心電圖的數據能顯示心臟活動的狀況。Holter 是常用的心電訊號採錄及儲存的儀器。可是,採下的數據不能即時被分析,其中一個解決的方法是利用無線電技術,把心電訊號即時傳送。

採錄心電訊號的電路設計對訊號的質素有很大的影響。因用者的流動性甚高,所以訊號因而常被干擾,包括: 1.) 用者的動作所產生的噪音 2.) 附近的電子儀器,電源線,光管和無線通訊儀器所發出的電磁干擾。不同的前置放大器和右腿推動電路的設計,能有效地降低頻率高達 kHz 的噪音,但對頻率在 MHz 至 GHz 的干擾,噪音會因一般集成電路內的非綫性反應而產生。最壞的情況,就是當前置放大器飽和時,心電訊號便無法挽回。其中一個解決的辦法是安裝電磁干擾濾波器,在右腿推動電路中,這樣,已改良的電路測試結果証明電磁干擾濾波器的加插,可令心電訊號採錄的電路對高頻干擾抵抗有一定的幫助。另外,我們更利用了 LMS (Least-Mean Square) 自適應濾波器,有效地除去一部份採錄電路輸出中剩餘的噪音。

另一方面,這論文探討的是 WAP (Wireless Application Protocol) 在遠程醫療的應用,包括讀取心電圖,血壓和心率等生理數據。這系統主要是利用 WML (Wireless Markup Language) 和 Perl 編寫的程式及 MySQL 管理的資料庫所組成。透過模擬軟件及附有 WAP 功能的無線電話示範,我們可看到該系統的可行性及應用在其他遠程醫療上的潛質。

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Chapter 1: Introduction

1.1 Objectives

This research will present the design and implementation of selected stages of a wireless electrocardiogram (ECG) monitoring system. Emphasis will be on the noise reduction techniques that utilize electromagnetic interference (EMI) filters and adaptive filters to reduce noise caused by nearby wireless communication units, and Wireless Application Protocol (WAP) applications that have been developed for remote browsing of the acquired ECG and other biomedical data.

1.2 Need for Patient-Monitoring System

For the past decades, many systems have been developed for the continuous monitoring of patients. There is an increasing need for ambulatory patient-monitoring services, especially ECG monitoring, for two main reasons: an aging population and an increasing number of people with heart disease.

1.2.1 Aging Population

Statistics have shown that the world population is aging. The age profile of the world's population is forecast to be older, mainly as a result of current and anticipated changes in fertility [1]. The number of persons aged 60 years or older is projected to be almost 2 billion by 2050, and it will be the first time in human history that the population of older persons will be larger than that of children (0 to 14 years) [2].

According to U.S. Census Bureau's International Data Base (IDB) [3], which is a computerized source of demographic and socio-economic statistics for 227 countries and areas of the world, Hong Kong and China will both face the same situation in the next few decades. The anticipated changes in demography for Hong Kong and China are shown in the charts and graphs in Appendix A. The percentages of persons aged 60 or above in the populations is summarized as in Table 1.1. Another recognizable trend is the increase in life expectancy, as summarized in Table 1.2.

	Percentage of persons aged 60 or above in the population		
	2000	2025	2050
Hong Kong	14.2%	29.0%	39.8%
China	10.8%	19.7%	30.4%

Table 1.1: Increase in percentage of older persons in the population in Hong Kong and in China. Source: U.S. Bureau of the Census, International Data Base.

	Life Expectancy at Birth		
	2000	2025	2050
Hong Kong	79.5	82.2	83.7
China	71.4	77.4	80.9

Table 1.2: Increase in life expectancy in Hong Kong and in China. Source: U.S. Bureau of the Census, International Data Base.

These statistics have triggered the United Nations to discuss many social development issues related to meeting the specific needs of the elderly, including requirements for health care, social welfare services, and housing [1]. They have noted that there is a need to put more resources into geriatric health services and facilities for treating chronic diseases. One of the health-care problems identified in the discussion was the uneven geographical distribution of medical services in developing countries in Asia. Hospitals with services for the aged are still mostly located in urban areas. The problem in many cases is not a lack of services, but their uneven distribution, resulting in unavailable services to the majority of aging persons living in rural areas.

Today, chronic illnesses represent the key health problems affecting middle-aged and older adults. The prevalence of chronic conditions, especially heart conditions, hypertension, varicose veins, arthritis, diabetes, diseases of the urinary system, visual and hearing impairments, and orthopedic impairments, among the elderly is generally higher than among younger persons [4]. Diseases in the elderly tend to be chronic rather than acute, and symptoms tend to be more subtle and vague [5]. Thus, recognition and diagnosis of disease in the elderly requires a high degree of alertness.

Long-term and remote monitoring services would be useful for meeting the medical need of the elderly, especially those elderly people living in rural areas.

1.2.2 Increasing Population with Heart Diseases

In Hong Kong, heart disease ranked second in the ten leading causes of death in the past 30 years [6]. Table 1.3 shows these figures. It accounted for 15% of all deaths in 1998, and 84% of these deaths were from people aged 65 or above. In 1999, heart disease accounted for 30% of all deaths worldwide [7].

	1961	1971	1981	1991	1996	1997	1998
Cause of Death	(No. of Deaths per 100,000 Population)						
1. Cancer	72.0	104.7	127.1	153.5	156.3	158.0	160.9
2. Heart Diseases	**58.9**	**73.0**	**73.9**	**84.5**	**74.7**	**73.2**	**76.1**
3. Pneumonia	84.1	55.9	41.2	31.6	61.4	62.5	55.5
4. Cerebrovascular Diseases	44.2	48.4	62.7	52.3	47.8	46.1	49.6
5. Injury and poisoning	34.7	35.5	37.5	31.5	25.8	29.1	28.7
Others	297.5	183.1	139.6	145.2	128.3	119.8	120.8
All Causes	**591.5**	**500.7**	**481.9**	**498.6**	**494.3**	**488.7**	**491.8**

Table 1.3: Death Rate for Leading Causes, 1961 – 1998 (Ranking According to 1998 Data)

From these data, it can been seen that there is an increasing need for ambulatory ECG monitoring, as it will be beneficial for heart disease patients. Such monitoring services allow early detection and diagnosis of pathological symptoms, and thus lead to earlier treatment.

1.3 ECG Basics

The left atrium, right atrium, left ventricle, and right ventricle of the heart serve as the pump for the circulatory system. The well-coordinated pumping actions of these four chambers are a result of series of electrical depolarizations and repolarizations over different regions of the heart, and these activation sequences establish conduction fields which also extend to the body surface. The heart can be viewed as an electrical equivalent generator, and at each instant of time, the electrical activity of the heart can be represented by a net equivalent current dipole located at a point of the heart [8]. The thoracic medium can be considered as a resistive load, resulting in attenuation of the field with increasing distance from the source, as well as potential drops measured between two points measured on the body surface. Measurement of the resulting electrical potentials between different sites on the body surface is called the electrocardiogram (ECG). The ECG provides information on the electrical activity, and thus the condition of the heart. Its dynamic range is from 10μV to 5mV. Its bandwidth is from 0.05Hz up to 1000Hz, but 0.05Hz to 80Hz is adequate for most monitoring purposes [9].

1.4 Existing ECG-Monitoring Technologies

The communication links in a patient-monitoring system can be wired, wireless, or a combination of both. For the past few decades, various patient-monitoring technologies have been developed, aimed at providing 'in-bed' or ambulatory monitoring services. This section describes some of the previous work done by other parties.

After a heart attack or period of arrhythmia, a patient may be required to carry a Holter monitor for up to a few days. The monitor is a portable device that captures ECG data on tape. The unit must be brought back to the hospital for analysis by a coronary care nurse or computer. Although it offers some help in understanding the patient's condition, it still has significant limitations. The pathological symptoms might not appear during the time of recording. Many dangerous cardiac events can occur only once every few days or even weeks [10]. Even if a pathological event is captured, it would not be noticed until offline analysis is run on the tape, and thus no immediate action is possible following the event. Monitoring typically provides continuous, real-time information about the state of the patient, so the name Holter monitoring is inappropriate [11]. Recognizing these limitations, many parties have participated in the development of real-time ECG monitoring systems with capabilities of remote, online analysis.

Magrabi *et al.* [12] have demonstrated a web-based longitudinal ECG monitoring system. In a store-and-forward manner, it allowed viewing of captured ECG and offline disease classification through the Internet using Common Gateway Interface (CGI). A 12-lead ECG acquisition card was connected to a personal computer (PC) located at the patient's home. The computer then loaded the recorded ECG to a web server.

Park *et al.* [13] went further and built a real-time patient monitoring system that captured ECG, respiration, temperature, blood oxygen saturation (SpO_2), invasive blood pressure (IBP), and non-invasive blood pressure (NIBP) from a patient in bed. The whole system was operated over a Local Area Network (LAN), so the parameters could be viewed remotely in real-time at other computers in the network.

The scenarios mentioned so far involved wired systems. Some wireless systems have also been developed, allowing a greater degree of mobility. The aim was to provide real-time monitoring services even when the patient was not in bed. Shimizu [14] has demonstrated patient monitoring by mobile communication. Compressed audio, video, ECG, and blood pressure data were multiplexed and sent from a mobile station, where the patient was situated, to a remote station through a mobile phone. The experiment was then repeated using direct satellite communication.

A group from Tsinghua University [15] designed and developed a home-use wireless ECG monitoring system. It consisted of a portable ECG acquisition and transmitting unit, a receiving unit, a PC-based home monitor, and a workstation at the hospital. The ECG was first captured, digitized, and sent to the PC on a conventional short-range radio-frequency (RF) link. Online arrhythmia analysis was carried out at the PC. If an abnormality was detected, the PC would activate an alarm before sending the captured ECG to the remote workstation through the telephone line. Further analysis was then done at the workstation.

Leung [16] developed a wireless ECG system that only required a single electrode assembly. The design utilized concentric electrodes for acquisition, a sigma-delta converter for sampling, and conventional FM circuit for short-range digital transmission.

A spread spectrum system is an attractive option for biotelemetry because of its rejection ability against electromagnetic interference. Kyoso *et al.* [17] developed such a system for transmitting ECG, and have shown its acceptable reliability under interference from an electric knife in hospital environment.

Besides RF, the wireless ECG link can also utilize Infrared communication. The advantages and disadvantages of diffuse infrared biotelemetry were discussed by Santic [18]. With infrared, no interference is emitted to medical equipment; however, applications are restricted to a single room, and power consumption is higher than that of an RF telemetry system. The major disadvantage is the difficulty with multi-system operation within the same room due to the limited bandwidths.

1.5 Challenges in Patient-Monitoring

Although many wireless monitoring systems have been developed, there are still some limitations. These systems can be used only strictly in an indoor or an outdoor environment. There seems to be no standard mechanism available for the "handoff" of monitoring service when a patient is traveling from indoors to outdoors and vice versa. Since many of the current systems are site-specific and task-specific, the cost for design and implementation is high. When a system has to be installed, it is almost "tailor-made" to suit the layout of the site. Any additional features later added to the system would be difficult and costly.

1.6 Development of an ECG-Monitoring System

This section will present the general aspects in the design and implementation of a typical indoor, wireless ECG-monitoring system.

1.6.1 Overall Structure

Figure 1.2 shows the functional blocks of the system. It consists of preamplifier, bandpass filter, Analog-to-Digital Converter (ADC), telemetry circuits, microcontroller (MCU), and personal computer.

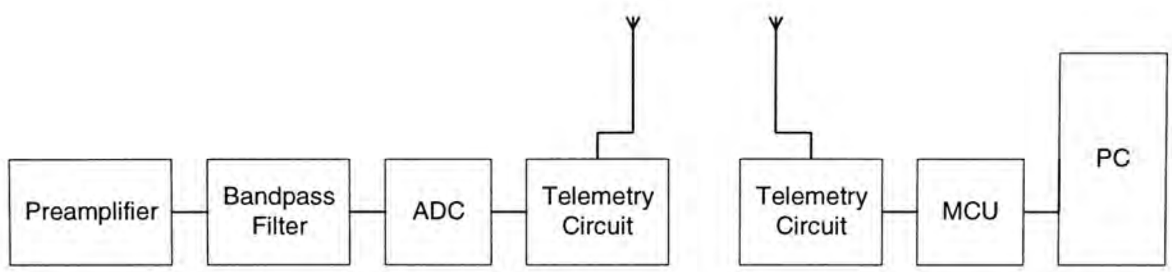


Figure 1.2: Blocks in a wireless ECG monitoring system

Currents are carried in the body by ions, whereas currents in electronic equipment are carried by electrons. Biopotential electrodes are placed on the skin to transduce ionic currents into electric currents that can be detected by electronic circuits. These electrodes can be applied to the body using a number of techniques. They may be dry when applied directly to the skin. In some cases gel with electrolytic properties is added between the skin and electrode to enhance coupling. The silver/silver chloride electrode is commonly used because of its non-polarizable properties [8].

A major parameter in characterizing the input of the system is the input impedance, Z_{in} which is the ratio of input signal voltage to input signal current. In this case, the currents flowing from the electrodes to the preamplier through the lead wires should be as small as possible in order to avoid excessive signal attenuation. Therefore, Z_{in} of the preamplifer should be as large as possible [9]. Another advantage of a larger Z_{in} is the reduction of signal distortion introduced by the varying impedances and frequency-dependence of the skin-electrode interface. Typical values for Z_{in} are of the order of $10M\Omega$ but may be as high as $G\Omega$.

The preamplifer should also have a high common-mode-rejection ratio (CMRR), since common-mode voltages, which are typically much larger than the potential measured between the electrodes, very often appears on the body surface. A common preamplifier used is the differential amplifier that consists of three operational amplifiers, as shown in Figure 1.3. This configuration is also called an instrumentation amplifier.

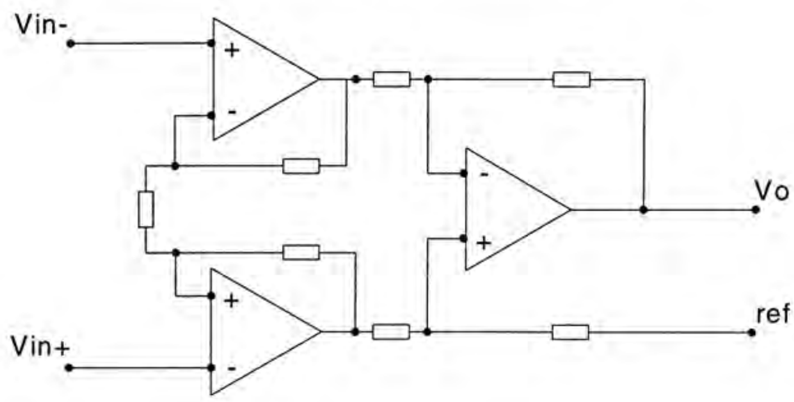


Figure 1.3: An instrumentation amplifier

A bandpass filter is used for filtering out the high-frequency noise and DC-drifts in the preamplified ECG. For monitoring purposes, a passband from 0.05Hz to 150Hz is adequate. In addition to this, a 50/60 Hz notch filter, also referred to as the 'hum' filter, can be used to reduce the 50/60Hz interference caused by powerline. The required gain of the signal before entering the ADC stage is typically from 100 to 1000. In some systems the preamplifier provides all the gain, and in other systems this overall gain is incorporated using cascades of amplifiers following the preamplifier and bandpass filter.

The ADC converts the ECG to a digitized form for digital wireless transmission. An 8-bit ADC sampling at 200Hz is adequate for monitoring ECG [10]. Using telemetry circuits, the wireless link transmits the signal to a local station. The receiver side links up to the MCU, which pushes the data into a computer through serial port. The computer, which may be connected to a remote monitoring agent through a network, then performs online analysis. These components described above form a low-cost, wireless ECG monitoring system for use at home.

1.6.2 Considerations

The portion of the system responsible for ECG acquisition, digitization, and transmission should be small enough for portable use by the patient, who may have to carry it from place to place. Power consumption should be low, so that the patient-worn monitor can run on batteries for at least a few days. The overall cost of implementing a complete system should be affordable by an average household, as it is intended to be for long-term use at home.

Chapter 2: EMI Filters in ECG Acquisition Circuit

2.1 Overview of Noises in ECG Acquisition

The objective of biopotential recording is to reproduce a signal that represents the electrical event of interest. Any undesired component superimposed on the desired signal is considered as noise. In ECG recording, noise is often introduced into the system in several ways.

2.1.1 Other Biopotentials

The electromyographic (EMG) signal, which is generated by contracting muscles located in proximity to the ECG electrodes, may also appear in the ECG recording. Figure 2.1 shows a lead I ECG recording contaminated by EMG signal. The location of electrode placement should be chosen so that minimum EMG is picked up. Thakor and Webster [19] suggested minimizing this effect in one-lead ambulatory monitoring by placing one electrode below the right clavicle and the other on the left axillary line above the lower border of the ribs.

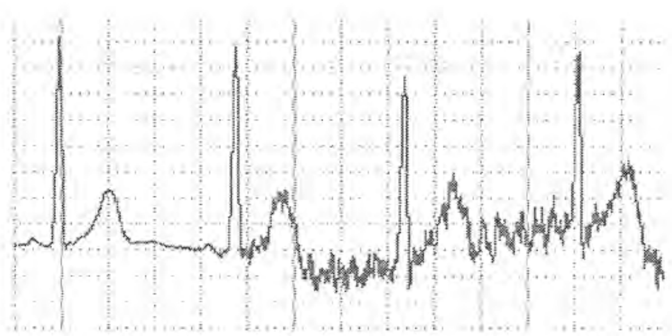


Figure 2.1: Electromyographic interference on the ECG

2.1.2 Motion Artifact

There are two main sources of motion artifact: movements in the skin-electrode interface, and skin stretch. When an electrode is in contact with an electrolyte, a double layer of charge forms at the interface, resulting in a potential difference called half-cell potential. Movement of the electrode with respect to the electrolyte would cause disturbance of the charge at the interface, and thus a momentary change of the half-cell potential would appear until equilibrium can be reestablished. Figure 2.2 shows the skin-electrode interface. If a pair of electrodes is in an electrolyte and one moves while the other remains stationary, a potential difference appears between the two electrodes during this movement [8].

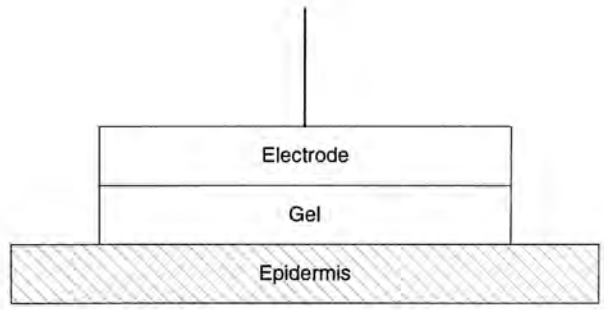


Figure 2.2: Skin-electrode interface

Figure 2.3 shows the anatomy of the skin. There is a skin potential of about 30mV across a barrier membrane between the stratum granulosum and stratum corneum. When the skin stretches, the skin potential decreases to about 25mV. This 5mV difference is amplified along with the ECG signal, and appears as motion artifact [19][20] in the form of severe DC shift or even saturation of the preamplifier.

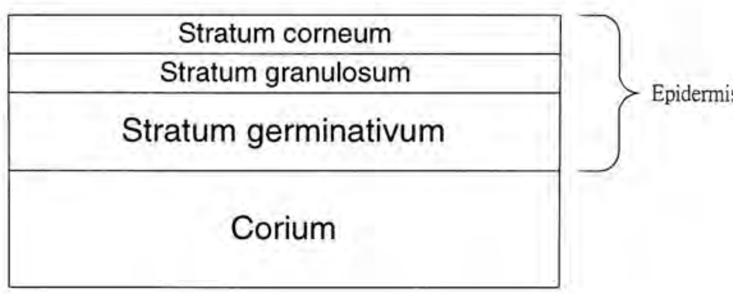


Figure 2.3: Outer layers of the skin

Motion artifact generated by electrode metal-to-solution interface movement is negligible with paste-filled recessed Ag-AgCl electrodes [21], which are used in standard ambulatory ECG recordings nowadays. The standard method to reduce the remaining motion artifact, which is due skin stretch, is by skin abrasion [20]. Tam and Webster [21] showed that about 20 strokes of very fine sandpaper on the skin reduced the 5mV change to a negligible value. Although this method is commonly used, it is hard to tell how much abrasion is needed for an area. Too much abrasion would lead to skin irritation, whereas too little abrasion would not reduce motion artifact.

Recognizing this drawback, some parties have tried using an adaptive filter to reduce motion artifact. Develin *et al.* [22] used the electrode/skin impedance variations to estimate the relative amount of electrode motion artifact in the ECG. Assuming that the impedance change was correlated with the motion artifact, they were able to reduce motion artifact only in some cases.

Hamilton and Curley [23] noted that this impedance signal used did not necessarily correlate to motion artifact. Based on observation that skin stretch had a direct relationship with motion artifact, they used a miniature displacement sensor mounted on the foam electrode for getting a 'skin-stretch signal', which was used in an adaptive filter for removal of motion artifact. The most significant reduction in artifact was achieved with three to four coefficients. Although this method would improve the fidelity of ambulatory ECG, it is impractical due to the high cost of 600 US dollars per sensor.

Cable movement can also cause motion artifact. Klijn and Kloprogge [24] noted that when ECG is recorded during exercise, friction and deformation of the cable insulation acts as a piezoelectric movement transducer. This problem can be solved by shortening and securing the cables and by placing a preamplifier at each electrode to drive the cable.

2.1.3 Power-line Interference

A major type of interference encountered in an indoor environment is power-line interference. Besides being connected to equipment, power lines are present in the walls, floors, and ceilings. A 50/60Hz potential is always present in these lines, and it introduces interference into the ECG recording by two independent mechanisms: electric field coupling and magnetic field coupling [25-27].

As shown in Figure 2.5a, lead wires running from the patient to the preamplifier form a conductive loop, which can be in the presence of a changing magnetic field produced from the power-line. As a result, a potential (electromotive force), which is proportional to the area of the loop, its orientation, and the magnitude of the magnetic flux density, is induced in it. According to the Maxwell-Faraday law of magnetic induction, the induced potential is calculated as follows [25]:

$$induced\_potential = -\frac{d\Phi}{dt} = -\frac{d}{dt}\int B \cdot dS = -\frac{dB}{dt}S$$, where

Φ = flux, in Wb,

$B = B_M \cos\phi \cos\theta \cos\omega t$ = magnetic flux density, in Wb/m^2,

$\omega = (2\pi)(50)$, in rad/s,

$\cos\phi \cos\theta$ = oreientation of loop, (ϕ and θ specify the polar coordinates), and

B_M = peak-to-peak magnitude of magnetic flux density, in Wb/m^2.

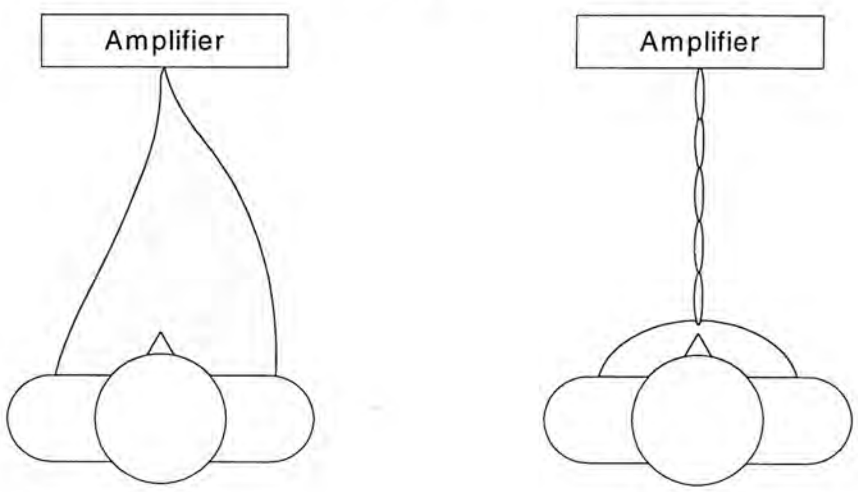
After taking the derivative,

$$\text{Induced\_potential} = \omega S B_M \cos\phi \cos\theta \sin\omega t.$$

Assuming that the frequency and loop orientation are constant,

$$\text{Induced\_potential} = K B_M S, \text{ where K is a constant.}$$

This shows that the induced potential that results from magnetic coupling is directly proportional to S, the area of the loop. Thus, a way to eliminate this interference is to minimize the size of the loop formed by the electrode lead wires. This is achieved by twisting the leads up to the body, as shown in Figure 2.5b.



(a) (b)

Figure 2.5: Twisting the wires together up to the body minimizes the loop area.

Electric-field coupling between the power-line and ECG circuit is a result of the electric fields surrounding main power lines and power cords connected to electrical apparatus. The fields can be present even when the apparatus is not turned on, in which case a 50/60Hz potential is still present on one of the wires up to the ON-OFF switch. A changing electric field would capacitively couple displacement currents into the patient, the lead wires, and the ECG acquisition circuit. Since the electric field results from a changing potential above ground, displacement currents in the system would flow to ground by the path of least resistance. Figure 2.6 is a model for electric-field coupling in ECG recording. It is based on the models [25][26-37] previously accepted in studying 50/60Hz interference.

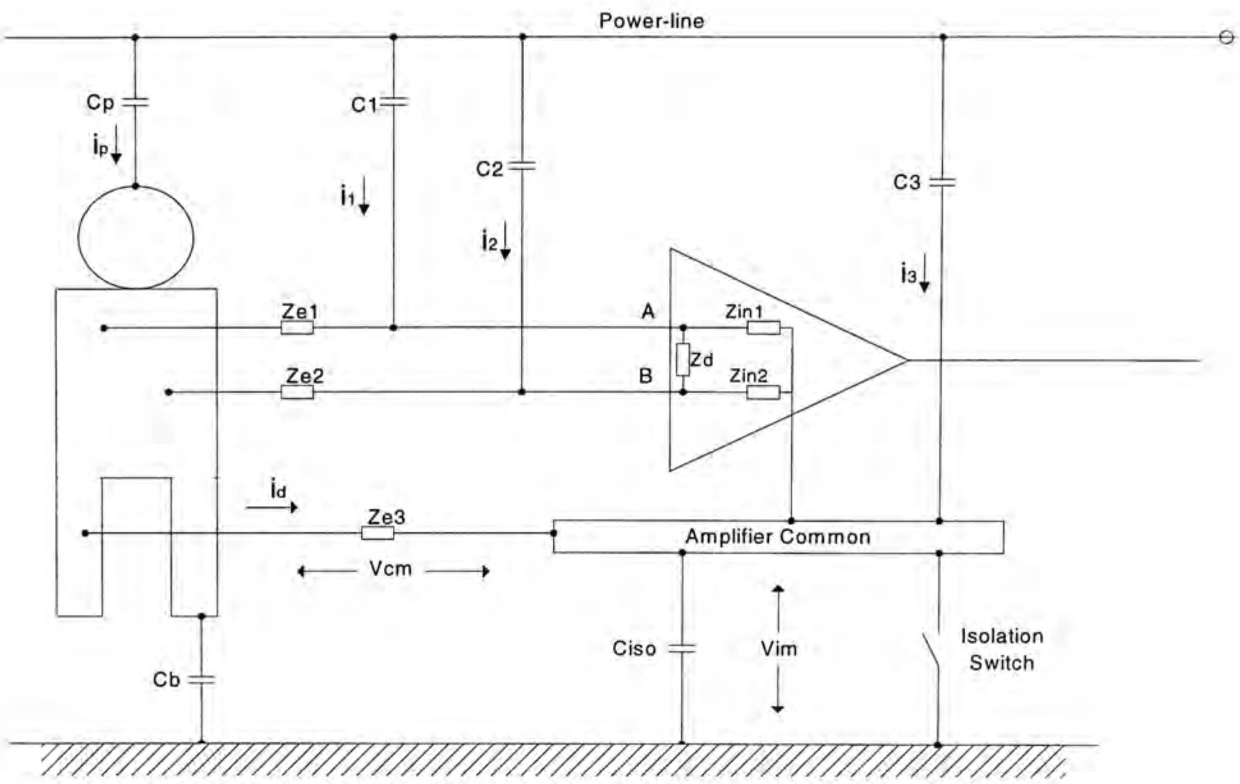


Figure 2.6: Model for electric-field coupling in ECG recording

Three lead wires connect the patient to the amplifier. Z_{e1} and Z_{e2} are the skin-electrode impedances of the measuring electrodes, and Z_{e3} is the skin-electrode impedance of the reference electrode. Z_{in1} and Z_{in2} are the amplifier common-mode input impedances, and Z_d is the amplifier differential input impedance. C_p, C1, C2, and C3 are the stray capacitances between the power-line and the system. C_b and C_{iso} are the stray capacitances between the system and ground. The amplifier common is isolated when the isolation switch is open.

First, consider the displacement currents, i_1 and i_2, into the lead wires. Power-lines are coupled to the leads through capacitors C1 and C2. Z_{in1}, Z_{in2} and Z_d are typically very large in an ECG preamplifier; therefore, most currents induced in the wires would flow to the body through the electrodes, and then from the body to earth through C_b, and Z_{e3} in series with C_{iso}. Since the potential difference of interest appears between inputs A and B, skin-electrode impedance imbalance ($Z_{e1} \neq Z_{e2}$) or unequal values of displacement currents into the measuring leads ($i_1 \neq i_2$) can cause interference. This relationship can be approximated by:

$$V_{AB} = i_1 Z_{e1} - i_2 Z_{e2}$$

Next, consider the displacement current i_p into the body. The currents would flow to ground through C_b and through Z_{e3} in series with C_{iso}, producing a potential difference between the circuit common and the body. This appears as a common mode voltage, V_{cm}, on the body, and is expressed as:

$$V_{cm} = i_d Z_{e3}$$

Even if the amplifier has a very high common-mode rejection ratio (CMRR), a potential difference would still appear as interference between inputs A and B due to the potential divider effect [25] and the finite value of CMRR. CMRR is frequency dependent, and is defined as:

$$CMRR = \frac{A_D}{A_{CM}},$$

$$CMRR_{dB} = 20\log\left(\frac{A_D}{A_{CM}}\right),$$

where A_D and A_{cm} are the preamplifier's differential gain and common-mode gain, respectively, at a specific frequency. The magnitude of the interference due to the limited CMRR is expressed as:

$$V_{AB} = \frac{V_{cm}}{CMRR}.$$

A higher CMRR would contribute to less V_{AB}. Magnitude of the interference due to the potential divider effect is given by:

$$V_{AB} = V_{cm}\left\{\frac{Z_{in1}}{Z_{in1}+Z_{e1}} - \frac{Z_{in2}}{Z_{in2}+Z_{e2}}\right\}.$$

This interference depends on magnitude of V_{cm}, $Z_{in1} - Z_{in2}$, and $Z_{e1} - Z_{e2}$. If $Z_{in1} = Z_{in2}$ and $Z_{e1} = Z_{e2}$, V_{cm} would lead to no interference; however, this is not the case in a practical situation. Most of the interference from the potential divider effect is due to the unavoidable skin-electrode impedance imbalance, which converts the common-mode voltage into a differential input voltage. It is clear that V_{cm} should be minimized. A solution is to use the driven-right-leg circuit [28]. Figure 2.7 shows such a configuration, in which the common-mode voltage on the body is sensed by an averaging circuit at the preamplifier. Using a feedback amplifier, it is then inverted, amplified, and injected into the body through the right leg.

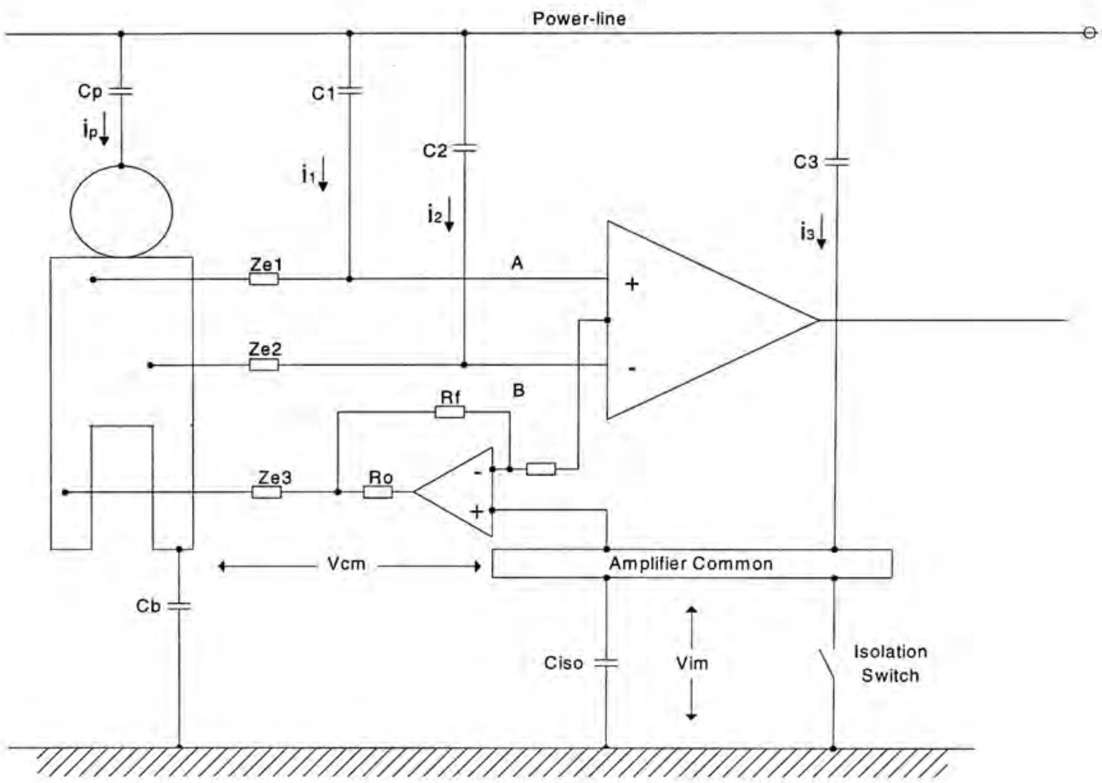


Figure 2.7: Configuration of a Driven-Right-Leg Circuit

Spinelli *et al* [36] proposed a design that used a transconductance amplifier instead of a voltage amplifier to drive patient's body. Compared to the conventional configuration, it showed better electromagnetic interference (EMI) rejection for frequencies around a few kHz. This feature is desirable for fluorescent light EMI rejection.

The amplifier's common can couple to the power-line through C3, causing an additional displacement current to flow from the amplifier common to ground through C_{iso} and through Z_{e3} in series with C_b. The part that flows through Z_{e3} also contributes to the common-mode voltage on the body.

Another way to reduce power-line interference is to use a 50/60Hz notch filter or an active comb filter [41] following the preamplifier. Noting the significant effect of change in skin-electrode impedances, Adli and Yamamoto [42] used an impedance balancing system to reduce power-line interference to a very low value.

2.1.4 High-Frequency Electromagnetic Interference

High-frequency electromagnetic interference (EMI) is a major concern in biopotential recording, especially in ambulatory ECG, in which case the patient may go near devices producing high levels of EMI. In the hospital, such devices are electrosurgical units (ESU's), x-ray machines, magnetic resonance imaging (MRI) machines, and switches and relays on heavy-duty equipment. In the home and office environments, these devices might include cellular and cordless phones, televisions, radio communication sets, fluorescent lights, computers, and other electronics.

All semiconductor devices, including the preamplifier used in ECG recording, are susceptible for high-frequency (HF) interference. The bandwidth of the preamplifier is typically below 1600Hz. Shielding of the preamplifier and the following stages is a way to protect the circuits; however, some HF currents would still flow into the amplifier's inputs due to capacitive coupling between the source of interference and the patient body and lead wires [8][26][38]. Due to the non-linearity in the amplifier, the HF currents are rectified by the p-n junctions into modulation components that are within the frequency response passband of the amplifier [43]. As noted by Horst *et al.*[38], the interference appearing at the amplifier output is like dc-shifts and low-frequency signals coming from AM (amplitude modulation) detection of the varying HF signal. In some cases the amplitude of the interference is so large that the amplifier becomes saturated, and any additional filtering techniques in the following stages would then be useless in retrieving the lost information. Some have attempted to combat this problem with various techniques.

deJager *et al.* [39] proposed a circuit that used three operational amplifiers. A channel containing the ECG along with the HF interference was fed directly to one of the amplifiers. The same channel was also fed to another amplifier through a passive high-pass filter. Assuming that the low-frequency outputs that result from the HF interference were identical in both amplifiers, a third amplifier was used to subtract one output from the other in order to obtain a clean ECG signal. However, several factors were neglected. If the first two amplifiers become saturated due to the high level of interference, the ECG would not be retrievable. Also, the third amplifier used in subtraction could be affected directly if the interference is from a radiating source.

Laudon *et al.* [40] reported a similar technique that allowed simultaneous ECG recording when a patient was subjected to 64MHz RF pulses during an MRI scan. One input of the system carried contaminated ECG, while another input was attached to an external loop for picking up RF current. The system was shielded in a metal container, and the two signals were fed into it the through separate 1-nF feed-through capacitors. The two channels then went through separate and identical low-pass filters and ECG amplifiers. The final stage was a difference amplifier that subtracted the noise channel from the signal channel. The shielding and feed-through capacitors prevented saturation of the amplifiers and interference into the difference amplifier. However, some interference still remained at the system output. They suspected that it was partly due to the component mismatch between the two channels.

Carr and Brown [43] pointed out that two ways for combating HF EMI in ECG recording are filtering and shielding. They suggested installing a π-section filter, consisting of an inductor element called an RF choke (RFC) and two capacitors, where each lead wire goes through the shield conductor. The π-section filter is a low-pass RF filter having a cutoff frequency well below the frequency of the interfering signal, and well above the highest frequency in the Fourier spectrum of the preamplifier's output signal.

In previous studies on reducing interference in ECG recording, the use of EMI filters and shielding seemed like a favorable option, however, there is so far not much detailed discussion on how the type of EMI filters and their parameters can affect the performance of an ambulatory ECG monitoring system. With today's availability of high input impedance amplifiers, much consideration is needed before installing such filters at the inputs. They may lower the overall input impedance at the frequency range of the ECG, and thus deteriorate the SNR considerably. Since such a system is likely to be carried outside the hospital, it is also worthwhile to look into how it would be affected in the presence of mobile phone EMI.

The aim of this chapter is to present some analysis on using different commercially available EMI filters at the input stage of the ECG acquisition circuit.

2.2 EMI Filters

2.2.1 Introduction to EMI Filters

An EMI filter is a passive device used to suppress conducted interference present on any power line or signal line. The filter's characteristics are described by insertion loss (IL), input and output impedances, attenuation in passband, skirt fall-off, and steady-state and transient voltage ratings [44]. The IL is the ratio of voltages across the load with and without the filter inserted in the circuit.

$$IL(dB) = 20\log_{10}\left(\frac{V_1}{V_2}\right),$$

where V_1 = the output voltage of the signal source without the filter being connected in the circuit, and V_2 = the output voltage of the signal source at the output terminals of the filter with the filter in the circuit. Although it indicates the filter's effectiveness, it only refers to performance in a 50Ω system, so it is not the actual performance of the filter within the targeted system.

The input and output impedances of the filter are important parameters for both the study of EMI filter performance and the design of filter element values [45]. Since the filters are usually designed to operate between specified input and output impedances, the output response is different when these impedances differ from the specified impedances of the filter [44].

2.2.2 Types of EMI filter

A capacitor filter is a shunt capacitor connecting the signal line to ground. In practice, a capacitor also contains equivalent series resistance (ESR) and equivalent series inductance (ESL), as shown in Figure 2.6.

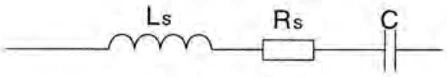


Figure 2.6: An actual capacitor with parasitic elements

The inductive effect causes the component to resonate at the self-resonance frequency (SRF), which is given by:

$$f = \frac{1}{2\pi\sqrt{L_S C}},$$

where C is the capacitance, and L_S is the ESL. The filter would exhibit capacitive reactance below the SRF and inductive reactance above SRF [44]. This type of filter is most effective when the source and load impedances are very high, and is least effective when the source and load impedances are very low.

An inductor filter is connected in series with the signal line. In practice, an inductor also has series resistance and interwinding capacitances, which produce self resonance. An ordinary inductor is shown in Figure 2.7.

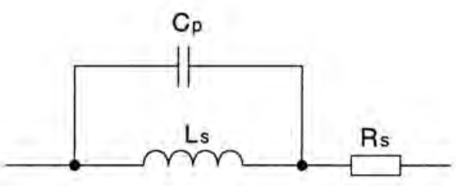


Figure 2.7: An actual inductor with parasitic elements

The filter would exhibit inductive reactance below the resonance frequency. Above that frequency, it has capacitive reactance with decreasing impedance [44].

This type of filter is most effective when the source and load impedances are very low and is least effective when the source and load impedances are very high. For the two filters above, the IL increases until the frequency reaches a resonant frequency, and then decreases as the frequency continues to increase.

The disadvantage of single-element filters are that their step band edge is not sharp enough and the filter cannot resolve problems with low source impedance and high load impedance or high source impedance and low load impedance [44]. To solve these problems, the low-pass EMI filter can use a combination of capacitors and inductors. This provides more efficient filtering with steeper attenuation slopes, and allows filtering when there is a large mismatch between the source and load impedances. Such a configuration has series inductors, which has high impedance with increasing frequency, and shunting capacitors, which presents a low impedance with increasing frequency. The series inductance impedes the flow of high-frequency content and effectively shorts it to ground through the shunt capacitance.

An L-section (LC) filter consists of a series inductor and a shunt capacitor. Figure 2.8a and 2.8b show two types of LC filters.

(a) (b)

Figure 2.8: LC filters

When the source and load impedances are not equal, the largest IL is usually achieved when the capacitor shunts the higher impedance. The filter may resonate and oscillate when the input signal is transient, and at the resonant frequency, it may exhibit an insertion gain rather than insertion loss.

A Pi-section filter consists of a series inductor between two shunt capacitors. It is preferred when both source and load impedances are high. Figure 2.9 shows a Pi-section filter.

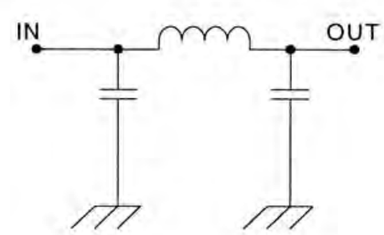


Figure 2.9: Pi-section filter

Due to its high insertion loss over a broad frequency band, it is used where high attenuation is needed down to very low frequency, such as in power line or shielded chamber. It is not very effective against transient interference.

A T-section filter consists of a shunt capacitor between two series inductors. It is best for low source and load impedances. It is also effective in reducing transient interference. Figure 2.10 shows a T-section filter.

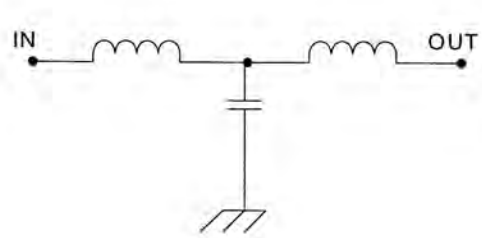


Figure 2.10: T-section filter

Table 2.1 summarizes the suitable filter configurations for different source and load impedances.

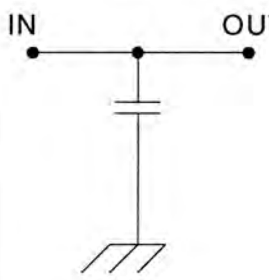
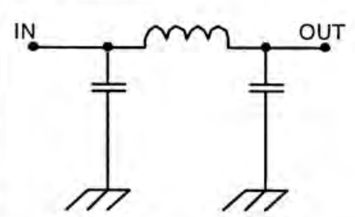
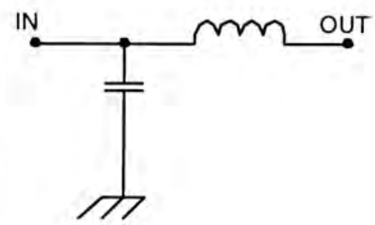
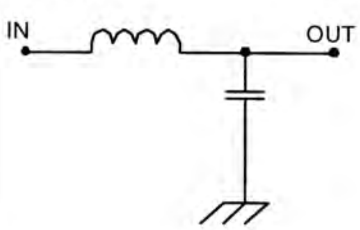
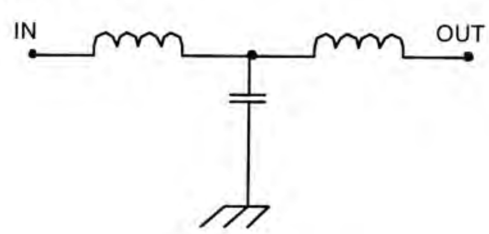
		Load Impedance	
		High	Low
Source Impedance	High	Capacitor:  Pi-Section: 	L-Section: 
	Low	L-Section: 	Inductor:  T-Section: 

Table 2.1: Filter configurations for different source and load impedances

In any filtering configuration, capacitors should always "see" high impedances, and inductors should always "see" low impedances. As a good rule of thumb, the borderline between the so called "high" or "low" impedance should be 50Ω [46].

Among the various packaging of filters, feedthrough structures are preferred. Feedthrough capacitors are coaxial structures where the dielectric material is filled in between the center pin electrode and the outer tubular or peripheral electrode. The outer armature can be soldered, screwed, or pressed into the chassis or PC board ground plane [46]. This structure minimizes the parasitic inductance, and greatly increases the resonance frequency. High-frequency performance is thus improved. Whenever wires cross a metal shielding enclosure, feedthrough filters prevent leakage at penetrations. Figure 2.11 shows a feedthrough capacitor and its schematic representation.

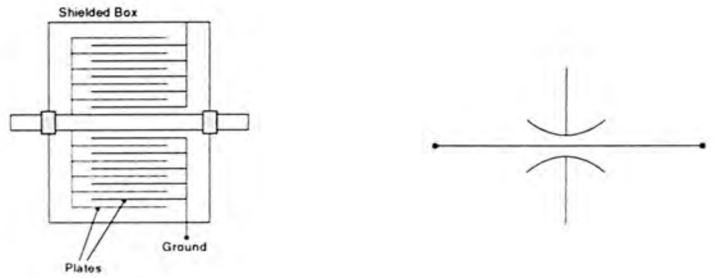


Figure 2.11: Feedthrough capacitor and its schematic representation

2.2.3 EMI Filters in ECG Monitoring

The performance of an EMI filter is highly dependent on the character and magnitude of the source and load impedances. Although there are known relationships for calculating the IL of a filter configuration, they are not useful for designing the filter element values because they were derived for a particular filter configuration and impedance condition [45]. Knowledge of the source and load impedances, or at least their magnitudes, is important for selecting the most appropriate filter configuration.

Consider an ECG acquisition circuit placed inside a metal enclosure. For monitoring, three lead wires are needed for recording a one-lead ECG. Two of these are for differential input to the preamplifier, while the third wire is for a reference, which can also serve as a driven-right-leg feedback path. Installing an EMI filter where each of the lead wires enters the metal enclosure may seem like a solution for protecting the preamplifier from HF currents. However, much consideration is needed when selecting the type of filter configuration and parameters, since, unlike in typical circuits, the source and load impedances are no longer fixed at 50Ω or at other values.

The source impedance involves the series combination of lead wire and skin-electrode impedance, which can vary greatly. At the output, the filter either "sees" the high input impedance of the preamplifier or the preamplifier's common. Obviously, the technical data on the insertion loss of the filter is no longer valid in such an application. Caution is also needed to ensure that the input impedance of this new system at the frequency range of ECG is still high enough, so that ECG can be detected by the preamplifier with sufficient SNR.

Another concern is whether the addition of EMI filters at the input lead wires would worsen the impedance imbalance situation within the frequency range of ECG. These suggest that although EMI filters can protect front-end circuits from saturation that results from the HF currents, they may also introduce other problems if improper filter configuration and parameters are used.

2.3 Modeling of interference in an ECG-Monitoring System

2.3.1 Model and Parameters

In the past, various circuit models have been developed for studying the coupling and effects of interference in an ECG acquisition circuit [27, 30, 31, 47]. Despite the different model structures and simulation tools used, all of them consisted of the following elements:

i.) Patient body
ii.) Skin-electrode interface
iii.) Lead wires
iv.) Preamplifier
v.) Coupling between interference and system and between system and ground
vi.) Interference

Based on the previous designs, a model has been developed for studying the effects of installing different EMI filters in the system. The structures and values of the components are chosen as follows:

i.) Patient body impedance

Without the skin and with the living body tissue considered purely resistive, the resistance R of a body segment is determined by the mean resistivity, ρ, mean length, L, and mean cross-sectional area, A. R can be approximated by:

$$R = \frac{L\rho}{A}$$

Since the cross-section area of the torso is large, its resistance is much less than that of the finger. Many previous models used a 20Ω resistor to represent the subcutaneous impedance of the torso.

ii.) Skin-electrode interface impedance

The skin-electrode interface is known to be frequency dependent, and has been modeled by the structure as shown in Figure 2.12.

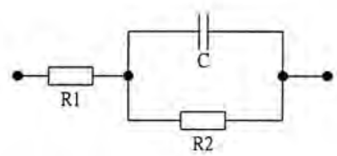


Figure 2.12: Model for skin-electrode interface

The values of the components differed from one model to another, but the order of magnitudes were about the same. In this new model, the values of R1, R2, and C are 10kΩ, 1.4MΩ, and 20nF, respectively. These are based on the parameters used in the model by Burke and Gleeson [37].

The value of the impedance between two skin surface electrodes is usually dominated by the contribution of the skin. A model for skin impedance is as shown in Figure 2.13. It is based on Tregear's model [48], where each layer of the skin is represented by a capacitor and a resistor in parallel. The outmost layer is on the right. Values of R and C are 5MΩ and 0.1μF, respectively.

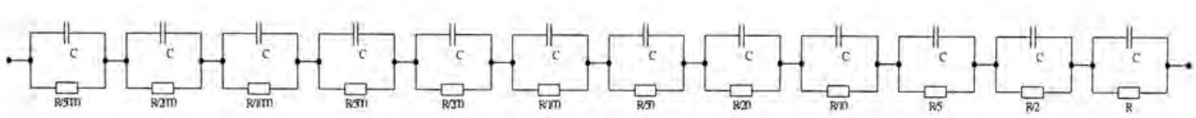


Figure 2.13: Tregear's model of the skin impedance

iii.) Lead wires

As in previous models, the lead wires in the new model are assumed to be short, perfect conductors.

iv.) Preamplifier

As in previous models, the preamplifier is represented by its differential-mode and common-mode input impedances. The values used are that in the specification of a typical instrumentation amplifier:

Differential-mode input impedance: 10GΩ || 1pF
Common-mode input impedance: 10 GΩ || 4pF

v.) Coupling mechanism

Coupling of interference into the lead wires and patient body is represented by the direct injection of currents. The coupling between the patient and ground is through a 200pF capacitor, as in most of the previous models. For an isolated system, two levels of coupling between the amplifier common and ground are used: 20pF and 200pF. For the non-isolated system, the amplifier common is shorted to ground.

vi.) Interference source

Both the 50Hz power-line interference and HF EMI are modeled as current sources injecting 100nA AC currents into the system.

2.3.2 Methods

As in some of the previous studies on interference, the model used in this study will also be simulated with Pspice. The model of the setup with pi-section EMI filters installed is shown in Figure 2.14. Figure 2.15 shows the setup without EMI filters. The first set of simulations involved power-line interference, and the second set involved coupling EMI at a range of frequencies. Since the study is aimed at ambulatory applications, the coupling between the amplifier common and ground is represented by a 200pF capacitance.

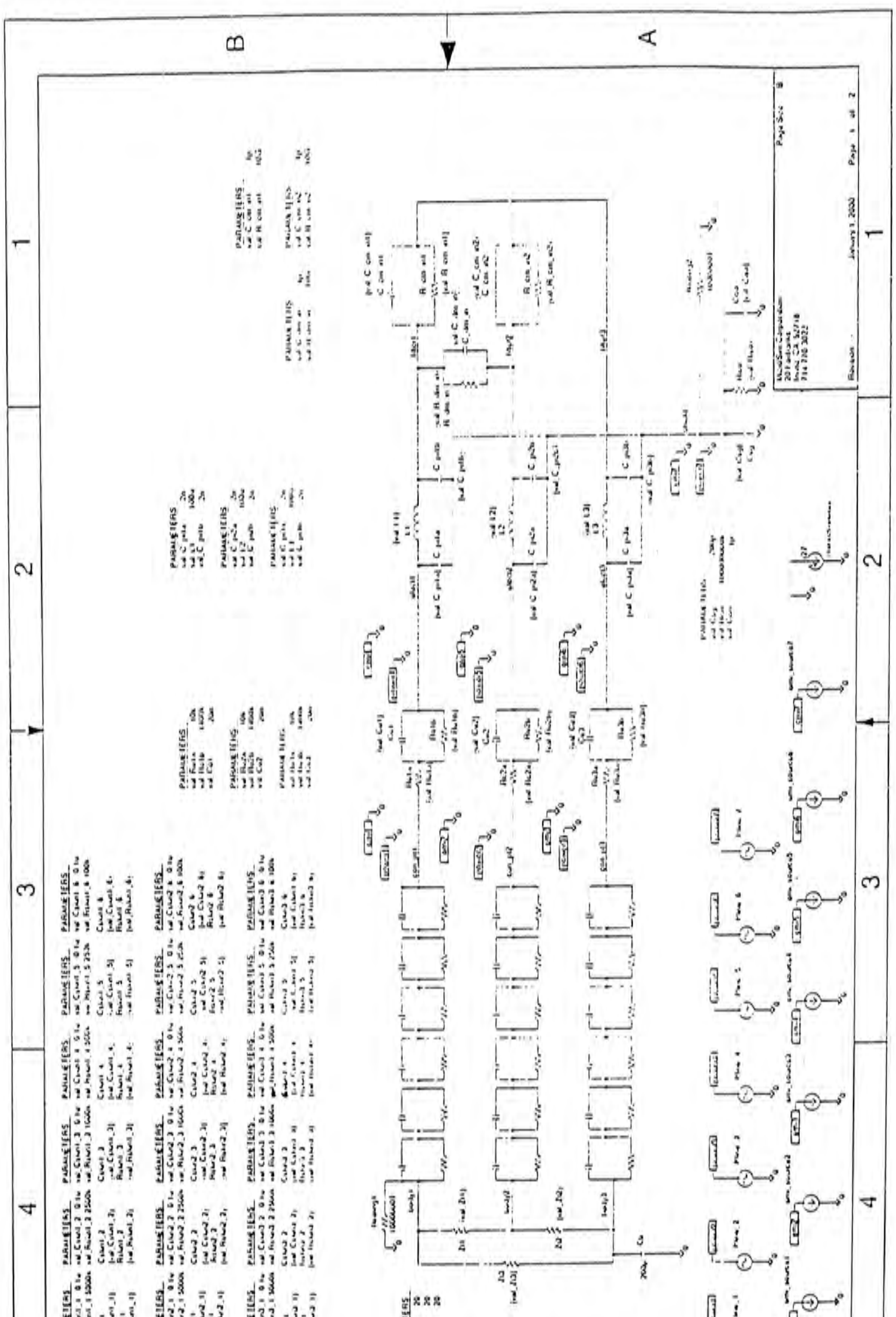


Figure 2.14 Setup with pi-filters

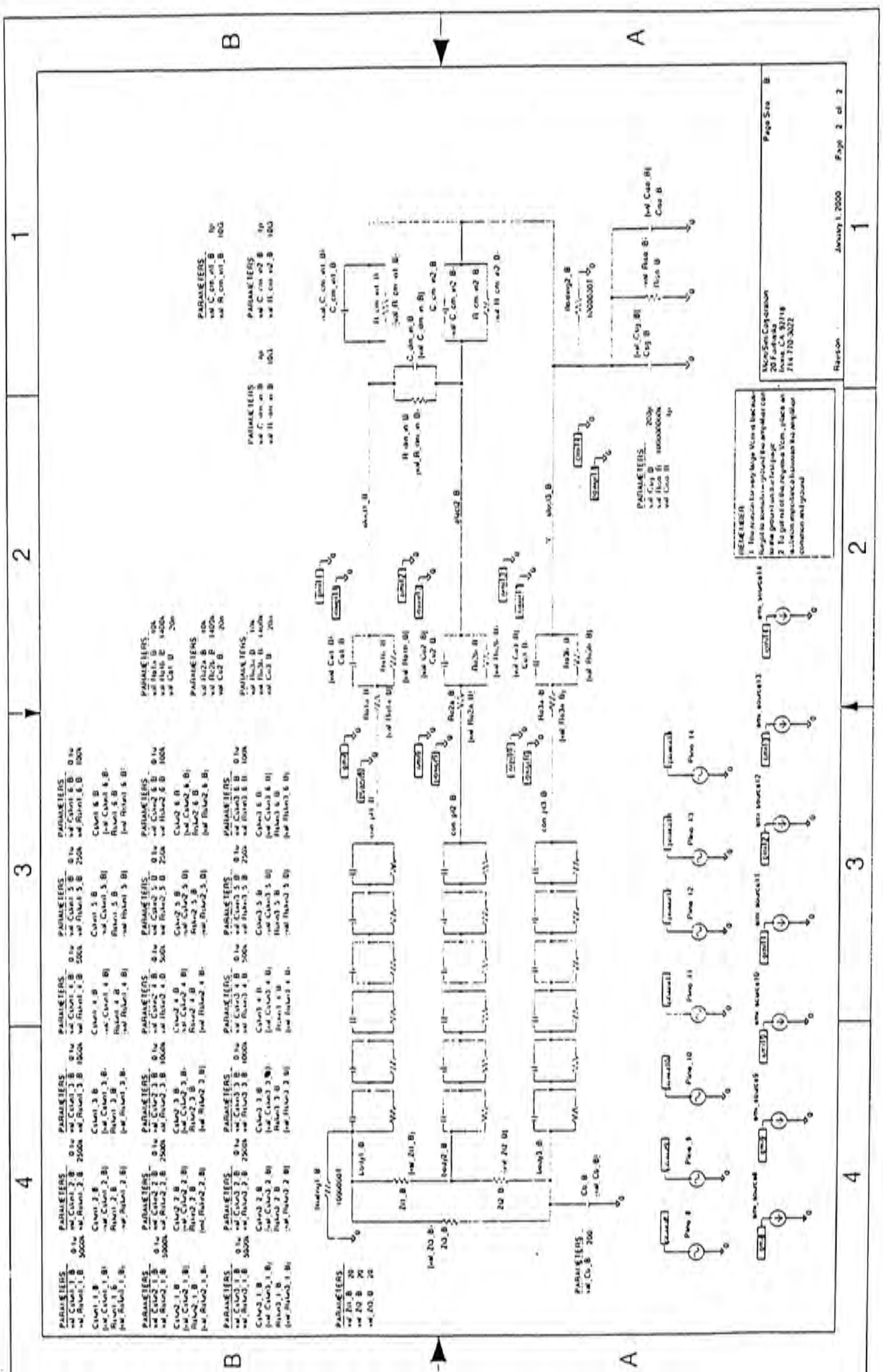


Figure 2.15 Setup without EMI Filter

2.3.3 Results

Since many parties have already performed similar simulations for power-line interference, the emphasis will be on HF EMI. Power-line Interference simulation was done by injecting the 50Hz currents into the leads as common-mode interference. The currents and voltages at different junctions were recorded as the skin-electrode impedance was varied. The value of interest is the resulting voltage difference between the inputs of the amplifier. Figure 2.16 shows the maximum RMS voltage between the amplifier's differential input versus impedance imbalance for the setup in Figure 2.15. The Re1a_B resistance was varied from 10kΩ to 1MΩ.

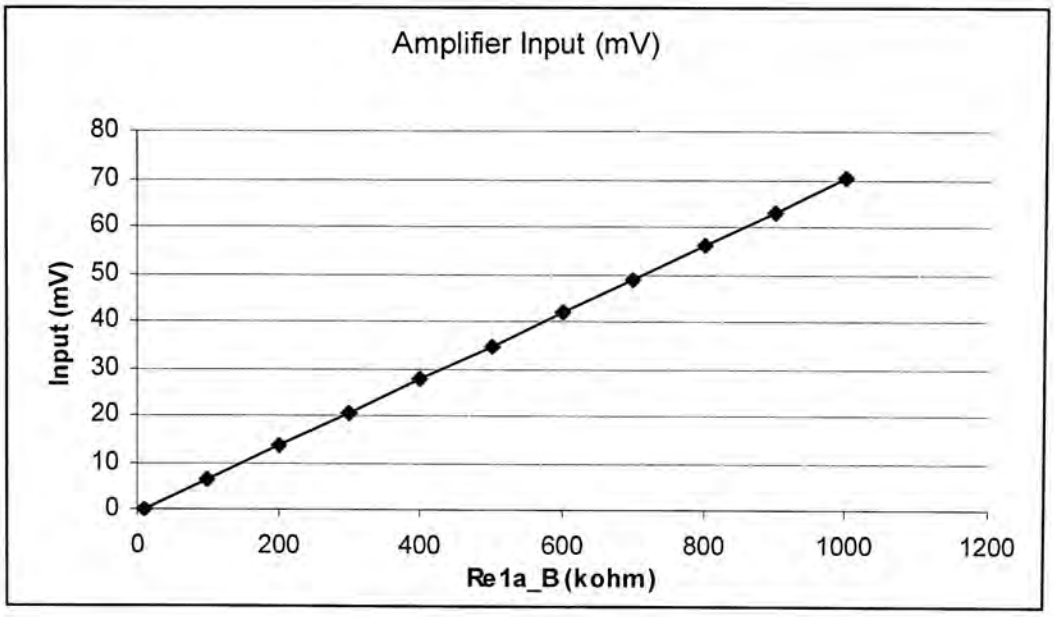


Figure 2.16: Interference voltage appears at the amplifier's input due to skin-electrode impedance imbalance

For simulation of EMI at different frequencies, 100nA alternating currents, over a frequency range from 10Hz to 10GHz were injected into one of the lead wires. Different types of EMI filters with various parameters were placed between each lead and the amplifier. The values chosen were close to the order of magnitude of the values in the actual EMI filters that are used for experiments in the following sessions.

Figures 2.17 and 2.18 show the simulation results for the setup with C-filters with capacitance of 1pF, 100pF, 1000pF, and 10000pF. Figure 2.17 is a plot of voltage appearing at the amplifier's differential inputs as a result of the EMI at different frequencies being coupled into one of the leads. Figure 2.18 is a plot of EMI filter insertion difference versus frequency. The insertion difference is the ratio of the interference voltage at the amplifier of the setup without an EMI filter to the interference voltage in the setup with an EMI filter.

Note that this is not the insertion loss, which is specifically used for describing a system with 50Ω input and output impedance. Figure 2.19 and 2.20 shows the insertion difference for the LC and Pi-filter configurations.

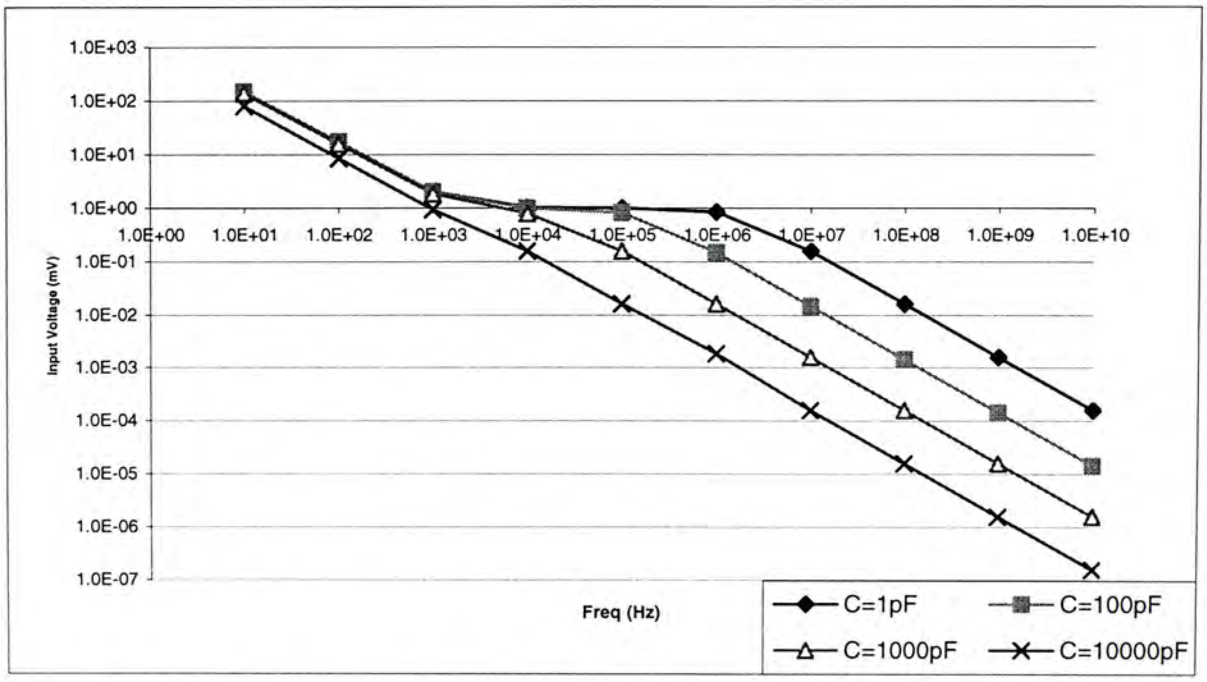


Figure 2.17: Interference voltage versus frequency for setup with C-filters

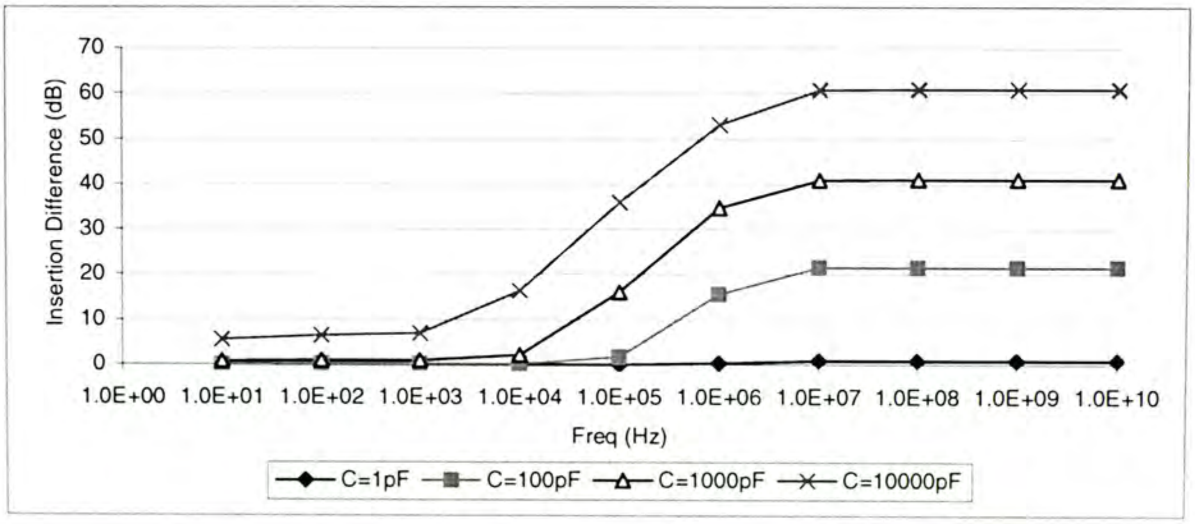


Figure 2.18: Insertion difference versus frequency for setup with C-filters

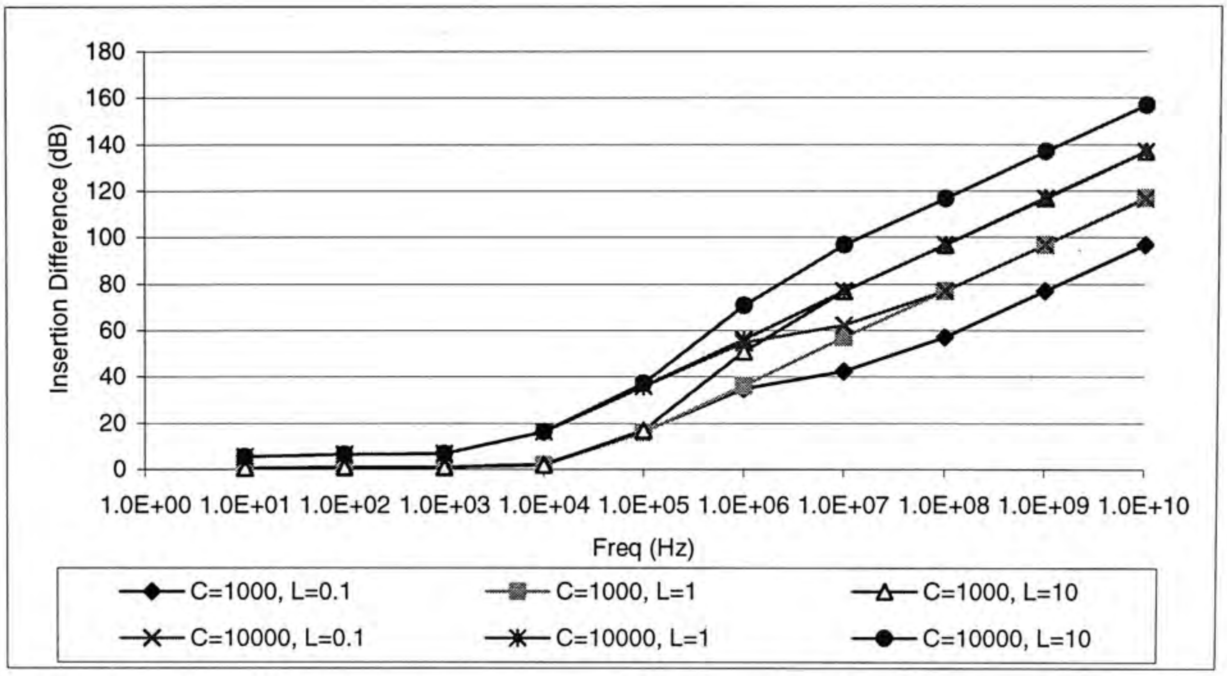


Figure 2.19: Insertion difference versus frequency for setup with LC-filters

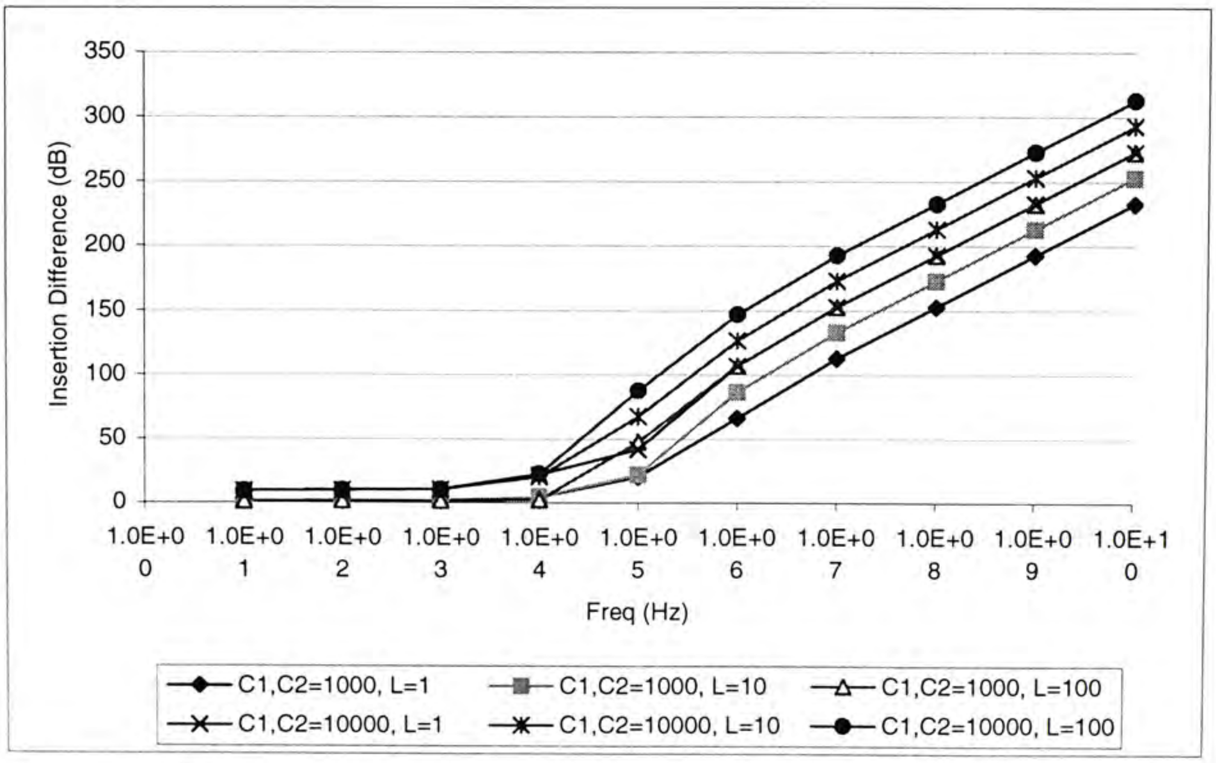


Figure 2.20: Insertion difference versus frequency for setup with Pi-filters

2.3.4 Discussion

The model used gave an approximate idea of how interference would affect ECG measurement when EMI filters are installed between the electrode leads and the preamplifier, and facing the input and output impedances at those locations. For all the cases in which EMI filters were installed, the insertion differences were positive, meaning that the interference voltages between the amplifier's inputs were lower then in the case without any EMI filter.

In the frequency range from MHz to GHz, the Pi-filters showed the highest insertion difference among the three types, and the C-filters showed the lowest insertion difference. Insertion difference was generally higher for filters with higher capacitance or higher inductance values.

The model used for simulation was similar to many previous models. However, it may be inadequate for reflecting the real situation. Assumptions, such as perfect conducting properties of the wires and of the shield, unchanging impedances within the system, and absence of parasitics, were made. To investigate how EMI filters perform under real condition, an actual system for experimentation is needed.

2.4 Building an ECG Acquisition Circuit with EMI Filters

2.4.1 Purpose

An ECG acquisition circuit was built to investigate the effectiveness of installing different types of commercially available EMI filters where the lead wires enter the metal enclosure of the circuit.

2.4.2 Experimental Setup and Method

Two circuit configurations were tested. The first configuration is shown in Figure 2.21. The circuits were placed within an aluminum enclosure, which was isolated from ground. 3M Red Dot pre-jelled, Ag-AgCl electrodes were placed on the subject's chest for obtaining lead I ECG. The three lead wires ran from the electrodes to the circuit through EMI filters that were mounted on the enclosure. After the EMI stage, two of the wires were fed into the differential input of a Burr Brown INA118 instrumentation amplifier, and the third wire was connected to the common of the same amplifier. After amplification of 1000, the output ran through an AC coupling stage, formed by a series 0.94μF capacitance, and a lowpass filter, which was built using a Burr Brown UAF42 universal filter, having a cutoff frequency of 150Hz. Since the setup was meant to be similar to that of an ambulatory monitoring system, where the circuit should be isolated from ground, both the INA118 and UAF42 operated on two 9V batteries. The final output was then obtained from a Burr Brown ISO124 isolation amplifier, which output side operated on a separate grounded power supply, placed after the lowpass filter.

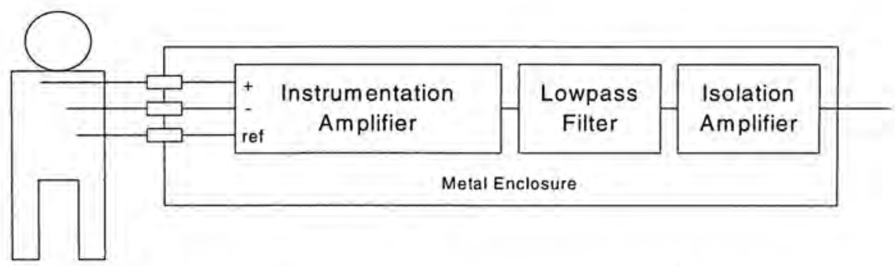


Figure 2.21: Configuration of the ECG acquisition circuit with EMI filters

The layout of the INA118 is shown in Figure 2.22. It has a high CMRR of 110dB at a gain of 1000, and high input impedance of up to 10GΩ. The gain is calculated from:

$$G = 1 + \frac{50k\Omega}{R_G},$$

where R_G is the value of the resistor on the left.

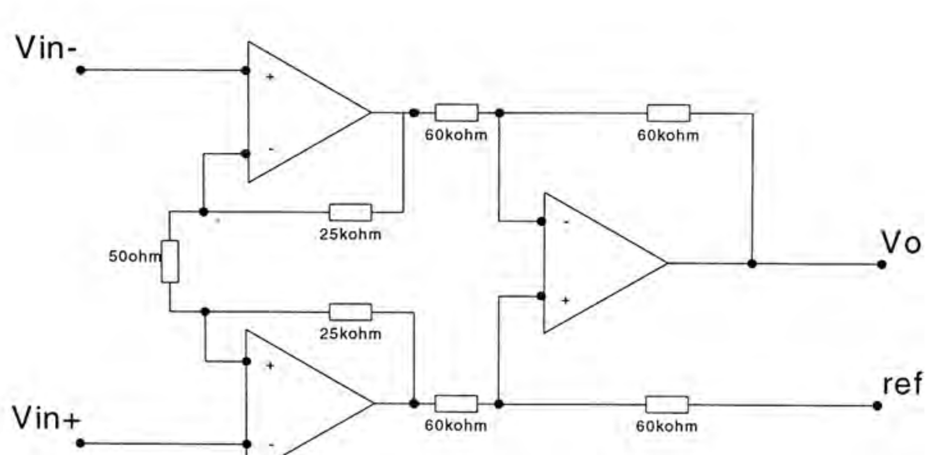


Figure 2.22: Schematic of INA118 instrumentation amplifier

The second configuration was similar, but a driven-right-leg (DRL) circuit, built from two OPA2604 operational amplifiers, was added. The output of the DRL circuit was fed into the subject through the EMI filter that was originally used for reference in the first configuration. The configuration is shown in Figure 2.23.

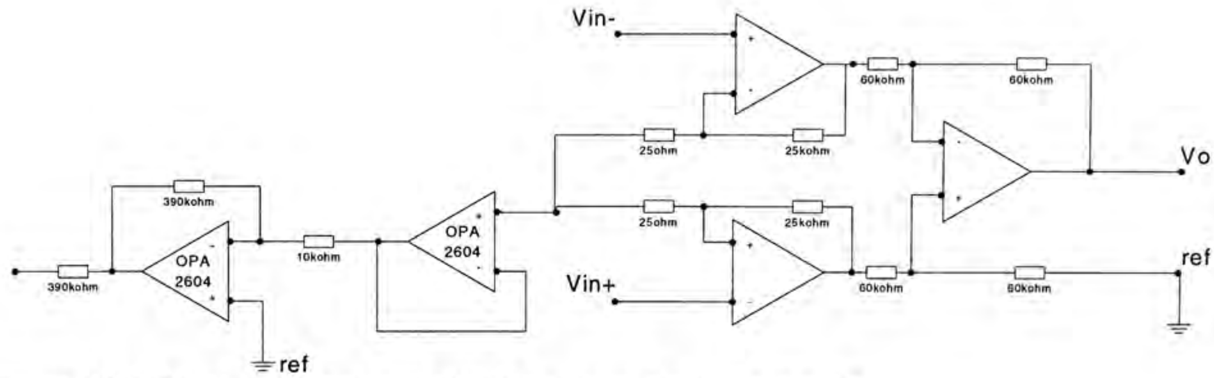


Figure 2.23: Preamplifier along with the driven-right-leg circuit

Seven sets of commercially available chassis mounting EMI filters from Oxley, as listed in Table 2.2, were chosen for testing.

Set No.	Filter Type	Min. Capacitance	Approx. Inductance
1	C	100pF	--
2	C	680pF	--
3	C	10000pF	--
4	LC	4700pF	0.5mH
5	LC	22000pF	0.5mH
6	Pi	1500pF	4.8mH
7	Pi	5000pF	4.8mH

Table 2.2: EMI filters used

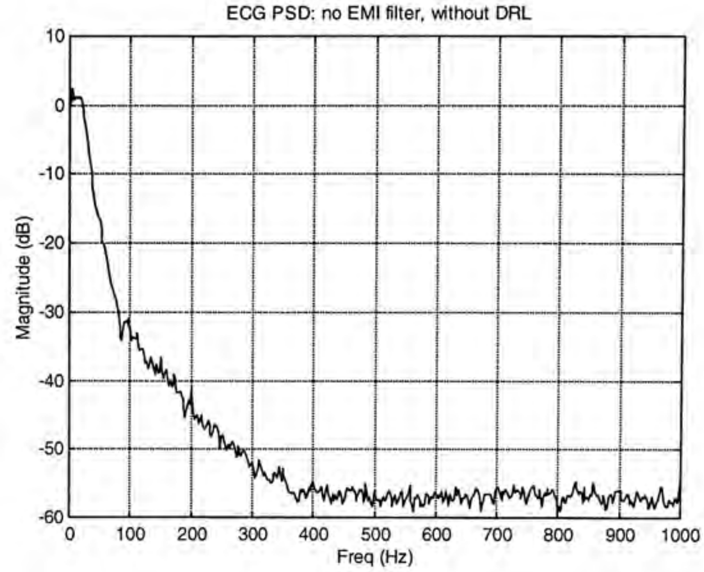
Three types of EMI were introduced to the system for testing. The sources were:

1. GSM1800 mobile phone (Siemens 2568i),
2. Radio Communication Unit (Yaesu FT-50R) operating at 145MHz,
3. Radio Communication Unit (Yaesu FT-50R) operating at 430MHz.

For each of the three interference cases, the source of interference was placed at different distances from the metal enclosure, and the output of the isolation amplifier was recorded by WINDAQ, a computer-based data acquisition (DAQ) unit, at 2000 samples/s. Each recording session was 15 seconds long.

2.4.3 Results

One of the concerns for installing the EMI filters was the possibility of causing more impedance mismatch between the input lead wires. Before introducing the HF EMI to the system, power-line interference analysis was carried out. The setup was placed in the presence of a power-line interference signal. The time-domain waveform and the PSD of the measured ECG were as shown in Figure 2.24a and Figure 2.24b, respectively.



(a) (b)

Figure 2.24a: Time-domain waveform for ECG recorded in the presence of power-line interference. No EMI filter and no DRL circuit was installed.

Figure 2.24b: PSD for ECG recorded in the presence of power-line interference. No EMI filter and no DRL circuit was installed.

The harmonics of the power-line interference were mainly at multiples of 50Hz. Let the sum of peak powers at multiples of 50Hz in the range from 0Hz to 1000Hz be denoted as P_p, and the sum of powers from 0Hz to 1000Hz be denoted as P_{all}. The ratio of these two values, NI_1, was used as a noise index for the amount of power-line interference on the observed ECG. A large NI_1 would indicate that the 50Hz interference contributed to a large portion of the entire ECG spectrum. For the setup with no DRL circuit and no EMI filter,

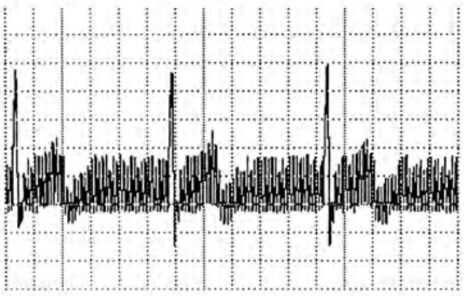
$P_p = 0.0223$ (-16.5dB),

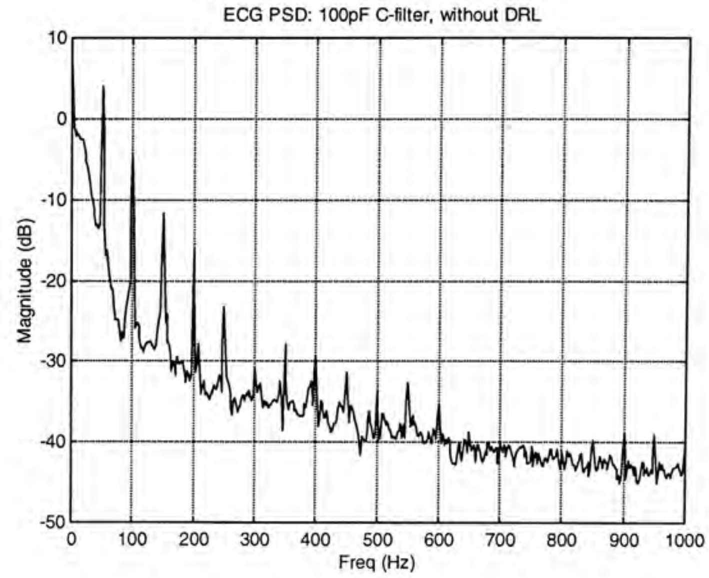
$P_{all} = 17.2408$ (12.4dB), and

$$NI\_1 = \frac{P_p}{P_{all}} \times 100$$

$$= 0.13\%.$$

After a set of 100pF feedthrough capacitors were added to the lead wires and mounted to the enclosure, the time-domain waveform and the PSD were as shown in Figure 2.25a and 2.25b, respectively.





(a) (b)

Figure 2.25a: Time-domain waveform for ECG recorded in the presence of power-line interference. 100pF C-filters were installed, but no DRL circuit was installed.

Figure 2.25b: PSD for ECG recorded in the presence of power-line interference. 100pF C-filters were installed, but no DRL circuit was installed.

P_p = 3.0350 (dB),

P_{all} = 18.7328 (dB), and

NI_1 = 16.20%.

The signal-to-noise ratio (SNR) was calculated as:

$$SNR1 = \frac{P_{S1}}{P_{N1}},$$

where P_{S1} was the sum of all powers from 0Hz to 200Hz for the ECG recorded prior to introduction of the 50Hz interference, and P_{N1} was the average of powers at all multiples of 50Hz in the range between 0Hz to 1000Hz. For the circuit with 100pF C-filters installed,

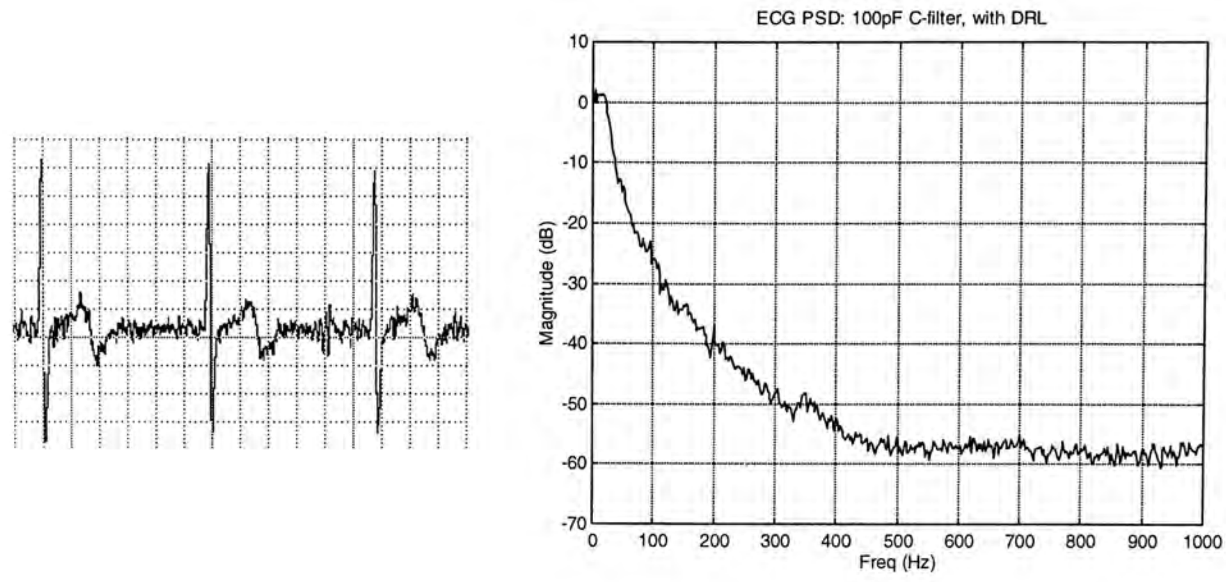
P_{S1} = 17.2391,

P_{N1} = 3.0350 / 20 = 0.1518,

$$SNR1 = \frac{17.2391}{0.1518}$$

= 113.6088.

It could be seen that insertion of EMI filter introduced more power-line interference into the system, due to the difference in tolerances of the set of filters. To mitigate this effect, the DRL circuit described in 2.4.2 was inserted to reduce the common-mode voltage on the body surface. The resulting time-domain waveform and PSD were as shown in Figure 2.26a and 2.26b.



(a) (b)

Figure 2.26a: Time-domain waveform for ECG recorded in the presence of power-line interference. 100pF C-filters and DRL circuit were installed.

Figure 2.26b: PSD for ECG recorded in the presence of power-line interference. 100pF C-filters and DRL circuit were installed.

The resulting NI_1 was 0.25%, and SNR1 was increased to 7968.3. The insertion of other types of filters showed similar effects. Table 2.3 and 2.4 show the NI_1 and SNR1, respectively, for different filters in the two cases of with and without the DRL circuit. Figures 2.27 and 2.28 summarize these results in bar graph. With any set of filters, considerable SNR improvement was achieved after the DRL circuit was added.

	NI_1						
	C100	C680	C10000	LC4700	LC22000	Pi1500	Pi5000
Without DRL	16.20%	13.67%	3.59%	2.17%	5.72%	1.96%	2.11%
With DRL	0.25%	0.28%	0.25%	0.76%	0.22%	0.28%	0.31%

Table 2.3: Comparison of NI_1 for different EMI filters with and without DRL circuit.

	C100	C680	C10000	LC4700	LC22000	Pi1500	Pi5000
SNR1 (without DRL)	113.6088	190.5435	665.2830	1390.7	492.0383	1031.6	1207.9
SNR1 (with DRL)	7968.3	5586.0	9158.0	2869.2	10128	8576.1	8291.7
SNR1 Improvement (dB)	36.9	29.3	22.8	6.3	26.3	18.4	16.7

Table 2.4: Comparison of SNR1 for different EMI filters with and without DRL circuit.

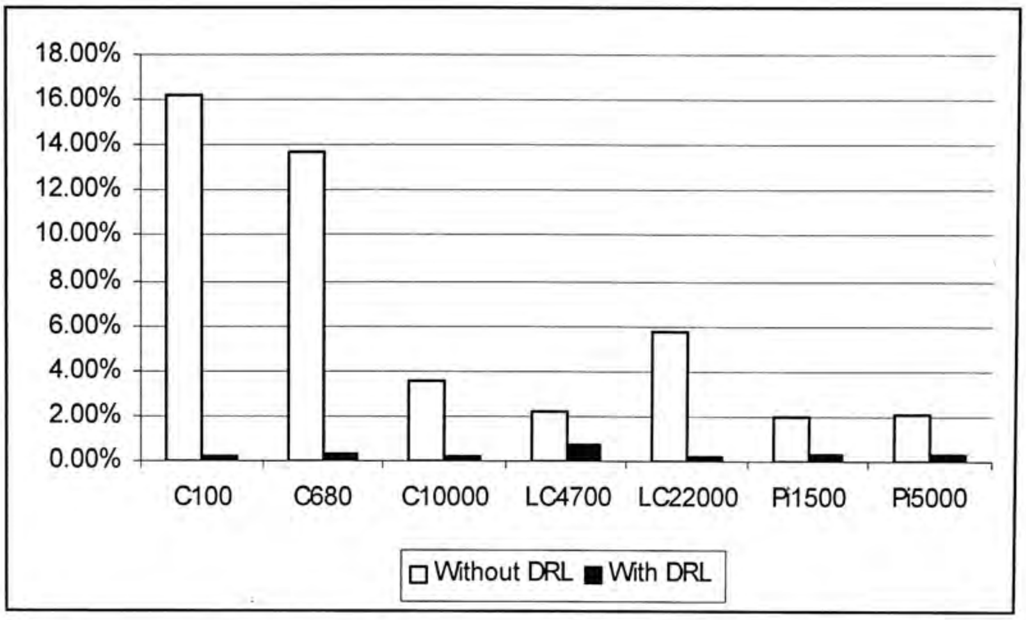


Figure 2.27: Comparison of NI_1 for different EMI filters with and without DRL circuit.

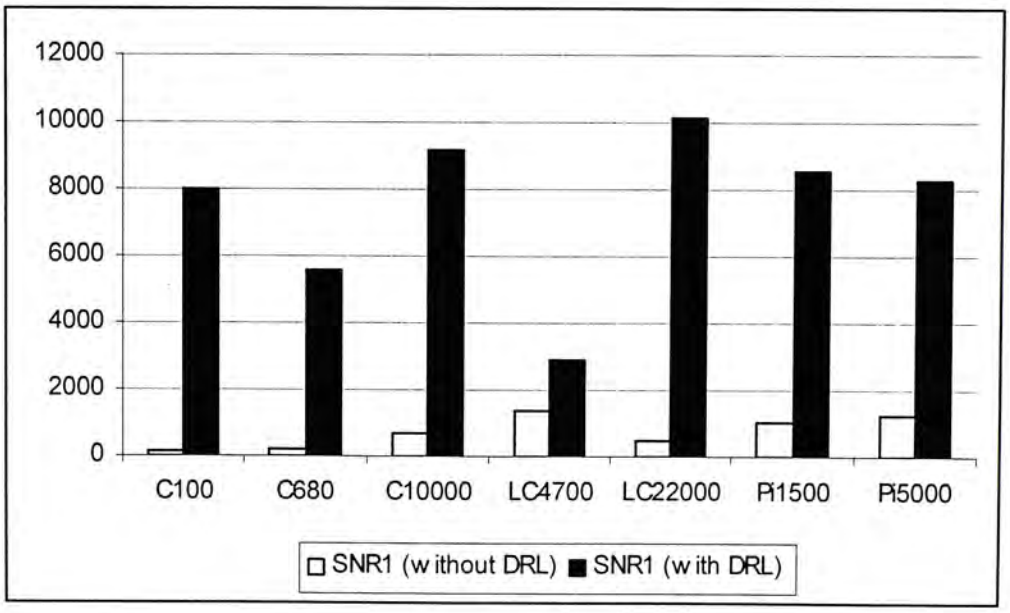
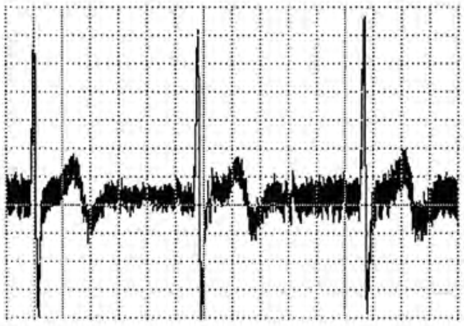


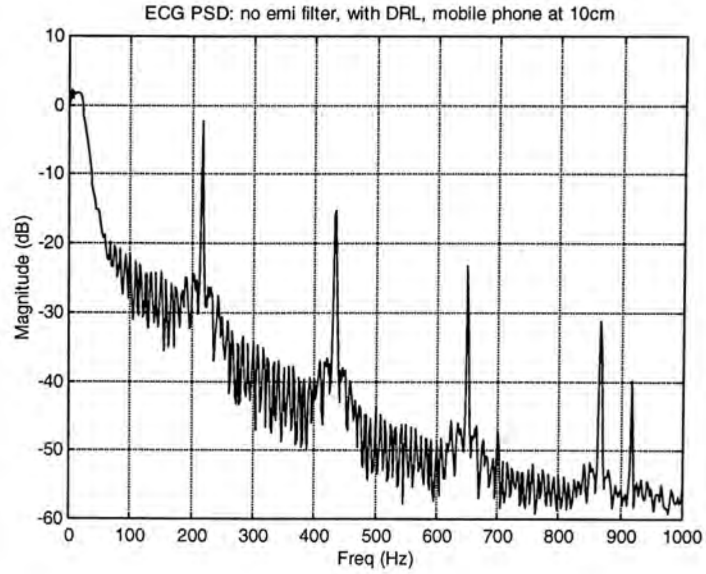
Figure 2.28: Comparison of SNR1 for different EMI filters with and without DRL circuit.

Mobile phone interference:

The second set of tests involved introducing mobile phone interference to the circuit at different distances. First, mobile phone interference was introduced to the circuit that had DRL circuit, but no EMI filter installed.



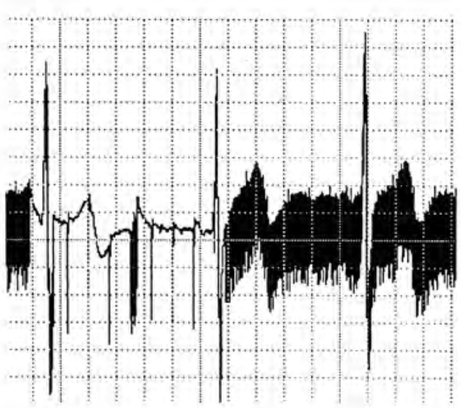
(a)



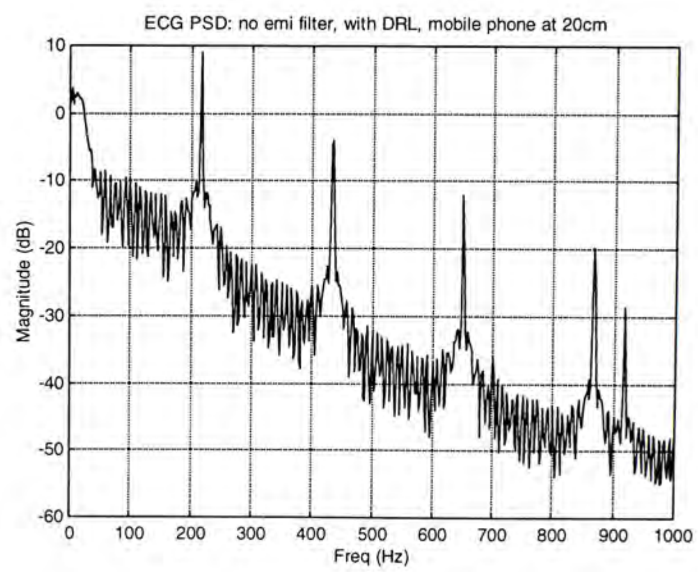
(b)

Figure 2.29a: Time-domain waveform for ECG recorded with dialing mobile phone at 10cm from the circuit. No EMI filter was installed.

Figure 2.29b: PSD for ECG recorded with dialing mobile phone at 10cm from the circuit. No EMI filter was installed.



(a)

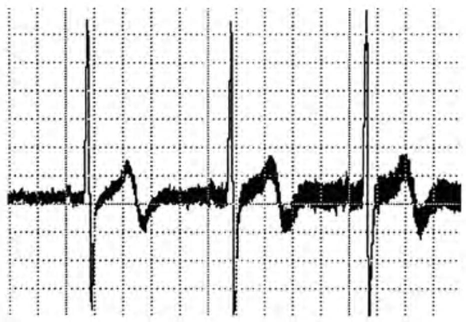


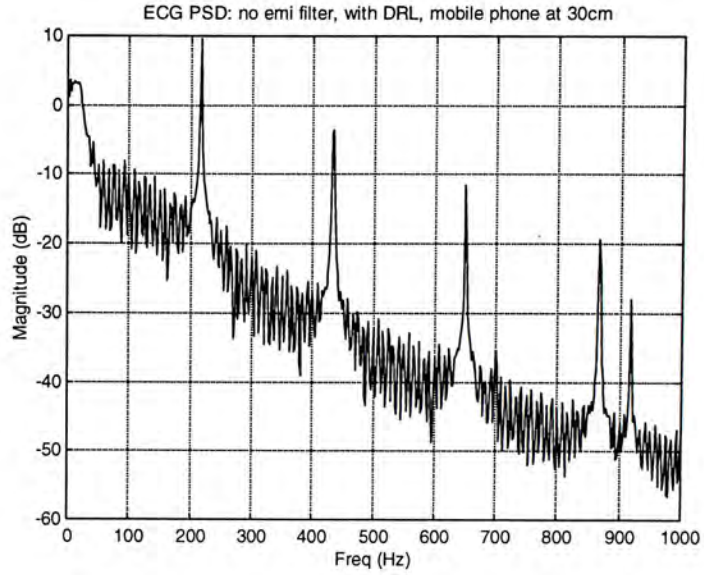
(b)

Figure 2.30a: Time-domain waveform for ECG recorded with dialing mobile phone at 20cm from the circuit. No EMI filter was installed.

Figure 2.30b: PSD for ECG recorded with dialing mobile phone at 20cm from the circuit. No EMI filter was installed.

The time-domain waveforms and PSD's are as shown in Figures 2.29 to 2.33. For all cases of different distances, the PSD's show that the interference appears mainly at 216Hz, 434Hz, 650Hz, 866Hz, and 918Hz.

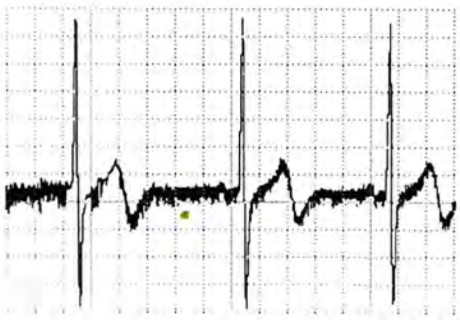


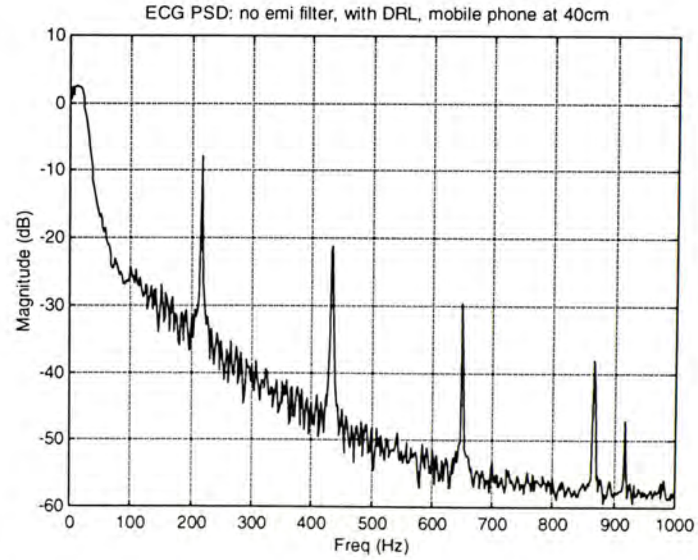


(a) (b)

Figure 2.31a: Time-domain waveform for ECG recorded with dialing mobile phone at 30cm from the circuit. No EMI filter was installed.

Figure 2.31b: PSD for ECG recorded with dialing mobile phone at 30cm from the circuit. No EMI filter was installed.

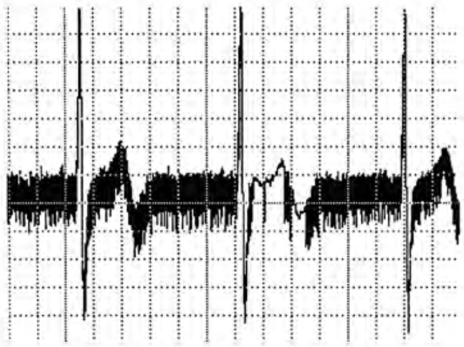




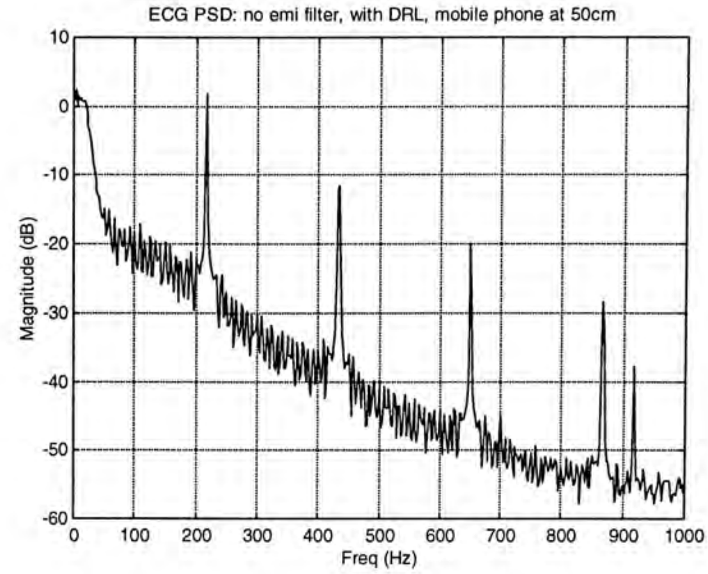
(a) (b)

Figure 2.32a: Time-domain waveform for ECG recorded with dialing mobile phone at 40cm from the circuit. No EMI filter was installed.

Figure 2.32b: PSD for ECG recorded with dialing mobile phone at 40cm from the circuit. No EMI filter was installed.



(a)



(b)

Figure 2.33a: Time-domain waveform for ECG recorded with dialing mobile phone at 50cm from the circuit. No EMI filter was installed.

Figure 2.33b: PSD for ECG recorded with dialing mobile phone at 50cm from the circuit. No EMI filter was installed.

To compare how noise affected the recorded ECG, both the SNR and NI were used. The SNR was calculated as:

$$SNR2 = \frac{P_{S2}}{P_{N2}},$$

where P_{N2} was the average of powers at 216Hz, 434Hz, 650Hz, 866Hz, and 918Hz for the interference-contaminated ECG, and P_{S2} was the sum of all powers from 0Hz to 200Hz for the 'clean' ECG recorded prior to the introduction of interference. The noise index was calculated as:

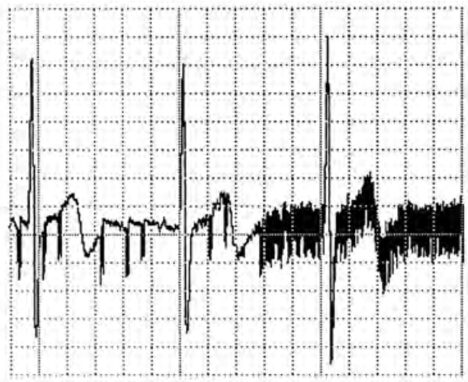
$$NI\_2 = \frac{P_p}{P_{all}} \times 100,$$

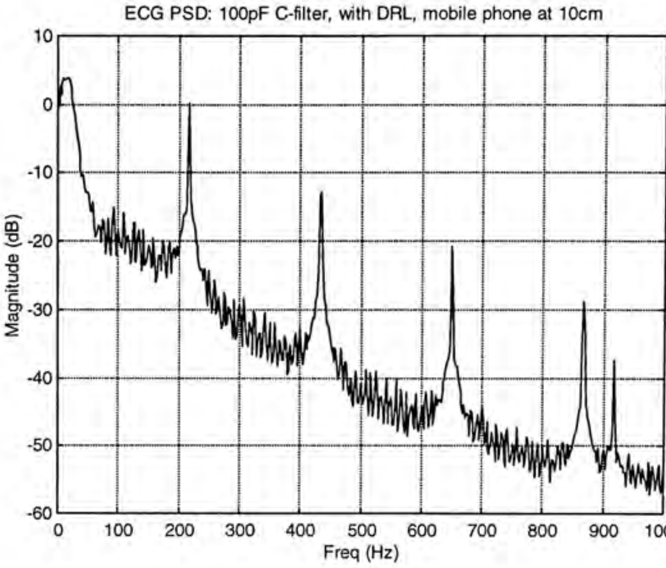
where P_p was the sum of powers at 216Hz, 434Hz, 650Hz, 866Hz, and 918Hz for the interference-contaminated ECG, and P_{all} was the sum of all powers from 0Hz to 1000Hz for the interference-contaminated ECG. The following table summarizes the SNR2 and NI_2 for the ECG recorded by a circuit, which had no EMI filter installed, at different distances.

Distance	**10cm**	**20cm**	**30cm**	**40cm**	**50cm**
SNR2	181.6125	13.4824	11.8327	648.8445	70.9751
NI_2	3.08%	20.09%	20.24%	0.80%	8.01%

Table 2.5: NI_2 and SNR2 values for ECG recorded by a circuit without EMI filters and with DRL circuit at different distances from a dialing mobile phone

Mobile phone interference was then introduced to the circuit that had a DRL circuit and EMI filters installed. For the case with 100pF C-Filters, the time-domain waveforms and PSD were as shown in Figures 2.34 to 2.38.

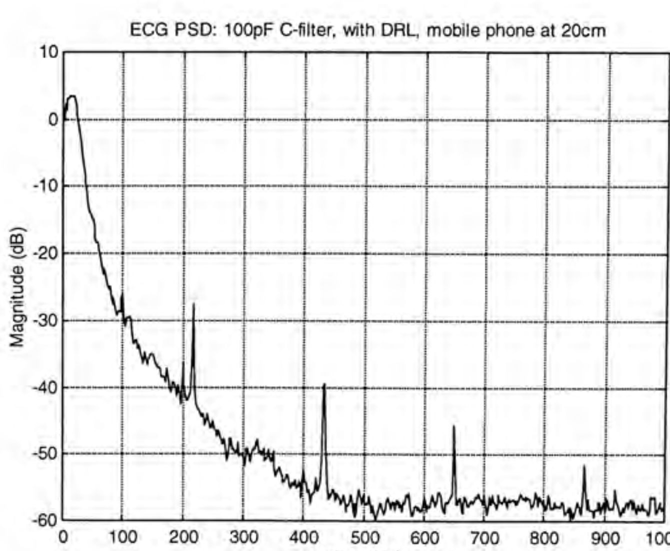




(a) (b)

Figure 2.34a: Time-domain waveform for ECG recorded with dialing mobile phone at 10cm from the circuit. 100pF C-filter were installed.

Figure 2.34b: PSD for ECG recorded with dialing mobile phone at 10cm from the circuit. 100pF C-filter were installed.

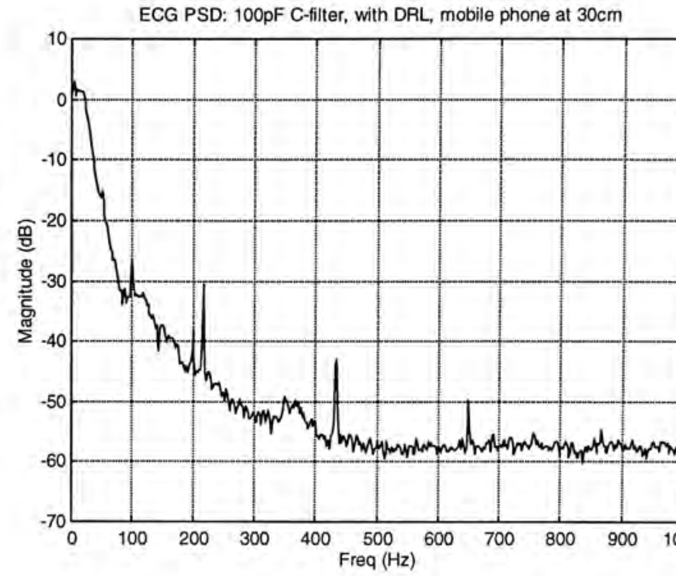


(a) (b)

Figure 2.35a: Time-domain waveform for ECG recorded with dialing mobile phone at 20cm from the circuit. 100pF C-filter were installed.

Figure 2.35b: PSD for ECG recorded with dialing mobile phone at 20cm from the circuit. 100pF C-filter were installed.

(a)

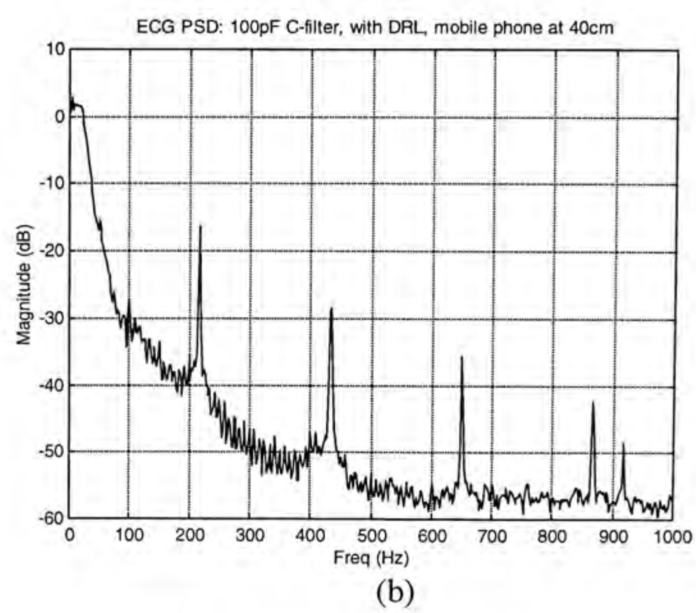


(b)

Figure 2.36a: Time-domain waveform for ECG recorded with dialing mobile phone at 30cm from the circuit. 100pF C-filter were installed.

Figure 2.36b: PSD for ECG recorded with dialing mobile phone at 30cm from the circuit. 100pF C-filter were installed.

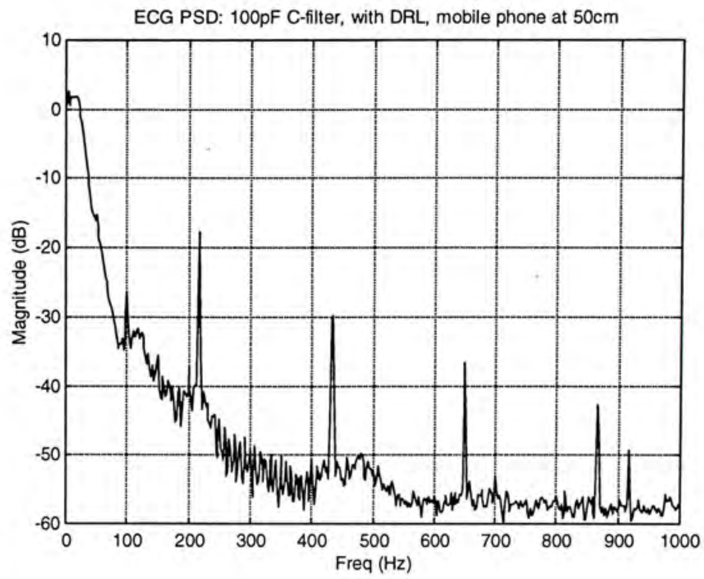
(a)



(b)

Figure 2.37a: Time-domain waveform for ECG recorded with dialing mobile phone at 40cm from the circuit. 100pF C-filter were installed.

Figure 2.37b: PSD for ECG recorded with dialing mobile phone at 40cm from the circuit. 100pF C-filter were installed.



(a) (b)

Figure 2.38a: Time-domain waveform for ECG recorded with dialing mobile phone at 50cm from the circuit. 100pF C-filter were installed.

Figure 2.38b: PSD for ECG recorded with dialing mobile phone at 50cm from the circuit. 100pF C-filter were installed.

Table 2.6 summarizes the SNR2, SNR improvement, and NI_2 for the ECG recorded by the circuit, which had EMI filters installed, with a dialing mobile phone at different distances. The SNR improvement was calculated as follows:

$$SNR\_imp = \frac{SNR2a}{SNR2b},$$

where SNR2a was calculated from the ECG recorded with EMI filters installed, and SNR2b was calculated from the ECG recorded without any filter.

C-Filter: 100pF

Distance	**10cm**	**20cm**	**30cm**	**40cm**	**50cm**
SNR2	78.1724	4569.6	9184.6	3437.3	4766.2
SNR_imp (dB)	7.3218	50.6022	57.7995	14.4815	36.5413
NI_2	3.6594%	0.0075%	0.0051%	0.1289%	0.0926%

C-Filter: 680pF

Distance	**10cm**	**20cm**	**30cm**	**40cm**	**50cm**
SNR2	121660	1411800	1364500	1221300	292710
SNR_imp (dB)	56.5200	100.400	101.2378	65.4936	72.3066
NI_2	0.0050%	0.0004%	0.0004%	0.0005%	0.0019%

C-Filter: 10000pF

Distance	**10cm**	**20cm**	**30cm**	**40cm**	**50cm**
SNR2	409110	767770	1208900	5114.6	7944.0
SNR_imp (dB)	67.0539	95.1093	100.1861	17.9334	40.9787
NI_2	0.0012%	0.0005%	0.0004%	0.0957%	0.0547%

LC-Filter: 4700pF

Distance	10cm	20cm	30cm	40cm	50cm
SNR2	70063	264660	397500	42312	12855
SNR_imp (dB)	51.7269	85.8584	90.5251	36.2865	45.1593
NI_2	0.0066%	0.0017%	0.0011%	0.0101%	0.0342%

LC-Filter: 22000pF

Distance	10cm	20cm	30cm	40cm	50cm
SNR2	263290	1404100	2102700	133960	882600
SNR_imp (dB)	63.2258	100.3526	104.9939	46.2967	81.8932
NI_2	0.0017%	0.0004%	0.0002%	0.0037%	0.0005%

Pi-Filter: 1500pF

Distance	10cm	20cm	30cm	40cm	50cm
SNR2	837740	23960	29556	986.9081	1167.8
SNR_imp (dB)	73.2793	64.9944	67.9512	3.6427	24.3252
NI_2	0.0005%	0.0179%	0.0145%	0.5147%	0.4121%

Pi-Filter: 5000pF

Distance	10cm	20cm	30cm	40cm	50cm
SNR2	16436	10262	982330	3043.1	2963.3
SNR_imp (dB)	39.1330	57.6293	98.3835	13.4235	32.4134
NI_2	0.0296%	0.0425%	0.0004%	0.1322%	0.1437%

Table 2.6: SNR, SNR improvement, and NI for the ECG recorded by the circuit, which had EMI filter installed, with a dialing mobile phone at different distances.

The following graph summarizes the SNR improvement after the EMI filters were installed.

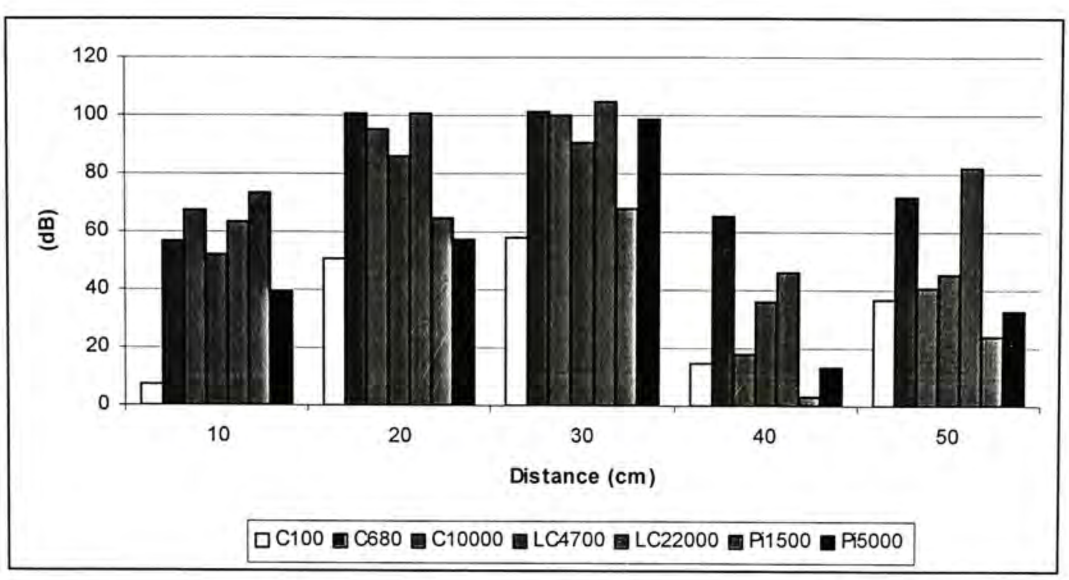


Figure 2.39: SNR improvement for the ECG recorded by the circuit, which had EMI filters installed, with a dialing mobile phone at different distances.

Walkie-Talkie Interference:

Similar tests were then performed with a Yaesu walkie-talkie that had a maximum transmit power of 2W. It was tuned to 145MHz and 430MHz. Since the ECG output of the acquisition circuit was, in most cases, saturated by the interference, the maximum normalized cross-correlation between the ECG under no interference and the ECG under the walkie-talkie interference was used as an index for the effectiveness of the EMI filters. This index was valid because the ECG was recorded from a healthy subject, and showed no pathological sign. Table 2.7 and Figure 2.40 show these indexes for the setup without EMI filter.

	Without EMI Filter: Maximum normalized cross-correlation between ECG under Walkie-Talkie interference and ECG under no interference				
	10cm	20cm	30cm	40cm	50cm
415MHz	0.5851	0.5228	0.5199	0.5085	0.5285
430MHz	0.4973	0.6125	0.5748	0.5679	0.5316

Table 2.7: Maximum normalized cross-correlation between the ECG under walkie-talkie 145MHz and 430MHz interference and the ECG under no interference. No EMI filter was used.

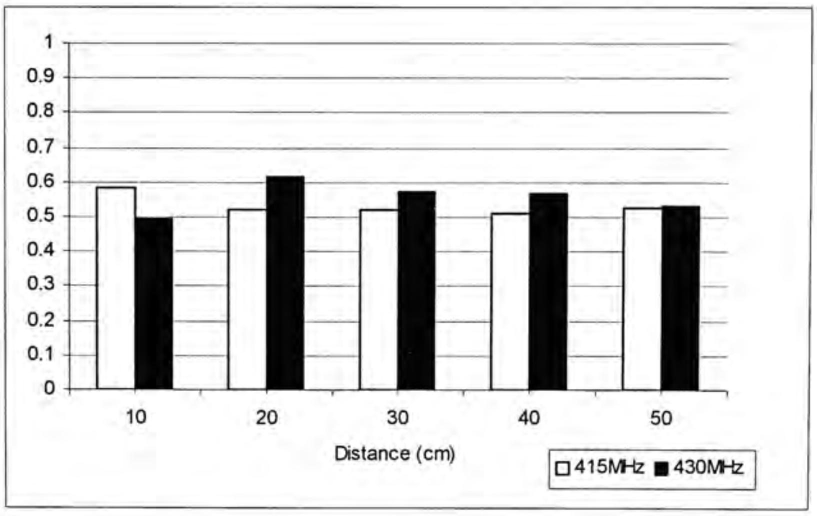


Figure 2.40: Maximum normalized cross-correlation between the ECG under walkie-talkie 145MHz and 430MHz interference and the ECG under no interference. No EMI filter was used.

The same set of tests were then performed with EMI installed on the circuit. Tables 2.8 and 2.9 and Figures 2.41 and 2.42 summarize the maximum normalized cross-correlation values for the filters at different distances under 145MHz and 430MHz interference.

	With EMI Filter: Maximum normalized cross-correlation between ECG under 145MHz interference and ECG under no interference				
	10cm	20cm	30cm	40cm	50cm
C-100	0.6218	0.5918	0.6160	0.6208	0.8073
C-680	0.5728	0.6637	0.9608	0.9739	0.9975
C-10000	0.6131	0.7055	0.9855	0.9969	0.9981
LC-4700	0.5759	0.9056	0.9980	0.9979	0.9956
LC-22000	0.5815	0.7183	0.9923	0.9986	0.9991
Pi-1500	0.5864	0.9188	0.9958	0.9983	0.9969
Pi-5000	0.5343	0.6239	0.9868	0.9955	0.9978

Table 2.8: Maximum normalized cross-correlation between ECG under 145MHz interference and ECG under no interference. Different EMI filters were used.

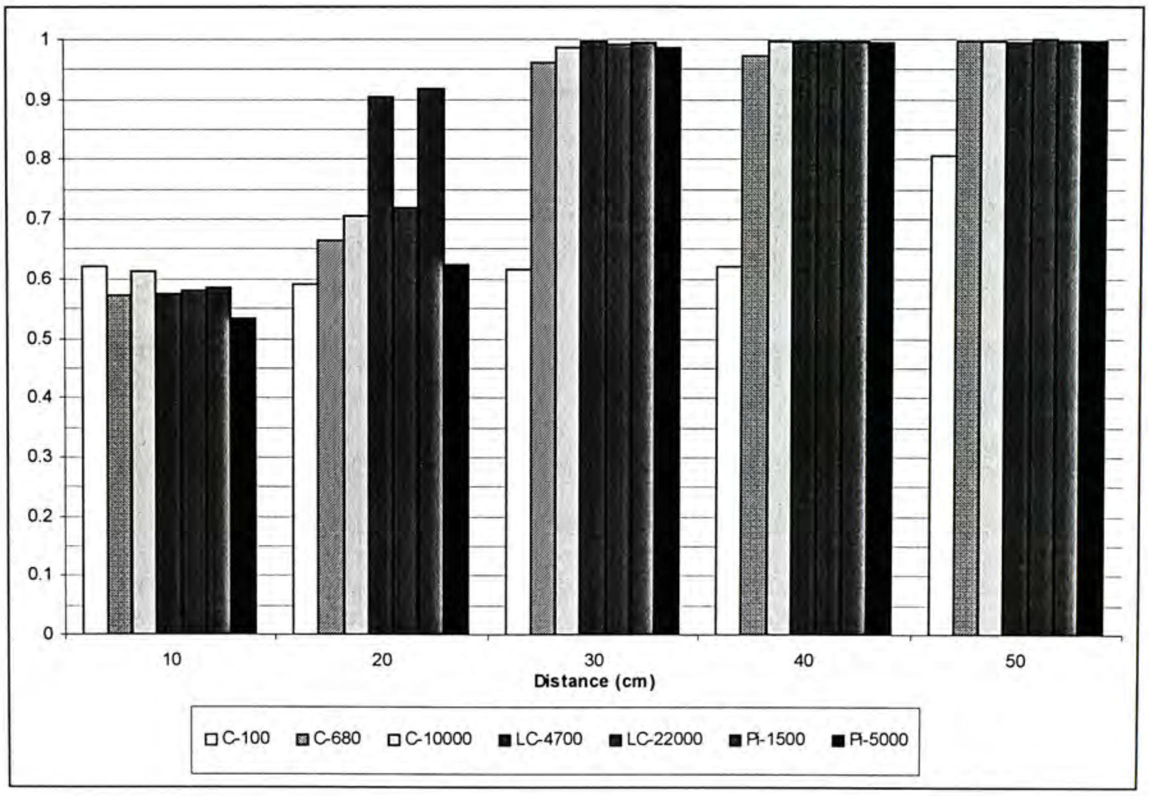


Figure 2.41: Maximum normalized cross-correlation between ECG under 145MHz interference and ECG under no interference. Different EMI filters were used.

Filter Type	With EMI Filter: Maximum normalized cross-correlation between ECG under 430MHz interference and ECG under no interference				
	10cm	20cm	30cm	40cm	50cm
C-100	0.5984	0.9970	0.9968	0.9982	0.9985
C-680	0.7144	0.9959	0.9972	0.9979	0.9992
C-10000	0.6865	0.9806	0.9942	0.9960	0.9979
LC-4700	0.5593	0.9869	0.9923	0.9984	0.9985
LC-22000	0.6509	0.8498	0.9947	0.9979	0.9942
Pi-1500	0.4426	0.9093	0.9949	0.9904	0.9977
Pi-5000	0.4813	0.9565	0.9974	0.9957	0.9973

Table 2.9: Maximum normalized cross-correlation between ECG under 430MHz interference and ECG under no interference. Different EMI filters were used.

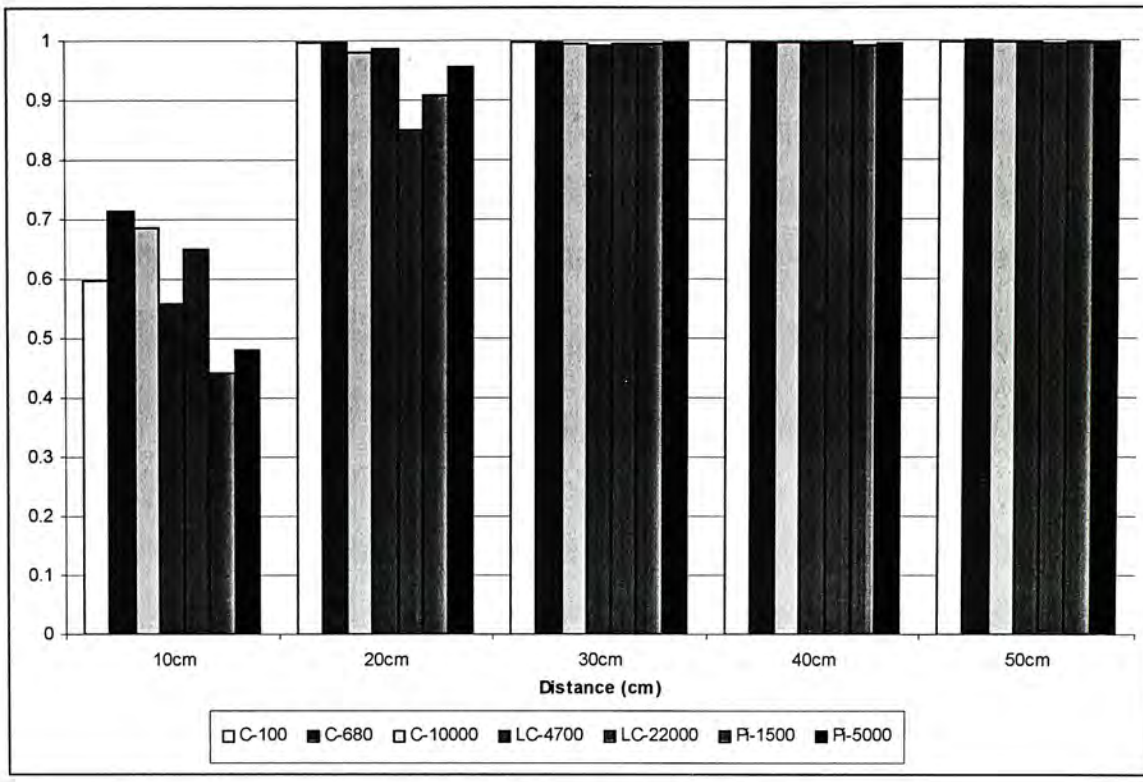


Figure 2.42: Maximum normalized cross-correlation between ECG under 430MHz interference and ECG under no interference. Different EMI filters were used.

2.4.4 Discussion

As expected, the insertion of EMI filters at the leads caused impedance imbalance between the leads, thus introducing more power-line interference voltage at the preamplifier's input. The addition of the DRL circuit mitigated this effect considerably with each set of filters used. SNR improvements ranged from 6.3dB to 36.9dB.

The system was subjected to interference of a dialing mobile phone operating at GSM1800. From the PSD of the system output, interference mainly appeared at 216Hz, 434Hz, 650Hz, 866Hz, and 918Hz, as a result of the demodulation effects in the IC used. The addition of EMI filters into the circuit reduced this noise with positive SNR improvement up to 105dB for 22000pF LC-filters at 30cm. With the phone at 10cm form the system, the SNR improvements for the setup with different sets of EMI filters installed ranged from 7.3dB to 73.3dB. At distances within 30cm, SNR improvements were above 40dB except for 100pF C-filters.

Since walkie-talkie interference at 145MHz and 430MHz caused saturation of the circuit in most cases, the maximum normalized cross-correlation between the ECG prior to introduction of interference and the ECG under interference was used as an index for comparison. With no EMI filter in the setup, the index calculated was in the 0.5 to 0.6 range for distances from 10cm to 50cm. Except for the setup with 100pF capacitor filters that was under 145MHz interference, the index increased to above 0.9 for distances at and beyond 30cm after EMI filters were installed. The study above showed that the installation of commercially available feedthrough EMI filters along with shielding could reduce the noise in the recorded ECG considerably. Among the sets of filters used, the 100pF capacitor filters were comparatively less effective in reducing GSM1800 mobile phone interference and 145MHz walkie-talkie interference.

This study can be carried out further by using other EMI filters of different values and introducing interference from other types of mobile phones. The results in this chapter indicate that the use of EMI filters is successful for reducing HF interference; however, some noise is still present in the final output. The next chapter proposes using an adaptive filter to further reduce the remaining noise.

Chapter 3: Adaptive Filter

3.1 Objective

It was found in Chapter 2 that even though installation of the EMI filters in the ECG acquisition circuit improved the SNR, some noise still remained. This chapter will present the addition of an adaptive filtering technique, aimed at removing the remaining noise that was still present at the system output.

3.2 Introduction to Adaptive Filtering

A digital filter produces its outputs by operating on the input based on a set of predefined coefficients, while an adaptive filter contains coefficients that are updated by an adaptive algorithm to optimize the filter's response to a desired performance criterion.

Two processes take place within an adaptive filter:

1. The adaptive process, which involves updating the filter coefficients, and
2. The filtering process, which produces output based on the updated filter coefficients.

Adaptive filters are commonly used in applications such as signal and parameter estimation, tracking, and change detection. In biomedical signal processing, an adaptive filter is often used as a noise canceller [49], especially in situations where the signal and noise have overlapping frequency spectra. The noise canceller chosen in the following study is based on an adaptive filter using the Least Mean Square (LMS) algorithm. The general system model is shown in Figure 3.1.

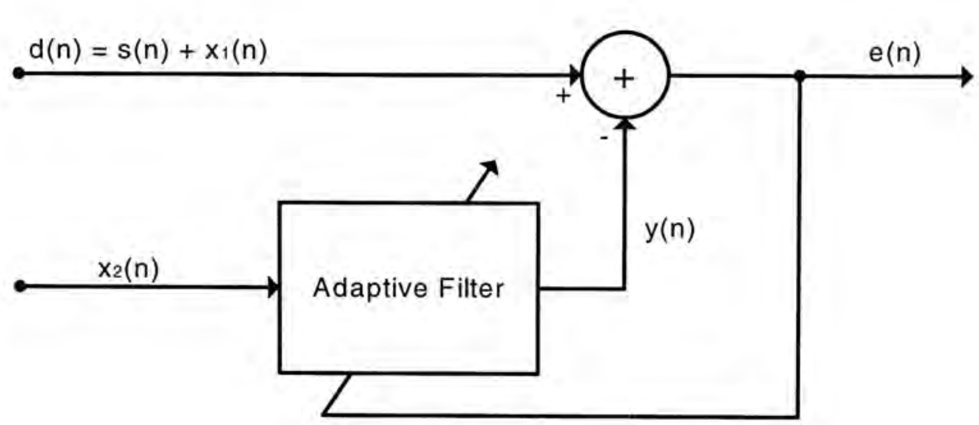


Figure 3.1: Structure of an adaptive filter used in noise cancellation.

The primary input of the filter is:

$$d(n) = s(n) + x_1(n), \tag{3.1}$$

where s(n) is the uncorrupted signal, and $x_2(n)$ is the noise. The noise is considered additive and uncorrelated with the signal. The secondary input is:

$$x_2(n),$$

which is considered correlated to the noise $x_1(n)$. It can be used as a reference signal for noise cancellation. Upon receiving a new $x_2(n)$, the adaptive filter outputs y(n), which is a close estimate of $x_1(n)$. This y(n) is then subtracted from d(n) to produce the error signal:

$$e(n) = d(n) - y(n), \tag{3.2}$$

which is the noise cancellation output that is fed back to update the weights (or coefficients) of the adaptive filter. The LMS algorithm uses instantaneous estimates of the gradient vector, based on sample values of $x_2(n)$ and e(n).

An adaptive finite impulse response (FIR) filter can be implemented in a transversal structure, as shown in Figure 3.2.

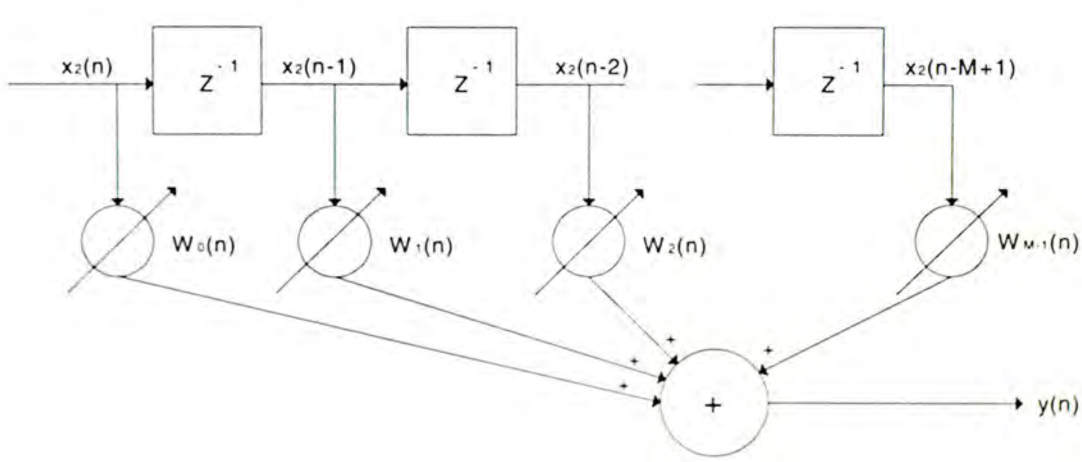


Figure 3.2: Transversal FIR adaptive filter structure

The output y(n) is found from the weighted sum of the x_2 vector:

$$y(n) = \sum_{i=0}^{M-1} w_i(n) x_2(n-i) \tag{3.3}$$

where n is the time index, and M is the order of filter or filter length. The weights are updated sample-by-sample based on the Widrow-Hoff LMS algorithm [50]:

$$\mathbf{w}(n+1) = \mathbf{w}(n) + 2ue(n)\,\mathbf{x}_2(n), \tag{3.4}$$

where u is the adaptation step size, $\mathbf{w}(n+1)$ is the updated weight vector, $\mathbf{w}(n)$ is the old weight vector, and $\mathbf{x}_2(n)$ is the reference input vector. All the weights are initially set to zero. The updated weight vector is obtained by incrementing the old weight vector by an amount proportional to the product of reference input vector and the error signal. The choice of step size u for such a filter involves trade-off between convergence rate and accuracy. A small value of u leads to higher accuracy, but lower convergence rate.

The entire adaptive filtering process is as follows:

1. At time n, y(n) and the corresponding e(n) are calculated using equations 3.2 and 3.3.
2. The weights are then updated using equation 3.4.
3. Finally the time index is incremented by one, and the process repeats starting from step 1.

3.3 Method

The LMS filter was used to remove the remaining noise in the acquired ECG; therefore, an addition channel was needed to acquire a reference that was correlated with the EMI. As discussed in the last chapter, the noise was a result of the high frequency interference being rectified by the non-linear elements in the semiconductor parts of the circuits. In order to get a reference that was correlated with the noise in the ECG, another circuit, which was identical to the ECG acquisition circuit, was built and placed within the same metal enclosure. The inputs of this second circuit were connected to an axial 10mH inductor, instead of the subject's body. After going through the EMI filters, the inputs then entered the differential inputs of an INA118 instrumentation amplifier also set to a gain of 1000. Following this was a lowpass filter, built from a UAF42 with a cutoff frequency of 150Hz. All EMI filters installed in the two circuits were 5000pF Pi-section filters. The setup is shown in Figure 3.3.

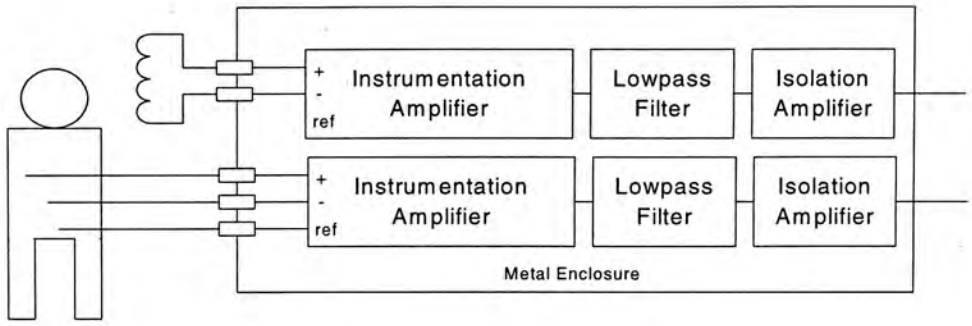


Figure 3.3: Setup of the circuit for ECG and noise acquisition

The two outputs of the circuits were sampled at 2000 samples/s per channel on the Windaq computer-based data acquisition unit. Each recording was 30 seconds long. A dialing mobile phone operating at GSM1800 was placed at different distances from the ECG acquisition circuit. The data was then loaded and processed offline using an LMS adaptive filter, which was realized with Visual Basic 6.0. The primary input d(n) of the filter was presented with the raw ECG, which also contained noise. The noise reference signal captured by the second circuit was fed to the secondary input $x_2(n)$. Programming codes of the adaptive filter are presented in Appendix B. The application interface is shown in Figure 3.4.

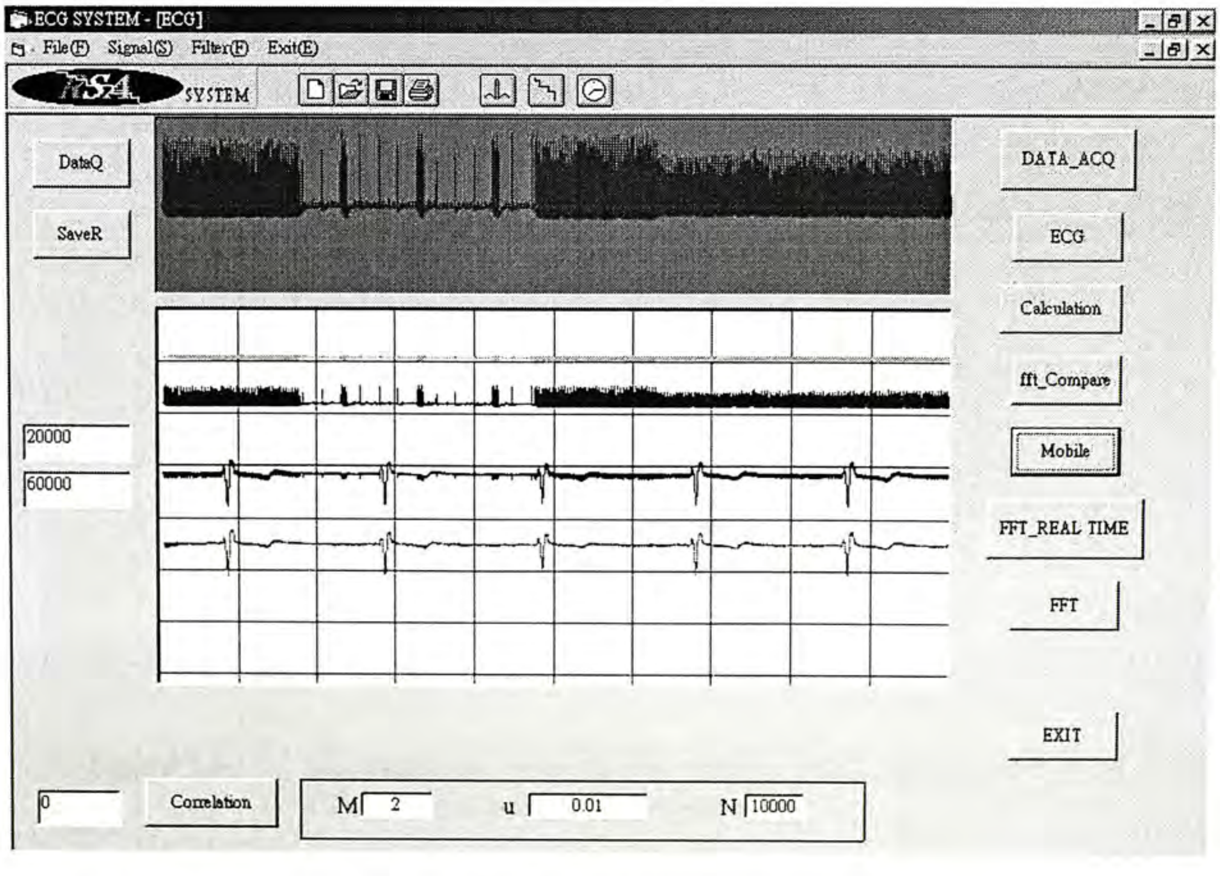


Figure 3.4: Interface of the adaptive filter application

The program required the user to choose the step size, filter order, and the two file names for the two filter inputs. After filtering, the corresponding output and parameters during the filtering process were displayed and stored in separate files.

3.4 Results

Figure 3.5 shows the raw ECG signal and noise reference acquired on the two channels when the dialing phone was 10cm from the circuit, which had no EMI filter installed. The resulting interference appearing on both channels had similar patterns and occurrence times. Figure 3.6 shows the recording when EMI filters were installed.

Relative energy spectrum densities (ESD) of the signals in Figures 3.5 and 3.6 are shown in Figure 3.7. The spectrums Raw_1 and Ref_1 were the ESD of the raw ECG and reference signal recorded from a setup without EMI filter, while the spectrums Raw_2 and Ref_2 were the ESD of the raw ECG and reference signal recorded from a setup with EMI filter. The ESD's show that the noise component was mainly at 218Hz and its harmonics. This noise was significantly reduced in both the raw ECG and reference channels when EMI filters were installed.

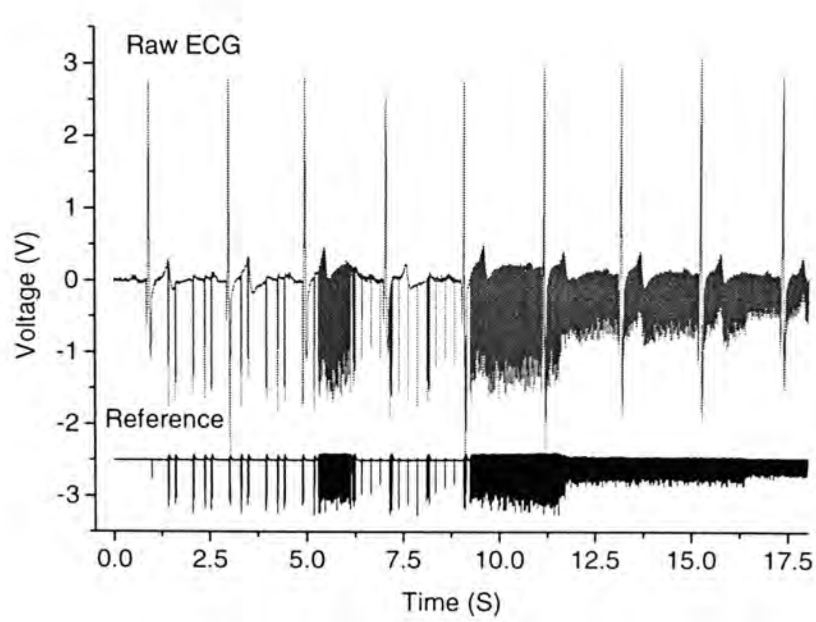


Figure 3.5: Simultaneous recording of the raw ECG signal and noise reference. EMI filters were not installed.

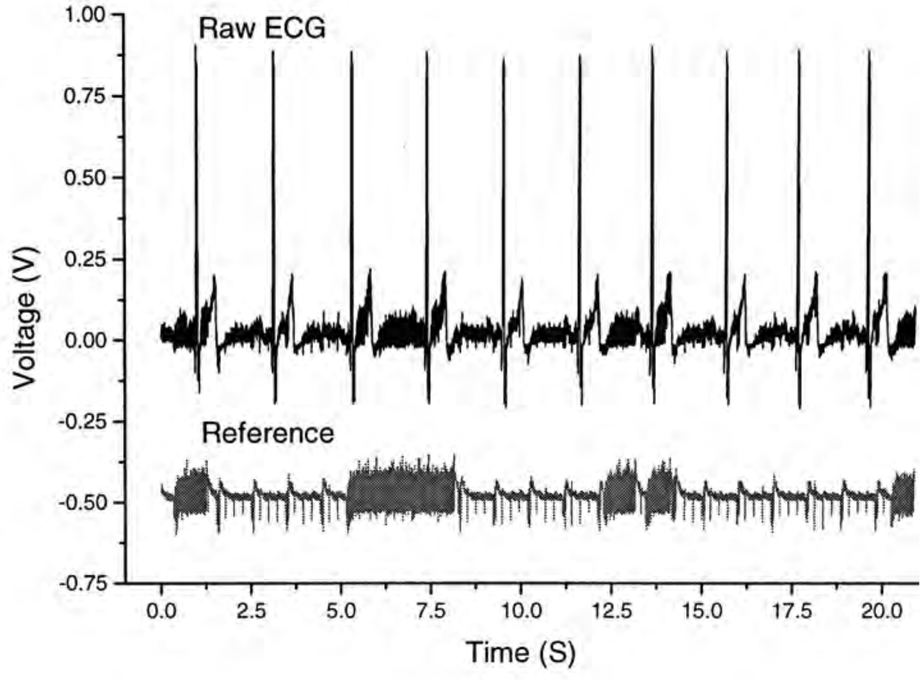


Figure 3.6: Simultaneous recording of the raw ECG signal and noise reference. EMI filters were installed.

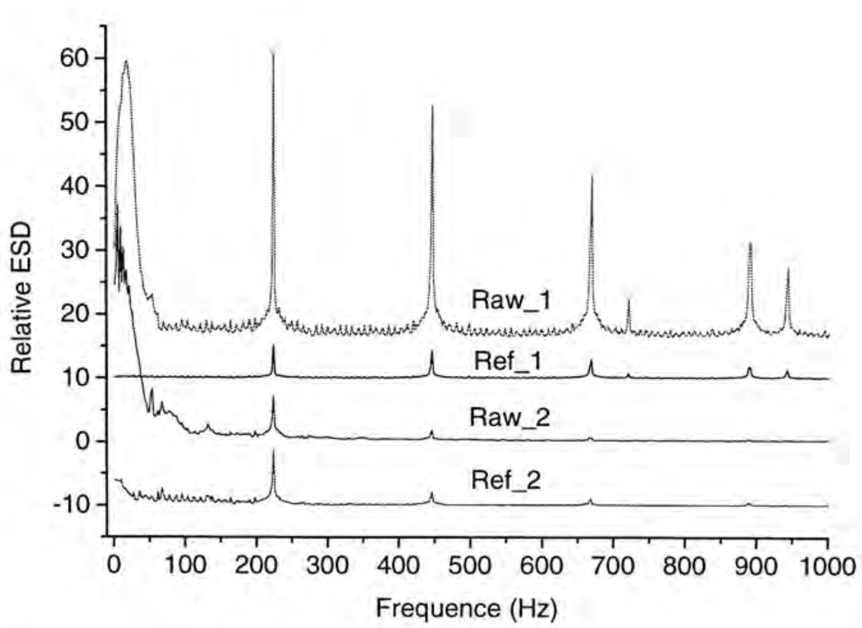


Figure 3.7: Spectrum of the raw ECG and reference signal in the two cases of with and without EMI filters installed.

Figure 3.8 shows the input, output, and parameters of the adaptive filter that was operating on signals recorded from a setup installed with EMI filters. The waveforms shown from top to bottom are the pure ECG recorded prior to the introduction of mobile phone interference, the raw ECG and noise reference recorded during introduction of mobile phone interference, the estimated ECG at the adaptive filter's output e(n), and the estimated noise y(n).

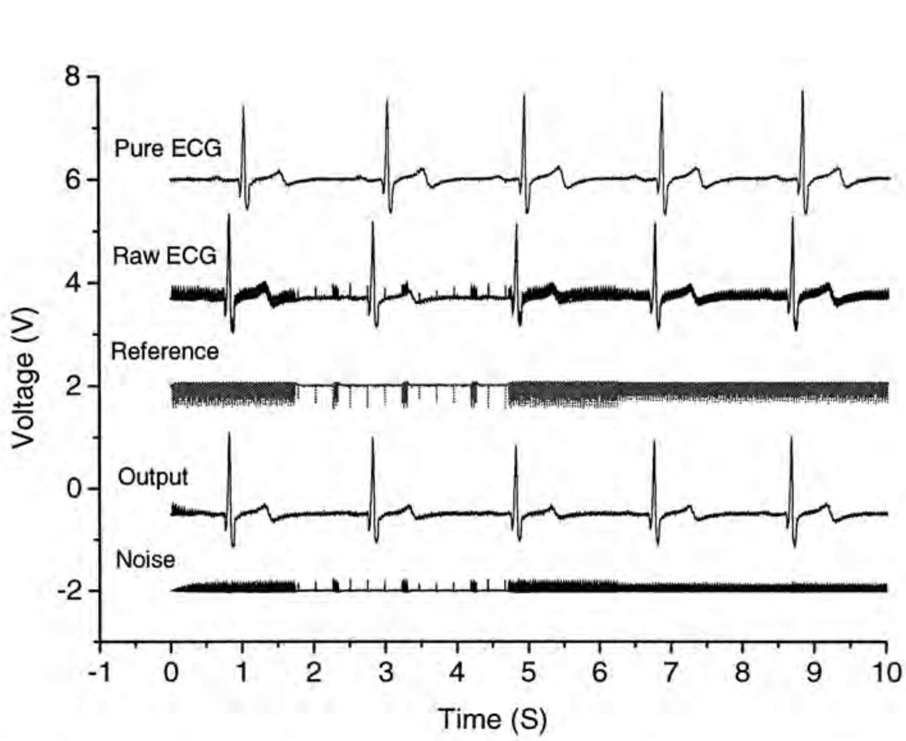


Figure 3.8: An example of adaptive mobile phone interference cancellation. M = 2, u = 0.01.

The relative ESD of the waveforms in Figure 3.8 are shown in Figure 3.9. The time-domain and frequency-domain results show that the adaptive filter had removed most of the noise at 128Hz and its harmonics, while introducing slight distortion to the ECG.

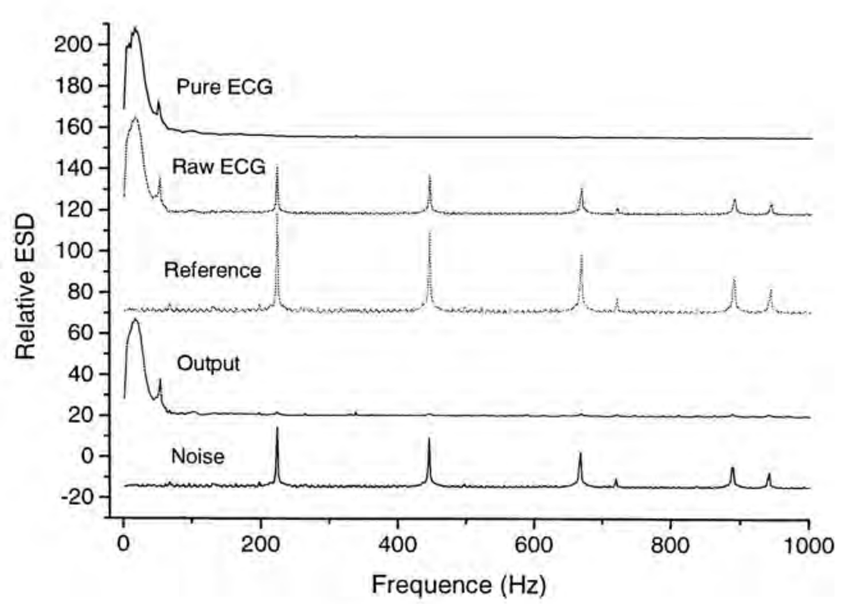


Figure 3.9: Spectrum analysis of adaptive mobile phone interference cancellation

It is known that the step size u and filter order M can both affect the performance of the adaptive filter. Figure 3.10 shows the adaptive filter outputs for u = 0.01 and different values of M.

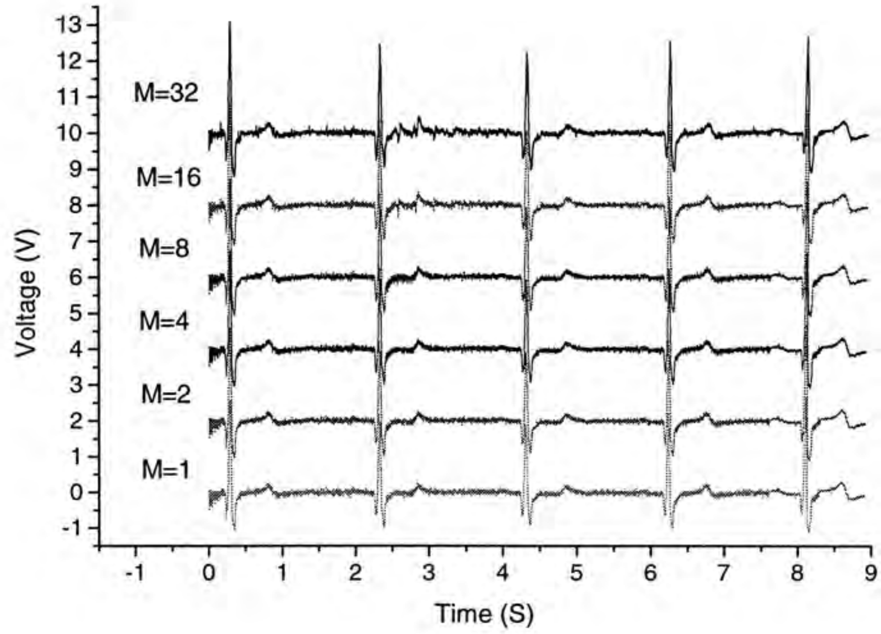


Figure 3.10: Output of adaptive filter for u = 0.01 and different filter lengths

Figure 3.11 shows how filter length affects the ratio of the total energy of the estimated noise to the total energy of the raw ECG. The ratio indicates how much of the raw ECG was filtered out. The three cases presented were:

1. EMI filters installed; dialing mobile phone 50cm from the circuit;
2. EMI filters installed; dialing mobile phone 40cm from the circuit;
3. No EMI filter installed; dialing mobile phone 10cm from the circuit.

The ratio increased as the filter length was increased from one to two; the ratio decreased as the filter length was increased from 2 to 32. This corresponded to results shown in Figure 3.10, where less noise is being filtered out for large filter length. Figure 3.12 shows how different values of u can affect the output of the adaptive filter.

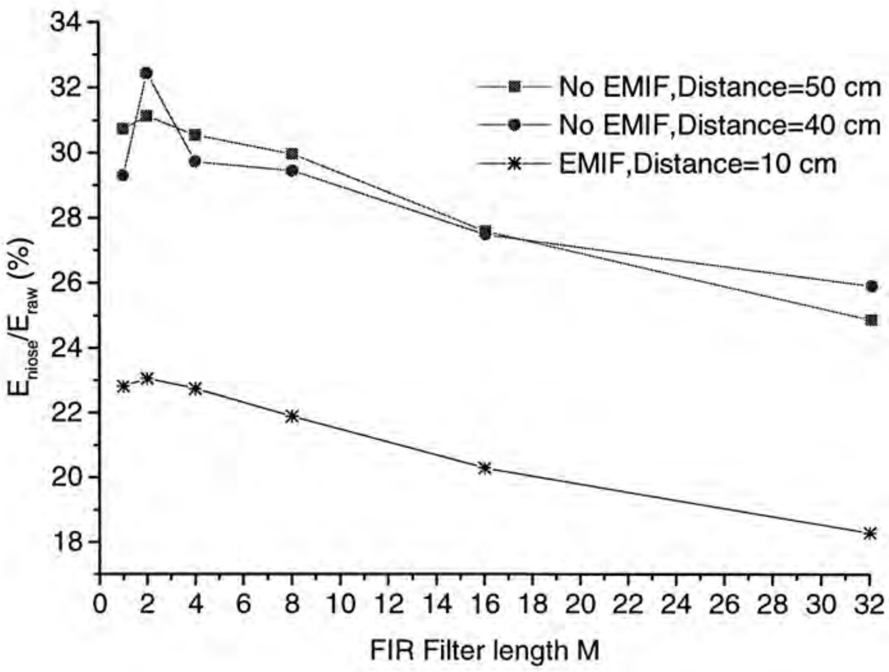


Figure 3.11: Effect of filter length in adaptive noise cancellation.

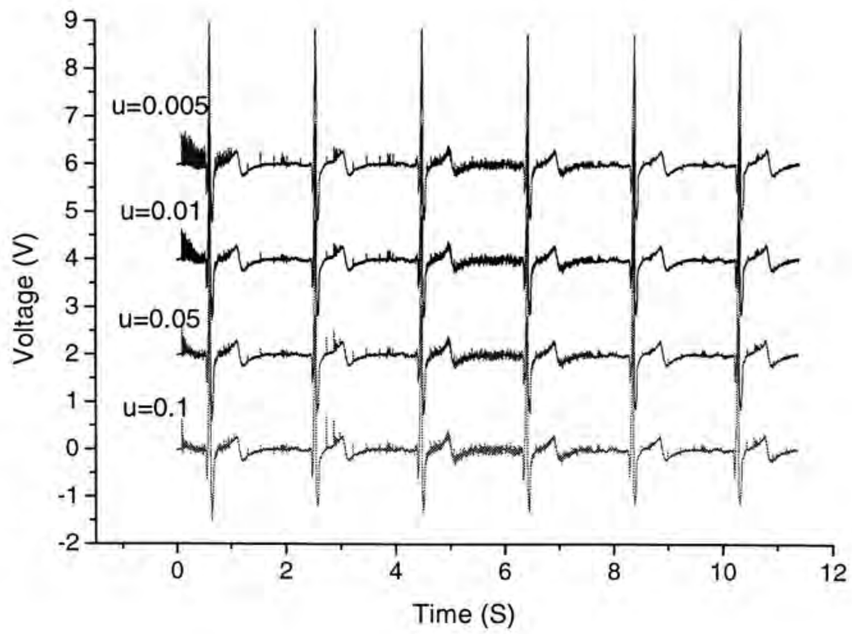


Figure 3.12: Output of adaptive filter for M=2 and different values of u.

Figure 3.13 shows how the step size affects the ratio of the total energy of the estimated noise to the total energy of the raw ECG. The four cases presented were:

1. EMI filters installed; dialing mobile phone 10cm from the circuit;
2. EMI filters installed; dialing mobile phone 20cm from the circuit;
3. No EMI filter installed; dialing mobile phone 40cm from the circuit;
4. No EMI filter installed; dialing mobile phone 50cm from the circuit.

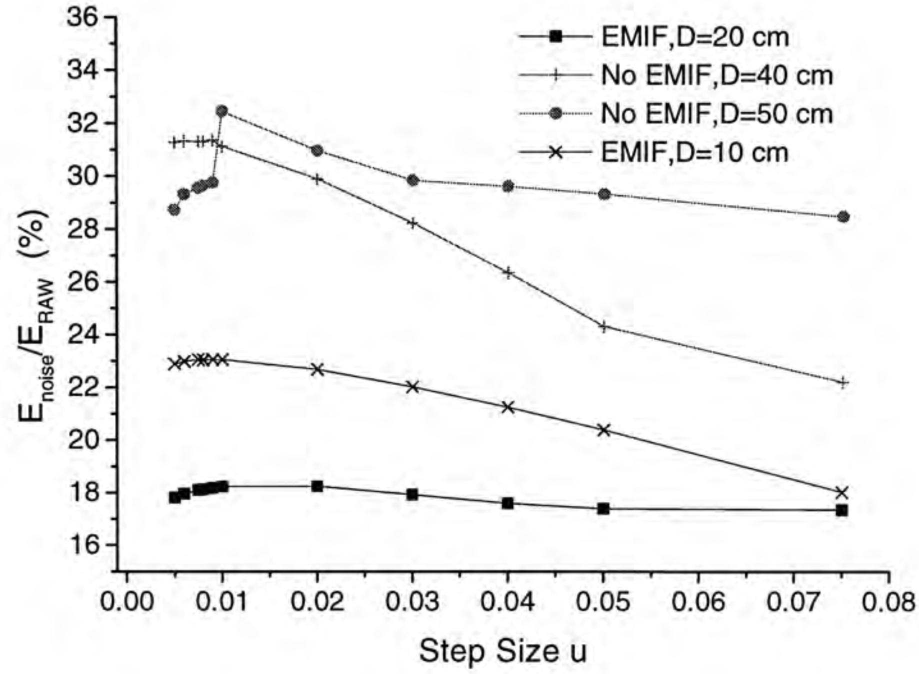


Figure 3.13: Effect of step size in adaptive noise cancellation.

Since the LMS algorithm is based on minimizing the mean square error (MSE) of the output, it is possible to find the optimal step size and filter length. Figure 3.14 to 3.16 show the effect of filter length and step size on the MSE.

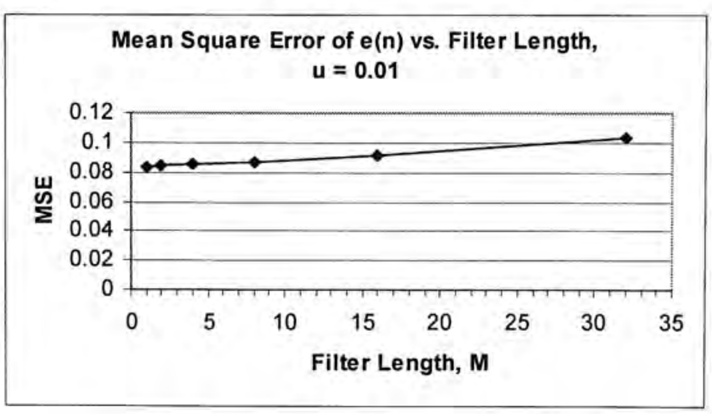


Figure 3.14: Effect of filter length on MSE, u = 0.01

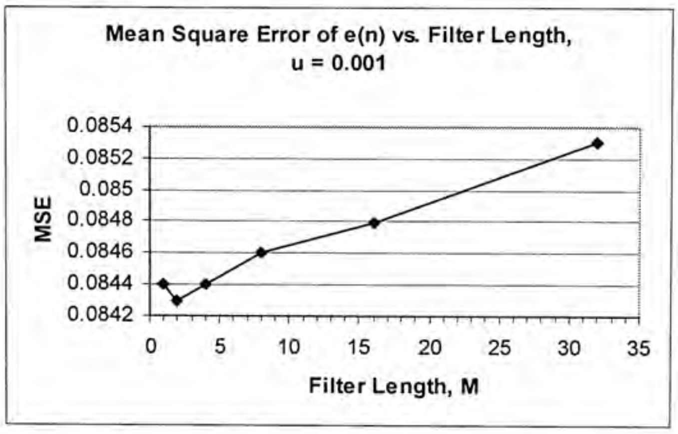


Figure 3.15: Effect of filter length on MSE, u = 0.001.

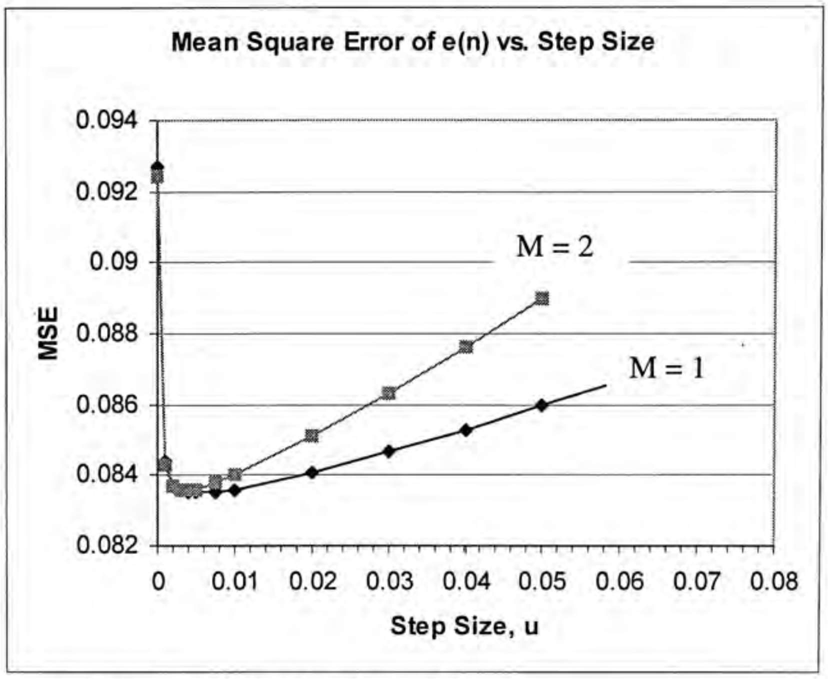


Figure 3.16: Effect of step size on MSE, M = 1 and M = 2

3.5 Discussion

The above study has demonstrated the use of LMS filter to remove the remaining noise that resulted from mobile phone interference. The results have shown that most of the noise was reduced for step size of 0.01 and filter length of 2. The MSE analysis showed that for M = 2, optimal u = 0.004, and for M = 1, optimal u = 0.005. For u = 0.001, optimal M = 2.

However, there is still room for improvement for the system. It was found that the output from the reference circuit was sometimes too weak to be used for noise reference signal. Sensitivity of the reference circuit was weaker than that of the ECG acquisition circuit in some cases, and it heavily depended on the inductor's orientation. A stronger reference was detected when the axial inductor was parallel to an imaginary straight line stretched from the inductor to the mobile phone. Further improvements may include reference signal amplitude or sensitivity automatic adjustment, trials with other inductors with different values or other EMI sensing front-ends, and tests with other kinds of mobile phones and sources of interference.

At this stage, the analysis was only performed offline. The ultimate goal is to develop a system that can perform adaptive filtering in real-time during monitoring. In a typical ECG monitoring system, the LMS filter can be implemented either at the computer terminal, which receives the ECG from a telemetry unit, or immediately at the user's side, where the signal is preprocessed prior to transmission to the computer terminal. The former approach is usually not preferred because the wireless transmission would introduce some noise into the signal, and thus worsen the performance of the adaptive filter. Some DSP (Digital Signal Processing) chips are suitable for the latter approach. For example, TMS320C25 and TMS320C30 from Texas Instruments combine the power, high speed, flexibility, and architecture optimized for adaptive signal processing. They are designed for real-time tasks in telecommunications, speech processing, image processing, and high-speed control.

Chapter 4: WAP-based Telemedicine Applications

4.1 Introduction to Telemedicine

Telemedicine refers to the utilization of telecommunication technology for medical diagnosis, treatment, and patient care [51]. Its aim is to provide expert-based health care to remote sites through telecommunication and information technologies.

The significant advances in technologies have enabled the introduction of a broad range of telemedicine applications, which are supported by computer networks, wireless communication, and the information superhighway. For example, some hospitals are using tele-radiology for remote consultation [52]. Such a system includes medical imaging devices networked with computers and databases. Another growing area is patient monitoring, in which sensors are used to acquire biomedical signals, such as ECG, blood pressure, and body temperature, from a remote patient, who could be in bed [12-13] or moving freely [53]. The signals are then relayed to remote systems for viewing and analysis.

Telemedicine can be divided into two basic modes of operations [51]: real-time mode, in which the patient data can be accessed remotely in real-time, and store-and-forward mode, in which the acquired data does not have to be accessed immediately.

In the recent years, many parties have demonstrated various telemedicine applications based on the Internet [12-13][52] and cellular phone [14][54] as these two fields have been developing rapidly. A current, recognizable trend in telecommunication is the convergence of wireless communication and computer network technologies [64]. This has been reflected in recently developed telemedicine systems. For example, in 1998 Reponen *et al.* have demonstrated transmission and display of computerized tomography (CT) examinations using a remote portable computer wirelessly connected to a computer network through TCP/IP on a GSM cellular phone [55]. Two years later, they carried out the same tests with a GSM-based wireless personal digital assistant (PDA) [56].

4.2 Introduction to WAP

The emergence of WAP (Wireless Application Protocol) devices is a more recent example of merging of the two technologies. The WAP Forum was founded in 1997 to create a global protocol specification for all wireless networks. The WAP specification has already undergone several revisions, and further development is expected. A typical WAP phone provides, other than the ordinary voice and data transmission, wireless connection to the Internet. As WAP is expected to be a feature also found in future cellular phones and in various hand-held communication devices, it is worthwhile to investigate its possible applications in telemedicine.

This chapter describes the implementation and initial experiences with some of the WAP-based telemedicine applications that have been developed.

4.3 WAP Applications

A WAP communication model, shown in Figure 4.1, consists of the a handheld WAP-compatible device, the content server, which stores information and responds to the users' requests, and a WAP gateway, which translates and passes information between the WAP device and the server [57].

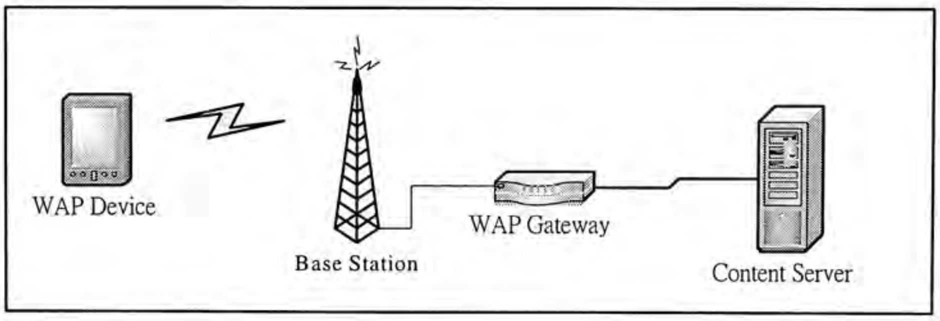


Figure 4.1: WAP communication model

To access an application stored at the content server, the WAP browser on the device first initiates a connection with the WAP gateway. It then sends a request for the contents. The gateway converts these requests coming from the WAP device into HTTP, which is the format used on the Internet. Upon receiving the requests, the server sends the contents to the gateway, which then translates them into WAP format before sending them to the WAP device. The layers of WAP protocols govern the communication. The architecture is shown in Figure 4.2.

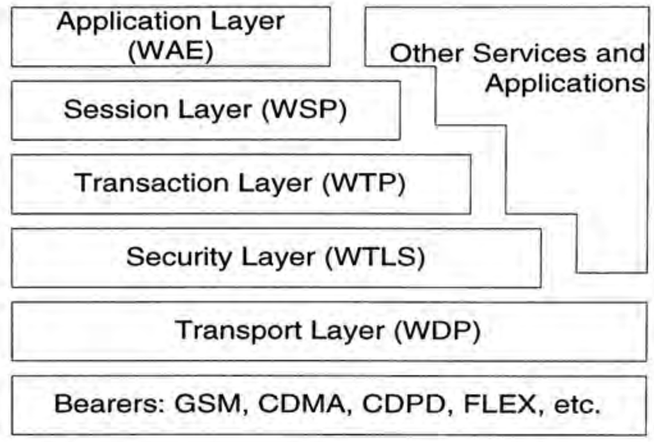


Figure 4.2: WAP Architecture

To determine which telemedicine applications are feasible with WAP, it is important to first examine the capabilities of a typical WAP device. Such a device has limited processing power, memory, battery life, display size and resolution, and entry capability. Compared to wired networks, most currently used wireless networks for WAP have low bandwidth, resulting in perceptible delay between data request and response at the mobile device. Due to the nature of such a network, requests and responses are required to be concise for minimal latency.

This latency depends on the type of bearer used. With a GSM network, some possible bearers are SMS (Short Message System), CSD (Circuit-Switched Data), and GPRS (General Packet Radio Switching) [58]. When running WAP over SMS, the WAP gateway has to divide the content sent to the WAP device into packets, each containing at most 160 bytes. The device then reassembles these packets. This procedure is the most time-consuming among the three.

With CSD, a data connection, which takes several seconds of time, is first set up between the WAP device and the gateway before data transfer. Typical connection speed is 9.6 Kbps, providing faster services. GPRS provides even a higher speed of up to 171.2 Kbps. It does not require the connection time as in CSD. When a GPRS phone is switched on, it is always online and is ready to start receiving and sending data in less than one second. GPRS is expected to be commercially available sometime this year.

WML (Wireless Markup Language) is designed for creating WAP applications, and is user-interface independent. It has fewer capabilities than HTML. It supports text, images, user input, variables, navigation mechanisms, multiple languages, and state and management server requests. WML has been designed to adapt to the high-latency and narrow-band of the wireless network, so connections with the server should be avoided unless necessary. WML is mainly intended for displaying text-based contents. When a user accesses a WAP site, it sends back contents in the form of a deck, which is made up of cards. The user can then browse through the deck of cards.

The Wireless Bitmap Format (WBMP), defined by the WAP Forum, is a graphics format optimized for efficient transmission over low-bandwidth networks and minimal processing time in WAP devices. The format uses no compression to suit the limited processing power at the WAP device. Current WBMP images are only in black and white.

The above technical capabilities suggest that use of current WAP devices in telemedicine is feasible in areas where the application operates in a store-and-forward, client-server, and low-bandwidth fashion [59]. The displayed information is limited to text and low-resolution WBMP static images. When displaying graphical information, it is better to first construct the image at the server, thus reducing the usage of memory and processing time at the device.

A WAP-based system has been developed for some telemedicine applications. These include viewing of general patient information, previously captured blood pressure (BP) and heart rate readings, and recorded ECG waveforms. It also allows remote request for doctor's appointments, and general inquiries on clinic and hospital information. Targeted users are doctors, patients, and system administrators. Figure 4.3 shows the general features of the system.

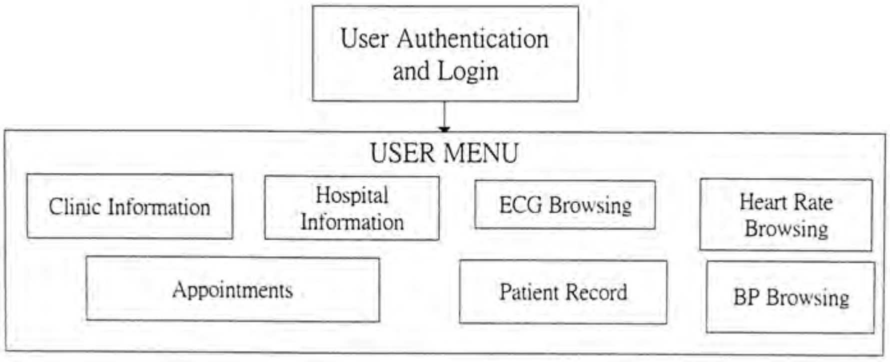


Figure 4.3: General features of the WAP-based telemedicine system

A major concern for displaying the ECG is the small screen size and low display resolution. ECG has been displayed on a 160 x 144 pixels LCD gray-scale display on a hand-held video game platform, and it was shown that some basic features such as R-R intervals were still recognizable with the user's selection of the lead displayed and time scale used [60]. Noting that the display resources on a WAP device are similar to those of the game platform, design of the ECG browsing part of the WAP-based system can follow a similar approach.

4.4 System Implementation

4.4.1 Overall Structure

A system has been developed for testing the feasibility of telemedicine with WAP [59]. Figure 4.4 shows its structure.

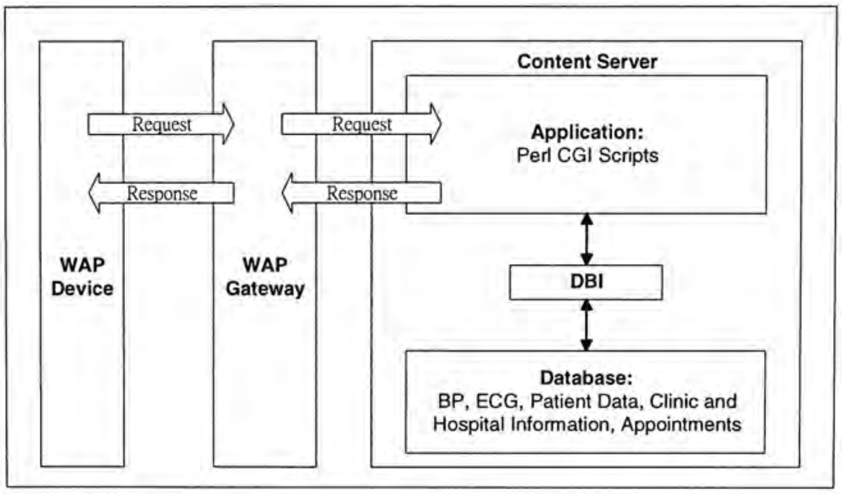


Figure 4.4: Structure of the system

The applications were stored in the content server. Part of the user-interface was written in WML and WMLScript. These were executed at the WAP device after they had been downloaded from the server. The other part of the application, written in Perl [61], was executed in the Linux-based content server. It provided the common gateway interface (CGI) for more complex tasks. Using the GD and Common Gateway Interface (CGI) modules, the Perl program could dynamically create WBMP graphics and WML decks upon requests from the WAP device. Graphics displayed included simple graphs and ECG waveforms. Each graphical object was first constructed in the server before being sent to the user agent as one WBMP file. The data that the applications access and manipulate are stored in a relational database.

4.4.2 Relational Database

A relational database is a database made up of tables and columns that relate to one another. MySQL [62] is a relational database management system (DBMS) that allows multithreaded operation. It also has various application programming interfaces (APIs), including Perl, TCL, Python, C/C++, JDBC, and ODBC. MySQL uses the Structured Query Language (SQL) to manipulate, create, and show data within a database.

A MySQL relational database was set up to store data, including blood pressure and heart rate readings, patient records, clinic and hospital information, doctors' appointments with patients, and ECG data. These were accessed by the applications through Perl's Database Interface (DBI), as shown in Figure 4.4.

Figure 4.5 shows the entity-relationship (ER) model [63], a high-level conceptual representation of data contained within the database. The data are organized as tables, as shown in Appendix D.

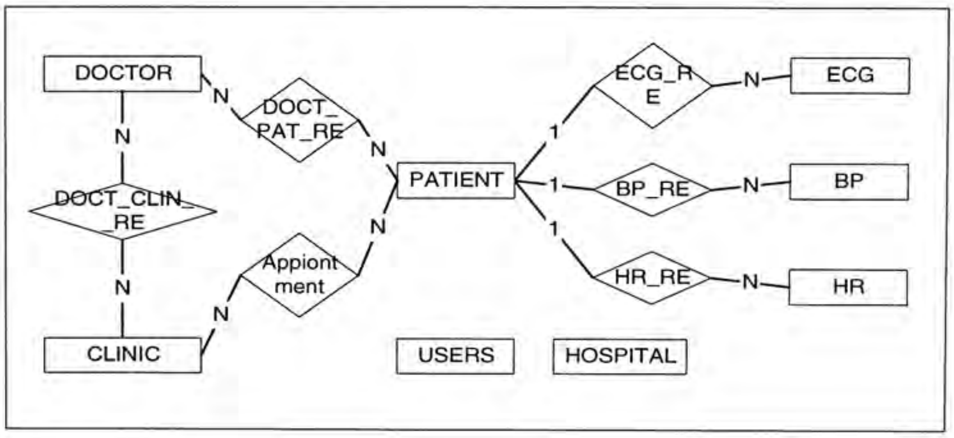


Figure 4.5: Entity-relationship model of the database

An entity type is represented in the ER model as a rectangular box. It describes the schema for a set of entities that have the same structure. Attributes that describe each entity type are shown as bubbles attached to the rectangle. Among these, the attribute that has a unique value for each individual entity can be considered a primary key for the entity type. Relationship type indicates the relationship between entities, and is represented as diamond-shaped box. The cardinality ratio at each side of a relationship type specifies the number of relationship instances than the entities can participate in.

4.4.3 Program Flow

The WAP sites, related programming codes, and data were stored in the same content server. The flow of the program started when the user accessed the first WML deck at a predefined site. The following WML decks that the user interacts with are then generated by Perl. Appendix C contains the main WML and Perl programming codes and documentation. The flow of the application is as follows:

The user first logs into the WAP site and loads the first card login.wml, which prompts for username and password. Using CGI with method 'post', Perl first takes the user inputs. It then accesses the TABLE USER of the database through the DBI. If the user inputs are valid, it generates a menu in WML cards for the user, according to the user's access level. The three access levels are: administrator, doctor and patient. An administrator can view all data. A doctor can only view his or her own patients' data, and a patient can only view his or her own data. The user then chooses to view either appointments of clinics or patient information. The flow is shown in Figure 4.6.

If the user chooses to view patient information, the patient ID has to be entered. A menu is then generated if the patient ID is valid and accessible. The user has the choices of: general information, single blood pressure reading, day log of blood pressures, ECG browsing, and heart rate reading. The flow is shown in Figure 4.6. After choosing the type of data to view, another menu is created. The parameters containing patient ID, user's access level and username are passed on to the next Perl program through method 'post'.

The menu for patient general information allows the user to choose to view the name, birth-date, contact numbers, address, and picture of the patient. After one of these items are chosen, Perl looks up the TABLE PATIENT in the database and creates the WML card accordingly. For the case of presenting the patient's picture, the database contains the picture's filename, directing the program to load the preprocessed WBMP file at the specified location.

The menu for single blood pressure reading works in a similar way. After a list of BP recording sessions is displayed, the user chooses the session. Perl searches through TABLE BP, and charts out the date, time, pulse rate, and the systolic, diastolic, and mean pressure values in WML. Day log for blood pressure allows the user to view all the pressure values of a day in charted or graphed form. To display graphs, the program first searches through TABLE BP and stores the necessary values in an array, which is then used along with the GD module to create a WBMP file, which is called by the WML card. Scrollable graphs work by updating the array with a new set of data from the database whenever the user chooses to scroll forward or backward. The flows of these are presented in Figures 4.7 and 4.8

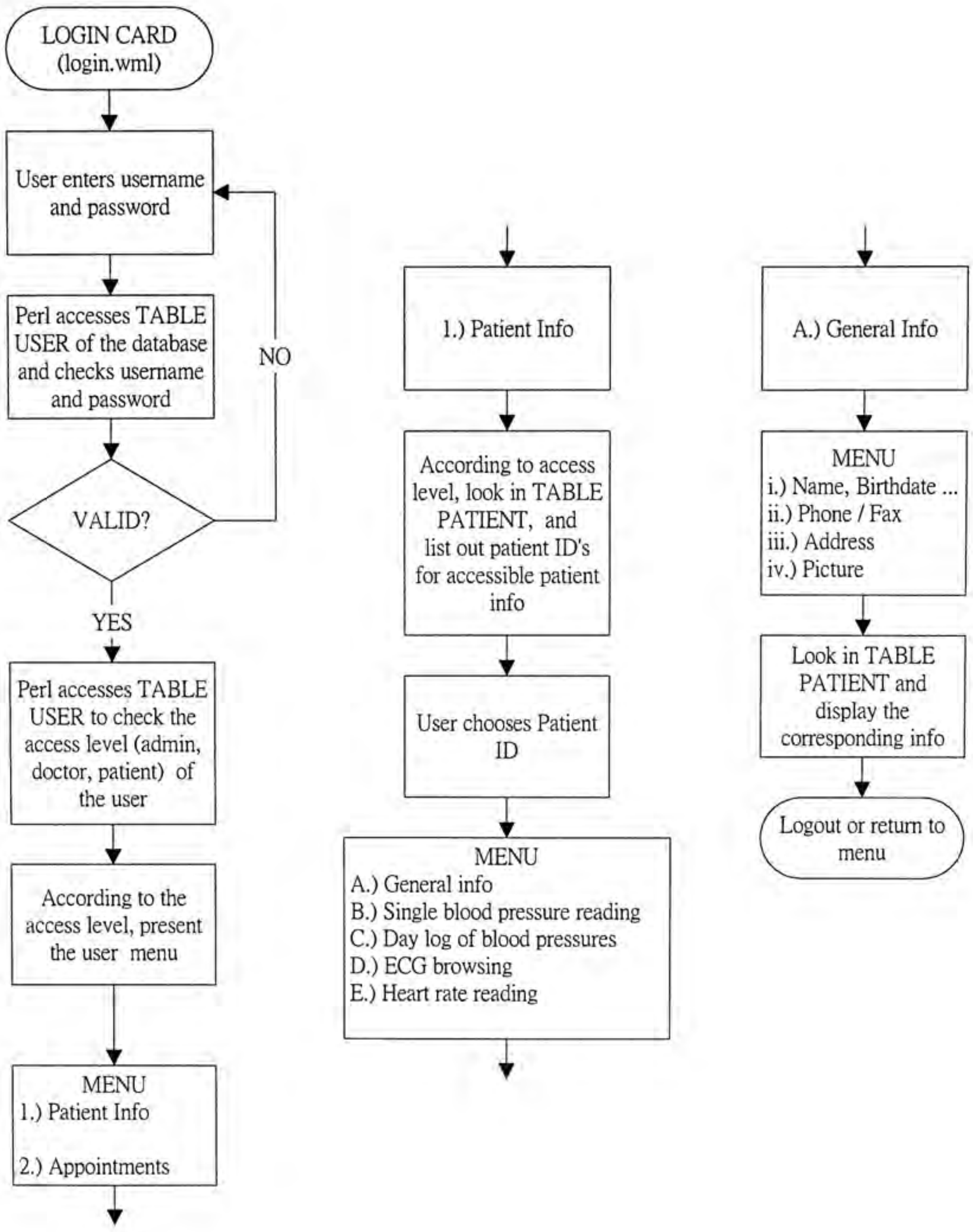


Figure 4.6: Flow of the WAP application; login, patient information menu, and patient general information.

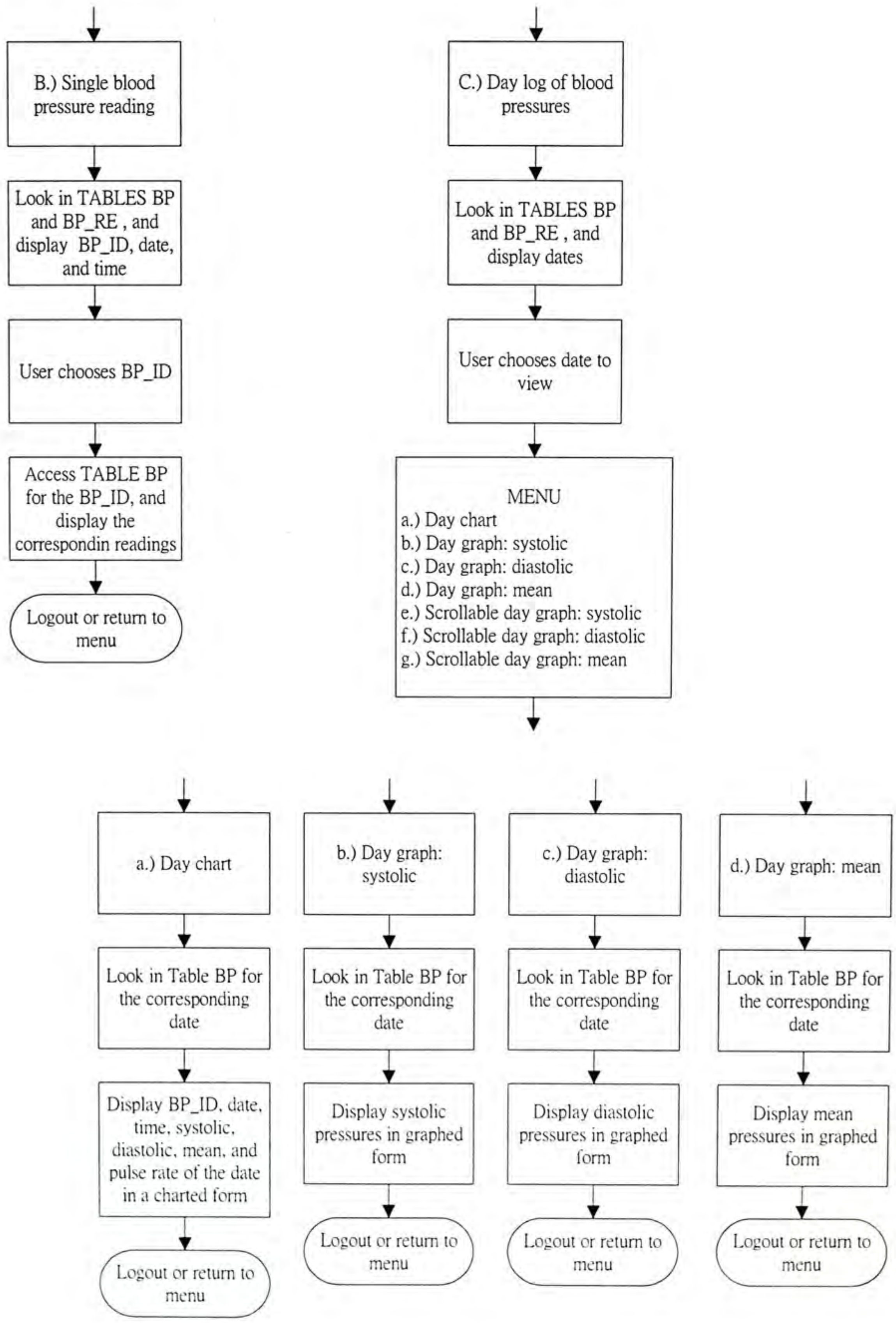


Figure 4.7: Flow of the WAP application; viewing of blood pressures.

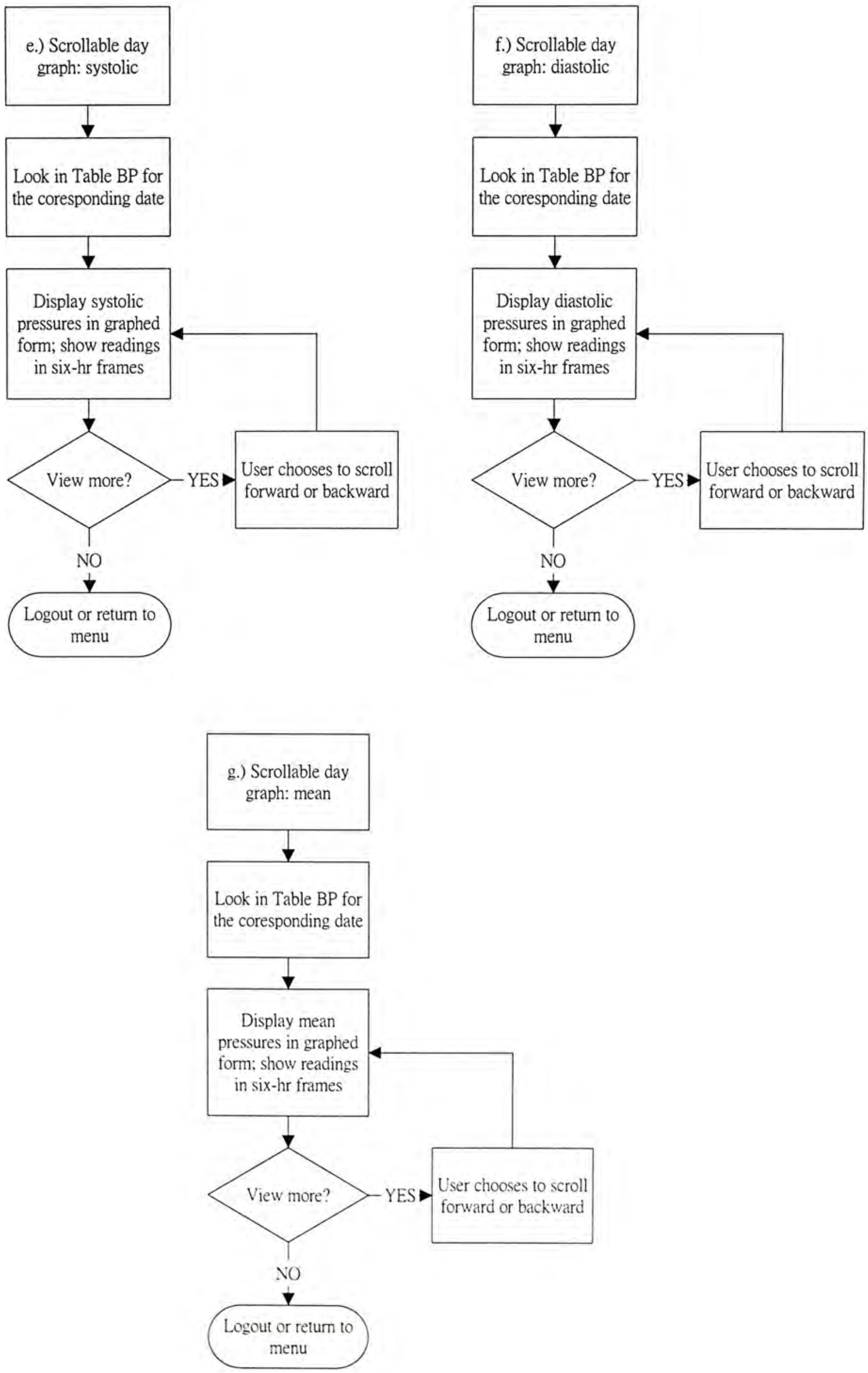


Figure 4.8: Flow of the WAP application; viewing of blood pressures.

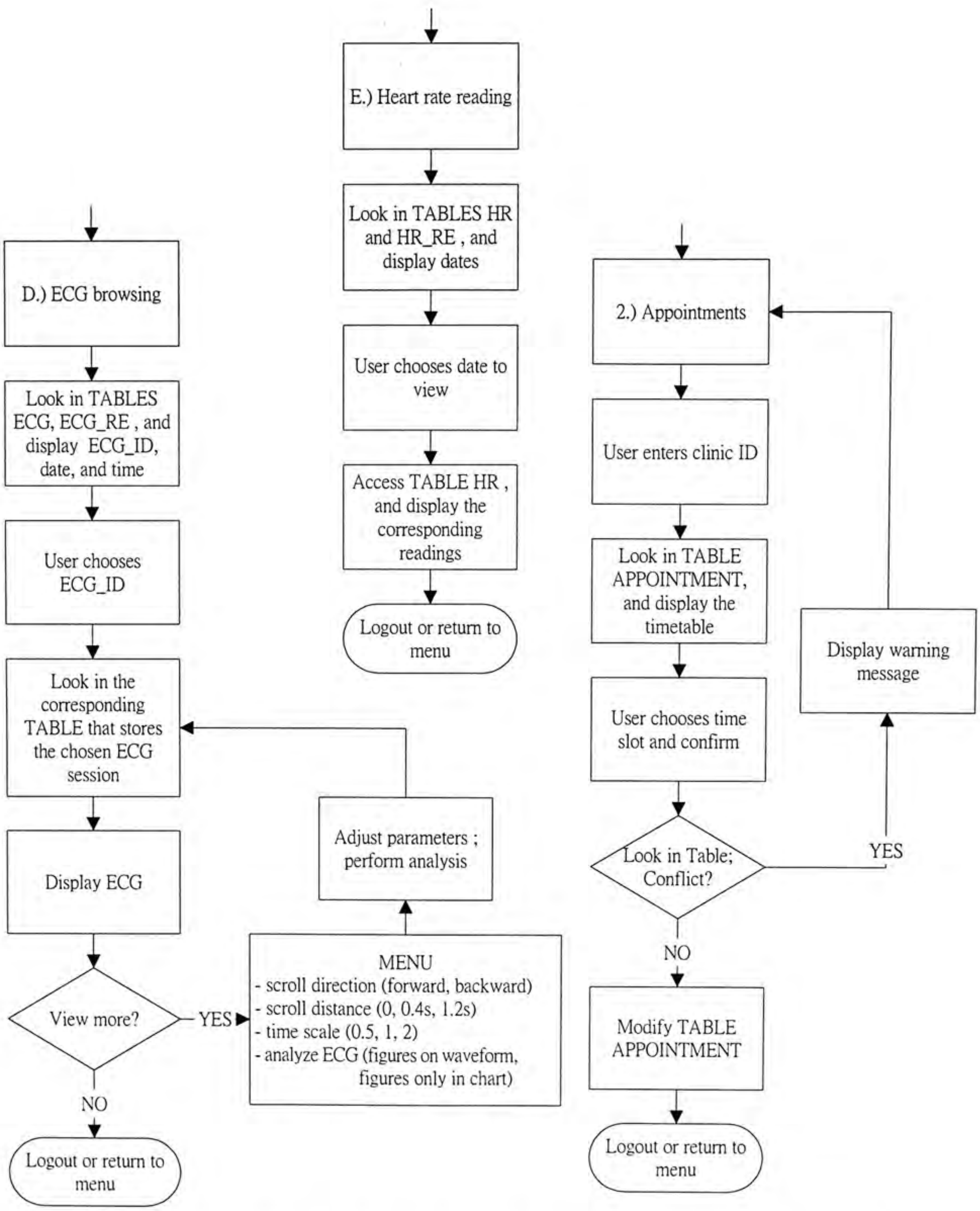


Figure 4.9: Flow of the WAP application; ECG browsing, heart rate reading, and appointments

When a user wishes to browse through the ECG waveform for a specified recording session, the session is first chosen. The program then searches through TABLE ECG for details, such as sampling rate and recording duration of the session. Each session is stored in a separate table named according to the names in TABLE ECG. To display the ECG, the program traverses through this table with a pointer, and loads the necessary data points into a temporary array. According to the information in TABLE ECG and predefined scales, it creates a WBMP for each new frame of ECG waveform. The user can view the waveform with the choice of time-scale, scrolling forward or backward, and scroll distance. A function also allows instant request for estimation of QRS occurrence and R-R intervals. The flow is summarized in Figure 4.9, and the technique is discussed in detail in the Section 4.4.4.

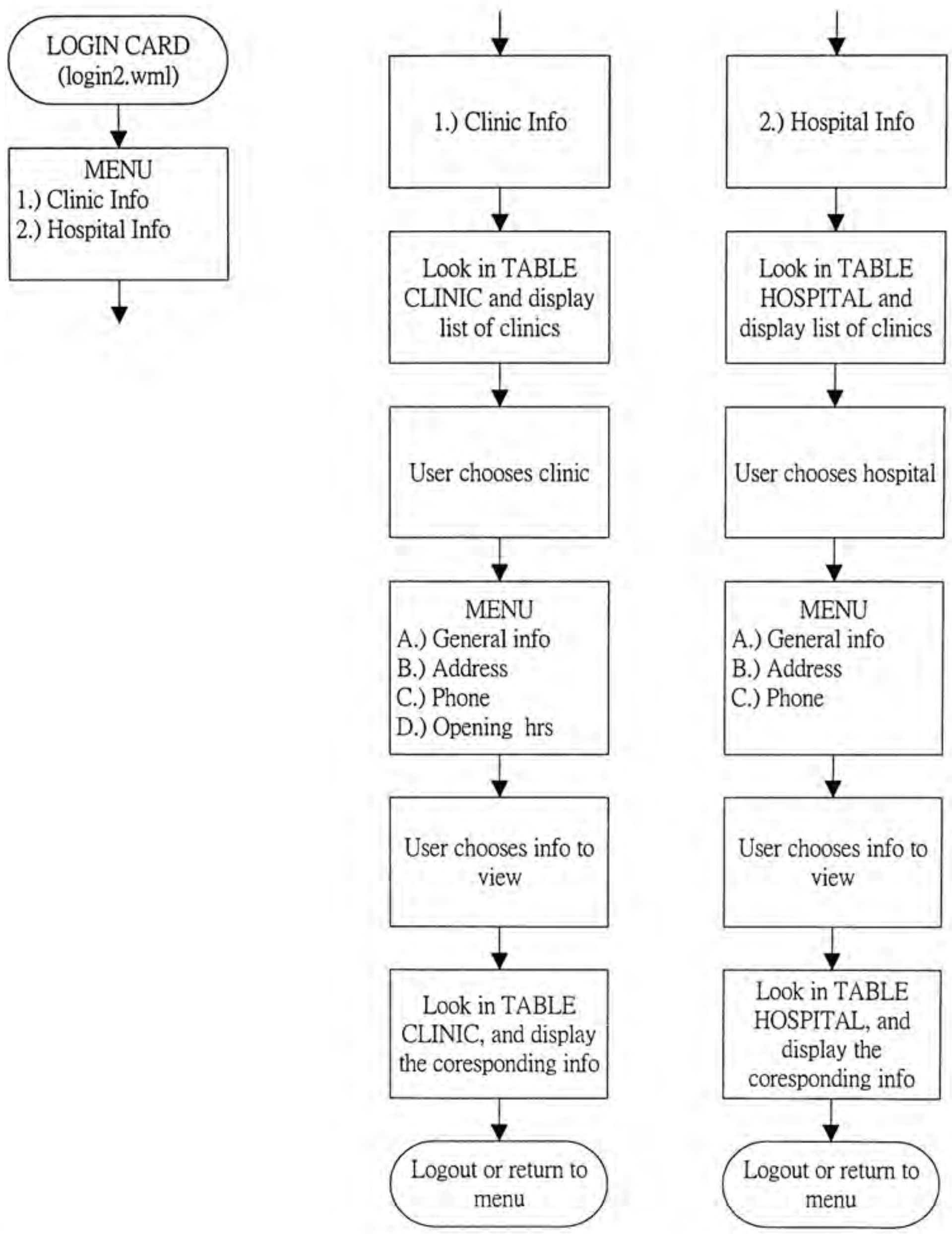


Figure 4.10: Flow of the WAP application; hospital and clinic information inquiry.

The inquiry service for hospital and clinic information is available at another WAP site, login2.wml. Through accessing TALBES CLINIC and HOSPITAL, the program presents the information according to the user's request. The flow is shown in Figure 4.10.

4.4.4 ECG Browsing and Feature Extraction

For testing ECG browsing, a Lead I waveform from a subject was sampled at 250 samples/s by a data acquisition unit, stored as delimited numbers in a file, and loaded into the content server. A Perl script then extracted the sample points from the file and stored them inside an indexed table in the database. Each recording session was stored in a separate table.

To display the ECG waveform on a WAP device, the user first selects a session. The application then retrieves the corresponding data from the database and reconstructs that part of waveform as a WBMP file. A time index is used to traverse through the table in order to keep track the part of the ECG session displayed in the current frame. Thus, the user can navigate to different parts of the session, and a different WBMP file is generated as the time index is updated accordingly. The display time scale can also be selected by the user. Graphs for hourly measured blood pressure and heart rate readings are displayed in a similar manner.

Since the display size and resolution are limited on a WAP device, performing feature extraction would further enhance the feasibility of using WAP in viewing the acquired data. To demonstrate this, a QRS detection program was written in PERL, allowing users to perform simple ECG analysis through a WAP device. It provides functions such as estimation of QRS occurrence times and R-R intervals. The algorithm used was based on amplitude and first derivative [65].

Upon receiving a request for estimating the QRS occurrence times, the program retrieves the ECG data of the specified part of the recording session from the database, and puts it into a one-dimensional array of sample points of the ECG. For 9000 sample points, the array is in the form:

$$X[n] = X[0], X[1], X[2], \ldots\ldots X[8999].$$

The first derivative, Y[n], is then calculated at each point of X[n]:

$$Y[n]= X[n + 1] - X[n - 1], \qquad 1 < n < 8998.$$

A QRS candidate occurs when three consecutive points in the Y[n] array exceeds a predefined positive slope threshold, TH_POS, and are followed within the next 100ms by two consecutive points which exceed a predefined threshold, TH_NEG.

$$Y[i], Y[i + 1], Y[i + 2] > TH\_POS \qquad ,\text{and}$$
$$Y[j], Y[j+1] < TH\_NEG \qquad ,\text{where}$$
$$(i + 2) < j < (i + 25) .$$

The value of 25 is based on the sampling rate of 250 samples/s. Each sample interval is

$$\frac{1}{250} = 0.004\,\text{sec}\ .$$

Therefore, the number of samples that corresponds to 100ms is:

$$\frac{0.1}{0.004} = 25\ .$$

Once such a QRS candidate is detected, all X[n] data points that are between the onset of the rising slope and before the end of the descending slope must exceed the amplitude threshold, TH_AMP in order to be considered a valid QRS complex.

$$X[i], X[i+1], \ldots, X[j+1] > \text{TH\_AMP}\ .$$

Finally, the occurrence times of the highest points in the QRS complexes are put into an array, which is then used in the dynamic construction of chart or graphical display in WML and WBMP format.

4.5 Emulation

All the applications were first tested with an emulation software before using actual WAP phones. The Nokia™ WAP Toolkit was used on a Windows 9x platform to emulate how the applications would appear on a WAP phone. Applications were loaded directly from the server through the Internet. The setup is as shown in Figure 4.11. Figures 4.12 to 4.15 show some screenshots of the interface.

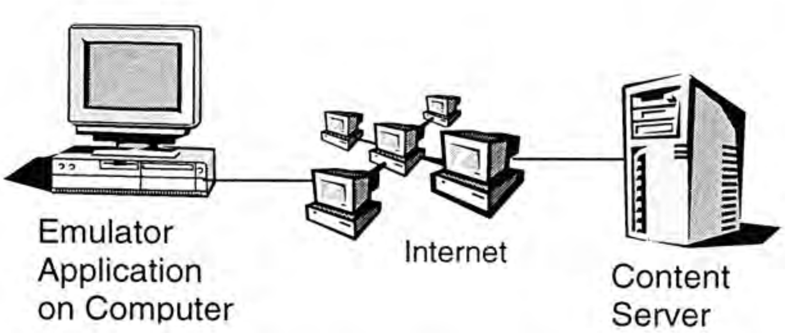


Figure 4.11: Setup for accessing WAP applications with emulation software

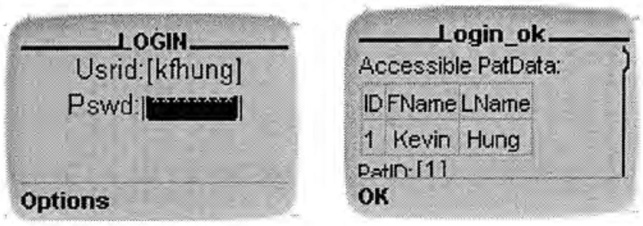


Figure 4.12: Login and patient data menu

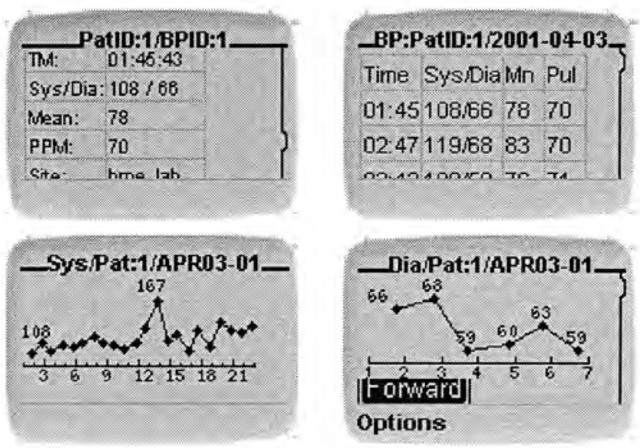


Figure 4.13: Display of blood pressure readings. Top-left: readings from a single blood pressure measurement; Top-right: readings within a day; Bottom-left: graphical display of systolic pressures within a day; Bottom-right: graphical display of diastolic pressures within six hours.

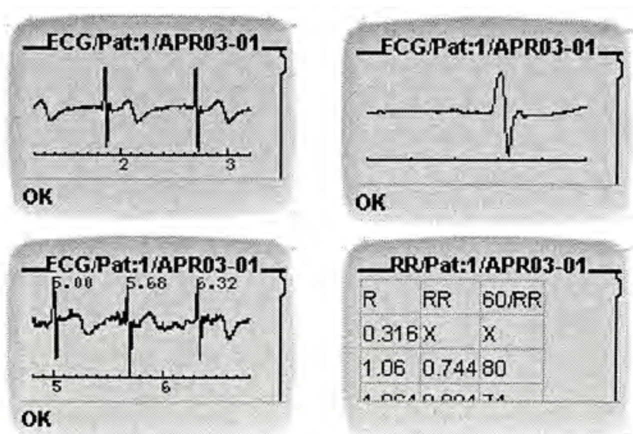


Figure 4.14: ECG browsing. Top-left: ECG browsing with a 2-sec window; Top-right: ECG browsing with a 0.5-sec window. Bottom-left; ECG browsing with estimated QRS occurrence times; Bottom-right: Chart for estimated QRS occurrence times and R-R intervals.

Figure 4.15: Display of patient general data

4.6 Experience with WAP Phone

An actual WAP phone compliant with WAP 1.1 was used at GSM 1800MHz through CSD to connect to the same WAP site. The gateway used in the link was provided by one of the mobile phone service providers in Hong Kong. The setup is shown in Figure 4.16. Figures 4.17 to 4.20 show some screenshots of the interfaces.

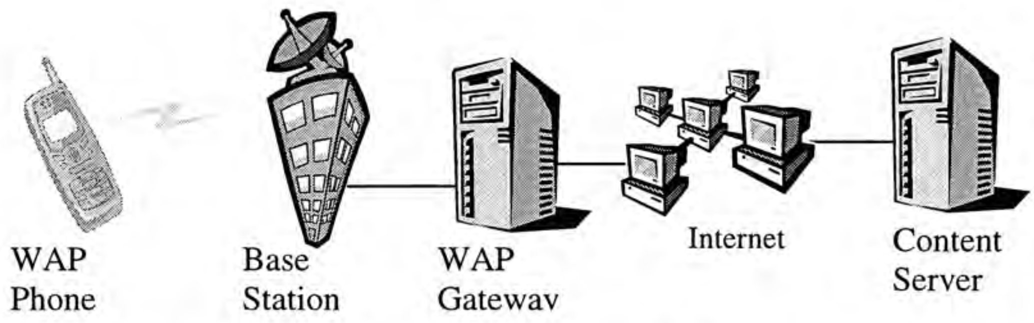


Figure 4.16: Setup for accessing WAP applications with WAP phone

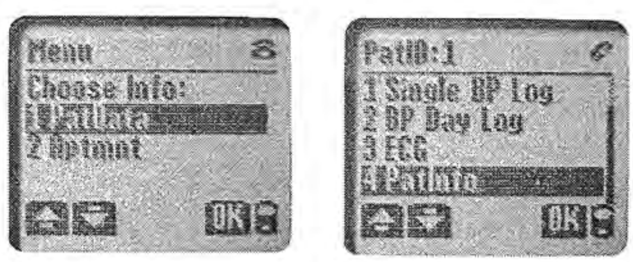


Figure 4.17: User menus

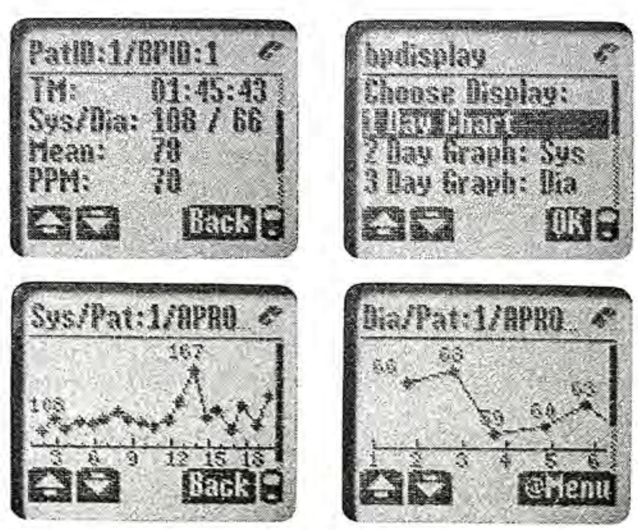


Figure 4.18: Display of blood pressure readings. Top-left: readings from a single blood pressure measurement; Top-right: BP menu; Bottom-left: graphical display of systolic pressures within a day; Bottom-right: graphical display of diastolic pressures within six hours.

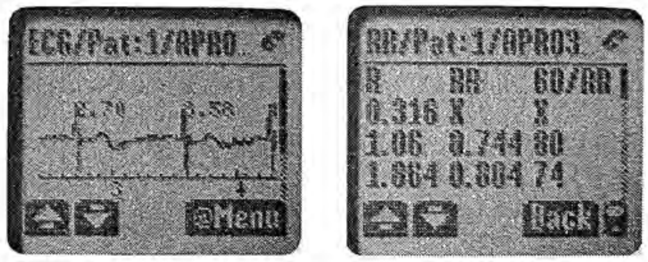


Figure 4.19: ECG browsing. Left: ECG browsing with estimated QRS occurrence times; Right: Chart for estimated QRS occurrence times and R-R intervals.

Figure 4.20: Display of patient general data

The time required to establish a connection to the site was about 10 to 12 seconds. Starting from the time of request for information at the phone, the time required for database query, dynamic generation of WML and WBMP, and display of new information at the device ranged from 3 to 5 seconds on average.

4.7 Discussion and Conclusion

Some WAP-based telemedicine applications have been demonstrated. Although response time was long, the feasibility of such a system is expected to improve in the future, as newer revisions of the WAP specification will be integrated into the third-generation mobile phone, which operates at a much higher data rate and has more on-board resources. Interactive feature extraction of the medical data has been demonstrated in a simple ECG analysis.

An issue of concern, as in all telemedicine applications, is security. The security features of a WAP-based system are implemented at several levels. WAP implements most of its security in WTLS (Wireless Transport Layer Security) protocol, which is the wireless equivalent of TLS (Transport Layer Security) protocol. The TLS uses a key-exchanging scheme, providing an end-to-end secure channel between a client and a server. All data is encrypted and cannot be decrypted by any intervening nodes.

The WTLS secure session is only between the phone and the WAP gateway, not between the phone and the content server. Data is only encrypted between the phone and the gateway, at which point it is decrypted by the gateway before being re-encrypted and sent on to the content server over a TLS connection over the Internet. The WAP gateway therefore has access to all of the data in decrypted form. Therefore, using a WAP gateway hosted by a third party is not recommended for telemedicine applications. The solution is to setup a private WAP gateway for the application. It is unlikely there will be significant changes to WTLS itself in the near future, largely because it is based on TLS, which is already a mature protocol

From WAP 1.2 and above, it will be possible to push content towards a WAP client without any request made by the client. WAP-based push services can use SMS or cell-broadcast as the bearer to transmit packets over the wireless network. Location-based push content is also possible. This will further enhance the feasibility of using WAP for patient monitoring. When a pathological abnormality is detected in the recorded data, the content server will be able to send a short message to the doctor or the patient's family.

Chapter 5: Conclusion and Future Work

5.1 Conclusion

A patient under ambulatory ECG monitoring is often exposed to many kinds of EMI, since he/she is mobile. As the usage of cellular phones in living and working environments is rapidly increasing, a major type of EMI that can contaminate the ECG is that from cellular phones. Noise would appear in the ECG as the high-frequency EMI is rectified in the circuit. There had been attempts by others in combating this problem with noise subtraction using identical acquisition circuits. This method faced the problem with component mismatch between the two channels and with the saturation of preamplifiers. EMI filters, specifically the 1nF C-filters had been used for preventing saturation. Installation of EMI filters had also been proven useful in ensuring proper function of implantable pacemakers and defribillators. However, there has been no comparative analysis on the effects of installing different EMI filters in the ECG acquisition circuit, subjected to HF EMI. This thesis has studied the performance of seven sets of EMI filters. Chapter 2 has shown that installing commercially available feedthrough EMI filters where the three ECG lead wires enter a shielding enclosure could reduce this noise considerably. The addition of the filters caused impedance imbalance between the two lead wires, so inclusion of a driven-right-leg circuit was recommended when EMI filters were used.

Noise still remained after the EMI filters were installed. Chapter 3 described how an LMS adaptive filter was used to reduce most the remaining noise successfully. The assumption that the noise in the contaminated ECG and the noise in the other identical channel being correlated to each other was valid. This solved the problem with component mismatch between the two circuits.

WAP, a new feature in mobile phones and PDA's, still has many unexplored applications. Chapter 4 has presented the implementation and usage of some new WAP-based telemedicine applications, including offline viewing and analysis of blood pressure values, heart rates, and ECG.

5.2 Future Work

The ultimate goal of the above areas of research is to integrate them, along with a telemetry link and a network connection between the computer terminal and content server, into a reliable ECG monitoring system. Such a system would consist of EMI filters installed at the ECG acquisition circuit. At the same time another circuit to capture a noise reference, as demonstrated in Chapter 3, would be added. The output of the two circuits is each followed by an analogue-to-digital converter (ADC). An adaptive filter implemented on a DSP chip then takes these two signals and performs further real-time noise reduction before sending the final output to the computer terminal through a telemetry link. From the computer terminal the data is relayed to a content server through network. This content server can then be accessed and analyzed remotely through WAP. The overall structure of a complete system is shown in Figure 5.1.

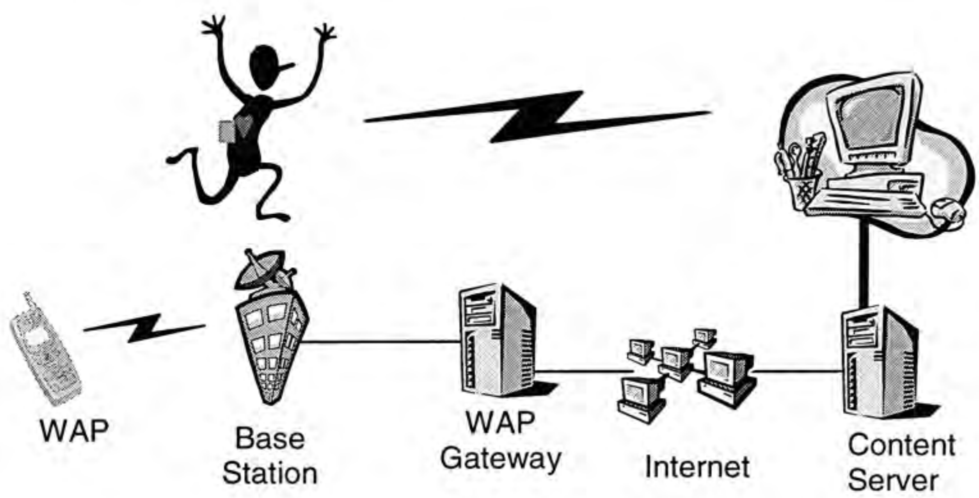


Fig 5.1: Complete telemedicine system

For the investigation of using EMI filters and adaptive filters in noise reduction, there still remains some unexplored areas. Future work should include testing with other kinds of EMI filters under interference from other types of mobile phones and radio communication units, testing of different adaptive algorithms, and trials with other types of EMI sensors.

WAP at this moment is still not fully mature. However, it will be a standard feature in future mobile communication devices, and newer versions of WAP are expected to emerge. WAP 1.2 will include 'push' services that would enable server-initiated messages that are automatically sent to the mobile device. This feature would be useful for a patient monitoring application, where an alarm can be sent out to a remote mobile device once a pathological symptom is detected.

Another part that needs to be developed for the complete system is the telemetry link for the transmission of ECG and other parameters. An option is to use Bluetooth. Bluetooth technology is an open specification for short-range (up to 100m), wireless voice and data communications, intended to replace all local data cables that are necessary today. It provides local wireless transmission of both voice and data, and is thus designed to unify devices by enabling all sorts of communications. Since this technology will be in almost all communication devices, it will eventually be used in telemedicine at low cost. Also, WAP is already one of the protocols mentioned in the Bluetooth specification.

The small size, low power consumption, and spread spectrum operation of the Bluetooth radio makes it an attractive option in portable monitoring devices. The feasibility of applying Blueooth in biomedical applications heavily depends on the data rate supported. Support for 64Kbps voice link and up to 723.2Kbps data link provides an adequate data rate for many biomedical signals, including ECG, PPG, heart and lung sounds, and low-resolution real-time images. Figure 5.2 shows the block diagram of wireless-ECG link with Bluetooth.

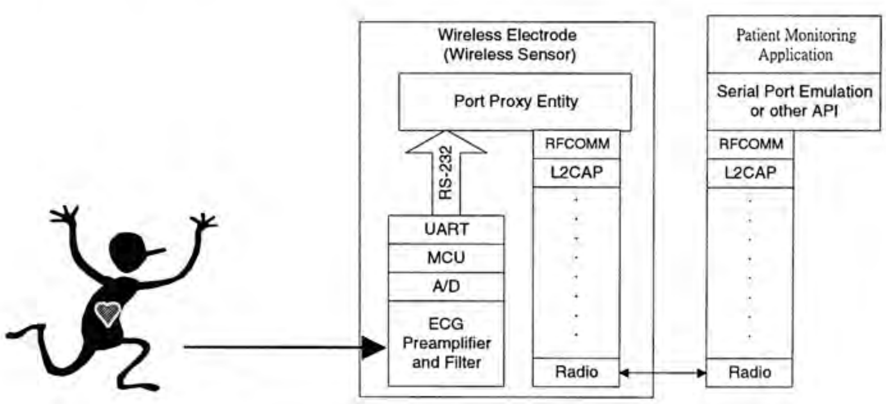


Fig. 5.2: Bluetooth in Wireless ECG

5.3 Market Analysis

The worldwide mobile phone market will continue to grow rapidly over the next few years, and it is expected that there will be 1.3 billion subscribers by 2004. More than 1.5 billion handsets, PDA's, and Internet appliances will have wireless capability by the end of 2004. Based on the 1999 statistics on deaths related to heart disease and the world population aged 60 or above, the immediate potential market of sales is estimated to be 765 million USD in ECG monitoring. These figures show that there is definitely a huge market for tele-ECG monitoring systems, and at the same time, mobile phone interference will be an increasing concern. According to this analysis, remote-monitoring systems will be beneficial and future work is warranted.

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Appendix A:

Demographic Data for Hong Kong and China

Age	Male	Female	Both Sexes
All ages	3,539,819	3,575,801	7,115,620
0- 4	217,137	192,396	409,533
5- 9	232,386	202,372	434,758
10-14	226,883	207,338	434,221
15-19	233,709	220,389	454,098
20-24	236,423	230,778	467,201
25-29	263,625	286,877	550,502
30-34	296,958	358,269	655,227
35-39	353,061	400,756	753,817
40-44	346,658	354,625	701,283
45-49	281,766	272,971	554,737
50-54	228,140	200,685	428,825
55-59	142,332	116,475	258,807
60-64	137,798	121,529	259,327
65-69	125,402	123,165	248,567
70-74	96,233	107,866	204,099
75-79	62,088	79,470	141,558
80-84	34,817	51,293	86,110
85+	24,403	48,547	72,950

Table A-1: Midyear Population, by Age and Sex: Hong Kong S.A.R., 2000
Source: U.S. Bureau of the Census, International Data Base

Age	Male	Female	Both Sexes
All ages	4,305,479	4,449,446	8,754,925
0- 4	198,137	186,077	384,214
5- 9	217,071	198,887	415,958
10-14	228,080	203,319	431,399
15-19	231,335	203,486	434,821
20-24	239,914	211,335	451,249
25-29	252,546	221,991	474,537
30-34	270,577	249,960	520,537
35-39	273,904	274,398	548,302
40-44	289,686	300,692	590,378
45-49	294,729	311,291	606,020
50-54	308,763	346,264	655,027
55-59	320,574	387,309	707,883
60-64	346,182	403,441	749,623
65-69	310,081	338,618	648,699
70-74	222,374	243,194	465,568
75-79	147,980	161,383	309,363
80-84	69,289	79,015	148,304
85+	84,257	128,786	213,043

Table A-2: Midyear Population, by Age and Sex: Hong Kong S.A.R., 2025
Source: U.S. Bureau of the Census, International Data Base

Age	Male	Female	Both Sexes
All ages	3,760,359	3,995,530	7,755,889
0- 4	154,664	145,961	300,625
5- 9	159,751	150,773	310,524
10-14	163,547	154,386	317,933
15-19	169,844	160,420	330,264
20-24	181,073	171,281	352,354
25-29	196,785	185,609	382,394
30-34	215,100	198,272	413,372
35-39	225,310	202,419	427,729
40-44	227,541	202,101	429,642
45-49	234,320	208,995	443,315
50-54	243,597	217,902	461,499
55-59	255,420	242,432	497,852
60-64	248,761	261,000	509,761
65-69	247,799	277,248	525,047
70-74	228,757	272,199	500,956
75-79	205,154	277,191	482,345
80-84	166,160	264,956	431,116
85+	236,776	402,385	639,161

Table A-3: Midyear Population, by Age and Sex: Hong Kong S.A.R., 2050
Source: U.S. Bureau of the Census, International Data Base

Age	Both Sexes	Male	Female
All ages	1,261,832,482	648,977,040	612,855,442
0- 4	97,525,616	51,081,799	46,443,817
5- 9	103,461,244	54,187,319	49,273,925
10-14	119,880,099	62,770,888	57,109,211
15-19	98,867,290	51,262,343	47,604,947
20-24	95,420,725	49,038,587	46,382,138
25-29	118,072,492	60,593,187	57,479,305
30-34	124,482,367	63,972,829	60,509,538
35-39	102,440,077	52,475,657	49,964,420
40-44	82,070,329	42,615,831	39,454,498
45-49	83,943,499	43,092,546	40,850,953
50-54	61,072,930	31,698,491	29,374,439
55-59	45,905,478	23,865,306	22,040,172
60-64	40,916,223	21,121,960	19,794,263
65-69	34,926,430	17,570,811	17,355,619
70-74	25,426,113	12,280,759	13,145,354
75-79	15,908,100	7,059,825	8,848,275
80-84	7,725,615	3,069,292	4,656,323
85+	3,787,855	1,219,610	2,568,245

Table A-4: Midyear Population, by Age and Sex: China, 2000
Source: U.S. Bureau of the Census, International Data Base

Age	Male	Female	Both sexes
All ages	741,373,752	722,655,108	1,464,028,860
0- 4	45,082,798	42,646,273	87,729,071
5- 9	46,388,436	43,706,176	90,094,612
10-14	45,372,072	42,362,026	87,734,098
15-19	46,445,816	43,022,646	89,468,462
20-24	49,743,258	45,801,537	95,544,795
25-29	49,604,944	45,543,646	95,148,590
30-34	52,376,433	48,203,363	100,579,796
35-39	60,361,782	55,656,459	116,018,241
40-44	48,774,211	46,076,763	94,850,974
45-49	46,439,916	44,725,369	91,165,285
50-54	56,866,477	55,093,291	111,959,768
55-59	58,302,706	57,114,036	115,416,742
60-64	45,298,751	45,911,785	91,210,536
65-69	33,027,040	34,214,521	67,241,561
70-74	28,490,434	32,291,384	60,781,818
75-79	15,963,354	19,531,445	35,494,799
80-84	7,828,185	10,980,547	18,808,732
85+	5,007,139	9,773,841	14,780,980

Table A-5: Midyear Population, by Age and Sex: China, 2025
Source: U.S. Bureau of the Census, International Data Base

Age	Male	Female	Both Sexes
All ages	733,803,162	736,665,762	1,470,468,924
0- 4	39,093,765	36,916,900	76,010,665
5- 9	39,379,135	37,196,856	76,575,991
10-14	39,953,445	37,755,364	77,708,809
15-19	41,282,218	39,046,561	80,328,779
20-24	42,725,905	40,505,706	83,231,611
25-29	44,540,557	42,361,748	86,902,305
30-34	45,639,029	43,319,346	88,958,375
35-39	44,374,888	41,827,353	86,202,241
40-44	45,199,059	42,307,409	87,506,468
45-49	48,196,320	44,849,857	93,046,177
50-54	47,551,760	44,262,000	91,813,760
55-59	49,015,150	46,216,605	95,231,755
60-64	54,070,855	52,176,200	106,247,055
65-69	40,531,884	41,521,754	82,053,638
70-74	34,056,459	37,569,057	71,625,516
75-79	33,871,473	40,867,520	74,738,993
80-84	25,510,820	34,528,954	60,039,774
85+	18,810,440	33,436,572	52,247,012

Table A-6: Midyear Population, by Age and Sex: China, 2050
Source: U.S. Bureau of the Census, International Data Base

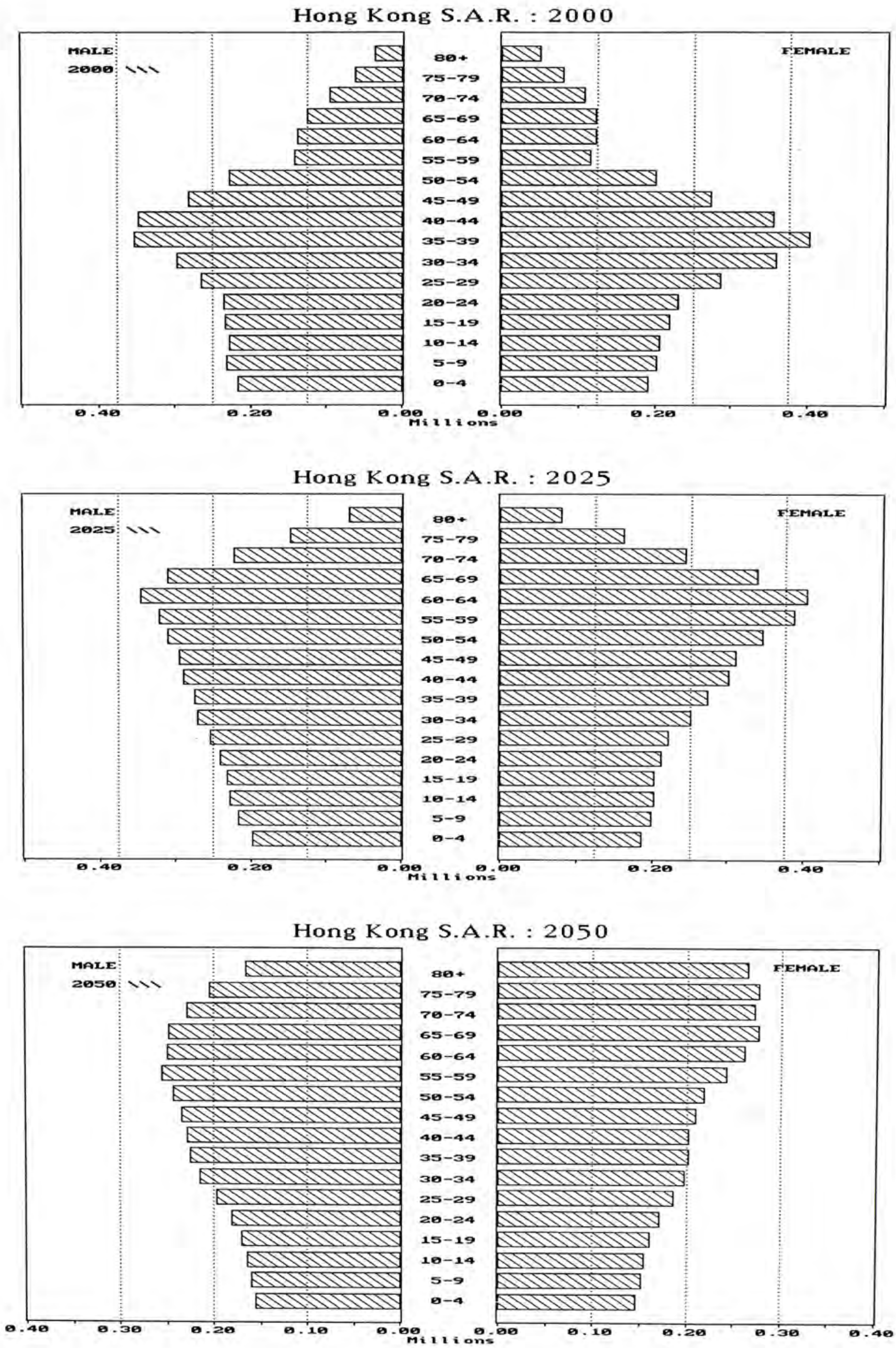

Figure A-1: Midyear Population, by Age and Sex: Hong Kong S.A.R., 2000, 2025, 2050
Source: U.S. Bureau of the Census, International Data Base

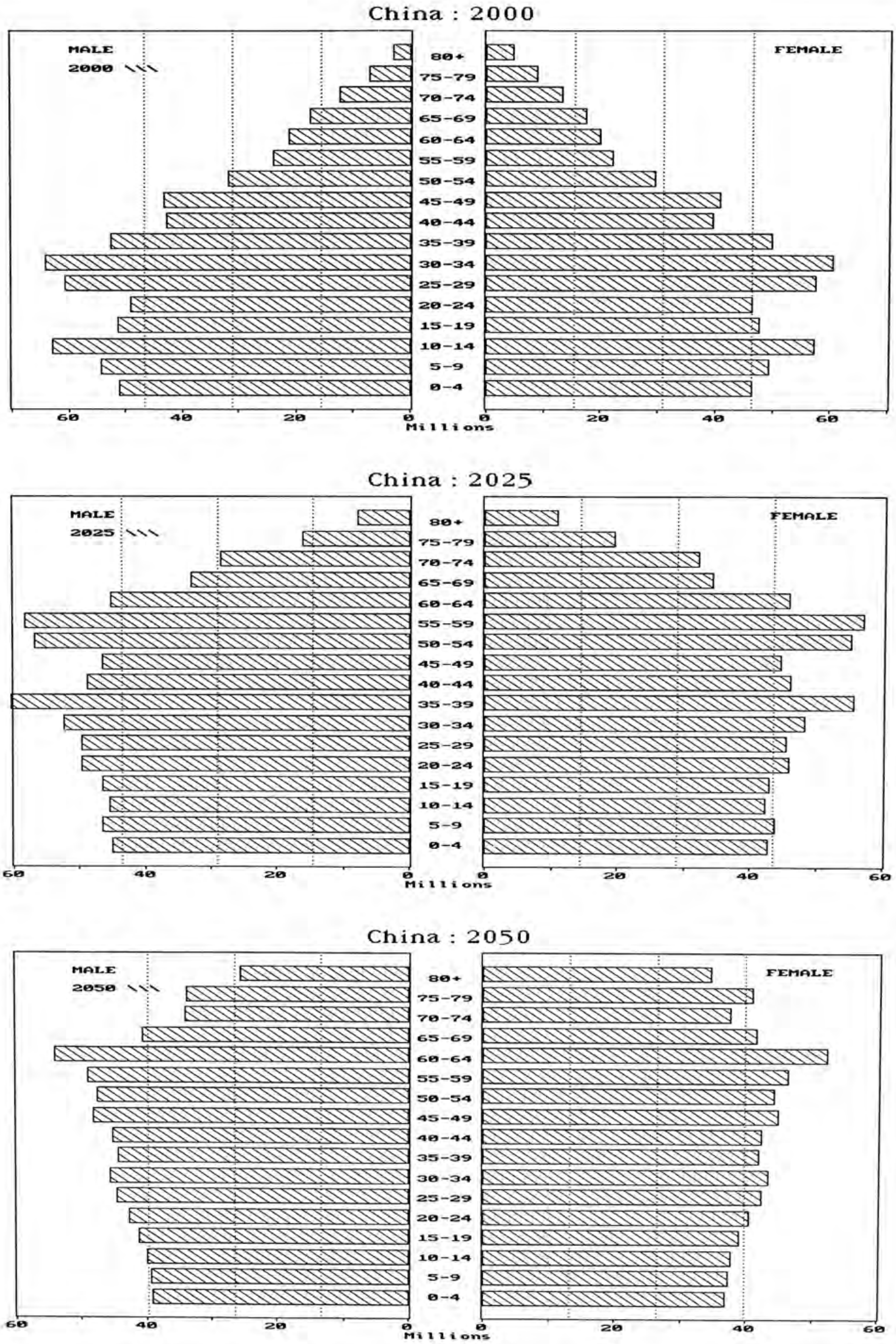

Figure A-2: Midyear Population, by Age and Sex: China, 2000, 2025, 2050
Source: U.S. Bureau of the Census, International Data Base

Appendix B:

Visual Basic Code for LMS Adaptive Filter

```
'***************************************************
'ADAPTIVE FILTER STARTS HERE

A = 0
Y = 0


For k = 1 To N - 1          'FOR 1; for the entire length N of the data

   A = Y

   For S = m To 2 Step -1   'shift the data in the x vector
      x(S) = x(S - 1)
   Next

   x(1) = Dref(k)            'load the next element of the reference into x vector

   D = Draw(k)               'get the next element of the raw signal

   Y = 0                    'reset output of adaptive filter to 0

   For f = 1 To m           'for the entire filter length M, update Y, which is
      Y = Y + x(f) * w(f)   'the output of the adaptive filter
   Next
                            'error is newest raw signal element minus Y, the
                            'output of the adaptive filter
   err(k) = D - Y
   noise(k) = Y              'this error is also the newest estimated noise

                            'update the weights for the entire lenght m of the filter

   For T = 1 To m
      wtemp(T) = w(T) + 2 * u * err(k) * x(T)
      w(T) = wtemp(T)
   Next

Next
                            'FOR 1
```

Appendix C:

WML and Perl Programming Codes

****
*

Filename: login.wml
Function: Login card; take username and password from user

```
<?xml version="1.0"?>
<!DOCTYPE wml PUBLIC "-//WAPFORUM//DTD 1.1//EN" "http://www.wapforum.org/DTD/wml_1.1.xml">
<wml>

<card id="login1" newcontext = "true" title="LOGIN">
      <onevent type="ontimer">
            <go href="#login2"/>
      </onevent>
      <timer value="30"/>
<p align="center">
<img align="top" src="icon.wbmp" alt="Login.." height="60" width="60" hspace="0" vspace="0"/>
</p>
</card>

<card id="login2" newcontext = "true" title="LOGIN">
<do type="accept">
            <go href="http://bme.tsimtung.com/cgi-bin/pre_telemon.cgi" method="post">
                        <postfield name = "name" value = "$user"/>
                        <postfield name = "pswd" value = "$pswd"/>
            </go>
</do>

<p align="center">

            <fieldset title="Login">
                        Usrid:
                        <input name = "user" maxlength = "8" emptyok = "false" /> <br/>
                        Pswd:
                        <input name = "pswd" maxlength = "8" type = "password" emptyok = "false" /> <br/>
            </fieldset>

</p>
</card>

</wml>
```

****
*

Filename: login2.wml
Function: Login card for clinic and hospital information

```
<?xml version="1.0"?>
<!DOCTYPE wml PUBLIC "-//WAPFORUM//DTD 1.1//EN" "http://www.wapforum.org/DTD/wml_1.1.xml">
<wml>

<card id="login1" newcontext = "true" title="LOGIN">
      <onevent type="ontimer">
            <go href="#login2"/>
      </onevent>
      <timer value="20"/>
<p align="center">
<img align="top" src="icon.wbmp" alt="Login.." height="60" width="60" hspace="0" vspace="0"/>
</p>
</card>

<card id="login2" newcontext = "true" title="Info">
<do type="accept">
            <go href="http://bme.tsimtung.com/cgi-bin/telemon2.cgi" method="post">
                        <postfield name = "info_type" value = "$info_type"/>
            </go>
</do>

<p align="center">
            Option:
            <br/>
            <select name = "info_type">
```

```
                    <option value = "clinic">Clinic</option>
                    <option value = "hospital">Hospial</option>
          </select>
</p>
</card>
</wml>
```

****
*

Filename: bp.cgi

Function: Display list of accessible single blood pressure readings; user chooses the session

```
#!/usr/bin/perl -w

use CGI qw(:standard);
use DBI;

my $cgi=new CGI;

my $b_patient_id = param('patient_id');
my $b_viewer_access = param('viewer_access');
my $b_viewer_id = param('viewer_id');

print "content-type:text/vnd.wap.wml\n\n";
print '<?xml version="1.0"?>';
print '<!DOCTYPE wml PUBLIC "-//WAPFORUM//DTD WML 1.1//EN"
    "http://www.wapforum.org/DTD/wml_1.1.xml">';

print "<wml>";
print '<card id="bp_menu" title="BP:PatID:';
print $b_patient_id;
print '">';

$DSN = "DBI:mysql:database=busybear";
my $dbh = DBI->connect($DSN, "busybear", "6282bear")
or die "Error connection to database";

my $sth = $dbh->prepare("SELECT re_bp_id FROM bp_re WHERE
            re_bp_pat_id='$b_patient_id'");
$sth->execute();

my @ary = $sth->fetchrow_array();

if (!defined $ary[0]) {
        print "<p>0 Rec</p>";
        $sth->finish;
        $dbh->disconnect;
        print "</card>";
        print "</wml>";

} #if no bp data exists for this patient

else {
    #else bp data exists for this patient
    #now look in table BP for an index of these BP data

        $sth->finish;

    print '<do type="accept">';
    print       '<go href="http://bme.tsimtung.com/cgi-bin/view_bp.cgi" method="post">';
    print           '<postfield name = "patient_id" value = "';
        print                   $b_patient_id;
        print                   '"/>';
    print           '<postfield name = "viewer_access" value ="';
    print           $b_viewer_access;
    print           '"/>';
    print           '<postfield name = "viewer_id" value = "';
    print           $b_viewer_id;
    print           '"/>';
    print           '<postfield name = "bp_id" value = "$bp_id"/>';
    print       '</go>';
    print '</do>';
```

```
#          print "<p>";
#       print  '<fieldset title = "b_pat_int">';
#       print  '<small>Enter BPID:</small>';
#       print  '<input name = "bp_id" maxlength = "8" format="*N" emptyok = "false"/>';
#       print  '</fieldset>';
#       print "</p>";

        my $sth = $dbh->prepare("SELECT * FROM bp AS B,
                        bp_re AS R WHERE
                        R.re_bp_pat_id='$b_patient_id' AND
                        B.bp_id = R.re_bp_id");
        $sth->execute();

            print '<p>';

        print  '<fieldset title = "b_pat_int">';
        print  '<small>Enter BPID:</small>';
        print  '<input name = "bp_id" maxlength = "8" format="*N" emptyok = "false"/>';
        print  '</fieldset>';

            print '<small>';
            print '<table columns = "3">';
        print "<tr>";
        print "<td><small>BP</small></td>";
            print "<td><small>Tm</small></td>";
            print "<td><small>Dt</small></td>";
            print "</tr>";

            while (my $ref = $sth->fetchrow_hashref()){
                    print "<tr>";
            print "<td><small> $ref->{'bp_id'} </small></td>";
            print "<td><small>";
                    print substr($ref->{'bp_time'},0,5);
                    print "</small></td>";
            print "<td><small> $ref->{'bp_date'} </small></td>";
            print "</tr>";
            } #while

            $sth->finish;

            print "</table>";
            print "</small>";

#       print  '<fieldset title = "b_pat_int">';
#       print  '<small>Enter BPID:</small>';
#       print  '<input name = "bp_id" maxlength = "8" format="*N" emptyok = "false"/>';
#       print  '</fieldset>';
        print "</p>";

            print '</card>';
            print '</wml>';

            $dbh->disconnect;

} #else data exists for this patient

exit;
```

****
*

Filename: view_bp.cgi
Function: Display chart for single blood pressure reading

```
#!/usr/bin/perl -w

use CGI qw(:standard);
use DBI;

my $cgi=new CGI;

my $b_bp_id = param('bp_id');
my $b_patient_id = param('patient_id');
```

```
my $b_viewer_access = param ('viewer_access');
my $b_viewer_id = param('viewer_id');

print "content-type:text/vnd.wap.wml\n\n";
print '<?xml version="1.0"?>';
print '<!DOCTYPE wml PUBLIC "-//WAPFORUM//DTD WML 1.1//EN"
      "http://www.wapforum.org/DTD/wml_1.1.xml">';

my $found_err = 0;

if ($b_bp_id eq "") {
      $found_err = 1;
}

if ($found_err == 0) {
      #case for non-empty input

      $DSN = "DBI:mysql:database=busybear";
      my $dbh = DBI->connect($DSN, "busybear", "6282bear")
      or die "Error connection to database";

            #check if the entered BP_ID corresponds to the PATIENT ID
      my $sth = $dbh->prepare("SELECT * FROM bp_re WHERE re_bp_id = '$b_bp_id'");
      $sth->execute();

      my @ary = $sth->fetchrow_array();
      $sth->finish;
      $dbh->disconnect;

            if (!defined $ary[0]) {
            #if the entered BP_ID is not associated with the PATIENT ID
            print "<wml>";
            print '<card id="non_exist" title="Attn">';
            print '<onevent type = "ontimer">';
            print          '<go href = "http://bme.tsimtung.com/login.wml"/>';
            print '</onevent>';
            print '<timer value = "5"/>';
            print '<p>';
            print "Invalid BP_ID";
            print '</p>';
            print "</card>";
            print "</wml>";

                        exit;
            }

            else {
              #case where the entered BP_ID is associated with the PATIENT ID
              #show the BP data

                        $DSN = "DBI:mysql:database=busybear";
            my $dbh = DBI->connect($DSN, "busybear", "6282bear")
            or die "Error connection to database";

            my $sth = $dbh->prepare("SELECT * FROM bp WHERE bp_id = '$b_bp_id'");
            $sth->execute();

            my @ary = $sth->fetchrow_array();
            $sth->finish;
            $dbh->disconnect;

                        print "<wml>";
                        print '<card id="view_bp" title="PatID:';
                        print $b_patient_id;
                        print '/BPID:';
                        print $ary[0];
                        print'">';
            print '<p>';
                        print '<small>';
                        print '<table columns = "2">';

            print "<tr>";
            print "<td><small>DT:</small></td>";
            print "<td><small>";
            print $ary[7];
```

```
            print "</small></td>";
            print "</tr>";

            print "<tr>";
            print "<td><small>TM:</small></td>";
            print "<td><small>";
            print $ary[1];
            print "</small></td>";
            print "</tr>";

            print "<tr>";
            print "<td><small>Sys/Dia:</small></td>";
            print "<td><small>";
            print $ary[2];
                        print ' / ';
                        print $ary[3];
            print "</small></td>";
            print "</tr>";

            print "<tr>";
            print "<td><small>Mean:</small></td>";
            print "<td><small>";
            print $ary[4];
            print "</small></td>";
            print "</tr>";

            print "<tr>";
            print "<td><small>PPM:</small></td>";
            print "<td><small>";
            print $ary[5];
            print "</small></td>";
            print "</tr>";

            print "<tr>";
            print "<td><small>Site:</small></td>";
            print "<td><small>";
            print $ary[6];
            print "</small></td>";
            print "</tr>";

                        print "</table>";
                        print "</small>";
                        print "</p>";

                        print "</card>";
                        print "</wml>";
            exit;

            } #case where the entered BP_ID is associated with the PATIENT ID

} #if input of patient_id not empty

else {
#case for empty input for patient_id

            print "<wml>";
       print '<card id="non_exist" title="Attn">';
       print '<onevent type = "ontimer">';
       print        '<go href = "http://bme.tsimtung.com/login.wml"/>';
       print '</onevent>';
       print '<timer value = "5"/>';
       print '<p>';
       print "BP ID not filled in";
       print '</p>';
       print "</card>";
       print "</wml>";
       exit;
}
```

****
*

Filename: bp_day.cgi

Function: Display list of accessible day log of blood pressure readings; user chooses the date

```
#!/usr/bin/perl -w

use CGI qw(:standard);
use DBI;

my $cgi=new CGI;

my $b_patient_id = param('patient_id');
my $b_viewer_access = param('viewer_access');
my $b_viewer_id = param('viewer_id');

print "content-type:text/vnd.wap.wml\n\n";
print '<?xml version="1.0"?>';
print '<!DOCTYPE wml PUBLIC "-//WAPFORUM//DTD WML 1.1//EN"
      "http://www.wapforum.org/DTD/wml_1.1.xml">';

print "<wml>";
print '<card id="bp_menu" title="BP:PatID:';
print $b_patient_id;
print '">';

$DSN = "DBI:mysql:database=busybear";
my $dbh = DBI->connect($DSN, "busybear", "6282bear")
or die "Error connection to database";

my $sth = $dbh->prepare("SELECT re_bp_id FROM bp_re WHERE
                re_bp_pat_id='$b_patient_id'");
$sth->execute();

my @ary = $sth->fetchrow_array();

if (!defined $ary[0]) {
        print "<p>0 Rec</p>";
        $sth->finish;
        $dbh->disconnect;
        print "</card>";
        print "</wml>";

} #if no bp data exists for this patient

else {
    #else bp data exists for this patient
    #now look in table BP for dates of these BP data

        $sth->finish;

    print '<do type="accept">';
    print       '<go href="http://bme.tsimtung.com/cgi-bin/trans_bp_day.cgi" method="post">';
    print           '<postfield name = "patient_id" value = "';
        print                       $b_patient_id;
        print                       '"/>';
    print           '<postfield name = "viewer_access" value ="';
    print           $b_viewer_access;
    print           '"/>';
    print           '<postfield name = "viewer_id" value = "';
    print           $b_viewer_id;
    print           '"/>';
    print           '<postfield name = "bp_date" value = "$bp_date"/>';
    print       '</go>';
    print '</do>';

#       print "<p>";
#   print '<fieldset title = "b_pat_int">';
#   print '<small>Date:</small>';
#   print '<input name = "bp_date" format="NNNN\-NN\-NN" emptyok = "false"/>';
#   print '</fieldset>';
#   print "</p>";

    my $sth = $dbh->prepare("SELECT bp_date, COUNT(*) AS num FROM bp AS B,
                bp_re AS R WHERE
                R.re_bp_pat_id='$b_patient_id' AND
```

```
			B.bp_id = R.re_bp_id GROUP BY B.bp_date");
		$sth->execute();

		print '<p>';
		print '<small>';
		print '<table columns = "2">';
	print "<tr>";
	print "<td>Date</td>";
		print "<td>Recs</td>";
		print "</tr>";

	while (my $ref = $sth->fetchrow_hashref()){
		print "<tr>";
		print "<td> $ref->{'bp_date'}</td>";
		print "<td> $ref->{'num'} </td>";
		print "</tr>";
	} #while

		$sth->finish;

		print "</table>";
		print "</small>";
		print '</p>';

		print "<p>";
	print  '<fieldset title = "b_pat_int">';
	print  '<small>Date:</small>';
	print  '<input name = "bp_date" format="NNNN\-NN\-NN" emptyok = "false"/>';
	print  '</fieldset>';
	print "</p>";

		print '</card>';
		print '</wml>';

		$dbh->disconnect;

} #else data exists for this patient

exit;
```

****
*

Filename: trans_bp_day.cgi
Function: Display menu; Choice:

1. **Blood pressure day chart**
2. **Day graph: systolic**
3. **Day graph: diastolic**
4. **Day graph: mean**
5. **Scrollable day graph: systolic**
6. **Scrollable day graph: diastolic**
7. **Scrollable day graph: mean**

```
#!/usr/bin/perl -w

use CGI qw(:standard);
use DBI;

my $cgi=new CGI;

my $bp_date = param('bp_date');
my $patient_id = param('patient_id');
my $viewer_access = param ('viewer_access');
my $viewer_id = param('viewer_id');

print "content-type:text/vnd.wap.wml\n\n";
print '<?xml version="1.0"?>';
print '<!DOCTYPE wml PUBLIC "-//WAPFORUM//DTD WML 1.1//EN"
	"http://www.wapforum.org/DTD/wml_1.1.xml">';

my $found_err = 0;
```

```
if ($bp_date eq "") {
      $found_err = 1;
}

if ($found_err == 0) {
      #case for non-empty input

      $DSN = "DBI:mysql:database=busybear";
      my $dbh = DBI->connect($DSN, "busybear", "6282bear")
      or die "Error connection to database";

            #check if the entered BP date corresponds to the PATIENT ID
      my $sth = $dbh->prepare("SELECT * FROM bp AS B, bp_re AS R WHERE B.bp_date = '$bp_date' AND
                                                            R.re_bp_pat_id = '$patient_id'");
      $sth->execute();

      my @ary = $sth->fetchrow_array();

            $sth->finish;
      $dbh->disconnect;

            if (!defined $ary[0]) {
            #if the entered BP date is not associated with the PATIENT ID
            print "<wml>";
            print '<card id="non_exist" title="Attn">';
            print '<onevent type = "ontimer">';
            print           '<go href = "http://bme.tsimtung.com/login.wml"/>';
            print '</onevent>';
            print '<timer value = "5"/>';
            print '<p>';
            print "Invalid date";
            print '</p>';
            print "</card>";
            print "</wml>";

                        exit;
            }

            else {
              #case where the entered BP date is associated with the PATIENT ID
              #user can selec to show the day BP data either in chart or graph

                        print "<wml>";
                        print '<card id="view_bp" title="bpdisplay">';

            print '<do type = "accept">';
            print   '<go href="http://bme.tsimtung.com/cgi-bin/view_bp_day.cgi" method="post">';

            print   '<postfield name="b_req_type" value="$b_req_type"/>';
            print   '<postfield name="patient_id" value="';
            print   $patient_id;
            print   '"/>';
            print   '<postfield name="viewer_access" value="';
            print   $viewer_access;
            print   '"/>';
            print   '<postfield name="viewer_id" value="';
            print   $viewer_id;
            print   '"/>';
            print   '<postfield name="bp_date" value="';
            print   $bp_date;
            print   '"/>';
            print   '<postfield name="scr_dir" value="';
            print   0;
            print   '"/>';
            print   '<postfield name="index" value="';
            print   0;
            print   '"/>';
            print   '<postfield name="fresh_wbmp" value="';
            print   0;
            print   '"/>';

            print   '</go>';
            print '</do>';
```

```
                print "<p>";

        print 'Choose Display:';
        print '<select name="';
        print 'b_req_type';
        print '">';
        print '<option value="chart">Day Chart</option>';
        print '<option value="graph_sys">Day Graph: Sys</option>';
        print '<option value="graph_dia">Day Graph: Dia</option>';
        print '<option value="graph_mean">Day Graph: Mean</option>';
        print '<option value="graph_scr_sys">Scroll Graph: Sys</option>';
                print '<option value="graph_scr_dia">Scroll Graph: Dia</option>';
                print '<option value="graph_scr_mean">Scroll Graph: Mean</option>';
                print '</select>';
                print "</p>";
                print "</card>";
                print "</wml>";
        exit;

        } #case where the entered BP_ID is associated with the PATIENT ID

} #if input of patient_id not empty

else {
#case for empty input for bp_date

        print "<wml>";
    print '<card id="non_exist" title="Attn">';
    print '<onevent type = "ontimer">';
    print       '<go href = "http://bme.tsimtung.com/login.wml"/>';
    print '</onevent>';
    print '<timer value = "5"/>';
    print '<p>';
    print "BP Date not filled in";
    print '</p>';
    print "</card>";
    print "</wml>";
    exit;
}
```

****
*

Filename: view_bp_day.cgi
Function: Display the day's blood pressure in graph of chart form

```
#!/usr/bin/perl -w

use CGI qw(:standard);
use GD;
use DBI;

my $cgi=new CGI;

my $b_patient_id = param('patient_id');
my $b_viewer_access = param('viewer_access');
my $b_viewer_id = param('viewer_id');
my $b_bp_date = param('bp_date');
my $b_req_type = param('b_req_type');
my $b_scr_dir = param('scr_dir');
my $b_index = param('index');
my $b_fresh_wbmp = param('fresh_wbmp');

if ($b_req_type eq "chart") {

        print "content-type:text/vnd.wap.wml\n\n";
        print '<?xml version="1.0"?>';
        print '<!DOCTYPE wml PUBLIC "-//WAPFORUM//DTD WML 1.1//EN"
                "http://www.wapforum.org/DTD/wml_1.1.xml">';

        print "<wml>";
        print '<card id="bp_menu" newcontext="true" title="BP:PatID:';
        print $b_patient_id;
        print '/';
```

```
            print $b_bp_date;
            print '">';

            $DSN = "DBI:mysql:database=busybear";
            my $dbh = DBI->connect($DSN, "busybear", "6282bear")
            or die "Error connection to database";

        my $sth = $dbh->prepare("SELECT *  FROM bp AS B,
                        bp_re AS R WHERE
                        R.re_bp_pat_id='$b_patient_id' AND
                        B.bp_id = R.re_bp_id AND B.bp_date = '$b_bp_date'");

            $sth->execute();

            print '<p>';
            print '<small>';
            print '<table columns = "4">';
        print "<tr>";
        print "<td>Time</td>";
            print "<td>Sys/Dia</td>";
            print "<td>Mn</td>";
            print "<td>Pul</td>";
            print "</tr>";

            while (my $ref = $sth->fetchrow_hashref()){
                        print "<tr>";
                        print "<td>";
                        print substr($ref->{'bp_time'},0,5);
                        print "</td>";
            print "<td>";
                        print $ref->{'sys_pr'};
                        print "/";
                        print $ref->{'dia_pr'};
                        print "</td>";
                        print "<td>";
                        print $ref->{'mean_pr'};
                        print "</td>";
            print "<td>";
                        print $ref->{'bp_pulse'};
                        print "</td>";
                        print "</tr>";

            } #while

            $sth->finish;

            print "</table>";
            print "</small>";

            print '</p>';
            print '</card>';
            print '</wml>';

            $dbh->disconnect;
            exit;

} #for showing the day bp in chart form

##################################################

if (($b_req_type eq "graph_sys") || ($b_req_type eq "graph_dia") || ($b_req_type eq "graph_mean")) {

    #show the entire day bp in graph form

        $DSN = "DBI:mysql:database=busybear";
        my $dbh = DBI->connect($DSN, "busybear", "6282bear")
        or die "Error connection to database";

        my $sth = $dbh->prepare("SELECT *  FROM bp AS B,
                        bp_re AS R WHERE
                        R.re_bp_pat_id='$b_patient_id' AND
                        B.bp_id = R.re_bp_id AND B.bp_date = '$b_bp_date'");

        $sth->execute();
```

```
        my $i=0;
        my @xdata;
        my @ydata;

        my $pr_type;
        my $pr_disp;

        if ($b_req_type eq "graph_sys") {
                $pr_type = 'sys_pr';
                $pr_disp = 'Sys';
        }
        elsif ($b_req_type eq "graph_dia") {
                $pr_type = 'dia_pr';
                $pr_disp = 'Dia';
        }
        elsif ($b_req_type eq "graph_mean") {
                $pr_type = 'mean_pr';
                $pr_disp = 'Mean';
        }

    while (my $ref = $sth->fetchrow_hashref()){

        $xdata[$i] = $ref->{'bp_time'};
                $ydata[$i] = $ref->{$pr_type};

                $i++;

    } #while

        $sth->finish;
        $dbh->disconnect;

        my $im = new GD::Image(120,50);
        my $white = $im->colorAllocate(255,255,255);
        my $black = $im->colorAllocate(0,0,0);

        my $max_y = 50;
        my $max_x = 120;
        my $max_time = 1440;

        for ($i = 0; $i <= ($#xdata); $i++){

        $xdata[$i] = 600*substr($xdata[$i],0,1) + 60*substr($xdata[$i],1,1) +
                10*substr($xdata[$i],3,1) + substr($xdata[$i],4,1);
        }

        my @ordered_x = sort {$a <=> $b} @xdata;
        my $min_x_data = $ordered_x[0];
        my $max_x_data = $ordered_x[$#ordered_x];

        my $x_factor =  (($max_x-15) / abs($max_x_data - $min_x_data));

        my @ordered_y = sort {$a <=> $b} @ydata;
        my $min_y_data = $ordered_y[0];
        my $max_y_data = $ordered_y[$#ordered_y];

        my $y_factor =  (($max_y-25) / abs($max_y_data - $min_y_data));

        for ($i = 0; $i <= ($#xdata); $i++){

        if ($i == 0) {
        #if it's the first point of the plot
                $im->arc(5, int ($max_y - $y_factor*($ydata[0]-$min_y_data) - 14  ), 5, 5, 0,
                        360, $black);

                        if (($ydata[0] == $max_y_data) || ($ydata[0] == $min_y_data)) {
                        #if this first point is the max or min value of the whole day
                        #then print out value on top of this point

                        $im->string(gdTinyFont, 0, int ($max_y -
                $y_factor*($ydata[$i]-$min_y_data) - 28 ), $ydata[0],
$black);

                        } #if
                }
```

```
        else {
        $im->line(int ($x_factor* ($xdata[$i-1] - $xdata[0]) +5 ), int($max_y -
                 ($y_factor*($ydata[$i-1]-$min_y_data ) ) -14 ),
        int ($x_factor* ($xdata[$i] - $xdata[0]) +5), int ($max_y -
                 ($y_factor*($ydata[$i]-$min_y_data )) -14 ), $black);

        $im->arc(int ( $x_factor*($xdata[$i]-$xdata[0]) +5 ), int ($max_y -
        $y_factor*($ydata[$i]-$min_y_data) -14 ), 5, 5, 0, 360, $black);

    if (($ydata[$i] == $max_y_data) || ($ydata[$i] == $min_y_data)) {
    #if this point is the max or min value of the whole day
    #then print out value on top of this point

        $im->string(gdTinyFont, int ( $x_factor*($xdata[$i]-$xdata[0]) -5 ),
                            int ($max_y - $y_factor*($ydata[$i]-$min_y_data) - 25 ),
                                      $ydata[$i],$black);
                 } #if
        } #else

} #for loop

#this part is to draw the scale for x (time)

my $scale_min = (int ($min_x_data/60) )*60;

my $scale_max = (int ($max_x_data/60)+1)*60;


$im->line(int $x_factor*($scale_min-$xdata[0])+5, $max_y-8,
int $x_factor*($scale_max-$xdata[0])+5, $max_y-8, $black);

my $t = $scale_min;

while ($t <= $scale_max) {
$im->line(int ($x_factor*($t-$xdata[0])+5), $max_y-8,
        int ($x_factor*($t-$xdata[0])+5), $max_y-9, $black);

if ( ($#xdata < 9) ||
( ( ($t/60) % 2 == 0) && ($#xdata<17) && ($#xdata>=9) ) ||
( ( ($t/60) %3 == 0) && ($#xdata>=17) )
                  )

{
$im->string(gdTinyFont, int ($x_factor*($t-$xdata[0])+3 ),
                           $max_y-7,
        ($t/60), $black);

$im->line(int ($x_factor*($t-$xdata[0])+5), $max_y-9,
        int ($x_factor*($t-$xdata[0])+5), $max_y-11, $black);
}
    else {}

        $t = $t + 60;

} #while loop for constructing x scale

$filename = bp_.$b_viewer_access.$b_viewer_id;

open(FILE1,">$filename.wbmp") or die "Can't find file\n";
binmode FILE1;
print FILE1 $im->wbmp($black);
close FILE1;

system "chmod 0755 '$filename'.wbmp";

print "content-type:text/vnd.wap.wml\n\n";
print '<?xml version="1.0"?>';
print '<!DOCTYPE wml PUBLIC "-//WAPFORUM//DTD WML 1.1//EN"
"http://www.wapforum.org/DTD/wml_1.1.xml">';

print "<wml>";
print '<card id="bp_menu" newcontext="true" title="';
    print $pr_disp;
    print '/';
```

```
        print 'Pat:';
    print $b_patient_id;
    print '/';


        my $mon = "";

        if (substr($b_bp_date,5,2) eq '01') {
                $mon = 'JAN';
        }
    elsif (substr($b_bp_date,5,2) eq '02') {
        $mon = 'FEB';
    }
    elsif (substr($b_bp_date,5,2) eq '03') {
        $mon = 'MAR';
    }
    elsif (substr($b_bp_date,5,2) eq '04') {
        $mon = 'APR';
        }
    elsif (substr($b_bp_date,5,2) eq '05') {
        $mon = 'MAY';
    }
    elsif (substr($b_bp_date,5,2) eq '06') {
        $mon = 'JUN';
    }
        elsif (substr($b_bp_date,5,2) eq '07') {
        $mon = 'JUL';
    }
    elsif (substr($b_bp_date,5,2) eq '08') {
        $mon = 'AUG';
    }
    elsif (substr($b_bp_date,5,2) eq '09') {
        $mon = 'SEP';
    }
    elsif (substr($b_bp_date,5,2) eq '10') {
        $mon = 'OCT';
    }
    elsif (substr($b_bp_date,5,2) eq '11') {
        $mon = 'NOV';
    }
    elsif (substr($b_bp_date,5,2) eq '12') {
        $mon = 'DEC';
    }

    print $mon;
        print substr($b_bp_date,8,2);
        print '-';
        print substr($b_bp_date,2,2);
    print '">';

        print '<p>';
        print '<img  alt="Loading.." src="';
        print $filename;
        print '.wbmp" vspace="0" hspace="0"/>';
        print '</p>';

        print "</card>";
        print "</wml>";

        exit;

} #show day bp in graph form


##################################################

if (($b_req_type eq "graph_scr_sys") || ($b_req_type eq "graph_scr_dia") ||($b_req_type eq
            "graph_scr_mean")) {

#this part is for viewing the day bp in a scrollable graphical form
#First show values of the first 6 values


    $DSN = "DBI:mysql:database=busybear";
    my $dbh = DBI->connect($DSN, "busybear", "6282bear")
```

```
or die "Error connection to database";

my $sth = $dbh->prepare("SELECT *  FROM bp AS B,
                 bp_re AS R WHERE
                 R.re_bp_pat_id='$b_patient_id' AND
                 B.bp_id = R.re_bp_id AND B.bp_date = '$b_bp_date'");

$sth->execute();

my $i=0;
my @xdata;
my @ydata;

my $pr_type;
      my $pr_disp;


if ($b_req_type eq "graph_scr_sys") {
      $pr_type = 'sys_pr';
      $pr_disp = 'Sys';
      }
elsif ($b_req_type eq "graph_scr_dia") {
      $pr_type = 'dia_pr';
                  $pr_disp = 'Dia';
}
elsif ($b_req_type eq "graph_scr_mean") {
      $pr_type = 'mean_pr';
                  $pr_disp = 'Mean';
}

while (my $ref = $sth->fetchrow_hashref()){

      $xdata[$i] = $ref->{'bp_time'};
      $ydata[$i] = $ref->{$pr_type};

      $i++;

} #while

$sth->finish;
$dbh->disconnect;

my $im = new GD::Image(120,50);
my $white = $im->colorAllocate(255,255,255);
my $black = $im->colorAllocate(0,0,0);

my $max_y = 50;
my $max_x = 120;
my $max_time = 1440;

      my @x_temp;
      my @y_temp;

      my $index;
      my $x_range;

      if ($b_scr_dir eq '0') {
                  $index = 0;
                  $x_range = 5;
      }
      elsif ($b_scr_dir eq 'scr_forward') {
                  if ($#xdata - $b_index <= 6) {
                              $index = $b_index;
                              $x_range = $#xdata - $b_index;
                  }
                  elsif ( ($#xdata - $b_index < 12) && ($#xdata - $b_index > 6) ){
                              $x_range = $#xdata - $b_index - 6;
                              $index = $b_index + 6;
                  }
                  elsif ($#xdata - $b_index >= 12) {
                              $index = $b_index + 6;
                              $x_range = 5;
                  }
      }
```

```
        elsif ($b_scr_dir eq 'scr_backward') {
                if ($b_index == 0) {
                        $index = $b_index;
                        $x_range = 5;

                }
                else {
                        $index = $b_index - 6;
                        $x_range = 5;
                }
        }

        $refer = $index;

        my $k = 0;

        for ($i = $refer; $i <= $refer + $x_range; $i++) {
                $x_temp[$k] = $xdata[$i];
                $y_temp[$k] = $ydata[$i];
                $k = $k + 1;
        }

        @xdata = @x_temp;
        @ydata = @y_temp;

    for ($i = 0; $i <= ($#xdata); $i++){

        $xdata[$i] = 600*substr($xdata[$i],0,1) + 60*substr($xdata[$i],1,1) +
                10*substr($xdata[$i],3,1) + substr($xdata[$i],4,1);
    }

    my @ordered_x = sort {$a <=> $b} @xdata;
    my $min_x_data = $ordered_x[0];
    my $max_x_data = $ordered_x[$#ordered_x];

        my $max_x_scale = 60* int($max_x_data/60) + 60;
        my $min_x_scale = 60* int($min_x_data/60);

    my $x_factor =  (($max_x-15) / abs($max_x_scale - $min_x_scale));

    my @ordered_y = sort {$a <=> $b} @ydata;
    my $min_y_data = $ordered_y[0];
    my $max_y_data = $ordered_y[$#ordered_y];

    my $y_factor =  (($max_y-25) / abs($max_y_data - $min_y_data));

    for ($i = 0; $i <= ($#xdata); $i++){

        if ($i == 0) {
        #if it's the first point of the plot
            $im->arc($x_factor*($xdata[0]-$min_x_scale) + 5, int ($max_y -
                                        $y_factor*($ydata[0]-$min_y_data) - 14 ), 5,
                                        5, 0,
            360, $black);

             $im->string(gdTinyFont, 5, int ($max_y -
             $y_factor*($ydata[$i]-$min_y_data) - 24 ), $ydata[0], $black);

        }

        else {
            $im->line(int ($x_factor* ($xdata[$i-1] -
## $xdata[0])
                                        $min_x_scale)  +5 ), int($max_y -
                ($y_factor*($ydata[$i-1]-$min_y_data  ) ) -14  ),
            int ($x_factor* ($xdata[$i] -
## $xdata[0])
                                        $min_x_scale) +5), int ($max_y  -
                ($y_factor*($ydata[$i]-$min_y_data  )) -14 ), $black);

            $im->arc(int ( $x_factor*($xdata[$i]-
## $xdata[0])
                                        $min_x_scale) +5 ), int ($max_y  -
```

```
                $y_factor*($ydata[$i]-$min_y_data) -14 ), 5, 5, 0, 360, $black);

                $im->string(gdTinyFont, int ( $x_factor*($xdata[$i]-
## $xdata[0])
                                    $min_x_scale) ),
                  int ($max_y - $y_factor*($ydata[$i]-$min_y_data) - 24 ),
                        $ydata[$i],$black);

                    }           #else
    } #for loop

    #this part is to draw the scale for x (time)

    $im->line(5, $max_y-8,
        int ($x_factor*($max_x_scale-$min_x_scale))+5, $max_y-8, $black);

        my $t = $min_x_scale;

    while ($t <= $max_x_scale) {
        $im->line(int ($x_factor*($t-$min_x_scale)+5), $max_y-8,
            int ($x_factor*($t-$min_x_scale)+5), $max_y-9, $black);

            $im->string(gdTinyFont, int ($x_factor*($t-$min_x_scale)+3 ),
                                    $max_y-7, ($t/60), $black);

            $im->line(int ($x_factor*($t-$min_x_scale)+5), $max_y-9,
                int ($x_factor*($t-$min_x_scale)+5), $max_y-11, $black);
        $t = $t + 60;

    } #while loop for constructing x scale

    $filename = bp_.$b_viewer_access.$b_viewer_id.$b_fresh_wbmp;

        $b_fresh_wbmp++;

    open(FILE1,">$filename.wbmp") or die "Can't find file\n";
    binmode FILE1;
    print FILE1 $im->wbmp($black);
    close FILE1;

    system "chmod 0755 '$filename'.wbmp";

    print "content-type:text/vnd.wap.wml\n\n";
    print '<?xml version="1.0"?>';
    print '<!DOCTYPE wml PUBLIC "-//WAPFORUM//DTD WML 1.1//EN"
        "http://www.wapforum.org/DTD/wml_1.1.xml">';

    print "<wml>";
    print '<card id="bp_menu" newcontext="true" title="';
    print $pr_disp;
    print '/';
    print 'Pat:';
    print $b_patient_id;
    print '/';

    my $mon = "";


    if (substr($b_bp_date,5,2) eq '01') {
        $mon = 'JAN';
    }
    elsif (substr($b_bp_date,5,2) eq '02') {
        $mon = 'FEB';
    }
    elsif (substr($b_bp_date,5,2) eq '03') {
        $mon = 'MAR';
    }
    elsif (substr($b_bp_date,5,2) eq '04') {
        $mon = 'APR';
    }
    elsif (substr($b_bp_date,5,2) eq '05') {
        $mon = 'MAY';
    }
    elsif (substr($b_bp_date,5,2) eq '06') {
        $mon = 'JUN';
```

```
}
elsif (substr($b_bp_date,5,2) eq '07') {
      $mon = 'JUL';
}
elsif (substr($b_bp_date,5,2) eq '08') {
      $mon = 'AUG';
}
elsif (substr($b_bp_date,5,2) eq '09') {
      $mon = 'SEP';
}
elsif (substr($b_bp_date,5,2) eq '10') {
      $mon = 'OCT';
}
elsif (substr($b_bp_date,5,2) eq '11') {
      $mon = 'NOV';
}
elsif (substr($b_bp_date,5,2) eq '12') {
      $mon = 'DEC';
}

print $mon;
print substr($b_bp_date,8,2);
print '-';
print substr($b_bp_date,2,2);
print '">';

      print '<do type = "accept">';
print  '<go href="http://bme.tsimtung.com/cgi-bin/view_bp_day.cgi" method="post">';
      print       '<postfield name="b_req_type" value="';
      print       $b_req_type;
      print       '"/>';
print  '<postfield name="scr_dir" value="$scr_dir"/>';
print '<postfield name="index" value="';
      print       $index;
      print       '"/>';
print  '<postfield name="fresh_wbmp" value="';
print  $b_fresh_wbmp;
print  '"/>';
      print  '<postfield name="patient_id" value="';
print  $b_patient_id;
print  '"/>';
print  '<postfield name="viewer_access" value="';
print  $b_viewer_access;
print  '"/>';
print  '<postfield name="viewer_id" value="';
print  $b_viewer_id;
print  '"/>';
print  '<postfield name="bp_date" value="';
print  $b_bp_date;
print  '"/>';
      print  '</go>';
print '</do>';

print '<p>';
print '<img alt="Loading.." src="';
print $filename;
print '.wbmp" vspace="0" hspace="0"/>';

      print '<select name="';
print 'scr_dir';
print '">';
print '<option value="scr_forward">Forward</option>';
print '<option value="scr_backward">Backward</option>';
print '</select>';


      print '</p>';
print "</card>";
print "</wml>";

      exit;

} #for showing graphical scrollable format .. first 6 values
```

****
*

Filename: ecg.cgi
Function: List all accessible ECG recording sessions

```
#!/usr/bin/perl -w

use CGI qw(:standard);
use DBI;

my $cgi=new CGI;

my $e_patient_id = param('patient_id');
my $e_viewer_access = param('viewer_access');
my $e_viewer_id = param('viewer_id');

print "content-type:text/vnd.wap.wml\n\n";
print '<?xml version="1.0"?>';
print '<!DOCTYPE wml PUBLIC "-//WAPFORUM//DTD WML 1.1//EN"
      "http://www.wapforum.org/DTD/wml_1.1.xml">';

print "<wml>";
print '<card id="ecg_menu" title="ECG:PatID:';
print $e_patient_id;
print '">';

$DSN = "DBI:mysql:database=busybear";
my $dbh = DBI->connect($DSN, "busybear", "6282bear")
or die "Error connection to database";

my $sth = $dbh->prepare("SELECT re_ecg_id FROM ecg_re WHERE
                re_ecg_pat_id='$e_patient_id'");
$sth->execute();

my @ary = $sth->fetchrow_array();

if (!defined $ary[0]) {
            print "<p>0 Rec</p>";
            $sth->finish;
            $dbh->disconnect;
            print "</card>";
            print "</wml>";

} #if no ecg data exists for this patient

 else {
    #else ecg data exists for this patient
    #now look in table ecg for dates of these ecg data

            $sth->finish;

       print '<do type="accept">';
       print     '<go href="http://bme.tsimtung.com/cgi-bin/trans_ecg.cgi" method="post">';
       print          '<postfield name = "patient_id" value = "';
            print                  $e_patient_id;
            print                  '"/>';
       print          '<postfield name = "viewer_access" value ="';
       print          $e_viewer_access;
       print          '"/>';
       print          '<postfield name = "viewer_id" value = "';
       print          $e_viewer_id;
       print          '"/>';
       print          '<postfield name = "ecg_date" value = "$ecg_date"/>';
       print     '</go>';
       print '</do>';

#           print "<p>";
#       print  '<fieldset title = "e_pat_int">';
#       print  '<small>Date:</small>';
#       print  '<input name = "ecg_date" format="NNNN\-NN\-NN" emptyok = "false"/>';
#       print  '</fieldset>';
#       print "</p>";
```

```
    my $sth = $dbh->prepare("SELECT ecg_date_start, COUNT(*) AS num FROM ecg AS E,
                ecg_re AS R WHERE
                R.re_ecg_pat_id='$e_patient_id' AND
                E.ecg_id = R.re_ecg_id GROUP BY E.ecg_date_start");
        $sth->execute();

        print '<p>';
        print '<small>';
        print '<table columns = "2">';
    print "<tr>";
    print "<td>Date</td>";
        print "<td>Recs</td>";
        print "</tr>";

    while (my $ref = $sth->fetchrow_hashref()){
        print "<tr>";
        print "<td> $ref->{'ecg_date_start'}</td>";
        print "<td> $ref->{'num'} </td>";
        print "</tr>";
    } #while

        $sth->finish;

        print "</table>";
        print "</small>";
        print '</p>';

        print "<p>";
    print  '<fieldset title = "e_pat_int">';
    print  '<small>Date:</small>';
    print  '<input name = "ecg_date" format="NNNN\-NN\-NN" emptyok = "false"/>';
    print  '</fieldset>';
    print "</p>";

        print '</card>';
        print '</wml>';

        $dbh->disconnect;

} #else data exists for this patient

exit;
```

****
*

Filename: trans_ecg.cgi
Function: Menu for user to choose ECG session

```
#!/usr/bin/perl -w

use CGI qw(:standard);
use DBI;

my $cgi=new CGI;

my $ecg_date = param('ecg_date');
my $patient_id = param('patient_id');
my $viewer_access = param ('viewer_access');
my $viewer_id = param('viewer_id');

print "content-type:text/vnd.wap.wml\n\n";
print '<?xml version="1.0"?>';
print '<!DOCTYPE wml PUBLIC "-//WAPFORUM//DTD WML 1.1//EN"
    "http://www.wapforum.org/DTD/wml_1.1.xml">';

my $found_err = 0;

if ($ecg_date eq "") {
    $found_err = 1;
}

if ($found_err == 0) {
    #case for non-empty input
```

```
$DSN = "DBI:mysql:database=busybear";
my $dbh = DBI->connect($DSN, "busybear", "6282bear")
or die "Error connection to database";

      #check if the entered ECG date corresponds to the PATIENT ID
my $sth = $dbh->prepare("SELECT * FROM ecg AS E, ecg_re AS R WHERE E.ecg_date_start=
                              '$ecg_date' AND R.re_ecg_pat_id = '$patient_id'");
$sth->execute();

my @ary = $sth->fetchrow_array();

      $sth->finish;
$dbh->disconnect;


      if (!defined $ary[0]) {
      #if the entered ecg date is not associated with the PATIENT ID
      print "<wml>";
      print '<card id="non_exist" title="Attn">';
      print '<onevent type = "ontimer">';
      print         '<go href = "http://bme.tsimtung.com/login.wml"/>';
      print '</onevent>';
      print '<timer value = "5"/>';
      print '<p>';
      print "Invalid date";
      print '</p>';
      print "</card>";
      print "</wml>";

                exit;
      }

      else {
        #case where the entered ecg date is associated with the PATIENT ID
        #user can select which ecg session to display

                print "<wml>";
                print '<card id="view_ecg" title="ecgdisplay">';

      print '<do type = "accept">';
      print  '<go href="http://bme.tsimtung.com/cgi-bin/view_ecg.cgi" method="post">';

      print  '<postfield name="ecg_id" value="$ecg_id"/>';
      print  '<postfield name="patient_id" value="';
      print  $patient_id;
      print  '"/>';
      print  '<postfield name="viewer_access" value="';
      print  $viewer_access;
      print  '"/>';
      print  '<postfield name="viewer_id" value="';
      print  $viewer_id;
      print  '"/>';
      print  '<postfield name="ecg_date" value="';
      print  $ecg_date;
      print  '"/>';
      print  '<postfield name="scr_dir" value="';
      print  0;
      print  '"/>';
      print  '<postfield name="index" value="';
      print  0;
      print  '"/>';
      print  '<postfield name="fresh_wbmp" value="';
      print  0;
      print  '"/>';
      print  '<postfield name="scr_length" value="';
      print  0;
      print  '"/>';
      print  '<postfield name="sec" value="';
      print  2;
      print  '"/>';
      print  '<postfield name="anal" value="';
      print  0;
      print  '"/>';
```

```
print '</go>';
print '</do>';


$DSN = "DBI:mysql:database=busybear";
my $dbh = DBI->connect($DSN, "busybear", "6282bear")
or die "Error connection to database";

#get all ECG sessions that corresponds to the PATIENT ID and ecg_date
my $sth = $dbh->prepare("SELECT * FROM ecg AS E, ecg_re AS R WHERE E.ecg_date_start=
    '$ecg_date' AND R.re_ecg_pat_id = '$patient_id'");
$sth->execute();


        print "<p>";

print 'Choose Session:';
print '<select name="ecg_id">';

while (my $ref = $sth->fetchrow_hashref()){
print '<option value="';
                print $ref->{'ecg_id'};
                print '">';
print substr($ref->{'ecg_time_start'},0,5);
print '</option>';

} #while

        print '</select>';

$sth->finish;
$dbh->disconnect;

        print "</p>";
        print "</card>";
        print "</wml>";
exit;

} #case where the entered ECG_ID is associated with the PATIENT ID

} #if input of patient_id not empty

else {
#case for empty input for ecg_date

        print "<wml>";
    print '<card id="non_exist" title="Attn">';
    print '<onevent type = "ontimer">';
    print       '<go href = "http://bme.tsimtung.com/login.wml"/>';
    print '</onevent>';
    print '<timer value = "5"/>';
    print '<p>';
    print "ECG Date not filled in";
    print '</p>';
    print "</card>";
    print "</wml>";
    exit;
}
```

****
*

Filename: view_ecg.cgi

Function: Display ECG waveform; user has the choice of time-scale, scroll direction, scroll distance; request for QRS occurrence estimation available

```
#!/usr/bin/perl -w
use CGI qw(:standard);
use GD;
use DBI;
my $cgi=new CGI;

my $e_ecg_id = param('ecg_id');
```

```
my $e_patient_id = param('patient_id');
my $e_viewer_access = param('viewer_access');
my $e_viewer_id = param('viewer_id');
my $e_ecg_date = param('ecg_date');
my $e_scr_dir = param('scr_dir');
my $e_index = param('index');
my $e_fresh_wbmp = param('fresh_wbmp');
my $e_scr_length = param('scr_length');
my $e_sec = param('sec');
my $e_anal= param('anal');

my @QRS_time;

if (($e_anal eq 'chart') || ($e_anal eq 'graph') ){
            goto CHART;
}

GRAPH:

$DSN = "DBI:mysql:database=busybear";
my $dbh = DBI->connect($DSN, "busybear", "6282bear")
      or die "Error connection to database";

my $sth = $dbh->prepare("SELECT ecg_sampling FROM ecg WHERE ecg_id = $e_ecg_id");
$sth->execute();
my $sampling = $sth->fetchrow_array();
$sth->finish;

my $tablename = ecg_data_.$e_ecg_id;
my $i=0;
my $j=0;
my @ydata;
my $index = 0;

$sth = $dbh->prepare("SELECT COUNT(*),MAX(data),MIN(data) FROM $tablename");
$sth->execute();
my @ary = $sth->fetchrow_array();
my $count = $ary[0];
my $max_all_data = $ary[1];
my $min_all_data = $ary[2];

$sth->finish;

my $getdata = $sampling * $e_sec;
#e_sec is the number of seconds to be taken into the array
#getdata is the number of samples to be taken into the array

my $no_scroll = 0;

if ($e_scr_dir eq 'scr_forward'){

            if ($sampling * ($e_index + $e_scr_length) > $count) {
                        $scr_length = 0;
                        $no_scroll = 1;
            }
            else {
                        $scr_length = $e_scr_length;
            }
}
elsif ($e_scr_dir eq 'scr_backward'){

            if ($sampling * ($e_index - $e_scr_length) < 0) {
                        my $scr_lenght = 0;
                        $no_scroll =1;
            }
            else {
                        $scr_length = -$e_scr_length;
            }
}
elsif ($e_scr_dir eq '0'){
                        my $scr_length = 0;
}

$e_index = $e_index + $scr_length;
$index = $sampling * $e_index;
```

```
$sth = $dbh->prepare("SELECT data FROM $tablename where idx >= $index AND
                        idx <= ($index + $getdata) ");
$sth->execute();

while (my $ref = $sth->fetchrow_hashref()){
                        $ydata[$j] = $ref->{'data'};
                        $j++;
} #while

$sth->finish;
$dbh->disconnect;

my $im = new GD::Image(110,50);
my $white = $im->colorAllocate(255,255,255);
my $black = $im->colorAllocate(0,0,0);

my $max_y = 50;
my $max_x = 110;

my $x_factor = ($max_x-15)/$getdata;

my @ordered_y = sort {$a <=> $b} @ydata;
my $min_y_data = $ordered_y[0];
my $max_y_data = $ordered_y[$#ordered_y];

#my $y_factor = (($max_y-35) / abs($max_y_data - $min_y_data));
my $y_factor =   (($max_y-20) / abs($max_all_data - $min_all_data));

my $min_x_scale = $index;
my $max_x_scale = $index + $getdata;

for ($i = 0; $i <= ($#ydata); $i++){

            $im->setPixel(int ( $x_factor*$i +5 ), int ($max_y  -
            $y_factor*($ydata[$i]-$min_y_data) - 10 ), $black);

            if ($i > 0){
                        $im->line(int ($x_factor*($i-1) +5), int ($max_y -
                                    $y_factor*($ydata[$i-1]-$min_y_data) - 10),

                                     int ($x_factor*$i + 5), int ($max_y -
                                    $y_factor*($ydata[$i] - $min_y_data) -10),
                                     $black);
            } #if

            if ($e_anal eq 'graph') {
                        for ($v=0; $v <= ($#QRS_time); $v++) {
                                    if (($e_index < $QRS_time[$v]) &&
                                                ($e_index+$e_sec > $QRS_time[$v])) {
                                                            $im->string(gdTinyFont,
                                                            int($x_factor*($QRS_time[$v]-$e_index)*$sampling+5),
                                                                        12,substr($QRS_time[$v],0,4),$black);

                                    } #if
                        } #for
            } #if
} #for

### this part draws the time axis

$im->line(5, $max_y-8,
            int ($x_factor*($max_x_scale-$min_x_scale))+5, $max_y-8, $black);

my $t = $min_x_scale;

my $mark_height;

while ($t <= $max_x_scale) {
            if ( $t % $sampling == 0) {
                        $mark_height = 11;
                        $im->string(gdTinyFont,int ($x_factor*($t-$min_x_scale)+5),
                          $max_y - 7,$t/$sampling, $black)
            }
            else {
```

```
                $mark_height = 9;
        }

        $im->line(int ($x_factor*($t-$min_x_scale)+5), $max_y-$mark_height,
          int ($x_factor*($t-$min_x_scale)+5), $max_y-9, $black);

        $t = $t + ($sampling/10);
        #a mark for each second
} #while

$filename = ecg_.$e_viewer_access.$e_viewer_id.$e_fresh_wbmp;

if ($no_scroll == 1) {
        goto NO_SCROLL;
}

$e_fresh_wbmp++;

NO_SCROLL:

open(FILE1,">$filename.wbmp") or die "Can't find file\n";
binmode FILE1;
print FILE1 $im->wbmp($black);
close FILE1;

system "chmod 0755 '$filename'.wbmp";

print "content-type:text/vnd.wap.wml\n\n";
print '<?xml version="1.0"?>';
print '<!DOCTYPE wml PUBLIC "-//WAPFORUM//DTD WML 1.1//EN"
        "http://www.wapforum.org/DTD/wml_1.1.xml">';

print "<wml>";
print '<card id="ecg" newcontext="true" title="';
print 'ECG';
print '/';
print 'Pat:';
print $e_patient_id;
print '/';

my $mon = "";

if (substr($e_ecg_date,5,2) eq '01') {
        $mon = 'JAN';
}
elsif (substr($e_ecg_date,5,2) eq '02') {
        $mon = 'FEB';
}
elsif (substr($e_ecg_date,5,2) eq '03') {
        $mon = 'MAR';
}
elsif (substr($e_ecg_date,5,2) eq '04') {
        $mon = 'APR';
}
elsif (substr($e_ecg_date,5,2) eq '05') {
        $mon = 'MAY';
}
elsif (substr($e_ecg_date,5,2) eq '06') {
        $mon = 'JUN';
}
elsif (substr($e_ecg_date,5,2) eq '07') {
        $mon = 'JUL';
}
elsif (substr($e_ecg_date,5,2) eq '08') {
        $mon = 'AUG';
}
elsif (substr($e_ecg_date,5,2) eq '09') {
        $mon = 'SEP';
}
elsif (substr($e_ecg_date,5,2) eq '10') {
        $mon = 'OCT';
}
elsif (substr($e_ecg_date,5,2) eq '11') {
        $mon = 'NOV';
}
```

```
elsif (substr($e_ecg_date,5,2) eq '12') {
            $mon = 'DEC';
}

print $mon;
print substr($e_ecg_date,8,2);
print '-';
print substr($e_ecg_date,2,2);
print '">';

print '<do type = "accept">';
print  '<go href="http://bme.tsimtung.com/cgi-bin/view_ecg.cgi" method="post">';
print  '<postfield name="ecg_id" value="';
print  $e_ecg_id;
print  '"/>';
print  '<postfield name="scr_dir" value="$scr_dir"/>';
print  '<postfield name="index" value="';
print  $e_index;
print  '"/>';
print  '<postfield name="fresh_wbmp" value="';
print  $e_fresh_wbmp;
print  '"/>';
print  '<postfield name="patient_id" value="';
print  $e_patient_id;
print  '"/>';
print  '<postfield name="viewer_access" value="';
print  $e_viewer_access;
print  '"/>';
print  '<postfield name="viewer_id" value="';
print  $e_viewer_id;
print  '"/>';
print  '<postfield name="ecg_date" value="';
print  $e_ecg_date;
print  '"/>';
print  '<postfield name="scr_length" value="$scr_length"/>';
print  '<postfield name="sec" value="$sec"/>';
print       '<postfield name="anal" value="$anal"/>';

print  '</go>';
print '</do>';

print '<p>';
print '<img align="top" alt="Loading.." src="';
print $filename;
print '.wbmp" vspace="0" hspace="0"/>';

print '<select name="';
print 'scr_dir';
print '">';
print '<option value="scr_forward">Forward</option>';
print '<option value="scr_backward">Backward</option>';
print '</select>';

print '<select name="';
print 'scr_length';
print '">';
print '<option value="1.2">1.2s</option>';
print '<option value="0.4">0.4s</option>';
print '<option value="0">0s</option>';
print '</select>';

print '<select name="';
print 'sec';
print '">';
print '<option value="2">2s</option>';
print '<option value="1">1s</option>';
print '<option value="0.5">0.5s</option>';
print '</select>';

print '<select name="';
print 'anal';
print '">';
print '<option value="none">No anal</option>';
print '<option value="chart">R-R cht</option>';
print '<option value="graph">R-R grph</option>';
```

```
print '</select>';

print '</p>';
print "</card>";
print "</wml>";

goto END;

############################

CHART:


$DSN = "DBI:mysql:database=busybear";
my $dbh = DBI->connect($DSN, "busybear", "6282bear")
      or die "Error connection to database";

my $sth = $dbh->prepare("SELECT ecg_sampling FROM ecg WHERE ecg_id = $e_ecg_id");
$sth->execute();

my $sample_rate = $sth->fetchrow_array();

$sth->finish;

my $tablename = ecg_data_.$e_ecg_id;

my $i=0;
my $j=0;
my $m=0;
my $n=0;
my $p=0;
my $q=0;
my $u=0;
my $v=0;
my @ecg_data;
my @ecg_temp;
my @deriv;
my $index = 0;
my $peak;
my $peaktime;


$sth = $dbh->prepare("SELECT COUNT(*),MAX(data),MIN(data) FROM $tablename");
$sth->execute();
my @ary = $sth->fetchrow_array();
my $count = $ary[0];
my $max_all_data = $ary[1];
my $min_all_data = $ary[2];
$sth->finish;

$sth = $dbh->prepare("SELECT data FROM $tablename");
$sth->execute();

while (my $ref = $sth->fetchrow_hashref()){
            $ecg_data[$i] = $ref->{'data'};
            $i++;
} #while

$sth->finish;
$dbh->disconnect;

for ($i=0; $i <= ($#ecg_data); $i++ ){
      if ($i % int($sample_rate/250) == 0) {
            $ecg_temp[$p] = $ecg_data[$i];
            $p++;
      }
} #for

@ecg_data = @ecg_temp;

for ($i=0; $i <= ($#ecg_data); $i++ ){
      if ( ($i > 0) && ($i < $#ecg_data) ) {
            $deriv[$j] = $ecg_data[$i+1] - $ecg_data[$i-1];
            $j++;
      } #if
```

```
} #for

my $sampling = 250;

$j=0;

while ($j <= ($#deriv) ){
      if (   ($j > ( 3*int($sampling/250) ) -1) &&
               ($j < ( $#deriv - (0.1*$sampling)) )    ){

            for ($k=0; $k<=( 3*int($sampling/250) ) -1; $k++ ){
                #predefined period for upward slope

                  if ($deriv[$j-$k] <= 0.06*(250/$sampling) ) {

                   #if upward slope not steep enough
                       goto FIND_NEXT;

                  } #if

            } #for

            #now just found a long enough period with steep enough positive slope

            for ($m=0; $m<= (0.1*$sampling -1); $m++){
                  #now look in the next 100ms

                        for ($n=0; $n<=(2*int($sampling/250) ) -1; $n++){
                              #predefined period for downward slope

                              if ($deriv[$j+$m+$n]>=-0.05*(250/$sampling) ) {
                                    #down slope not steep enough

                                    goto FIND_NEXT2;

                              } #if


                              #now, found part of upward and part of downward
                              #slope both qualified, so see if all data
                              #between onset and offset of wave larger than
                              #amplitude threshold

                              if (($ecg_data[$j] > 5.3)
                              && ($ecg_data[$j+$m] > 5.3)) {

                                    my $peaktime = ($j+$m)/$sampling;
                                 #   print "\n";
                                 #   print $peaktime;
                                    $QRS_time[$u] = $peaktime;
                                                                    $u++;
                                                                    $j= $j + (0.2*$sampling) -1;

                              }
                        } #for loop for n

                        FIND_NEXT2:

            } #for loop for m

            FIND_NEXT:
      } #if

      $j++;

 } #while

 #$sth->finish;
 #$dbh->disconnect;

 if ($e_anal eq 'graph') {
             goto GRAPH;
 } #if

 print "content-type:text/vnd.wap.wml\n\n";
```

```
print '<?xml version="1.0"?>';
print '<!DOCTYPE wml PUBLIC "-//WAPFORUM//DTD WML 1.1//EN"
       "http://www.wapforum.org/DTD/wml_1.1.xml">';

print "<wml>";
print '<card id="ecg_chart" newcontext="true" title="';
print 'RR';
print '/';
print 'Pat:';
print $e_patient_id;
print '/';

my $mon = "";

if (substr($e_ecg_date,5,2) eq '01') {
       $mon = 'JAN';
}
elsif (substr($e_ecg_date,5,2) eq '02') {
       $mon = 'FEB';
}
elsif (substr($e_ecg_date,5,2) eq '03') {
       $mon = 'MAR';
}
elsif (substr($e_ecg_date,5,2) eq '04') {
       $mon = 'APR';
}
elsif (substr($e_ecg_date,5,2) eq '05') {
       $mon = 'MAY';
}
elsif (substr($e_ecg_date,5,2) eq '06') {
       $mon = 'JUN';
}
elsif (substr($e_ecg_date,5,2) eq '07') {
       $mon = 'JUL';
}
elsif (substr($e_ecg_date,5,2) eq '08') {
       $mon = 'AUG';
}
elsif (substr($e_ecg_date,5,2) eq '09') {
       $mon = 'SEP';
}
elsif (substr($e_ecg_date,5,2) eq '10') {
       $mon = 'OCT';
}
elsif (substr($e_ecg_date,5,2) eq '11') {
       $mon = 'NOV';
}
elsif (substr($e_ecg_date,5,2) eq '12') {
       $mon = 'DEC';
}

print $mon;
print substr($e_ecg_date,8,2);
print '-';
print substr($e_ecg_date,2,2);
print '">';
print '<p>';

print '<small>';
print '<table columns = "3">';
print "<tr>";
print "<td>R</td>";
print "<td>RR</td>";
print "<td>60/RR</td>";
print "</tr>";

my $RR;

for ($u = 0; $u <= ($#QRS_time); $u++){
              print "<tr>";
              print "<td>";
              print $QRS_time[$u];
              print "</td>";

              if ($u != 0) {
```

```
                    $RR = $QRS_time[$u] - $QRS_time[$u-1];
                print "<td>";
                    print substr($RR,0,5);
                    print "</td>";
                    print "<td>";
                    print int(60/$RR);
                    print "</td>";
        } #if
        else {
                    print "<td>";
        print "X";
        print "</td>";
        print "<td>";
        print "X";
        print "</td>";

        } #else

        print "</tr>";
} #for

print "</table>";
print "</small>";
print '</p>';
print "</card>";
print "</wml>";

goto END;

END:
exit;
```

****
*

Filename: clinic2.cgi
Function: Display of clinic information according to user's request

```
#!/usr/bin/perl -w

use CGI qw(:standard);
use GD;
use DBI;

my $cgi=new CGI;

my $c_clinic_id = param('clinic_id');
my $c_info_type = param('info_type');

if ($c_info_type eq "general") {

        print "content-type:text/vnd.wap.wml\n\n";
        print '<?xml version="1.0"?>';
        print '<!DOCTYPE wml PUBLIC "-//WAPFORUM//DTD WML 1.1//EN"
                "http://www.wapforum.org/DTD/wml_1.1.xml">';

        print "<wml>";
        print '<card id="clinic" newcontext="true" title="ClinicID:';
        print $c_clinic_id;
        print '">';

        $DSN = "DBI:mysql:database=busybear";
        my $dbh = DBI->connect($DSN, "busybear", "6282bear")
        or die "Error connection to database";

    my $sth = $dbh->prepare("SELECT *  FROM clinic WHERE
                                                clinic_id='$c_clinic_id'");

        $sth->execute();

        print '<p>';
        print '<small>';

        while (my $ref = $sth->fetchrow_hashref()){
```

```
                    print 'Name:';
                    print $ref->{'clinic_name'};
            } #while

            print "</small>";

            print '</p>';
            print '</card>';
            print '</wml>';

            $sth->finish;
            $dbh->disconnect;

            exit;

} #for showing clinic general info


if ($c_info_type eq "address") {

        print "content-type:text/vnd.wap.wml\n\n";
        print '<?xml version="1.0"?>';
        print '<!DOCTYPE wml PUBLIC "-//WAPFORUM//DTD WML 1.1//EN"
              "http://www.wapforum.org/DTD/wml_1.1.xml">';

        print "<wml>";
        print '<card id="clinic" newcontext="true" title="ClinicID:';
        print $c_clinic_id;
        print '">';

        $DSN = "DBI:mysql:database=busybear";
        my $dbh = DBI->connect($DSN, "busybear", "6282bear")
        or die "Error connection to database";

        my $sth = $dbh->prepare("SELECT *  FROM clinic WHERE
                                                        clinic_id='$c_clinic_id'");

        $sth->execute();

        print '<p>';
        print '<small>';

        while (my $ref = $sth->fetchrow_hashref()){
              print 'Add:';
              print $ref->{'clinic_address_1'};
              print ',';
              if (defined $ref->{'clinic_address_2'}) {

                                    print $ref->{'clinic_address_2'};
              print ',';

                          } #if

                          if (defined $ref->{'clinic_add_region'}) {

                                    print $ref->{'clinic_add_region'};
                                    print ',';

                          }

                          print $ref->{'clinic_add_city'};
                          print ',';

                          if (defined $ref->{'clinic_add_zip'}) {

                                    print $ref->{'clinic_add_zip'};
                                    print ',';

                          }

                          if (defined $ref->{'clinic_add_state'}) {

                                    print $ref->{'clinic_add_state'};
                                    print ',';
```

```
                    }

                    print $ref->{'clinic_add_country'};
    } #while

    print "</small>";

    print '</p>';
    print '</card>';
    print '</wml>';

    $sth->finish;
    $dbh->disconnect;

    exit;

} # showing clinic address

if ($c_info_type eq "phone") {

    print "content-type:text/vnd.wap.wml\n\n";
    print '<?xml version="1.0"?>';
    print '<!DOCTYPE wml PUBLIC "-//WAPFORUM//DTD WML 1.1//EN"
          "http://www.wapforum.org/DTD/wml_1.1.xml">';

    print "<wml>";
    print '<card id="clinic" newcontext="true" title="ClinicID:';
    print $c_clinic_id;
    print '">';

    $DSN = "DBI:mysql:database=busybear";
    my $dbh = DBI->connect($DSN, "busybear", "6282bear")
    or die "Error connection to database";

        my $sth = $dbh->prepare("SELECT *  FROM clinic WHERE
                                                    clinic_id='$c_clinic_id'");

    $sth->execute();

    print '<p>';
    print '<small>';

    while (my $ref = $sth->fetchrow_hashref()){

                    print 'Ph: ';
        print $ref->{'clinic_phone'};
        print '<br/>';


        } #while

        print "</small>";
    print '</p>';
    print '</card>';
    print '</wml>';

    $sth->finish;
    $dbh->disconnect;

    exit;

} #showing clinic phone

if ($c_info_type eq "hours") {

    print "content-type:text/vnd.wap.wml\n\n";
    print '<?xml version="1.0"?>';
    print '<!DOCTYPE wml PUBLIC "-//WAPFORUM//DTD WML 1.1//EN"
          "http://www.wapforum.org/DTD/wml_1.1.xml">';

    $DSN = "DBI:mysql:database=busybear";
    my $dbh = DBI->connect($DSN, "busybear", "6282bear")
    or die "Error connection to database";

    my $sth = $dbh->prepare("SELECT *  FROM clinic WHERE
```

```
                              clinic_id='$c_clinic_id'");
        $sth->execute();

print "<wml>";
print '<card id="clinic" newcontext="true" title="ClinicID:';
print $c_clinic_id;
print '">';
        print '<p align="center">';
        print '<small>';

while (my $ref = $sth->fetchrow_hashref()){

                print 'Mon: ';
                print '<br/>';

        if (defined $ref->{'open_mon_1'}) {
                print substr($ref->{'open_mon_1'},0,5);
                print '-';
                                print substr($ref->{'close_mon_1'},0,5);
                                print '<br/>';

                                if (defined $ref->{'open_mon_2'}) {
                                        print substr($ref->{'open_mon_2'},0,5);
                        print '-';
                        print substr($ref->{'close_mon_2'},0,5);
                        print '<br/>';
                                } #if2
        } #if1
                        else {
                                print 'Closed';
                                print '<br/>';
                        }

        print 'Tue: ';
        print '<br/>';

        if (defined $ref->{'open_tue_1'}) {
                print substr($ref->{'open_tue_1'},0,5);
                print '-';
                print substr($ref->{'close_tue_1'},0,5);
                print '<br/>';

                if (defined $ref->{'open_tue_2'}) {
                        print substr($ref->{'open_tue_2'},0,5);
                        print '-';
                        print substr($ref->{'close_tue_2'},0,5);
                        print '<br/>';
                } #if2
        } #if1
        else {
                print 'Closed';
                print '<br/>';
        }

        print 'Wed: ';
        print '<br/>';

        if (defined $ref->{'open_wed_1'}) {
                print substr($ref->{'open_wed_1'},0,5);
                print '-';
                print substr($ref->{'close_wed_1'},0,5);
                print '<br/>';

                if (defined $ref->{'open_wed_2'}) {
                        print substr($ref->{'open_wed_2'},0,5);
                        print '-';
                        print substr($ref->{'close_wed_2'},0,5);
                        print '<br/>';
                } #if2
        } #if1
        else {
                print 'Closed';
                print '<br/>';
        }
```

```
print 'Thu: ';
print '<br/>';

if (defined $ref->{'open_thu_1'}) {
	print substr($ref->{'open_thu_1'},0,5);
	print '-';
	print substr($ref->{'close_thu_1'},0,5);
	print '<br/>';

	if (defined $ref->{'open_thu_2'}) {
		print substr($ref->{'open_thu_2'},0,5);
		print '-';
		print substr($ref->{'close_thu_2'},0,5);
		print '<br/>';
	} #if2
} #if1
else {
	print 'Closed';
	print '<br/>';
}

print 'Fri: ';
print '<br/>';

if (defined $ref->{'open_fri_1'}) {
	print substr($ref->{'open_fri_1'},0,5);
	print '-';
	print substr($ref->{'close_fri_1'},0,5);
	print '<br/>';

	if (defined $ref->{'open_fri_2'}) {
		print substr($ref->{'open_fri_2'},0,5);
		print '-';
		print substr($ref->{'close_fri_2'},0,5);
		print '<br/>';
	} #if2
} #if1
else {
	print 'Closed';
	print '<br/>';
}

print 'Sat: ';
print '<br/>';

if (defined $ref->{'open_sat_1'}) {
	print substr($ref->{'open_sat_1'},0,5);
	print '-';
	print substr($ref->{'close_sat_1'},0,5);
	print '<br/>';

	if (defined $ref->{'open_sat_2'}) {
		print substr($ref->{'open_sat_2'},0,5);
		print '-';
		print substr($ref->{'close_sat_2'},0,5);
		print '<br/>';
	} #if2
} #if1
else {
	print 'Closed';
	print '<br/>';
}

print 'Sun: ';
print '<br/>';

if (defined $ref->{'open_sun_1'}) {
	print substr($ref->{'open_sun_1'},0,5);
	print '-';
	print substr($ref->{'close_sun_1'},0,5);
	print '<br/>';

	if (defined $ref->{'open_sun_2'}) {
		print substr($ref->{'open_sun_2'},0,5);
		print '-';
```

```
                    print substr($ref->{'close_sun_2'},0,5);
                    print '<br/>';
                } #if2
            } #if1
            else {
                print 'Closed';
                print '<br/>';
            }

    } #while

            print '</small>';
    print '</p>';
    print '</card>';
    print '</wml>';

    $sth->finish;
    $dbh->disconnect;

            exit;

} #showing clinic hours
```

****
*

Filename: hospital2.cgi
Function: Display of hospital information according to user's request

```
#!/usr/bin/perl -w

use CGI qw(:standard);
use GD;
use DBI;

my $cgi=new CGI;

my $h_hosp_id = param('hosp_id');
my $h_info_type = param('info_type');

if ($h_info_type eq "general") {

        print "content-type:text/vnd.wap.wml\n\n";
        print '<?xml version="1.0"?>';
        print '<!DOCTYPE wml PUBLIC "-//WAPFORUM//DTD WML 1.1//EN"
                "http://www.wapforum.org/DTD/wml_1.1.xml">';

        print "<wml>";
        print '<card id="hospital" newcontext="true" title="HospID:';
        print $h_hosp_id;
        print '">';

        $DSN = "DBI:mysql:database=busybear";
        my $dbh = DBI->connect($DSN, "busybear", "6282bear")
        or die "Error connection to database";

    my $sth = $dbh->prepare("SELECT *  FROM hospital WHERE
                                                hosp_id='$h_hosp_id'");

        $sth->execute();

        print '<p>';
        print '<small>';

        while (my $ref = $sth->fetchrow_hashref()){
                print 'Name:';
                print $ref->{'hosp_name'};
        } #while

        print "</small>";

        print '</p>';
        print '</card>';
        print '</wml>';
```

```
            $sth->finish;
            $dbh->disconnect;

            exit;

} #for showing hospital general info


if ($h_info_type eq "address") {

        print "content-type:text/vnd.wap.wml\n\n";
        print '<?xml version="1.0"?>';
        print '<!DOCTYPE wml PUBLIC "-//WAPFORUM//DTD WML 1.1//EN"
                "http://www.wapforum.org/DTD/wml_1.1.xml">';

        print "<wml>";
        print '<card id="hospital" newcontext="true" title="HospID:';
        print $h_hosp_id;
        print '">';

        $DSN = "DBI:mysql:database=busybear";
        my $dbh = DBI->connect($DSN, "busybear", "6282bear")
        or die "Error connection to database";

        my $sth = $dbh->prepare("SELECT *  FROM hospital WHERE
                                                  hosp_id='$h_hosp_id'");

        $sth->execute();

        print '<p>';
        print '<small>';

        while (my $ref = $sth->fetchrow_hashref()){
                print 'Add:';
                print $ref->{'hosp_address_1'};
                print ',';
                if (defined $ref->{'hosp_address_2'}) {

                                print $ref->{'hosp_address_2'};
                print ',';

                        } #if

                        if (defined $ref->{'hosp_add_region'}) {

                                print $ref->{'hosp_add_region'};
                                print ',';

                        }

                        print $ref->{'hosp_add_city'};
                        print ',';

                        if (defined $ref->{'hosp_add_zip'}) {

                                print $ref->{'hosp_add_zip'};
                                print ',';

                        }

                        if (defined $ref->{'hosp_add_state'}) {

                                print $ref->{'hosp_add_state'};
                                print ',';

                        }

                        print $ref->{'hosp_add_country'};
        } #while

        print "</small>";

        print '</p>';
        print '</card>';
```

```
        print '</wml>';

        $sth->finish;
        $dbh->disconnect;

        exit;

    } # showing hospital address

    if ($h_info_type eq "phone") {

        print "content-type:text/vnd.wap.wml\n\n";
        print '<?xml version="1.0"?>';
        print '<!DOCTYPE wml PUBLIC "-//WAPFORUM//DTD WML 1.1//EN"
              "http://www.wapforum.org/DTD/wml_1.1.xml">';

        print "<wml>";
        print '<card id="hospital" newcontext="true" title="HospID:';
        print $h_hosp_id;
        print '">';

        $DSN = "DBI:mysql:database=busybear";
        my $dbh = DBI->connect($DSN, "busybear", "6282bear")
        or die "Error connection to database";

              my $sth = $dbh->prepare("SELECT *  FROM hospital WHERE
                                                              hosp_id='$h_hosp_id'");

        $sth->execute();

        print '<p>';
        print '<small>';

        while (my $ref = $sth->fetchrow_hashref()){

                        print 'Ph: ';
              print $ref->{'hosp_phone'};
              print '<br/>';


              } #while

              print "</small>";
        print '</p>';
        print '</card>';
        print '</wml>';

        $sth->finish;
        $dbh->disconnect;

        exit;

    } #showing hospital phone and fax
```

Appendix D:

MySQL Database Tables

	Attribute	Value Type	NULL cond	KEY TYPE	Remark
USER	username	VARCHAR(8)	NOT NULL	PRIMARY KEY	
	password	VARCHAR(8)	NOT NULL		
	access_level	SET('admin', 'doctor', 'patient')	NOT NULL		
	last_login	DATETIME			
	con_id	SMALLINT UNSIGNED	NOT NULL		
PATIENT	pat_id	SMALLINT UNSIGNED	NOT NULL	PRIMARY KEY	
	pat_fname	VARCHAR(30)	NOT NULL		
	pat_lname	VARCHAR(30)	NOT NULL		
	pat_gender	SET('F', 'M')	NOT NULL		
	pat_bdate	DATE	NOT NULL		
	pat_address_1	VARCHAR(60)	NOT NULL		
	pat_address_2	VARCHAR(60)			
	pat_add_region	VARCHAR(60)			
	pat_add_city	VARCHAR(60)	NOT NULL		
	pat_add_zip	VARCHAR(20)			
	pat_add_state	VARCHAR(60)			
	pat_add_country	VARCHAR(60)	NOT NULL		
	pat_phone_hm	BIGINT UNSIGNED	NOT NULL		
	pat_phone_cont	BIGINT UNSIGNED			
	pat_fax	BIGINT UNSIGNED			
DOCTOR	doct_id	SMALLINT UNSIGNED	NOT NULL	PRIMARY KEY	
	doct_fname	VARCHAR(30)	NOT NULL		
	doct_lname	VARCHAR(30)	NOT NULL		
N:N					
DOCT_PAT_RE	re_doct_id	SMALLINT UNSIGNED	NOT NULL		index
	re_pat_id	SMALLINT UNSIGNED	NOT NULL		index
N:N					
DOCT_CLIN_RE	re_clin_doct_id	SMALLINT UNSIGNED	NOT NULL		index
	re_clin_clin_id	SMALLINT UNSIGNED	NOT NULL		index
BP	bp_id	INT UNSIGNED	NOT NULL	PRIMARY KEY	
	bp_time	TIME	NOT NULL		
	sys_pr	SMALLINT UNSIGNED	NOT NULL		
	dia_pr	SMALLINT UNSIGNED	NOT NULL		
	mean_pr	SMALLINT UNSIGNED	NOT NULL		
	bp_pulse	SMALLINT UNSIGNED	NOT NULL		
	bp_location	VARCHAR(60)	NOT NULL		
1:N					
BP_RE	re_bp_pat_id	SMALLINT UNSIGNED	NOT NULL		index
	re_bp_id	INT UNSIGNED	NOT NULL		index
HR	hr_id	INT UNSIGNED	NOT NULL	PRIMARY KEY	
	hr_date	DATE	NOT NULL		
	hr_time	TIME	NOT NULL		
	hr_location	VARCHAR(60)	NOT NULL		
1:N					
HR_RE	re_rt_pat_id	SMALLINT UNSIGNED	NOT NULL		index
	re_rt_id	INT UNSIGNED	NOT NULL		index
ECG	ecg_id	INT UNSIGNED	NOT NULL	PRIMARY KEY	
	ecg_date_start	DATE	NOT NULL		
	ecg_time_start	TIME	NOT NULL		
	ecg_date_end	DATE	NOT NULL		
	ecg_time_end	TIME	NOT NULL		
	ecg_location	VARCHAR(60)	NOT NULL		
	ecg_sampling	SMALLINT UNSIGNED	NOT NULL		
	ecg_duration	SMALLINT UNSIGNED	NOT NULL		
	ecg_data	MEDIUMTEXT	NOT NULL		
1:N					
ECG_RE	re_ecg_pat_id	SMALLINT UNSIGNED	NOT NULL		index
	re_ecg_id	INT UNSIGNED	NOT NULL		index

CLINIC	clinic_id	SMALLINT UNSIGNED	NOT NULL	PRIMARY KEY	
	clinic_name	VARCHAR(60)	NOT NULL		
	clinic_address_1	VARCHAR(60)	NOT NULL		
	clinic_address_2	VARCHAR(60)			
	clinic_add_region	VARCHAR(60)			
	clinic_add_city	VARCHAR(60)	NOT NULL		
	clinic_add_zip	VARCHAR(20)			
	clinic_add_state	VARCHAR(60)			
	clinic_add_country	VARCHAR(60)	NOT NULL		
	clinic_phone	BIGINT UNSIGNED	NOT NULL		
	open_mon_1	TIME			
	close_mon_1	TIME			
	open_mon_2	TIME			
	close_mon_2	TIME			
	open_tue_1	TIME			
	close_tue_1	TIME			
	open_tue_2	TIME			
	close_tue_2	TIME			
	open_wed_1	TIME			
	close_wed_1	TIME			
	open_wed_2	TIME			
	close_wed_2	TIME			
	open_thu_1	TIME			
	close_thu_1	TIME			
	open_thu_2	TIME			
	close_thu_2	TIME			
	open_fri_1	TIME			
	close_fri_1	TIME			
	open_fri_2	TIME			
	close_fri_2	TIME			
	open_sat_1	TIME			
	close_sat_1	TIME			
	open_sat_2	TIME			
	close_sat_2	TIME			
	open_sun_1	TIME			
	close_sun_1	TIME			
	open_sun_2	TIME			
	close_sun_2	TIME			
HOSPITAL	hosp_id	SMALLINT UNSIGNED	NOT NULL	PRIMARY KEY	
	hosp_name	VARCHAR(60)	NOT NULL		
	hosp_phone	BIGINT UNSIGNED	NOT NULL		
	hosp_address_1	VARCHAR(60)	NOT NULL		
	hosp_address_2	VARCHAR(60)			
	hosp_add_region	VARCHAR(60)			
	hosp_add_city	VARCHAR(60)	NOT NULL		
	hosp_add_zip	VARCHAR(20)			
	hosp_add_state	VARCHAR(60)			
	hosp_add_country	VARCHAR(60)	NOT NULL		
APPOINTMENT	app_pat_id	SMALLINT UNSIGNED	NOT NULL		index
	app_doct_id	SMALLINT UNSIGNED	NOT NULL		index
	app_clinic_id	SMALLINT UNSIGNED	NOT NULL		index
	app_date	DATE	NOT NULL		index
	app_time	TIME	NOT NULL		index