INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH & DEVELOPMENT

ISSN: 2278 – 0211 (ONLINE)

A Review On Design Of Portable Ecg System

Vidyashree K N
M.Tech student, Biomedical Signal Processing and Instrumentation, Dept of Instrumentation Technology,
R.V. College of Engineering, Bangalore, Karnataka,India

Dr. B. S. Sathyanarayana
Principal, R.V. College of Engineering,
Bangalore, Karnataka, India

Dr. S. C. Prasanna Kumar
Professor and HOD, Dept. of Instrumentation Technology, R.V. College of Engineering, Bangalore, Karnataka, India

Dr. B. G. Sudarshan
Assistant Professor, Dept. of Instrumentation Technology, R.V. College of Engineering, Bangalore, Karnataka, India

Abstract:

The electrical activity of the heart is represented by the ECG signal. A wide range of heart conditions can be detected by ECG interpretation. Hence it is increasingly being used in medical sciences and technology as a valuable diagnostic tool. The commonly used ECG-machine used for diagnosis and supervision at the present is expensive and stationary. The design of a portable , affordable, user friendly ECG monitor system that can be manageable by common man is a great research area. This paper presents review on the considerations for design of portable ECG machine, which mainly deals with the circuitry of ECG machine, such as electrodes, analog front end unit, processing and display units. By choosing the appropriate components a portable ECG machine can be constructed.

1. Introduction

The electrical activity of the heart is represented by the ECG signal. ECG signal is a kind of body signal with 0.05Hz to 100Hz bandwidth and about 1 mV peak to peak voltage, and mixed with high frequency noises and 50 Hz utility power interrupt[1].

1.1Evolution of ECG

The development of the EKG(ECG) began with the discovery of the electronic potential of living tissue. This electromotive effect was first investigated by Aloysio Luigi in 1787. Through his experiments, he demonstrated that living tissues, particularly muscles, are capable of generating electricity.

Afterwards, other scientists studied this effect in electronic potential. The variation of the electronic potential of the beating heart was observed as early as 1856, but it was not until Willem Einthoven invented the string galvanometer that a practical, functioning EKG machine could be made. The string galvanometer was a device composed of a coarse string that was suspended in a magnetic field. When the force of the heart current was applied to this device, the string moved, and these deflections were then recorded on photographic paper.

The first EKG machine was introduced by Einthoven in 1903. It proved to be a popular device, and large-scale manufacturing soon began soon in various European countries.

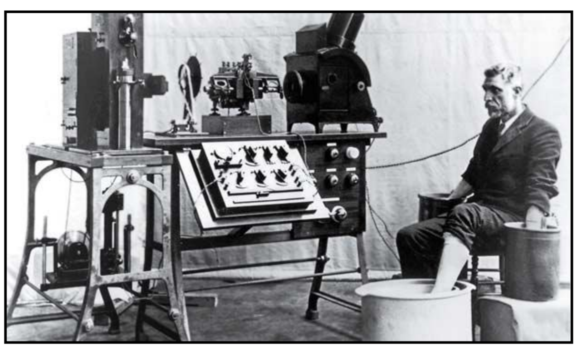


Figure 1: First Electro-cardiogram recording arrangement

Early manufacturers include Edelmann and Sons of Munich and the Cambridge Scientific Instrument Company. The EKG was brought to the United States in 1909 and manufactured by the Hindle Instrument Company. Improvements to the original EKG machine design began soon after its introduction. One important innovation was reducing the size of the electromagnet. This allowed the machine to be portable.

Another improvement was the development of electrodes that could be attached directly to the skin. The original electrodes required the patient to submerge the arms and legs into glass electrode jars containing large volumes of a sodium chloride solution. Additional improvements included the incorporation of amplifiers, which improved the electronic signal, and direct writing instruments, which made the EKG data immediately available. The modern EKG machine is similar to these early models, but microelectronics and computer interfaces have been incorporated, making them more useful and powerful.

1.2 Waveform Description:

The ECG scan is essentially a periodic waveform. One cycle of the blood transfer process from the heart to the arteries is represented by one period of the ECG waveform. This part of the waveform is generated by an electrical impulse originating at the Sinoatrialnode in the right atrium of the heart. The impulse causes contraction of the atria which forces the blood in each atrium to squeeze into its corresponding ventricle. The resulting signal is called the P wave. The atrioventricular node delays the excitation impulse until the blood transfer from the atria to the ventricles is completed, resulting in the PR interval of the ECG waveform. The excitation impulse then causes contraction of the ventricles which squeezes the blood into the arteries. This generates the QRS part of the ECG waveform.

During this phase, the atria are relaxed and filled with blood. The T wave of the waveform represents the relaxation of ventricles. The complete process is repeated periodically, generating the ECG trace.

Each portion of the ECG waveform carries various types of information for the physician analyzing a patient’s heart condition. For example, the amplitude and timing of the P and QRS portions indicate the condition of cardiac muscle mass. Loss of amplitude indicates muscle damage, whereas increased amplitude indicates abnormal heart rates. Too long a delay in the atrioventricular node is indicated by very long PR interval. Likewise, blockage of some or all of the contraction impulses is reflected by intermittent synchronization between P and QRS waves. Most of these abnormalities can be treated with various drugs. A normal cardiac cycle in summary would include the following:

Sl N0.	Physiologic Event	ECG Evidence
1	SA node initiates impulse	Not Visible
2	Depolarization of atrial muscle	P Wave
3	Atrial contraction	Not Visible
4	Depolarization of AV node & Common Bundle	Not Visible
5	Repolarization of atrial muscle	Not Visible
6	Depolarization of ventricular Muscle	QRS Complex
7	Contraction of Ventricular muscle	Not Visible
8	Repolarization of Ventricular muscle	T Wave

Table :1 Summary of cardiac events

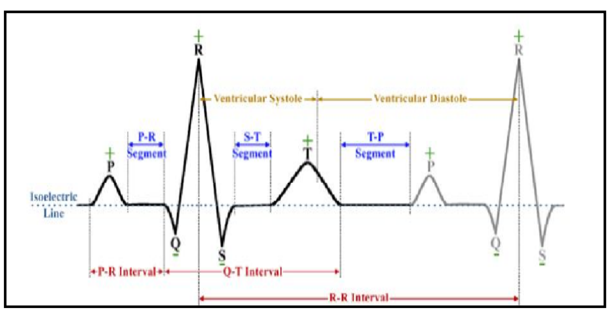


Figure 2: Components of the ECG and electrical and mechanical events of the cardiac cycle

The main areas of concern in the design of an ECG system are

- ECG Sensors/Electrodes
- Analog front end unit
- Processing and analysis platforms.

The features and architectures of these vary depending on various applications.Some of them are discussed below.

1.2.1. Ecg Sensors/Electrodes

Electrodes records the electrical activity of the heart.

There are 3 important factors in the waveform of ECG, acquired through electrodes.

1) Upward deflection: Its recorded when positive wave of depolarization of the heart move towards a positive electrode.
2) Downward deflection: Its recorded when positive wave of depolarization of the heart move away from positive electrode.
3) Isoelectric line: Its recorded when wave of depolarization of the heart cells occur at 90 degrees with respect to positive electrode.

The 3 waveforms are as shown below.

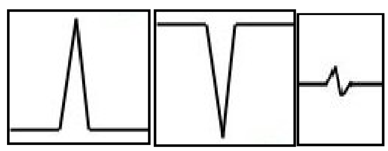


Figure 3: Waveforms

There are multiple electrode combination (leads) such as

1) Bipolar leads: For ECG measurement. Two different points on the body are selected.
2) Unipolar leads: Here, One point is selected on the body and a reference point is taken at the centre of the heart.

There are different types of ECGs, that can be referred by the number of leads that are recorded, such as 3-lead, 5-lead or 12-lead ECG's. In 12-lead ECG, 12 different electrical signals are recorded approximately at the same time and used as a one–off recording of an ECG, and printed on a paper copy. Whereas 3-lead and 5-lead ECG are monitored continuously and viewed on the screen of an appropriate monitoring device.

In portable ECG device, 3-lead is widely used. Using 3-lead ECG, a physician can observe heart rate, heart beat and heart rhythm. It is common and non invasive method, which quickly gives information about a patient's heart. So this ECG can helps in diagnosing cardiovascular problems such as heart attack, heart rhythm problems and heart failure.

LEAD	VIEWS	HEART CHAMBERS
Lead I	Lateral	Left ventricle, left atrium
Lead II	Inferior	Left and right ventricle
Lead III	Inferior	Right and left ventricle

Table 2: Three views of heart can be obtained using 3-lead system.

Together, 3 leads are able to simultaneously monitor multiple regions of the heart.

Types of electrodes:

Wet electrodes uses electrolytic gel and causes skin irritation. In Sticky pads, electrode is pasted on patient skin and it is disposable. Metal clips are cheap, reusable but need large contact area. In suction type electrode, no adhesive is required but not suitable for long term monitoring. Whereas Wireless electrodes are used in WBAN's and it includes on-chip signal conditioning unit and wireless module. Wearable Type electrodes are used in Lifestyle products.

Recent Developments:

MEMS based ECG sensors: Latest technology has paved a way to design a novel MEMS-based electrode for ECG Measurement. . Compared with conventional ECG electrodes, micromachined electrode is more comfortable; no direct contact of gel with the human skin and imposes no side effects to human for long term measurement. A unique characteristic feature of the proposed electrode is that the micro needle array is made of heavily doped silicon, which is electrically Conductive and eliminates the requirement to dope Ag/AgCl or metal layer on the microneedles for electric contact. The microneedles can directly pierce through the outer skin surface, lowering the electrode-skin-electrode impedance (ESEI) and eliminating the need for skin preparation which is prerequisite for wet electrode. [2]-[3]

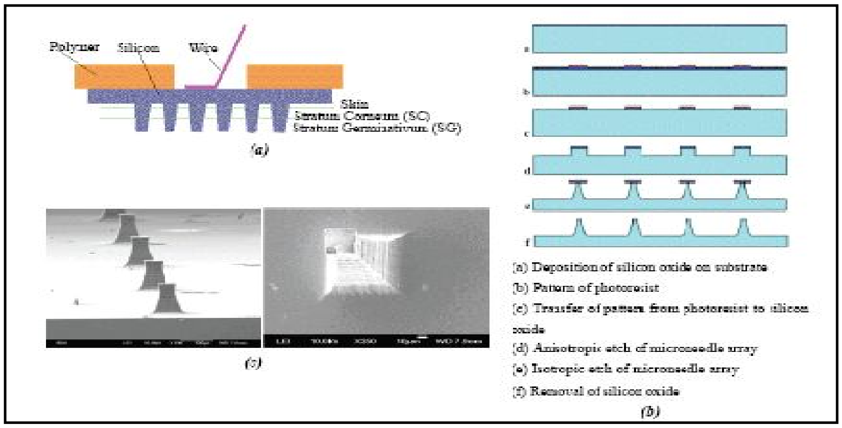


Figure 4: Construction of MEMS based ECG Electrode (a) Schematic view of novel micromachined electrode, (b) Micomachining process(c) SEM photos of Microneedle array and Microneedle [2]

Another important research is “Miniaturized One-Point Detectable Electrocardiography Sensor for Portable Physiological Monitoring Systems**”.**In this, a mechanically flexible ECG sensor for one-point detection was proposed. The ECG sensor consists of an outer hook-shaped sensing electrode and an inner circular-shaped referencing electrode. The ECG measurement capability was examined by attaching the sensor to the human chest at different positions. Performance of the proposed sensor was then compared with that of the commercial Ag/AgCl electrodes. The results of this letter demonstrated that ECG could be measured using the proposed sensor at only one point on the body.[4]

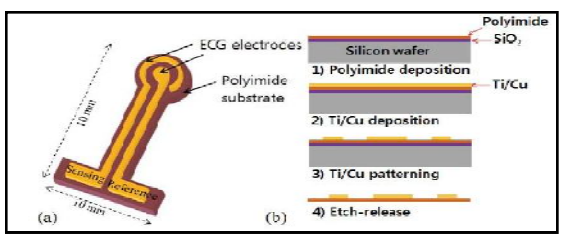


Figure 5: (a) Schematic of the ECG sensor. (b) Sequence of the steps used to fabricate the MEMS-based ECG sensor.

ECG signal quality can be improved by following ways:

Good skin preparation-Skin is a poor conductor of electricity and may create artifact that distorts the ECG signal.

Use of quality Electrodes-All electrodes selected should be of the same brand and type to help minimize noise.

Proper electrode application-explain the electrode application procedure to the patient to decrease anxiety and increase relaxation.

Good electrode-to-patient contact-Once attached , electrodes should not move in any way.

Artifact removal-To reduce muscle tremor and patient movement, attempt to warm a shivering patient or make them more comfortable in a reclined position.

1.2.2 Analog Front End Unit

ECG Analog front end unit includes amplifier and filter circuitry.The main challenges in the design of analog front end circuits are associated with the nature of physiological signals. In order to deal with ECG signals whose amplitude range from 1mV to 5mV, the analog front end should be designed with low input referred noise, reconfigurable bandwidth and programmable gain to accommodate the weak signal and high dynamic range.

For affordable applications, instrumentation amplifier can be used.

A normal ECG signal falls in the range of 1 – 5mV. Amplifier is required to increase this weak signal into an acceptable level for practical purposes. The amplification system consists of two-stage amplification where the first stage is the instrumentation amplifier and the second stage is the operational amplifier. The gain is computed using this equation:

$$G = \frac{49.4\ K\,\Omega}{R_G} + 1$$

For accuracy, R_G was chosen 5.49K, 1% tolerance, so the gain achieves approximately 10. The second stage amplifier is designed to produce a high gain of 100. Thus, the overall output voltage from this amplification circuit is kept to a range of 1 – 5V.[5]

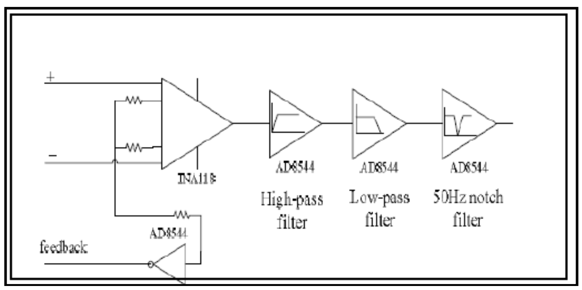
The requirements of an IA include

- Stability in low gain(Gain 1-10)
- High common mode rejection

- Good swing to the output rail
- Very low offset and drift

Fan Aihua et al in china proposed an ECG signal detection front end. The signal first level amplifier used high accuracy ,low power consumption instrumentation amplifier INA118 , ADI (Analog Devices Inc) AD8544 is used as the second level amplifier and with PF(>0.5Hz), LPF(<110Hz) and 50Hz notch filtering.[6].

Sungkil Hwang et al in Tuffs University designed an asynchronous ECG acquisition system with a low noise front end amplifier, with a tuneable bandwidth, an asynchronous ADC and a DSP. The advantage of this design is the signal dependent sampling rate which makes it attractive for compact ECG systems.



Figuer 6: ECG analog front end [6]

Texas Instrument has designed a complete analog front end for ECG named ADS1298. It is eightchannel,24-bit first in a family of fully integrated analog front ends (AFEs) for patient monitoring, portable and high-end electrocardiogram. The advantages of this include Reduce components and board size by 95%, 1mW/channel reduces solution power by 95% and Single-chip solution increases system reliability and patient mobility.[6]

CARDIC (p/n AUM441CX) is a low power integrated circuit which is a multi Sensor front end acquisition system with onboard ADC (12bit @ 83KS/sec) and serial interface communication protocol[7].This IC has channels for ECG recording and measurement of vitals like Blood Pressure and temperature.

A product by National Instruments named low cost E-series PCI-6034E is data acquisition board which is included with NI-DAQ software. This software integrates the full functionality of DAQ hardware to LABVIEW for further display and processing.[8].

The system on chip concept applied to front end design improves performances in terms of cost, area, speed and power consumption compared to discrete or partly integrated solutions. An SOC for ECG acquisition and processing is discussed in [9] which include features like time sharing of amplifiers within ADC in order to lower the power consumptions and to save area, Built In Self Test (BIST) and auto calibration capabilities to enhance reliability.This unit serves a basic unit of the system as it provides the signal in appropriate form and electrical characteristics required for further processing.

Filter circuitry:

An ECG signal is often stained by noise produced by various sources like 50Hz power line interference, low frequency baseline wander up to 0.5Hz and disturbances due to electronic components.

Band Pass Filter Circuit:

The conventional ECG signal frequency range is 0.05-100Hz and it contains the main energy components. Therefore a BPF is designed to pass this frequency band and make the signal out of the range significantly attenuate. This BPF is constructed as cascade of low pass filter of 100Hz and high pass filter of 0.05 Hz.

The Cutoff is given by the formula : $f=1/2\pi RC$

Low Pass Filter Design: For Cutoff frequency of 100 Hz, RC elements are chosen as

$R1=15M\Omega$, $C1=0.1nF$

High pass filter Design: For Cutoff frequency of 0.05 Hz, RC elements are chosen as

$R1=6.8M\Omega$, $C1=0.47\mu F$

Notch Filter Circuitry: In the process of signal detection 50Hz interference is the main interference of ECG signal. A notch filter is used to eliminate this.A notch filter is a band-stop filter with a narrow stop band (high Q factor). Other names include 'band limit filter', 'T-notch filter', 'band-elimination filter', and 'band-rejection filter'.

Typically, the width of the stop band is less than 1 to 2 decades (that is, the highest frequency attenuated is less than 10 to 100 times the lowest frequency attenuated). In the audio band, a notch filter uses high and low frequencies that may be only semitones apart. Here the notch filter is constructed by the operational amplifier TL074.

1.2.3. Processing And Analysis Platforms:

Originally, ECG systems were intended to just display the heart electrical activity.The latest devices include the capability to do large amounts of autonomous signal analysis to reduce the burden on the person using it. Here different platforms are discussed.

Texas Instruments DSP (TIMS320C67X) based starter kit (DSK) with a two electrode ECG preamplifier. This kit is provided with an integrated development environment (IDE) called Code Composer Studio (CCS).This CCS is a high level language which has built in FFT, wavelet and other functions for signal processing. The kit has a built in 16bit CODEC to acquire the ECG signal. The kit can process 5000 samples and can display 2048 samples a time[9]

Another platform for effective acquisition and processing of ECG is Matlab. It is universally accepted data processing platform. Its connectivity with many advanced programming languages (C, Java, and VB) and available of a wide range of signal processing tool boxes makes it popular use in ECG system too. Automatic ECG analysis using different techniques provides the patient the cardiac information or assists the cardiologist in detecting abnormalities.

The advent of Virtual Instrumentation has revolutionized the way the circuits are designed and the processing methods. Labview is one such platform which uses PC to perform measurements, calculations and analysis for testing. The advantages include its flexibility and automation feature. It is a graphical programming technique. It has number of built in tools which makes it so powerful. The toolboxes which could be used for our application include Digital Filter Design, Advance Signal Processing, Spectral measurements etc. Another added feature is that it can also include visual and audio alerts for better conveying the information.

The development of embedded systems based on Linux Operating system is most among the Smart Devices and embedded System Developers, covering 45.5% of the projects. It has been successfully ported to different architectures like ARM9.ECG algorithms like filtering, analysis and detection of arrhythmias and heart patient’s diseases in real time could be effectively implemented using this Linux platform.The display of ECG could be made on the following depending on the type of application for which it is used. The first ECG was recorded on an optically sensitive plate.

Display	Application
Graph Paper	Clinical Applications
Computer	Research and Surgery
LCD or Touch Screens	Portable or Handheld
PDA or Mobile phone	Telemedicine

Table 3:Various ECG display options

The display of ECG on a graph paper would require a printer to be interfaced to the ECG system. Data acquisition cards are needed to display the ECG on computer monitor. The display of ECG on LCD or Touch Screen would require a powerful microcontroller. PDA and Mobile phone displays would require suitable mobile software for display operations.

1.2.4 Latest Products

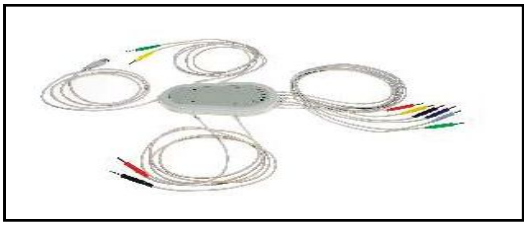
Many companies like Freescale, Microchip, Texas Instruments ,Maxim , Analog Devices ,GE healthcare and many more have proposed solutions for components of an ECG system. They include ICs for amplifiers, Filters, battery management, protection circuitry, microcontrollers, LCDs, audio alerts etc.

Some companies have designed their own ECG monitor as discussed below.

Neurosynaptic has developed an ECG machine with USB interface. It is 12 channel system with simultaneous acquisition. It provides a world class diagnostic ECG and has optional upgrade to include fetal ECG. Its small size makes it to be carried anywhere easily.

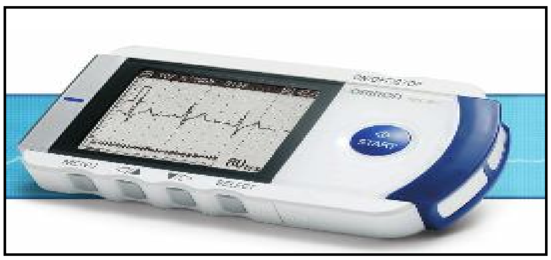
The world’s smallest wearable cardiac monitor called the silicon locket is developed by IIT professor in collaboration with TCS. It is a real time cardiac monitor which can perform classification of heart beat and severity of cardiac condition. It can act as Bedside Monitor, Holster Monitor and a portable ECG monitor. It can contact the monitoring centre when cardiac disorder is detected.

The available commercial products uses 3 leads or 12 leads and latest ones just use palm electrodes for recording of ECG. They offer data transfer capability through interfaces like USB. They are lightweight and hence can be used as a life style product.



a)*Neurosynaptic*

b)Silicon Locket Cardiac monitor



c) Omaron Portable ECG Monitor

d) Welch pocket Resting ECG

Figure 7: Few Examples of market ECG products

Sl No	Product Title	Important Features
1	Biolog 3000i	Built-in backplate chest electrode. Low weight 270gm

2	Welch Allyn Pocket ECG	Can carry to any remote locations, Based on windows CE(Pocket PC) platform
3	Omaron HCG801 portable ECG Monitor	Fast recording within 30s Can be used in home,clinics,hospitals
4	GE MAC 800 Resting ECG Analysis System	Can record upto 250 ECGs Multiple communication options
5	Prince 180B Easy ECG Monitor	Simple measurement of 1 channel ECG LCD display with backlight
6	Jindal Hand Held ECG Monitor	Exquisite,compact and comfortable design Easy carry, simple operation, Quick result

Table 4. some portable ECG products available in market.

2. Conclusion

There is a growing demand for affordable, portable ECG machine.The remote monitoring of the patients proposes to tackle this problem,by using portable monitoring systems.So by choosing the appropriate components suitable for portable applications, portable ECG machine can be developed. It is especially required that these systems can perform reliable measurements, they have extended power autonomy, and also they are generic enough for reducing the costs.

3. References

1. Medical Electron: Front end of electrocardiogram, Texas instruments Corporation website.

2. Eng Hock Tay, Dagang Guo," Development of A Wearable an WBAN-Based Vital Signal Monitoring System for Low-cost Personal Healthcare in Qatar", Biomedicine Poster Presentation, Singapur, 2009, pp 96-97.
3. Yu Mike Chi," Dry-Contact and Noncontact Biopotential Electrodes: Methodological Review", IEEE Reviews In Biomedical Engineering,ISBN: 1937-3333 2010,DOI:10.1109/RBME.2010.2084078 ,vol. 3, pp 106-119.
4. Hong-Lae Kim, Min-Gu Kim, Chungkeun Lee, Myoungho Lee, and Yong-Jun Kim, IEEE SENSORS JOURNAL, VOL. 12, NO. 7, JULY 2012 "Miniaturized One-Point Detectable Electrocardiography Sensor for Portable Physiological Monitoring Systems"
5. Yin Fen Low, Izadora Binti Mustaffa, Norhashimah Binti Mohd Saad, Abdul Hamid Bin Hamidon,Faculty of Electronics and Computer Engineering,Kolej Universiti Teknikal bangsaan Malaysia,Locked Bag 1200, Ayer Keroh, 75450, Malacca, Malaysia. "Development of PC-Based ECG Monitoring System".
6. Dipali bansal, Munna Khan, Ashok K Salhan,"A computer wireless system for online acquisition, monitoring and digital processing of ECG waveforms", Computers in Cardiology and Medicine 39, 2009, DOI:10.1016/j.compbiomed.2009.01.013 ,vol 39, issue 4,pp 361-367.
7. C Zywietz , G Joseph, R Fischer, "A system for integrated ECG analysis and cardiac emergency care",Computers in Cardiology 2000 Proceedings, Cambridge, MA,2000, DOI:10.1109/CIC.2000.898644 pp 793-796.
8. Z D Nie , L Wang et al ,"A Low Power Biomedical Signal Processor ASIC Based on Hardware Software Codesign",31st Annual International Conference Of IEEE EMBS, USA,Sep2009,DOI:10.1109/IEMBS.2009.5335295 pp 2559-2562.
9. D. Balasubramaniam, D. Nedumaran," Implementation of ecg signal processing and analysis techniques in digital signal processor based system" Memea-International workshop on medical measurements and applications, Italy,May2009,DOI:10.1109/MEMEA.2009.5167955, pp 60-63.
10. "Low cost ecg monitor for developing countries", Brian A. Walker, Ahsan H. Khandoker, And Jim Black Intelligent Sensors, Sensor Networks and Information Processing (ISSNIP), 5th International Conference,Australia,2009.
11. " Essentials of Medical Physiology", K Sembulingam ,Prema Sembulingam, 5th Edition, JAPEE Brothers Medical Publishers(P) Ltd,2010,ISBN:978-81-8448-704-6.

12. "Design of Portable ARM Processor based ECG Module For 12 lead ECG Data Acquisition and Analysis", Chandrashekhar Ghule , Dr. D.G. Wakde , Gurjinder Virdi, Neeta R. Khodke, 2009 IEEE.