Volume 3, Issue 4, April 2013 ISSN: 2277 128X
International Journal of Advanced Research in Computer Science and Software Engineering
Research Paper
Available online at: www.ijarcsse.com

Design of ECG Data Acquisition System

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Abstract— ECG, electrocardiogram plays a vital role in the diagnosis of heart related problems. Good quality ECG is used by the doctors for identification of physiological and pathological phenomena. ECG is very sensitive in nature and even if small amount of noise interferes with it, the characteristics of the signal change. The main objective of the processing of ECG signal is to provide us the accurate, fast and reliable information of clinically important parameters like duration of QRS complex, the R-R interval, occurrence, amplitude and duration of P,R and T waves. This demands that the pre processed waveform should be free from noises, which in turn depends on the method of recording the ECG from the patient's body. In this paper two important methods of ECG data acquisition are enlisted, the 3-lead and the 12-lead ECG data acquisition systems.

Keywords— ECG, VCG, AFE, 12 – Lead System, 3-Lead System, Cardiac Vector, Einthoven's Triangle

I. INTRODUCTION

ECG is a continuous record of voltage changes as a result of physiological changes occurring in the heart muscles. It is usually recorded from the skin using electrodes that are connected to a galvanometer (surface ECG). It can also be recorded by positioning electrodes in the oesophagus in the chambers of heart or directly from myocardium (transesophagial ECG). Surface ECG is the simplest and least expensive technology for diagnosis of cardiac diseases [1]. One of the important considerations in the ECG acquisition is the bandwidth requirement. For a clinical 12 lead ECG, the bandwidth is 0.05-100Hz however for intensive care patients and for ambulatory recordings the bandwidth is 0.5-50Hz only. This is because for ICU patients the more important is the rhythmic disturbances. Various ECG systems have been developed. They can be classified into following categories, namely conventional 12-lead ECG systems, body surface mapping systems (BSM), vector cardiographic (VCG) systems, and Ambulatory ECG monitoring [2]. Conventional 12-lead ECG systems use 10 electrodes on the patient's body to form 12 leads. In clinics it is this 12 lead ECG system which is used and cardiologists are well trained to read these ECGs. Because of this reason a huge number of ECG systems are using 10 electrodes and placement configuration which are further discussed in this paper. Electrocardiographic body surface mapping (BSM) is a technique that uses a number of leads (generally 80 or more) to detect electrical activity of the heart. BSM systems generally consists of an 80-lead (made from 32 to 212 electrodes) disposable electrode array in the form of a sleeveless garment (vest), that includes a conducting gel. This gel is applied to the subject's chest and back. This system displays clinical information in three forms; a 3-D torso image, an 80-lead single beat view, and the 12-lead ECG. The torso images are said to allow the specialist to rapidly scan the heart for significant abnormalities. However, the complexity of the placement of these electrodes on the human body in BSM systems hinders their wide employment in the clinical environment. In VCG systems body surface potentials are obtained that are used to generate a three dimensional vector model of the cardiac excitation. Based on a hypothesis that the electrical activity of the heart can be represented by a stationary dipole, the potentials recorded at the three leads are proportional to one rectangular component of the assumed heart dipole vector [3].

II. IMPORTANT COMPONENTS OF ECG ACQUISITION SYSTEM

Initial healthcare systems were generally developed for hospital applications. The healthcare systems are changing due to raising healthcare costs, busier lifestyles, increasing population, strengthening health consciousness and growing economy. Eventually there is a need for radical changes in how health care will be provided, targeting preventive care, effective provision of continuous treatment, personalized and connected health [4]. Nowadays cardiac healthcare is the fastest growing field of research, as cardiovascular diseases are one of the leading causes of death in the world. Out the various medical or healthcare information sources, electrocardiogram is best way to measure and diagnose the different abnormalities in the functioning of the heart .Since it is measured by externally placing electrodes on the body; it is painless, also inexpensive and measuring quantity and thus has become one of the most vital in the area of healthcare. The ECG machine has a vast history that has lead to its prominently visible future in medical science. In 1856, Mueller discovered the electrical activity of the heart i-e, repolarisation (heart in its relaxed condition) and depolarization (when contraction occurs) due to different electric potentials of cells in the heart muscles. Alexander Muirhead attached wires to a feverish patient's wrist to obtain a record of his heartbeat while studying for his D.Sc (in electricity) in 1872 using a Lippmann capillary electrometer fixed to a projector. The trace from the heartbeat was projected on a photographic plate which was itself fixed to a toy train. In 1903, the first practical electrocardiogram was recorded by Holland physiologist

W. Einthoven when he first developed the string galvanometer, and recorded the practical electrocardiogram on an optically sensitive plate through an optical amplifier [5]. With the advancements in the science and technology particularly the development of electronic technology, fabrication technology, microelectronics and tremendous development in information technology has made a great way in reducing the size of electronic equipments. These developments like small sized ECG amplifiers and other circuitry used with PC lead a transition from large sized ECG system to pocket sized ECG monitoring systems. Before coming to our discussion on 3 lead systems and 12 lead systems, let us first consider the main components of an ECG acquisition system. There are basically three components involved in the design of an ECG acquisition system which include an analog front end unit, microcontroller and processing unit and the display and analysis unit. The features and architecture of these units vary according to the application i-e; the purpose for which the ECG is being acquainted A brief introduction of these components is given as:

A. Analog front end unit

The analog front end (AFE) units of the ECG acquisition systems are typically designed with components from various semiconductor vendors or they can also be designed as application-specific integrated circuits (ASICs) [6]. The cost of application specific integrated circuits for AFE units goes in millions of dollars and most of the medium and small companies can't afford. The first and foremost function of the AFE unit of ECG acquisition system is to fully understand the signal that is to be processed by the system. Thus the front end of an ECG acquisition system must be able to deal with extremely small voltage signals ranging from 0.5 mV to 5.0 mV, combined with a dc component about 300 mV, resulting from the contact between electrode and skin and a common-mode component of up to 1.5 V, resulting from the potential difference between ground and the electrodes. The primary components of a traditional discrete ECG AFE unit include ECG sensor, instrumentation amplifiers, operational amplifiers that implement low pass and high pass filters, and analog-to-digital converters (ADCs). The first unit ECG sensor/electrodes serve as an interface between the patient's body and the electric circuitry. The ECG acquisition system may be 3 lead, 5 lead, 6 lead or 12 lead. Any of these systems could be used depending on the application and complexity of the placement of electrodes. The important design considerations for a sensor are [7]:

- It should be able to sense very low amplitudes in the range of 0.05 to 10 mV.
- Should have high input impedance of >5 mega ohms.
- Low input leakage current <1 μA.
- Flat frequency response 0.05-150Hz.
- High common mode rejection ratio.

The instrumentation amplifier is adopted as the preamplifier in the analogue front-end system to obtain a high common mode rejection ratio. Besides providing high common mode rejection ratio, the instrumentation amplifier with chip INA-128 also provide a high precision, low power consumption, and low quiescent current. Also the gain of this amplifier (with INA-128) can be adjusted to an appropriate level to fit the operation condition of the chip [8]. The filter section of an AFE unit of ECG acquisition system consists of a high pass filter with cut-off frequency greater than 0.5Hz, a low pass filter with cut-off frequency less than 110Hz and a notch filter of 50Hz frequency [5]. The high pass and the low pass filter give us the bandwidth of the ECG signal while as the notch filter is used to remove the power line interference from the signal. The last stage of the analog front end unit is the analog to digital converter (ADC). The analog front-end hardware for an ECG acquisition unit could be reduced if we use with it an ADC with very high resolution (approximately 24 bits) and high-speed (approximately 100 kbps).Such a solution is possible using the latest high-speed, high-resolution delta-sigma ADC from Texas Instruments. Fig 1 below shows a schematic of AFE (without ADC).

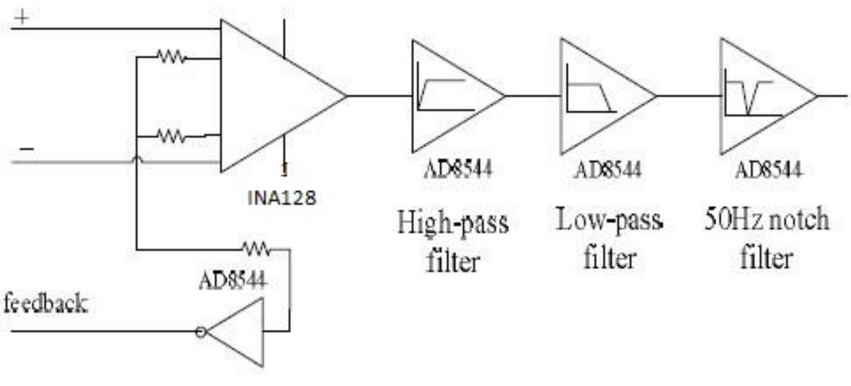

Fig 1 Analog front end unit (without ADC)

B. Microcontroller and processing unit

For any embedded medical device like heart rate monitor or other wearable or implantable devices such as continuous health monitors and Pacemakers, microcontrollers are considered as the most important part. Once the data is accumulated, it has to be processed. The processing of this data is carried out by the micro controller. The processing steps may include serial port transfer of the data, read/write operation or other arithmetic operations. Some of the microcontrollers used for this purpose are

- ARM7 processor provided by Atmel. This is a 32 bit processor particularly for mobiles and low power devices.
- The second one is the MSP430 which is provided by the Taxas Instruments. This is a 16 bit microcontroller. This can be used for a wide range of low power and biomedical applications.

The latest technology is the invention of the biochips. The biochips can be used for a variable no of ECG applications. Advantages of biochips are improved capability of performing real time processing of input data, faster reaction to abnormal heart alterations and higher accuracy of diagnosing heart diseases.

The choice of a microcontroller is very important as it provides an exact combination of programming, cost and power consumption.

C. Display and analysis unit

The display units are used to analyse the acquired ECG waveform. Initially a CRO was used to analyse the ECG waveform. Nowadays ECG waveforms are printed on the graph papers. Also due to modern technologies ECG obtained from the patient's body are directly displayed on PCs and LCD monitors and on PDAs. Also these PCs are provided with the software that is very fast in extracting the different components of the waveform. This software is capable of doing enormous amount of signal processing to reduce the burden on humans and also produce the results which are easily interpreted by the specialist. There are two options to transfer the acquired ECG to the PC, one is wired option i-e; through the serial port and other is the wireless (Bluetooth). The microcontroller unit is connected with the PC or LCD by a serial communication port to display results on it. Special type of hardware is developed by a no. of companies like the Taxas Instruments, Analog Devices etc for performing signal processing operations on a very high speed in millions of floating point operations per second (MFOPS). An example of such a system is DSK (Digital Signal processing KIT), TIMS320C67X. 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 [9].

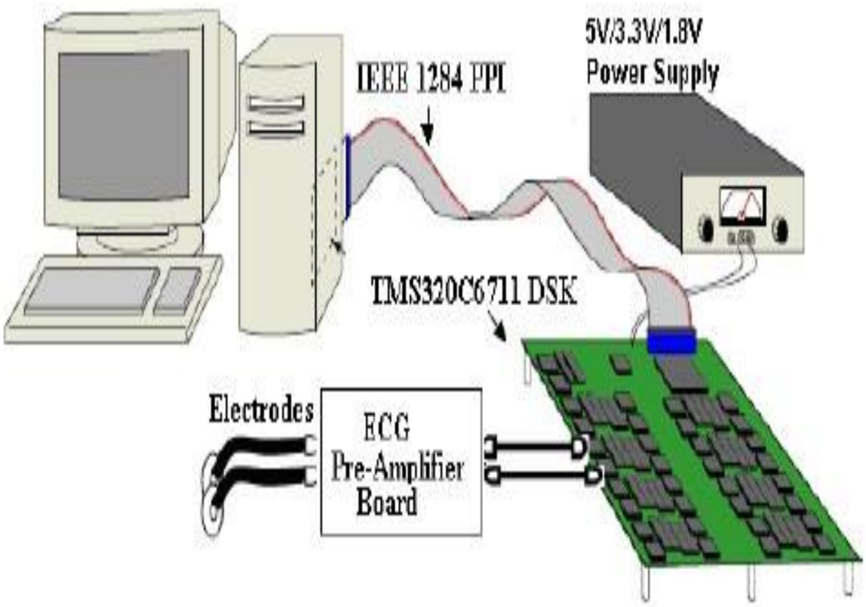

Fig 2 DSP starter kit based ECG analysis setup

Now a days universally accepted platform for signal processing is Matlab. Its properties like easy connectivity with programming languages like (C, Java, VB) and also availability of wide range of tool boxes like Signal processing toolbox, communication tool box, filter design tool box etc make it a very important tool for ECG processing also [10].

III. ECG DATA ACQUISITION SYSTEM

A. 12-Lead ECG data acquisition system

The standard 12 lead ECG acquisition system has a total of 10 electrodes which combine to form 12 leads. Out of these three leads are bipolar and as such are called bipolar limb leads. These are designated as [1]:

- Lead I measures potential difference between Right arm (RA) and Left arm (LA).
- Lead II measures potential difference between RA and Left leg (LL).
- Lead III measures voltage between Left arm (LA) and Left leg (LL).

The other nine leads are unipolar. Out of these unipolar leads, three are called augmented leads and designated as aVR, aVL and aVF. These leads are formed by connecting leads I, II and III by simple resistive networks. aVR measures right arm signal, aVL measures left arm signal and aVF measures left foot signal. The other six leads are called precordial leads. These record the potential between electrodes on chest wall and central terminal (point formed by connecting the RA, LA and the left LL electrode together. The average potential at this terminal is zero). Surface ECG leads can be thought of as mere reflections of the cardiac vector (the cardiac vector gives the direction of depolarization in time. The ECG measured from any one pair of bipolar leads is time varying, one dimensional projection of the cardiac vector and can be represented by using Einthoven's triangle) on the sides of Einthoven's triangle (hypothetical triangle for which limb leads form three vertices). The placement of electrodes in case of 12 lead ECG systems is shown in the fig 3 below:

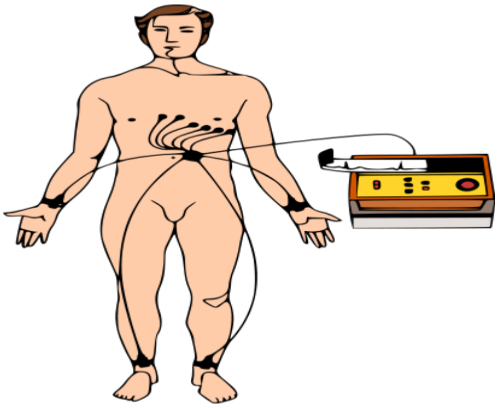

Fig 3 Placement of electrodes in case of 12 lead ECG

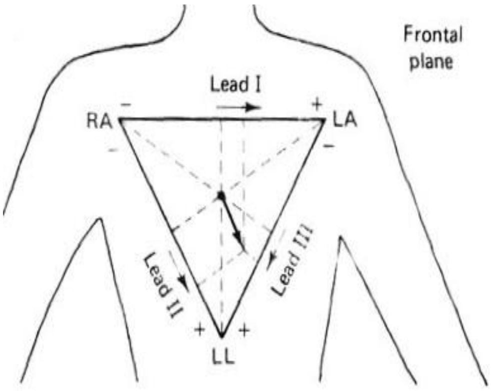

Fig 4 Einthoven's triangle and cardiac vector.

The augmented limb leads are derived from the limb leads as :

$$aVR = RA - \frac{1}{2}(LA + LL) = \frac{3}{2}(RA - V_W)$$
$$aVL = LA - \frac{1}{2}(RA + LL) = \frac{3}{2}(LA - V_w)$$
$$aVF = LL - \frac{1}{2}(RA + LA) = \frac{3}{2}(LL - V_w)$$

The augmented leads are amplified in this manner because the amplitude of signal is very low to be useful. These augmented limb leads can also be calculated using I and II leads only.

$$aVR = -\frac{I+II}{2},\quad aVL = I - \frac{II}{2},\quad aVF = II - \frac{I}{2}$$

Table 1 Clinical lead group

CATEGORY	COLOR	LEADS	ACTIVITY
Inferior leads	Yellow	II, III and aVF	Look at electric activity of heart from diaphragmatic surface of heart (inferior surface).
Lateral leads	Green	I, aVL, V5 and V6	Look at electrical activity of heart from vantage point of lateral wall of left ventricle. The positive electrode of leads I and aVL is located distally on left arm because of which these leads are sometimes referred to as high lateral leads. For V5 and V6 as they are located on patients chest, they are sometimes referred to as low lateral leads.
Septal leads	Orange	V1 and V2	Look at electrical activity of heart from septal wall of heart.
Anterior leads	Blue	V3 and V4	Looks at electrical activity from stern costal surface of heart.

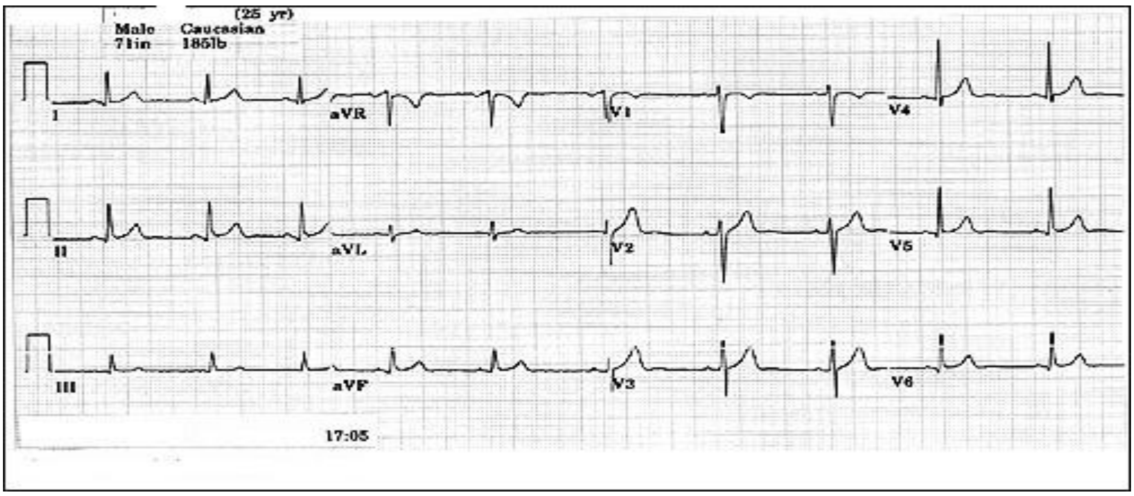

Fig 5 example of 12 lead ECG

B. 3-Lead ECG data acquisition system

In the three lead acquisition systems only three electrodes are used to form the leads. The electrodes RA, LA and LL are used. Actually two of the electrodes are used to form lead and the third is used as the ground. With the exception of the modified chest lead (MCL) all the electrodes have the same placement position as in the case of 12 lead system. For the MCL, we place lead I just to the right of sternum in the forth intercostals space with other two lead positions as such. The goal for the 3 lead acquisition system is to capture the three-dimensional extent of the heart dipole. For this, it is necessary to measure potential differences not just in the frontal plane, as in the limb leads, but along the antero-posterior (front-to-back) axis of the body. The fig 6 below shows the original 3 lead orthogonal system called the Frank lead system. In this system three subcomponent signals which are called x, y and z are recorded with electrodes and placed as shown in the figure 6 [11].

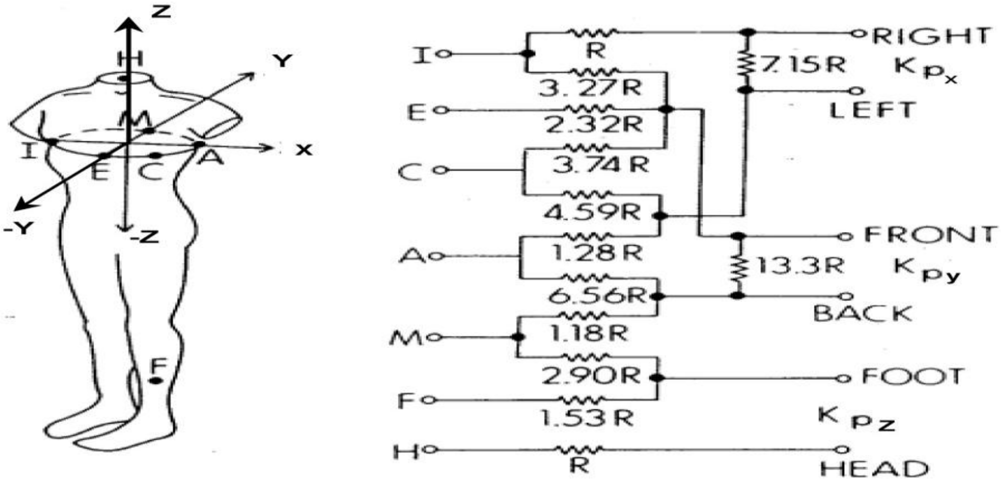

Fig 6 Frank electrode system to record the three-dimensional projection of the heart dipole

IV. CONCLUSIONS

The study of the cardiac arrhythmias is one of the most important aspects in the biomedical engineering as cardiac disease is one of the major causes of deaths in the world. The importance of the electrocardiogram in the diagnosis of cardiac diseases, demands the advances in the medical technology to develop low cost acquisition systems with increased efficiency. With the development of information technology, microelectronics and the communication technology, low power microprocessors, more efficient signal processors and obviously an efficient software platform/tool to analyse the results should be developed.

ACKNOWLEDGMENT

I am greateful to Mr.Vineet kumar, Astt Professor Lovely Professional University who helped me a lot in understanding different concepts in this study. Also i am grateful to my friend Mr Sunil Kumar, who helped me from time to time in completing this study.

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