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A Review on ECG System Design

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Abstract—

Portable low cost user friendly Electrocardiograph (ECG) monitoring system that can be affordable and manageable by the user is a great research area. The ECG system design, size, cost, performance, recording time etc. has undergone a great transition along with timeline. More efficient ECG systems, with compact low power embedded hardware technology and advanced signal processing platforms have emerged. The ECG system is used for patients, are now being used as a life style product. In this paper, a review on design of ECG machine dealing with blocks such as electrodes/sensors, analog front end unit, processors and recording/display unit are being discussed. By choosing appropriate components a portable ECG machine can be designed.

Index Terms—
Analog front end unit, Electrocardiograph (ECG), Long-time monitoring, Ultra-Low Power, Microprocessor/ Microcontroller, Portable size.

1. INTRODUCTION

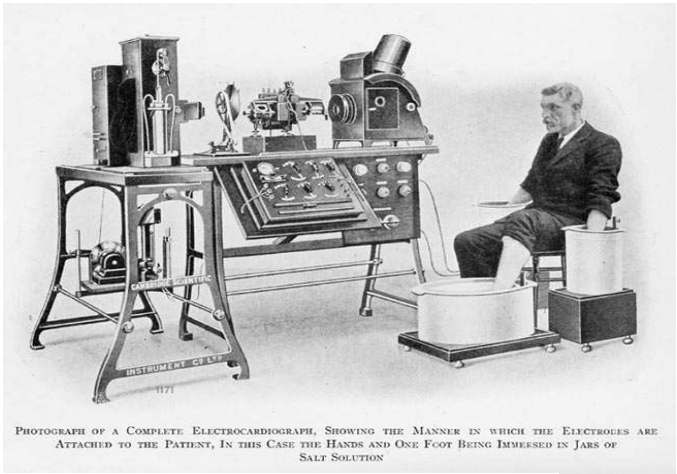
Electrocardiography (ECG or EKG from Greek word: kardia, means heart) [1] is a transthoracic (chest) interpretation of the electrical activity of heart over a period of time [3].

The non-invasive procedure is used for ECG waveform recording. The electrodes are placed on body skin where the electrical potential on the skin can be recorded: the recording is known as electrocardiogram [18]. This waveform is used to measure the rate and regulation of heartbeats, as well as the position and size of chambers of the heart.

1.1 Evolution of ECG

In 1887, Augustus De'sire' Waller was the first to record the electrical activity of the human heart. He called the record as an "electro-gram", later known as "cardiograms". Einthoven introduced the term which we now use as, "electrocardiogram".

In 1902, Einthoven published the first electrocardiogram recorded on a string galvanometer [5]. This electrocardiogram recording system developed by Einthoven became popular in various European countries and its large scale manufacturing started during a short period of time. The first electrocardiogram recording system is shown in figure 1.



PHOTOGRAPH OF A COMPLETE ELECTROCARDIOGRAPH, SHOWING THE MANNER IN WHICH THE ELECTRODES ARE ATTACHED TO THE PATIENT, IN THIS CASE THE HANDS AND ONE FOOT BEING IMMERSED IN JARS OF SALT SOLUTION

Figure 1: First Electro-cardiogram recording arrangement. [4]

1.2 Mechanism of ECG Waveform

ECG waveform is a graphical record of the heart's electrical activity and is used in the

diagnosis of heart disease. The ECG device detects and amplifies the tiny electrical signals on the skin. At rest, the heart muscle cell has a negative charge. Decreasing this negative charge towards zero is called depolarization[17].

Figure 2 shows the standard ECG Waveform of a normal human's heart and also mentioned P, QRS complex and T waves.

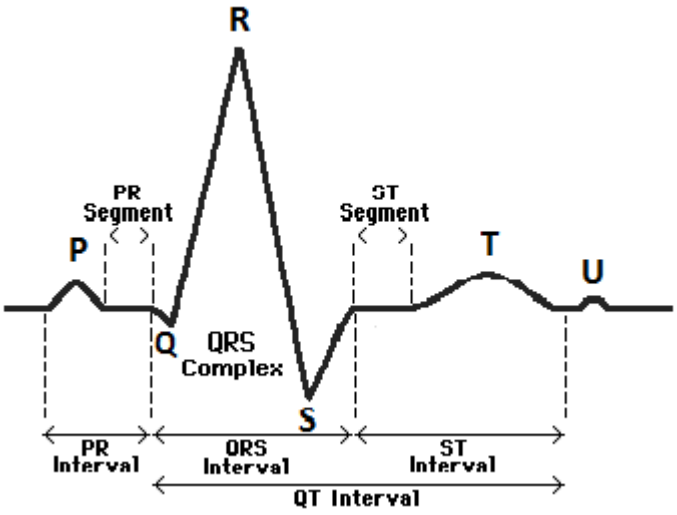


Figure 2: ECG Waveform.

Sinoatrial node (SA node, situated at the right top corner on heart and is called natural pacemaker) generates electrical impulses spontaneously. This electrical impulse is propagated throughout the right atrium and through Bachmann's bundle to the left atrium, making a 'P wave'. In other words, activation (depolarization) of atria is called "**P wave"**.

Atrioventricular node (AV node, situated at the lower part of the right atrium) is another mass of specialized group of cells. AV node is a source to generate the electrical signals. These electrical impulses travel from SA node to the AV node.

QRS complex: Composed of three individual waves, it is produced from ventricular depolarization and signals the onset of ventricular contraction.

T wave represents the repolarization of ventricles and precedes ventricular relaxation.

The ***U wave*** appears commonly in patients who have ischemia, hypokalemia or hypomagnesaemia. Often the U wave present in healthy people.

1.3 ECG Analysis

Modern ECG machines often include analysis software that attempts to interpret the pattern automatically. Advantage of an automatic ECG analysis leads to the gradual development of a commonly accepted set of diagnostic criteria [20].

Generally ECG machines print one or two "rhythm strips" as well along the bottom of the ECG paper. The lead II (which shows the electrical signal from the atrium, the P-wave, well) shows the standard rhythm for the whole time (usually 5–6 sec) with all leads [21].

Using Linux platform ECG algorithms like QRS detection algorithms, filtering analysis, detection of arrhythmias and heart patient's diseases in real time could be implemented effectively [20].

QRS detection algorithms, most of the simple QRS detection algorithms are based on one of the following methods: mathematical morphology, filter-banks, derivatives, wavelets, and correlation [20].

For easily performing the complex and tedious calculations, various mathematical platforms like Matlab, Scilab, and Lab-view etc are available. [21].

1.4 Applications of ECG

The various applications of ECG monitoring are available in the areas like health-care, sports, military, and home-care services etc. useful for personal ECG systems. The monitoring of patients away from doctor can be possible using advance communication technologies. [10]. Present ECG system designs are using low voltage operated processors, rechargeable batteries; Bluetooth, zigbee etc. [14].

2. OVERVIEW OF ECG SYSTEM DESIGN

Most ECGs are used for diagnostics or research of human & animal heart

abnormalities. There are basically three different categories for ECG system design:-

i. Commercial ECG systems for Hospitals.

ii. ECG systems for Clinical assessment.

iii. Personal ECG Systems for Homes or working areas etc.

Currently, the researchers want to find out something that could bring the ECG measurement out of the hospitals to homes, working area etc. However this necessitates the following two modifications to the ECG system design:-

i. The ECG machine has to be made more compact, user friendly & cost effective.

ii. The process of ECG analysis has to be incorporated within the ECG machine to reduce/eliminate the dependence on clinical assessment & cost.

In this context, microcontroller based systems have succeeded over digital signal processors (DSP) or field programmable gate array (FPGA) based embedded systems as far as portability [12] and cost effectiveness of circuit is concerned because DSPs are good enough only for numerical capabilities and FPGAs lack the user-friendliness of a microcontroller.

In the design of a microcontroller based ECG system, these major parts are used:-

1. ECG Electrodes/ Sensors
2. Analog front end unit
3. Microcontroller (Processing) Unit
4. Recording/Display unit

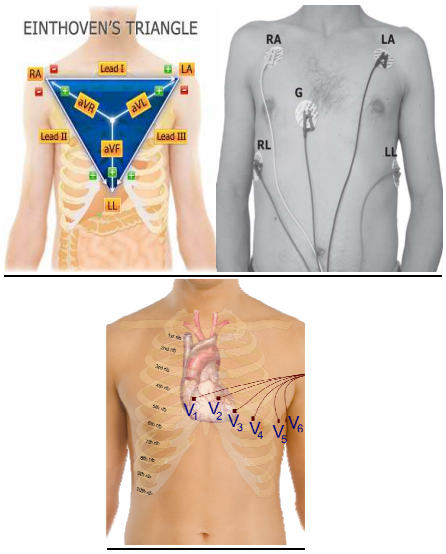
The features and architectures of these vary depending on applications. We have described these major parts below.

2.1 ECG Electrodes/Sensors

ECG electrodes make an interface between the heart‘s electrical activity and the further electric circuitry. The ECG system having different types of leads in quantity may be 12 leads, 6 leads ,5 leads or 3 leads. Depending on the clinical application or real time complexity with placement of electrodes used anyone leads system is employed. Figure 3 shows the Einthoven’s triangle & electrodes placement (a), (b) and (c) respectively.

Einthoven’s triangle is made by Bi-polar limb leads (I, II, III) and Uni-polar (augmented) limb leads (aVR, aVL and aVF).

For Unipolar Precordial leads (V_1, V_2, V_3, V_4, V_5 and V_6) the electrodes are placed directly on the chest.



(a) (b)

(c)

Figure 3: Electrodes placement & Einthoven’s triangle.

2.2 Analog front end unit

In order to deal with extremely weak signals (ranging 0.5 mV to 5 mV) the analog front end should be designed with low input referred noise, reconfigurable bandwidth and programmable gain amplifier.

Figure 4 shows the block diagram of Analog front end unit consisting of certain components such as Instrumentation amplifier, Filter, Analog to Digital converter, Oscillators, control register & SPI interface.

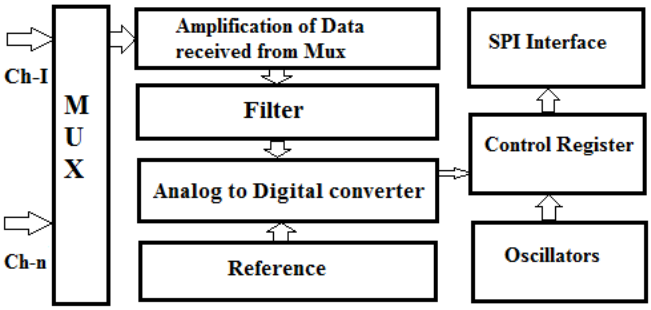


Figure 4: Analog front end block diagram.

Fan Aihua et al (china) [9] proposed an ECG signal detection front end. In this, the instrumentation amplifier integrated circuit (INA118) is used as a first level amplifier. INA118 has low power consumption & high accuracy. In the second level amplifier, used as ADI (Analog Devices) AD8544 with High Pass Filter (>0.5Hz), Low Pass Filter (<110Hz) and 50Hz notch filter.

Texas Instrument has designed a first complete fully integrated analog front end for ECG named ADS1298 for patient monitoring [9]. It has eight channels, 24-bit delta sigma (ΔΣ) analog-to-digital converters and filters [16]. It has advantages such as reduce components and board size till 95% make it portable, 1mW power consumption and Single-chip solution increases system reliability and patient mobility [8].

CARDIC (p/n AUM441CX) is a low power integrated circuit which is a multi-Sensor front end acquisition system with on-board ADC (12bit @ 83KS/sec) and serial interface communication protocol [10]. This IC has channels for ECG recording and measurement of vitals like Blood Pressure and temperature. 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.

2.3 Microcontroller (Processing) Unit

Microcontrollers play a key role in enabling portable devices (like health monitors) wearable and implantable devices such as pacemakers in medical electronics. The ultra-low power consumption of MCUs extends the battery life of these personal health devices [7]. Microcontrollers and processors further enhance the performance of the ECG systems. Microprocessor technology has been also employed in electrocardiographs to attain certain desirable features like removal of artifacts, baseline wander, etc. using software techniques (8).

The starter kit (DSK), based on DSP (TIMS320C67X) processors (Texas instruments) with a two electrode ECG preamplifier is provided with an integrated development environment (IDE) called Code Composer Studio (CCS). It has inbuilt FFT, wavelet functions for signal processing. The kit has a built in 16bit CODEC to acquire the ECG signal. It cans 5000 samples processing and 2048 samples display at a time [8].

Matlab software is another platform for effective acquisition and processing of ECG [6]. It is universally accepted data processing platform. It supports many advanced programming languages likes Java, C, VB etc., and having a wide range of signal processing tool boxes called “Simulink” [12].

In embedded systems, based on Linux operating system are the most popular smart devices and develops embedded system projects based on ARM processor [9]. ECG algorithms and heart patient’s diseases in real time could be effectively implemented using this Linux platform.

Medical Embedded Processor SoC with ARM Cortex-M3 requiring microwatt power consumption using for mapping medical applications [13]. Ultra-low power operation is achieved via 0.5 to 1V, a 28 fW/bit fully differential sub threshold 6T SRAM, a 90%-efficient DC-DC converter, and a 100-nJ fast Fourier transform (FFT) accelerator that reduces processor workload [7].

The MSP430 series microcontrollers from Texas Instruments are built around a 16-bit, low power RISC mixed-signal processor for embedded applications. The MSP430 microcontrollers has several low power modes, which disables the CPU and unneeded clocks, to reduce current draw to 1 uA (microampere) or lower while still keeping the peripherals active. The total system standby current of 1 μA will allow the instrument to operate with CR2032 220-mAh coin cell battery for over 20 years [7]. MSP430 series microcontrollers can wake up in less than 1 microsecond, which make a rapid response for external peripheral and keeping low power consumption [17]. It used in medical applications such as ECG, Heart rate monitor, Pulse Oximeter, Blood Glucose Meter, Digital Thermometer etc. Figure 5 shows the block diagram of ECG System design using MSP430 microcontroller.

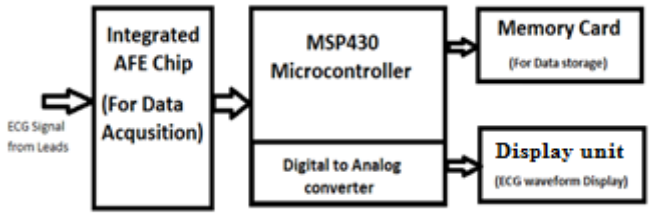


Figure 5: ECG using MSP430 microcontroller (Block Diagram).

The latest technology is the development of ECG biochip of variable ECG applications. The Block Diagram of ECG Biochip is shown below.

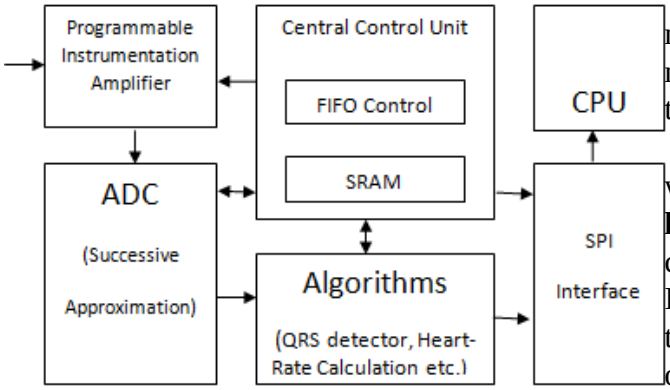


Figure 6: ECG Biochip (Block Diagram)

The advantages of Biochips are improved capability to perform real time analysis of input data, more accurate diagnosis of cardiac diseases and prompter reaction to abnormal heart alterations.

2.4 Display unit

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. After this ECG waveforms printed on a graphical paper. Presently the optically sensitive plate has been replaced with LCD/ TFT screen. ECG waveforms can be displayed on PC with the help of data acquisition cards. It has many features such as compact size, visualization clarity & low power consumption. The thermal printer and printing on thermal paper having compact size and we can analysis simultaneously, so due to these features widely used in ECG system.

2. PRODUCTS SURVEY

Many companies like Texas Instruments, Maxim, Analog Devices, GE healthcare, free-scale, Physio-Control, BPL, Microchip and many more have proposed solutions for components of an ECG system. They include ICs for amplifiers, Filters, protection circuitry, microcontrollers, LCDs, audio alerts, battery management etc. Some companies have designed their own ECG monitor as discussed below:-

Physio-Control was one of the first manufacturers to bring a combined monitor/defibrillator/12-lead ECG device to the pre-hospital setting in the mid-1990 [21].

Figure-7 shows the world's smallest wearable cardiac monitor called the **Silicon locket cardiac monitor** and is designed, characterized & developed by IIT professor at IIT Bombay and the silicon is fabricated through TSMC Taiwan. The device is optimized to acquire three simultaneous electrocardiogram (ECG) data and stores it in Micro SD card memory. An ultra-low power custom front-end IC (64-pin LQFP) for ECG signal conditioning is implemented in the analog section. The locket is equipped with an USB, RS232, IrDA and 2.4GHz direct sequence spread spectrum (DSSS) wireless connectivity for seamless integration in public network. The locket automatically sends an alert SMS to the doctor through mobile phone.

Figure 7: Silicon locket cardiac monitor

Figure 8 show the **Omron** FRHL-1104100 **portable ECG Monitor**. With this a recording of about 30 seconds can be made when symptoms occur at home or away. This ECG Monitor can be used in home, clinics &

hospitals. The, Heart scan ECG Monitor senses the heart waveform and indicates potential ECG abnormalities [19].

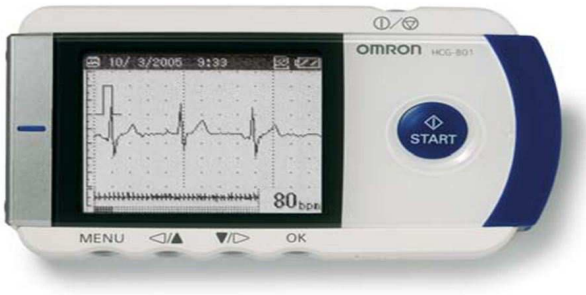


Figure 8: Omron Heart scan portable ECG monitor\

The Features of Collateral medical made **MD100B handheld ECG monitor** having small, portable and easy to operate, cable and electrode free measurement. It has 100 ECG records, Fast measurement (each record within 30-second) and after analysis gives the result. ECG waveform, heart-rate, analysis results and battery status display on LCD & results transmission to PC through USB mode, 13 kinds of analysis for arrhythmia. 2 batteries can take at least 500 times measurement [20].

Figure 9: Collateral medical made MD100B handheld ECG monitor (US FDA and CE approved).

3. CONCLUSION

There is a growing demand for affordable, portable/handheld ECG machine. The remote monitoring of the patients proposes to tackle this problem, by using portable/handheld monitoring systems. So by choosing the appropriate components suitable for portable applications, portable/handheld ECG machine can be developed. It can perform reliable measurements, extended power autonomy, and also they are generic enough for reducing the costs. By using low cost components and user friendly techniques, the product would reach to a common man. By integrating advances like communications, microelectronics, information technology, fabrication technology and power management an effective system could be designed meeting all the demands of developing countries.

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