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Android Based ECG Monitoring System

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Abstract: ***This document presents the development of a low power and portable ECG monitoring device based on MSP430 microcontroller and an Android Phone. This work is done in order to provide a reliable solution for cardiovascular patients who can help them analyze their ECG easily. There are many implementations of ECG monitoring devices at present but most of them are built using custom integrated ics. Moreover they are too expensive to be used in academic research and projects. An attempt is made to reduce cost and energy requirements and increase portability. This paper is divided into various sections. Section 1 discusses motivation behind this project. Section 2 puts light on ECG signals and noise which can corrupt an ECG signal. Section 3 describes design of Analog Front End of this project. Section 4 discusses software which is embedded into microcontroller and finally Section 5 explains the development of Android ECG app for this project.***

Keywords: ECG, MSP430, Android, Bluetooth, Mobile Health

1. Motivation and Background

Mobile computing platforms are going to dominate the information communication technology (ICT) sector in this age of rapid technological innovations. Mobile computing devices especially smart phones are complex communication and computing devices which have surpassed desktop PCs in terms of worldwide sales in just few years .Global ICT trends indicate that the future is definitely mobile as worldwide cellular subscriptions have reached 5.9 billion mark taking global penetration levels to 87% with 78% cellular density in the developing countries according to ITU`s current statistics. Nowadays, cardiac diseases are increasing in an alarming rate. According to the World Health Organization (WHO), cardiac disease is one of the leading causes of death in the developing world and is the leading cause in the developed world [1]. Mhealth (mobile-health) has become a key technology in the domain of healthcare. Health and medical application downloads will reach 142 million by 2016. The advantages of mhealth are unsurpassed when it comes to providing low cost healthcare delivery to unserved or under-served population. Mobile phones are already being used for increasing the effectiveness of public health programmes and managing/treating chronic diseases. The trend is compounded by the growing number of peripheral devices such as wearable biometric sensors. IBGStar glucometer [2] and ispirometer for measuring blood glucose and volume of air respectively are the success stories of Smartphone medical applications integrated with sensors. Management of diabetes, chronic pulmonary disorders and other chronic diseases are expected to play a larger role in market growth. It has been reported that cardiac monitoring devices have the most demand since insurers are likely to pay for them and heart disease is the one of biggest chronic disease for a high mortality rate in third world countries.

This paper discusses the implementation of a project which aims to develop an ECG monitoring system based on a smart phone platform. It is a low cost heart rate monitoring solution based on a low power MSP430 microcontroller, which is fully integrated with sensing electrodes on the transmitter side. The controller converts the analog signal to a digital signal via an inbuilt analog-to-digital converter, conditions and filters it for transmission via a Bluetooth transceiver IC compatible with the MSP430. The Bluetooth is chosen for its near-ubiquity in mobile phones apart from its lowest consumption as compared to Wi-Fi and GPRS. The real time data is received at the smart phone end and displayed in real-time. Android is the platform of choice because of its availability on most mobile phones apart from strong existing and future growth prospects. The android platform based smart phone will be used for diagnosis and will also be able to transmit captured images or videos to a healthcare center or a medical professional for specialist advice.

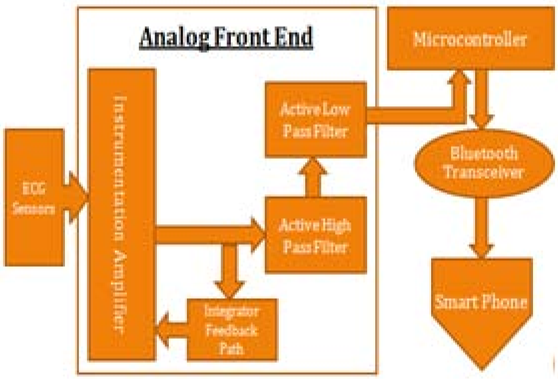
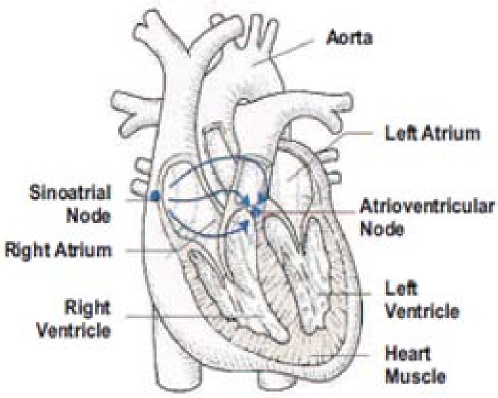


Figure 1: Block diagram of implementation

The benefits of the project are low cost, supporting mobility, readily available connectivity for transmitting information, early diagnosis and emergency healthcare via symptom moderating drugs. Figure 1 shows block diagram of our implementation.

2. ECG Signal and Sources of Noise in ECG Signal

This section discusses basics of ECG signal and different sources of noise in an ECG signal. An electrocardiogram (ECG) is a graph showing electrical activity in the heart. It is the trace of voltage generated by the cardiac muscle during a heartbeat as shown in figure 2. It has become a medical standard to test the human heart for defects and diseases. The heart generates an electrochemical impulse that spreads out in the heart in such a fashion as to cause the cells to contract and relax in a timely order and, thus, give the heart a pumping characteristic. This sequence is initiated by a group of nerve cells called the SinoAtrial (SA) node, resulting in a polarization and depolarization of the cells of the heart. This pulse travels from the SA node through the surrounding cells of the heart and then to the AtrioVentricular (AV) node. The AV node acts as a gate that allows the atria to finish contraction before allowing the pulse to move on to the ventricles. Each atrium pumps blood to a corresponding ventricle. The right atrium pumps blood to the right ventricle to provide blood to the lungs. The left ventricle, sourced by the left atrium, is the chamber that pumps blood throughout the body. Because this action is electrical in nature and the body is conductive with its fluid content, this electrochemical action can be measured at the surface of the body. An actual voltage potential of approximately 1mV develops between various body points.



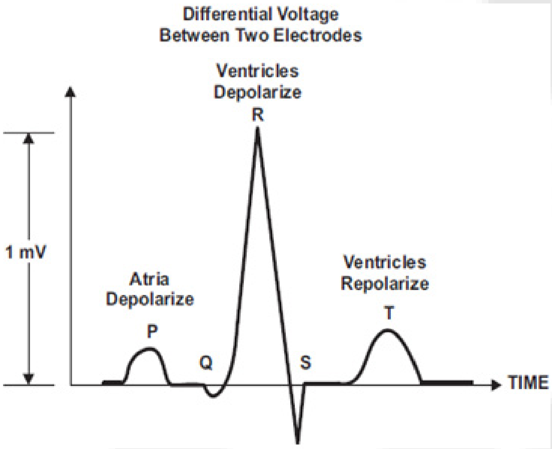


Figure 2: ECG Waveform

This can be measured by placing electrode contacts on the body. In this application, the subject's finger tips act as the differential point of contact with conductive pads to detect the ECG signal. The ECG waveform shown in figure 2, can be used for extrapolation of data such as the number of heart-beats per minute (BPM) and the values can range from 30 to 200 BPM or 0.5 to 4 Hz.

ECG interpretation relies heavily on the QRS complex [3]. It starts with a small downward deflection called a Q wave. It is narrow and small in amplitude. It is followed by first positive deflection of QRS complex called R wave. S wave is the first wave after the R wave that dips below the baseline. The end of the S wave occurs where the S wave begins to flatten out. This is called J point. The width of QRS complex often indicates the location of originating electrical impulse. Its duration is <0.11sec. The slope of qR segment determines the BW of the signal. Roughly it has duration of 0.04sec and the peak is approx. 1mV. Noise considerations also affect the BW of signal. The analog front end circuit for detection of ECG must be able to deal with extremely weak signals because raw ECG signal from electrodes ranges from 0.5 mV to 5.0 mV. It also has a dc component of up to ±300 mV that results from the electrode-skin contact plus a common-mode component of up to 1.5 V as a result of the potential between the electrodes and ground. The useful bandwidth of an ECG signal depends upon the particular application. It can range from 0.5 Hz to 50 Hz (for a monitoring application in intensive care units) up to 1 kHz (for late-potential measurements or pacemaker detection). A standard clinical ECG application has a bandwidth of 0.05 Hz to 100 Hz.

ECG signals may be corrupted by various kinds of noise [4]. The main sources of noise are:

- Power-line Interference: 50 Hz pickup and harmonics from the power mains
- Electrode contact noise: Variable contact between the electrode and the skin causes baseline drift.
- Motion Artifacts: Shifts in the baseline caused by changes in the electrode-skin impedance.
- Muscle Contraction: Electromyogram signals (EMG) are generated and mixed with the ECG signals [4].
- Respiration and Perspirations: Causes drift in the baseline
- Electromagnetic Interference: from other electronic devices, with the electrode wires serving as antennas, and noise coupled from other electronic devices, usually at high frequencies.

For meaningful and accurate detection, steps have to be taken to filter out or discard all these noise sources. But many things need to be considered while doing this.When filtering any biomedical signal care should be taken not to alter the desired information in any way [5]. A major concern is how the QRS complex influences the output of the filter. To the filter they often pose a large unwanted impulse. Possible distortion caused by the filter should be carefully quantified.A notch or low pass filter designed in analog or digital domain (FIR or IIR) with the cut off freq. = 50Hz can remove most of power line interference but at the cost of reduction of peak of QRS complex. Adaptive filtering needs to be done to cancel the effect of 50Hz power hum. Due to loose or improper contact between skin and electrode distortion is introduced in ECG signal as baseline wandering. It can cause problems to analysis of low freq components of ECG signal. Usually the noise due to this problem has freq < 0.5Hz. So this problem can be overcome by use of analog or digital high pass filter with a cut off freq smaller than 0.5 Hz such that it does not distort the signal. Linear filtering or polynomial fitting can be used to cancel out the effect of baseline wandering.

Due to motion of the person the skin to electrode impedance changes variably causing the dc offset drift which variably changes the position of base line of ECG. These artifacts generate abrupt shifts in ECG signal or extragenoeous low-frequency high bandwidth components. This problem can be resolved by the use of linear filtering and polynomial fitting to compensate the effect and a high pass filter with appropriate cut off freq.

EMG signal generated due to contraction of muscles can cause severe problems as low amplitude waveforms can be obstructed. This noise is not associated with a narrow band filtering but its more difficult since its spectral component overlap with that of ECG signal. The BW of EMG signal is 20 – 1000 Hz. This problem can be resolved by techniques like ensemble averaging [6]. Moreover low pass filter with cut off frequency<40 Hz can be used but at the cost of attenuation of ECG signal.

Respiration and Perspiration (effects electrode impedance) cause baseline wandering or low frequency high BW components. The effects can be removed by using high pass filter or linear filtering and polynomial fitting to cancel the effects. The human body, electrodes and the cables can act as antenna to pick up noises from electromagnetic devices. These sources are high freq. sources and their effects can be reduced to a great extent by using low pass filter with appropriate cut off freq.

3. Analog Front End

This section discusses the design of analog front end whose function is to pick analog ECG signals and transmit them to microcontroller after some basic filtering. This is the most critical portion of ECG measurement since the detection and filtering of raw ECG signal completely depends upon the components used and design so as to reduce the noise associated with ECG signal. The front end is divided into 4 stages (shown in figure 3) each with a specific function to reduce the noises mentioned above. The gain of the stages must be so that the noise offered by amplifiers is minimum. Noise figure of cascaded amplifier referred to input is given as,

$$F_1 + \frac{(F_2 - 1)}{G_1} + \frac{(F_3 - 1)}{G_1 G_2} + \frac{(F_4 - 1)}{G_1 G_2 G_3}$$

Where, F= Noise figure of stages and G= Gain of the stages.

The ECG electrodes are directly connected to the differential inputs of the amplifier. Due to CMRR the amplifier serves to remove common mode dc offset, common mode noise like 50 Hz hum and EM interferences to a considerable amount. The gain of this stage is limited by the noise components of ECG single and dc component in ECG signal which can cause saturation due to large amplification. The total gain of the amplifier is set to 24.

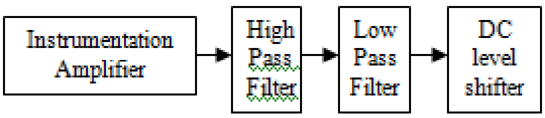


Figure 3: Analog Front End

High pass and Low pass filter stages are implemented using Sallen- Key topology [7]. It is an electronic filter topology used to implement 2^{nd} order active filters and is known for its design and implementation simplicity. Its characteristics include high input impedance, higher roll off rate (12dB/octave) and independence in setting gain and cut off frequency.

The high pass filter stage removes dc offset from the signal and also provides necessary gain to the signal. It removes noise generated due to base line drift and low freq. high BW components. The gain of filter is limited by the noises in the pass band like EMG signal, 50 Hz hum and EMC interferences etc. The design of the filter should avoid any distortion of the signal of interest. The operational used must be low noise and low dc offset. So, the gain of filter is chosen to be close to 11 with cut off frequency approximately 0.3 Hz.

The cut off freq. of filter is given as,

$$f_c = \frac{1}{2\pi\sqrt{R_1 C_1 R_2 C_2}} = 0.28 \text{ Hz}$$

Where, R_1 = 180K, R_2 = 18K and C_1 = C_2 = 10u

The gain of the filter is given as,

$$G = \frac{R_3 + R_4}{R_3}$$

Where, R_3 = 18K and R_4 = 180K

The low pass filter stage removes higher freq. noises from the signal and provides gain to the signal such that it is convertible to digital signal. It removes 50 Hz hum, EMG signal and EM interference noise from the signal and limits the signal band of freq. Due to the cut off at earlier freq. ECG signal will be attenuated but it will serve the monitoring purpose. Again low noise and low dc offset amplifier is used in this stage. The gain is set to 5.5 to make gain of overall circuit to be approx. 1000. The cut off freq. is set to be near 30 Hz because 50 Hz signal is very dominant source of noise so it should be greatly attenuated to have clean ECG signal. The cut off freq. of filter is given as,

$$f_c = \frac{1}{2\pi\sqrt{R_1 C_1 R_2 C_2}} = 33.86 \text{ Hz}$$

Where, R_1 = 470K, R_2 = 47K, C_1 = 0.01u, C_2 = 0.1u
The gain of the filter is given as,

$$G = \frac{R_3 + R_4}{R_3}$$

Where, R_3 = 180K, R_4 = 820K

Last stage of Analog Front End is a DC level shifter. The function of this stage is to give dc offset to the signal such that the entire signal has positive values. This allows the signal to be digitized by microcontroller's A/D convertor. It also provides isolation from the next circuitry. The circuit of non-inverting level shifter is shown in figure 4. REF is attenuated by 0.37. This give offset level of 1.3V since supply used is of 3.6 V. This circuit can run with a single supply.

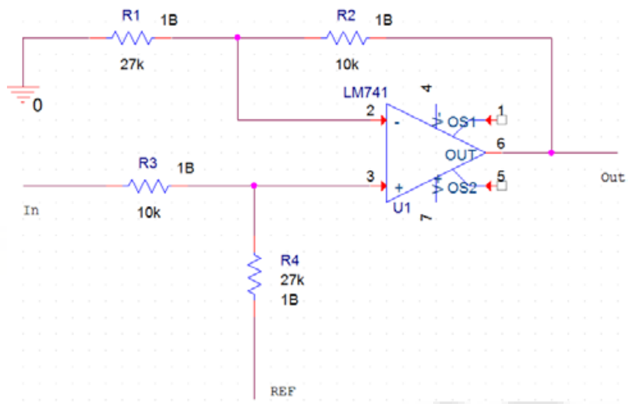


Figure 4: Non-Inverting Level Shifter

The circuit is designed using these relations:

$$A = \left(\frac{R_4}{R_1}\right)\left(\frac{R_1 + R_2}{R_3 + R_4}\right)$$

$$B = \left(\frac{R_3}{R_1}\right)\left(\frac{R_1 + R_2}{R_3 + R_4}\right)$$

Where, A=Gain of the input signal B =Gain of the offset signal

For the gain of input signal equal to 1. We must have,

$$\frac{R_1 + R_2}{R_2} = \frac{R_3 + R_4}{R_4}$$

and then for gain of offset to be equal to 0.37, We have,

$$R_4 = R_3 \times 2.7$$

Choosing R_3 = 10K gives R_4 = 27K. The condition of gain = 1 then gives,

$R_4 = R_1$ = 27K
$R_2 = R_3$ = 10K

The electrodes used for the signal acquisition are Silicon Bulb Electrodes. The silicon bulb should be pressed before connecting to the skin and released to fix the position of electrodes. The electrodes are connected to the analog front end circuit using 3.5 mm audio cables. While connecting the cable in the circuit one terminal should be connected to input of instrumentation amplifier while other terminals must be properly grounded. The operational amplifiers used are LM353 (dual op amp) and TL071. Both are low noise and low dc offset amplifiers. Both can work with small supply and are available in 8 pin PDIP (Plastic Dual In-Line Package) [8]. The power supplies used for all the circuit are two 3.6 volts batteries. The use of batteries reduces the noise of 50 Hz hum and also since the circuit is low power consuming they are a right choice. Capacitors of 100u and 0.1u should be connected between ground and supply pins of ICs as close as possible to smooth out the voltage. The circuit should be properly shielded to avoid noise pick up from surroundings.

4. A/D Conversion of Signal and Transfer to Mobile

Once properly amplified and filtered ECG signal is obtained, the next step is to feed this signal to a microcontroller. Microcontroller converts this analog signal into a digital signal and interfaces with a transceiver module (Bluetooth module) so that signal can be transmitted to mobile device. The microcontroller which we are using for this project belongs to MSP430 family of microcontrollers (MSP430G2553). MSP430 is the family name of 16-bit mixed-signal RISC processors from Texas Instruments, which are characterized by low power consumption. A benchmarking document issued by TI in 2006 shows a comparison of the MSP430 with many other microcontrollers. The architecture combined with five low power modes, is optimized to achieve extended battery life in portable measurement applications. The MSP430-EXP430G2 low-cost experimenter board called Launch pad is a complete development solution for various MSP430 microcontrollers. It covers MSP430G2xx value Line series. It can also be easily interfaced with a PC using flash emulation tool that helps in easy programming, debugging and evaluation. This board can be used with IAR Embedded Workbench IDE or Code Composer Studio IDE and provides support to write, download and debug applications.

In order to transmit signal wirelessly to a remote device, we decided to use Bluetooth protocol of wireless transmission. Bluetooth is a widely used wireless technology standard for exchanging data over short distances(using short-wavelength radio transmissions in the ISM band from 2400-2480 MHz) from fixed and mobile devices, creating personal area networks (PANs) with high levels of security [9]. It can be used to connect several devices. Bluetooth was intended for portable equipment and its applications. So, it is the best choice for our particular application.Rn-42 is the selected Bluetooth module. The RN-42 is a small form factor, low power, class 2 Bluetooth radio for designer's who want to add wireless capability to their products. The RN-42 supports multiple interface protocols, is simple to design in, and is fully certified, making it a complete embedded Bluetooth solution. With its high-performance, on-chip antenna and support for Bluetooth EDR, the RN-42 delivers up to a 3 Mbps data rate for distances up to 20meters. Baud rates of 1,200 bps up to 921 Kbps are supported; non-standard baud rates can be programmed [10].

Application which is embedded into microcontroller works as explained in next lines. First step is to stop watchdog timer and set clocks of the microcontroller. We are not using any crystal but clock is generated by digitally controlled oscillator (DCO). Moreover this clock is set to 16 MHZ.

There are various registers needed to be set for configuration of ADC_10 module. Input channel is set to Channel 5. We can use various clock sources for adc module. In this case we are using internal clock source (in range of 5MHz) of ADC module. Sample and hold time is set to 64*ADC clock cycles. [11] As a result sampling frequency for input signal becomes much greater than our threshold frequency since ECG signal is a low frequency signal. Upper reference voltage of ADC is Vref+ (3.3V) and lower reference voltage is Vss. all the interrupts of ADC are enabled. So that whenever ADC converts a sample, CPU can be interrupted. Analog input which is fed to ADC is enabled. Module of UART is configured also. Data sheet provides a table to set various registers for common baud rates. We are using baud rate of 115200 so registers were set accordingly. UART interrupts are enabled. Whenever UART receives or transmits a character interrupt is set. On reception UART moves that character from receiving buffer to a user register and on transmission interrupt character is sent to transmission buffer. Microcontroller receives run signal from Android app and starts converting analog signal to digital samples. When it takes a fixed amount of samples, it scales them so that they can be displayed on Mobile Phone screen. Application which is run in microcontroller scales data samples so that the signal can be displayed on mobile screen accurately. Microcontroller's adc has a resolution of 1024, this means if we want each level of discrete sample of digital signal to be displayed as a unique pixel, signal displaying screen should have a height of 1024 pixels. Average resolution of phones lie in range of 200*400 to 400*800 pixels. So there is a need to scale those samples to fit them in smaller screens. Further processing on signals is also done here. After this microcontroller sends all these samples on a UART connection to Bluetooth module.

5. Android Application

The Android platform(Linux based) which is the most widely used operating system on smart phones and hand held tablet devices is important target for mobile application developers and hardware manufacturers. The aim of this thesis is to develop a prototype android ECG application that works with the ECG analog end unit discussed previously. The application will be used for the realization of ECG data signals that are sent from the heart rate monitoring device via Bluetooth communication. We believe that the paper layouts a foundation for present and future research and development works that can be carried out in this regard. The Java programming language, Eclipse and the android Software development Kit (SDK) are used as the development tools and environment. Integrated development with the Eclipse IDE is selected for the development as it offers direct invoking of tools that are used for developing applications through the eclipse Android Development Tools (ADT) plug-in. In Android terms, an Activity is an application component that provides a screen with which users can interact in order to do something, such as dial the phone, take a photo, send an email, or view a map.[12] An application usually consists of multiple activities that are loosely bound to each other. Typically, one activity in an application is specified as the "main" activity, which is presented to the user when launching the application for the first time. Each activity can then start another activity in order to perform different actions. The Android platform includes support for the Bluetooth network stack, which allows a device to wirelessly exchange data with other Bluetooth devices. The application framework provides access to the Bluetooth functionality through the Android Bluetooth APIs. These APIs let applications wirelessly connect to other Bluetooth devices, enabling point-to-point and multipoint wireless features. Android provides whole library for drawing graphics. Moreover external libraries can also be used. There are two basic ways of drawing 2D objects in Android. Drawing to a View, is the best option only when your object is static. If your object is moving, or you otherwise regularly need to redraw, you're better off with a Canvas. Use a secondary thread to do so, for best user responsiveness.

Different requirements which are required to be satisfied by this application can be explained with the help of use case diagram as shown in figure. Application needs to launch with a splash screen. Splash screen is like a welcoming screen which is used in lot of applications. Once user is welcomed to application, application should take user to a point where he is provided with some of options to choose. One of those options is to connect to a device which can be any Bluetooth device. After connecting to a Bluetooth connection user can choose option to start showing ECG waveform and can also stop that any time.

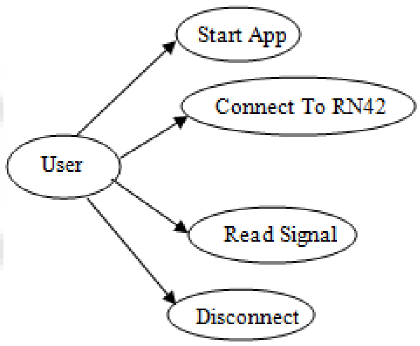


Figure 5: Use Case Diagram

Splash activity is entry point into application. It shows a display (shown in figure 6) for a short time and then moves to main activity of this application where all functionalities are implemented. Activity runs a thread to stay on same welcoming screen for some time.

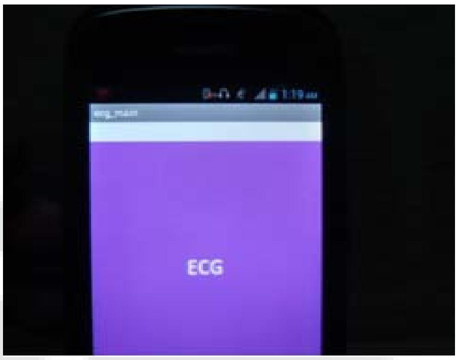


Figure 6: Splash Activity

From Splash.java, application is taken automatically to Bluetooth java activity. This is the main activity of the application which controls all the activity of the application. This activity is also responsible for making a connection to another remote device which is done by clicking connect button. BluetoothRfcommClient.java activity is basically responsible for creating Bluetooth connection to other devices and also keeps updating main activity about different events. DeviceListActivity.java activity is responsible for providing a list of all the Bluetooth devices that are available in the range of the device. It also tells about devices that have been paired with the device before and those that are new. WaveformView.java is the most important Class of this Application. This is the place where all displaying functions are performed. This class is the child class of SurfaceView class. WaveformPlotThread.java thread class is created and used in WaveformView class where it keeps on running the displaying routines. Figure 7 shows signal analyzer window of this application and figure 8 shows ECG signal being displayed.

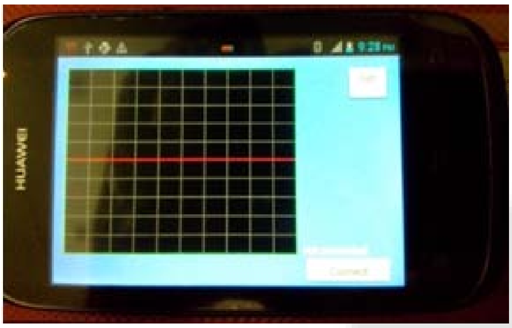


Figure 7: Signal Analyzer Window

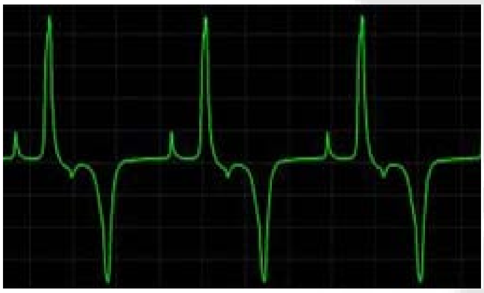


Figure 8: ECG Signal

6. Conclusion

The objective of this thesis was to develop a compact ECG monitoring device. All the steps for the development of this project have been described in this thesis. We have discussed every aspect of the project from analog front end design to Android phone application which is the most significant part of the project. Struggle for design of analog front end has shown new ways of signal processing. We have tried to present a clear ECG signal keeping in view all bandwidth and noise requirements. The advancement in mobile and wireless health care solutions is contributing in different aspects of our lives that range from diagnosis to treatment of different diseases like cardiovascular disease. Android applications are also a part of diverse solutions that are offered as healthcare solutions together with a variety of health monitoring devices.. The result of the project has achieved part of the objectives that were set at the beginning. The bachelor's thesis was an opportunity to extend and discover new skills in Mobile application development. The final result of the application can also be adapted as a reference for Bluetooth application development in the android platform. The Paper lays out a foundation for future developments that are focused on wireless health solutions in the android platform. Some of the features that can be included are integrated SMS (texting) functions, options for saving the data on the device or data streaming function that can work with a control server in a health center. These features will help clinicians to monitor patients efficiently and therefore improve service. It is also important to include more options like zooming functionality, which will improve the usability of the app. In addition, the application can be customized to offer more business opportunities. For example; it is possible to add GPS tracker features that can be used during exercises like cycling and running.

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