

Bluetooth Controlled Life Savior System

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Abstract: Over the past ten years, researches of monitoring human health using sensor and wireless network technologies have been evolving rapidly. The wireless monitoring health system that we present can not only monitor biomedical data over a long period of time, but can also reduce resources and costs of medical manpower to a very large extent. In the future, wireless monitoring system will be a striking feature in determining one's health condition and information. Here, we propose a lithe, robust, ultra-low power medical device that satisfies the mobility, the convenience, as well as the accuracy required for long-term healthcare applications. The proposed system removes cumbersome wires from ECGs and EEGs, making it convenient and satisfies our prerequisite. This complete monitoring system under guarantee of safety and accuracy is very efficient to prevent the progress of heart and brain diseases. It also has an accelerometer riveted to calculate calories burned during various day-to-day activities. Majority of existing devices are only capable of recording ECG and EEG of patients that are analyzed later on by experts. The proposed system can continuously monitor the ECG and EEG which can be analyzed by the user himself any time. In this work, we intend to detect and prevent the cardiovascular and brain diseases using a portable ECG & EEG measurement system. The small signals from the electrodes are amplified, filtered and adjusted for hassle-less detection of peaks and other phenomena. The data is transferred to a personal computer using Bluetooth standard, IEEE 802.15.1-2002.

Keywords – *Electrocardiogram(ECG), Portable ECG, Wireless interface, EEG, 3-axis Accelerometer, Daubechies Wavelets, Feature Extraction.*

I. INTRODUCTION

Ageing presents some formidable challenges, particularly the need for healthcare facilities especially chronic care at home. Chronic diseases and diabetes are becoming the world's leading causes of death and disability, and will account for almost three-fourths of all deaths by 2020.

Providing appropriate method to reduce health care services cost and limitation to the patient along with applying most of the requirements is essential. Innovations in wearable devices for tele-home healthcare can enhance usability, efficiency, and popularity of home-based telemedicine. These devices can allow long-term, continuous, and unobstructed

monitoring of physiologic information to the user. Moreover, in many applications, the EEG and the electrocardiogram needs to be simultaneously measured for ambulatory monitoring[1, 2].

Regardless of effectiveness of EEG and ECG in monitoring physiologic signals of human being, using dozens of electrodes for EEG and ECG recording is usually inconvenient, and some times, the usage of many electrodes often causes stress to the subjects. It is therefore desirable if we are able to simultaneously record EEG and ECG signals with a single measurement using the same electrodes. In our work, we come up with a cost effective and scalable solution to encounter this problem. Our first goal was to develop a measurement method through experimental studies to record both EEG and ECG signals that are available to further processing of the signal. Then our next goal was to develop a signal processing algorithm that can remove the noise from the ECG signals using Daubechies Wavelet and can extract the information of all the peaks and R-R interval of an ECG trace for further heart rate analysis.

So, we designed a multifunctional and compact device that can measure ECG, EEG and number of calories burned during a workout and records heart and brain activities for more than 48-hours on a memory card for further diagnosis. Further, the data can be transferred to PC via bluetooth where features of ECG trace were extracted.

The report is organized as follows. Section II describes basics of the ECG system employed and its advantages. Section III demonstrates the EEG system, selection of various components and removing noise from the signal. Extraction of information using accelerometer is accounted in section IV. Section V demonstrates the SD-MMC feature of the system. The Bluetooth transmission and further work is reported in section VI. Peak detection algorithm is discussed in Section VII. We discuss and conclude the paper in Section VIII.

II. ECG DESIGN

The electrocardiogram (ECG) is an electrical recording of potential differences between specific electrodes placed on the patient's skin. *3 Lead ECG System have been used in our case.* The aim was to limit the number of leads present over the body. A 2 lead system was also developed but the electrodes had to be worn on the chest which made the system less handy as the subject had to adjust accordingly. Hence, we utilized a 3-lead ECG system which is easier to wear, with 2 leads on each hand and another on the right leg.

A. Physiology of ECG

The ECG signal is quasi-periodic, coming from heartbeat repetitions. Each beat is composed of three waves: the P wave, QRS complex and the T wave. These waves represent the sequential depolarization and repolarization of the cardiac muscle. The potential created by the heart wall contraction spreads electrical currents from the heart throughout the body. The diverging electrical impulses create different potentials at different points on the body. Leads are placed on the body in several pre-determined locations to provide information about heart conditions. The cardiac signal, typically 5mV peak to peak, is an AC signal with a bandwidth of 0.05 Hz to 100 Hz. The ECG signal is characterized by five peaks and valleys labeled with successive letters of the alphabet P, Q, R, S & T.

B. Three lead ECG system

The placement of the electrodes on the body determines the view of the vector as a function of time. The basic form of the electrode placement is based on Einthoven's triangle.[4] This theoretical triangle is drawn around the heart with each apex of the triangle representing where the fluids around the heart connect electrically with the limbs. Einthoven's law also states that the value of any point of the triangle can be computed as long as values for the other two points are known.

- Lead I is the voltage between the (positive) left arm (LA) electrode and right arm (RA) electrode.
- Lead II is the voltage between the (positive) left leg (LL) electrode and the right arm (RA) electrode.
- Lead III is the voltage between the (positive) left leg (LL) electrode and the left arm (LA) electrode

Circuit design of the presented work comprises of 3 fundamental steps: Amplification, filtering and conversion. The amplitude of a raw ECG signal ranges from 50 to 2000 μV in normal conditions. Required bandwidth of operation is in the range of 0.05-150Hz.[5]

A. Amplification

Monolithic implementation of instrumentation amplifier by using traditional three op-amp configuration needs accurate matching of the resistors used in its feedback network to achieve high CMRR. Secondary features such as low power consumption, single supply operation are also important. A single supply, micro-power IA, INA 122 was utilized to fulfill these requirements. The minimal CMRR of INA122 is up to 96dB. The gain of INA122 can be set with an external resistor only.

An Integrator was designed that formed a negative-feedback loop. The purpose of this circuit is to provide an inverted version of the common-mode interference to the user's right leg, with the intention of cancelling out the interference. Additionally it serves as a virtual ground, for the raw ECG signal.[3]

B. Filters

A band pass filter was implemented by cascading a low pass and a high pass filter.

- **Low Pass Filter:** The cutoff of the low pass filter was set to the maximum frequency component of interest, i.e. 150 Hz. The Sallen and Key active filter configuration was preferred to multiple feedback due to its less component count. The Butterworth filter of second order was selected due to its pass-band flatness.
- **High Pass Filter:** A simple RC-high pass filter was implemented with cutoff frequency, 0.5 Hz.

D. Baseline Wandering

Due to high sensitivity of the IA used, the output of the amplifier is highly susceptible to any variation in contact resistance between the skin and electrode. This condition results in deviation of DC content of the amplified differential signal and manifests itself as a drift in the *baseline* of the signal. This phenomenon is often referred to as *baseline wander*.[6] This problem is overcome by high pass filter, which was not included initially.

D. DC offset

The ADC peripheral used in this work is unipolar, i.e. it cannot digitize signals below ground level. For this reason, a DC offset circuit was implemented to bring out the voltage in a desired range.

E. Digitization

The analog output is fed to a sample and hold circuit, and finally to the ADC of microcontroller. Further processing is discussed in VII section.



Fig.1 ECG Signals

III. EEG SYSTEM

Electroencephalogram (EEG) measures the electrical activity of the brain as seen from electrodes placed on the scalp. The presence of electrical current in the brain was discovered by an English physician, Richard Caton in 1975. The electrical activity is due to nerve cell activity and shows a continuous oscillating electrical activity known as rhythm.[8]The EEG rhythm and waveforms are varied by the position of electrode placements on certain parts of the brain (Fig.2). **Alpha** wave occurs at a frequency between 7.5 and 13Hz. The alpha waves are produced when a person is in a conscious, relaxed state with eyes closed; the activity is suppressed when the eyes are open. The amplitude of the alpha rhythm is largest and intensely occurs in the occipital region and can be best recorded at parietal and frontal regions of the scalp. **Beta** waves normally occur in the frequency range of 14-30Hz and sometimes even as high as 50Hz for intense activity. Beta waves activities are present when people are alert or anxious, with their eyes open.

Theta potentials are large amplitude, low frequency signal between 3.5 and 7.5Hz. Theta is abnormal in alert adults but seen during sleep, and small children. Theta waves occur mainly in the parietal and temporal region. **Delta** waves have the largest amplitudes and the lowest frequency in less than 3.5Hz. It is normal rhythm for infants less than one year old and in adults in deep

sleep. This wave can thus occur solely within the cortex, independent of the activities in lower regions of the brain.[9]

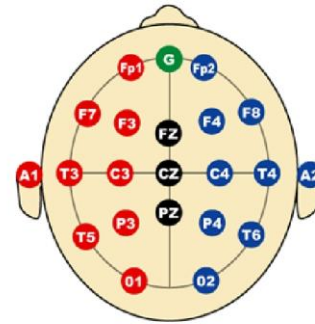


Fig.2 Electrodes Placement

The system most often used to place electrodes for monitoring the clinical EEG is the International Federation 10-20 system. The 10-20 system is not how many electrodes to be put on the scalp but rather a measurement of percentage of 10% or 20% on a certain anatomical landmarks to standardize the placement of electrodes. The positions are defined by certain anatomical reference points as follows: Reference points are nasion, which is the delve at the top of the nose, level with the eyes; and inion, which is the bony lump at the base of the skull on the midline at the back of the head. From these points, the skull parameters are measured in the transverse and median planes.

In our work, 3 electrodes were used, where one of them is a reference electrode, just like ECG. Electrodes are placed at the place of interest e.g. Frontal Cerebrum region for detecting Beta Waves, or at the Occipital region for Alpha Waves. Measurement can be made by a bipolar electrodes which is between each member of a pair electrodes (differential measurements are made between successive pairs of electrodes), or mono polar electrodes where one mono polar lead and a distant reference electrode (usually attached to one or both ear lobes), or between one mono polar lead and the average of all the leads. Circuit design here again comprises of three basic steps, amplification, filtering and conversion along with few more necessary steps discussed below.

A. Amplification

The EEG has a magnitude of about 100uV, so a reasonably high gains, high quality biopotential amplifier is needed. Instrumentation amplifier INA114 was utilized for EEG system. It is very suitable for medical instrumentation application and uses low power consumption which makes it good for portable design.

The general purpose instrumentation amplifier offering excellent accuracy that rejects common signal with 115dB (common mode rejection ratio, CMRR = 115dB), has very low offset voltage of 50 μ V (DC component that amplifier adds to the signal), very low drift voltage of 0.25 μ V/ $^{\circ}$ C (another DC component that amplifier adds to the signal that is a function of temperature).

Along with the instrumentation amplifier, a driven right leg (DRL) circuit is used as a connection between the signal source and the amplifier common. A DRL circuit reduces the common mode voltage by driving from INA 114 actively to the potential of the amplifier common. A DRL, in addition, protects the user from the consequences of amplifier defects.[10] Also, we used a second stage amplification using TL082. The 2nd Stage amplifier will amplify the signal to 21 times with high precision, low power non- inverting operational amplifier.

B. Filters

- **High pass filters:** Similar to the ECG circuit, high pass filters are applied after the Instrumentation Amplifier to remove DC offsets. Its cutoff frequency is 0.16Hz. After the first Instrumentation Amplifier, there is a second high pass filter stage, identical to the first filter are applied after the first operational amplifier because amplification brings some new DC component to signal cause of amplifier offset and drift.
- **Low pass filters:** A low-pass filter passes low-frequency signals but attenuates frequencies higher than the cutoff frequency. The second order low pass Butterworth filter will limit the frequency up to 59Hz. Theoretically EEG frequency band is from 0.05 – 100Hz. 59Hz was chosen to filter out the unnecessary signal bigger than 60Hz. It is because Alpha wave is from 7-14Hz, and Beta wave is 15-50Hz.

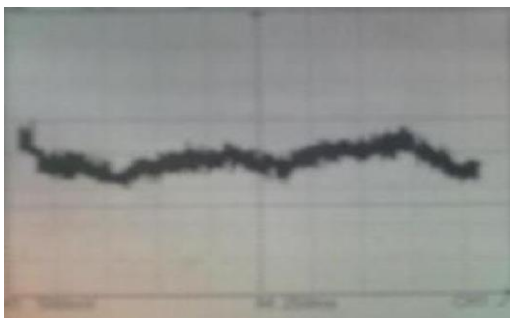


Fig. 3 EEG signal acquisition

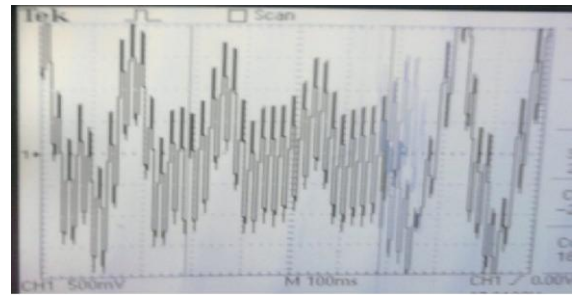


Fig. 4 Eye Blink Test

C. Digitization

Similar to the ECG circuit, the analog output is fed to a sample and hold circuit, and finally to the ADC of microcontroller. This topic is further discussed in the later sections.

IV. ACCELEROMETER SYSTEM

This Section describes the application of IEEE 1451.4 standard which allowed us to add self-describing features of accelerometer used for extracting speed. User speed and weight gives enough information about the calories burned during the day.

For measuring the acceleration, we have utilized MMA7341 by Freescale Semiconductor which is a low power, low profile capacitive micro machined accelerometer.

A. Monitoring Accelerometers

First step was to determine the position of placement of the accelerometer for exact measurement of speed. After various trials, it was found that the best position to extract the information was the waist line. But it was seen that placing the accelerometer on the thighs also provided good results. Next step was to determine a fixed alignment of axis. For this, we studied the changes in the values of acceleration when the subject was allowed to walk while wearing the device. We plotted the values with respect to the time axis (Fig.5,6)

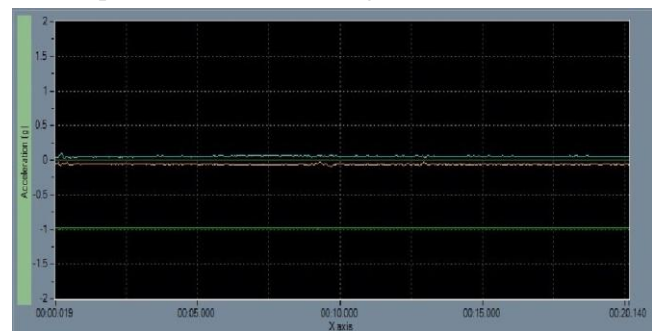


Fig. 5 Accelerometer reading at rest

Here, orange, green and blue lines represent X, Y and Z axis respectively. Note that the initial values vary from person to person; depends upon the tilt of a person and the above shown graph is not valid for every test case.

The graph is plotted between values of g (acceleration) sensed by the accelerometer in each direction and time. Slight variations in the graph can be neglected as they may arise due to slightest motion.

While monitoring, our next step was to log the values of acceleration when the subject is walking with a normal pace. Values of acceleration in all 3 directions are logged for 50 seconds. The following graph shows the graphical view of this.

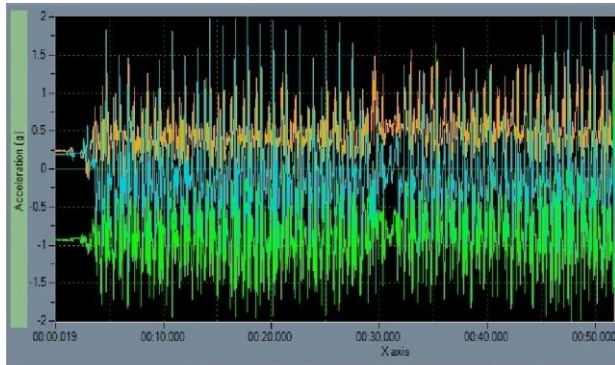


Fig. 6 Accelerometer reading while subject is in motion

Variations in the graph show motion of the subject. At certain time interval, we see no variation in Z axis (blue line). These points infer motion of subject when it is not moving straight, i.e. while turning.

Before obtaining the raw data, we had to convert the output of MMA7341 to units of acceleration. MMA7341 used a conversion rate to convert acceleration to a 6-bit digital value. The sensitivity of MMA7341 under 3-g mode is 440mV/g.

B. Digital Integration

Given a position versus time of an object, $x(t)$, the velocity, $v(t)$, can be found by taking the first derivative. Acceleration, $a(t)$, can be found by taking the second derivative of position or first derivative of velocity. In principle, using integration on an acceleration signal to get a velocity signal, the initial velocity must be known. After the integration, the initial velocity should be added to the result. These operations are illustrated in the following equation:

$$v(t) = v(t_0) + \int_{t_0}^t a(t) dt$$

Where t_0 is the initial time and $v(t_0)$ is the initial velocity, which is a constant.

There are a number of discrete integration algorithms available to perform integration numerically. Here, we have utilized the trapezoidal rule. The results are more accurate with this method than with the rectangular method. The difference equation for trapezoidal integration is:

$$y(n) = y(n-1) + \frac{1}{2f_s} [x(n-1) + x(n)], \quad n > 0$$

Trapezoidal integration acts as a first order hold on the system, whereas rectangular integration acts as a zero order hold. The trapezoidal method is more accurate in approximating the area under the curve.

C. Choice of sampling

The choice of sampling rate, f_s , is also a critical factor in integration. The higher the sampling rate, the more accurate the integration will be, though a very high sampling rate can cause difficulties with digital filtering later. From calculus, the limit as the sampling rate approaches infinity results in the Riemann integral. It is obvious that the integral of the signal sampled at the higher rate will be more accurate because it is a better approximation of the original signal.

We followed the Trapezoidal integration for above mentioned reasons and initial values of acceleration and velocity were stored in a register of microcontroller which was updated after every sample taken. Sampling frequency was set to 100Hz using timers in PWM mode.

After calculating the instantaneous velocity, next step was to calculate the calories burned during the workout. Please note that this value is an estimate of the actual calories burned. We have utilized the METS (Metabolic Equivalents) method to determine the calories burned.[11]

A MET is defined as the resting metabolic rate, that is, the amount of oxygen consumed at rest, sitting quietly in a chair, approximately. As such, work at 2 METS requires twice the resting metabolism or 7.0 ml O₂/kg/min and three METS requires three times the resting metabolism (10.5 ml O₂/kg/min), and so on. Energy expenditure is calculated as:

Energy Expenditure (kcal) =

$$1.5 * \text{METS} * \text{duration (hour)} * \text{weight (kg)}$$

D. Calculating Estimated Energy Expenditure value

The accelerometer also used to calibrate the activity of the subject, broadly divided into 3 categories, idle (i.e. no motion), walking and running. The METS value for

the first category is 1.1. For the second and third category, we use the following formula:

$$\text{METS} = 0.0272 * \text{speed (m/min)} + 1.2$$

$$\text{METS} = 0.093 * \text{speed (m/min)} - 4.7$$

In this way, we are able to find an estimation of calories burned during various activities. The information is also stored into the SD card which is explained in the next section.

V. DATA STORAGE

Data storage is of top concern for healthcare measurements. Long term storage can be quite important for accurately studying a patient. In this work, we utilized an SD card for storing the data.

SD card is flash memory storage based device and support proprietary data transfer protocols using four data bits, and are compatible though having different initialization. SD card is designed to provide optional security by allowing encryption of the device contents. It supports a basic SPI type interface for simple connection to embedded devices. The SD card specifications state a maximum clock frequency of 25MHz.

We had used 2GB microSD card of SanDisk. The microcontroller is AVR ATmega32 running at 8 Mhz internal clock. MAX232 is used to interface the circuit with PC for monitoring the data. A 3.3v supply is used for powering the mega32, microSD and max232. 7 pins of the microSD are used.

We had used 51k pullups on CMD/DAT lines. This gives better stability with different cards. Also, two 3.6v zeners were used to protect SD since our ISP programmer voltage levels were of 5V.

The aim was to transfer all the data measured by our device ie records of the electrical activity of heart and brain and number of calories burnt during his/her workout to SD card for further reference which is obtained by transferring the data in raw format to any block of microSD and reading that block. Once raw data transfer was achieved, card was formatted with windowXP(FAT32) and reloaded it with the data files which were stored in root directory of card.

VI. APPLICATION OF BLUETOOTH STANDARD (IEEE SA - 802.15.1-2002) AND HEALTH STANDARD (IEEE 11073)

After successfully extracting the ECG over a DSO, next step was to digitize the signal for transmission using a microcontroller. Atmel's Mega32 was utilized for

digitalization and transmission. To make the device cost effective, we switched to Atmega16. It has 8 single-ended 10 bit resolution ADC, which was sufficient for our purpose. However, an additional feature of only storing the ECG reading was also utilized using a microSD card, as discussed in the previous section. Here, AtMega16 fails to provide good result against Mega32 because of insufficient memory. Before feeding the signal to ADC, it was passed through a trivial sample and hold circuit, using LF398.

After Digitization and storage, the next important phase was application of the Bluetooth standard, IEEE SA – 802.15.1-2002. We started working on transmission of data to a mobile phone using the Bluetooth protocol. But this initial thought was changed and we transmitted the data to a personal computer primarily because a mobile phone was not much capable of computation and further signal processing, especially for ECG system where we thought to develop an algorithm for detection of various features of ECG by utilizing Daubechies wavelets. This thought changed our system overview from a cell phone to a personal computer. Now our system overview consisted of three blocks: the hardware, the data acquisition module and a personal computer which serves as an access point as well as a station supporting telemedicine application, utilizing the IEEE 11073 health standard.



Fig.6 Bluetooth Module

A. Transmission

For transmission purpose, initial step was to transmit the data using wired serial communication between the microcontroller and the personal computer. After successful transmission, we utilized a BlueLINK's Bluetooth module (Fig. 6) for wirelessly transmitting the data. The motive of using Bluetooth technology was its availability and popularity. *Bluetooth* is a low-cost, low-power, secure and robust standard for short-range connectivity. The technology has been designed for ease of use, simultaneous voice and data and multi-point communications. It supports a range of 10 m, which can be increased up to 100 m with the use of an amplifier. The received signal was then plotted on the real time

axis using MATLAB, in accordance to the IEEE 11073, Health Standard.

The utilized Bluetooth module is a serial TTL module by BlueLINK which works on frequency of 2.4~2.524 GHz and is Bluetooth core V2.0 compliant. This module is configured using AT commands and accepts or establishes connections with other devices using Serial Port Profile (SPP). It confirms the Bluetooth standard, IEEE SA – 802.15.1-2002.

B. Health Standard (IEEE 11073)

The primary goals of IEEE 11073 Health standard are to:

a) Provide real time plug-and-play interoperability for citizen-related medical, healthcare and wellness devices. This was taken care during transmission and display of signals on a personal computer, as discussed in the previous subsection.

b) Facilitate efficient exchange of care device data, acquired at the point-of-care, in all care environments. The data extracted during the whole process is of prime importance. The processed data is fed to a personal computer using the Bluetooth protocol or the Data Storage feature. The digital data can thus be exchanged as per requirements.

VII. FEATURE EXTRACTION

This step was thought after starting the work. Transmitting the data to a mobile phone was a one step process but here we try to transmit to a personal computer using Bluetooth protocol. Bluetooth has adopted a common data and object specification that enables devices to communicate over a wireless connection in a standard way.

The ECG feature extraction system provides fundamental features to be used in subsequent automatic analysis. It is therefore important to accurately extract features of prime importance. For example, distance between consecutive R peaks. The basic objects of the analysis were: P-wave, QRS-complex, T-wave, P-Q interval, S-T segment, and Q-T interval.[6] Wavelet Transform has been proposed as an alternative way to analyze the non-stationary biomedical signals, which expands the signal onto the basis functions. The wavelet transform acts as a mathematical microscope in which we can observe different parts of the signal by adjusting the focus.[7]

A. Wavelet Transform

Due to its symmetry with a QRS complex as well as concentration of the energy spectrum at lower frequencies, Daubechies wavelets are utilized. Number of constant terms for Daubechies wavelets was decided between 4 or 6. After many trials, Db4 was chosen over Db6 as it provided excellent results in our case. Then, Wavelet decomposition of the ECG samples is performed upto four levels which results in the samples at much lower frequency than the original signal. Thus, QRS complex is preserved. Further, extracting and then plotting the coefficients at each level results in the plot of cleaner signal. It is clear from figure 7 that 2nd level decomposed data is noise free. Therefore, we consider this signal as ideal ECG signal from which all the peaks are detected.

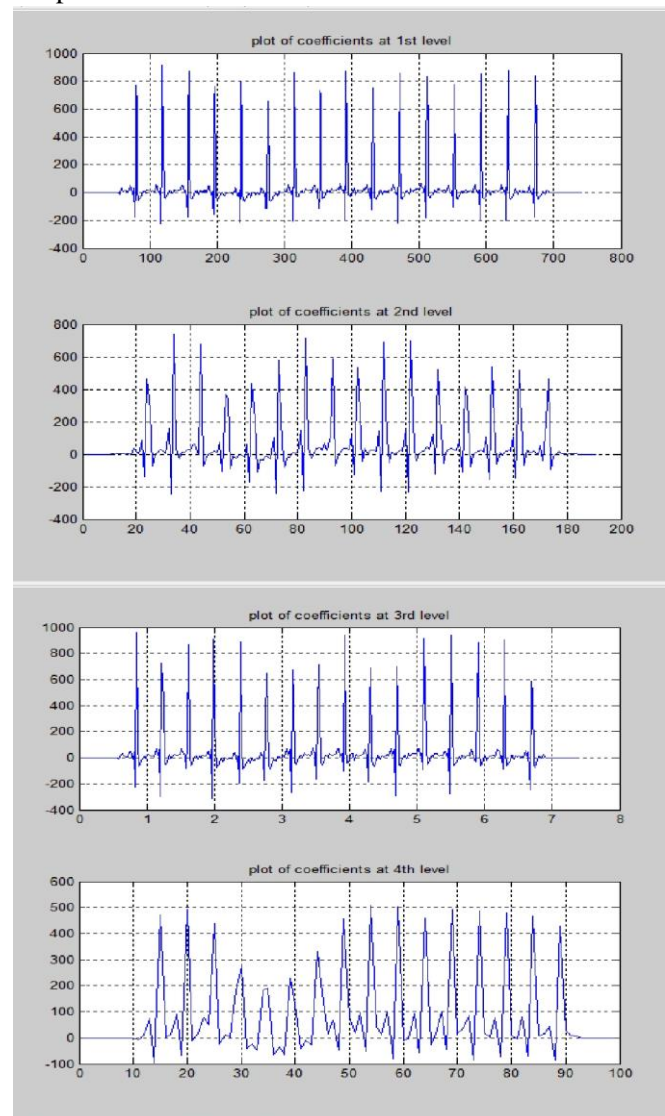


Fig.7 Plot of the Coefficients

B. P,Q,R,S and T peaks Detection

Our first job was to detect the tallest peak i.e. R peak of an ECG. It was found by setting an appropriate threshold and storing all the y-coordinates above that threshold in an array in MATLAB. Thereafter, for particular range of time, we get the maxima of stored y-coordinates which results the magnitude of R-peak in that range. Continuing the process gave us the respective amplitudes of R-peaks.

A QRS complex corresponds to the depolarization of right and left ventricles and usually lasts for 0.6 to 1.0 sec. Q is the local minima before the above calculated R-peak while S complex is the local minima after one R-peak. Hence, the reconstructed wave was used and Q & S points are observed.

For P and T peaks detection, we used the similar method. we find the local maxima point prior to Q-point to find P. Similarly, we find local minima after S-point to find T. Roughly, local maxima and minima points are determined by zero crossing of the signal, which was fixed in the analog circuitry part(refer section III-D).

VIII. CONCLUSION

The integration of ECG, EEG, calorie counter and wireless transmission represents a promising advance system. We were successful in storing the data in SD card and displaying the ECG and EEG trace on a personal computer using the recorded data. Further, by using the wavelet transform, we were able to detect various features from the ECG signal. We also succeeded in eliminating noise and baseline drift that could degrade the accuracy of obtained data. It can be concluded through this study that in a view to solve the problems related to the patients regularly (in relation to the design), this system proposes a better method to ease healthcare facilities for the citizens. The portable design works up-to our expectations during the tests.

ACKNOWLEDGEMENT

This project was funded by IEEE mini-grant programme and we are thankful to the selection committee for the same.

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