Experimental Studies on Intelligent, Wearable and Automated Wireless Mobile Tele-Alert System for Continuous Cardiac Surveillance

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ABSTRACT
Myocardial malfunctioning harms human health and since most people are affected by arrhythmia. It is one of the major causes for sudden death. The chance of occurrence of severe myocardial problem will be increased after the first heart block. Detecting the onset of malfunctioning is ever challenging. This paper proposes to find out how the onset of myocardial problem can be detected automatically in an early stage by an uninterrupted surveillance device. When the device detects any abnormal myocardial functions, then it automatically alerts the patient and the doctor through the GSM (global system for mobile) mobile phones and the patient will be given first order medical attention as soon as possible. Eventually this increases greatly the chance of survival of the victim.

Keywords: electrocardiography (ECG), global system for mobile (GSM), telemetry, LabVIEW and wireless transmission.

1. Introduction

According to a recent survey by WHO (World Health Organization), myocardial malfunctioning is the major cause for sudden cardiac deaths all over the world [8]. There are about 5 lakhs numbers of deaths in India every year and the number runs to millions worldwide [10]. Each year the American Heart Association (AHA), National Institute of Health takes the survey to update the statistics on death due to heart diseases, strokes and other vascular diseases [6]. It would be useful to take preventive actions based on the survey to safeguard lives of such patients at least for the future [16]. In 2007 the overall death rate from Cardio Vascular Disease (CVD) was 251.2 per 100000 [12]. By 2007, the death rate had increased to 27.8% according to the last survey. Based on this survey, now we know that 2200 people die each day at an average of 1 death for every 39 seconds [11]. The 2011 survey also shows that the lack of a proper diet (obesity) is the major cause for cardiac attacks [9]. The elderly groups are largely affected by this problem. Among children from 2 to19 years old, 31.9% are fat and obese [2]. Among people in the range of 20 years old and above, 67.37% are plump and obese [4].

Our aim in this paper, is to create an equipment that allow us to detect the cardiac disorder in an early (initial) stage. This proposed model will be mainly useful for the elderly population with heart rate variability and the patients under critical condition. The goal is to detect the cardiac disorder earlier consequently t the patient will be given first-order medical attention within the first few critical hours, which would greatly improve their chance of survival. The device acquires the ECG from the patient's body and the raw ECG is preprocessed and post processed. It is sent as input to the heart rate (HR) retrieval system. Then, the HR is sent as input to the PIC microcontroller. If any abnormalities are detected then accordingly , the alert signal is sent through the short messaging service (SMS), to indicate the patient¨s critical condition to the medical practitioner) and also as a self-alert to the patient.

2. Existing systems

To create a wireless sensor network system, that can continuously monitor and detect the cardiovascular disease and send the ECG wave of the patient to their mobile and to the central node which transmits the wave to the doctor too[1]. Using the pervasive technology, it is possible to collect the user symptoms and the onset of heart attack by analyzing ECG recordings [5]. Three different models are proposed to detect the pathological degeneration. They are cell model, heart model and chest model [8]. These three models cannot be finished yet because they require a lot of unknown parameters. Monitoring the cardiovascular patient is not feasible, to prevent further risks. Hence, the early detection is needed. Aholter is a device used in this paper to detect the myocardial malfunctioning [10]. By attaching the GSM to the holter, we were able to diagnose myocardial ischaemia and we also were able to detect therapeutic and preventive procedures. This procedure was mainly based on the ST versus HR relations [14]. This paper proposes a model to analyze the electrocardiography using the advancement in the wireless technology.

3. Problem formulation

After the evaluation of the systems cited above [1], [5], [8], [10], [14], the following troubles can be recognized.

a) In the traditional medical method, the mobility of both the doctor and the patient are restricted.

b) All the existing methods are web based, without Internet they cannot be utilized.

c) Some of the systems give false alarms due to various environmental constraints.

d) Many existing systems use expensive hardware components and complex software tools.

4. Proposed work

The ECG signal from the patient's body is picked up using ECG/Infra-Red (IR) sensors. The obtained signal is protruded with internal and external noises. The voltage level of the myocardial waves are in millivolts. At this range the preprocessing and postprocessing is not possible at all, so the obtained signal must be amplified and filtered. For the filtering purpose the adaptive filter is used. In order to provide amplification and isolation to the patients, the bio-amplifier is used. At that point, the obtained analog signal is converted into digital using pic microcontroller where the A/D circuit is inbuilt. Then the comparison of QRS complex amplitude levels are done and the corresponding alarm signal will be activated as it is shown in Figure 1.

4.1 LM234 amplifier

The LM234 is a three terminal device and its operating current level varies from 1μA to 10mA. The operating voltage level goes from 0.8V to 30V and the regulation is 0.02%/V. LM234 draws no reverse current and it can be used as a linear temperature sensor. The applications of LM234 are current limiter, micro-power bias network, buffer for photoconductive cell, current mode temperature sensing and constant-gain bias for bipolar stage.

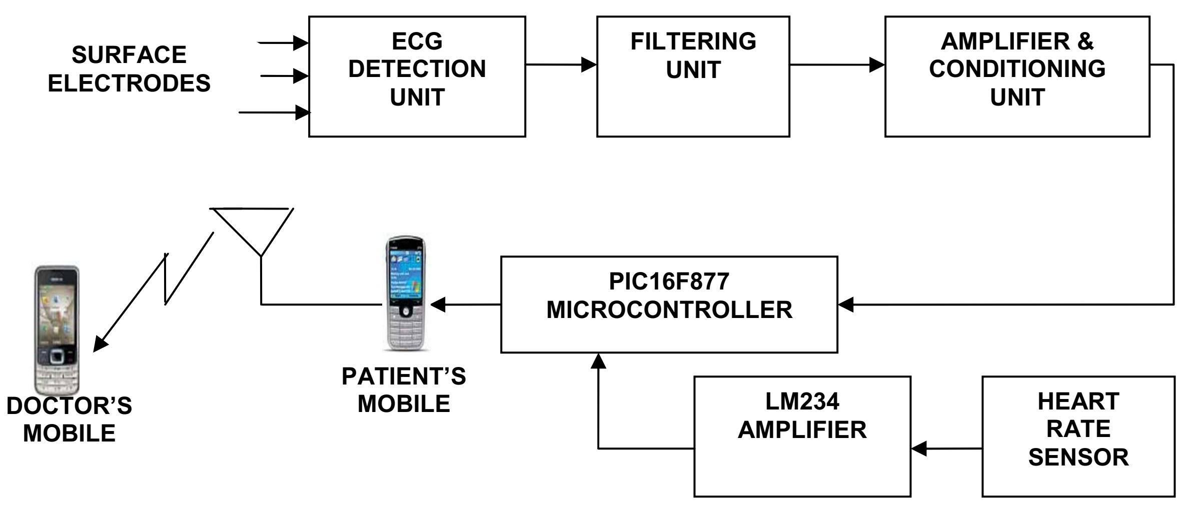

Figure 1. Block diagram of proposed cardiac Tele-monitoring system.

4.2 Adaptive filter

Even though the ECG is picked by using high technical and efficient sensors, it is impossible to have a noise free ECG signal. But if the noise level is too high then it leads to the wrong estimation about the state of the heart and patient's health. Due to this high power, time consumption is required for the signal processing.

Thus the filter section is very important. Some noises are P and T wave type, powerline interference, EMG from muscle, operating room condition. Mostly the filter option is bandpass filter. But it is not suitable if it is used for the elderly groups, hence, we choose the adaptive filter which adapts its nature by itself according to the time and range. It does not require any prior knowledge about the signal and the nature of the noise.

4.3 Bio amplifier

It is a combination of the instrumentation amplifier and a power amplifier. The instrumentation amplifier by itself is not enough to get the amplified QRS complex. So we utilize a power amplifier. It is an amplifier used to provide isolations. It amplifies the QRS complex by its own..

4.4 PIC microcontroller

The PIC microcontroller is considered the heart of this proposed work and it has an inbuilt analog to digital converter (ADC). The PIC has a set of registers that can function as a general purpose RAM. Special control registers for hardware resources are mapped to data space. All PIC can handle the data in 8-bit chunks.

The addressability unit of the code space is different to the data space. Actually, the code space can be implemented as ROM, EPROM and flash ROM. Generally, external code memory is indirectly addressable because of lacking external memory interface. The instructions can vary from low-end PIC to high-end PIC, with the low-end and high end PIC having instructions varying from about 35 instructions to over 80 instructions respectively. The features of the PIC micro controller are code efficiency, safety, instruction set, speed, static operation, drive capability. The advantages of PIC microcontroller include a brief instruction set to learn, a built in oscillator with selectable speed, inexpensive microcontrollers, and a wide range of interfaces including USB and Ethernet.

5. Algorithms for telemetry applications

The following list shows the various detection algorithms that are available for telemetry/telemedicine applications. Some of them are listed below.

- Turning point algorithm
- Aztec algorithm
- Fan algorithm
- QRS detection algorithm

Turning algorithm, even though it is simple and fast, it is not able to detect the wide QRS signal and it also produces time distortion. In Aztec algorithm, it is able to detect wide QRS but it does not produce fixed reduction rate. The QRS detection algorithm overcomes both disadvantages of turning and aztec algorithm. QRS detection algorithm is able to detect wide QRS and also produces constant reduction rate which is needed for the clinical process and it is shown in Figure. 2.

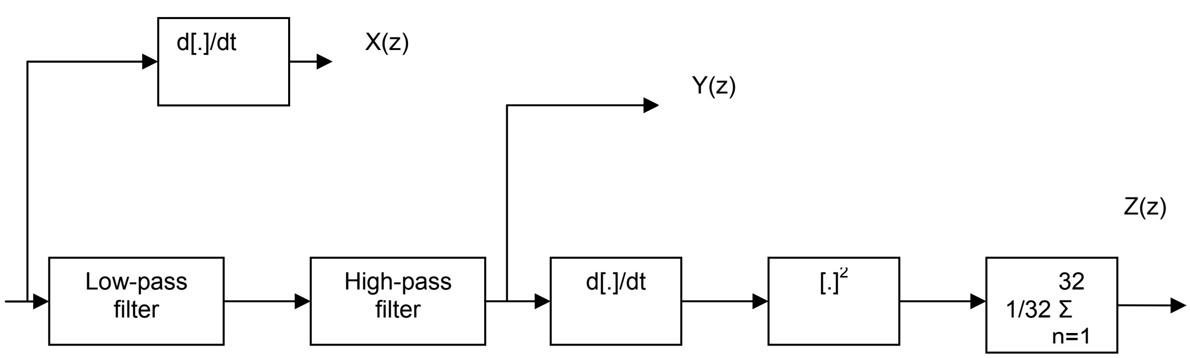

Figure 2. Steps involved in ECG QRS detection algorithm for tele-monitoring system.

5.1 QRS detection algorithm

For this detection algorithm we design a bandpass filter from a special class of digital filter which only requires a coefficient. It is very difficult to design digital bandpass filter directly, therefore, we design a cascaded connection of lowpass and high pass filter. It attenuates the low frequency characteristics of P and T waves and baseline drifts and high frequency characteristics like power line interference and electrocardiographic noises.

5.1.1 Low pass filter

The transfer function of the second order filter is

$$H(z)=(1-z-6)/(1-z-1)2 \qquad (1)$$

The difference equation of the filter is

$$Y(nT)=2y(nT-T)-y(nT-2T)+x(nT)-2x(nT-6T)+x(nT-12T) \qquad (2)$$

This filter has purely linear phase response. Power line is highly attenuated. All the frequencies are attenuated by more than 250dB. Any 60Hz noise or muscle noises are highly attenuated.

5.1.2 High pass filter

The high pass filter is implemented by subtracting the low pass filter from all pass filters with delay. The low pass filter is an integer coefficient filter with transfer function,

$$H_{lp}(z)=Y(z)/X(z)=1-z^{-32}/1-z^{-1} \qquad (3)$$

And the difference equation is:

$$Y(nT)=y(nT-T)+x(nT)-x(nT-32T) \qquad (4)$$

The transfer function of the high pass filter is:

$$H_{hp}(z)=P(z)/X(z)=z^{-16}-H_{lp}(z)/32 \qquad (5)$$

And the difference equation is:

$$p(nT)=x(nT-16T)-\sum 1/32[y(nT-T)+X(nT)-X(nT-32T \qquad (6)$$

5.1.3 Derivatives

After the filtering process, the signal is differentiated to get a clear information about the slope of the QRS complex. A five point derivative has a transfer function of:

$$H(z)=0.1(2+z^{-1}-z^{-3}-2z^{-4}) \qquad (7)$$

the difference equation is given by:

$$Y(nT)=[2x(nT)+x(nT-T)-x(nT-3T)-2x(nT-4T)]/8 \qquad (8)$$

5.1.4 Squaring function

The squaring function is a non linear function. The equation that implements this function,

$$Y(nT)=[x(nT)]2 \qquad (9)$$

This operation makes all the data point in the processed signal to be positive and also amplifies the output of the derivative non-linearly. In this operation the output of this stage is hard-limited to a certain level which is based on the number of bits used to represent the data type of the signal.

5.1.5 Moving window integral

The slope of the R wave by itself ,is not a guaranteed way to detect the QRS events. Many abnormal QRS complex has large amplitude and long duration. This type of complex cannot be detected using the information about slope of the R wave alone. To extract more information about the QRS complex this type of moving integral is used. It is implemented with the difference equation

$$Y(nT)=1/N[x(nT-(N-1)T)+x(nT-(N-2)T)++x(nT)] \qquad (10)$$

Where, N - Number of samples in the width of the moving integral

5.2 Why ECG QRS detection algorithm?

The size of the moving window is chosen by experiment;

- If the size is too big then the QRS complex merges with the T wave.

- If the size is too small then the QRS complex produces several peaks at the output.

The first two algorithms are only useful for data reduction. With this we are only able to reduce the memory space needed to store the ECG wave. We need an effective algorithm to detect the QRS complex from the ECG signal. Since we are only analysyng the QRS complex which causes high risk to the patients.

6. Results and discussion

6.1 Simulation results–analysis of ECG noise removal & abnormality detection:

LabVIEW is a software tool used to simulate the system and get the response to know how well the system is working according to our expectation. Since LabVIEW is highly reliable and user friendly both, the electrical and electronic device systems can be simulated. The first stage in the QRS detection is noise reduction and recovering the original signal from the noise contained signal as shown in Figures. 3 and 4.

There are various types of noise such as base line fluctuation, 60Hz artifact, 60Hz artifact amplitude, DC offset, randomize magnitude. For the noise removal unit, we have chosen the adaptive filter, the filtering process which will be explained below. One sample ECG signal is taken from the ECG simulator, then we add a type of noise as mentioned above. Then we take the adaptive (wavelet) transformation for that signal as shown in Figure 4. Then the signal looks like a fully contaminated signal.

Inverse adaptive transformation is taken to reconstruct the original signal as such. From it,the feasibility of recovering the original signal from the noise by using adaptive filter can be proved. Afterward, the same procedure is followed to reduce the other type of noises.

But here we add and test the particular 60 Hz noise only because it is the major noise in the real time ECG signal. The same adaptive filtration is performed to recover the signal.

Figure.5 shows the actual implementation of the adaptive filter. On it we use all the standard signals and all kind of noises as shown in Figures 6 and 7.

We take one standard signal and add different type of noises one by one and try to recover the signal using the same process. The standard signal and noise is added and it is passed through the adaptive filter. After processing it, the original signal is recovered as in Figure 7.

From the previous discussion, QRS detection system and the tele - alerting mechanism can be implemented without the dominant disturbances from the various types of noises by using the LabVIEW.

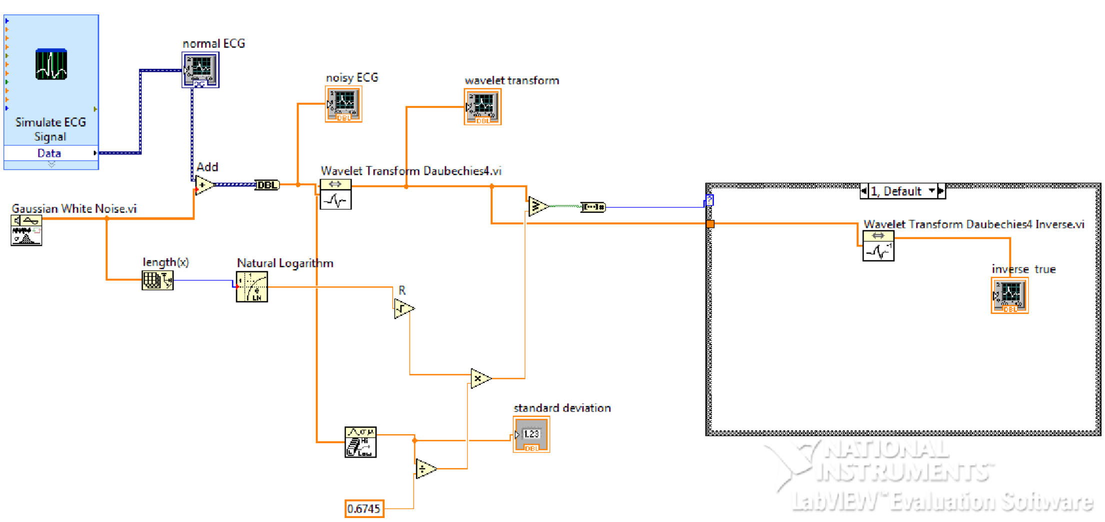

Figure 3. LabVIEW design for of ECG noise analysis.

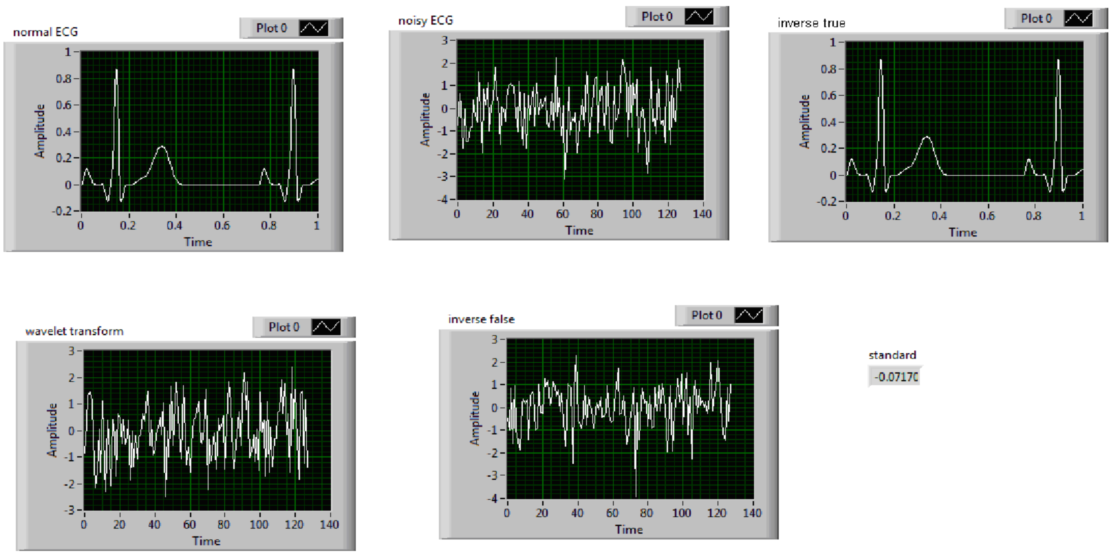

Figure 4. Feasibility result for the noise removal of ECG.

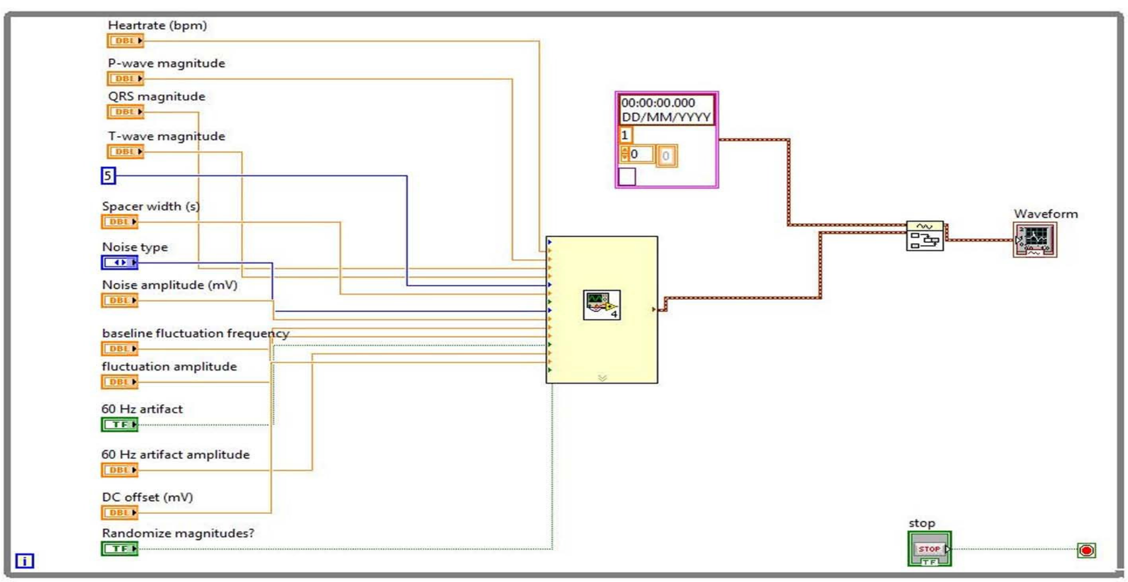

Figure 5. LabVIEW design for adaptive filter to produce noise-limited ECG.

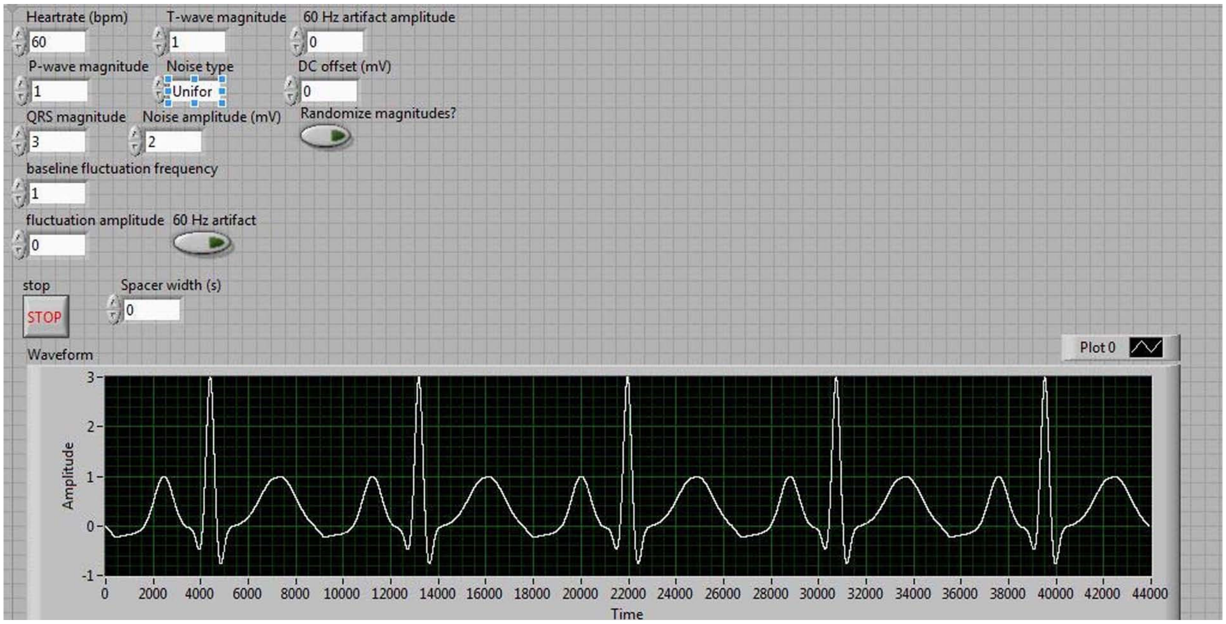

Figure 6. Noise-limited ECG from adaptive filter and heart rate estimation.

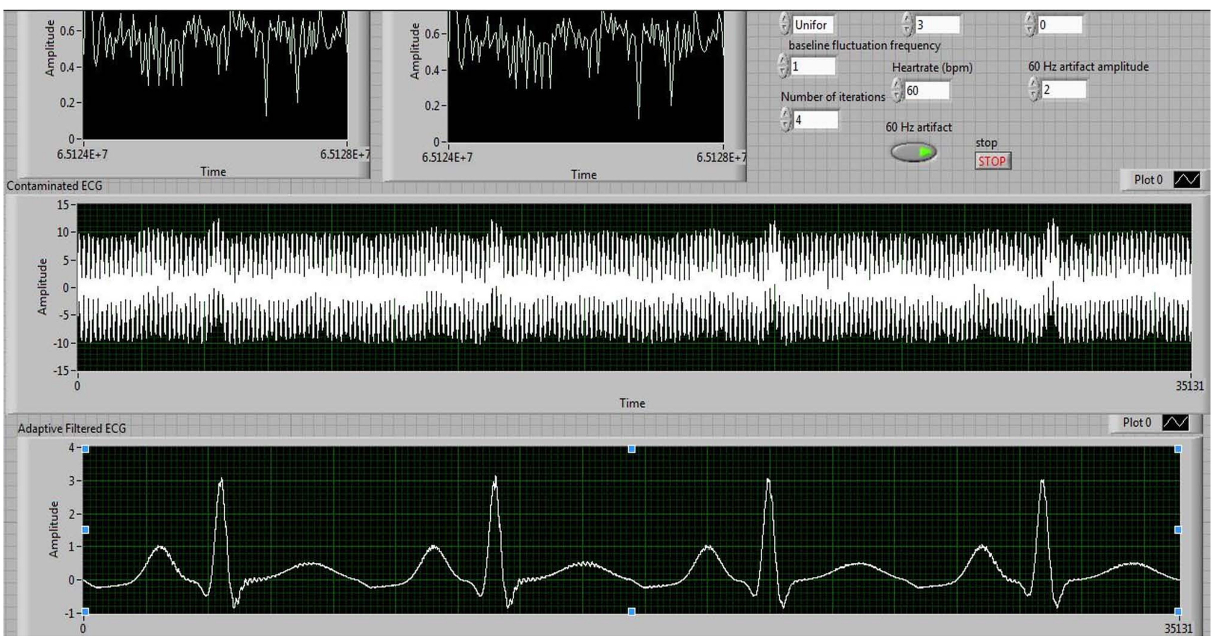

Figure 7. Contaminated (Noisy) ECG and filter-out (Noise-Limited) ECG.

Figure: 8 we use ECG simulator to create a standard ECG signal. The signal is then filtered and amplified and processed to detect the QRS complex. Here the peaks and valleys of the ECG signal is found and analyzed. The duration of the process can be selected manually.

If the peak is found then the location of the peak and the amplitude level of the peak is calculated. If more than one peak is found then the average for the peaks can be calculated and the maximum peak value is calculated and all this are calculated for the valleys also. Then the maximum peak to peak value and minimum peak to peak value is generated as shown in Figure 9.

LabVIEW is the best tool for analyzing the ECG for the single user; it is analyzed based on the following procedure. The RED and GREEN colour points in the above windows (Figure 9) denotes the peaks and valleys in the ECG signal. The RED denotes the peaks and the GREEN denotes the valleys. The QRS detection is done either between two GREEN points (time interval) or between te two GREEN and one RED point (amplitude).

If the ECG and the heart rate (HR) are normal (70 >HR && HR <90), then the GREEN light will glow, if the ECG and the heart rate (HR) are abnormal(HR>90 && HR<70) then automatically the RED light will glow as shown in Figure 10. On it, the amplitude of the ECG signal is varied manually by using the ECG simulator and then response is checked. The GREEN light glows for the normal ECG amplitude (≈ 1.6mVolts) and the RED light glows for the abnormal ECG amplitude (≠ 1.6mVolts). This shows that this optimal method is well suited for the early detection of myocardial infarctions immediately.

6.2 Numerical analysis

If the analysis of the ECG signal is to be done for ‘N’ number of users then the LabVIEW is not an optimal way. For this we can use LabChart, the procedure is more or less the same one as that of the LabVIEW.

For ‘N’ number of users the detection is not based on the single amplitude value. The mean and standard deviation are calculated for the ‘N’ users to carry out the numerical analysis as shown in Figure 11. Table1, shows the mean and standard deviation for abnormal cardiac patients, N = 25 and 209.

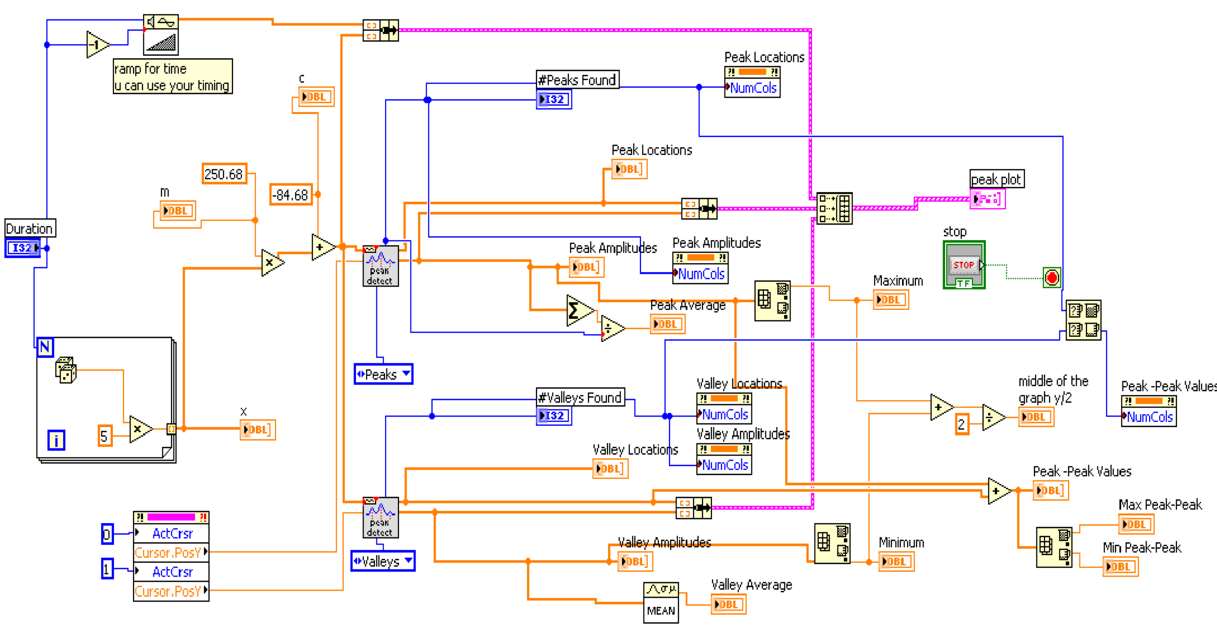

Figure 8. LabVIEW Design for ECG detection (peak and valley detection).

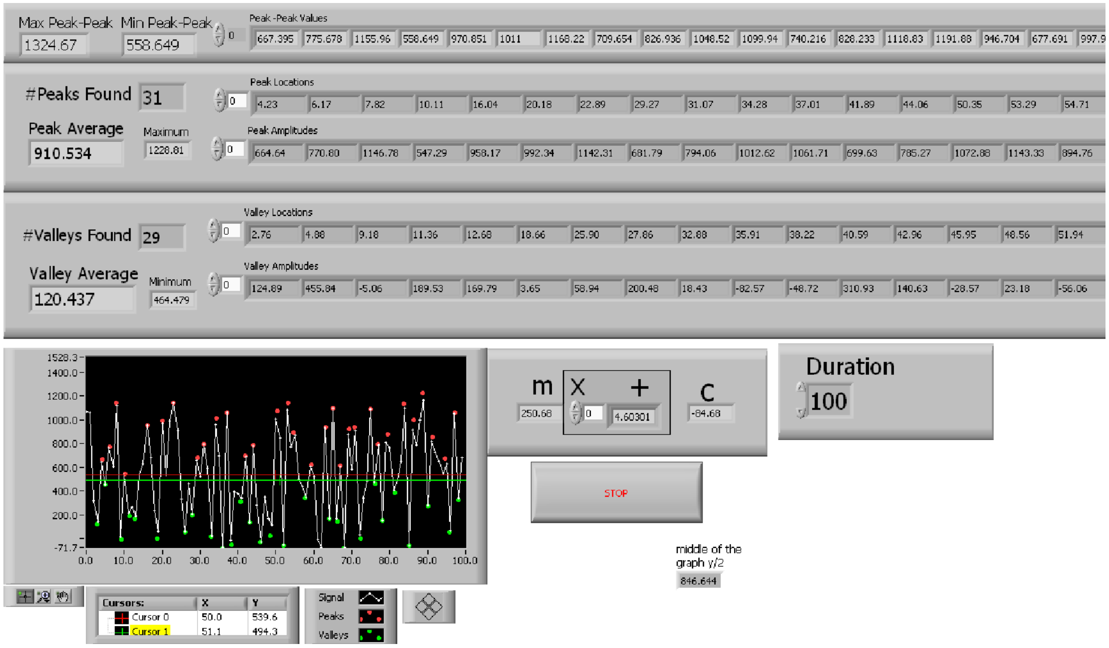

Figure 9. Peak and Valley Detection of ECG wave with its Max. & Min Values.

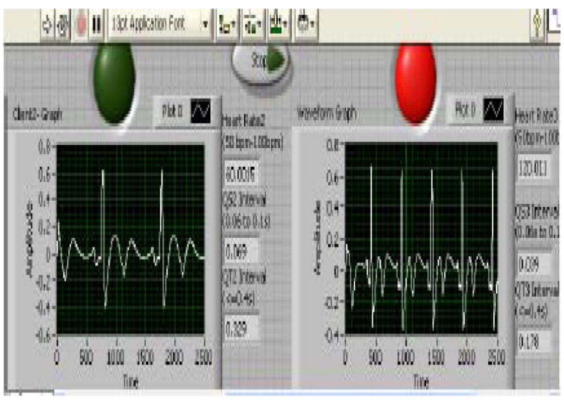

Figure 10. Abnormality detection of ECG wave in terms of amplitude level.

7. Conclusion

The proposed system could be used as a forewarning system for monitoring during normal activity or physical exercises. The most important value of this developed cardiac tele-monitoring system lies in the detection of ECG/Heart Rate of the patients who are located in remote areas or are traveling thus, are not in position of reporting to the doctor for immediate treatment. An alert SMS can be transmitted using the GSM technology to the doctors and help can be look for in order to save the patient´s life. The proposed system enables the heart patient to be on the move globally and keep on with his day to day work. In clinical application, we find that it can detect the difference between cardiovascular patients and normal persons. Comparing this developed cardiac tele-monitoring system to the existing systems [1-19], it has the following enhanced features .

- Do not requires any Internet facility.
- No need for any centralised server.
- Low fault tolerance level is $\pm$ 4 %
- Portable and easy to handle.
- Very low cost.
- Low power consumption.

These study results have great significance in researching, preventing and finding epidemics in the cardiovascular system throughout the country.

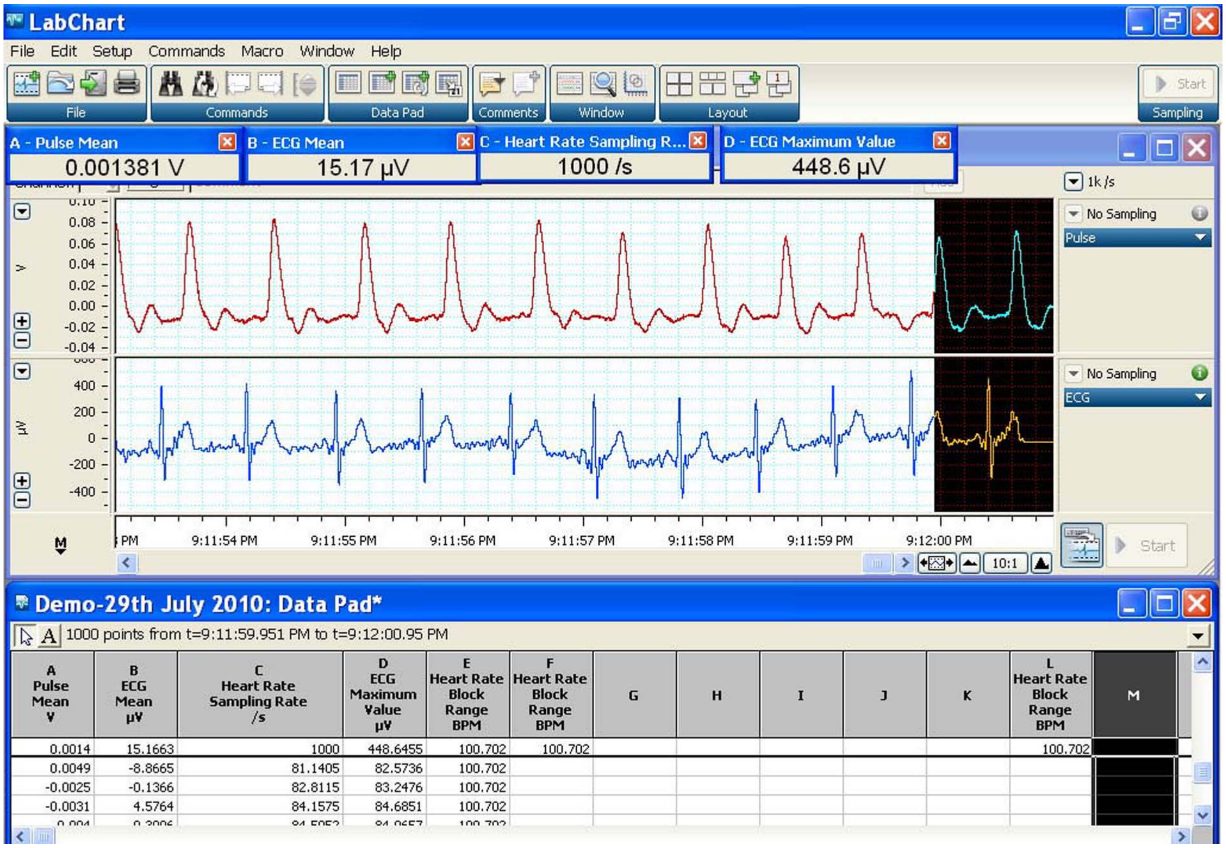

Figure 11. Labchart analysis of ECG mean, standard deviation for ‘N’ patients.

Variables	Abnormal ECG		P-value
	Yes Mean± SD N = 25	No Mean± SD N = 209	
Heart rate/min	101.1±17.2	101.2 ±11.8	0.9
Systolic blood pressure standing(mmHg)	102.8±15.6	104.1±10.5	0.09
Systolic blood pressure supine(mmHg)	103.9±14.1	108.5±16.4	0.7
Diastolic blood pressure standing (mmHg)	61.1±9.3	53.0±9.1	0.3
Diastolic blood pressure supine(mmHg)	65.4±11.1	68.9±5.8	0.01
Systolic difference (supine – standing)	3.5 ±12.7	8.6±9.8	0.02
Diastolic difference (supine – standing)	2.2±10.8	14.6±8.2	0.001

Table1. Consolidated chart- mean & standard deviation for ‘N’ abnormal cardiac patients.

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