Study and Analysis of ECG Signal Using MATLAB & LABVIEW as Effective Tools

M. K. Islam, A. N. M. M. Haque, G. Tangim, T. Ahammad, and M. R. H. Khondokar, *Member, IACSIT*

Abstract—**This paper deals with the study and analysis of ECG signal processing by means of MATLAB tool effectively. Study of ECG signal includes generation & simulation of ECG signal, acquisition of real time ECG data, ECG signal filtering & processing, feature extraction, comparison between different ECG signal analysis algorithms & techniques (i.e. Wavlet transform or so), detection of any abnormalities in ECG, calculating beat rate and so on using the most familiar and multipurpose MATLAB software along with LABVIEW. The proper utilization of MATLAB functions (both built-in and user defined), toolbox and Simulink can lead us to work with ECG signals for processing and analysis both in real time and by simulation with great accuracy and convenience.**

Index Terms—**ECG signal processing; MATLAB; wavlet transform; ECG simulator; LABVIEW; FFT; simulink;**

I. INTRODUCTION

Electrocardiogram (ECG or EKG) is a diagnostic tool that measures and records the electrical activity of the heart in exquisite detail. Interpretation of these details allows diagnosis of a wide range of heart conditions. These conditions can vary from minor to life threatening [1], [2].

An ECG is generated by a nerve impulse stimulus to a heart. The current is diffused around the surface of the body surface. The current at the body surface will build on the voltage drop, which is a couple of μV to mV with an impulse variation. Usually, this is very small amplitude of impulse, which requires a couple of thousand times of amplification.

A typical ECG tracing of a normal heartbeat (or cardiac cycle) consists of a P wave, a QRS complex and a T wave. A small U wave is normally visible in 50 to 75% of ECGs. The baseline voltage of the electrocardiogram is known as the isoelectric line. Typically the isoelectric line is measured as the portion of the tracing following the T wave and preceding the next P wave. The electrical activity of the heart can be recorded at the surface of the body using an

M. K. Islam is with the Signal Processing and VLSI Lab, Dept. of ECE, NUS Singapore, Singapore 117576 (e-mail: kafiul_islam@nus.edu.sg).

A. N. M. M. Haque is with the Department of Sustainable Energy System, KTH - Kungliga Tekniska högskolan, Stockholm, Sweden (e-mail: anmmha@kth.se)

G. Tangim is with Department of Electrical and Computer Science, University of Calgary, Calgary, AB T2N 1N4 Canada. (e-mail: gtangim@ucalgary.ca).

M. R. H. Khondokar and is with the Department of Electrical and Electronic Engineering, The University of Melbourne (e-mail: udyc1087@yahoo.com).

T. Ahammad is with the Department of Electrical Engineering, Petroleum Institute, Abu Dhabi, United Arab Emirates (e-mail: tanvir52@yahoo.com)

electrocardiogram. Therefore the electro-cardio-gram (EKG) is simply a voltmeter that uses up to 12 different leads (electrodes) placed on designated areas of the body. Figure 1 shows the typical ECG trace [2]. The electrical activity of the heart is generally sensed by monitoring electrodes placed on the skin surface. The electrical signal is very small (normally 0.0001 to 0.003 volt). These signals are within the frequency range of 0.05 to 100 Hertz (Hz.) or cycles per second.

In ECG signals, instrumentation plays a major role, since signals generated by human body are very low in amplitude. High gain must be obtained with high common-mode rejection ratio (CMRR). Two electrical circuits were studied in the present work, using common electronic parts and application specific parts. Signals were acquired using a NI USB acquisition platform. LABVIEW is a software application from National Instruments that is specially designed for easy and powerful data acquisition purpose. Thus, LABVIEW software was used for data recording and visualization, due to its known capabilities [3]. Since ECG signals are very noisy, usually 50Hz noise, MATLAB was used to test and adjust a digital filter [4], in order to obtain a good QRS complex, which represents the ventricular depolarization in the ECG, i.e., it shows the electrical impulse of heart as it passes through the ventricles.

Finally, LABVIEW were used again to implement real time filtering of the signal, with the MATLAB filter studied in the initial step, and it is implemented a small application for real-time visualization of an ECG.

II. ECG SIMULATOR

The aim of the ECG simulator is to produce the typical ECG waveforms of different leads and as many arrhythmias as possible. This ECG simulator is a MATLAB based simulator and is able to produce normal lead II ECG waveform [4], [5]. The use of a simulator has many advantages in the simulation of ECG waveforms. First one is saving of time and another one is removing the difficulties of taking real ECG signals with invasive and noninvasive methods. The ECG simulator enables us to analyze and study normal and abnormal ECG waveforms without actually using the ECG machine. One can simulate any given ECG waveform using the ECG simulator.

Significant features of ECG waveform: A typical scalar electrocardiographic lead is shown in Fig. 1, where the significant features of the waveform are the P, Q, R, S, and T waves, the duration of each wave, and certain time intervals such as the P-R, S-T, and Q-T intervals.

ECG signal is periodic with fundamental frequency determined by the heartbeat. It also satisfies the Dirichlet's

conditions. Hence Fourier series can be used for representing ECG signal. If we observe Fig. 1 carefully, we may notice that a single period of an ECG signal is a mixture of triangular and sinusoidal wave forms. Each significant feature of ECG signalcan be represented by shifted and scaled versions one of these waveforms as shown below.

- QRS, Q and S portions of ECG signal can be represented by triangular waveforms.
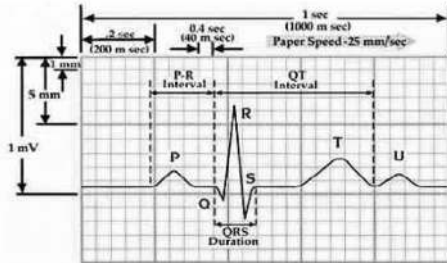- P, T and U portions can be represented by triangular waveforms.

Fig. 1. Typical one-cycle ECG signal tracking

Once we generate each of these portions, they can be added finally to get the ECG signal. So the generated output ECG signal by MATLAB is shown in Fig. 2. The specifications are default for this signal which can be changed according to the user's requirement while simulating the MATLAB code. We take heartbeat as 72, amplitude of P, R, Q, T waves as 25mV, 1.6mV, 0.025mV, 0.35mV respectively while the duration of P-R interval, S-T interval, P interval, QRS interval as 0.16s, 0.18s, 0.09s, 0.11s respectively.
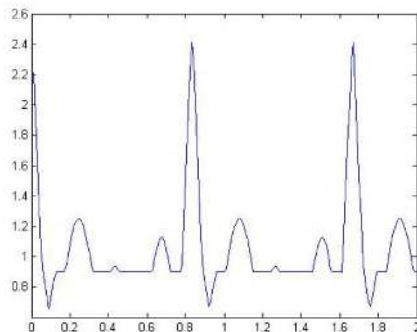

Fig. 2. Typical ECG output waveform simulated in MATLAB

III. ECG SIGNAL ACQUISITION

In MATLAB, the *Data Acquisition Toolbox* provides Simulink blocks for acquiring live data into Simulink models and for outputting live signals to the physical hardware [6], [7]. It uses the *Analog Input* block to acquire live analog data from a data acquisition device into Simulink. The acquired data is processed in Simulink and uses the Analog Output block to output data to an analog data acquisition device. The acquired ECG data by Simulink is shown in Fig. 3.

IV. ECG SIGNAL PROCESSING

Generally, the recorded ECG signal is often contaminated by noise and artifacts that can be within the frequency band of interest and manifest with similar characteristics as the

ECG signal itself. In order to extract useful information from the noisy ECG signals, we need to process the raw ECG signals.

ECG signal processing can be roughly divided into two stages by functionality: preprocessing and feature extraction. The preprocessing stage removes or suppresses noise from the raw ECG signal and the feature extraction stage extracts diagnostic information from the ECG signal [7]. As an example, Fig. 5 demonstrates this functionality but also demonstrates an example where ECG data may be embedded within another ECG signal, such as a Fetal ECG signal.

Fig. 3. This simulink Scope shows an acquired ECG signal with a sampling frequency of 1200 Hz

With LabVIEW and related toolkits, such as the Advanced Signal Processing Toolkit (ASPT) and the Digital Filter Design Toolkit (DFDT), one can conveniently build signal processing applications for both stages, including baseline wandering removing, noise cancellation, QRS complexes detection, fetal heart rate extraction and etc [3]. This section discusses typical ECG signal processing methods based on LabVIEW.
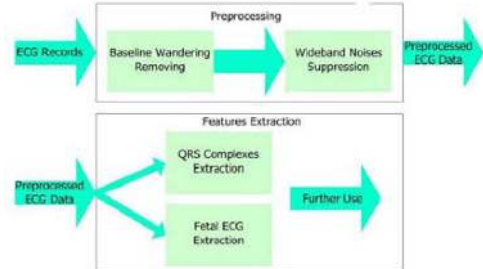

Fig. 4. Typical ECG signal processing flowchart

Preprocessing ECG signals helps us remove contaminants from the ECG signals. Broadly speaking, ECG contaminants can be classified into the following categories [8]:

- power line interference
- electrode pop or contact noise
- patient–electrode motion artifacts
- electromyographic (EMG) noise
- baseline wandering

Among these noises, the power line interference and the baseline wandering are the most significant and can strongly affect ECG signal analysis. Except for these two noises, other noises may be wideband and usually a complex stochastic process which also distort the ECG signal. The power line interference is narrow-band noise centered at 60 Hz (or 50 Hz) with a bandwidth of less than 1 Hz. Usually the ECG signal acquisition hardware can remove the power line interference. However the baseline wandering and other wideband noises are not easy to be suppressed by hardware equipments. Instead, the software scheme is more powerful and feasible

for offline ECG signal processing. We can use the following methods to remove baseline wandering and the other wideband noise.
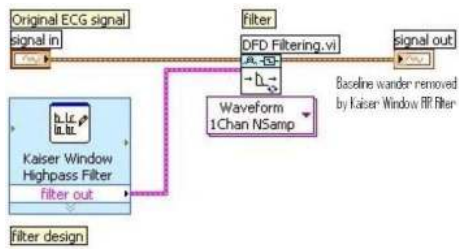

Fig. 5. Designing and using a highpass filter to remove baseline wandering.

A. Removing Baseline Wandering

Baseline wandering usually comes from respiration at frequencies wandering between 0.15 and 0.3 Hz, and we can suppress it by a high pass digital filter. We also can use the wavelet transform to remove baseline wandering by eliminating the trend of the ECG signal.

- Digital Filter Approach

The Lab VIEW DFDT provides an intuitive and interactive way to design and implement finite impulse response (FIR) or infinite impulse response (IIR) filters easily and effectively. For example, we can use the Classical Filter Design Express VI to design a Kaiser Window FIR high pass filter to remove the baseline wandering. Figure 6 shows an example of the specifications of the high pass filter and the block diagram of a sample VI that we can use to remove the baseline wandering.
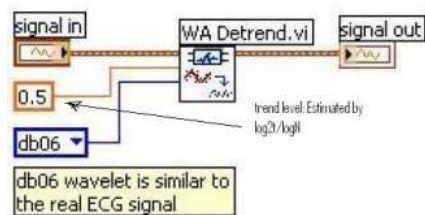

Fig. 6. Using the WA Detrend VI to remove baseline wandering

- Wavelet Transform Approach

In addition to digital filters, the wavelet transform is also an effective way to remove signals within specific subbands. The LabVIEW ASPT provides the WA Detrend VI which can remove the low frequency trend of a signal [9]. Fig. 7 shows an example of removing baseline wandering by using the WA Detrend VI.
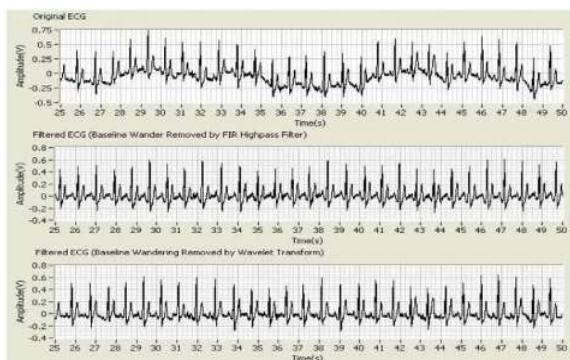

Fig. 7. Comparing the digital filter-based and wavelet transform-based approaches

This example uses the Daubechies6 (db06) wavelet because this wavelet is similar to the real ECG signal. In this example, the ECG signal has a sampling duration of 60 seconds, and 12000 sampling points in total. Therefore the trend level is 0.5 according to the following equation:

$$trend\ level = \left\lceil \frac{log_2\ 2t}{log_2\ N} \right\rceil$$

where t is the sampling duration and N is the number of sampling points. Figure 8 shows the original ECG signal and the resulting ECG signals processed by the digital filter based and wavelet transform-based approaches [9]. We can see that the resulting ECG signals contain little baseline wandering information but retain the main characteristics of the original ECG signal. It is also seen that the wavelet transform-based approach is better because this approach introduces no latency and less distortion than the digital filter-based approach.
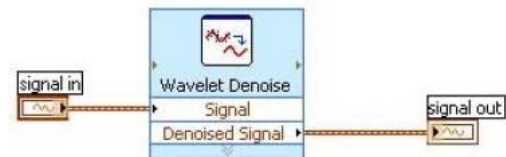

Fig. 8. Removing wideband noises from an ECG signal by applying the UWT

B. Removing Wideband Noise

After we remove baseline wandering, the resulting ECG signal is more stationary and explicit than the original signal [10]. However, some other types of noise might still affect feature extraction of the ECG signal. The noise may be complex stochastic processes within a wideband, so you cannot remove them by using traditional digital filters. To remove the wideband noises, we can use the Wavelet Denoise Express VI. This LabVIEW based higher-level Express VI first decomposes the ECG signal into several sub-bands by applying the wavelet transform, and then modifies each wavelet coefficient by applying a threshold or shrinkage function, and finally reconstructs the denoised signal. The following figure shows an example of applying the un-decimated wavelet transform (UWT) to the ECG signal.
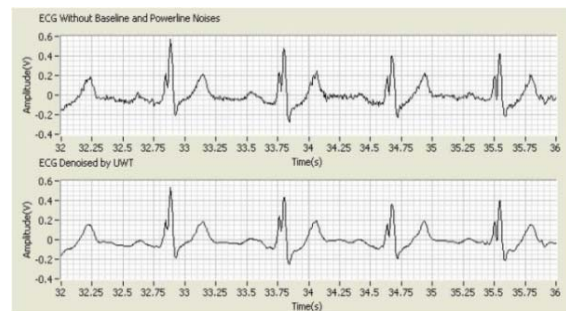

Fig. 9. ECG signals before and after UWT de-noising

C. Feature Extraction of ECG Signal

For the purpose of diagnosis, we often need to extract various features from the preprocessed ECG data, including QRS intervals, QRS amplitudes, PR intervals, ST intervals,
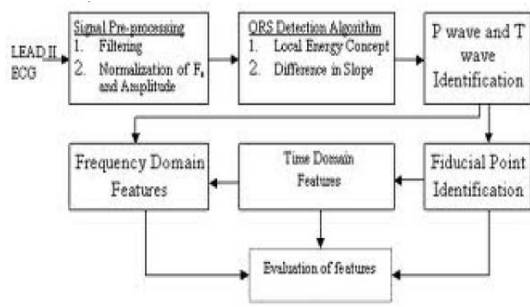
fetal heart rate, etc.
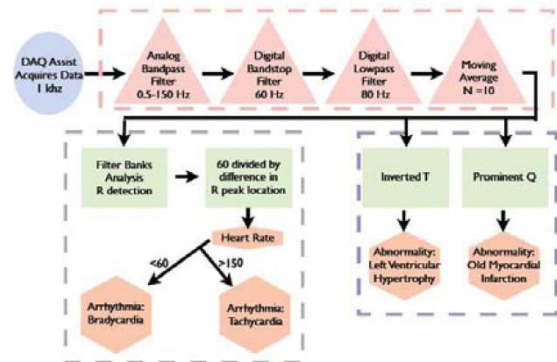

Fig. 10. Feature extraction steps

- QRS Complex Detection:

The detection of the R-peaks and consequently of the QRS complexes in an ECG signal provides information about the heart rate, the conduction velocity, the condition of tissues within the heart as well as various abnormalities. It supplies evidence for the diagnoses of cardiac diseases. For this reason, it has drawn considerable attention in the ECG signal processing field. However, the presence of noise and time-varying morphology makes the detection difficult. Fig. 12 shows the ECG signals processed by wavelet multi-resolution analysis (MRA) and peak/valley detection as well as the original ECG signal (from MIT-BIH database). In this figure, you can find that the peaks and valleys (especially Q and S points) become more distinct after wavelet multi-resolution analysis.

After extracting the features by performing QRS complex detection, we can analyze the features with other methods. For example, we can perform heart rate variability (HRV) analysis on the R-R interval signal to demonstrate the state of the heart and nerve system.

V. ECG SIGNAL ANALYSIS

A. Heart Rate Calculation

ECG Signal is analyzed using built-in function of Wavelet Transforms to calculate the heart rate. The normal value of heart beat lies in the range of 60 to 100 beats/minute. A slower rate than this is called bradycardia (Slow heart) and a higher rate is called tachycardia (Fast heart). If the cycles are not evenly spaced, an arrhythmia may be indicated. If the P-R interval is greater than 0.2 seconds, it may suggest blockage of the AV node. The equation to calculate heart rate is given below:

$$Heart\ Rate\ =\ (1/RR\ interval\ in\ sec.)\ *\ 60$$

Fig. 11. Original ECG, ECG after MRA and ECG after peak/valley detection
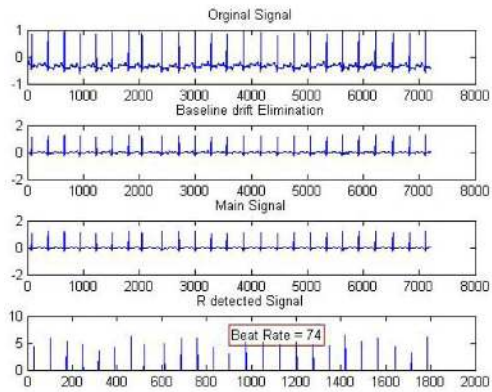

Fig. 12. ECG signal analysis flowchart

Fig. 13. Calculation of heart beat using WT intrinsic function

B. Abnormality Detection

Wavelet is found to be superior to the conventional FFT method in finding the small abnormalities in ECG signals. The wavelet analysis of ECG signal is performed using MATLAB. The waveforms with normality and abnormalities are shown in Fig. 2 and 14 respectively.

C. Signal Calculating ECG Intervals & Self Diagnosis

Software can be developed in MATLAB to process each acquired ECG signal. This processing consists of verifying the period, the sampling frequency and calculating the SA node frequency (sinus rhythm) [11], [12]. The software can also calculate the intervals P-R, QRS and Q-T, presenting the peaks P, Q, R, S and T. Figure 16 represents the calculation of P-R interval of an ECG signal. The user can select an interval, e.g., the P-R, and to obtain information about its contents. Abnormal cardiac rhythms in P-R interval can be detected using these developed algorithms, as the expansion of the atria. Also, AV block can be detected.
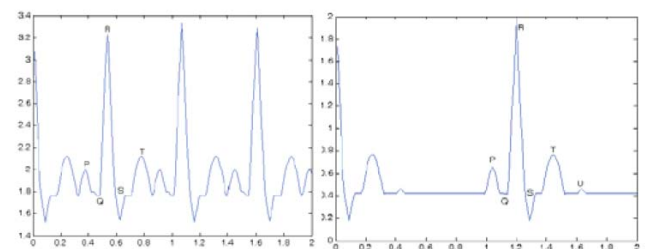

Fig.14. a) Sinus tachycardia. b) Sinus bradycardia.

VI. COMPARISON OF DIFFERENT PROCESSING TECHNIQUES

Though, the non-adaptive filtering is faster than the

adaptive filtering methods but the adaptive filtering after tuning the taps to some optimum value gives the best results [11]. Adaptive filtering in some cases though amplified the S-peaks, but it does not give any serious distortion effects onto the signal. However, the wavelet approach is more convenient than the conventional filtering techniques, which highlights the details of the ECG signal with optimal time-frequency resolution. If we analyze the ECG signal by both conventional FFT and Wavelet transform, then we have found Wavelet is to be superior to the conventional FFT method in finding the small abnormalities in ECG signals.
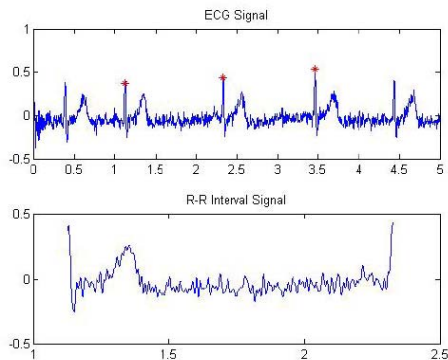

Fig. 15. Calculation of P-R interval

VII. CONCLUSION

Both MATLAB and LabVIEW have immense effect on ECG signal processing. They are so useful and handy that even one can monitor his/her heart condition simply utilizing the power of MATLAB and/or LabVIEW without having an ECG machine and also self diagnosis is possible. All these examples and techniques that are discussed here can be really useful for experimental/lab purpose even we don't have any ECG data we still can simulate and analyze it.

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M. K. Islam completed his BSc from Islamic University of Technology (IUT) and then joined SECS, Independent University, Bangladesh (IUB). He is now pursuing PhD in Electrical and Computer Engineering from National University Singapore (NUS). His research interest are Digital System Design, Biomedical Signal Processing, VLSI.

A. N. M. Mushfiqul Haque was born in Bogra, Bangladesh in 1988. He graduated in Electrical and Electronic Engineering from the Islamic University of Technology, Bangladesh 2009. He worked as a Junior Lecturer at the School of Engineering and Computer Science in the Independent University, Bangledesh. Currently he is pursuing his graduate studies in the Royal Institute of Technology (KTH), Sweden in Environomical Pathways for Sustainable Energy Systems (SELECT) with the specialization in Electrical Systems. His research interest includes Smart grid technologies, Pulsed power technology in biomedical appliances, Power quality issues etc.

G. Tangim is pursuing MSc in Electrical and Computer Engineering (ECE) in the Faculty of Engineering, University of Calgary. His research interest includes Fault-Tolerant Nanoarchitectures, VLSI and Computer Aided Design of Digital logic circuits. Tangim has a BSc in Electrical and Electronics Engineering from Islamic University of Technology (IUT), Bangladesh. He served as a junior Lecturer in the School of Engineering and Computer Science (SECS) in Independent University, Bangladesh (IUB) for two years. He is a student member of IACSIT.

T. Ahammad was born in Bangladesh in 1988. He received the Bachelor of Science in Electrical and Electronic Engineering (EEE) from Islamic University of Technology (IUT), Dhaka, Bangladesh in 2008.
He has been served as a Lecturer of EEE department in Stamford University Bangladesh, Dhaka, Bangladesh in 2009. He has joined as a student of Masters of Science in the Department of Electrical Engineering (EE) in The Petroleum Institute, Abu Dhabi, United Arab Emirate (UAE) since 2011. He has been working in Power Electronics Lab of Petroleum Institute under the supervision of Dr. Abdul R. Beig. His main areas of research interest are Direct Torque Control of Induction Motor, Application of Sliding Mode control in Machine Drives, Three Level Inverter, Space Vector Pulse Width Modulation. He is supposed to complete his Graduation by January 2013.

M. R. H. Khondokar completed his BSc from Islamic University of Technology (IUT) in 2008. He joined the School of Engineering and Computer Science (SECS) in Independent University, Bangladesh (IUB) since. His research interest includes Acoustic signal processing, Digital signal processing, Biomedical Signal processing, Wireless Communication.