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Real-Time Heart Rate and ECG Monitoring System Using LabVIEW and Data Acquisition Hardware

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ABSTRACT

Electrocardiogram (ECG) monitoring plays a crucial role in the diagnosis and monitoring of cardiovascular diseases. This project presents the design and implementation of a real-time ECG signal acquisition and heart rate monitoring system using LabVIEW and National Instruments Data Acquisition (NI-DAQ) hardware. The system utilizes an AD8232 ECG sensor module to capture the bio-electrical signals generated by the human heart through Ag/AgCl electrodes placed on the body. Since ECG signals are extremely weak and susceptible to noise, the AD8232 module performs signal amplification and preliminary conditioning before transmitting the analog signal to the NI USB-6008 DAQ device. The DAQ device digitizes the incoming signal and transfers it to the LabVIEW environment for further processing and visualization.

In LabVIEW, the acquired ECG signal undergoes digital signal processing using cascaded filtering techniques to eliminate noise, baseline wander, and power-line interference. The filtered signal is then visualized in real time using waveform charts on the LabVIEW front panel. A peak detection mechanism is implemented to identify the R-peaks of the ECG waveform, which represent heartbeats. The time interval between successive peaks is calculated to determine the heart rate in beats per minute (BPM). The developed system provides real-time visualization of raw and filtered ECG signals along with heart rate and frequency measurements. The proposed system offers a reliable, cost-effective, and efficient platform for real-time cardiac monitoring and biomedical signal analysis.

1. INTRODUCTION

Cardiovascular diseases remain one of the leading causes of mortality worldwide, making early diagnosis and continuous monitoring of cardiac activity extremely important. The **Electrocardiogram (ECG)** is one of the most widely used non-invasive diagnostic tools for analyzing the electrical activity of the heart. ECG signals provide valuable information about cardiac rhythm, heart rate, and abnormalities such as arrhythmia, myocardial infarction, and other heart-related disorders. Because of its clinical importance, the development of reliable systems for ECG acquisition, processing, and analysis has become a significant research topic in biomedical engineering.

In recent years, various signal processing and machine learning techniques have been applied to improve ECG analysis and diagnosis. For example, spectrogram-based analysis combined with convolutional neural networks has been used for automated arrhythmia classification, demonstrating high accuracy in identifying abnormal cardiac patterns [1]. Similarly, ECG signal processing methods implemented using LabVIEW have been explored for parameter extraction and real-time visualization of biomedical signals [2]. Wavelet transform techniques have also been widely used to analyze ECG signals due to their ability to detect time–frequency characteristics of cardiac waveforms effectively [3].

Several research works have focused on the development of ECG monitoring systems for real-time medical applications. Telemedicine-based ECG monitoring systems enable remote patient monitoring and improve healthcare accessibility in rural and remote areas [4]. LabVIEW-based implementations are particularly popular because they provide powerful graphical programming capabilities and seamless integration with data acquisition (DAQ) hardware. Real-time ECG feature extraction systems developed using NI LabVIEW have demonstrated the ability to detect important cardiac parameters efficiently [5]. Advanced virtual instrumentation techniques have also been used for early detection of cardiac abnormalities and arrhythmias [6].

Signal processing plays a crucial role in ECG analysis because the acquired signals are often affected by various types of noise such as baseline drift, motion artifacts, and power-line interference. Wavelet-based analysis techniques have been used to detect heart rate from ECG signals with improved accuracy in LabVIEW environments [7]. Expert systems and decision support systems have also been proposed for identifying heart abnormalities using LabVIEW-based platforms [8]. Furthermore, real-time ECG monitoring systems have been developed to provide continuous visualization and analysis of cardiac signals for clinical and research purposes [9].

Researchers have also investigated feature extraction and heart rate variability analysis techniques using biomedical signal processing tools [10]. Software environments such as MATLAB and LabVIEW have proven to be effective for ECG signal analysis due to their built-in signal processing libraries and visualization capabilities [11]. Modern developments in ECG monitoring also include implantable monitoring devices and wireless data transmission systems, which enable continuous cardiac monitoring in clinical environments [12]. Earlier work in virtual instrumentation demonstrated the feasibility of real-time ECG monitoring systems using computer-based data acquisition platforms [13].

Noise reduction and signal enhancement remain important challenges in ECG processing. Several denoising techniques have been studied to remove noise from ECG signals while preserving important waveform characteristics [14]. Baseline drift removal techniques have also been proposed to improve ECG signal quality and enable accurate detection of cardiac events [15]. Additionally, advanced signal processing methods such as Kalman filtering have been applied for detecting specific ECG waveform components like the P-wave in arrhythmia detection systems [16]. Machine learning techniques such as support vector machines and neural networks have further enhanced the capability of automated heart disease detection systems [17].

Based on these developments, this work focuses on the **design and implementation of a real-time ECG signal acquisition and heart rate monitoring system using LabVIEW and National Instruments data acquisition hardware**. The proposed system utilizes an AD8232 ECG sensor to capture bio-electrical signals from the human body, which are then processed using digital filtering and peak detection algorithms within the LabVIEW environment. The system provides real-time visualization of ECG waveforms and calculates heart rate in beats per minute (BPM), offering a reliable and efficient platform for biomedical signal monitoring and analysis.

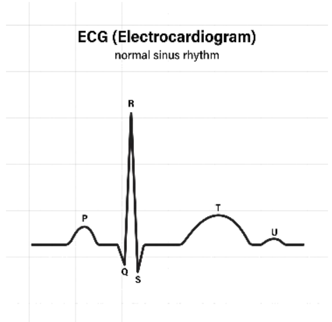

Figure 1 Typical ECG waveform showing the main components: P wave, QRS complex, and T wave, which represent different phases of the cardiac electrical cycle.

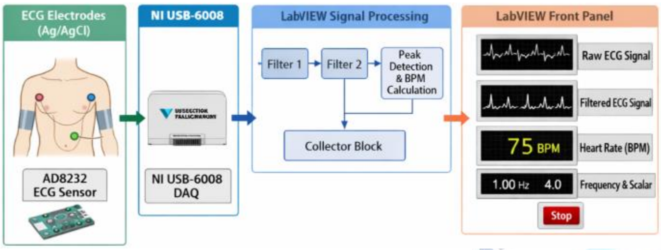

Figure 2 System architecture of the real time ECG monitoring system

The working architecture of the proposed real-time ECG monitoring system is illustrated in Fig. 1 and Fig. 2. Fig. 1 presents the basic structure of an ECG waveform showing the important components such as the P wave, QRS complex, and T wave, which correspond to different phases of the cardiac electrical cycle. These waveform components are essential for analyzing heart activity and identifying cardiac abnormalities. The R-peak within the QRS complex is particularly important because it is used to determine the heart rate by measuring the time interval between successive peaks.

The overall system architecture used for acquiring and processing ECG signals is shown in **Fig. 2**. In this system, **Ag/AgCl electrodes connected to the AD8232 ECG sensor** capture the weak bio-electrical signals generated by the human heart. The sensor amplifies and conditions these signals before transmitting them to the **NI USB-6008 data acquisition (DAQ) device**, which converts the analog signal into digital data. The digitized ECG signal is then processed in the **LabVIEW environment**, where digital filters are applied to remove noise and baseline drift. A peak detection algorithm is used to identify the R-peaks of the ECG waveform, enabling the calculation of the heart rate in **beats per minute (BPM)**. The processed signals and calculated parameters are displayed in real time on the **LabVIEW front panel**, allowing continuous monitoring of ECG waveforms and heart rate measurements.

2. Related Work

Electrocardiogram (ECG) signal analysis has been widely studied for the detection and diagnosis of cardiovascular diseases. Many researchers have proposed different techniques for ECG acquisition, signal processing, and automated heart rate detection using various hardware and software platforms. Huang et al. [1] proposed an ECG arrhythmia classification method using Short-Time Fourier Transform (STFT) based spectrograms combined with Convolutional Neural Networks (CNN). Their work demonstrated that deep learning models can effectively classify different types of arrhythmias from ECG signals by extracting spectral features from time–frequency representations.

Several studies have also focused on the use of graphical programming environments such as LabVIEW for ECG signal processing. Keskes et al. [2] developed a system for ECG parameter extraction using LabVIEW, where signal processing blocks were used to analyze important cardiac parameters in real time. Saritha et al. [3] investigated ECG signal analysis using wavelet transforms, showing that wavelet-based techniques provide efficient time–frequency analysis for detecting ECG waveform components such as P, QRS, and T waves. Similarly, Haque and Ahmed [4] developed an ECG-based heart disease detection system designed for telemedicine applications, enabling remote monitoring of cardiac signals.

Real-time ECG feature extraction and monitoring systems have also been developed using virtual instrumentation techniques. Ay et al. [5] implemented a real-time ECG feature extraction system using NI LabVIEW, demonstrating the ability to extract important cardiac features directly from acquired signals. Sharma and Shukla [6] designed a virtual instrumentation-based toolbox for early arrhythmia detection, highlighting the importance of signal processing and automated analysis for improving diagnostic accuracy. Kaya et al. [7] proposed a wavelet-based method for heart rate detection using LabVIEW, where wavelet decomposition was applied to extract heart rate information from ECG signals.

Several expert systems have also been proposed to assist in cardiac abnormality detection. Jain et al. [8] developed a LabVIEW-based expert system for detecting heart abnormalities from ECG signals. Nandagopal et al. [9] presented a real-time ECG monitoring system using LabVIEW that provided continuous visualization and monitoring of ECG signals for biomedical applications. Vijoriya and Maheshwari [10] investigated ECG signal acquisition and feature extraction using biomedical workbench tools, focusing on heart rate variability (HRV) analysis for cardiac health assessment.

Various software environments have been used for ECG signal analysis and processing. Islam et al. [11] conducted a comparative study showing that MATLAB and LabVIEW are effective tools for analyzing ECG signals due to their advanced signal processing capabilities. Lee and Seo [12] developed an ECG monitoring system integrated with an implantable device capable of wireless charging, demonstrating advancements in wearable and implantable cardiac monitoring technologies. Kumar et al. [13] earlier proposed a real-time ECG monitoring system using virtual instrumentation, which showed the feasibility of computer-based ECG acquisition and analysis systems.

Noise reduction and signal quality improvement are also important aspects of ECG processing. Velayudhan and Peter [14] conducted a survey on different ECG denoising techniques used to remove noise while preserving important cardiac waveform features. Luo et al. [15] proposed a hierarchical method for removing baseline drift in biomedical signals, improving ECG signal quality for accurate analysis. Rahimpour and Asl [16] presented a P-wave detection method using an extended Kalman filter to analyze ECG signals in different arrhythmia contexts. Additionally, Begum and Manza [17] explored machine learning techniques such as Support Vector Machines (SVM) and Artificial Neural Networks (ANN) for detecting cardiomyopathy using ECG signals.

From the existing literature, it is evident that significant research has been carried out in ECG signal processing, feature extraction, and automated cardiac diagnosis. However, many systems either rely on complex machine learning models or specialized medical equipment. Therefore, the proposed work focuses on developing a real-time ECG monitoring system using the AD8232 sensor, NI DAQ hardware, and LabVIEW environment, which provides reliable ECG acquisition, noise filtering, waveform visualization, and heart rate calculation in a cost-effective and efficient manner.

3. Proposed System

The proposed system is designed to acquire, process, and analyze Electrocardiogram (ECG) signals in real time using a combination of biomedical sensing hardware and LabVIEW-based signal processing techniques. The system integrates an AD8232 ECG sensor module, National Instruments data acquisition hardware, and LabVIEW graphical programming software to create a reliable platform for monitoring cardiac activity. The primary objective of the system is to capture the electrical activity of the heart, remove unwanted noise from the signal, and compute the heart rate in beats per minute (BPM) while providing real-time visualization of the ECG waveform.

The ECG signal acquisition begins with the placement of Ag/AgCl electrodes on the human body, typically on the chest or limbs, which detect the small electrical potentials generated by the heart during its contraction and relaxation cycles. These signals are extremely weak, usually in the range of a few millivolts, and therefore require amplification and conditioning before further processing. The AD8232 ECG sensor module performs signal amplification and basic filtering to produce a cleaner analog output suitable for data acquisition.

The conditioned analog signal is then transmitted to the NI USB-6008 Data Acquisition (DAQ) device, which converts the analog ECG signal into digital data using its analog input channels. The digitized signal is transferred to the computer through the DAQ interface and processed using LabVIEW. Within the LabVIEW block diagram, the incoming signal first passes through digital filtering stages designed to remove noise components such as baseline drift, motion artifacts, and power-line interference.

After filtering, the processed ECG signal is analyzed using a peak detection mechanism to identify the R-peaks of the ECG waveform. These peaks correspond to heartbeats and are used to determine the time interval between successive beats. The heart rate is then calculated using the standard formula based on the detected peaks. The final processed signal and calculated parameters, including raw ECG waveform, filtered ECG waveform, heart rate (BPM), and signal frequency, are displayed on the LabVIEW front panel in real time.

The overall architecture of the proposed ECG monitoring system is illustrated in Fig. 3, which shows the interaction between the sensing unit, data acquisition module, signal processing block, and visualization interface.

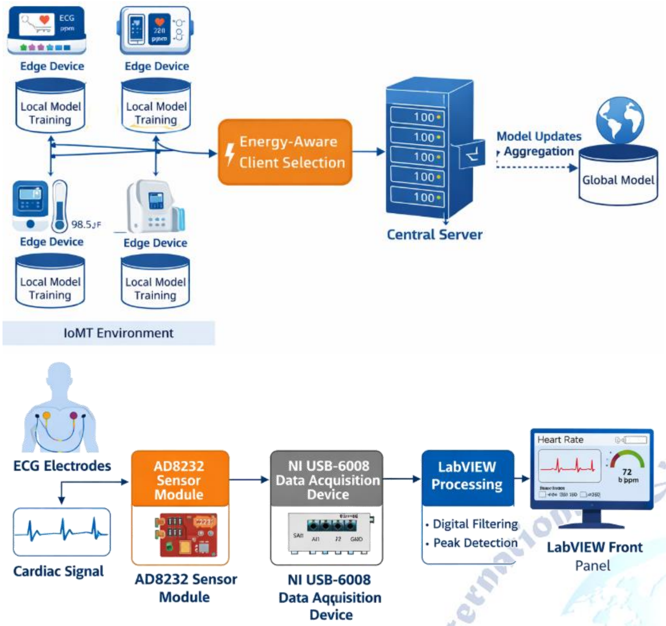

Figure 3 Block diagram of the proposed real-time ECG monitoring system.

The ECG electrodes capture cardiac signals, which are amplified by the AD8232 sensor module. The signal is digitized using the NI USB-6008 data acquisition device and processed in LabVIEW using digital filtering and peak detection algorithms. The processed ECG waveform and heart rate are displayed on the LabVIEW front panel for real-time monitoring.

4. Methodology

The proposed ECG monitoring system follows a structured methodology that integrates hardware-based signal acquisition with software-based signal processing in the LabVIEW environment. The methodology consists of four main stages: ECG signal acquisition, signal conditioning and filtering, feature extraction, and heart rate computation. The system ensures that weak bio-electrical signals generated by the human heart are accurately captured, processed, and visualized in real time.

A. ECG Signal Acquisition

ECG signals are captured using Ag/AgCl electrodes placed on the human body. These electrodes detect the electrical activity produced during cardiac cycles. The AD8232 ECG sensor module amplifies the small bio-electrical signals (typically 1–3 mV) and performs initial signal conditioning. The conditioned analog signal is transmitted to the NI USB-6008 data acquisition device, which converts the analog signal into digital data for processing in LabVIEW.

B. Signal Filtering

The raw ECG signal often contains noise such as baseline drift, muscle artifacts, and power-line interference. To obtain a clean ECG waveform, digital filtering techniques are applied inside LabVIEW. A combination of high-pass and low-pass filters is used.

High-pass filter equation:

$y[n] = \alpha(y[n-1] + x[n] - x[n-1])$

Low-pass filter equation:

$y[n] = (1/N) * \Sigma\, x[n]$

These filters remove unwanted frequency components and allow the system to retain important ECG waveform features such as the P-wave, QRS complex, and T-wave.

C. Peak Detection and Feature Extraction

After filtering, the system detects the R-peaks of the ECG waveform. The R-peak corresponds to the highest amplitude point in the QRS complex and represents a heartbeat. A threshold-based detection algorithm is implemented to identify peaks above a predefined amplitude level.

Algorithm 1: R-Peak Detection

Step 1: Acquire filtered ECG signal.

Step 2: Set threshold value T (e.g., 0.6).

Step 3: For each sample x(i) in ECG signal:

If $x(i) > T$ and $x(i) > x(i-1)$ and $x(i) > x(i+1)$

Mark as R-peak.

Step 4: Store time index of detected peaks.

Step 5: Repeat until the end of the signal.

D. Heart Rate Calculation

The heart rate is calculated based on the time interval between successive R-peaks (R–R interval). The BPM value is computed using the following expression:

Heart Rate Formula:

BPM = 60 / (R-R Interval in seconds)

Alternatively, if the number of detected peaks is counted within a fixed time window (e.g., 15 seconds), the heart rate can be estimated using:

BPM = (Number of Peaks / 15) × 60

Algorithm 2: Heart Rate Computation

Step 1: Detect R-peaks from filtered ECG signal.

Step 2: Measure time difference between consecutive peaks.

Step 3: Compute average R-R interval.

Step 4: Calculate BPM using BPM = 60 / (R-R interval).

Step 5: Display BPM on LabVIEW front panel.

E. Visualization

The processed ECG signal and calculated heart rate are displayed on the LabVIEW front panel. The interface shows the raw ECG waveform, filtered ECG waveform, calculated heart rate (BPM), and frequency information in real time. This allows continuous monitoring of the patient's cardiac activity.

5. Results and Discussions

The proposed real-time ECG monitoring system was implemented using the AD8232 ECG sensor module, NI myDAQ data acquisition device, Arduino interface, and LabVIEW software environment. The system was tested by placing Ag/AgCl electrodes on the subject's arm to capture the electrical activity of the heart. The acquired signals were transmitted through the ECG sensor module and digitized using the NI DAQ device. LabVIEW was used for real-time signal processing, filtering, visualization, and heart rate computation.

The experimental setup of the proposed ECG monitoring system is shown in Fig. 4. The hardware configuration includes the NI myDAQ module, Arduino Uno, breadboard circuitry, and AD8232 ECG sensor module connected to the electrodes attached to the subject's arm. The ECG electrodes capture the bio-electrical signals generated by the heart and transmit them to the sensor module. The sensor amplifies the signal and sends it to the NI DAQ device for digitization and further processing in LabVIEW.

Fig. 5 shows the complete hardware arrangement used for the experiment. The ECG electrodes are placed at different points on the arm to obtain a stable ECG signal. The AD8232 sensor module is connected to the NI DAQ device through the breadboard interface. The Arduino board assists in signal interfacing and communication with the LabVIEW environment. This configuration enables continuous acquisition of ECG signals from the subject.

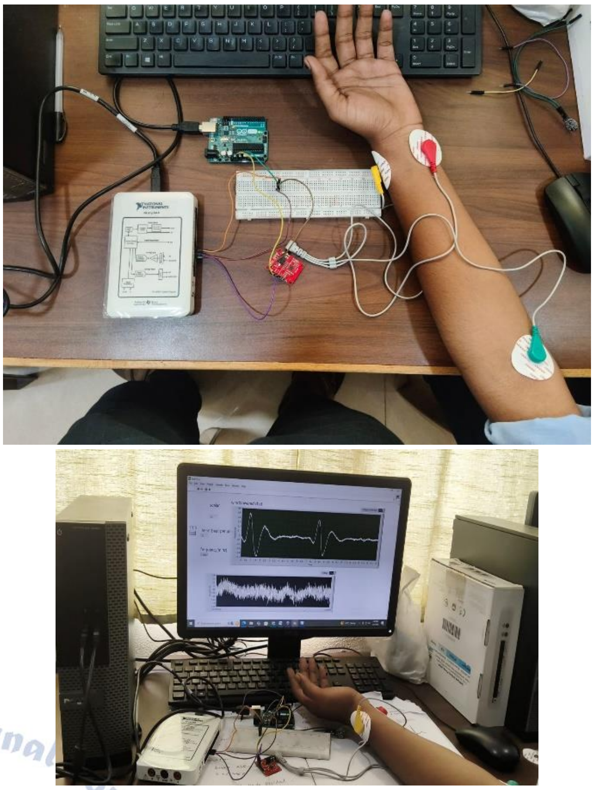

Figure 4 Experimental setup of the real-time ECG monitoring system showing the ECG electrodes connected to the AD8232 sensor module, NI myDAQ device, and Arduino interface.

The LabVIEW block diagram used for ECG signal processing is illustrated in Fig. 6. The system begins with the DAQ Assistant block, which acquires the analog ECG signal from the NI DAQ device. The signal then passes through two digital filtering stages (Filter and Filter2) to remove noise components such as baseline drift and power-line interference. The filtered signal is then processed by the Collector block, which organizes the signal data for further analysis.

A Statistics block is used to extract the maximum amplitude of the ECG signal, which helps identify the R-peaks of the ECG waveform. A threshold value is applied to detect the peaks corresponding to heartbeats. Based on the detected peaks, the system calculates the heart rate using the BPM computation formula implemented in the LabVIEW block diagram.

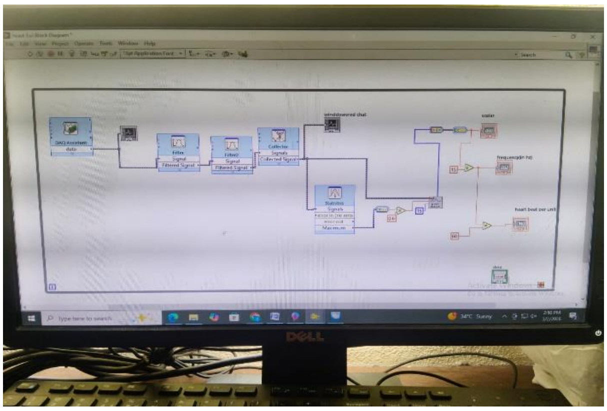

Figure 5 LabVIEW block diagram for ECG signal acquisition and processing using digital filtering and peak detection.

The real-time output of the system is displayed on the LabVIEW front panel, where the raw ECG waveform, filtered ECG waveform, frequency, and calculated heart rate (BPM) are visualized simultaneously. The waveform chart shows the characteristic ECG signal pattern, including the P wave, QRS complex, and T wave, indicating that the filtering process successfully removes noise while preserving the important features of the ECG signal.

The obtained results demonstrate that the proposed system can reliably capture and process ECG signals in real time. The filtering techniques effectively reduce noise and baseline drift, enabling accurate detection of R-peaks and precise heart rate calculation. The integration of hardware acquisition and LabVIEW-based signal processing provides a cost-effective and efficient solution for biomedical signal monitoring applications. The system can be further extended for advanced cardiac analysis, remote healthcare monitoring, and integration with telemedicine platforms..

6. Conclusion

This work presented the design and implementation of a real-time ECG signal acquisition and heart rate monitoring system using the AD8232 ECG sensor, NI myDAQ data acquisition hardware, and LabVIEW graphical programming environment. The developed system successfully captures the bio-electrical signals generated by the human heart using Ag/AgCl electrodes and processes these signals in real time for visualization and analysis. The AD8232 sensor module performs amplification and preliminary conditioning of the weak ECG signals, while the NI DAQ device digitizes the analog signals for further processing within the LabVIEW environment.

The proposed system incorporates digital filtering techniques to eliminate noise components such as baseline drift, motion artifacts, and power-line interference. These filtering stages enable the extraction of a clear ECG waveform containing the essential cardiac components, including the P wave, QRS complex, and T wave. A peak detection mechanism is implemented to identify the R-peaks of the ECG signal, which are used to calculate the heart rate in beats per minute (BPM). The processed ECG waveform, heart rate, and other signal parameters are displayed in real time on the LabVIEW front panel.

The experimental results demonstrate that the system provides accurate and stable ECG signal monitoring with effective noise reduction and reliable heart rate detection. The integration of hardware-based data acquisition with LabVIEW signal processing offers a flexible and efficient platform for biomedical signal analysis. Furthermore, the proposed system can be extended for advanced cardiac monitoring applications such as arrhythmia detection, remote patient monitoring, and integration with telemedicine systems. Therefore, the developed ECG monitoring system provides a cost-effective and scalable solution for real-time cardiac health monitoring and biomedical research applications.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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