Design of a user-friendly LabVIEW-based toolbox for real-time monitoring and diagnosis of vital signals

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Abstract: This paper introduces a powerful LabVIEW-based toolbox for monitoring, diagnosis and management of vital biosignals [electrocardiogram (ECG) and electromyogram (EMG)]. The main features of this software present in user-friendly graphical user interface, the patient’s data management, real-time monitoring of heart and muscles activities, reviewing patient’s progress through variety of charts, diagnosis of heart and muscles disorders and data transmission to remote clinician. The experimental validation of this toolbox showed that it has good performance and demonstrated a superior assurance quality in optimising clinical decisions based on real-time analysis of patient’s vital signals.

Keywords: vital signals; LabVIEW-based toolbox; real-time monitoring.


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1 Introduction

The ECG is a vital signal that is used over the years to monitor changes and diagnose irregularities in the heart such as heart attack, heart blocks, enlarged heart muscles and rhythm disturbances (Schamroth, 2001; Weyman, 1994; Engel et al., 1990). The EMG signals are clinically used to diagnose neuropathic, myopathic, neuromuscular diseases and disorders of motor unit control (Cram, 1997; Oh, 2002). They are also used as control signals for prosthetic devices such as prosthetic hands, arms, lower limbs and intelligent muscle stimulators (Raze et al., 2006). Thus, detection of EMG with powerful techniques is clinically very important due to its significance in diagnosis of different neuromuscular disorders. Furthermore, many patients suffer from both cardiovascular diseases and neuromuscular impairments. In such clinical cases, the ECG and EMG signals must be monitored simultaneously, in order to provide accurate diagnosis and treatment of different cardiovascular and neuromuscular disorders for the same patient.

Despite the ongoing advances in ECG and EMG monitoring systems and signal processing algorithms (Timothy et al., 1996; Pan and Tompkins, 1985; Micera et al., 2001), various remain as treadmill systems due to their insufficient features and limited applications. The majority of conventional designs is limited for monitoring ECG or EMG but not both and also suffers from different drawbacks. First of all, they lack a user-friendly graphical user interface (GUI), and even if it is available, it is usually programmed by traditional programming language which is not easy for the clinicians to design their own GUI to be suitable for their needs. Second, they lack the capability to manage patient’s data in order to follow up healthcare progress. Third, they lack the power to provide diagnosis of different cardiovascular and muscular diseases based on ECG and EMG signals, simultaneously, which leads to better diagnostic decision. Last, they lack the capability to transmit the ECG and EMG data to a remote physician to provide medical consultations. To overcome these drawbacks, extensive efforts have been made to develop a new design of user-friendly software based on the LabVIEW environment which is a graphical programming language. This software will be the ‘brain’ for any computer-based ECG and EMG monitoring and diagnostic system.

The LabVIEW is an efficient form of graphical programming language which makes it very attractive for GUI development in clinical applications (Chio et al., 2006; Moore,
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In recent study described in reference (Chio et al., 2006), a GUI has been developed based on LabVIEW program that can produce electrical stimulation signals by tuning the parameters in the interface. However, this design is denoted only for stimulation controllers.

In this paper, we propose a user-friendly LabVIEW-based toolbox for real-time monitoring of ECG and EMG signals and also diagnosis of heart diseases and muscles disorders. It provides comprehensive management of patient’s data and monitoring of vital signals that are required for precise diagnosis of heart diseases and neuromuscular disorders. Additional contribution made in this toolbox is that it is capable to provide wireless data transmission based on TCP/IP technique, which enables remote clinician to provide real-time advices for the treated patient available in remote location (home, work, and hospital), which makes this system very attractive for monitoring of patients in rural locations.

2 Materials and methods

A block diagram of the designed ECG and EMG data acquisition and monitoring system is depicted in Figure 1. The system consists of: lead selector switch, isolated signal conditioner unit, data acquisition unit (DAU), multichannel stimulation unit and personal computer (PC) which is built-in with the developed software that represents the core of this paper.

In the acquisition part, ECG and EMG signals require three main phases:

a acquiring the signals from the leads
b processing the lead-signals
c analysis.

First, the lead selector switch is responsible for selecting either ECG or EMG signal to be acquired. Second, the acquired signals are sent to the isolated signal conditioner unit for amplification and filtration purposes. Thirdly, the processed data pass to the DAU that consists of universal asynchronous receiver/transmitter (UART) converter and a microcontroller with built-in A/D and D/A converters. Last, the acquired signals are sent to a PC that utilises the developed software to analyse, manage the data, extract important features and transmit results to the remote physician or hospital.

The developed toolbox includes four main building modules:

1 patient’s data management
2 ECG and EMG monitoring, analysis and diagnosis
3 extraction of significant parameters from the captured vital signals
4 wireless data transmission.

The patient’s data management module represents important part of the developed toolbox and it is designed with a friendly-user GUI for collecting, managing, monitoring, storing and retrieving the patient’s data. It is characterised also by a level of security
ensuring confidentiality of patients’ data. Users are asked to supply a valid user name and password prior to obtaining access to the software. In the patient’s database page shown in Figure 2, there is a consistent organisation of important data represented by patient’s demographic data (name, gender, age, weight, and birthday) besides to other information that delineates patient’s case, diagnosis and recommendations that are entered by the user. Each patient has a unique file, which links all information stored about that patient. Once the ‘save’ button is pressed, the identification of each stored file will be specified automatically by six parameters. These parameters are: patient’s name, gender, birthday, acquired signal type, date and time of save process. It is important to note that there is a specific page as shown in Figure 3 for retrieving the stored data and as a trace of simplicity, there is an option that is based on entering some terms of the saved file for ease retrieving process; especially when there is large number of saved files.

**Figure 1** Block diagram of the developed ECG and EMG monitoring system (see online version for colours)

In particular, the designed software performs real-time signal processing, analysis and diagnosis of the captured ECG and EMG signals. In the ECG part, the acquired signal must pass first through the digital filtration to eliminate the noise effects on the ECG signal. The flowchart depicted in Figure 4 explains the analysis strategy and the extraction of vital ECG parameters. These parameters are: heart rate (HR), HR variability, PR-segment, ST-segment, S period, TP-segment, ST curve, QRS-complex, P wave, T wave and PS (Brignole, 2005). Clinically, the ECG signal has a frequency range 0.05–250 Hz and thus, PS was exploited to detect frequencies higher than 250 Hz that can provide useful indication about the presence of heart disease. The ECG durations and amplitudes are also estimated and the most important duration is the ST-segment because it is located between the depolarisation and repolarisation of the ventricles. If this duration is too large, this means that the AV node was lately stimulated or there is a delay in signal flow through Purkinje fibres (Boon et al., 2003). Also, the ST-segment changes with time, which can be displayed graphically by plotting its values versus real-time.
Figure 2  Patient’s database page (see online version for colours)

Figure 3  The patient’s data management page (see online version for colours)
The main reason for the interest in EMG signal analysis is its direct relation – as an important clinical diagnosis tool – to neuromuscular field, which has the capability to differentiate between muscular impairments that cause the pain. Today, the field of management and rehabilitation of muscular disabilities is identified as one of the most important application areas. The shape and firing rate of motor unit action potential (MUAP) (D’Alessio and Conforto, 2001) is explained in Figure 5, which provides an important source of information for diagnosis of neuromuscular disorders.

The designed LabVIEW-based toolbox calculates also all the parameters that govern the EMG signal such as amplitude, frequency, duration, area, number of phases, activity, rise-time, and the number of turns (Figure 6). Each of these parameters has standard values for normal muscles and each can provide a complementary method for investigation muscle integrity. Also, the EMG signal can be expressed in the frequency domain by application of the fast Fourier transform (FFT) in order to determine the power spectrum (PS). During a sustained contraction, the depolarisation and
propagation of muscle fibre action potentials are modified. These modifications produce time-dependent changes in the EMG signal, which results in a shift of the PS to the lower frequencies. Thus, the distribution of the PS can be quantified via calculation of its median frequency (MF) value. The fatigue index (FI) parameter is also estimated and it is used to display muscle contraction and determine whether the stimulated muscle reaches fatigue or not. The developed software calculates other important features of EMG signal necessary for diagnosis of neuromuscular disorders including average rectifying amplitude, number of motor units, motor units frequency (MU-frequency) and muscular activity (Figure 6).

**Figure 5** Motor units characteristics in EMG signal (see online version for colours)

![Motor units characteristics in EMG signal](image)

**Figure 6** Flowchart of the developed software for processing, analysis and diagnosis of EMG signal (see online version for colours)

![Flowchart of the developed software](image)
The average rectifying amplitude which is one of the main parameters that must be investigated to assess the muscle’s response and it gives a good indication of muscle’s fatigue. The rise-time is the time required for the motor unit potential to depolarise and it is necessary for diagnosis of different neuromuscular disorders. The motor unit frequency (MU frequency) equals one over the time difference between two successive motor unit potentials, which is used to assess the functionality of muscle’s stimulation progress. The frequency also represents the ability of the muscle to cope with the load and represents the pattern of recruitment of the muscle fibres. Thus, it provides good measures for any pathology either neuropathy or myopathy. Muscular activity is also estimated and it represents the relation between the durations of motor units’ potentials and the total time of EMG signal. In myopathy, muscular activity becomes higher in value at low voluntary contractions, while in neuropathy it is reduced (Katirji et al., 2002). The last important part of this toolbox is the wireless data transmission using transmission control protocol (TCP/IP). The developed software meets the growing demand for telemedicine services that improve the quality of patient healthcare by broadly following up medical consultations with specialists which is very important especially for patients in rural locations. This is why the main feature of this software is its capability to transmit/receive data to/from remote physician. This feature provides the clinician with the ability to transmit and receive the desired patient’s data. Thus, the designed software operates as either server or client.

**Figure 7** Monitoring and analysis of captured ECG signal (see online version for colours)
3 Results

The developed LabVIEW-based toolbox was validated using different ECG and EMG signals that cover various heart diseases and neuromuscular disorders. Each of these signals was managed, monitored and processed using the designed toolbox. Sample results of the extracted features from both signals are illustrated in Figure 7 to Figure 9. Figure 7 represents an ECG (lead II) signal with all extracted features (HR, PS, HR variability, amplitude of p-wave, T-wave and QRS complex and also ST-segment with its mean and standard deviation). The toolbox extracts also the breathing rate from the captured ECG without a need for a respiratory sensor. Furthermore, it is capable to provide real-time monitoring, diagnosis and management for 12-standard ECG leads (I, II, III, aVR, aVL, aVF and V1 to V6). Of course, there are different tools for accessing the parameters extracted from the captured ECG signal. For example, ECG durations and amplitudes are displayed as numerical indicators and HR as gauge indicator (Figure 7), while the ECG signal and the extracted curves can be monitored on charts. At this point, it is important to note that all these attractive features present continual quests from clinicians for optimal diagnosis that can have profound effect on the treatment process.

Figure 8 GUI for EMG signal acquisition, processing and management (see online version for colours)
Figure 9  Monitoring the power spectrum of captured EMG (see online version for colours)

The GUI for EMG signal acquisition and processing page is illustrated in Figure 8. As shown in this figure, all the extracted EMG parameters are represented by buttons and numerical indicators. All important features required for precise diagnosis of neuromuscular disorders are determined and accessible. These features include MU frequency, muscle activity, PS, muscle FI and average rectifying amplitude. As an example, Figure 9 presents the PS of the EMG signal shown in Figure 8. Finally, each of the obtained results can be saved, printed, or transmitted to a desired recipient using transmission control protocol technique.

4 Conclusions

This paper introduces a user-friendly LabVIEW-based toolbox suitable for monitoring, diagnosis and management of ECG and EMG data, simultaneously. It is characterised by new findings represented by user-friendly GUI, real-time monitoring and analysis of ECG and EMG signals, extraction of all important features from captured ECG and EMG required for correct diagnosis of different cardiovascular and neuromuscular diseases, and patient’s data management that enables remote clinicians to follow patient’s progress. The developed GUI can be easily modified to suit the clinician needs. Moreover, it enables wireless communication between patient and physician to enhance the performance and usability of the system for teleconsultation purposes.

The developed software possesses many advantages over the software used in conventional ECG and EMG systems and improves their performance significantly. In particular, it has the capability to analyse muscle’s and heart’s activities in order to
distinguish the source of the problem that causes the pain. In this manner, the proposed toolbox has the potential to provide reliable and safe diagnosis of various diseases. Furthermore, it can be used in rehabilitation and cardiology centres or in neurologist clinics, where the patient’s health progress can be online monitored, diagnosed and managed. In addition, due to the ease of use of this software, it can be adapted by all physiotherapists and cardiologists even those with little field experience in LabVIEW environment.

In conclusion, the designed software offers a way towards the alterations of real-time monitoring and diagnosis of vital signals associated with conventional systems, introducing new aspects in monitoring, diagnosis, data transmission and management of ECG and EMG signals and thus helping millions around the world to get their life back.

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References


