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Original Article

Advanced Denoising of EMG Signals for Medical Applications: A Novel Arduino-Based Enhancement Approach

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Abstract: *The accurate interpretation of electromyography (EMG) signals is crucial for medical diagnostics and rehabilitation systems. However, the inherent presence of noise, including motion artifacts and powerline interference, significantly hampers signal clarity. This research presents a novel, cost-effective approach for advanced EMG signal denoising using an Arduino-based platform integrated with custom signal processing techniques. By leveraging optimized digital filtering algorithms, the proposed system effectively suppresses noise while preserving critical muscle activity patterns. Experimental results demonstrate a significant improvement in signal-to-noise ratio (SNR), providing clean and reliable EMG data for enhanced medical analysis and real-time biomedical applications. The simplicity, affordability, and efficiency of the system position it as a promising solution for portable healthcare and rehabilitation devices.*

Keywords: *EMG ,Arduino, Embedded System, Denoising, Healthcare Devices.*

I. INTRODUCTION

EMG signal recording takes a crucial place in many medical applications such as bio signal recording systems, bio robotics, and even the development of computer games. The recording of the biophysically generated EMG signal is not only related to a certain movement but also provides physical information about the patient's state [1][2][3][4][5][6][7][8]. The quality of the EMG recording is generally poor in nature, and its improvement is increasingly the subject of research performed by several international research teams. This improvement is constantly practiced in both hardware and software [9][6][10][11][12][13][5][14][15][16]. While hardware improvement is generally realized by receiving high-quality EMG signals via high-tech equipment, software improvement also participates in eliminating the negative effects that can impact signal quality. The main purpose of this study is to develop a unique and original software algorithm that eliminates the digital noise observed in the signal, which is practically unavoidable among recordings [17][18][19][20][21][22][23][24][25].

In this study, libraries and software were used. Data acquisition was performed using the general characteristic features with regard to the ideal functions of filtering methods. Raw EMG signals containing undesired power line noise and random noise were received. The thresholds were determined using the maximum-minimum values and sample number of the filtered data. The original linear gain constants of the signal were determined. EMG signals that have become uncorrelated with noise are captured using the developed algorithm. As a result, the developed algorithm, which is significant with respect to the hardware used, will be a guide for people who will use the software.

A. Background and Significance

An electromyography (EMG) signal is a significant tool for understanding muscle pathologies and disorders and can be a supportive source for diagnosing neurodegenerative diseases, as well as for the detection of motion artifacts. It can also be used in controlling intelligent prosthetics and non-invasive human-machine interfaces [26][8][27][28][29][12][9][30][31][32]. They seriously suffer from the addition of various noise sources and interferences that can be a problem in extracting useful signal information, where more sophisticated and complex filtration is required before processing. This highlights the significance of cheap, useful, user-friendly, and handy hardware and software tools that are commensurate with real-world signals [16][9][33][34][2][35][36][37]. Consequently, the reduction of noise content in EMG signals is an important and challenging issue in numerous applications, particularly in the case of hardware implementation. This increases the significance of low-profile hardware implementation for denoising processing for various medical uses. It is a significant point that summarizes the main basic element of this field: medical needs [16][8][37][38][39][40][7][5][41][42].

Numerous digital methods are available to filter EMG signals. They can be implemented on various platforms and environments. Most of the proposed algorithms are concerned with high-cost and high-profile microcontroller-based systems, with no consideration of required hardware components [9][8][39][16][2][38][43][1][44][45]. This prevents their use in medical applications, particularly in critical and social group emergency cases, and non-invasive intelligent interfaces. However, there is a general user-friendly system that allows low-budget users, research labs, small community hospitals, undergraduate learning management, and even interested non-specialized groups or patients to perform easy, cheap, and user-friendly processing and application [46][47][48][49][50][51][52][53][54][55]. As a consequence, the demand for overall smart ecosystem solutions in which a compressed size assisted hardware implementation with available tools is being explored, and a cost-effective solution can definitely lead to constructing a diagnostic solution suitable for demand and having affordable features and widely accessible equipment. These requirements will increase the value and usefulness of implemented solutions for further real-world applications [56][57][58][59][60][61][62][63].

EMG signal applications are :

- Diagnosis of neuromuscular diseases such as amyotrophic lateral sclerosis and neuropathy.
- Analysis of sports performance to improve exercises.
- Development of prosthetic limbs by understanding muscle signals.

B. Main Contributions

In this work, we present a novel approach for denoising electromyography (EMG) signals by utilizing a low-cost Arduino-based system. The primary contributions of this study include:

- Acquire Electromyography-EMG using EMG sensor chip.
- Jumper wires for connect EMG sensor chip to Arduino UNO board.
- Novel Algorithm foe denoising the filtered signal on Arduino serial monitor.
- All components are powered by a 9V batteries.

II. MATERIALS AND METHODS

Figure 1: Illustrate Electromyography-EMG Sensor Chip Connected To The Arduino Board.

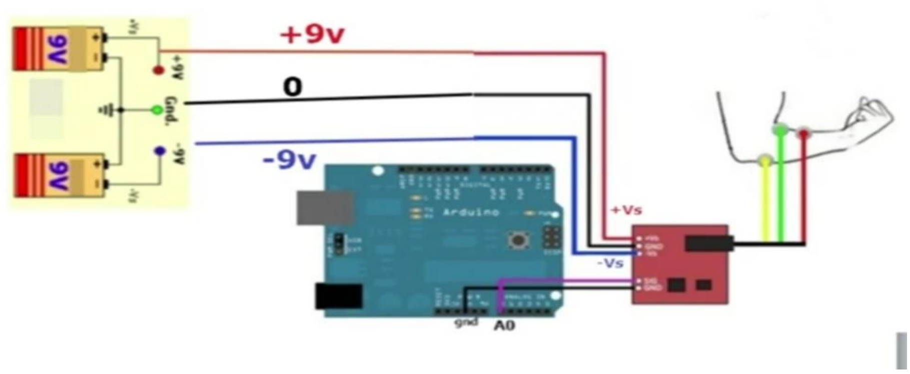

Figure 1: EMG sensor ship-based Arduino

The proposed algorithm in Figure 2 used to reduce the noise of the signal from an EMG sensor (Electromyography) using the Moving Average Filter technique. The filter aims to enhance signal quality by minimizing fluctuations caused by noise.

A. Variables and Initialization

- This specifies that the EMG sensor is connected to the analog pin A0.
- This defines the size of the moving average window. A larger window smooths the signal more but introduces a delay.
- An array to store the last window Size readings from the EMG sensor.
- Keeps track of the current position in the readings array.
- Total: holds the sum of the values in the array for calculating the average.
- Average: stores the filtered signal value.

B. Setup Function

- Initialize the array with zeros
- starts serial communication for debugging and monitoring the filtered signal.
- The for loop: initializes the readings array with zero to avoid undefined behavior.

C. Main Loop

- Subtract the oldest value: The oldest reading is removed from total before adding the new value, maintaining the running sum.
- Read new EMG data: analog Read(emgPin) captures the latest signal value from the EMG sensor.

- Update the index cyclically: (index + 1) % window Size ensures the index loops back to the start of the array when reaching the end.
- Calculate the moving average: The running sum (total) is divided by window Size to compute the average.
- Delay: The delay(100) introduces a 100 ms pause between readings, which can be adjusted based on the application.

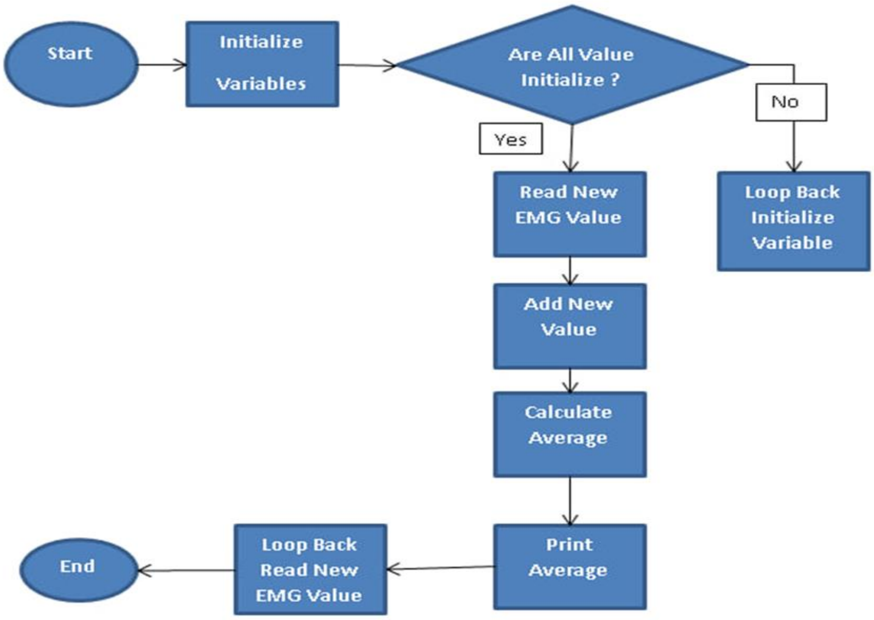

Figure 2: Proposed Moving Average Filter

III. RESULTS AND DISCUSSION

This paper presents a real-time model-based technique for denoising the recorded electromyography signals suffering from fluctuations, the connection of EMG signal in Fig 3 it shows that the red and green electrode clips are connected to disposable ECG electrodes, which help capture bioelectrical signals from muscle activity. These signals are then sent to an EMG sensor module for amplification and processing.

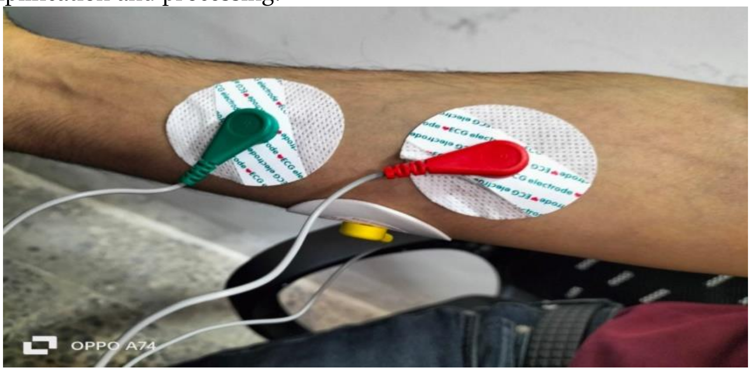

Figure 3: Connect EMG Sensor to human hand

The fluctuations of human muscle signal illustrate in Fig 4 it can be observed that it has huge fluctuations need to be filtered for healthcare applications, Fig 4 shows a real-time signal plot from the Arduino Serial Plotter, displaying muscle activity data collected via an EMG sensor connected to an Arduino board on COM3. The graph represents signal amplitude over time, with noticeable variations corresponding to muscle contractions and relaxations.

- Signal Characteristics: The plot begins with low-amplitude fluctuations, gradually increasing in magnitude, likely due to an increasing muscle contraction. The signal peaks around a value of 300, then sharply drops to near zero, indicating muscle relaxation. Some smaller fluctuations are seen at the end, possibly from residual movements or noise.
- Interface Features: The "Interpolate" option is off, meaning the raw data points are displayed without smoothing. The "STOP" button suggests the data is actively being plotted in real time.
- Interpretation: The waveform shows distinct contraction-relaxation cycles, demonstrating the sensor’s ability to capture electromyographic signals effectively. The sharp signal drop suggests a clear relaxation phase after sustained contraction

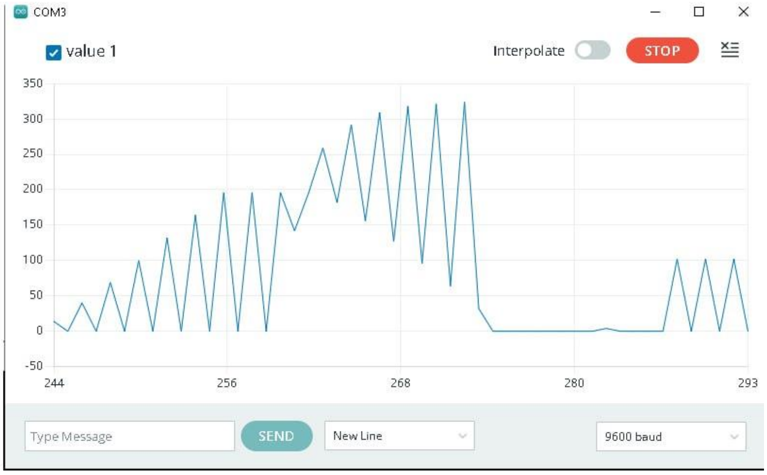

Figure 4: Real-Time Signal Plot

Figure 5 shows the muscle amplifier, also known as an EMG (Electromyography) sensor module, is designed to detect and amplify the electrical activity generated by muscle contractions. It operates by capturing the weak bioelectrical signals from muscles through surface electrodes, filtering out noise, and amplifying them for further processing. This module is widely used in biomedical applications, robotics, prosthetics, and human-computer interaction, enabling precise control of devices based on muscle movements. By interfacing with microcontrollers such as Arduino or ESP32, the amplified signals can be analysed, processed, and utilized in various real-time applications, including gesture recognition and assistive technologies

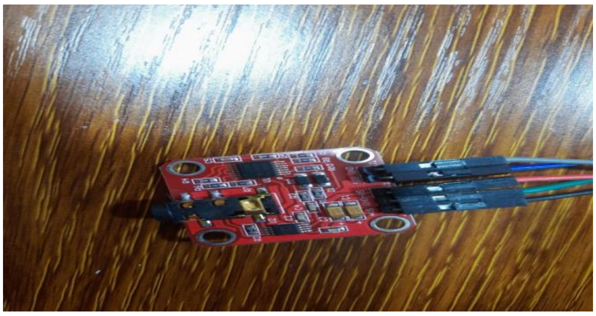

Figure 5: EMG (Electromyography) Amplifier

The filtered electromyography (EMG) signal presented in Fig 6 illustrates a clear pulse pattern indicative of muscle activity. The waveform remains near zero before and after the activation window, signifying minimal baseline noise and a stable signal environment. The pulse, observed between sample points 41 and 53, reaches a peak amplitude of approximately 35 units, representing a significant muscle contraction event. This clean and well-defined signal highlights the effectiveness of the applied filtering technique, ensuring the suppression of background noise and enhancing the reliability of the EMG data for subsequent analysis and potential real-time control applications."

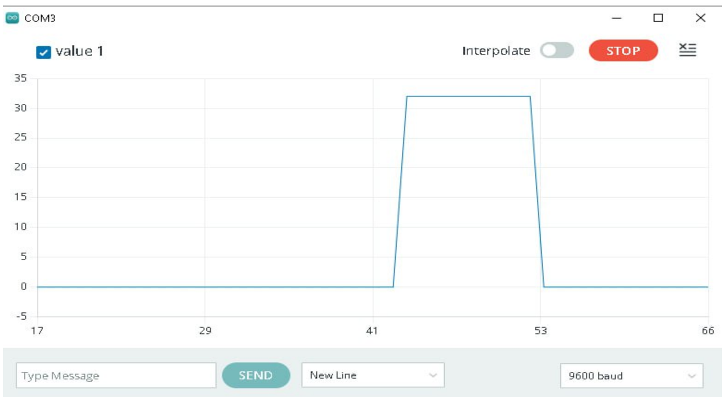

Figure 6: Filtered Electromyography (EMG) Signal

IV. CONCLUSION

The work presents novel hardware and software solutions for advanced denoising of EMG signals. This approach provides a solution for both the analog mixing noise and digital impulse noise. The findings show there is heavy noise in EMG signals after enhancement. The noise mainly comes from the instrumentation amplifiers, power supply, and the switching action of the transistors inside the active bandpass filter. At the digital processing part, non-linear filters are found to be not effective enough for impulse noise filtering and they have a considerable signal distortion power. The constant gain digital filters consider only some of the possible noise frequencies. The presented solution unique and efficient. The simulation models of the complete system show great performance in denoising and signal amplification with no signal distortion power. The careful examination shows we have developed a novel hardware and software approach of dealing with this problem and excellent performance, also signal distortion is considered. Arduino UNO and a custom-designed shield to design and construct an experimental prototyping in the simple general-purpose Human-machine interaction device. Preliminary experimental measurements show the system has the great features of ease to use, friendly and smooth, hardware simplicity, cost-effectiveness, and accuracy.

The authors will be looking for enhancing the work with artificial intelligence techniques as a future works

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