International Journal for Multidisciplinary Research (IJFMR)
E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

Electromyography-Based Signal Processing for Bionic Arms and Neurorehabilitation

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ABSTRACT
The EMG sensor has widely been applied in assistive technologies, biomedical, and human machine interfaces. This paper discusses the development of an EMG sensor with compact design and signal acquisition. This system captures, filters, and amplifies muscle signals to allow it to be used in many fields like prosthetics, rehabilitation, and diagnostics.

Keywords: EMG signal, Assistive devices, Signal amplification, Signal processing, Electromyography, Bionic arm, rehabilitation, Biomedical, Brain-computer interface, Wearable technology, Neuromuscular function, Prosthetic devices, electrical signals, Neurorehabilitation, Exoskeletons.

I. INTRODUCTION

Electromyography sensors capture the electrical activity caused by the muscle contractions, which enables applications in a wide range of fields from bionic arms, rehabilitation, biomedical diagnostics, human machine interfaces. Using EMG sensor, we record the electrical activity produced by muscles, which help physiotherapists to analyze the muscle activity and identify weak muscles. So, using this data rehabilitation program can be created for the patient. It is used in exoskeletons and bionic arm to support movement for patients with physical disabilities. They are helpful in customizing assistive devices by adapting to the user's unique muscle patterns and strength. More the sensors are compact it would increase the user experience. These sensors will monitor the muscle health and preventing atrophy in patients with chronic conditions.

About 30 million people worldwide require prosthetic limbs or other assistive devices, according to the WHO. EMG sensor plays important role in improving quality of life in the assistive technology sector. The technological advancement in machine learning would increases efficiency of the sensor. It would learn upon the user’s data and will be able to provide quick real-time feedback in case of bionic arm. This paper presents the development and implementation of a compact EMG sensor circuit.

II. LITERATURE REVIEW

In study done by Crea et al. (2019), electromyography signals allow users to control prosthetic limbs using muscle contractions.

In accordance, Liao et al. (2020), researched using EMG sensor with machine learning algorithms, which will enable precision control, reducing the feedback time and natural movements.

The functional electrical stimulation (FES) for rehabilitation patients with spinal cord injuries EMG sensor plays a vital role according to Basmajian et al. (2017). Stimulating specific muscles help patients regain motor control.

Study conducted by Haugland et al. (2018) the use of EMG sensors in biofeedback systems to guide stroke patients in muscle re-training.
Wireless EMG sensors has made and advancement for more applications (Perri et al., 2020).
But indeed, there are challenges faced to minimize the noise interference, signal clarity are the key areas of improvements analyzed by Schulte et al. (2017).
The EMG sensor designed by minimizes the unnecessary noise based on filters thus increasing the signal acquisition and clarity.

III. METHODS AND MATERIAL

In the initial prototype, we had mounted the circuit on breadboard because of which we couldn't capture the EMG signal due to loss of analog signal. The main challenge was to preserve analog signal from external interference and proper amplification with minimizing signal loss. To work around this, we decided to implement the circuit on PCB directly to test the functionality.
For minimal signal loss, the circuit layout was designed to have signal travel paths as short as possible. Conductive fibers of surface-mount electrodes were connected to single-strand wires using lugs, crimped and insulated with heat-shrinking tubes. These connections ultimately provided with standardized insulation necessary for our setup. The Arduino Mega 2560 was used for real-time visualization of EMG signals.
Circuit components:

- LM324 Operational amplifier
- Capacitors
- ICL7660
- Resistors
- Potentiometer
- Relimate connectors
- Self-adhesive electrodes
- Heat shrinking tube
- Lugs
- Arduino Mega 2560

Electrode Design and Setup:

The self-adhesive electrodes have been implemented to minimize the noise and signal loss. This is because the self-adhesive type of electrodes is composed of conducting fibers, which helps increase the electrode to skin interfacing ability. Consequently, this increases electrical conductivity with a reduction in impedance. These types of fibers consist of very highly conductive materials, for instance, silver or silver-chloride and carbon-based materials.
Mounting electrodes to areas on larger muscle groups is necessary for proper signal acquisition. Electrodes have to be mounted properly to ensure effective signal acquisition; for example, two electrodes are mounted on muscular areas while the other is mounted on a non-muscular area as a reference point.
There are two types of electrodes surface electrodes and intramuscular electrodes. We are using surface electrodes. Surface electrodes are non-invasive technology compared to intramuscular one, but they are restricted to superficial muscles. Intramuscular EMG detects activity by inserting monopolar needle electrode through the skin in muscle tissue. Earlier discomfort may arise in this case.

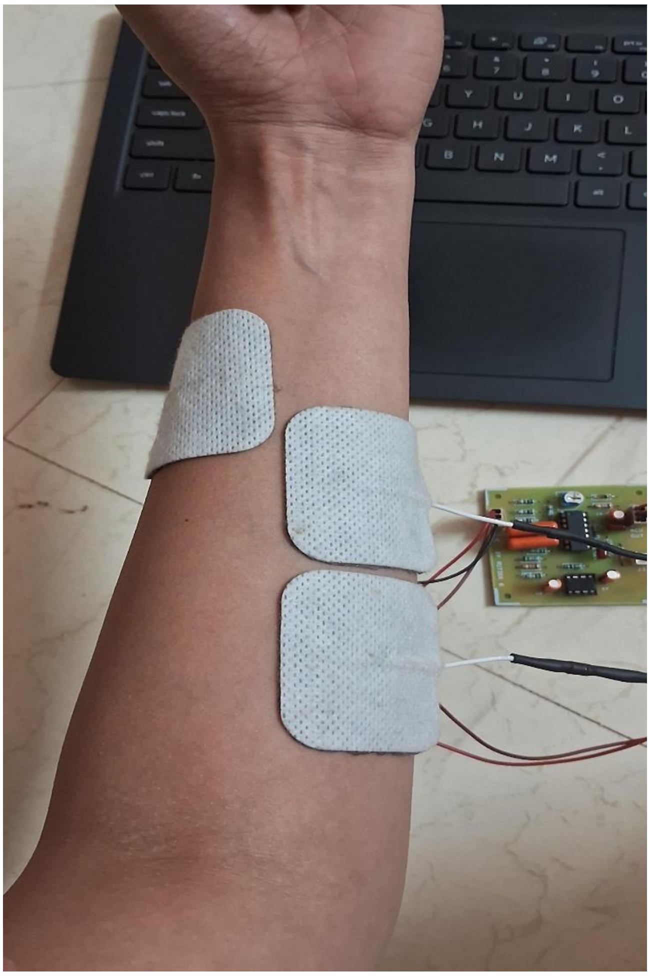

Figure 1: Self-adhesive electrode mounting

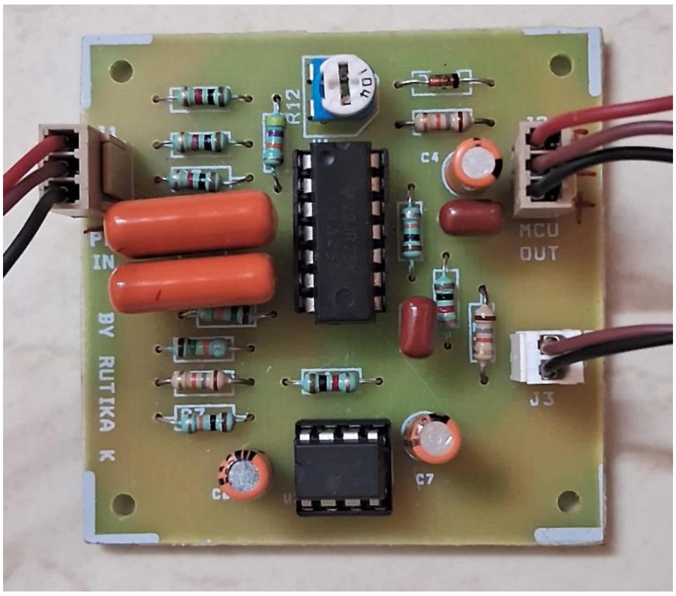

Figure 2: Final assembled PCB

IV. ARCHITECTURE

Circuit Design:

- **Differential Amplifier:**
  It is used for differential amplifier to enhance the small difference between the signal of the voltages taken from the electrodes and it rejects common mode noise. Gain = 47, High Common Mode Rejection Ratio because of matching resistors.
- **High-Pass Filter:**
  This high-pass filter eliminates unwanted low-frequency noises and motion artefacts as only relevant EMG signals will pass. The cut off frequency of this is 22.5Hz to remove drift noise and unwanted baseline noise.
- **Low-Pass Filter:**
  The low-pass filter eliminates high-frequency noise and smoothes the signal so that the output is clean and interpretable. The cutoff frequency is set to 482.6 Hz so that only the desired signal bandwidth is retained.
- **Tunable Amplifier:**
  The tunable amplifier provides adjustable gain, which ranges from 1 to 11, to amplify the processed signal to the desired level. This makes the signal suitable for further processing, visualization, or transmission to a microcontroller.
- **ICL7660 Voltage Converter:**
  Used to generate the negative rail required for the operational amplifiers, ensuring proper circuit operation.

Arduino Mega 2560 is used to take analog signal output from the EMG sensor and display on serial plotter of Arduino IDE. We choose the desired signal bandwidth by selecting resistor and capacitor values for High-pass and low-pass filters. Potentiometer in tunable amplifier is used to adjust the sensitivity of the EMG sensor.

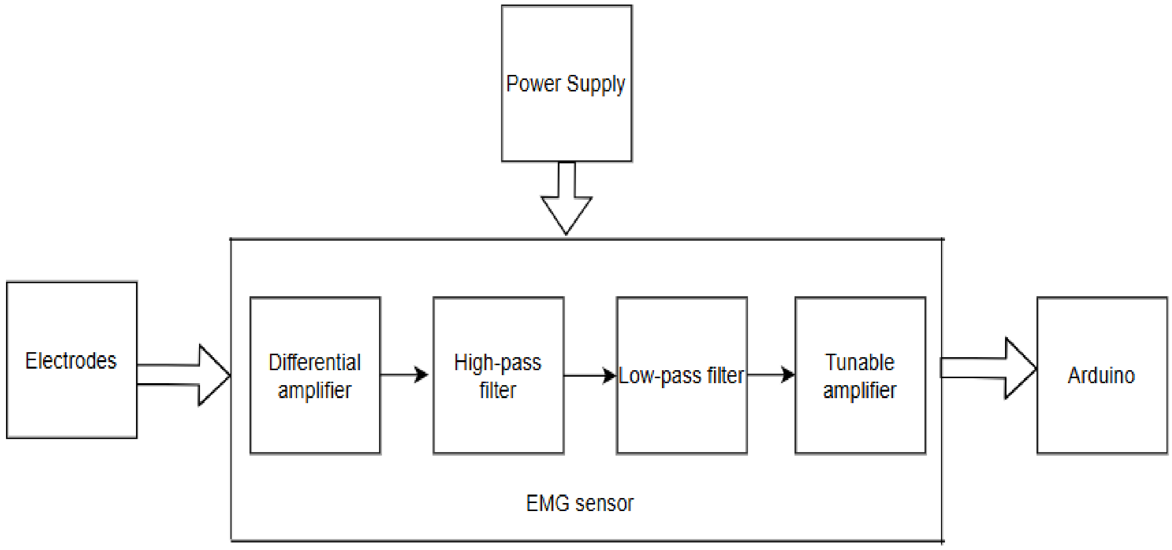

Figure 3: Block Diagram

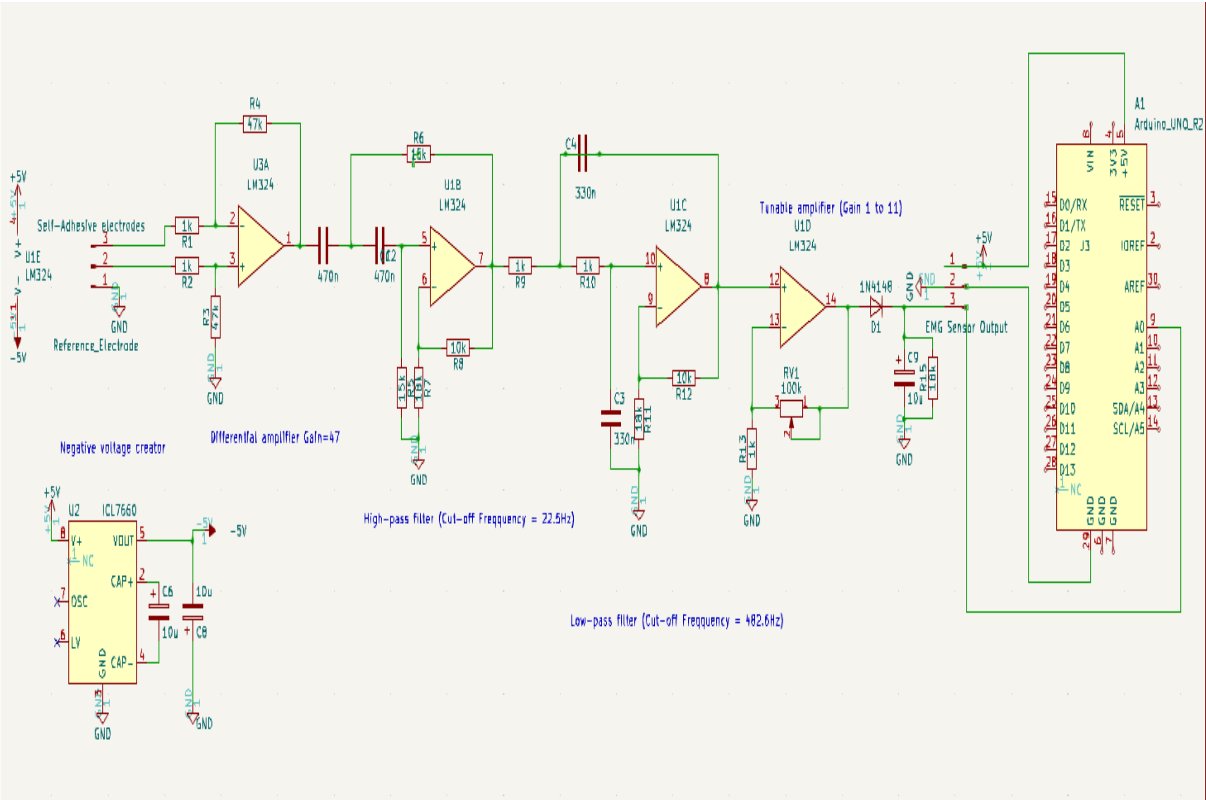

Figure 4: Circuit Diagram

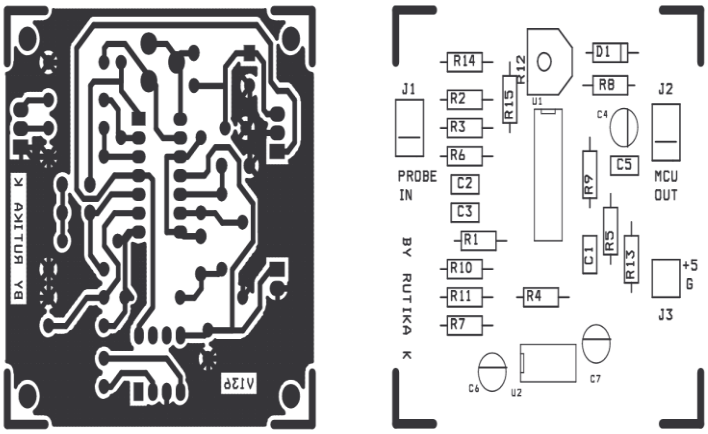

Figure 5: PCB layout

Muscle movement:

- The neural activity in the motor cortex in the brain signals to the spinal cord.
- Using motor neurons, the signal is sent to muscle part.
- Motor neurons directly stimulate muscles, which triggers release of calcium ions within muscle fibers, thus it creates mechanical change in the muscle.
- This mechanical change involves change in electromechanical gradient, which is detected by EMG.

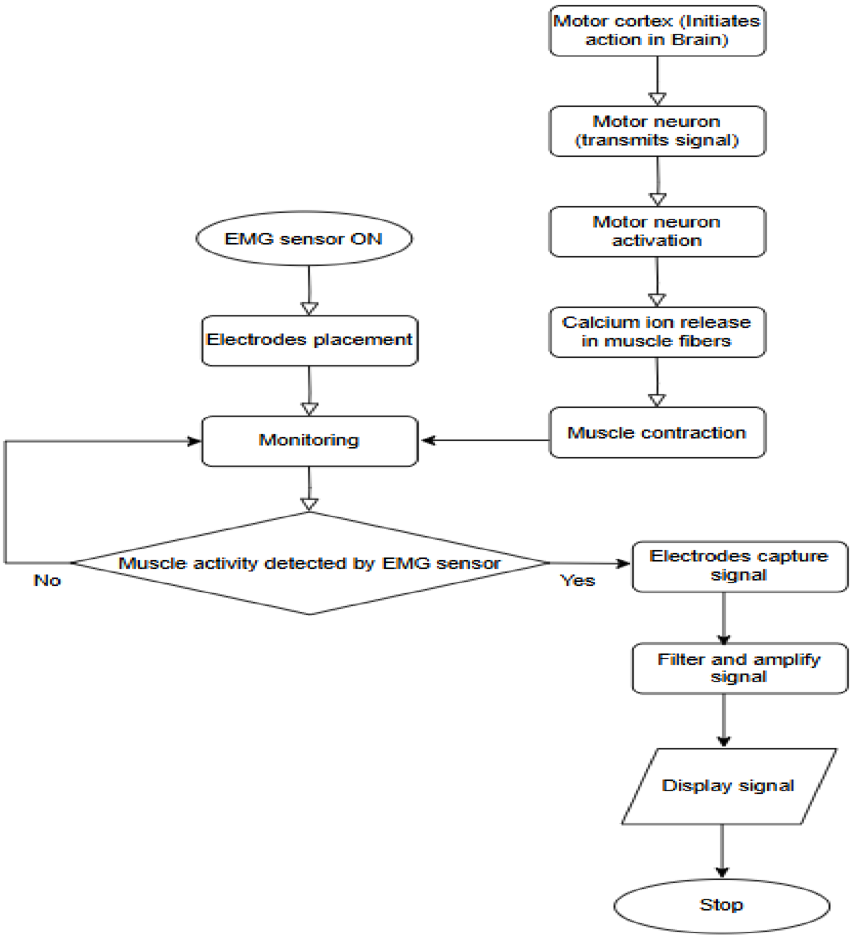

Figure 6: Flowchart

V. RESULTS AND DISCUSSION

The developed system was able to capture EMG signals corresponding to specific muscle motions, such as fist clenching and hand movements. The captured signals were clear and precise, which validated the efficacy of the sensor and the circuit design.Future improvements will involve the extension of the system's capabilities to detect more motions. This will be achieved by using additional electrodes and incorporating instrumentation amplifiers for better signal differentiation.

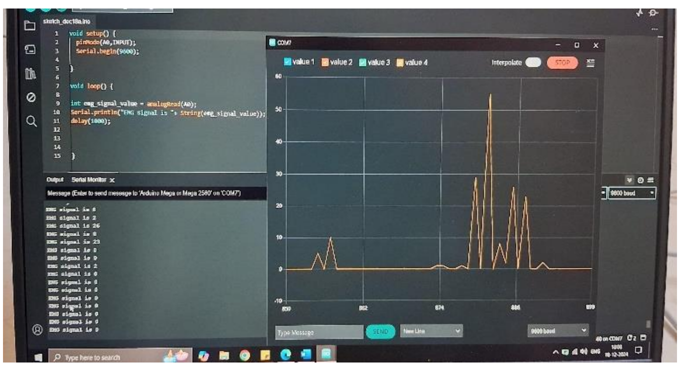

Figure 7: EMG signal graph for fist motion

VI. CONCLUSION

The developed EMG sensor provides a compact reliable solution for capturing muscle signals and has potential applications within prosthetics and assistive devices. However, there are challenges in individuals born without upper limbs because their neural pathways for muscle control are less developed. These challenges would require the development of neurofeedback training and adaptive signal processing.

VII. REFERENCES

Below are the references used to perform above development.

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