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Development Wearable EMG-Based Muscle Fatigue Analyzer for Real-Time Monitoring in Sports and Rehabilitation Applications

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Abstract - *Muscle fatigue is a critical factor affecting performance, rehabilitation, and workplace safety, yet continuous monitoring is often limited to expensive and non-portable clinical systems. This paper presents a low-cost wearable EMG-based muscle fatigue analyzer designed for real-time monitoring of muscle activity. The proposed system acquires surface electromyography signals using electrodes placed on the muscle and processes them through a signal conditioning module and microcontroller. Key features such as signal amplitude and frequency are analyzed to identify fatigue progression. The system classifies muscle condition into normal, moderate fatigue, and severe fatigue using threshold-based logic. A real-time display provides immediate feedback to the user, making the system suitable for applications in sports training, physiotherapy rehabilitation, and industrial fatigue monitoring. The device is compact, portable, and built using affordable components, making it accessible for practical use. Experimental validation demonstrates that muscle fatigue leads to an increase in signal amplitude and a decrease in frequency components over time, which are accurately captured by the system. The results confirm stable signal acquisition and reliable fatigue classification across multiple trials. The proposed solution bridges the gap between biomedical signal processing and wearable health technology by offering an efficient and economical alternative for continuous muscle fatigue monitoring.*

***Key Words*: Wearable Device, EMG Signal, Muscle Fatigue Detection, Real-Time Monitoring, Rehabilitation.**

1. INTRODUCTION

Muscle fatigue is a significant physiological phenomenon that affects human performance in various fields such as sports, rehabilitation, and industrial work environments. It is generally characterized by a decline in the muscle's ability to generate force due to prolonged or repetitive activity [1]. Early detection and monitoring of muscle fatigue are essential to prevent injuries, optimize training efficiency, and improve recovery outcomes. However, conventional methods for fatigue analysis rely on laboratory-based electromyography systems, which are expensive, non-portable, and not suitable for continuous real-time monitoring.

With the advancement of wearable technology and embedded systems, there is a growing need for low-cost and portable solutions that can provide real-time feedback on muscle activity. Surface electromyography is widely used as a non-invasive technique to measure electrical signals generated by muscle contractions [2]. These signals contain valuable information about muscle condition, including fatigue progression, which can be analyzed using both time-domain and frequency-domain features.

This paper presents the design and development of a wearable EMG-based muscle fatigue analyzer that enables real-time monitoring using affordable and easily available components. The system processes EMG signals using a microcontroller and classifies fatigue levels based on signal characteristics such as amplitude and frequency variations. The proposed solution aims to bridge the gap between clinical-grade monitoring systems and practical wearable applications.

1.1 Need for a Low-Cost Wearable Solution

The growing demand for continuous health monitoring has led to increased interest in wearable biomedical devices. However, most existing muscle monitoring systems are expensive, bulky, and confined to clinical environments, limiting their accessibility for everyday use. This creates a significant gap between advanced medical technology and practical real-world applications. A low-cost wearable solution enables continuous monitoring of muscle activity in a portable and user-friendly manner. By utilizing affordable components and efficient embedded processing, such systems can provide real-time feedback without requiring specialized infrastructure. This approach makes muscle fatigue monitoring accessible to a wider population, including athletes, patients, and industrial workers.

1.2 Muscle Fatigue in Sports and Rehabilitation

Muscle fatigue plays a critical role in determining performance and recovery in both sports and rehabilitation settings. In athletes, prolonged or intense physical activity leads to fatigue, which increases the risk of injury and reduces overall performance efficiency. Similarly, in physiotherapy and post-surgery rehabilitation, monitoring fatigue levels is essential to ensure safe and effective

recovery. Improper assessment of muscle fatigue can result in overtraining, delayed healing, and long-term musculoskeletal issues. Therefore, real-time fatigue monitoring helps in optimizing training intensity, preventing injuries, and improving rehabilitation outcomes. Continuous tracking of muscle condition allows practitioners and users to make informed decisions regarding exercise duration and intensity.

1.3 Surface EMG-Based Fatigue Detection

Surface electromyography (EMG) is a widely used non-invasive technique for measuring the electrical activity generated by muscle contractions. EMG signals provide valuable insights into muscle behavior, including activation level, coordination, and fatigue. During muscle fatigue, characteristic changes occur in the EMG signal, such as an increase in signal amplitude and a decrease in frequency components. These variations can be effectively analyzed using signal processing techniques such as Root Mean Square (RMS) and frequency analysis. Surface EMG-based fatigue detection offers a reliable and practical method for real-time monitoring without causing discomfort to the user. Its integration with wearable systems enables continuous assessment of muscle condition in both clinical and non-clinical environments.

2.PROPOSED METHODOLOGY

The proposed system focuses on real-time detection of muscle fatigue using a wearable EMG-based device. It acquires bioelectrical signals from muscles, processes them using embedded techniques, and classifies fatigue levels based on signal characteristics. The methodology integrates signal acquisition, processing, and real-time output into a compact and low-cost wearable system.

2.1 System Overview

The proposed system consists of surface EMG electrodes, a signal conditioning module, an Arduino Nano microcontroller, and a display unit. The electrodes are placed on the target muscle to capture electrical signals generated during muscle contraction. These signals are typically weak and noisy; therefore, they are amplified and filtered using the EMG sensor module. The conditioned signal is then fed into the microcontroller, where it is converted into digital form and processed in real time. Based on the processed data, the system classifies fatigue levels and displays the output instantly, enabling continuous monitoring.

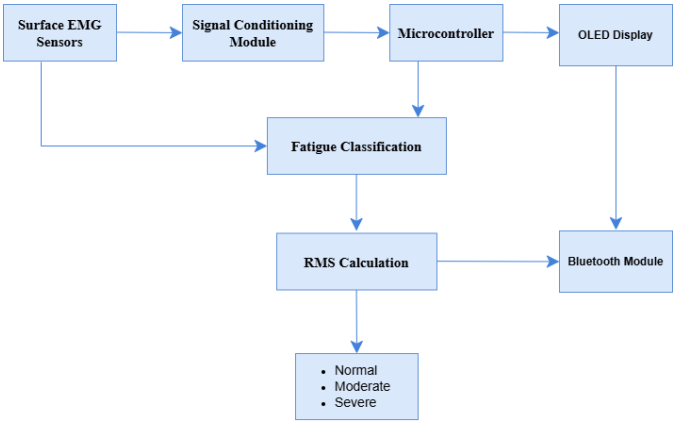

Fig -1: System Architecture

2.2 Fatigue Classification

The extracted features are used to classify muscle fatigue into three levels: Normal, Moderate Fatigue, and Severe Fatigue. Initially, when the muscle is not fatigued, the RMS value remains low and frequency components are high. As fatigue develops, the RMS value increases while the frequency decreases gradually. In severe fatigue conditions, the RMS reaches higher values and frequency components show a significant drop. A threshold-based classification method is used to determine the fatigue level in real time. This approach is simple, efficient, and suitable for implementation on embedded systems.

2.3 Real-Time Monitoring and Output Display

The system provides real-time feedback through an LCD or OLED display. The processed results, including fatigue level, are continuously updated and shown to the user. This allows immediate understanding of muscle condition during activity. The wearable design ensures portability and ease of use, making the system suitable for continuous monitoring in sports training, rehabilitation, and daily activities. The real-time output helps users take necessary actions to avoid overexertion and improve performance.

3. CONCLUSIONS

The proposed wearable EMG-based muscle fatigue analyzer presents an effective and low-cost solution for real-time monitoring of muscle activity. The system successfully acquires surface EMG signals, processes them using embedded techniques, and classifies fatigue levels based on amplitude and frequency characteristics. The experimental results demonstrate that muscle fatigue is associated with an increase in signal amplitude and a decrease in frequency components, which are accurately detected by the system.

Fig -2: *Experimental demonstration of wearable EMG-based muscle fatigue analyzer*

The developed device offers a compact and portable design, making it suitable for practical applications in sports training, physiotherapy rehabilitation, and industrial worker monitoring. The use of simple hardware components and efficient signal processing ensures reliable performance while maintaining low cost and power consumption. The system provides real-time feedback, enabling users to prevent overexertion and improve overall performance and recovery.

Overall, this project successfully bridges the gap between biomedical signal analysis and wearable health technology. It demonstrates the feasibility of implementing real-time muscle fatigue detection using affordable and accessible components, paving the way for future advancements in personalized healthcare and smart wearable systems.

REFERENCES

[1] W. Zhang, Z. Bai, P. Yan, H. Liu, and L. Shao, "Recognition of human lower limb motion and muscle fatigue status using a wearable FES-sEMG system," Sensors, vol. 24, no. 7, p. 2377, Apr. 2024.

[2] Y. Chen, S. Li, J. Kuang, X. Zhang, and Z. Zhou, "Biomechanical monitoring of exercise fatigue using wearable devices: A review," Bioengineering, vol. 13, no. 1, 2025.

[3] S. Kim, J. Lee, and H. Park, "Development of a wearable EMG monitoring system using wireless communication," IEEE Sensors Journal, vol. 20, no. 15, pp. 8785–8792, 2020.

[4] M. F. Rahman, M. S. Islam, and M. A. Rahman, "A wearable real-time EMG data acquisition system for muscle activity monitoring," 2019 International Conference on Electrical, Computer and Communication Engineering (ECCE), IEEE, pp. 1–5, 2019.

[5] A. Subasi, "Classification of EMG signals using machine learning methods," Expert Systems with Applications, vol. 39, no. 5, pp. 5109–5117, 2012. (Foundational, still widely cited)

[6] Z. Liu, W. Huo, Z. Yu, P. Bentley, and R. Vaidyanathan, "Continuous estimation of neuromuscular fatigue using wearable sensing systems," IEEE Journal of Biomedical and Health Informatics, vol. 29, no. 11, pp. 7969–7982, 2025.

[7] Y. Han, W. Zhao, X. Chen, and X. Meng, "High-speed low-consumption sEMG-based micro-gesture recognition for wearable devices," IEEE Access / arXiv preprint, 2024.

[8] Y. Zhang et al., "Multimodal fatigue detection system using sEMG and IMU signals with hybrid CNN-LSTM model," Sensors, vol. 25, no. 11, 2025.