**Title:**

**Developing a Novel Muscle Fatigue Index for Wireless sEMG Sensors: Metrics and Regression Models for Real-Time Monitoring**

**Abstract**

Muscle fatigue impacts performance in sports, rehabilitation, and daily activities, with surface electromyography (sEMG) widely used for monitoring. In this study, we analyzed sEMG signals, evaluating time, frequency, and combined-domain metrics to identify reliable fatigue indicators. Using these metrics, we developed a novel fatigue index through regression modeling, capturing fatigue progression and enabling personalized muscle-specific assessment. Integrated into a wireless BLE-enabled sensor platform, the system combines seamless body placement, mobility, and real-time data transmission. An initial calibration phase ensures adaptation to individual muscle profiles, enhancing accuracy. By balancing on-device processing with efficient wireless communication, this platform delivers scalable, real-time fatigue monitoring across diverse applications.

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Muscle fatigue impacts performance in sports, rehabilitation, and daily activities, with surface electromyography (sEMG) widely used for monitoring. In this study, we analyzed sEMG signals by evaluating time, frequency, and combined-domain metrics to identify reliable fatigue indicators. To ensure consistency across data sources, we applied a standardization process, calibrating signal-derived metrics to a common scale. *Using these standardized metrics, we explored different methods to derive a fatigue index, through feature extraction and dimensionality reduction, assessing their effectiveness in capturing fatigue progression.* We then trained and evaluated multiple machine learning models to predict fatigue levels, selecting the most effective approach for real-time monitoring. Integrated into a wireless BLE-enabled sensor platform, the system offers seamless body placement, mobility, and efficient data transmission. An initial calibration phase ensures adaptation to individual muscle profiles, enhancing accuracy. By balancing on-device processing with efficient wireless communication, this platform delivers scalable, real-time fatigue monitoring across diverse applications.

**1. Introduction**  
1.1 Background and Motivation

* Importance of **IoT in sports and rehabilitation**
* Significance of **sEMG for muscle fatigue detection**
* Gap in existing systems: lack of **real-time analysis and ML integration**

1.2 Related Work

* Summary of **previous research** (based on the thesis literature review)
* Key advancements in **sEMG-based fatigue monitoring**
* The role of **machine learning** in signal analysis

1.3 Contribution of This Work

* Development of an **IoT-based wearable system**
* **Integration of ML models** for regression analysis
* Creation of **datasets** from experimental sessions

**2. Materials and Methods**  
2.1 System Design

* **Hardware architecture** (sensors, microcontrollers, BLE communication)
* Overview and evaluation of **two sensors** (BioAmp EXG Pill vs MyoWare 2.0)

2.2 Data Collection

* Experimental setup: **Vastus Medialis**, **isometric leg-extension** exercise
* **Placement of electrodes** and noise reduction techniques
* Data acquisition using **Arduino and BLE**

2.3 Signal Processing and Feature Extraction

* Filtering: Bandpass **Butterworth IIR filter**
* ***Features Evaluation:*** 
  + What were we searching for?
  + What did we see?
  + Which ones did we decide and why
* Window size analysis:
  + What did we see in different windows?
  + Why did we choose: **800 samples window size, 75% overlap** = 200 samples step

**3. Metric Standardization and Fatigue Modeling**

1. **Baseline Establishment**

* Evaluating different calibration methods.
* Normalizing metrics to a dynamic global scale for consistency.

2. **Fatigue Estimation Approaches**

* Exploring different methods to define and quantify fatigue based on the accepted metrics.
* Selecting the most suitable approach based on evaluation criteria.

3. **Machine Learning Model Training**

* Using our calibrated standardized metrics as input and fatigue estimation as output.
* Training multiple models and comparing their performance.

4. **Model Evaluation & Selection**

* Analyzing results using accuracy, error metrics, or other relevant benchmarks.
* Choosing the best-performing model for further analysis.

**4. Results and Discussion (short)**

1. **Baseline and Metric Analysis**
   * Evaluation of signal consistency after standardization.
   * Impact of calibration on metric reliability.
2. **Fatigue Estimation Performance**
   * Comparison of different fatigue estimation approaches.
   * Correlation of estimated fatigue levels with observed physiological patterns.
3. **Machine Learning Model Performance**
   * Training outcomes of different models.
   * Accuracy, error metrics, and performance trends.
4. **Comparative Discussion**
   * Strengths and limitations of selected fatigue index.
   * Comparison with existing fatigue detection methods.
   * Implications for real-time monitoring in practical applications.

**5. Conclusion and Future Work (short)**

1. **Key Findings**
   * Summary of the most effective fatigue indicators.
   * Performance of the selected ML model in real-time fatigue prediction.
2. **Contributions of This Work**
   * Advancement in real-time, wearable fatigue monitoring.
   * Improved calibration techniques for personalized muscle assessment.
3. **Limitations**
   * Challenges in model generalization across different users and activities.
   * Potential issues with signal noise and real-time processing constraints.
4. **Future Work**
   * Expanding the dataset with more subjects and activities.
   * ***Enhancing real-time processing efficiency for embedded applications. Implementing the final product for such an application.***
   * Investigating long-term adaptation and personalization strategies.

**References**  
(Include citations from **thesis** and additional sources)

**Appendix**

* Details of **GitHub repo functionalities**
* Additional experiment logs

**(Figures & tables to be inserted in the appropriate sections)**