Muscle Synergy-Based Representation for Robust Myoelectric Pattern Recognition Under Varying Contraction Levels and Unknown Motions

Xiang Wang[1], Le Li[1]
[1] Institute of Medical Research, Northwestern Polytechnical University, Xi'an, China
Email: xiangwangbme@mail.nwpu.edu.cn

Summary

This study proposes a myoelectric pattern recognition (MPR) method with robust performance under varying contraction levels and unknown motion interference. Experimental results demonstrate that the proposed method achieves over 94% accuracy at specific contraction levels, which is significantly outperforming traditional methods ($p < 0.001$). The method achieves high rejection accuracy for unknown motions, approaching 98.30% across three distinct contraction conditions. These results indicate that varying contraction levels significantly impact MPR performance, and the proposed method ensures robust classification as well as effective rejection of unknown motions ($p < 0.05$).

Introduction

MPR technology enables prosthetic and human-machine interaction control by decoding surface electromyography (sEMG) signals. However, its commercial adoption is hindered by robustness issues caused by varying muscle contraction levels and unknown motion interference [1]. The challenge across different contraction levels stems from the asymmetric distribution of samples. While transfer learning with domain alignment algorithms effectively addresses this issue, its performance becomes unsatisfactory when unknown motion interference and varying contraction levels coexist, primarily due to the lack of knowledge about unseen categories. To overcome these limitations, this study proposes an MPR method robust to both varying contraction levels and unknown motion interference.

Methods

This study involved three healthy, right-handed participants (aged 30–55; 2 males, 1 female) who performed 10 gesture categories (G1–G10) at three contraction levels (Low, Medium, High) using a 32-channel electrode array on their forearm extensor muscles. Known gestures (G1–G5) included finger-palm motions, while unknown gestures (G6–G10) involved wrist movements. After preprocessing, muscle synergy decomposition via non-negative matrix factorization (NMF) was applied to extract force-invariant representations, factorizing data into muscle synergy vectors (**W**) and activation coefficients (**H**). The number of synergies (r) was determined by variance accounted for (VAF), and reconstructed samples were paired (same category: 1, different: 0) to train a Siamese neural network (SNN) for similarity measurement, following our previous model [2].

To evaluate the proposed method, two baseline methods were implemented: (1) LDA with Mahalanobis distance (LDA-MD) and (2) CNN with softmax and center loss (CNNSC) for unsupervised recognition.

Results and Discussion

Figure 1 compares time-domain features with the proposed muscle synergy decomposition method, showing that time-domain features exhibit poor class separation and sensitivity to contraction levels, while the proposed method achieves robust, contraction-level-invariant clustering with effective class separability (Figure 1). Without unknown motion interference, all methods achieved over 84% accuracy, with the proposed method (94.92±3.28%) significantly outperforming LDA-MD and CNNSC ($p < 0.001$). Cross-level performance reduced accuracy by over 5% for all methods ($p < 0.05$). With unknown motion interference, the proposed method achieved near 100% rejection accuracy, significantly surpassing LDA-MD and CNNSC (<85% at specific levels). The results highlight the impact of contraction levels on MPR performance and demonstrate the proposed method's robustness in classifying known motions and rejecting unknown motions across varying contraction levels ($p < 0.05$).

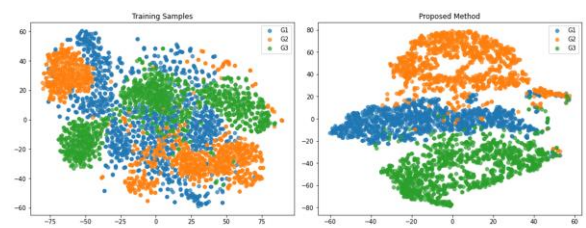

Figure 1: The t-SNE methodology is employed to show the distributions of time-domain features and the distributions of the proposed robust representation method.

Conclusions

This study proposes a robust MPR method addressing varying contraction levels and unknown motion interference, outperforming existing techniques with high accuracy. The results demonstrate its effectiveness under extreme conditions, highlighting its potential for reliable real-world myoelectric control applications.

Acknowledgments

This work was supported in part by the National Natural Science Foundation of China (No. 32071316, 32211530049) and Shenzhen Science and Technology Program (GJHZ20210705143401005).

References

[1] D. Farina et al. (2014). *IEEE TNSRE*, **22**: 797–809.
[2] X. Wang et al. (2023). *IEEE TNSRE*, **31**: 1697–1706.