Prediction of Grasp Forces Using Multi-Channel EMG Signals

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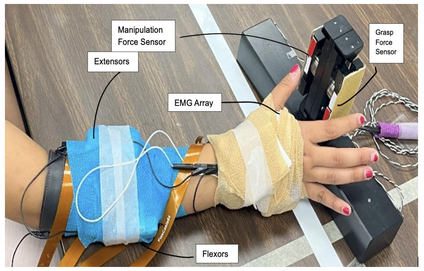
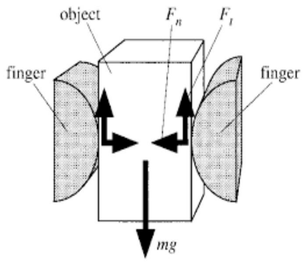
Introduction

Introduction: Dexterous hand movements require precise coordination between muscle activation and force production. High-density electromyography (HD-EMG) provides a non-invasive means of measuring muscle activity, but the large number of channels and signal variability make force prediction challenging. This project investigates whether grasp force (FG) and manipulation force (FM) can be predicted from HD-EMG signals using a deep learning framework.

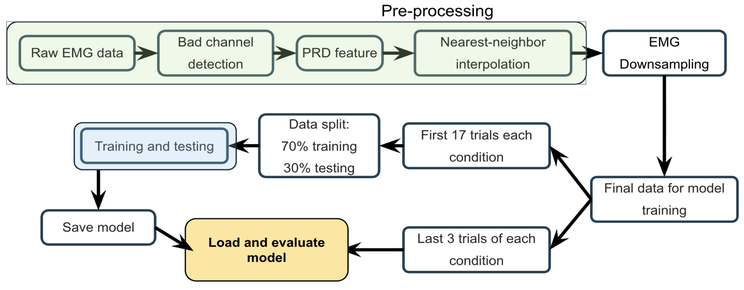
Objective: To predict grasp force (FG) and manipulation force (FM) from multi-channel HD-EMG signals during controlled grasping tasks, and to evaluate both model performance and data usability before scaling the analysis across all 20 subjects.



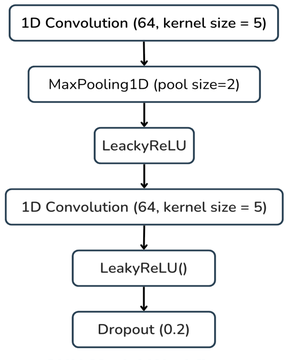


Experimental Setup of the Project

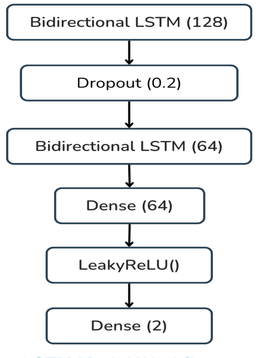
Methods



High-density EMG data processing and CNN model training/testing

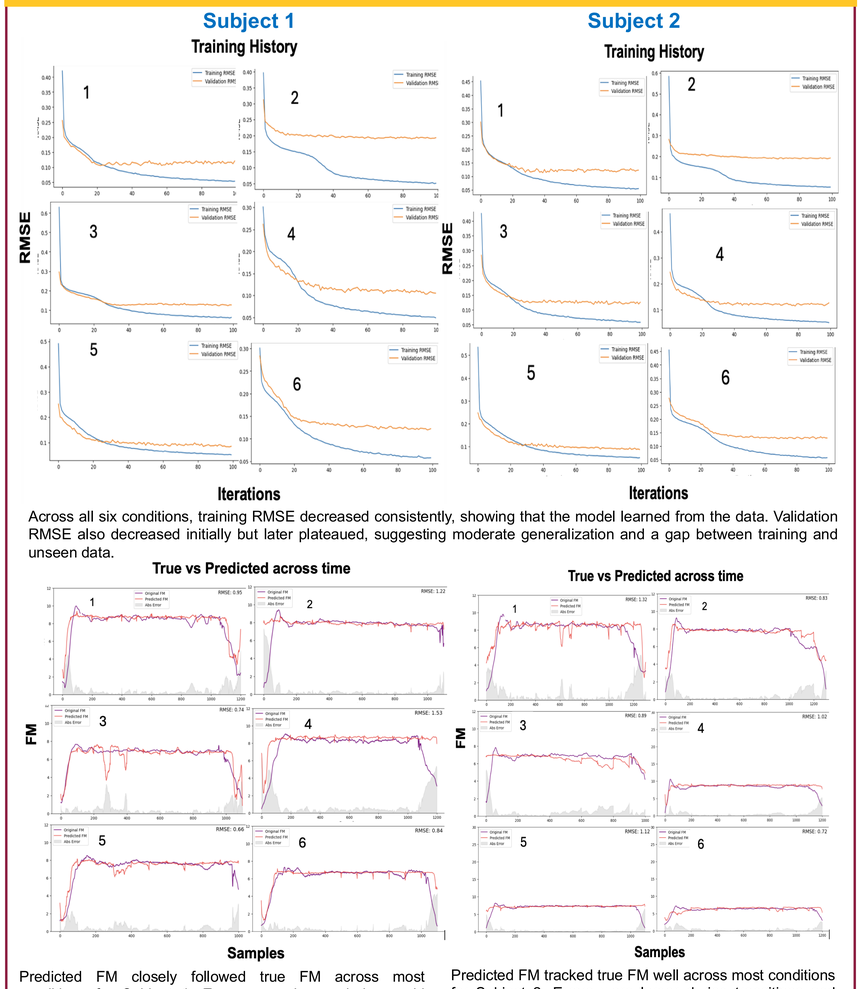


CNN Model Workflow



LSTM Model Workflow

Results



Across all six conditions, training RMSE decreased consistently, showing that the model learned from the data. Validation RMSE also decreased initially but later plateaued, suggesting moderate generalization and a gap between training and unseen data.

Predicted FM closely followed true FM across most conditions for Subject 1. Errors were larger during rapid transitions and end-phase drops. Condition-wise RMSE highlighted differences in task difficulty.

Predicted FM tracked true FM well across most conditions for Subject 2. Errors were larger during transitions and late-trial force changes. RMSE values showed condition-specific differences in model performance.

For Subject 1, the model captured the overall temporal pattern of grasp force, but prediction accuracy varied considerably across conditions, with the largest errors observed in LHP and LHD.

For Subject 2, the model captured the overall temporal pattern of grasp force, but prediction accuracy varied substantially across conditions, with the highest errors observed in LHP and RHP.

Results

- **14 subjects, 6 conditions, and 120 trials** were included in the condition-wise analysis workflow.
- Across the processed subjects, **MAE ranged from 1.75 to 15.40** across conditions.
- Predicted **FM and FG** captured the overall force trends, with stronger agreement during steady-state phases and larger errors during rapid transitions, peak-force regions, and end-phase drops.
- Condition-wise evaluation showed variability in prediction performance across task conditions.
- These findings motivated further **force inspection** and **EMG usability testing** before large-scale implementation of the full pipeline.

Summary, Conclusions and Future Directions

Conclusions: The CNN-LSTM framework captured the overall temporal patterns of grasp and manipulation forces from HD-EMG signals. Across subjects and conditions, predictions were more accurate during steady-state phases and less accurate during rapid transitions, highlighting the importance of condition-wise evaluation and continued analysis of data usability before large-scale implementation.

Future Work: Future work will focus on transitioning the current modeling pipeline to the PyTorch library and exploring interpretability methods for the CNN component of the model. This will allow for a more detailed examination of the features learned from the EMG signals and provide better insight into the model's internal behavior, supporting further refinement of the prediction framework.

References

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Acknowledgements

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