Muscle Synergies as the Basis for the Control of a Hand Prosthesis

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Research Objectives

About 60,000 people in the US alone live with a major upper-limb amputation. 70% of these individuals have an amputation that is distal to the elbow. The control of robotic hand prostheses using surface electromyographic (sEMG) signals is of particular interest in this patient population.

In this ongoing study, we are exploring the suitability of a novel technique based on the estimation of muscle synergies to control a hand prosthesis. The objective of the study is to detect the performance of thirteen distinct hand grasp movements (Figure 1) using EMG data. The method relies on projecting the EMG data using a basis derived via analysis of the muscle synergies.

The intriguing idea behind the synergy prediction is that this technique clusters the temporal activation of muscles that are active simultaneously. If one of the EMG channels contributing to the muscle synergy is not available, the synergy extraction algorithm can reconstruct the original synergy without loss of information. In other words, the technique allows one to infer the activity of muscles that are no longer part of the anatomy.

This approach would allow one to infer the activation patterns of distal muscles that are no longer part of the anatomy that would have otherwise contributed to a muscle synergy. This is possible as long as muscles proximal to the level of amputation - whose activity can be therefore recorded from the residual limb - contribute to that muscle synergy when the anatomy is intact.

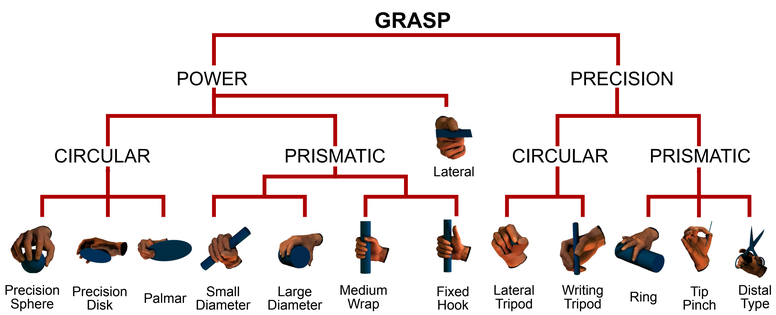


Figure 1. Schematic representation of the 13 grasps utilized in the study.

Materials & Methods

Five healthy subjects performed a set of thirteen distinct hand grasp movements while sEMG data was collected from the muscles shown in Figure 2. The non-negative matrix factorization algorithm was applied to the sEMG envelopes to derive four muscle synergies (Figure 3), which we found to be sufficient to reconstruct the muscle activation patterns with an average R^2 - across all sEMG channels - of 0.85 and a minimum R^2 of 0.70. These four muscle synergies were used as a projection basis and the output of the algorithm was analyzed using a template matching technique to detect the performance of the hand grasp movements.

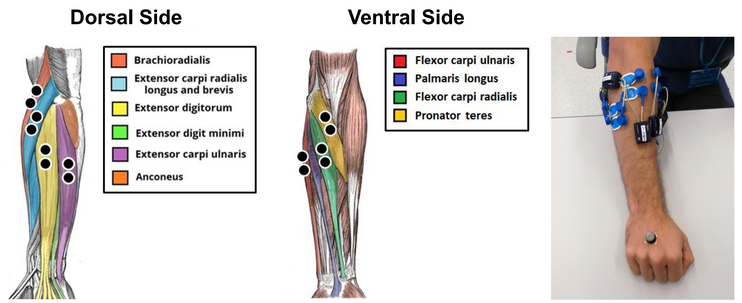


Figure 2. Schematic representation of the position of the sEMG electrodes (left panel) and photo of the arm of one of the study volunteers (right panel).

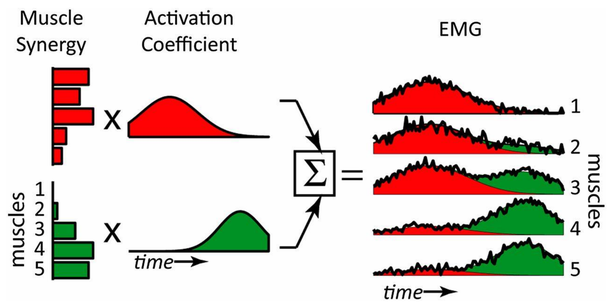
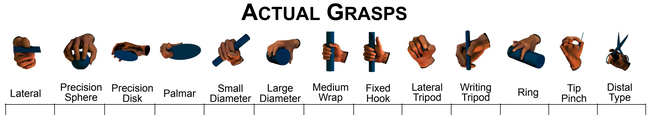


Figure 3. Representation of how muscles contribute to the muscle synergies. The extraction of muscle synergies aims to reconstruct the composition and temporal activation patterns (left) from the sEMG envelopes (right).

Results

The table below shows the confusion matrix summarizing the average results obtained for the five study participants. The diagonal of the confusion matrix (i.e. correct classifications) shows results ranging from 80% (for the *tip pinch* grasp) to 100% (for the *fixed hook* and *distal type* grasps). Results slightly vary from subject to subject. The average (across grasps) detection accuracy varied from 87.4% (subject #1) to 94.9% (subject #3).



ACTUAL GRASPS

PREDICTED GRASPS	Lateral	Precision Sphere	Precision Disk	Palmar	Small Diameter	Large Diameter	Medium Wrap	Fixed Hook	Lateral Tripod	Writing Tripod	Ring	Tip Pinch	Distal Type
Lateral	86.7	3.3							3.3	3.3			
Precision Sphere		90.0		3.3			3.3					3.3	
Precision Disk		3.3	96.7	3.3		3.3						3.3	
Palmar				93.3		3.3							
Small Diameter					90.0		6.7						
Large Diameter	3.3					86.7	10.0						
Medium Wrap					10.0	6.7	80.0						
Fixed Hook								100.0					
Lateral Tripod									90.0	3.3			
Writing Tripod	3.3		3.3						6.7	93.3		3.3	
Ring		3.3									93.3	6.7	
Tip Pinch	3.3										3.3	80.0	
Distal Type	3.3										3.3	3.3	100.0

Conclusions

The pilot study showed feasibility of predicting grasps using muscle synergies. Ongoing data collections are using a larger number of sEMG channels, are exploring with the impact of removing channels associated with distal muscles, and are beginning to investigate the accuracy of the proposed technique in amputees.

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