FIRST EVALUATION OF AN INTEGRATED SONOMYOGRAPHIC PROSTHESIS IN INDIVIDUALS WITH CONGENITAL LIMB DIFFERENCE

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ABSTRACT

Sonomyography (SMG) or ultrasound-based sensing of muscle deformation is an emerging modality for enhancing upper limb prosthesis control, offering the ability to spatially resolve muscle activity in both superficial and deep layers. Prior studies from our group as well as other groups have demonstrated the feasibility of SMG for prosthetic control using clinical ultrasound imaging systems and as well as miniaturized wearable ultrasound systems with several single-element ultrasound transducers for tracking muscle interfaces. However, the performance of SMG using miniaturized ultrasound sensors incorporated into a prosthetic socket has not been evaluated thus far. In this study, we incorporated single element ultrasound sensors into custom designed prosthetic sockets for two individuals with congenital transradial limb difference and evaluated the performance of classification and proportional control. Our work demonstrates the potential for SMG as well as highlights some challenges that need to be overcome.

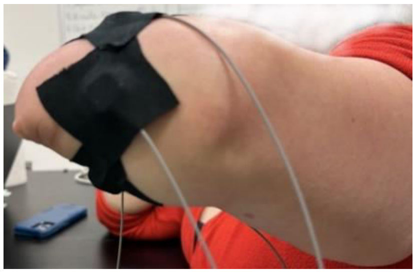
INTRODUCTION

Despite the longstanding commercial availability of myoelectric prosthetics, there continue to be inherent limitations associated with surface Electromyography (EMG) signals. EMG signals suffer from poor amplitude resolution, a low signal-to-noise ratio, and crosstalk from adjacent muscles [1],[2]. So, achieving intuitive control of prosthetic hands is still an open problem. Sonomyography (SMG), an emerging modality that utilizes ultrasound for sensing muscle deformation associated with volitional motor intent and provides control signals that have the potential for significant improvement in prosthesis functionality. Prior work has shown that ultrasound can feasibly generate discrete control signals for a large set of unique hand grasps [3]. Our prior research demonstrated that sonomyography (SMG) can accurately differentiate hand grasps using supervised learning algorithms, achieving high accuracy in both individuals with and without upper limb loss, and showed the potential for using a miniaturized and compact wearable ultrasound system [4], [5]. However, it is currently not known how the miniaturized ultrasound transducers will perform inside a prosthetic socket, especially when the arm is moved in different positions within the reachable workspace, since ultrasound signal quality can be affected by sensor shift and loss of contact with the skin. Our objective in this study was to investigate these questions.

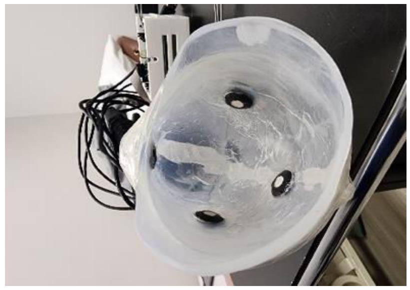
METHODS

In an ongoing study, we have recruited two individuals with congenital transradial limb difference. The first participant was an experienced myoelectric prosthesis user, while the second participant had never used a myoelectric prosthesis. Written informed consent was obtained under the guidelines and approval of GMU Institutional Review Board (IRB) prior to conducting the experiment. In this pilot phase of the study, we iteratively tested the performance of our prototype system in a variety of conditions to identify the challenges that need to be overcome. The first step of the process was to identify the sensor positions on the residual forearm. To identify suitable sensor placement locations, we palpated the participant's residual limb while they were attempting different volitional muscle contractions. The ultrasound transducers were then placed at these locations and held in place with adhesive tape. Subsequently, we recorded SMG data for each motion across multiple trials while the participant attempted different volitional grasps, and we evaluated the classification accuracy. When satisfactory performance was obtained, the locations were documented and communicated to our prosthetist.

In collaboration with our prosthetist, custom sockets were for our participants with transducers incorporated. The sockets were created with a set of soft thermoplastics where the sensors are attached and a hard outer shell where the prosthetic hand is attached. We iteratively refined the transducer housing to ensure that the sockets could be donned and doffed without any discomfort.



(A)



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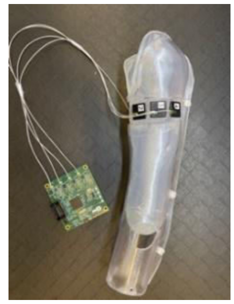

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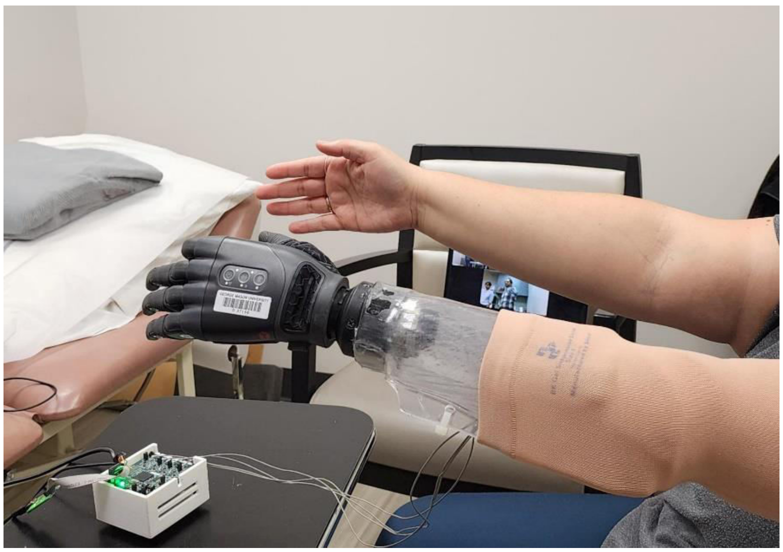


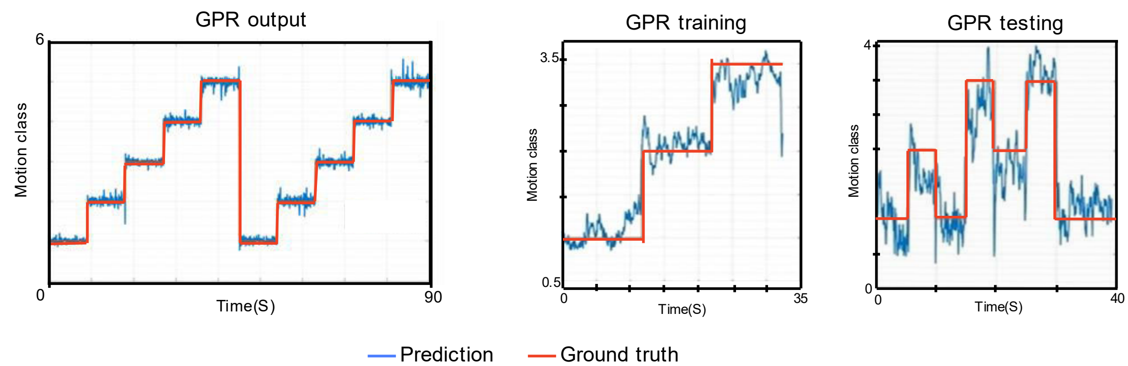
(D)

Figure.1. (A) SMG sensor location (B) Custom-fitted socket integrated SMG sensors for the second participant, (C) Custom-fitted socket integrated SMG sensors for the first participant, attached to our custom designed prototype ultrasound front end electronics circuit board, and (D) Our participant wearing the prosthetic socket with TASKA hand

In our study, we employed a supervised learning approach to test our prototype system. We utilized a dynamic training protocol that we have previously developed [6]. The dynamic training protocol takes less than 30 seconds and acquires data at multiple different arm positions within a large reachable workspace. Once the training data are obtained, the performance is then tested with different trials with the arm in different positions. Principal Component Analysis (PCA) was used for dimensionality reduction and Linear discriminant analysis (LDA) was used for classification of different motions. We also utilized Gaussian Process Regression (GPR) for classification and control. Our main goal in this study was to understand the impact of training method and the impact of dynamic movement on socket loading and sensor shift on classification performance. Through this investigation, we aimed to enhance our understanding of these critical factors in system performance and reliability.

RESULTS

The first participant was able to perceive three distinct volitional motions which were mapped to power grasp, pinch, and tripod. The second participant was able to perceive two distinct volitional motions which were mapped to power grasp and tripod. In addition, both participants were able to perform wrist rotation. Therefore, including rest as a separate class, we had 5 distinct classes for the first participant and 4 distinct classes for the second participant.

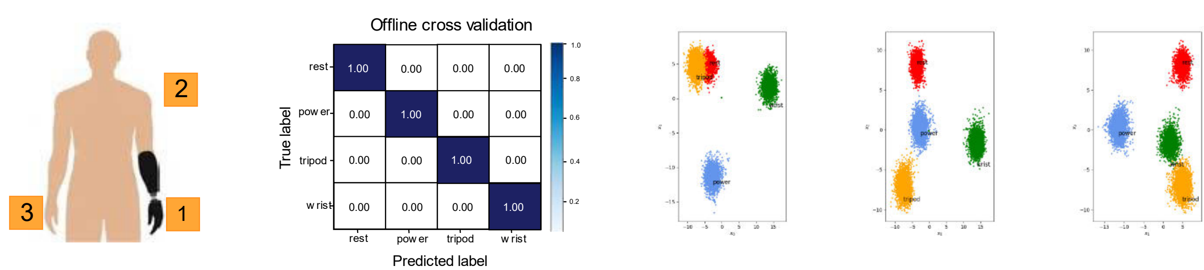


(A) (B.1) (B.2)

Figure. 2. (A) Test of 4-channel SMG system in the first participant. A Gaussian Process Regression was used to train and test with 2-fold cross validation. The participant repeated five movements (rest, power, tripod, wrist) and held each for 10 seconds. (B) Separate training and real-time testing of Gaussian process regression for three motion classes.

Using a dynamic training and dynamic testing paradigm, we obtained a classification accuracy of 81.6% for the first participant to differentiate between 5 classes. Using Gaussian process regression, we were able to demonstrate real-time transitions between three different classes (Figure 2).

Training data obtained from the second participant in three different arm positions (Figure 3A) exhibited a 100% cross-validation accuracy across all trials (Figure 3B). Furthermore, pooled data from four grasps performed at three different positions and projected onto Linear Discriminant Analysis (LDA) space showed consistent separation between the classes (Figure 3C).



(A) (B) (C)

Figure. 3. (A) Evaluation of signal quality from our first myoelectric naive participant at different arm positions, (B) offline cross validation from data collected at positions 1,2 and 3 with a prosthetic socket loaded with the TASKA hand, and (C)Pooled data from four grasps at all three positions projected into LDA space showing spatially where data is located, each plot shows the location of a motion on 2 of the projected axes.

To evaluate the effect of training and arm position, a single DOF (power grasp) was compared to rest for the second participant. Data were collected for multiple training trials and analysed offline, both for static arm position, and while the arm was moved rapidly from a neutral position to shoulder level. For the static arm positions, an accuracy of 85% was obtained for the first trial, and the accuracy increased to 100% by the fourth trial. For the dynamic trials, a peak accuracy of 94% was obtained, but the accuracy declined to approximately 60% with increasing trials. Analysis of the data from individual channels demonstrated that data were inconsistent from one of the sensors. Analysis of classification accuracy using one or combination of channels revealed that high classification accuracy could be obtained for both static and dynamic trials using a subset of channels. Table 1 presents the classification accuracy results from the session for static and dynamic training of rest and power motions, considering all four channels, subsets of channels, and each individual channel, respectively.

Table 1: Channel-wise classification accuracy

Static Trials							
Trials	**All Channels**	**Channel 2,3 & 4**	**Channel 2 & 4**	**Channel 1**	**Channel 2**	**Channel 3**	**Channel 4**
Trial_1	85%	70%	99%	90%	98%	53%	84%
Trial_2	89%	100%	99%	50%	90%	49%	86%
Trial_3	99%	100%	99%	61%	99%	86%	92%
Trial_4	100%	100%	100%	66%	99%	55%	94%
Dynamic Trials							
Trial_1	94%	97%	98%	56%	93%	62%	81%
Trial_2	55%	84%	79%	23%	62%	58%	70%
Trial_3	58%	70%	55%	46%	59%	60%	78%

DISCUSSION

To the best of our knowledge, this is the first report of the performance of a miniaturized SMG system incorporated into a prosthetic socket and tested with an attached end effector to evaluate the effect of socket shift and loading on SMG signal quality and classification performance. Preliminary results from two subjects with congenital limb difference indicate that SMG sensors incorporated into prosthetic sockets can be used to successfully classify between grasps with performance like that reported in the literature using clinical ultrasound systems, even for subjects who have never used a myoelectric prosthesis. However, our evaluation also revealed the challenges associated with sensor shift and coupling during dynamic movements. We anticipate that three strategies can be utilized to mitigate this challenge: (1) investigation of strategies to maintain adequate sensor contact, such as adjustable panels over each sensor that can be tightened with BOA cables; (2) utilizing signal analysis to automatically determine a subset of channels that provide adequate data quality and (3) incorporating a redundant number of sensors, or a to minimize the impact of any sensor shift on one or more sensors. We are currently investigating whether these strategies can lead to more robust functional task performance using SMG.

ACKNOWLEDGEMENTS

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REFERENCES

[1] Y.-K. Kong, M. S. Hallbeck, and M.-C. Jung, "Crosstalk effect on surface electromyogram of the forearm flexors during a static grip task," *J. Electromyogr. Kinesiol.*, vol. 20, no. 6, pp. 1223–1229, Dec. 2010, doi: 10.1016/j.jelekin.2010.08.001.

[2] E. A. Clancy, E. L. Morin, and R. Merletti, "Sampling, noise-reduction and amplitude estimation issues in surface electromyography," *J. Electromyogr. Kinesiol.*, vol. 12, no. 1, pp. 1–16, Feb. 2002, doi: 10.1016/S1050-6411(01)00033-5.

[3] V. Nazari and Y.-P. Zheng, "Controlling Upper Limb Prostheses Using Sonomyography (SMG): A Review," *Sensors*, vol. 23, no. 4, p. 1885, Feb. 2023, doi: 10.3390/s23041885.

[4] S. Engdahl *et al.*, "ASSESSING THE FEASIBILITY OF USING SONOMYOGRAPHY FOR UPPER LIMB PROSTHESIS CONTROL", *MEC Symposium, Aug. 22.*

[5] S. Acuña, S. Engdahl, A. Bashatah, P. Otto, R. Kaliki, and S. Sikdar, "A WEARABLE SONOMYOGRAPHY SYSTEM FOR PROSTHESIS CONTROL", *MEC Symposium, Aug. 22.*

[6] S. M. Engdahl, S. A. Acuña, E. L. King, A. Bashatah, and S. Sikdar, "First Demonstration of Functional Task Performance Using a Sonomyographic Prosthesis: A Case Study," *Front. Bioeng. Biotechnol.*, vol. 10, p. 876836, May 2022, doi: 10.3389/fbioe.2022.876836.