A Preliminary Evaluation of Acoustic Myography for Real-Time Muscle Force Inference*

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***Abstract*— We present a novel modeling framework for the measurement of muscle force via acoustic myography (AMG). Preliminary data indicate the framework's promise in inferring muscle force from multiple muscle groups, allowing for novel analysis of muscle synergies and joint stiffness for future use in assistive device control schemes.**

I. Introduction & Objectives

While there exist complex assistive devices that mechanically replicate the functionality of the human arm and hand, it is currently impossible to control the many degrees of freedom of such devices in a truly biomimetic manner. Neurological muscle activation via surface electromyography (sEMG) is often employed as a control signal, but a more informative measure of desired motion is muscle *force*, which varies with both activation and multiple downstream factors (including fatigue state and tissue ion concentration) [1].

In particular, muscle force is a function of both the number of fibers recruited and the firing rate of each motor unit — phenomena that are impossible to disambiguate from the sEMG signal, but are readily observable via acoustic myography (AMG) in the signal's amplitude and frequency, respectively [1]. We here develop a novel muscle force model based on the AMG signal — which was proved viable for device control in 1986 [2] — to probe both agonist and antagonist elbow muscles, whose interaction is critical to modulating joint stiffness during everyday tasks and largely ignored in current optimization-based modeling frameworks.

II. Proof-of-Concept Model

We can model the observed AMG amplitude A as approximately proportional to the number of activated fibers n, while the AMG frequency ν is approximately proportional to the mean fiber force $\bar{F}_f$ [1]. The output force F_m of a muscle can then be written as

$$F_m = n\bar{F}_f = \alpha A \nu$$

for some (positive) constant α.

Although this model is difficult to validate in vivo, as measurements of external forces admit an infinite range of possible forces exerted by each muscle, we perform preliminary validation analysis using the simplified sagittal model of the elbow shown in Fig. 1. Assuming a static configuration of the elbow, the following should hold: (1) under relaxed conditions (i.e., minimal elbow stiffening), $A_1\nu_1$ of the elbow flexor(s) should correlate positively with output torque τ; and (2) for a given τ, under varying elbow stiffness, $A_1\nu_1$ of the elbow flexor(s) should correlate positively with $A_2\nu_2$ of the elbow extensor(s) to maintain a constant output torque. We evaluate these hypotheses on a preliminary data set below.

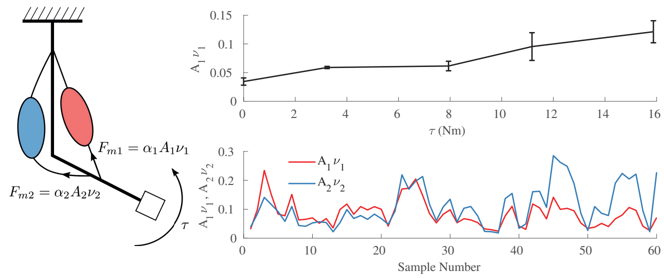

Fig. 1. Preliminary acoustic myography (AMG) data of the biceps and triceps show substantial correlation with muscle output force. *Left*: Simplified sagittal model of the elbow used in data analysis. *Right, top*: $A_1\nu_1$ of the biceps is highly correlated with output output torque τ ($r = 0.9, p < 10^{-6}$). *Right, bottom*: Example $A_1\nu_1$ and $A_2\nu_2$ trajectories (of the biceps and triceps, respectively) during random elbow stiffness modulation, showing significant correlation between the two data series ($r = 0.6, p < 10^{-7}$), consistent with maintaining constant output torque.

III. Preliminary Results & Future Directions

As an initial feasibility study, we collected data from the biceps and triceps brachii of a single subject (under University of California IRB Protocol 2016-01-8261), under multiple loads τ at the same elbow angle, while encouraging the subject to modulate their muscle stiffness at 3s intervals over which $A_1\nu_1$ and $A_2\nu_2$ were calculated. The data were consistent with hypotheses (1) and (2) above, as shown in Fig. 1, suggesting that $A\nu$ is well-correlated with muscle force. Future research will include fitting parameters α to enable output force inference, investigating both temporal and spatial resolution of the AMG signal (toward determining the shortest interval over which ν can be robustly calculated and the number of independent signals that can be extracted from neighboring muscles, respectively), and expanding the resultant models to complex multi-muscle systems.

References

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[2] D. T. Barry, J. A. Leonard, A. J. Gitter, and R. D. Ball, "Acoustic myography as a control signal for an externally powered prosthesis," *Archives of physical medicine and rehabilitation*, vol. 67, no. 4, pp. 267–269, 1986.

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