Beyond Surface Electromyography:
Acoustic Myography and Ultrasound Imaging for Real-Time Muscle Force Inference

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Problem

- **Intuitive control of high-degree-of-freedom (DoF) assistive devices** remains an open problem
- **Replicating human dexterity requires understanding and mimicry of complex muscle synergies**, including agonist-antagonist relationships
- Control systems using industry-standard surface electromyography (sEMG) are limited by the sensor's noisy and aggregate nature and by poor overall understanding of neurological motor control [1]

Solution

Measure in vivo mechanical signals (vibration and deformation) associated with muscle contraction to **build muscle dynamics models without requiring knowledge of motor control strategies**

Contributions

- **Novel model relating real-time muscle force to muscle vibration**, as measured via acoustic myography (AMG) (**P1**)
- **Novel data set allowing first-ever relation of muscle force to muscle deformation** in the presence of changing kinematic configuration, as measured via ultrasound and motion capture (**P2**)

P1: Aggregate Muscle Force via Vibration

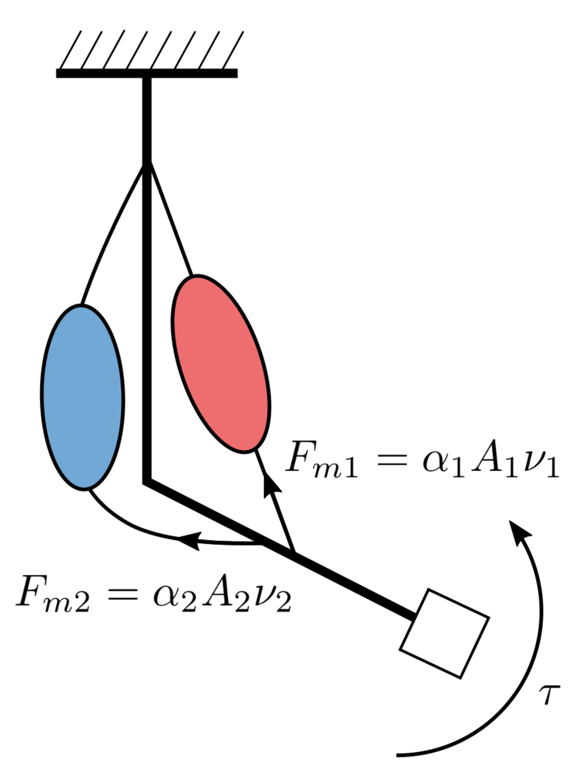
Project Objective

Predict in vivo muscle force from muscle vibration caused by contraction using acoustic myography (AMG) for use in real-time control schemes

Muscle Force Model

We model individual muscle output force F_m as

$$F_m = \overbrace{n}^{\text{\# activated fibers}} \underbrace{\bar{F}_f}_{\text{mean fiber force}} = \alpha \overbrace{A}^{\text{AMG amplitude}} \underbrace{\nu}_{\text{AMG frequency}}$$



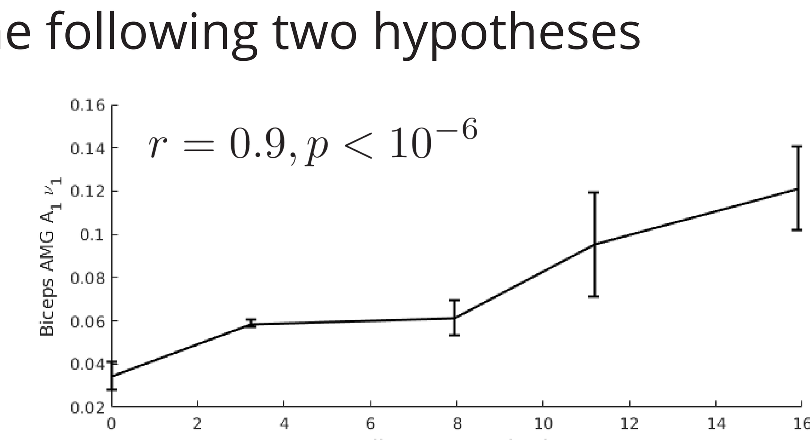
for some $\alpha > 0$, as it is conjectured that $A \propto n$ and that $\nu \propto \bar{F}_f$ [2].

We perform preliminary validation analysis using the simplified sagittal model of the elbow shown here.

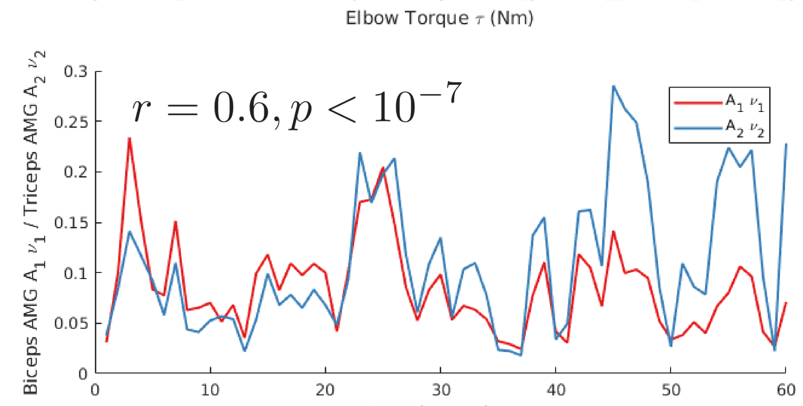
Preliminary Results

Preliminary single-subject data support the following two hypotheses consistent with the model above:

(1) Under relaxed conditions, $A_1\nu_1$ of the elbow flexor(s) correlates positively with output torque τ



(2) For a given τ, under varying elbow stiffness, $A_1\nu_1$ of the elbow flexor(s) correlates positively with $A_2\nu_2$ of the elbow extensor(s) to maintain constant output torque



Current / Future Work

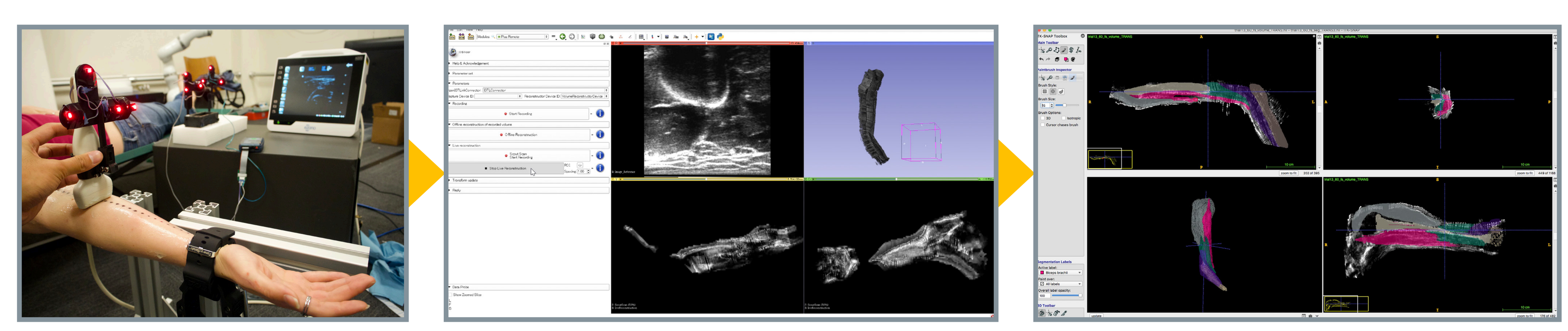
- **Fit parameters** α to enable **output force inference**
- Investigate **temporal and spatial resolution** of AMG signal
- Expand resultant models to **complex multi-muscle systems**
- Incorporate models into **multi-DoF device control schemes**

P2: Localized Muscle Force via Deformation

Project Objective

Build low-dimensional models relating muscle deformation to output force for use in real-time control schemes, robust to changes in kinematic configuration

Muscle Volume Extraction

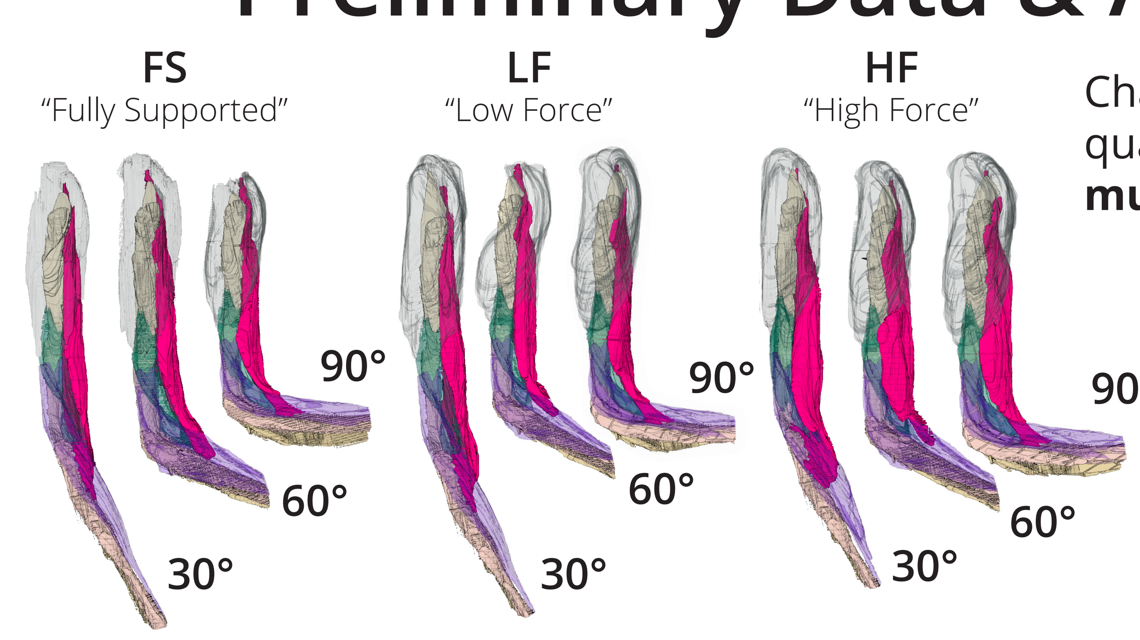


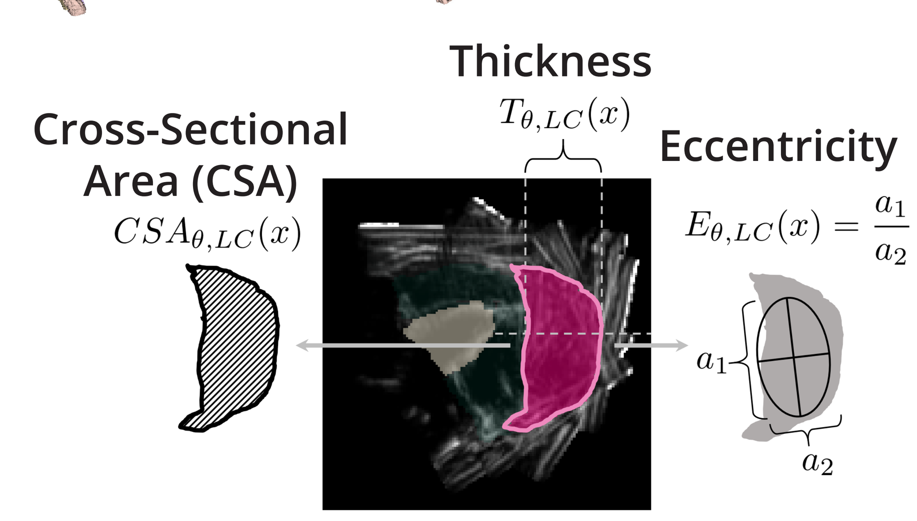
Raw Data Collection via Ultrasound & Motion Capture

Volumetric Reconstruction via PLUS Toolkit [3]–[5]

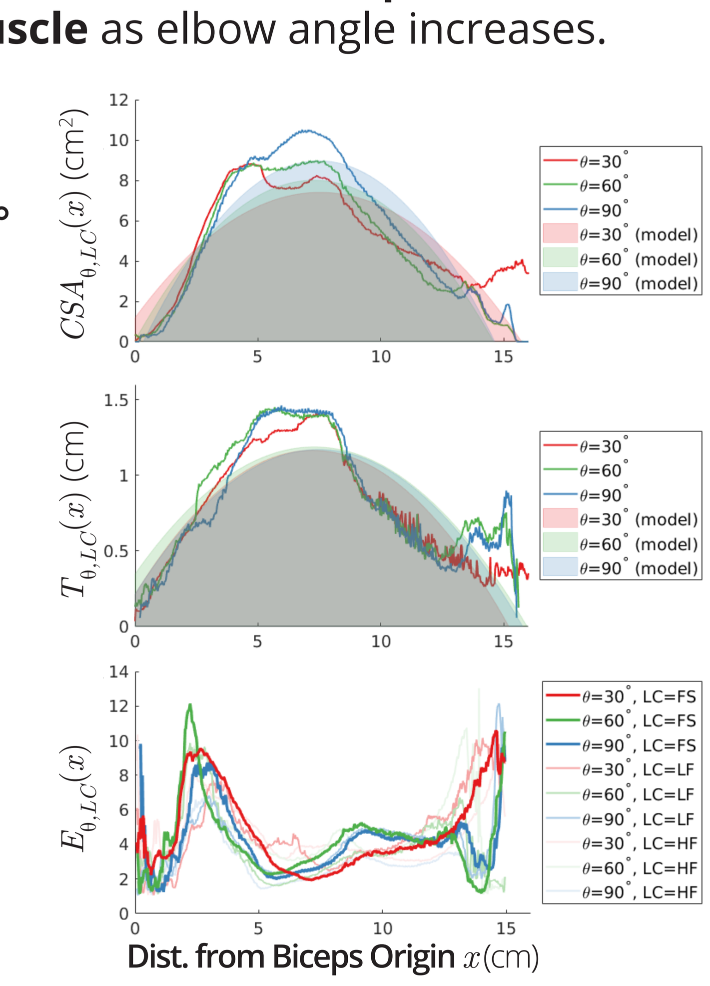
Tissue Segmentation in ITK-SNAP [6]

Preliminary Data & Analysis [7]





Changes in width of the fitted CSA quadratic **reflect compression of the muscle** as elbow angle increases.



Current / Future Work

- Extract low-dimensional models of deformation to enable **real-time force inference**
- **Automate segmentation of tissue structures** (current computational bottleneck) by leveraging image registration techniques [8] and neural networks [9]

Download the full data set at `hart.berkeley.edu/datasets`

Acknowledgments / Sponsors

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