Human Musculoskeletal Dynamics Modeling:
Current Research and Objectives

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Human-Assistive Robotic Technologies (HART) Lab

OVERVIEW
HART Lab Ecosystem

Levels of human modeling abstraction

Musculo-skeletal

Kinematic / Dynamic

Kinematic

Agent Interaction

Microscopic view

Macrosopic view

OVERVIEW
People (Musculoskeletal Modeling)

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Why model musculoskeletal dynamics?

Human dynamics modeling is essential for many applications.

- understanding forces imperative in physical HRI
- non-physiological models cannot sufficiently predict dynamics
Why model musculoskeletal dynamics?

Human dynamics modeling is essential for many applications.
• understanding forces imperative in physical HRI
• non-physiological models cannot sufficiently predict dynamics

It’s also difficult.
• complex dynamical system (how many DoF?)
• morphological variation
• limited sensing (esp. non-invasive)
Objective

We seek to develop models to predict human arm dynamics that

• have appropriate level of abstraction (as simple as possible while accommodating dynamically- and medically-relevant pathologies)

• are trainable/customizable using non-invasive sensing (MRI, ultrasound, EMG, AMG, etc.)

• can be used in assistive device control system using non-invasive, wearable sensing (EMG, AMG, ultrasound)
Objective: Predictive Upper-Limb Model

- predicts contact forces / joint torques of interest
- accommodates musculoskeletal pathology
  - injury
  - disease (e.g., MD)
- individualized
- computationally tractable
Existing Human Dynamics Models

- **(Static) Morphological Data**
  - (MRI, ultrasound)

- **Real-Time Data**
  - (sEMG, AMG, motion capture, ultrasound)

- **Morphological Assumptions**
  - (biomechanics tables, literature values)

- **Contextual Assumptions**
  - (gait cycle, motion primitives)

**DYNAMICS MODEL**

**Dynamics**
- (contact forces, joint torques)
Our Objective

DYNAMICS MODEL

- (Static) Morphological Data
  (MRI, ultrasound)
- Real-Time Data
  (sEMG, AMG, motion capture, ultrasound)
- Morphological Assumptions
  (biomechanics tables, literature values)
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  (gait cycle, motion primitives)

Dynamics
(contact forces, joint torques)
Our Objective

To achieve this, our models will need to be highly customizable using subject-specific data.
Possible Sensing Modalities

**sEMG** (surface electromyography)
- sensitive, noisy
- aggregate
- based on neurological signals 
  \( \text{(neurological disorder } \rightarrow \text{ poor signal)} \)
- well-explored
- industry standard

**AMG** (acoustic myography)
- improved SNR
- aggregate
- based on physiological signals
- novel
Possible Sensing Modalities

Ultrasound

3D View

Muscle Cross-Section

Inactive

Active

Inactive

Active

Force

Force

Time (s)
Possible Sensing Modalities \(\rightarrow\) Models

- **Option 1**: geometric models (MRI, ultrasound)
  - no ready “wearable” signal sources
  + highly localized
  - more computationally intensive?

- **Option 2**: stress-strain/elasticity models (AMG, cine DENSE)
  + AMG as “wearable” signal source
  - less localized
Possible Sensing Modalities ➔ Models

• **Option 1:** geometric models (MRI, ultrasound)
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• **Option 2:** stress-strain/elasticity models (AMG, cine DENSE)
  + AMG as “wearable” signal source
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Muscle Deformation Analysis via Ultrasound
Ultrasound Data Revisited

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<th>(25°)</th>
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<th>Max Force</th>
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Key Questions

• Can we differentiate muscle deformation associated with **kinematic configuration** from deformation associated with **force output**?

• If we account for pure configuration-associated deformation, can we infer a **clean relationship between force and deformation** that can be used as a control signal?
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• Can we differentiate muscle deformation associated with *kinematic configuration* from deformation associated with *force output*?

• If we account for pure configuration-associated deformation, can we infer a *clean relationship between force and deformation* that can be used as a control signal?

To answer these questions, we need a *factorial set of muscle scans* to compare across both joint positions and loading conditions.
**Approach**

**Model target:** elbow flexors (*biceps brachii, brachialis, brachioradialis*)

**Data set:**
- 3 subjects (1 F, 2 M)
- full arm ultrasound volumetric scan
- 4 elbow flexion angles, 0–90°
- 5 loading conditions
  - fully supported
  - gravity compensation only
  - light wrist weight (~225g)
  - medium wrist weight (~725g)
  - heavy wrist weight (~950g)

*Ultrasound volumetric data collection, HART Lab 2017*
Data Collection and Processing
Data Collection and Processing: PLUS/3DSlicer
Data Collection and Processing: ITK-SNAP
Preliminary Results

FS
(“Fully Supported”)

LF
(“Low Force”)

HF
(“High Force”)

Muscle Deformation Analysis via Ultrasound
Preliminary Results

Muscle Deformation Analysis via Ultrasound
Preliminary Results

Empirical Quantification and Modeling of Muscle Deformation:
Toward Ultrasound-Driven Assistive Device Control

Laura A. Hallock, Akira Kato, and Ruzena Bajcsy

ICRA 2018
Next Steps

• Impose and validate one or more deformation models:
  – cross-sectional area (CSA) changes
  – volume changes
  – superquadric models
  – shape models
  – FEM

• Refine experimental procedures to allow clean comparison of force conditions across angles

• Speed up / automate segmentation pipeline
CONCLUSIONS
Conclusions

By examining localized deformation models of human arm muscle morphology, we seek to generate a modeling framework that surpasses existing models in predictive accuracy and detail while remaining computationally tractable and useful in a wide range of applications.

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