Extracting Information from the Electrical Activity of Human Skeletal Muscle

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Presentation Overview

- <u>Brief</u> background:
 - Muscle electrical activity (EMG)
- Engineering models, methods for extracting "EMG amplitude"
- Applications of EMGamp:
 - Prosthesis control, gait biofeedback, EMGtorque, EMG-impedance
- Surface EMG arrays (newest stuff !!)



Background

The Motor Unit



(http://academic.wsc.edu/faculty/jatodd1/351/ch6outline.html)

- Muscle fibers contract "all or nothing"
- One mechanical twitch per contraction
- Regulate force via:
 - Number of active motor units (recruitment),
 - Firing rates
- Firing intervals independent (mostly)
- Electrical "action potential" recorded



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Background

Electromyogram (EMG) Signal Model





EMG Signal Origin [Basmajian and De Luca, 1985]

"Interference pattern" EMG: Superimposition of multiple MUAPs plus measurement additive noise.



EMGamp

EMG Amplitude (EMGamp) Estimation

- EMG Amplitude (EMGamp): "Intensity" of recorded EMG
 - "Time-varying standard deviation of EMG signal"
- Original estimator: Inman et al. [1956]
 - Analog full-wave rectify and RC low pass filter



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EMGamp

Improving EMGamp Estimation

- EMGamp improved by:
 - Removal of measurement noise
 - EMG signal whitening { Increases statistical bandwidth of EMG Reduces variance of amplitude estimate.
 - Adaptive whitening
 - > To reject measurement noise
 - Multiple EMG channels (for large muscles)
 - Optimal detectors
 - Optimal smoothing (bias vs. variance error)



Single Channel, Including Noise



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EMGamp

Multiple-Channel, Including Noise



Experimental Investigations

• Separate EMGamp evaluation from EMGamp-torque, EMGamp-impedance



EMGamp

Experimental Apparatus



Clancy, *IEEE Trans Biomed Eng* **46**:711–729, 1999. Worcester Polytechnic Institute





EMG Electrode Sites



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EMGamp

Multiple-Channel Whitening



Clancy and Hogan, IEEE Trans Biomed Eng 42: 203-211, 1995.

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Prosthetics

EMGamp: Myoelectric Control of Prosthesis

- Use remnant muscle EMG to command electric hand, wrist, elbow
 - Some lower limb prosthetics research



Boston Elbow

Major current effort by U.S. military to improve prosthetic limbs

- Improved myoelectric controls
- •Embedded neural sensors •To give more control •To provide feedback

Directly connect limb to bone



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Prosthetics

Nerve Re-Innervation for Myocontrol



 Kuiken nerve reinnervation surgery

- Nerves from severed limb re-connected to pectoralis muscle regions
- Several myocontrol sites created
- Substantial improvement

RIC Arm; www.popsci.com





Myoelectric Control Example (Movie)



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Opportunities in Myocontrol

- Newer prosthetic limbs circa 2002
 - Microprocessor
 - Digital control
 - Simultaneous control of multiple motors
- Advanced EMG processing now feasible – Not feasible previously in production arms



EMGamp: Gait Biofeedback

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Re-training after stroke, traumatic brain injury.

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Gait

Biofeedback Gait Re-Training

- <u>Motivation</u>: Some patients may not properly relearn gait motor patterns
 - Incorrect timing of plantar flexor firing
- Long-Term Objective: Re-train proper gait via biofeedback ("normative" gait vs. patients)
- Short-Term Objectives:
 - Determine normative gastrocnemius firing pattern over wide speed range (including slow)

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Acquire pilot clinical data



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Gait

Healthy Raw Data: Two Walking Speeds



Clancy et al., Am J Phys Med Rehabil 83: 507–514, 2004.

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<u>Gait</u>



Healthy Gastroc EMGamp Templates



Pilot Clinical Study

- Subjects:
 - 8 adults, > 2 years post-stroke, ambulatory
- Methods:
 - Treadmill walking, comfortable speed
 - EMG monitored, target EMG pattern shown
 - 12 training sessions (weekly, ~20–40 min)
- Result of before vs. after gait analysis

 - Affected side single support (5 subjects)

 - Ankle power (7 subjects)

Aiello *et al.*, 2006. Spaulding Hospital



EMG-torque Uses

- Non-invasive torque measurement for scientific studies
- Study/evaluation of worker safety
 - Repetitive, high-force tasks can lead to cumulative trauma injuries



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EMG-torque

Simple Elbow Mechanics Model



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EMG-torque Block Diagram

- Relate biceps, triceps EMGamp to elbow torque
- Compare conventional vs. advanced EMGamp processors



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EMG-torque: Static Contraction



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EMG-torque

EMG-Torque: Constant-Posture, Force-Varying



EMG-torque: Force-Varying, Results



EMG-Torque Summary

Better EMGamp -> Better Torque

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- Future directions
 - Applications in ergonomics
 - Constant-posture tasks
 - Relax postural constraints
 - Multi-joint systems



EMG-impedance EMG-Impedance Block Diagram



Higher-quality EMG amplitude estimates should give better impedance estimation.

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EMG-impedance

Elbow Mechanical Impedance Measurement

- Subject seated, shoulder 90° abducted, elbow 90° flexed.
- Right hand immobilized in cuff (2), connected to actuated joystick (1)
- Medio-lateral pseudo-random <u>force</u> <u>perturbations</u> (3)
- Measure medio-lateral movement through joystick encoders
- Assume second order linear system:
 k, b, J



Top View



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EMG-impedance

System Validation for Mechanical Impedance

- Known inertia, stiffness
- > 0–15 Hz torque input (20 sec)
- For 0, 20 and 40 degrees
- > 2% variation in stiffness
- ➢ % VAF = 92 %

%
$$VAF = 100 * \left[1 - \frac{\sum_{k=1}^{n} (f_k - \hat{f}_k)^2}{\sum_{k=1}^{n} (\hat{f}_k)^2} \right]$$





Slide courtesy Denis Rancourt.

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EMG-impedance

Impedance Project Status

- Much characterization of mechanical apparatus performance
- Data collected from ~16 subjects



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EMG Arrays

Motor Unit Decomposition



(http://www.neuro.wustl.edu/neuromuscular/pathol/diagrams/linkedpot.htm)

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Electrodes for EMG Decomposition

Needles (traditional)

- + High spatial resolution
 - (↓ superimpositions)



– Invasive → patient discomfort; cover small region

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• Surface arrays (experimental)

- + Noninvasive
- + Larger spatial range
 - ➔ fiber conduction velocity
- Less spatial resolution
- Mostly record surface fibers





High-Resolution Surface EMG

- Spatially selective; Resolve individual MUs
 - Locate neuromuscular junction
 - Measure conduction velocity
 - Non-invasively decompose EMG
- Output = Weighted sum of mono. electrodes



Array EMG Hardware

- Common mode rejection ratio (CMRR):
 - Requires precise weights
 - Rejects power-line; permits spatial combination
- For high CMRR, weight channels in hardware
 - Separate analog circuit for each channel
 - Too many combinations possible!
- So, either:
 - Pre-wire a few montages
 - Accept lower CMRR from software combination

NOTE: Problem is an instrumentation issue.



Software-Equalized Array



EMG Arrays

Equalization CMRR Results



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Pilot Spatial Filter Technique

- Simulate each <u>monopolar</u> surface electrode
 - Many xyz tripole (AP) locations within muscle
- Select <u>desired spatial filter</u> output voltage
 - Ones for regions of interest
 - Zeroes for regions of non-interest

Similar to DSP linear filter design

Solve for optimal weights using least squares

- Monopolar potentials & output voltages known
- Filter weights unknown

• Example:

 $Data = \begin{bmatrix} e_{11}(t) & e_{21}(t) & e_{31}(t) \\ e_{12}(t) & e_{22}(t) & e_{32}(t) \\ e_{13}(t) & e_{23}(t) & e_{33}(t) \end{bmatrix}$

$$V_{Spatial}(t) = w_{11}e_{11}(t) + w_{21}e_{21}(t) + w_{21}e_{21$$

$$w_{31}e_{31}(t) + \dots + w_{11}e_{11}(t)$$

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EMG Arrays

Example Results

Filtered Surface Potentials

- Top left: Monopolar Filter
 3 dB Area = 35.22 mm²
- Top right: NDD Filter
 3 dB Area = 22.24 mm²
- Bottom Left: LS Filter
 3 dB Area = 8.95 mm²

Second selectivity metric

- Bottom right: Case of two APs, LS and NDD Filters
 - Y-offset = 2 mm
 - LS Ratio = 0.121
 - NDD Ratio = 0.779



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EMG Arrays

Conclusions of Pilot Work

- Preliminary simulation results:
 - Least squares filters have superior spatial selectivity than NDD, monopolar configurations
 - Only simple simulation results so far!!
- Selectivity of LS filters dependent on:
 - Inter-electrode spacing, action potential depth, number of electrodes

Next steps:

- More realistic electrophysiologic models
- Incorporate measurement noise
- More mature optimization
- Test with physiologic data



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"EMGIab" on the Web

A forum for sharing software, data, and information related to EMG decomposition

EMGLAB

EMGLAB

http://emglab.stanford.edu/

Kevin McGill, VA Palo Alto & Stanford

A forum for sharing software, data, and information related to EMG decomposition.

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- Open-source software for EMG decomposition/ viewing
- EMG signal data base
- Data and annotation standards development



EMG decomposition provides information about the coordinated activity of the motoneuron pool and the architectural organization of the muscle. This information is of interest in muscle physiology, motor control, kinesiology, and clinical neurophysiology.

Software

Signals

Publications

The goals of this project are to promote

Home

- * decomposition as a research tool
- * exchange and discussion of EMG data
- * attention to accuracy and precision
- * algorithm innovation

Projects	Software	Publications	Tutorials
* Standards for data files	EMGLAB: an open-source matlab program for viewing and decomposing EMG signals. (download)	EMGLAB: An interactive EMG decomposition program. J Neurosci Meth, 2005. (view)	Please Contribute
* EMG signal database			Discussion
* Assessing accuracy			
* EMG analysis software			FAQ



Research Collaborators



... with several photos missing. ... and, hopefully, many more to add in the years to come!!

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