Estimation of Joint Torque and Impedance by Means of Surface EMG

Edward (Ted) A. Clancy

Department of Electrical and Computer Engineering
Department of Biomedical Engineering
Worcester Polytechnic Institute, USA

Denis Rancourt

Department of Mechanical Engineering
Sherbrooke University, Canada

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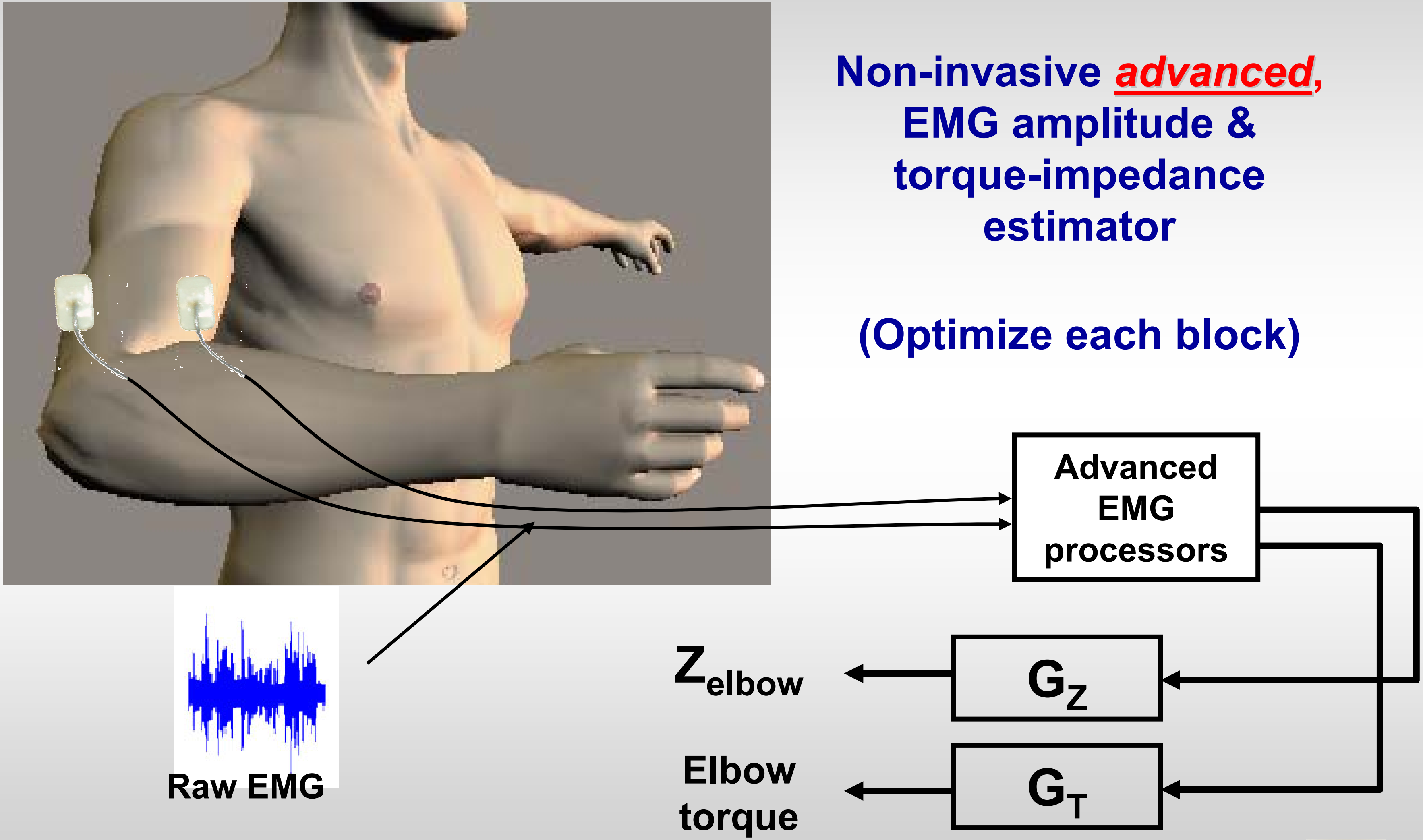
Research Aims

Non-invasive *advanced*, EMG amplitude & torque-impedance estimator

(Optimize each block)

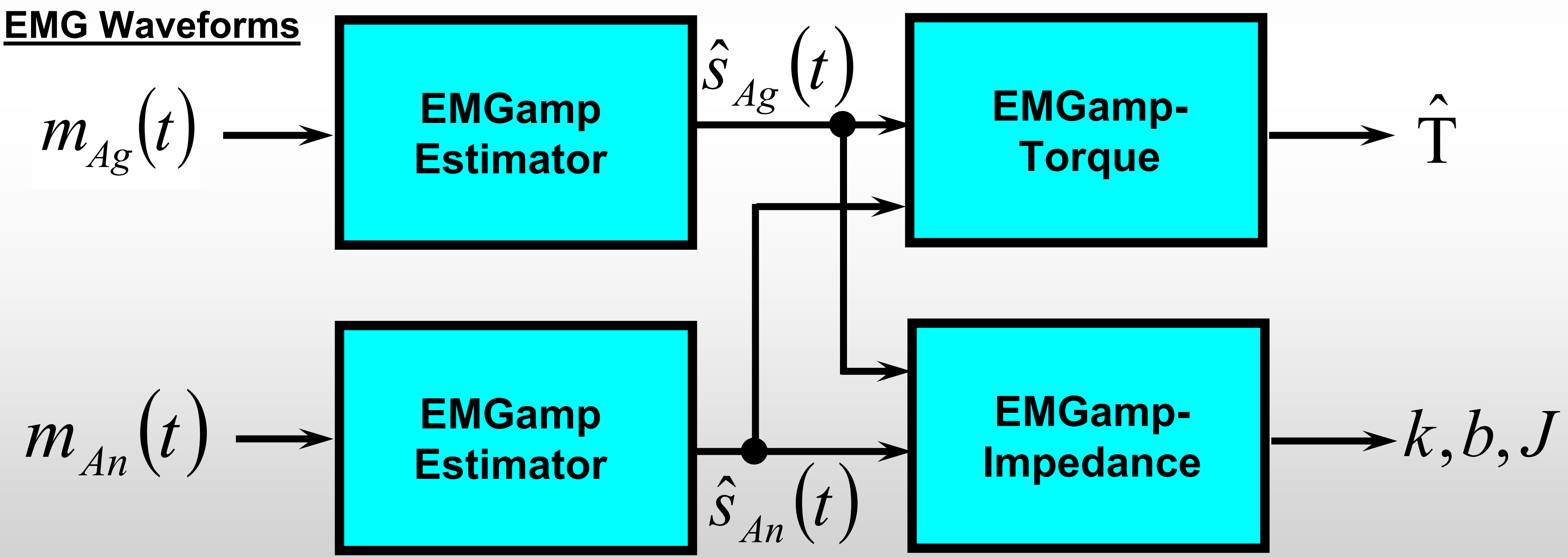


Research Applications

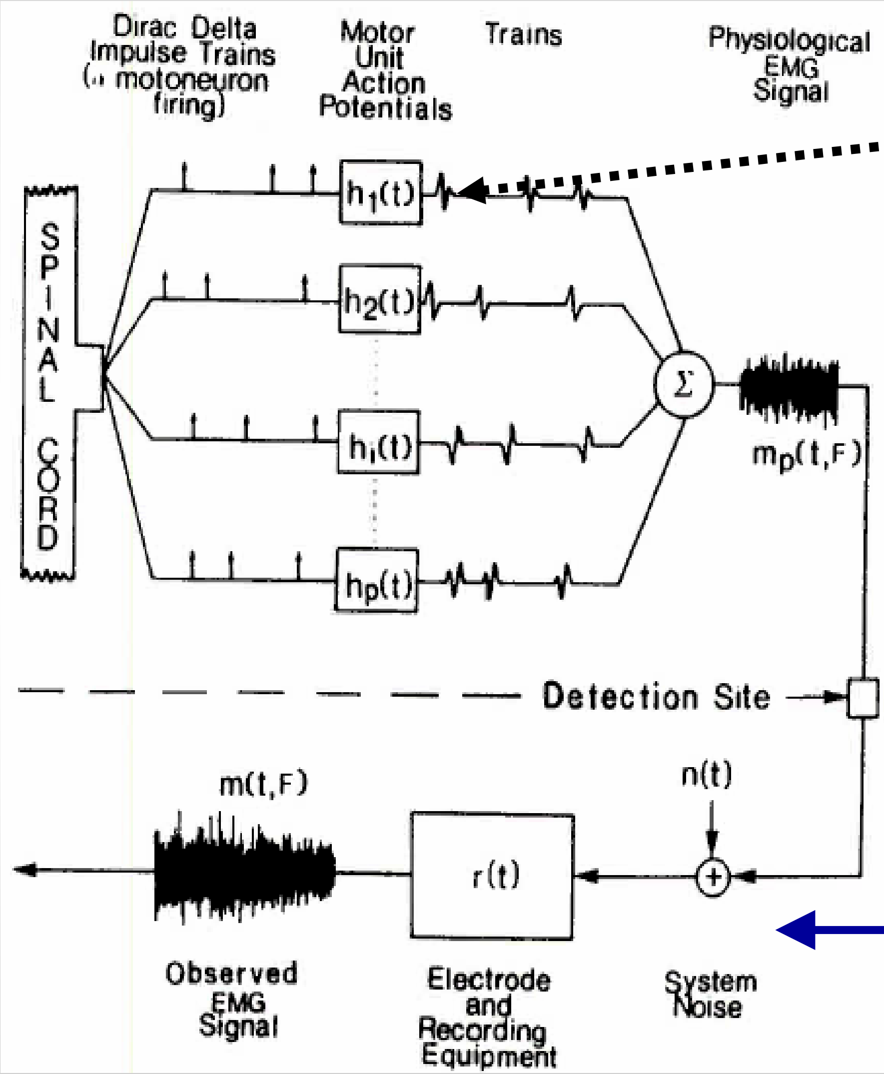
- Myoelectric control of prosthesis
- EMG biofeedback for rehabilitation
- Ergonomic analysis / task analysis
- Biomechanical modeling
- Measurement in motion control studies

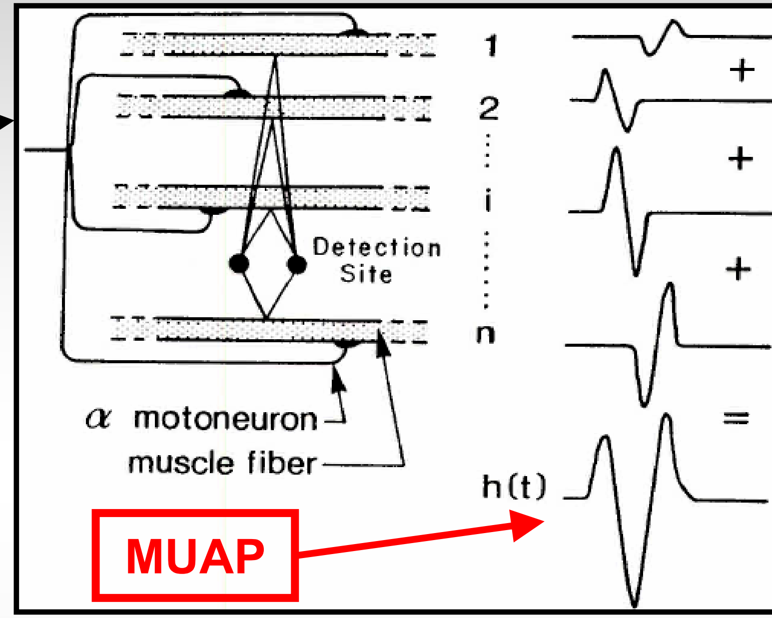
Presentation Overview

1. **EMG amplitude (EMGamp) estimation:** $\hat{s}(t)$
2. **EMG-torque estimation:** $\hat{\mathrm{T}}$
3. **EMG-impedance estimation:** k, b, J
   – Preliminary research



Electromyogram (EMG) Signal Model





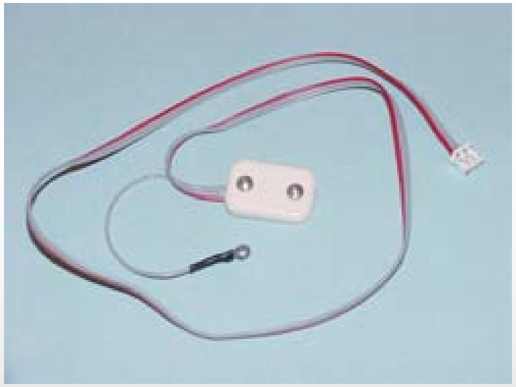
EMG Signal Origin [Basmajian and De Luca, 1985]

"Interference pattern" EMG:

Superimposition of multiple MUAPs plus measurement additive noise.

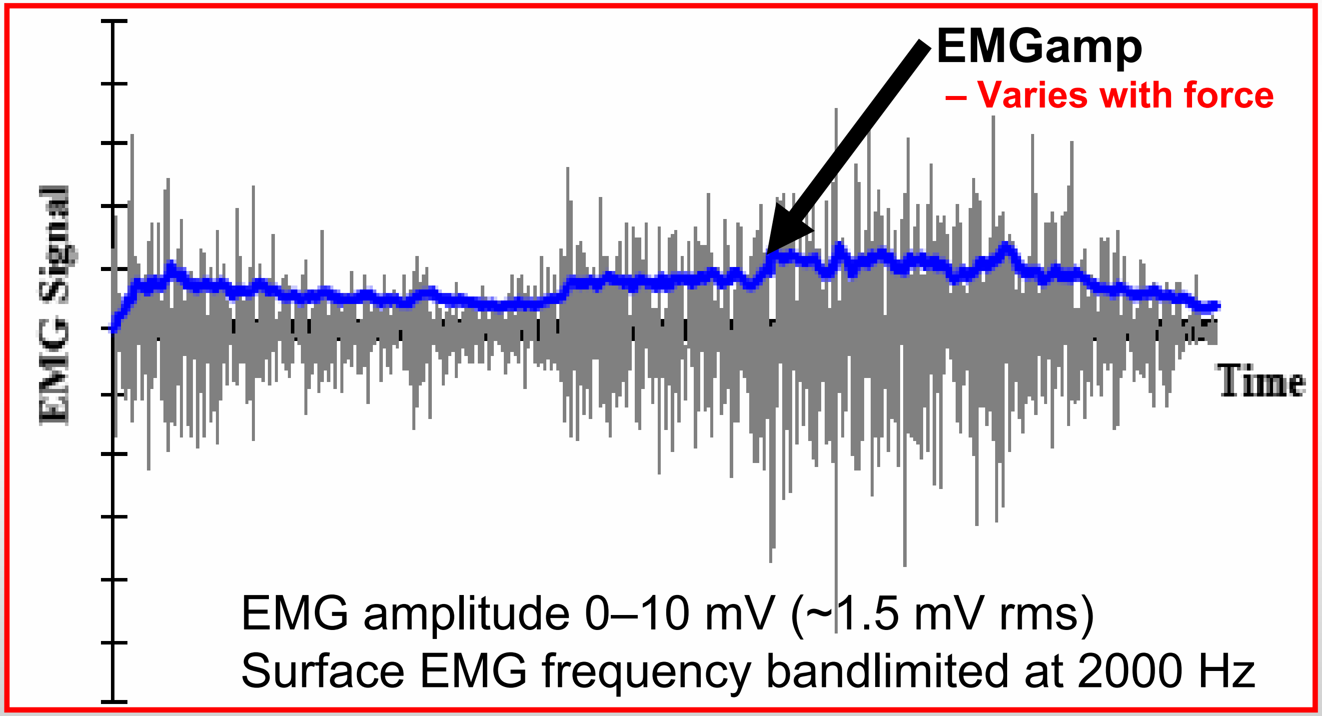
EMG Amplitude (EMGamp) Estimation

- **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**



Electrode-Amplifier

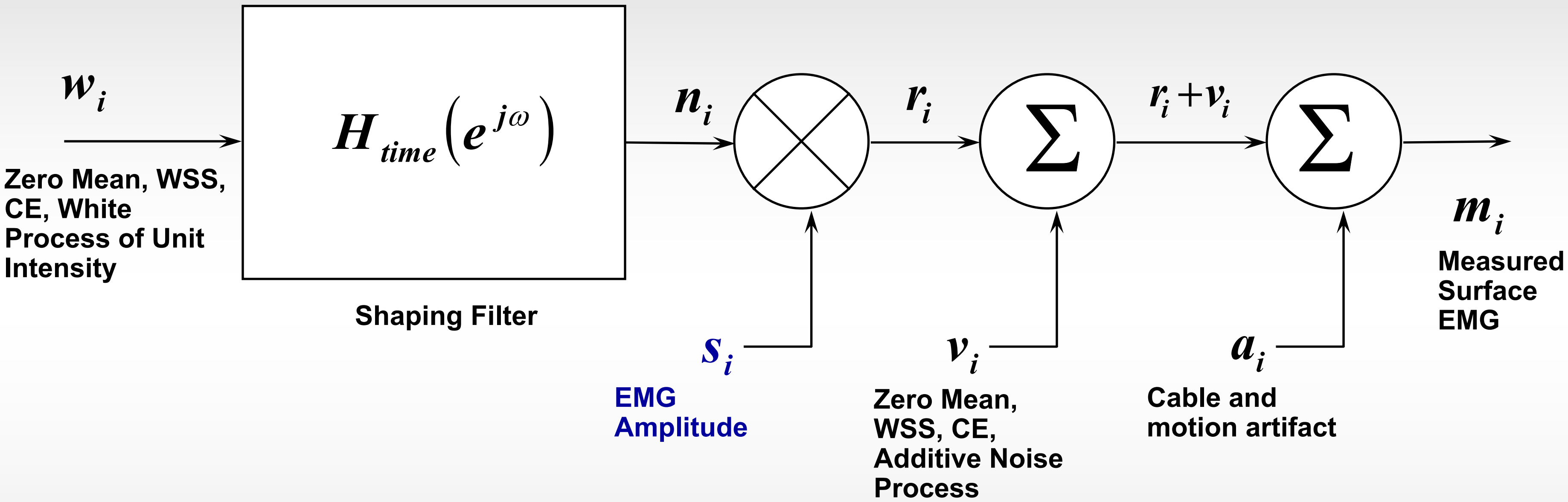
(From Liberating Technologies)



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

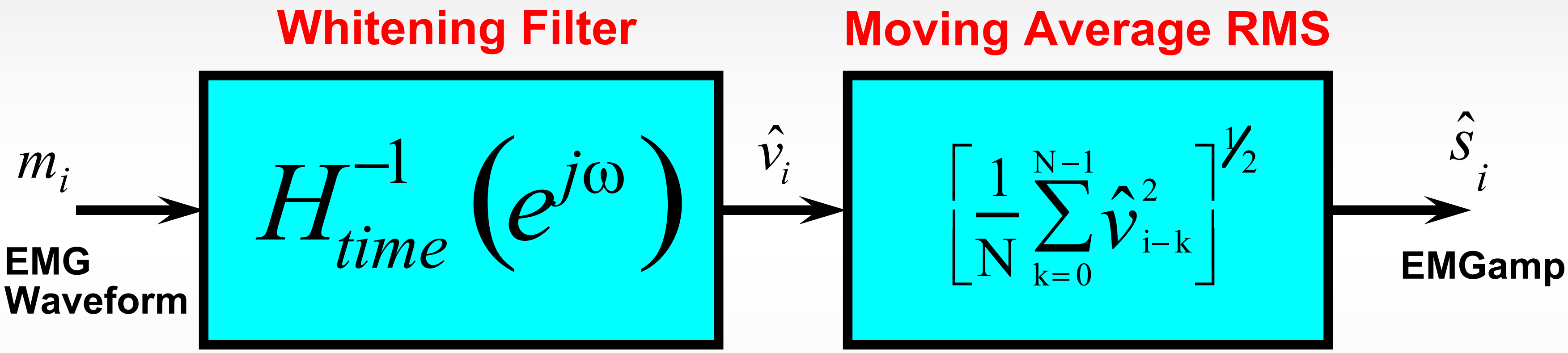


EMGamp ≡ standard deviation of m_i

Phenomenological Model

Prakash *et al.*, *IEEE Trans Biomed Eng* **52**: 331–334, 2005.

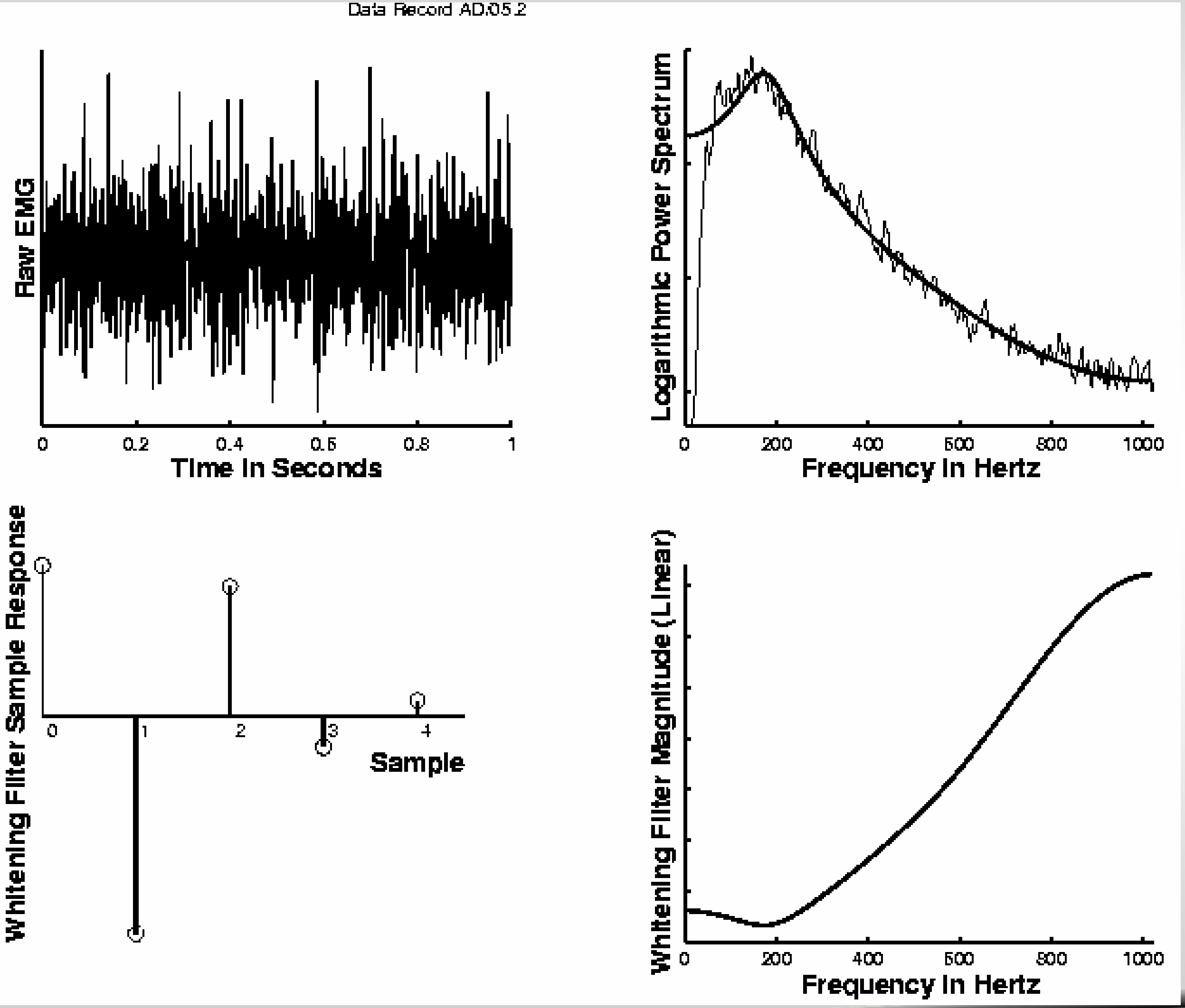
Optimal EMG Processor — Single Site



Note: Does not account for noise/interference.

Clancy and Hogan, *IEEE Trans Biomed Eng* **41**: 159–167, 1994.

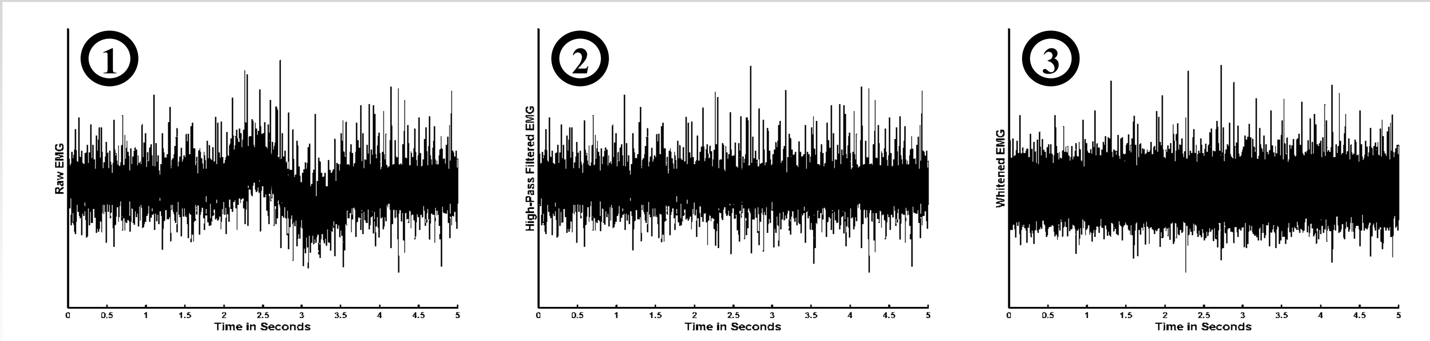
Whitening Example

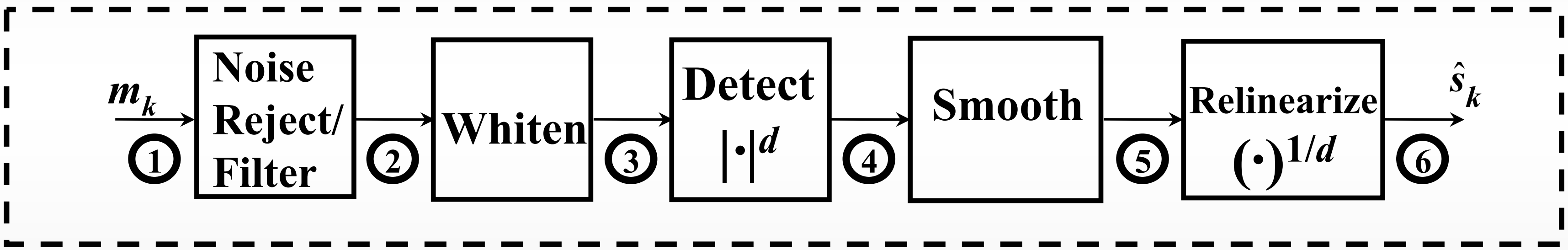


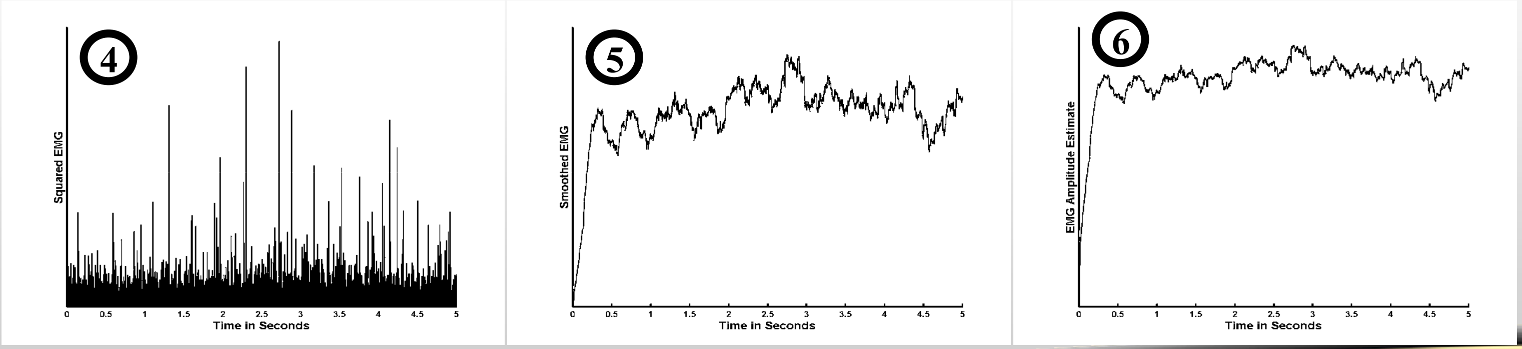
EAC07–139

Clancy and Hogan, *IEEE Trans Biomed Eng* **41**: 159–167, 1994.

Single-Channel EMGamp Processor







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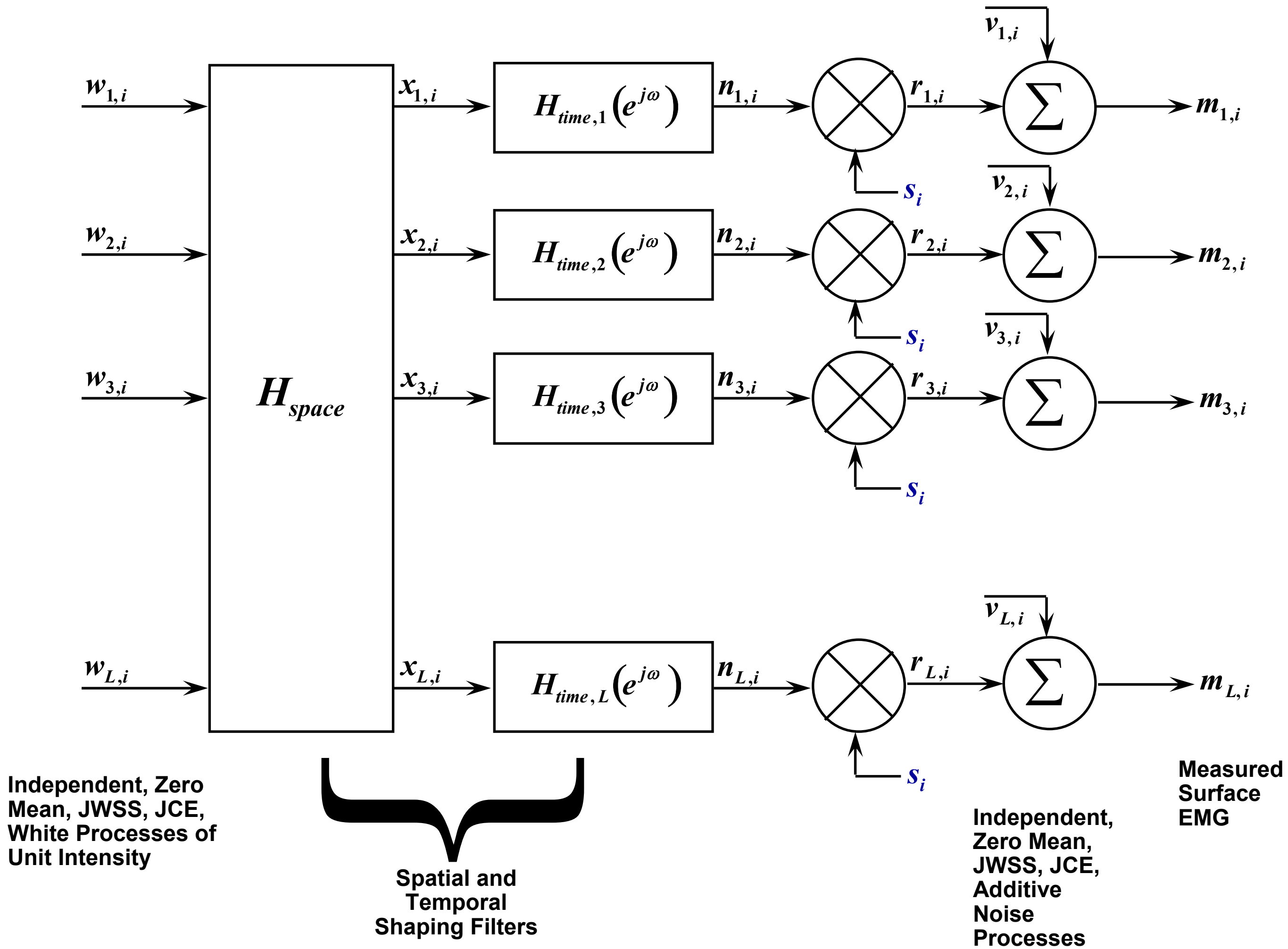
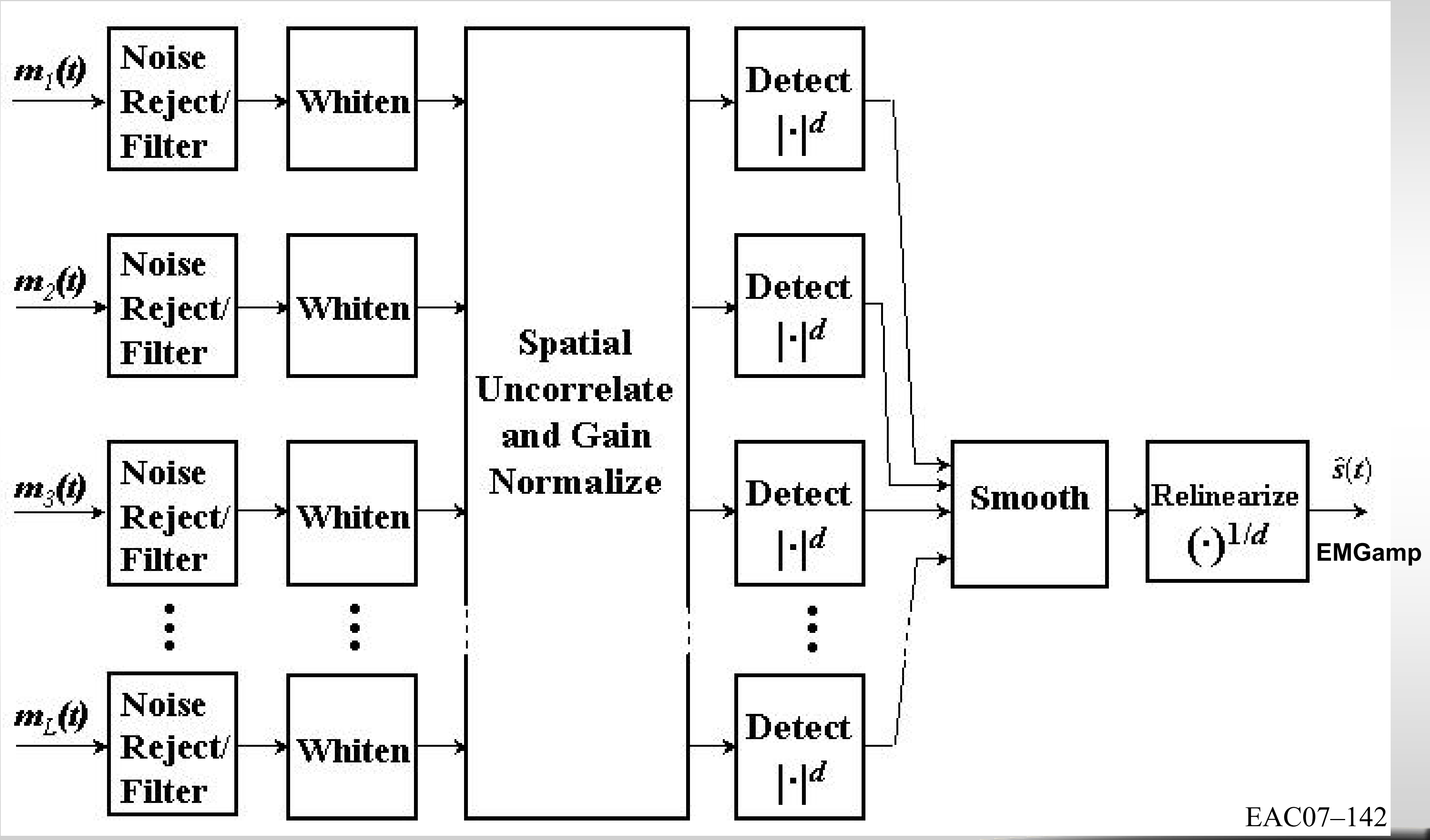
Multiple-Channel, Including Noise



Phenomenological Model

Clancy Ph.D., 1991.

Six-Stage EMG Amplitude Estimator

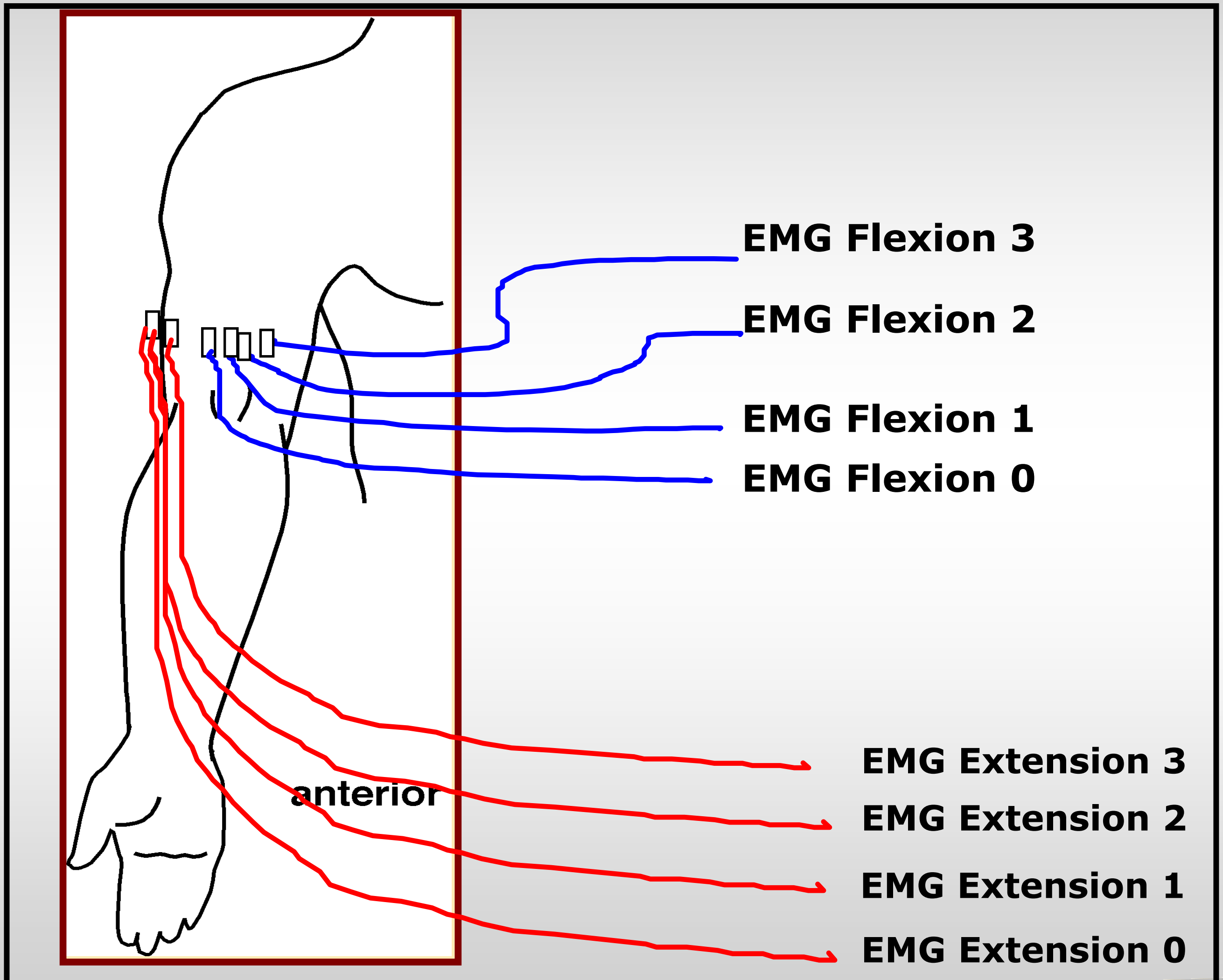


Clancy *et al.*, *J Electromyo Kinesiol* **12**:1–16, 2002.

Experimental Apparatus

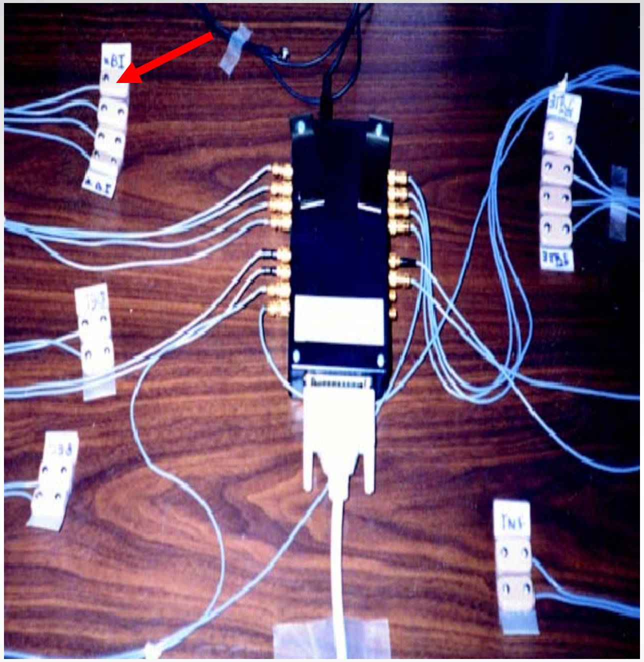
Clancy, *IEEE Trans Biomed Eng* **46**:711–729, 1999.

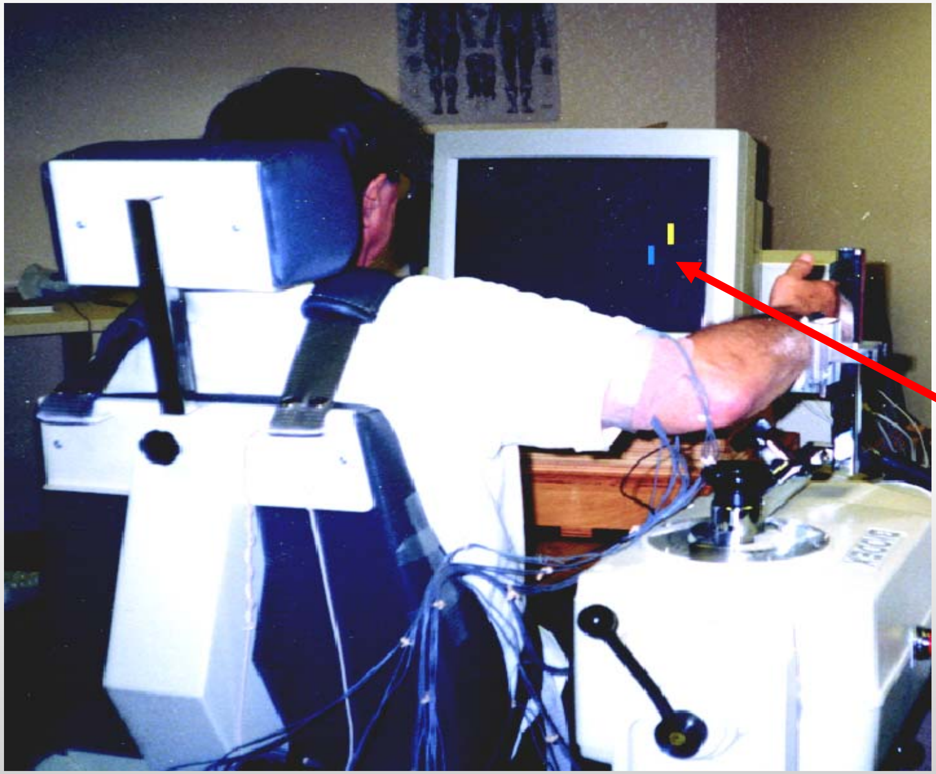
EMG Electrode Sites



Experiment Brief Description

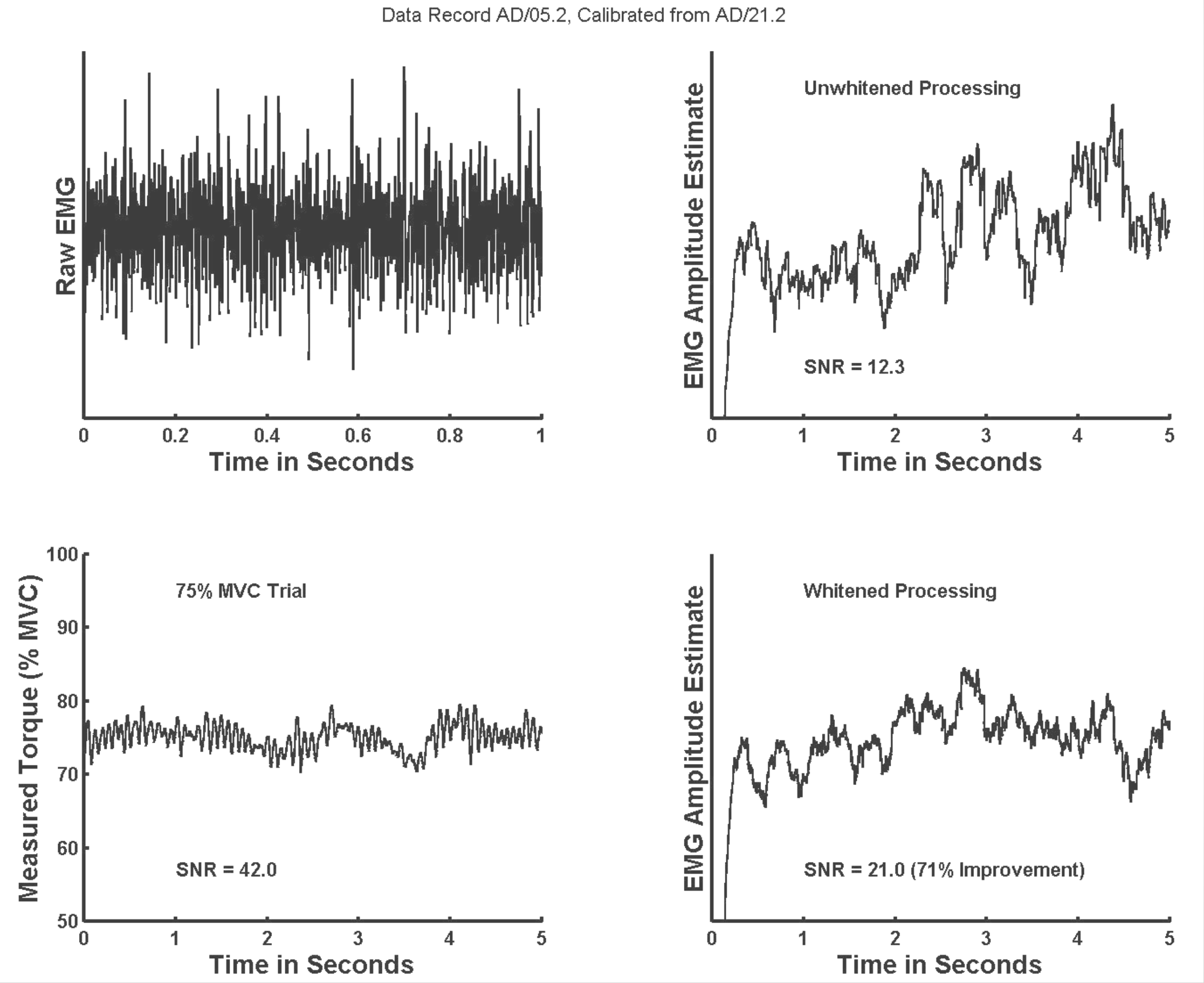
- Subjects seated in exercise machine
- Active bipolar electrode-amplifiers applied to both biceps and triceps





Subjects performed various static or dynamic contractions, tracking a target.

Single-Channel Whitening

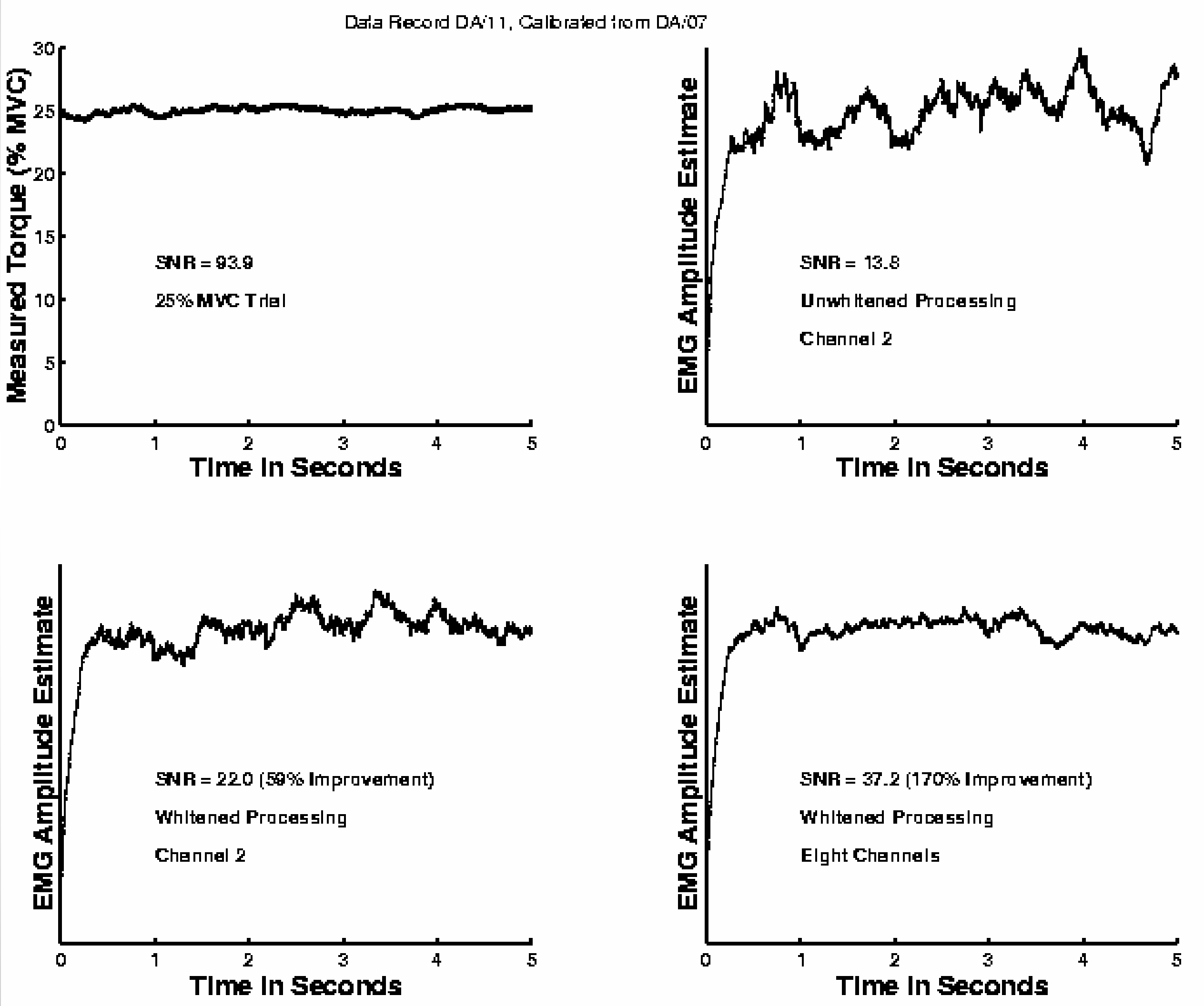


- **Constant-posture, constant-force contraction**

$$SNR \equiv \frac{\mu_{\hat{s}}}{\sigma_{\hat{s}}}$$

Clancy and Hogan, *IEEE Trans Biomed Eng* **41**: 159–167, 1994.

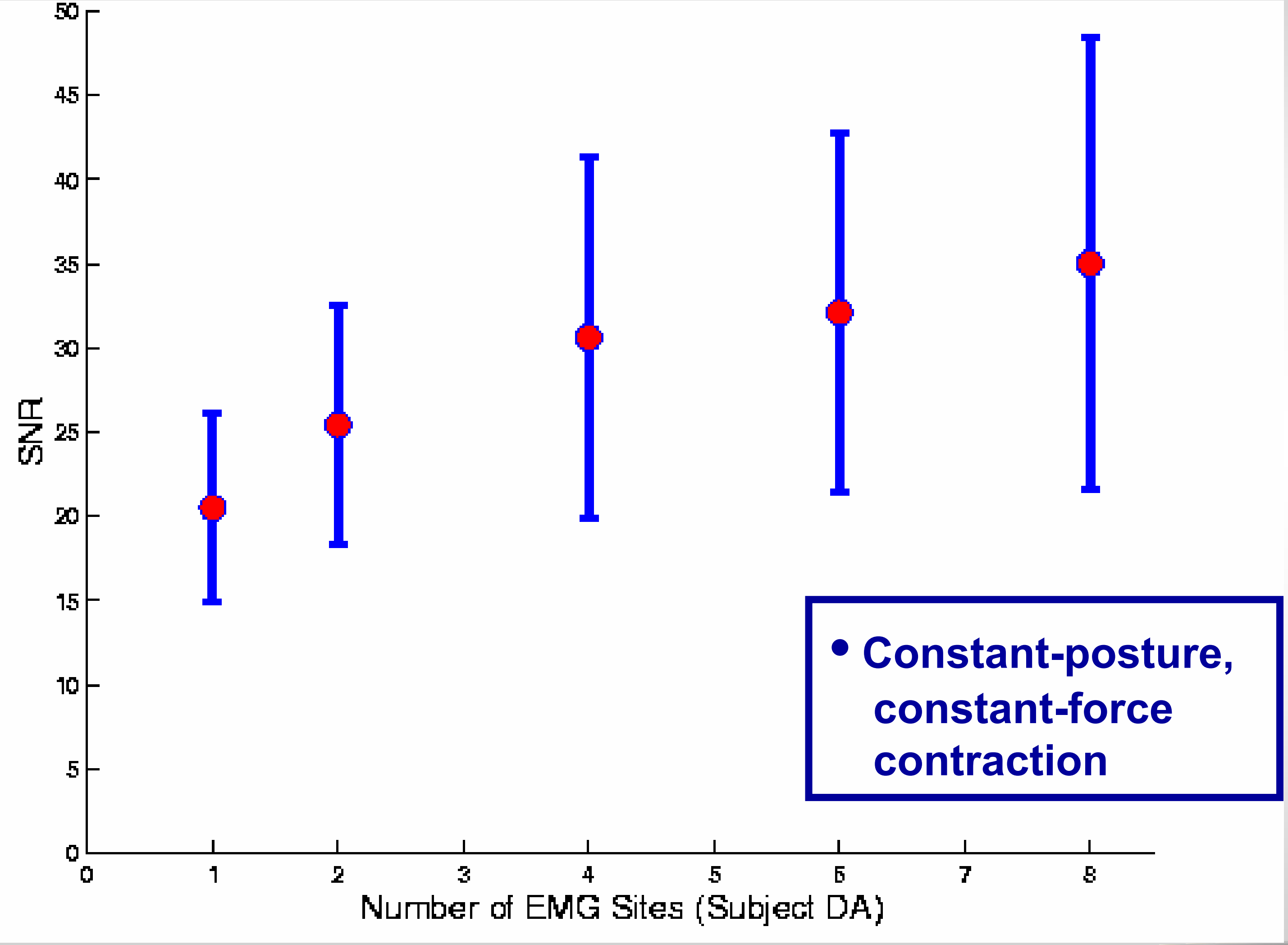
Multiple-Channel Whitening



- **Constant-posture, constant-force contraction**

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

Multiple-Channel Whitening — Average Results

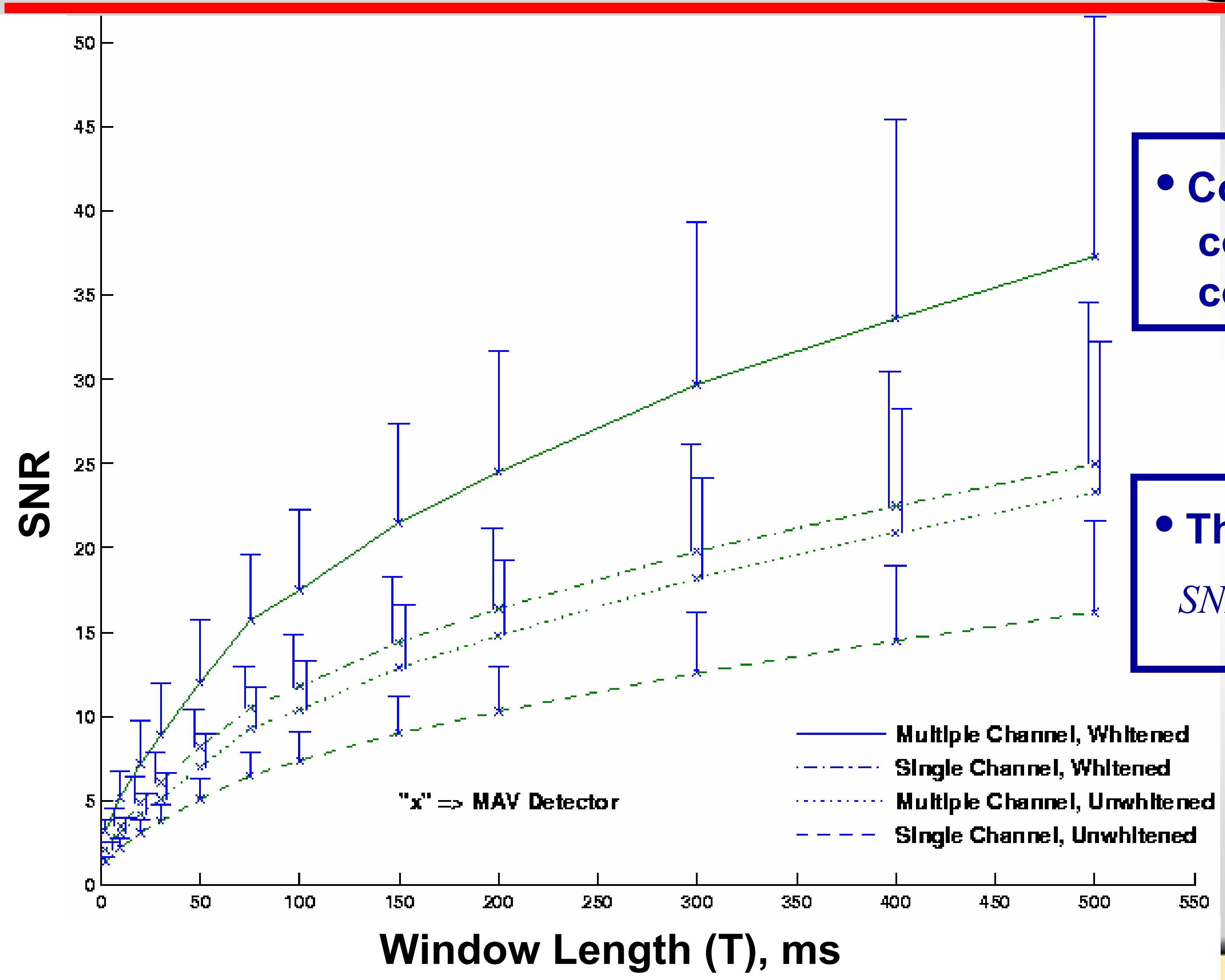


- Constant-posture, constant-force contraction

EAC07–148

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

SNR vs. Window Length



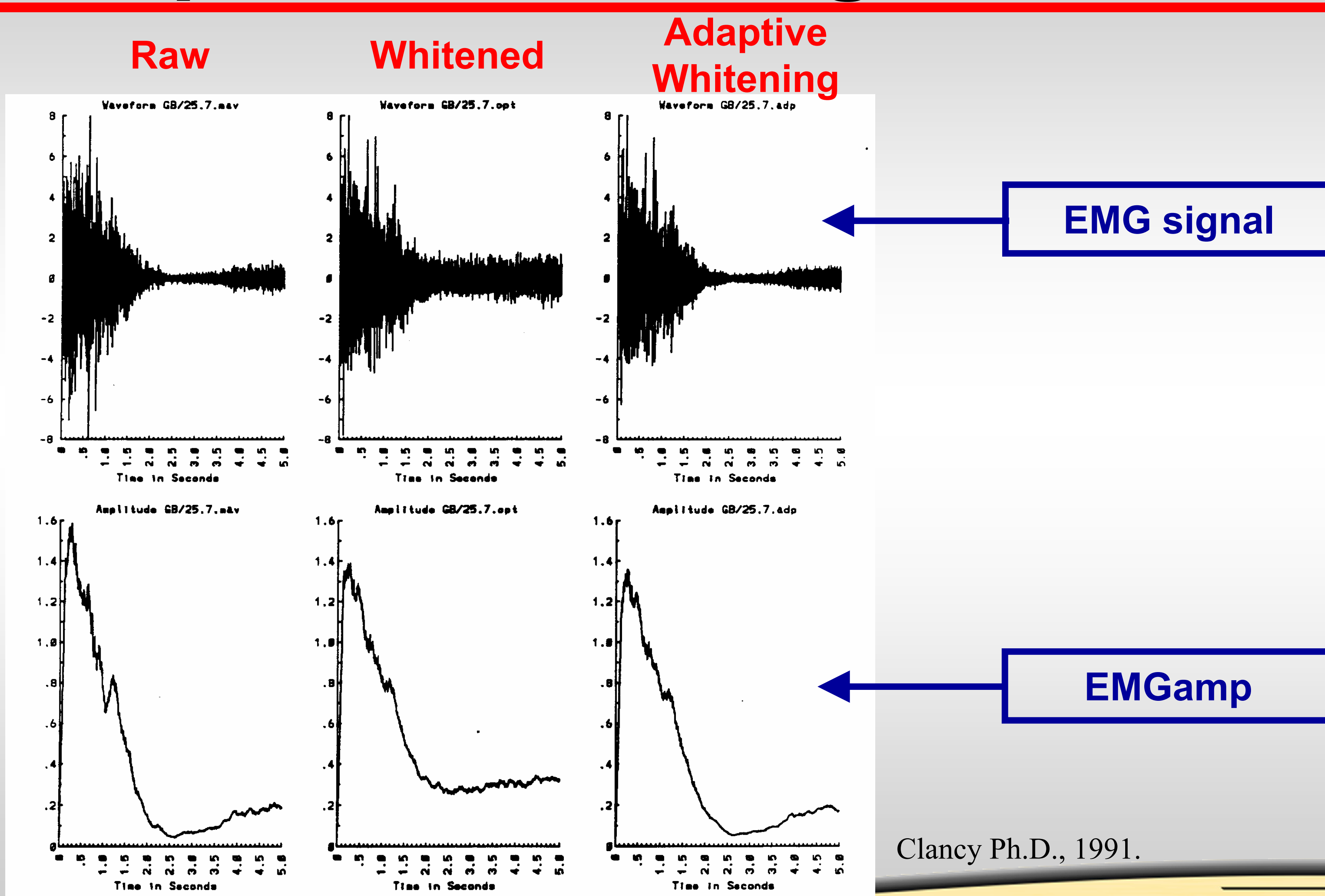
- **Constant-posture, constant-force contraction**

- **Theory:**

$$SNR = \sqrt{2 \bullet 2B_s \bullet L \bullet T}$$

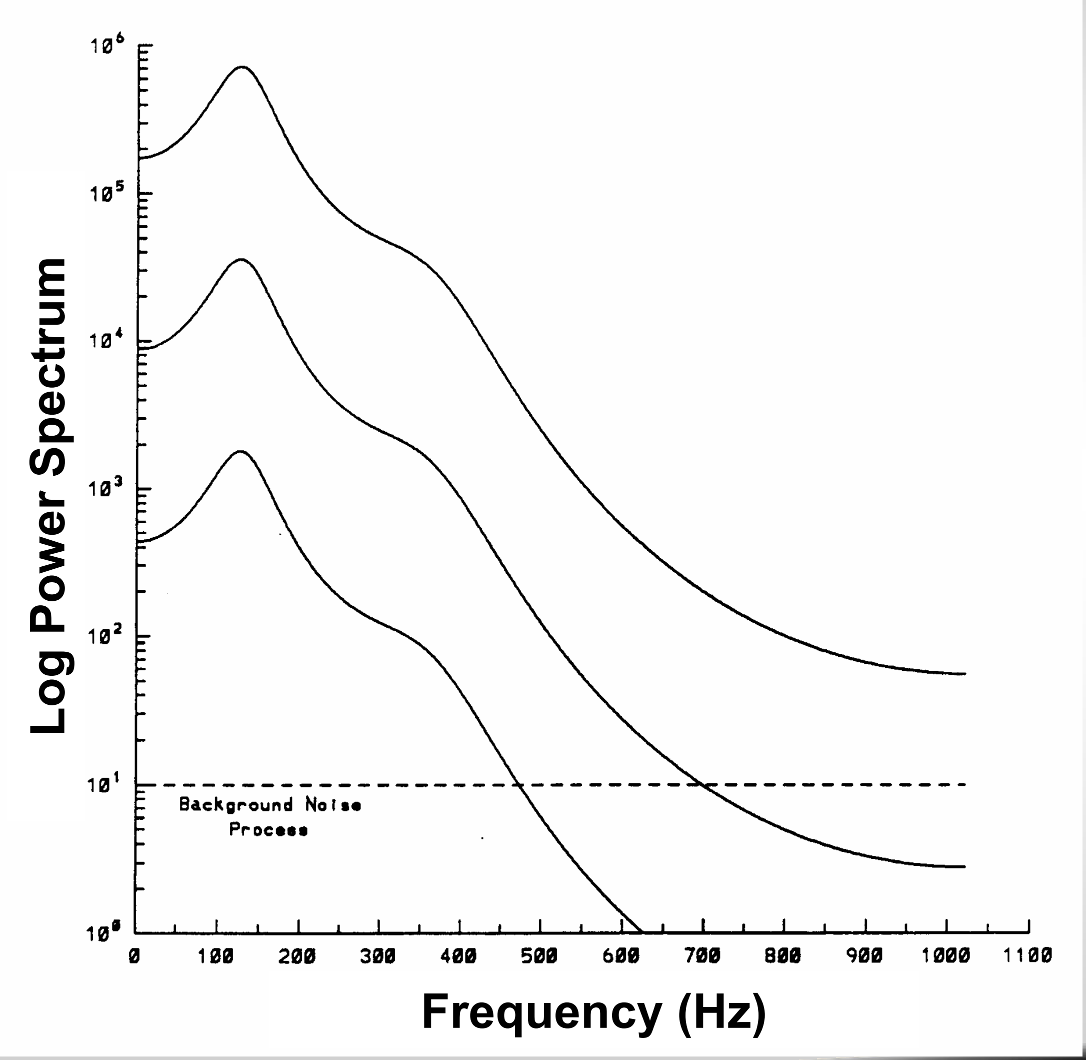
St-Amant *et al.*, *IEEE Trans Biomed Eng* **45**: 795–799, 1998.

Adaptive Whitening Problem



Clancy Ph.D., 1991.

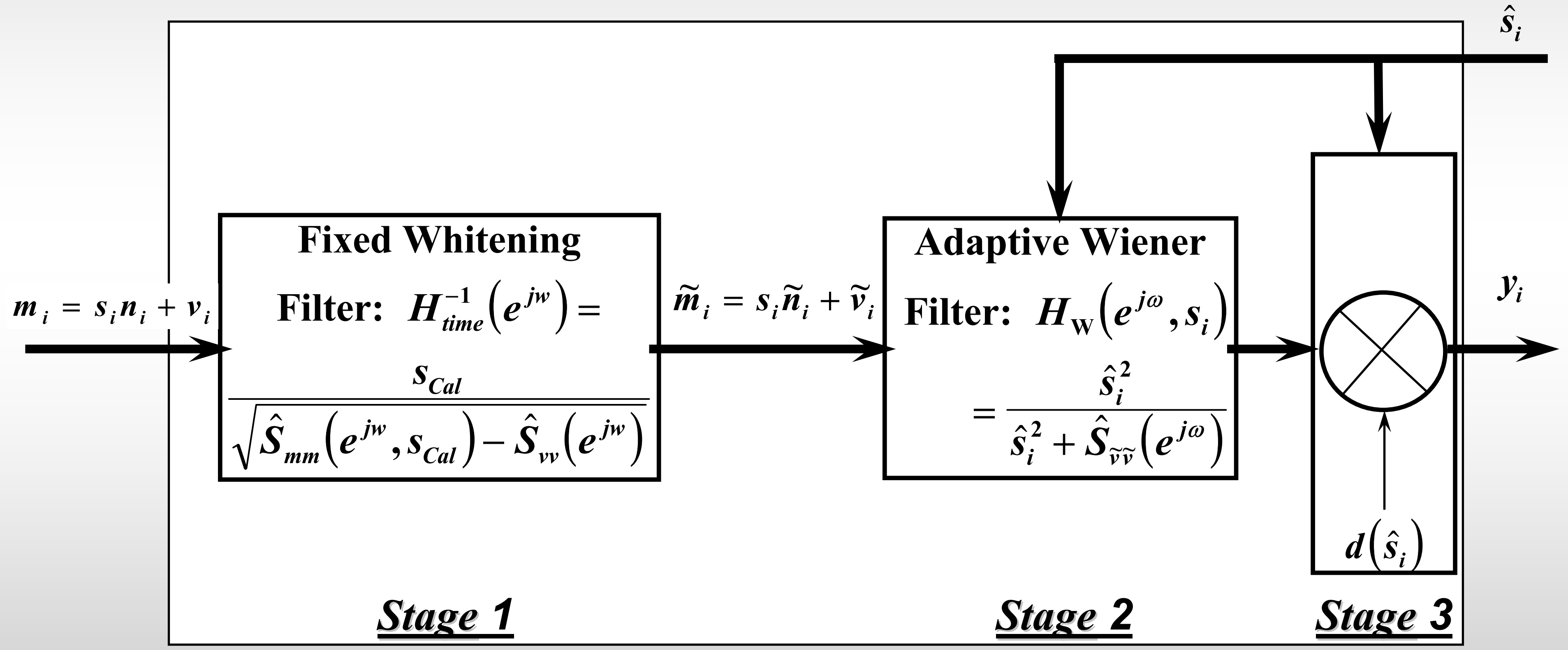
Power Spectrum of Amplitude-Modulated EMG



Clancy Ph.D., 1991.

Adaptive Whitening Solution

Adaptive Whitening Filter : $H_A(e^{j\omega}, s_i) = H_{time}^{-1}(e^{j\omega}) \cdot H_W(e^{j\omega}, s_i) \cdot d(s_i)$



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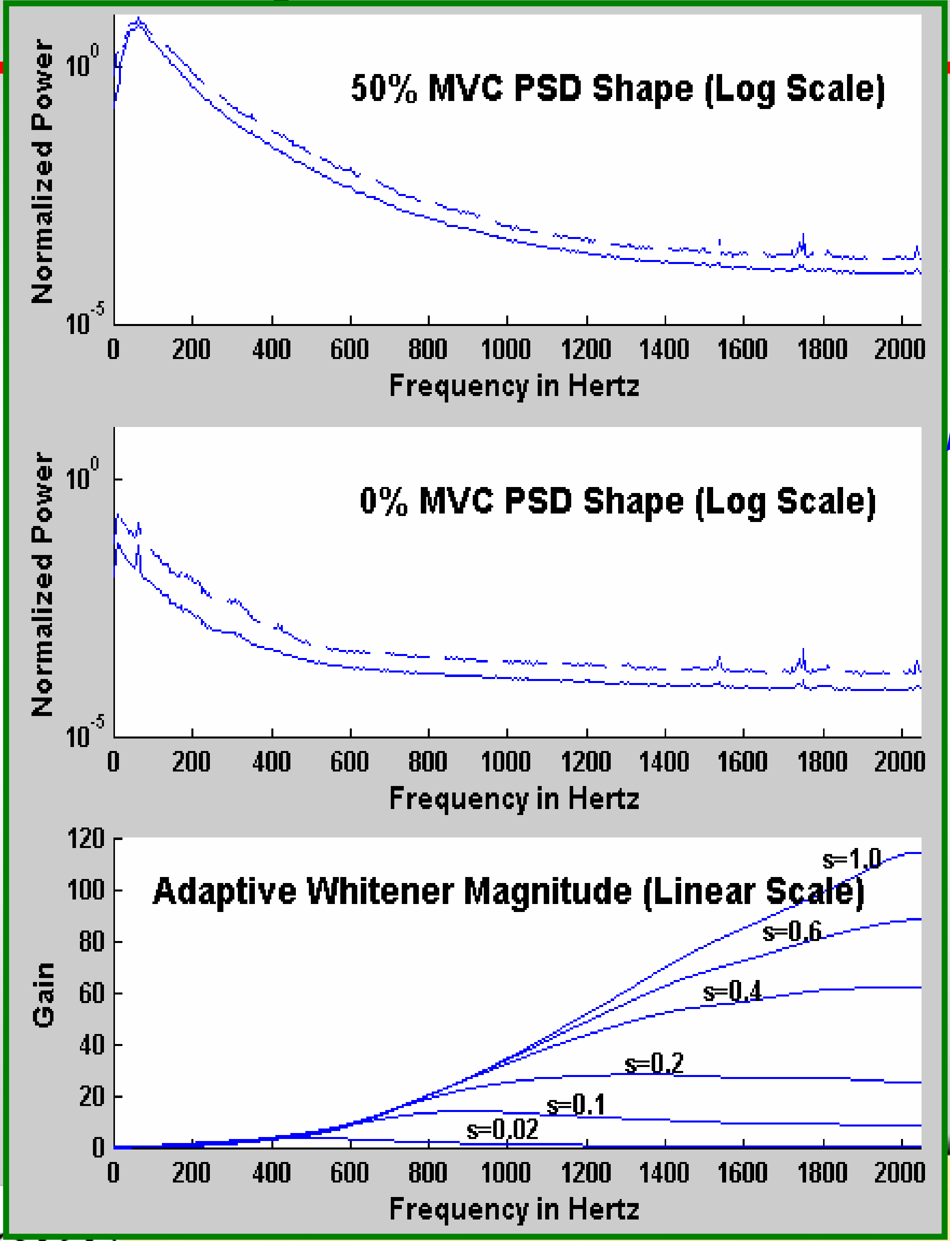
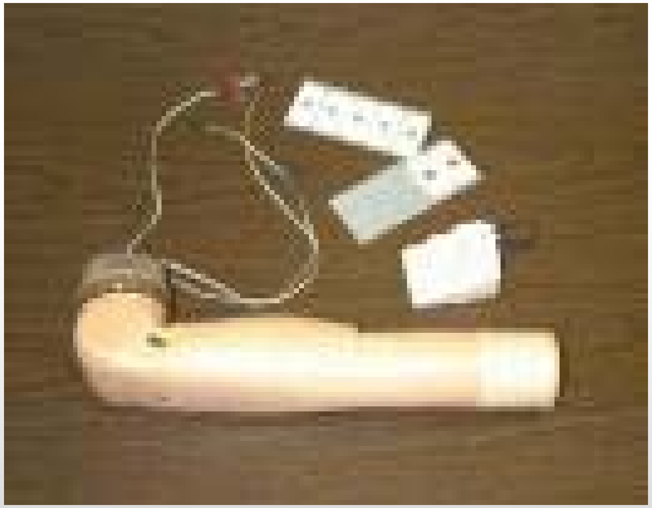
Sample Adaptive Whitening Filters



Mean value (solid line) plus one standard deviation (dash line)

EMGamp: Myoelectric Control of Prosthesis

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



Boston Elbow

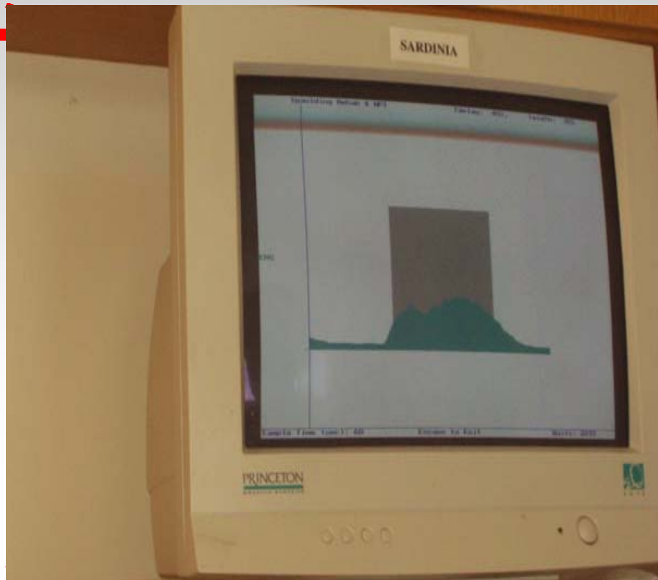
Major current effort by U.S. military to improve prosthetic limbs

- Improved myoelectric controls
- Embedded neural/myo sensors
  - To give more control
  - To provide feedback
- Directly connect limb to bone

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



Re-training after stroke, traumatic brain injury.

With Paolo Bonato, Spaulding Rehabilitation Hospital, Boston

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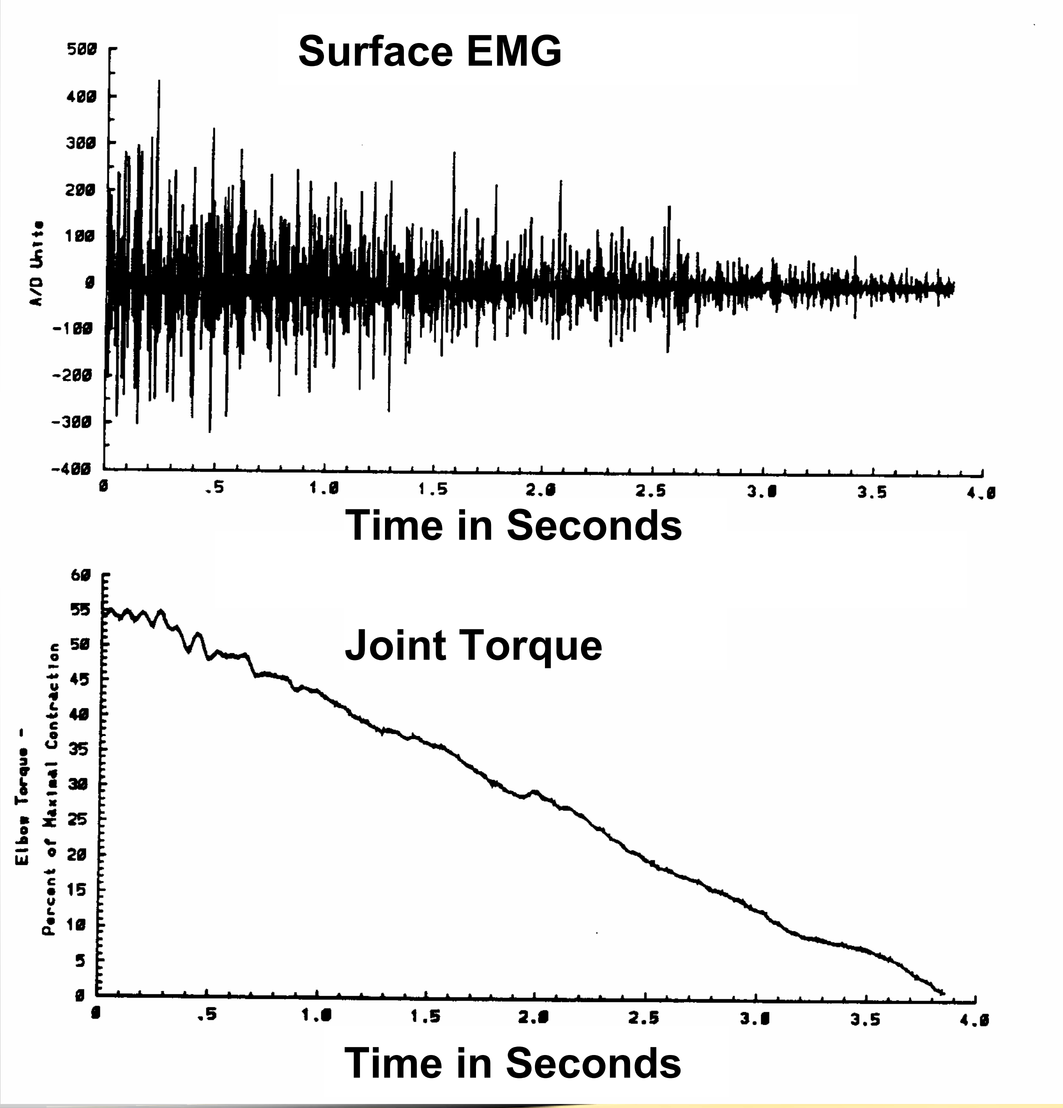
EMGamp: EMG-Torque Uses

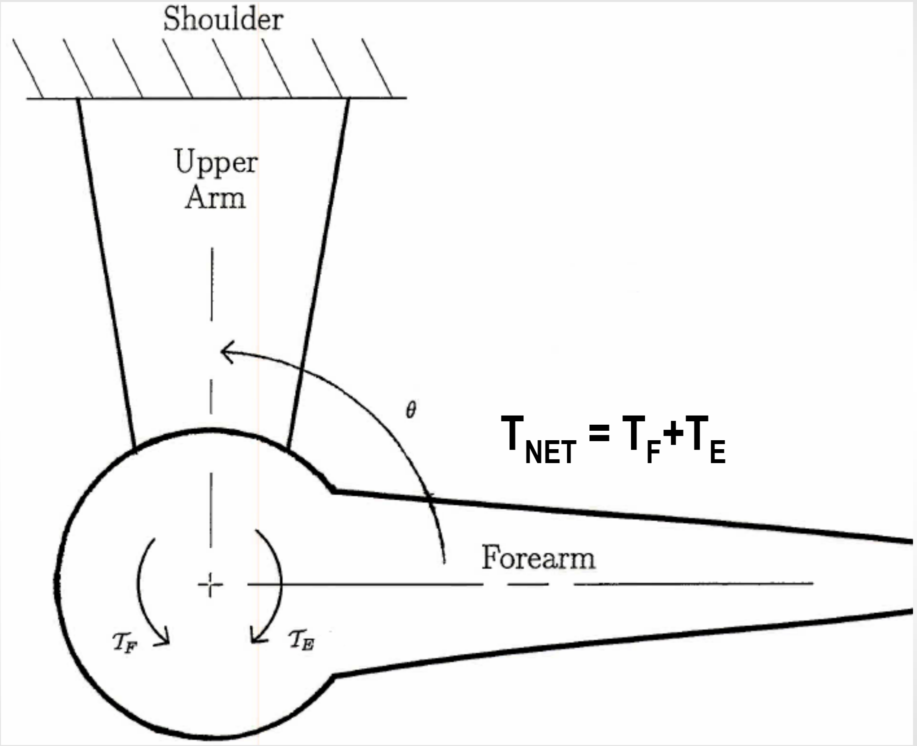
- Non-invasive torque measurement for scientific studies
- Study/evaluation of worker safety
  - Repetitive, high-force tasks can lead to cumulative trauma injuries

Surface EMG Signal and Joint Torque



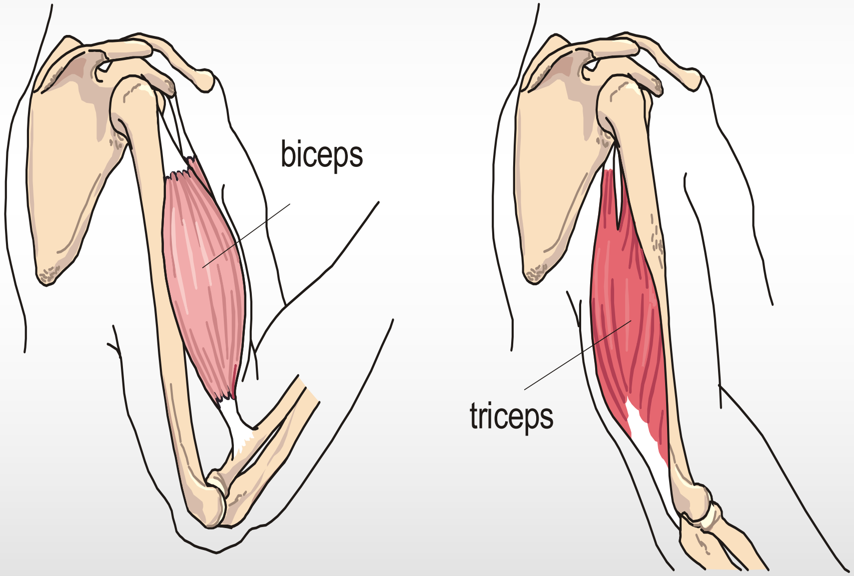
Clancy Ph.D., 1991.

Simple Elbow Mechanics Model



$$T_{NET} = T_F + T_E$$

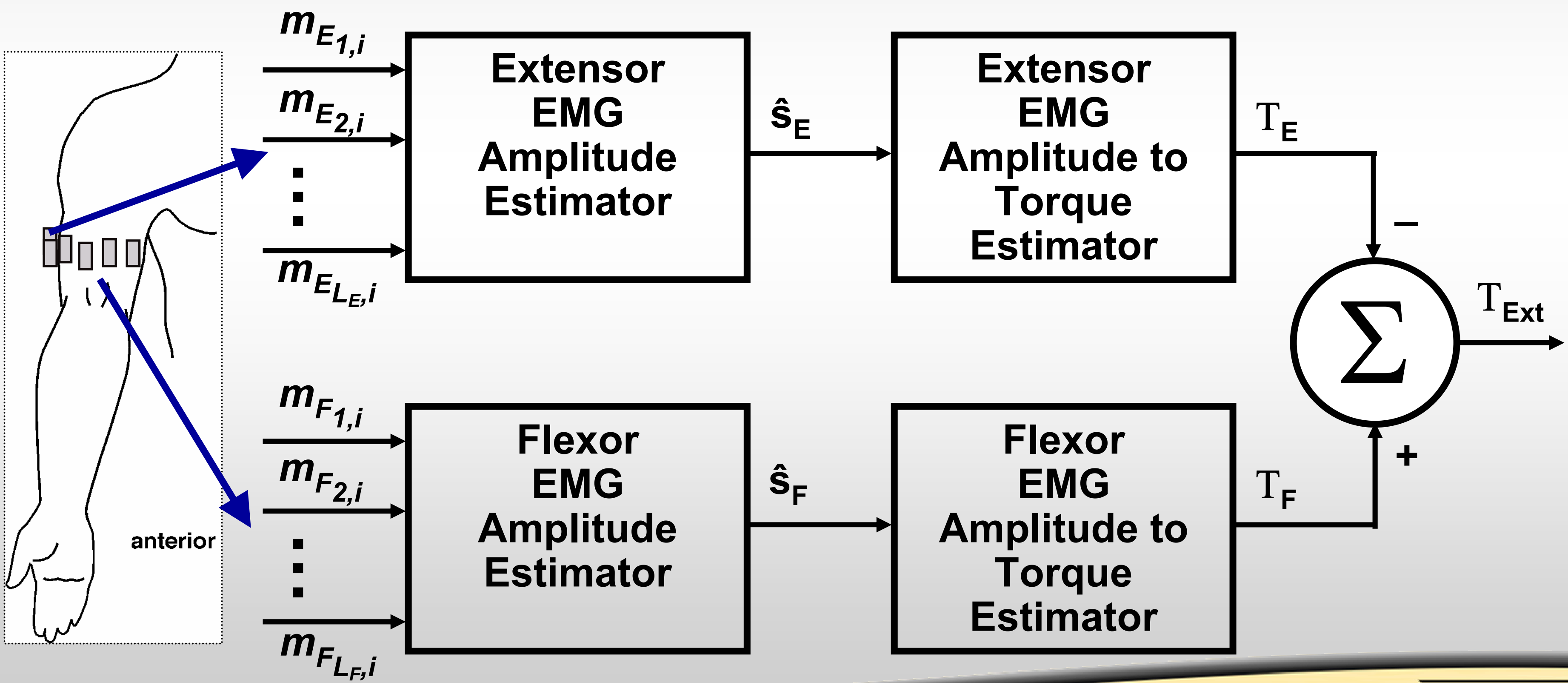
Clancy Ph.D., 1991



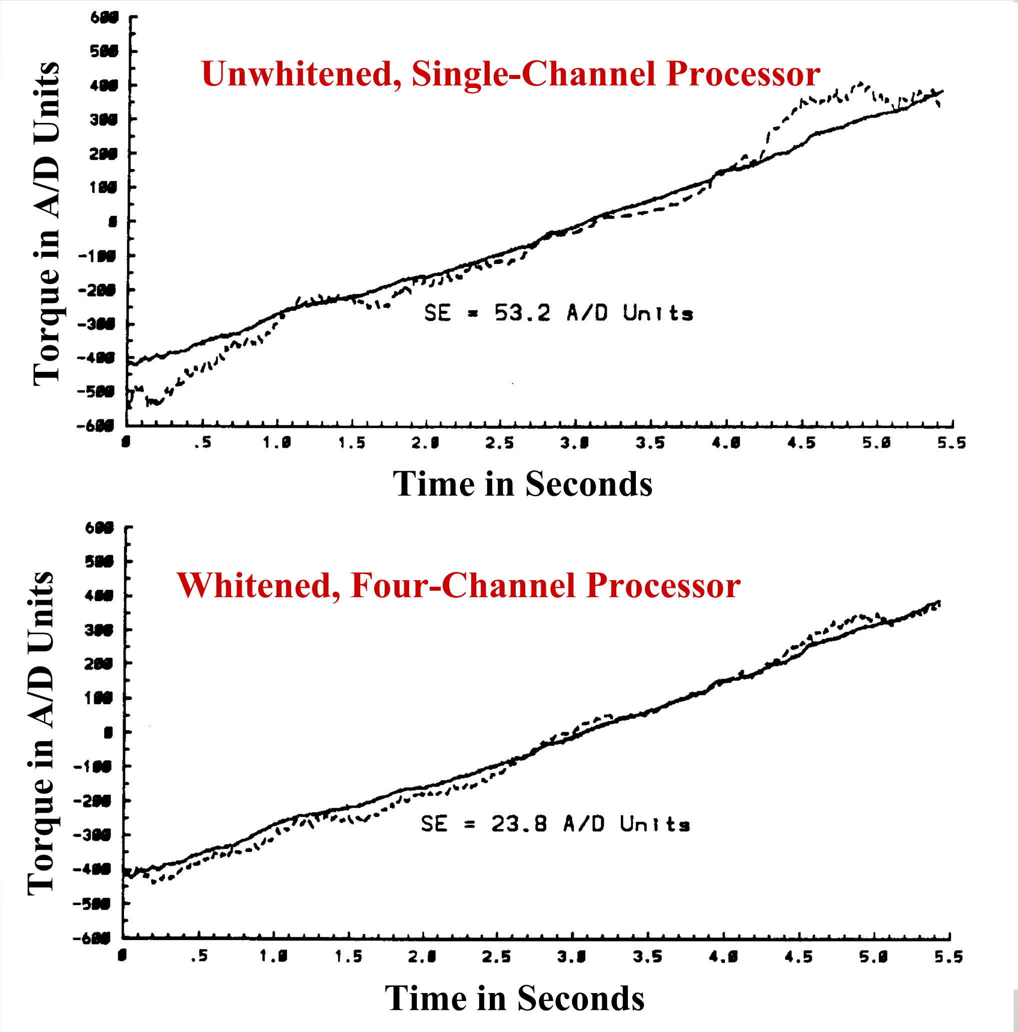
(www.mrothery.co.uk)

EMG-Torque Block Diagram

- ***Optimally*** **relate biceps, triceps EMGamp to elbow torque**
  - **Calibrate for each subject**
- **Compare conventional vs. advanced EMGamp processors**



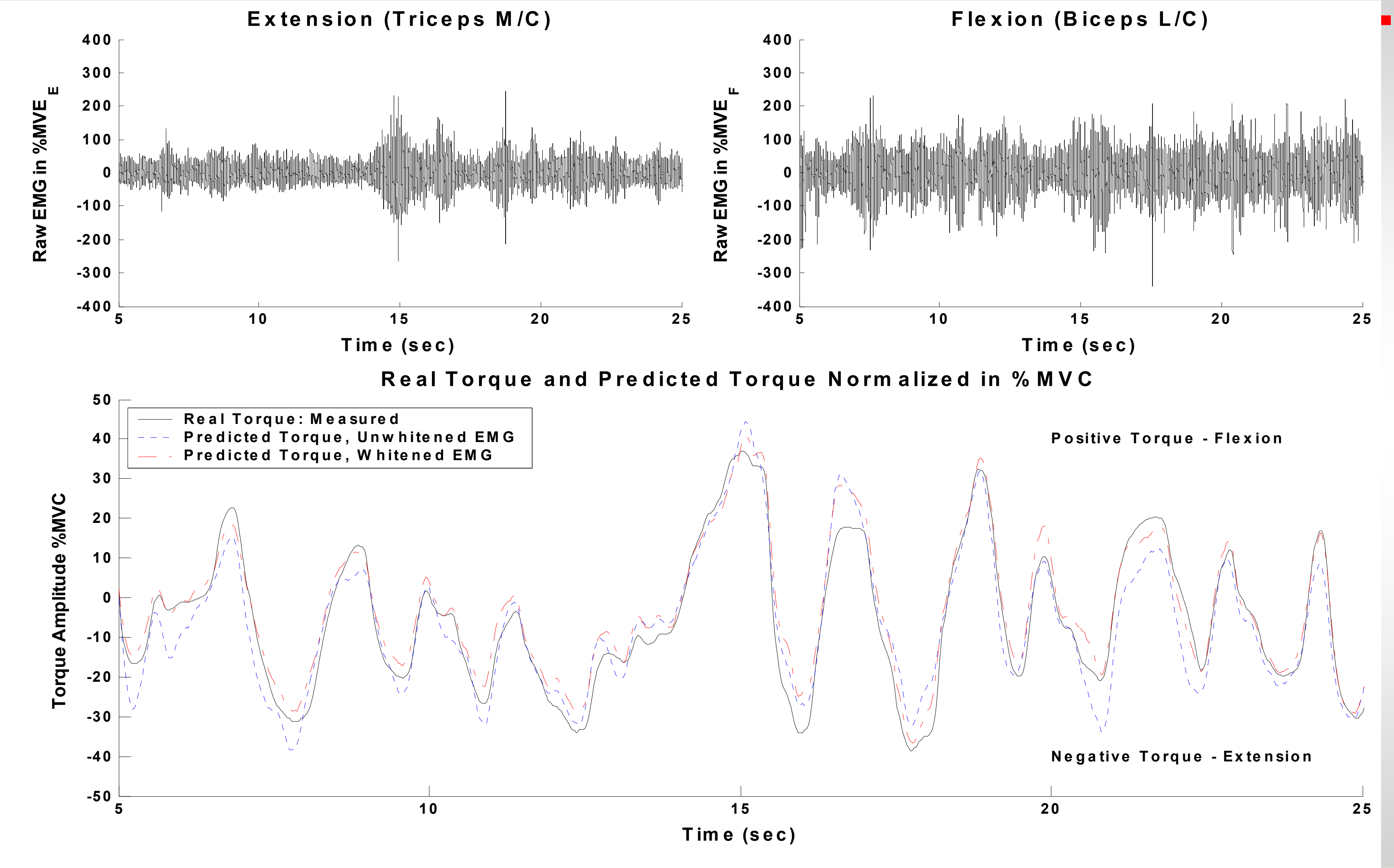
EMGamp-Torque: Quasi-Static Contraction



- Slowly force-varying
  ➔ No dynamics
- Constant Posture
- Polynomial model

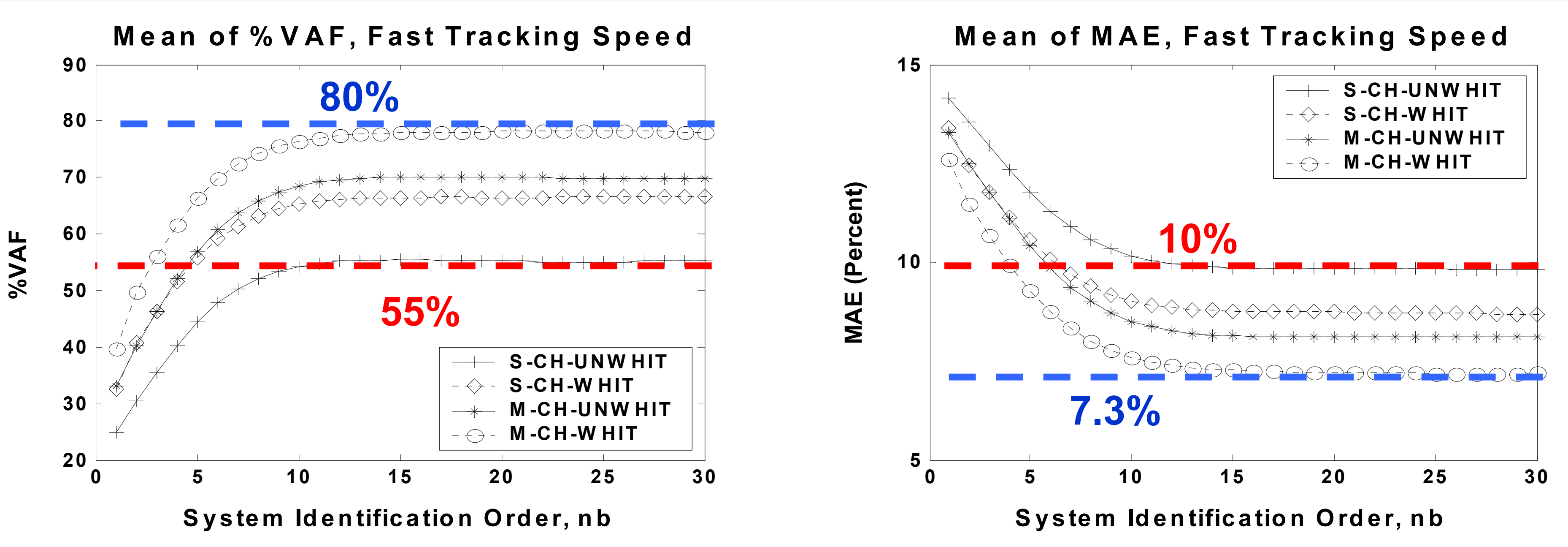
Clancy and Hogan, *IEEE Trans Biomed Eng* **44**: 1024–1028, 1997.

EMG-Torque: Constant-Posture, Force-Varying



Clancy *et al.*, *J Biomechanics*, 2006.

EMG-Torque: Force-Varying, Results



- **Linear (moving average) model**

Clancy *et al.*, *J Biomechanics*, 2006.

EMG-Torque Summary

Better EMGamp → Better Torque

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

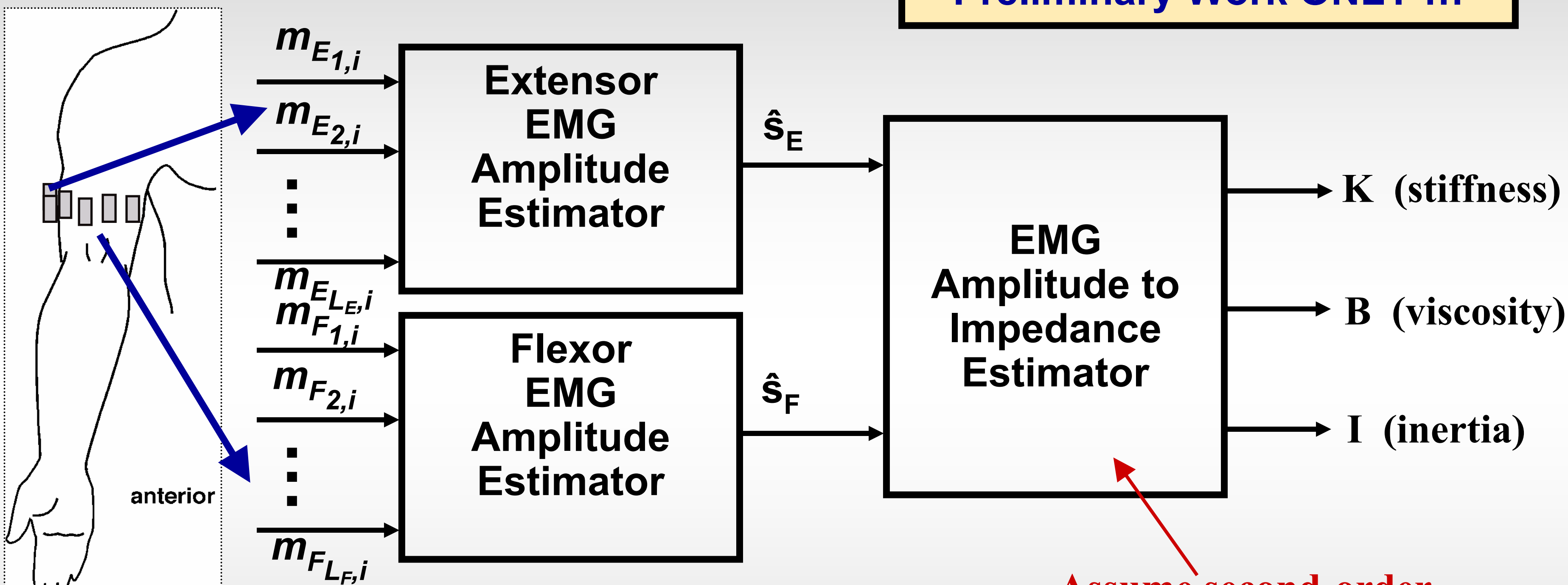
- Goal: Calibrate EMG-torque in apparatus; then estimate torque in unconstrained tasks

EMG-Impedance

- Rigorous representation of muscular co-activation
- Want optimized EMG-impedance relationship
  - Constant-posture, quasi-static conditions
  - Preliminary work
- Goal: Calibrate EMG-impedance in apparatus; then estimate impedance in unconstrained tasks

EMG-Impedance Block Diagram

Preliminary Work ONLY !!!

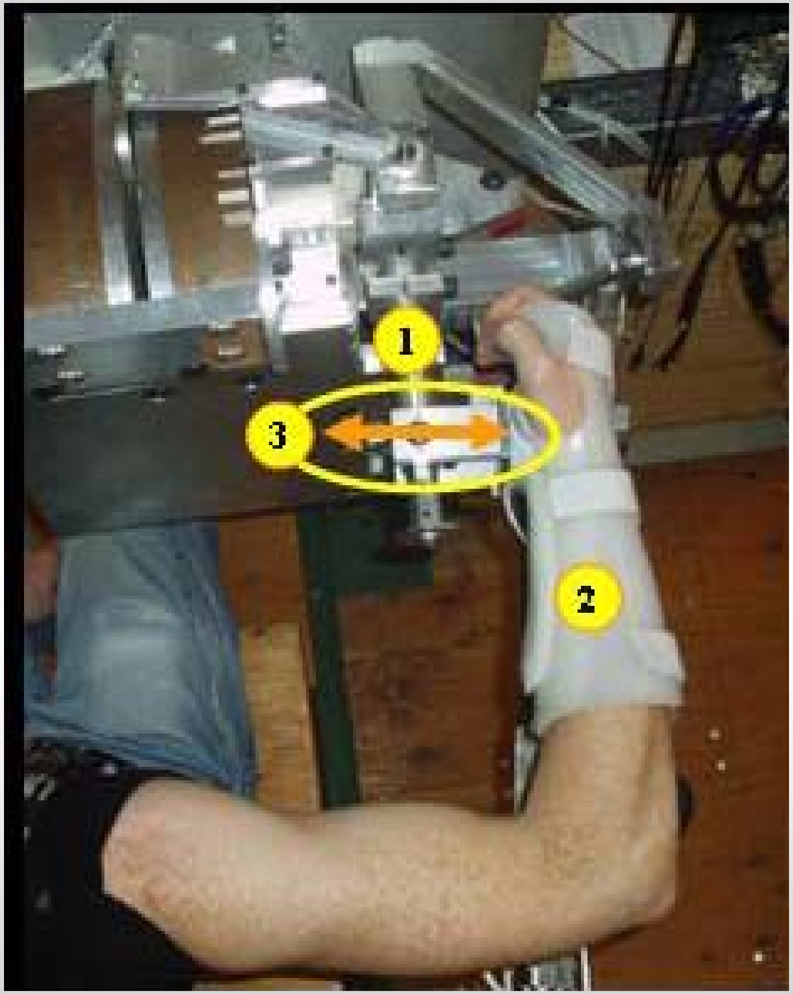


Assume second-order, linear model; constant operating point.

Higher-quality EMG amplitude estimates <u>should</u> give better impedance estimation.

Elbow Mechanical Impedance Measurement

- Subject seated, shoulder 90º abducted, elbow 90º flexed.
- Right hand immobilized in cuff (2), connected to actuated joystick (1)
- Medio-lateral pseudo-random FORCE perturbations (3)
- Measure medio-lateral movement through joystick encoders
- Assume second order linear system: K, B, I
  - Estimate I separately
- ***K, B vary with operating point***

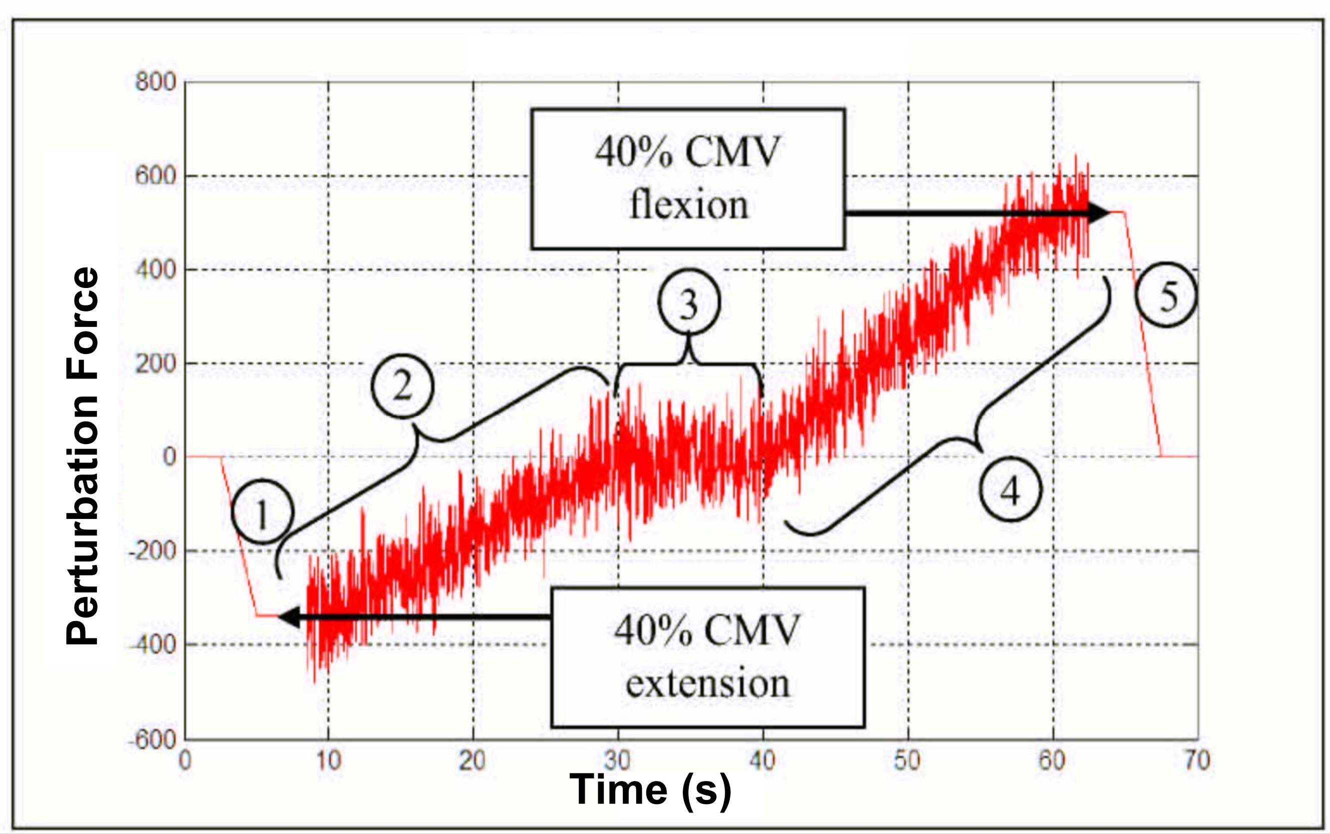


Top View

S. Martel, M.S. Thesis, U. Sherbrooke, 2007.

Impedance Calibration: Ramp Contraction Profile

- Slow ramp from extension-dominant to flexion-dominant



- Also test at fixed operating points

S. Martel, M.S. Thesis, U. Sherbrooke, Fig. 3.15, 2007.

Impedance Models

- **Fixed operating point ("constant torque"), λ:**

$$T_i = K(\lambda)\cdot\phi_i + B(\lambda)\cdot\dot{\phi}_i + I\cdot\ddot{\phi}_i$$

  - **T: Torque perturbation, ϕ: Angular perturbation**
  - **K: Stiffness, B: Viscosity, I: Inertia**
  - **Also measure EMG**

EMG amplitudes

- **Slowly varied operating point $\hat{s}_E, \hat{s}_F$:**

$$T_i = K(\hat{s}_E, \hat{s}_F)\cdot\phi_i + B(\hat{s}_E, \hat{s}_F)\cdot\dot{\phi}_i + I\cdot\ddot{\phi}_i$$

  - **Polynomial basis gives:**

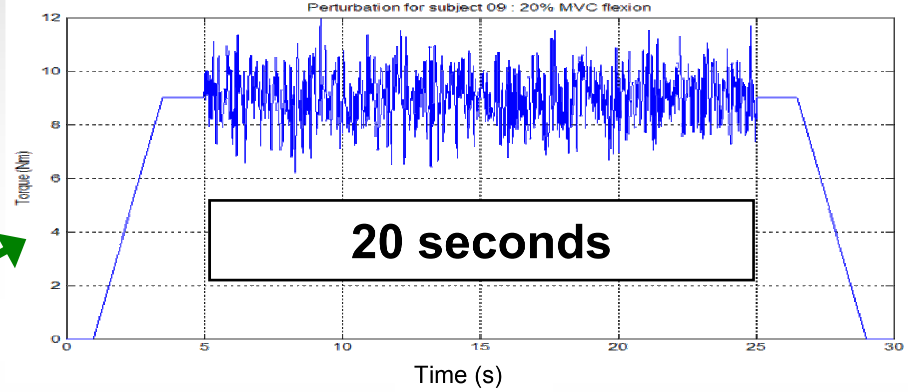
$$T_i = \left(k_0 + k_{E,1}\cdot\hat{s}_E + k_{F,1}\cdot\hat{s}_F\right)\cdot\phi_i + \left(b_0 + b_{E,1}\cdot\hat{s}_E + b_{F,1}\cdot\hat{s}_F\right)\cdot\dot{\phi}_i + I\cdot\ddot{\phi}_i$$

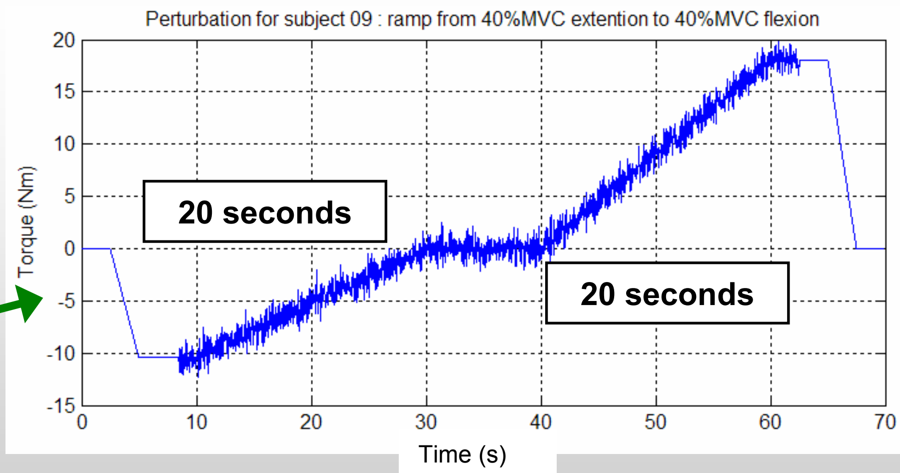
    - **Fit parameters:** k_0, $k_{E,1}$, $k_{F,1}$, b_0, $b_{E,1}$, $b_{F,1}$

System ID Protocol

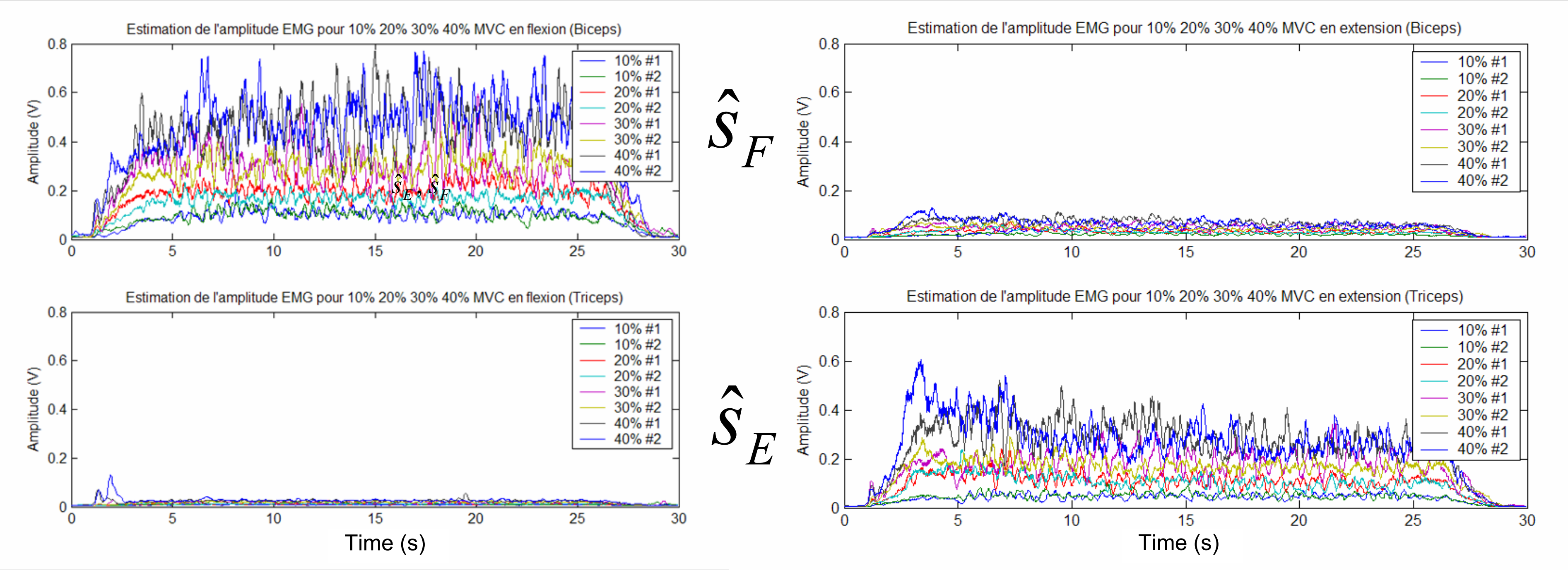
- 0–15 Hz, pseudo random torque
- EMG sampled at 4096 Hz
- Force, displacement sampled at 400 Hz, 1.5–8 Hz band pass
- Estimation of K and B
  1. 10%, 20%, 30%, 40% MVC flex
  2. 10%, 20%, 30%, 40% MVC ext
- Estimation of K and B versus time for slowly varying ramps (40% extension to 40% flexion MVC)
- 16 subjects

Target torque, perturbation superimposed





Constant Torque Data: EMG Amplitude



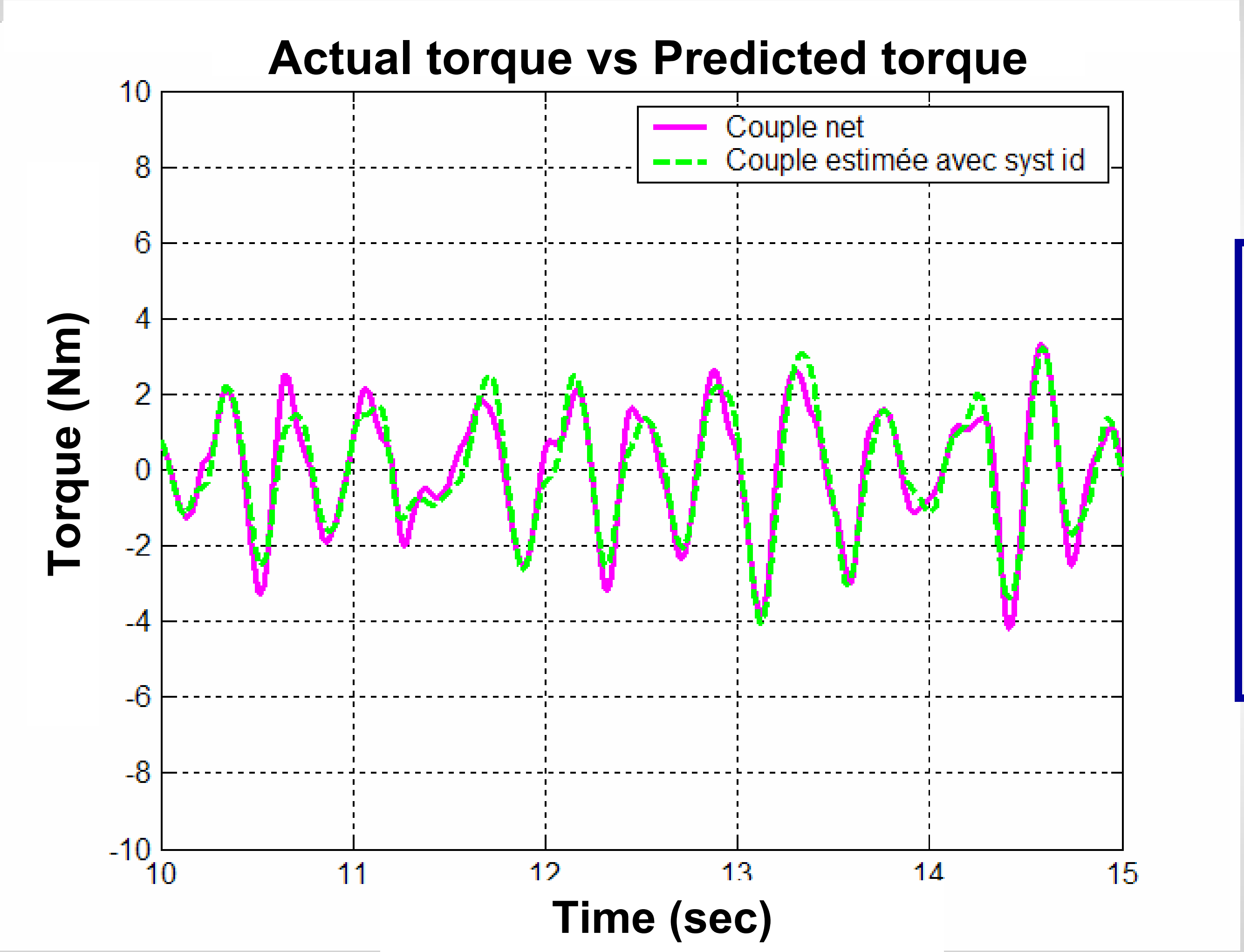
Normalized $\hat{s}_F$, $\hat{s}_E$

For constant-torque flexion tests

Normalized $\hat{s}_F$, $\hat{s}_E$

For constant-torque extension tests

Constant Torque Model Test: Torque Prediction

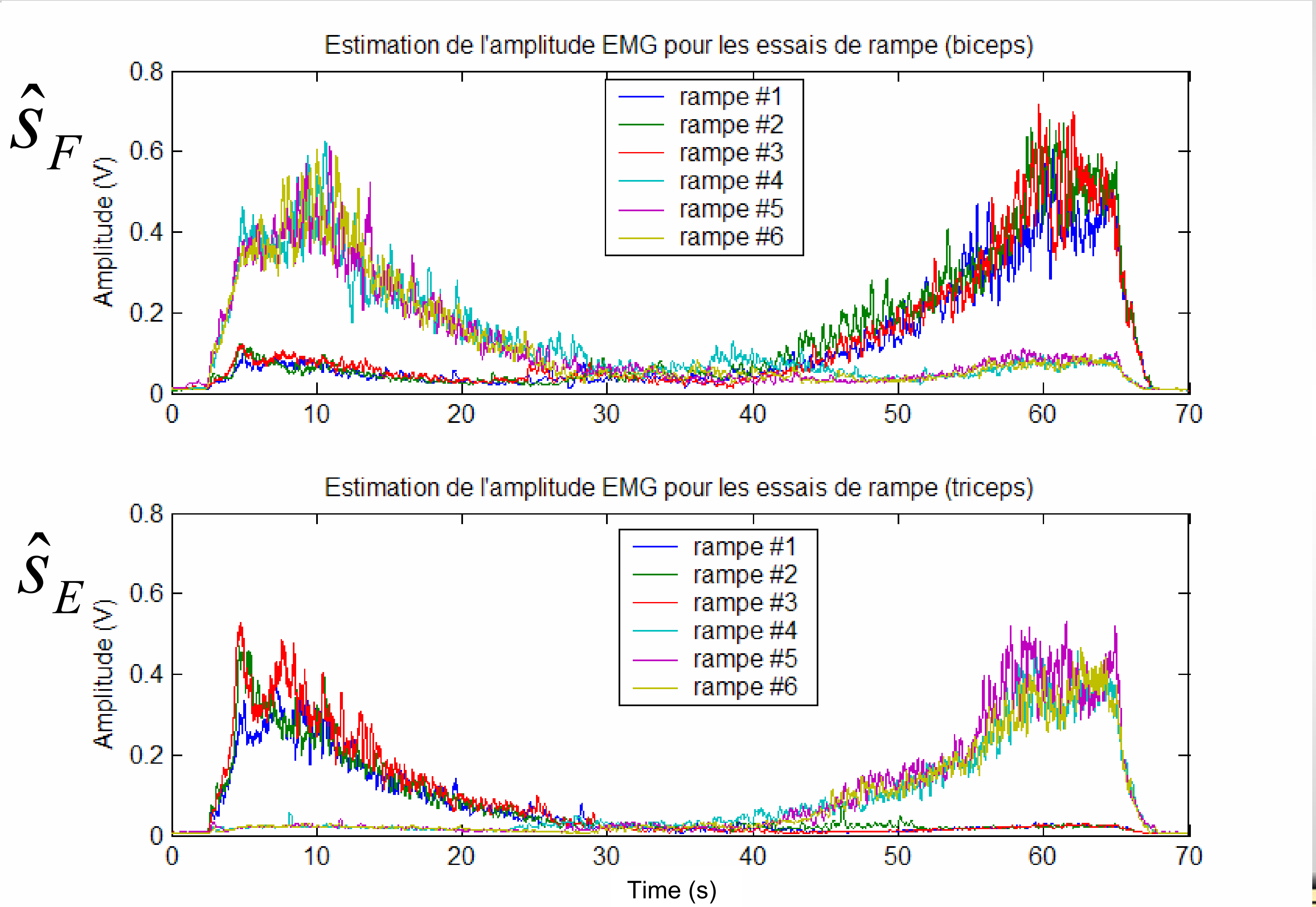


% VAF = 89% on estimated torque

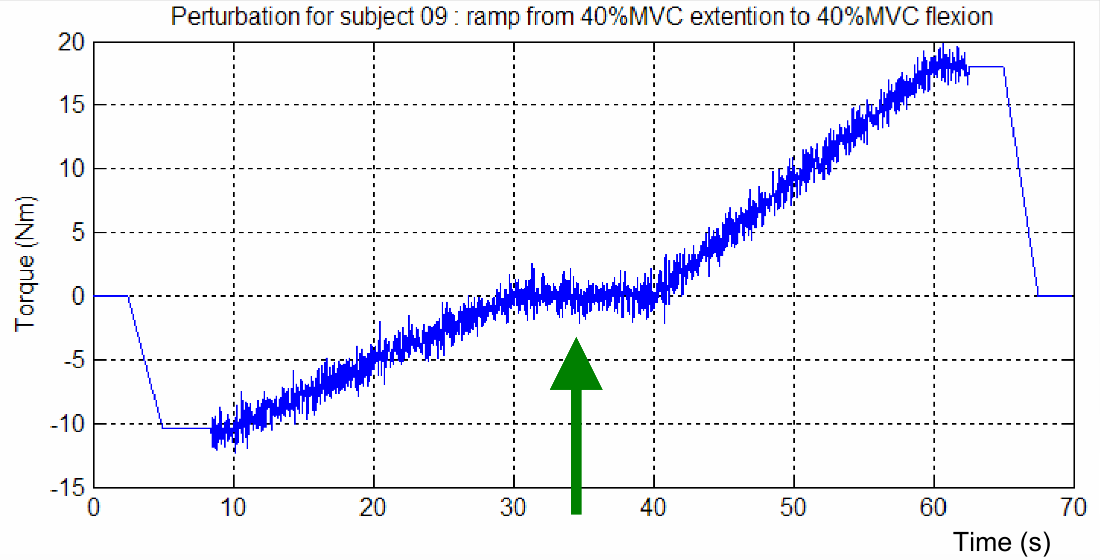
But, stiffness, viscosity parameters *NOT PHYSIOLOGIC*

… We're still working!!??!!

Ramp Torque Data: EMG Amplitude



Ramp Torque Issue at 0% MVC



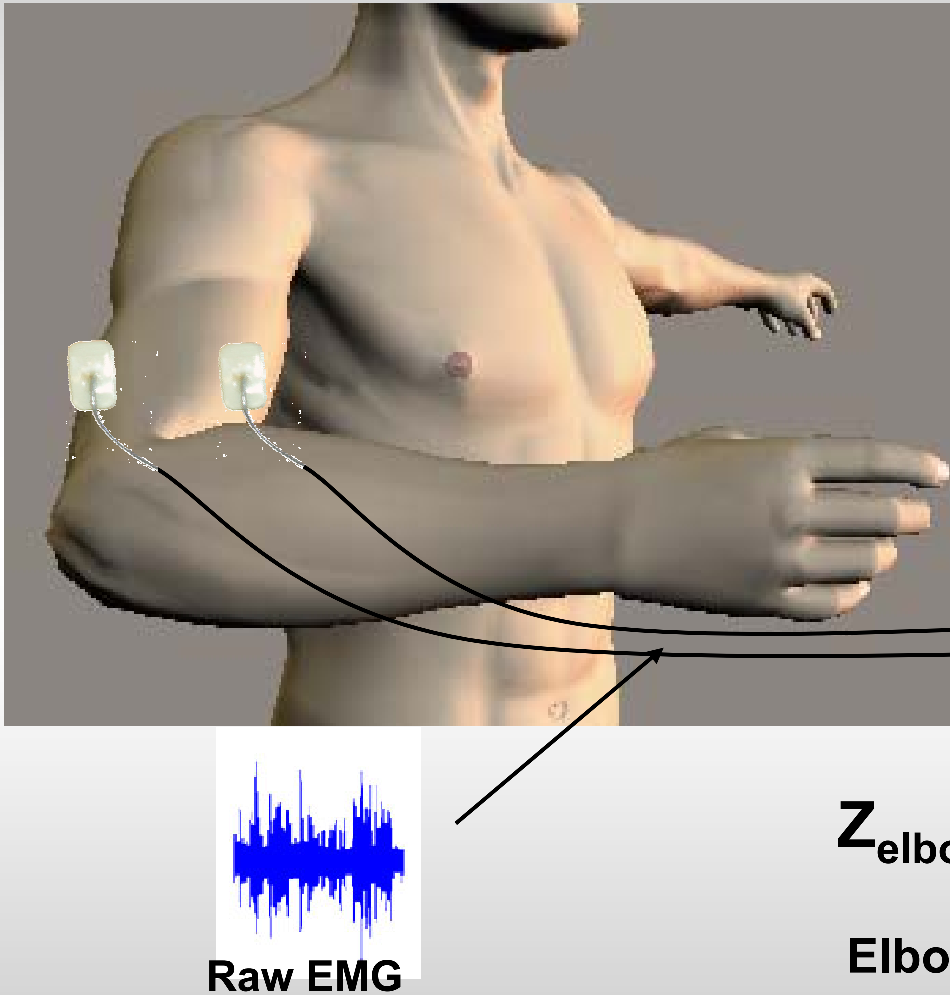
- **Force perturbations**
  - **At 0% MVC ➔ Position drifts**
- **Solutions:**
  1. **Do not pause at 0% MVC**
  2. **Position perturbations (Requires stronger motor)**

Impedance Study Status

- 0–15 Hz perturbation band sufficient
- Post-filtering (T, θ) 1.5–8 Hz essential to remove low freq modes
- Better torque prediction results obtained when remove inertial forces prior to ID

- First order model for EMG-impedance or H.O.?
- May use relaxed test to estimate k_0, b_0 instead?
- Ramp calibration may require position control?
- Will improved EMGamp estimators help?

Questions?



Non-invasive *advanced*, EMG amplitude & torque-impedance estimator

(Optimize each block)