EMG ACQUISITION AND MYOELECTRIC CONTROL STRATEGIES

MICHAEL TWARDOWSKI, RBE PHD STUDENT
“Electromyography is too easy to use and consequently too easy to abuse”

What is EMG?

“Electromyography (EMG) is the study of muscle function through the enquiry of the electrical signal the muscles emanate”

Muscles Alive
Basmajian & De Luca, 1985
The surface EMG (sEMG) signal can be used in the following applications

Obtain parameters from individual or groups of muscles
- Force Activation Time (ON – OFF)
- Fatigue

Compare behavior of different muscles
- Relative amount of contribution
- Co-activation
- Pattern identification (tasks)

Why Use the sEMG Signal?

Revealing and harnessing the neural control of movement
How the Brain Controls Muscles
The spinal cord is the major pathway of the nervous system.
Motor Unit

Motorneuron: neuron in the spinal cord that connects to muscles.

Motor Unit: Motorneuron, its axon and all of the muscle fibers that it connects to. It is the basic functional unit of the neuromuscular system.
Motorneuron Communication

Neuron Action Potential:

- change in electrical potential
- produced by flow of molecules in/out of cell
- propagates in one direction along cell
- Means of neural communication
Motor Unit Mechanical Output

sEMG Signal Acquisition
EMG Signal

- System subtracts two signals: 
  \[(m_1+n) - (m_2+n)\] noise is removed
- Resultant EMG signal: 
  \[(m_1-m_2)\] is amplified
• The quality of the sEMG signal should be the first concern of any tests performed to collect sEMG signals.

• The quality of the EMG signal depends on:
  • Sensor characteristics
  • Sensor Location
  • Electrode-skin interface
  • Noise contamination
  • Cross-talk from other muscles
Sensor Characteristics

• Small inter-electrode spacing
  • sensors for small muscles
  • selective recording from individual muscles
  • reducing cross-talk

• Differential amplification
  • removing ambient noise (50, 60 Hz, Radio frequencies)

• Fixed spacing of electrodes for consistent signal properties
  • Amplitude and frequency of signal is a function of the distance between the electrodes
Sensor Characteristics

- Crosstalk reduced at 10 mm spacing
- Crosstalk substantially reduced for 10 mm Double Differential
Sensor Location:

Proper sensor location

- Increases the signal
- Increases the signal to noise ratio
- Reduces cross-talk

Easiest, cheapest, most effective way of obtaining a better signal to noise ratio
Electrode Skin Interface

- Contoured surface maintains proper electrical contact with the skin during movement
Noise Contamination of the EMG Signal

Baseline noise = 1.2 uV RMS sEMG signal (Delsys sensors)

Baseline noise + EMG signal

![Baseline noise graph](image1.png)

![Baseline noise + EMG signal graph](image2.png)
Noise Contamination

- Physiological Noise
  - EKG, EOG, respiratory signals, etc.

- Ambient Noise
  - Power line radiation (50, 60 Hz)
    - Cable motion artifact

- Baseline Noise
  - Electro-chemical noise (skin-electrode interface)
  - Thermal noise (property of semi-conductors)

- Movement Artifact noise
  - Movement of electrode with respect to the skin (induced by force transients or movement of the skin)
  - This is the most obstreperous noise
Baseline Noise

• Reduce Baseline noise by preparing the skin
  • Clean skin with alcohol
  • Remove hair
  • Peel off top dead layer of skin with hypoallergenic tape
  • Use state-of-the-art active sensors
Movement Artifact

- Induced by force transmission through the muscle and skin
- Caused by relative movement of sensor with respect to skin
  - Poor electrical contact between electrode and skin
  - The electrolyte material between electrode and skin
- More dominant in low level EMG signals
- Contaminates EMG signal
  - Frequency components superimpose on those of EMG signal

How to Reduce Movement Artifacts
- Skin Preparation
- Not using electrolyte gel
- Filtering
Noise Contamination of EMG Signal

Baseline noise + EMG signal + Artifact

Power

Frequency

Movement Artifact

Filtering the sEMG Signal

EMG signal with Baseline noise and Artifact reduced

Filtering 20-450 Hz
On/Off and Proportional Control of Prostheses
Commercially available control schemes require unintuïtive, unnatural sequences of contractions to control multiple DOF.
Pattern Recognition Control
FEATURE EXTRACTION

- Amplitude Estimates (Signal Energy)
  - Root Mean Square
  - Mean Amplitude Value
- Signal Complexity
  - Waveform Length
  - Slope Sign Changes
  - Zero Crossings
- Frequency
  - Willison Amplitude
- Prediction Model
  - Autoregressive coefficients
- Time Dependencies
  - Mean Absolute Value Slope

Investigations have shown that the amplitude of the sEMG signal is nonlinearly related to the actual force of the contracting muscle.


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**Non Linearity sEMG vs. Force**

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<th>RMS (MVC %)</th>
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Implanted Electrodes
Motor unit action potentials (MUAPs) can be recorded with the use of needle EMG. The tip of the needle is the recording electrode.

Another method is fine wire EMG. The needle has a thin wire in it with a hook at the end. Once inserted, the needle is removed and only the wire remains in the muscle.
Implantable Myoelectric Sensors

- Control of 1 DOF for every 2 sensors
Implantation and maintenance of invasive neural interface:

- disturb the integrity of the residual nerves or muscles
- pose great health risks
- present substantially greater health costs

Intense fear and mutilation anxiety associated with surgery
THE INCEPTION OF A LEGACY
EMG Decomposition

First conceived and implemented by Carlo J. De Luca in 1982. By 2000s developed non-invasive surface dEMG.

IEEE TRANSACTIONS ON BIOMEDICAL ENGINEERING, VOL. BME-29, NO. 3, MARCH 1982

A Procedure for Decomposing the Myoelectric Signal Into Its Constituent Action Potentials—Part I: Technique, Theory, and Implementation

RONALD S. LEFEVER, MEMBER, IEEE, AND CARLO J. DE LUCA, SENIOR MEMBER, IEEE

Abstract—A technique has been developed which enables the decomposition (separation) of a myoelectric signal into its constituent motor unit action potential trains. It consists of a multichannel (via one electrode) myoelectric signal recording procedure, a data compression algorithm, a digital filtering algorithm, and a hybrid visual-computer decomposition scheme. The algorithms have been implemented on a PDP 11/34 computer. Of the four major segments of the technique, the decomposition scheme is by far the most involved. The decomposition algorithm uses a sophisticated template matching routine and details of the firing statistics of the motor units to identify motor unit action potentials in the myoelectric signal, even when they are superimposed with other motor unit action potentials. In general, the algorithms of the decomposition scheme do not run automatically. They require input from the human operator to maintain reliability and accuracy during a decomposition.

INTRODUCTION

THE motor control system is a complex neural system with a myriad of pathways. One of its output pathways consists of the ensemble of a motoneurons which activates the superposition of the MUAP's from all the MU's having fibers in the vicinity of the electrode. This signal is referred to as the myoelectric (ME) signal. Refer to De Luca [5] for a more detailed review of the electrophysiology.

The shape and amplitude of each MUAP waveform will generally differ from MU to MU due to the unique geometric arrangement of the fibers of each MU with respect to the recording site. MUAP waveforms from different MU's may, however, be nearly similar in amplitude and shape when the muscle fibers of two or more MU's in the detectable vicinity of the electrode have a similar spatial arrangement. The shape of the MUAP waveforms within a MUAP will remain constant if all the initial relationships between the electrode and the active muscle fibers remain constant: that is, if the geometrical arrangement between the recording electrode and active muscle fibers does not vary; if the relative time difference between the initiation of each constituent fiber action potential is constant; if the properties of the recording electrode do
dEMG

Decomposition

Motor Unit Number

Raw sEMG Signal

Force (% MVC)

Time (s)

Motor Unit Number

47
46
45
44
43
42
41
40
39
38
37
36
35
34
33
32
31
30
29
28
27
26
25
24
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22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1

50 uV

40
35
30
25
20
15
10
5
0
Force Gradation

Motor Unit Action Potential

Motor Unit Firing Train

Firing Rates

Recruitment Threshold, RT

Force

RFT
Onion Skin


Cross-Correlation Function

\[ c(t) = \int_{-\infty}^{\infty} x(\tau) y(t+\tau) \]
UNDERSTANDING MOTOR CONTROL

- Motor unit control properties
- Correlated control of motor units
- Biomechanical benefits of control schemes
From the NeuroMuscular Research Center

Scientific/Research Questions

- Conceptualize new EMG technology
- Advance understanding of human movement.

Development of EMG product

Enabling new research applications
Today’s University Talent Supports Tomorrow’s Innovations

Internship Programs → Future Employees

Research Fellowship Programs → Future Employees

Training Researchers for Over 40 years
25 MS Theses, 12 PhD Dissertations, 41 Research Associates
CONCEPTS THAT WILL SHAPE OUR FUTURE

Investigating EMG for Subvocal Speech
EMG-BASED SUBVOCAL COMMUNICATION

The alternative to voiced speech

- AAC – Augmentative and Alternative Communication
- Does not rely on acoustic excitation
- Utilizes subvocal (mouthed) speech
SUBVOCAL ALGORITHM ARCHITECTURE

Intelligent Signal Processing + Strategic Machine Learning

- TIMIT standardized speech data corpus
- Frequency-phoneme combinations to test unforeseen words
- State detection of Start/End of speech
- Separation of speech and non-speech muscle activity
- EMG features of speech
- LDA Feature reduction
- HMMs based on acoustic speech processing
- Deep Learning (experimental)
- Word error rates
- Subject specific parameter performance

EMG from multiple muscles processed concurrently

Parameterized data delivered to back end algorithms

Recognition results and error rates for each utterance
APPLICATIONS OF SUBVOCAL TECHNOLOGY

Consider the alternatives to voiced speech

- Subvocal prosthesis for speech impaired
- Subvocal speech translation
- Subvocal speech in quiet environments
- Subvocal speech for noisy environments
- Subvocal systems for stealth speech
Tracking Movement Disorders

CONCEPTS THAT WILL SHAPE OUR FUTURE
Consider Parkinson’s Disease, Essential Tremor, etc.

Movement disorder changes throughout the day

Tracking symptoms is important for treatment

But current monitoring methods are unreliable
SENSOR SYSTEM FOR MONITORING MOVEMENT

Automated real-time detection

Trigno™ EMG + IMU Sensors
- 1 Ch EMG,
- 9 Ch IMU (Acc, Gyro, Mag)
- synchronous sensors
- wireless transmission
SENSOR SYSTEM FOR MONITORING MOVEMENT

Proposed System

**Data Acquisition System**
- Data Logger & Sensor
- Tablet

**Platform-Generated Applications**
- Other....
- Essential Tremor
- Parkinson’s

**Movement Disorder Results**
- Summary Status
  - Normal
  - Freezing 7%
  - Dyskinesia 20%
  - Tremor 33%
  - Other....

**Table**: Movement Disorder Results
- Normal: 7%
- Freezing: 7%
- Dyskinesia: 20%
- Tremor: 33%
- Other: ....