Development of Complex Curricula for Molecular Bionics and Infobionics Programs within a consortial* framework**

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The Project has been realised with the support of the European Union and has been co-financed by the European Social Fund ***

**Molekuláris bionika és Infobionika Szakok tananyagának komplex fejlesztése konzorciumi keretben

***A projekt az Európai Unió támogatásával, az Európai Szociális Alap társfinanszírozásával valósul meg.

Neuromorph Movement Control

(Neuromorf mozgás vezérlés)

Electromyography: signal measuring,processing

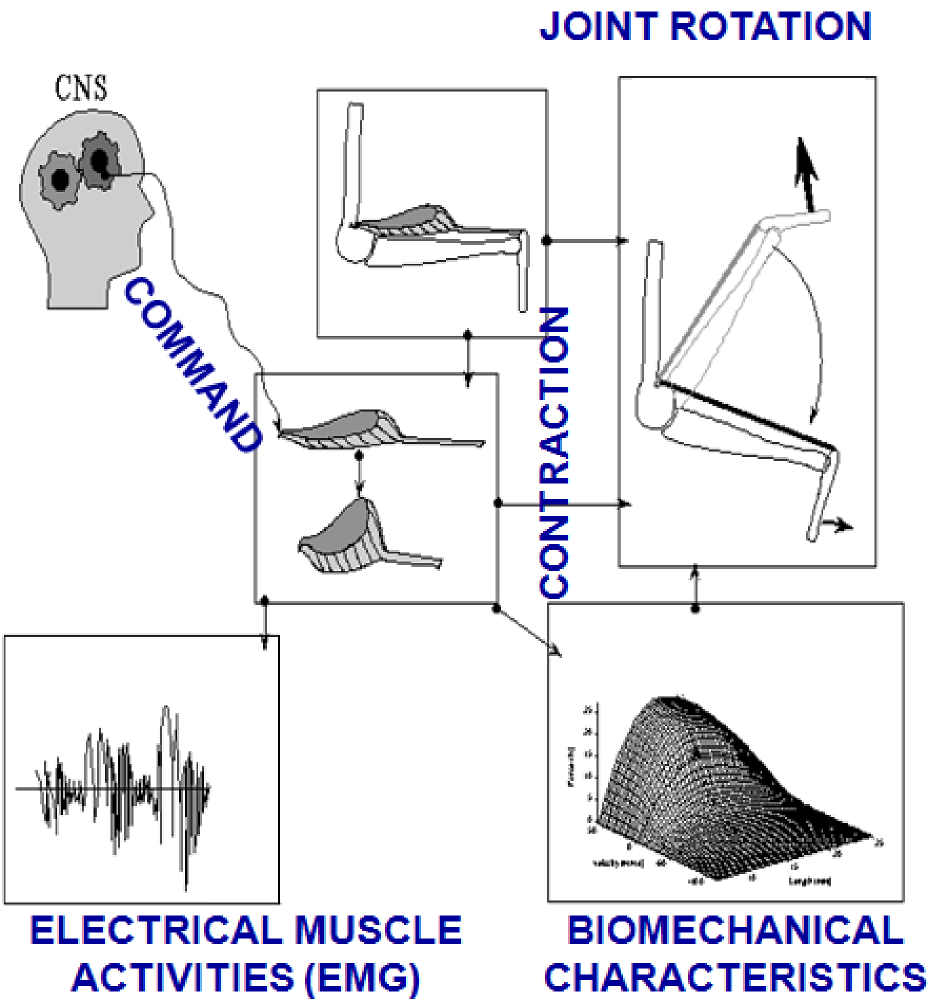
(Elektromiográfia: jel mérés, feldolgozás)

József LACZKÓ PhD; Róbert TIBOLD

Main points of the lecture

- The role of electromyography in generating joint rotations
- Structural approaches
    - Introducing Motor Units (MU)
    - The innervation of muscles
- EMG as a measurable feature
    - Factors effecting the measurement of EMG
    - Problems with EMG
    - Types of electrodes considering measurements problems
- EMG data processing
    - FFT,Filtering,smoothing
    - Case study of arm movements to show EMG’s

- Measured marker coordinates provide the required data to compute inter-segmental angles between adjacent body segments and pronation-supnation of individual body segments.
- Some features of geometry of the body segments (e.g. segment lengths) can also be measured and this data helps to estimate inertial properties of body segments and to compute joint torques and muscle forces.
- Although to get information about muscle forces, the electrical activities of muscles are also very important.
- Recorded EMG signals provide data for estimating muscle forces



Gererating joint rotation

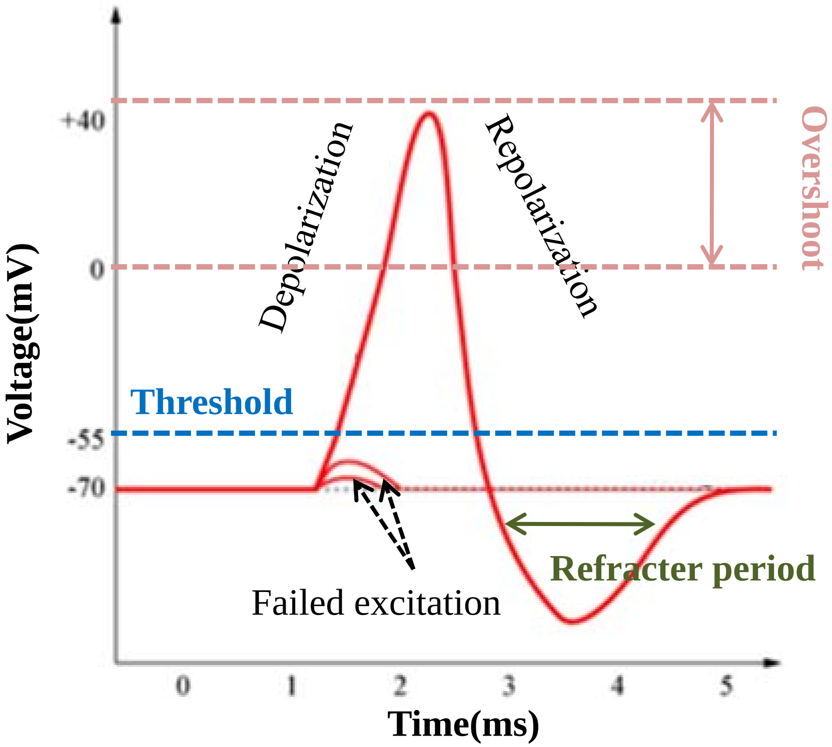
- **COMMAND from CNS (central nervous system)**
  - To the muscles
- **Electrical signal generation by motoneurons**
  - **RESULT:** muscle **CONTRACTION**
  Signals are measurable (Electromyogram, EMG signals)
- **Muscle contraction**
  - **RESULT: ROTATION** in the joint spanned by the muscle
  - Magnitude depends:
    - Biomechanical characteristics

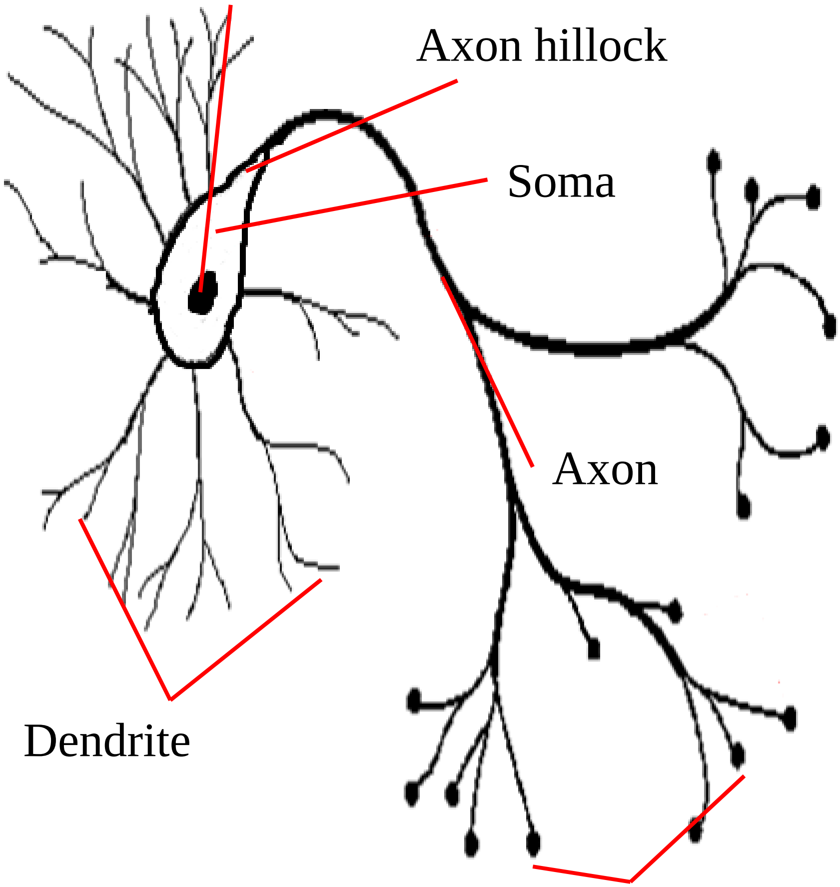
Action Potential

- Propagates without loss of amplitude
- No summation of AP's
- Absolute and relative refracter period

  -AP cannot be evoked

- AP's can be evoked on the axon or axon hillock (potential driven ion channels are located here)





Structural approach

- **The smallest unit playing an important role in movement generation**
  - **MOTOR UNIT (MU)**

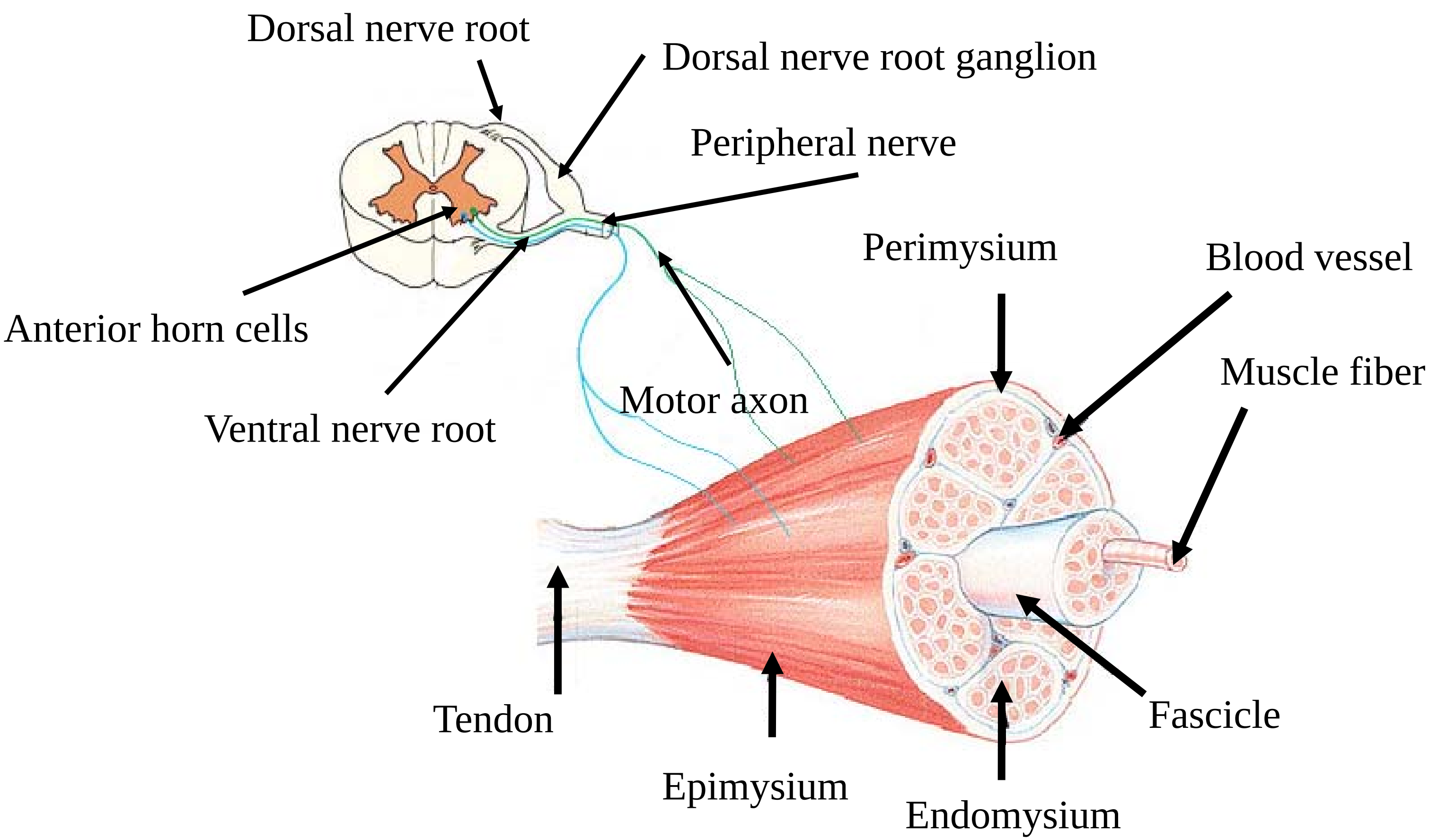
- **A MOTOR UNIT contains:**
  - **Nerve cell body**
  - **Axon**
  - **Branches**
  - **Muscle fibre**
- **Invasive stimulation of a nerve cell**
  - **Through the soma**

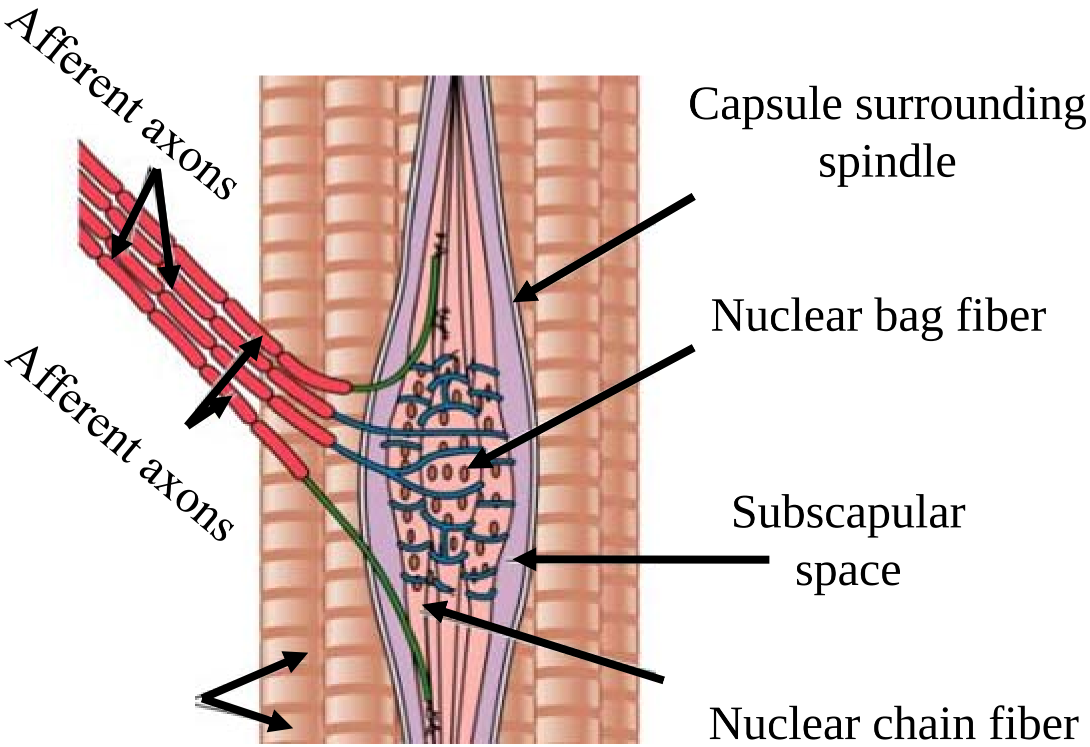
Overview on MU's

- **Motor units** have been found to modulate their firing rates simultaneously.
- The **firing rate of motor units** is **not constant**, even during constant force contractions; **it fluctuates**.
- The fluctuations in a force output of a muscle during a constant-force contraction are caused by the fluctuations in the firing rates of the motor units.

Structural approach

THE RELATION BETWEEN muscle and spinal cord





Structural approach

- **Innervation of muscle spindles**
  - **By the axons of motor units (MU)**
- **1 MU = 1 muscle sarcomere**

- **Small electrical current are present**
  - Prior to muscle force production
- Current is generated by the exchange of ions
  - On the fibre cell membrane = **EMG**
- **EMG** can be measured by
  - Applying conductive elements
  - Via electrodes
    - Non-invasively: placing on the skin surface
    - Invasively: implanting within the muscle
- **sEMG(surface EMG) vs invasive processes?**
  - sEMG is commonly used

Factors effecting the measurement of sEMG

- Amplitude varies within the following range
  - From uV to mV (20uV-20mV)
- sEMG amplitude,time,frequency domain depends on factors such as:
  1. Timing and intensity of muscle contraction
  2. Properties of the electrodes and amplifier used
  3. The contact between the skin and the electrodes
  4. Distance of the electrodes from the area to be studied (active muscle problem)
  5. Overlaying tissue problem

General problems in EMG measurement

Biological

- force of muscular contraction (number of MUs activated)
- length of muscle/s (changes during a movement)
- cross section of muscles
- position/s of muscle/s (they be in many layers)
- The selectivity (the effect of other muscles)
- thickness of subcutaneous fat
- Movements during the measurement
- others

General problems in measuring EMG's

Technical

- skin preparation
- distance between electrodes
- position of electrodes
- orientation of electrodes
- crosstalk recordings
- external electrical effects (noises)
- Sampling rate
- Others

Avoiding the impact of non-muscular factors

- The effect of such factors
  - Makes the sEMG records varying between and within subjects
  - Makes the explanation and interpretation more difficult

- Methods to reduce the impact of non-muscular factors
  - Using: (during the whole experiment)
    - The same electrodes
    - The same amplifier
  - Ensuring the quality of the contact between:
    - Skin and electrodes (assuring low skin impedance)
      - Alcoholic cleaning of the skin
      - Removing the hair from the skin

- Ensuring the quality of the contact between:
  - Skin and electrodes (assuring low skin impedance)
    - Alcoholic cleaning of the skin
    - Removing the hair from the skin (shaving

Minimize artefacts

Hardware level filtering

Reduce the presence of other electrical equipments

Using properly, sEMg signals give information about muscle fiber action potentials within 1 to 2 cm of the electrodes

Information to be gained from EMG measurements

- muscle activity onset time
- estimate force (qualitative relationship, accuracy?)
- fatigue information
- Quantify maximal voluntary muscle contraction

=> leads to applications in

- discovering neural disorders
- work-related musculoskeletal disorders
- robotic implants/prostheses
- disabled people applications: face movements etc

Sources of noise

- **There are 2 major types of noise**
  - ***Ambient***
  - ***Transducer***
- **Ambient**
  - Generated by electromagnetic devices
    - Computer,
    - cell phones
    - power lines
  - Wide range of frequecy components
    - Dominant frequency: 50Hz; 60Hz

Sources of noise

- **Transducer**
  - Generated at the contact of the skin and electrode
  - 2 types:
    - D/C voltage potential: Caused by differences between skin and electrode impedance
    - A/C voltage potential: Caused by the fluctuations of impedance between the conductive transducer and the skin
- **How to reduce impedance?**
  - USING Ag-AgCl electrodes

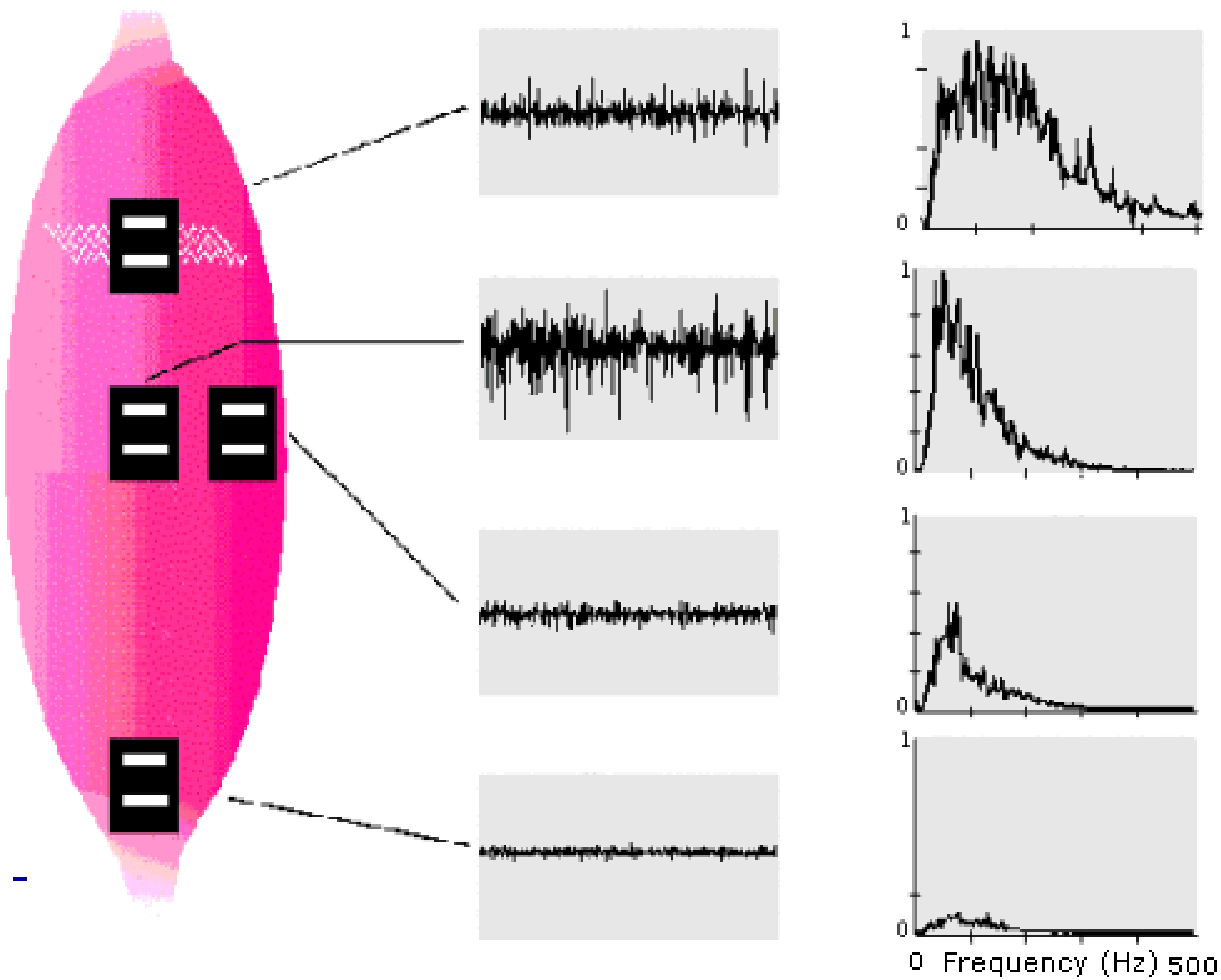
Types of electrodes

- **2 major types are discerned**
  1. Dry electrodes: making direct contact with the skin
  2. Gelled electrodes: using electrolite gel as a chemical interface between the skin adn the metallic part of the electrode
- **Dry:** is used in applications where geometry and size don’ allow the use of gel.
- **Gelled:** is commonly used.
  - Disposable and reusable
  - Less electrical noise (because of the use of electrolytical gel as an interface)

1.

2.

Innervation zone - top
Lateral edge - middle right



Preferred: midline of the belly of the muscle between the nearest innervation zone

- the myotendonous junction
- the myotendonous junction - bottom

A study of using sEMG – 1000 Hz sampling frequency

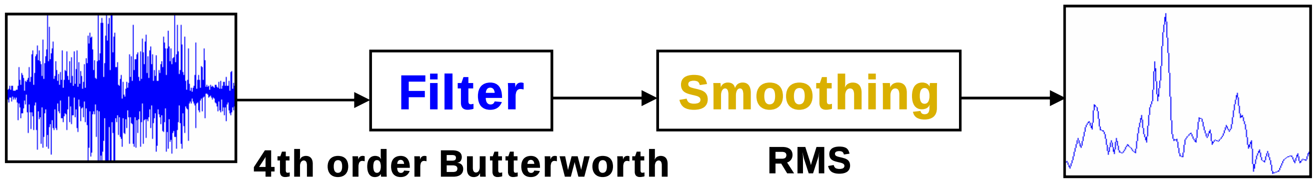
1 - is the EMG sensing and processing unit

○ -Are bipolar surface electrodes placed on 4 arm muscles
Biceps,triceps,deltoid anterior-posterior

◌ - Reference point on the elbow

EMG data processing of the study (filtering)

Processing algorithm in general:



- FFT analysis → **spectral analysis** → (1000Hz) useful signal (**50-450 Hz**)

- Butterworth filtering → bandpass filtering in MATLAB using normalized 0-1 values

- **R**oot **M**ean **S**quare smoothing →

$$RMS(n) = \sqrt{\frac{\sum_{k=n-a}^{n+a} EMG(k)^2}{2a+1}}$$

a=size of sampling window
n=time length of the sample

Fourier Transform

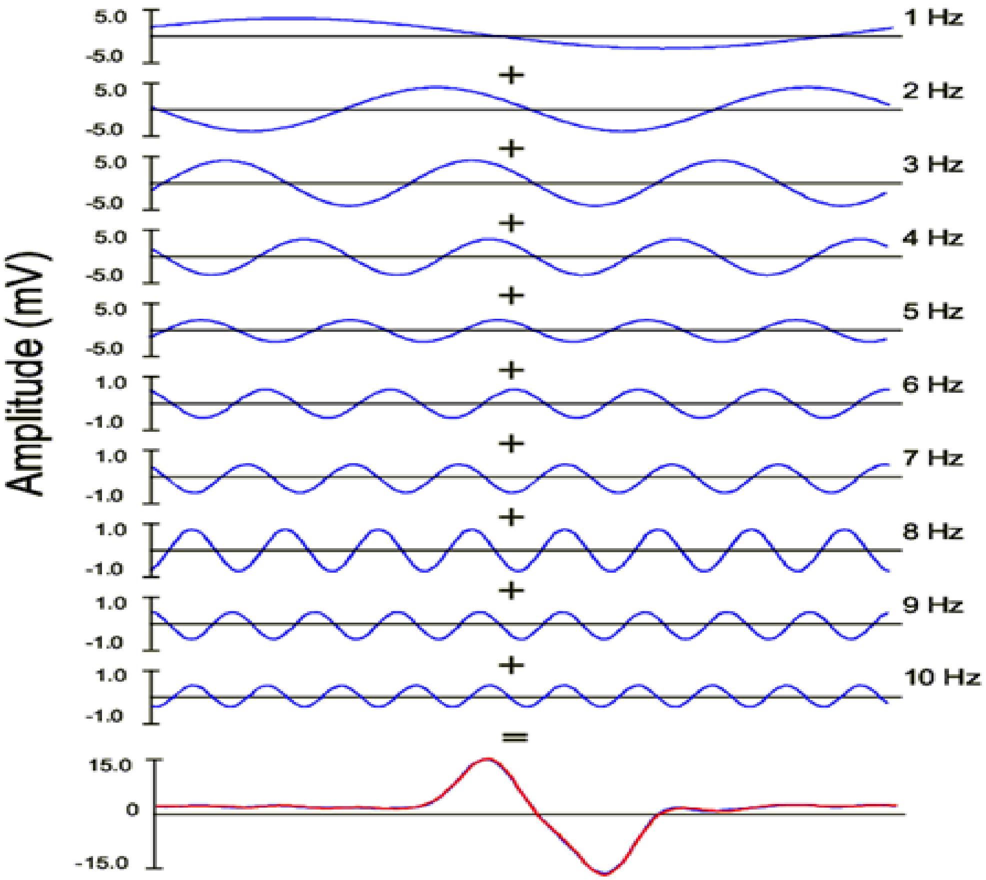
MAIN ISSUE: Each continous, periodic function can be described as the sum of infinite number of sine (cosine) functions.

$$x(t) = A + \sum_{n=1}^{\infty} \left[B_n \cos(f_n \cdot t) + C_n \sin(f_n \cdot t) \right]$$

$$x(t) = A + B_1 \cos(f_1 \cdot t) + C_1 \sin(f_1 \cdot t) + B_2 \cos(f_2 \cdot t) + C_2 \sin(f_2 \cdot t) \ldots$$

Result: the spectrum

Fast Fourier Transform (FFT) of a MU action potential

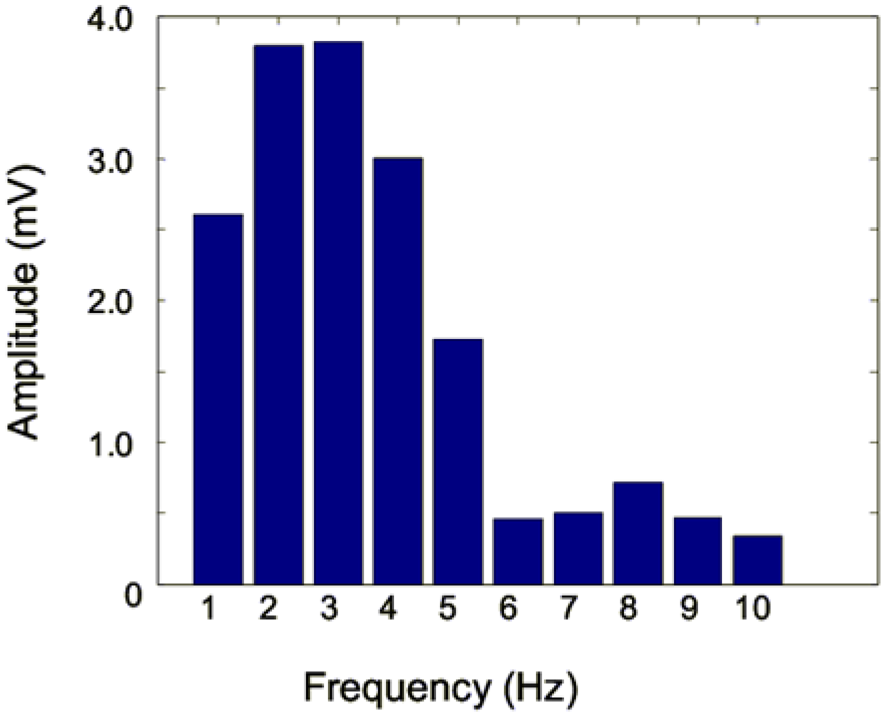


- Original signal

- Decomposed signals

The summation of superposed blue signals

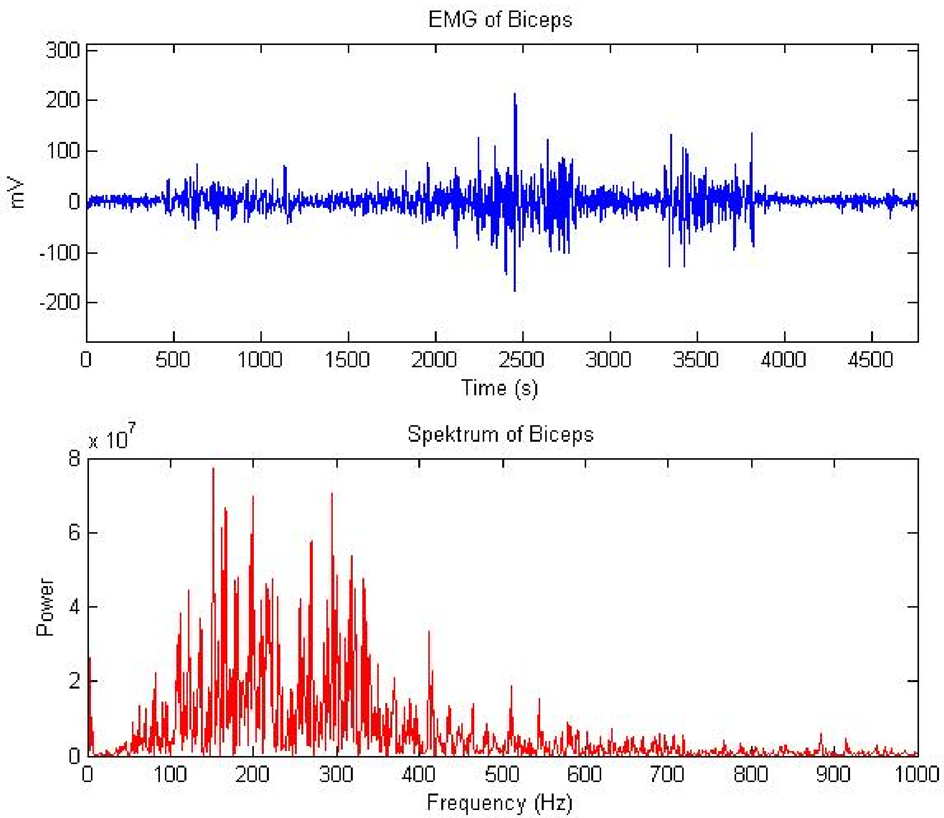
Fast Fourier Transform (FFT)



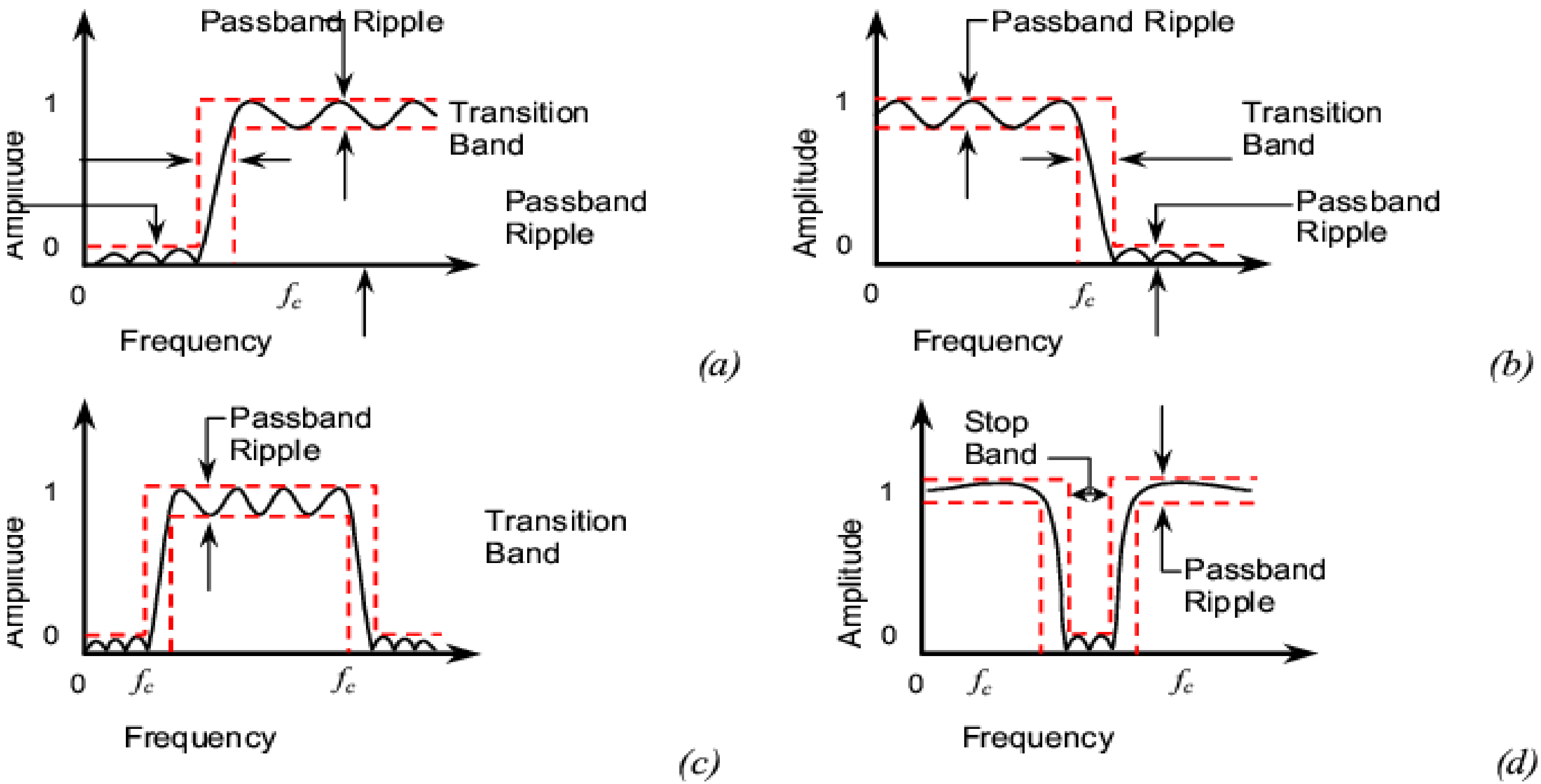
Amplitude histogramm of the action potential

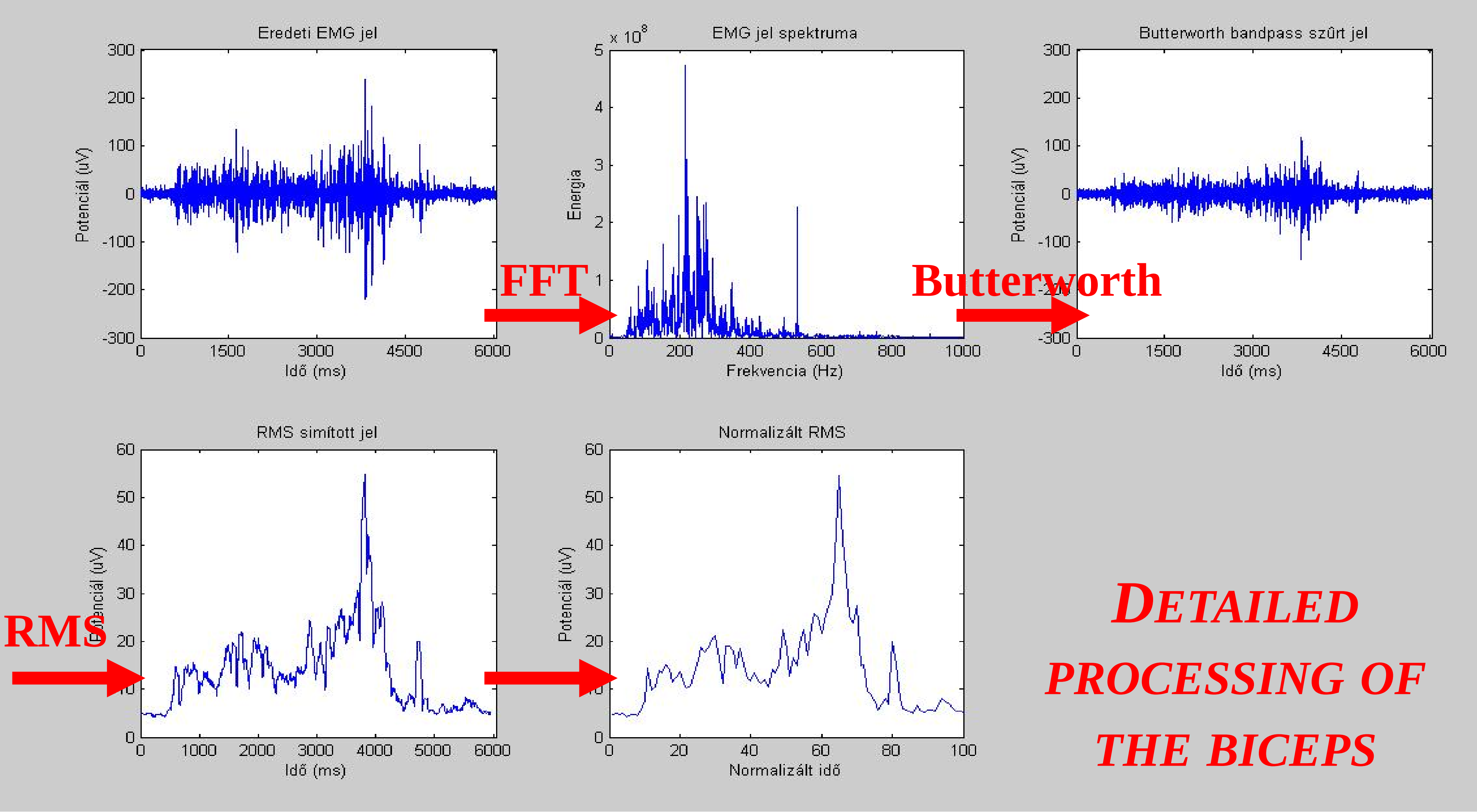
There is strong „signal activity" between 1Hz- 5Hz

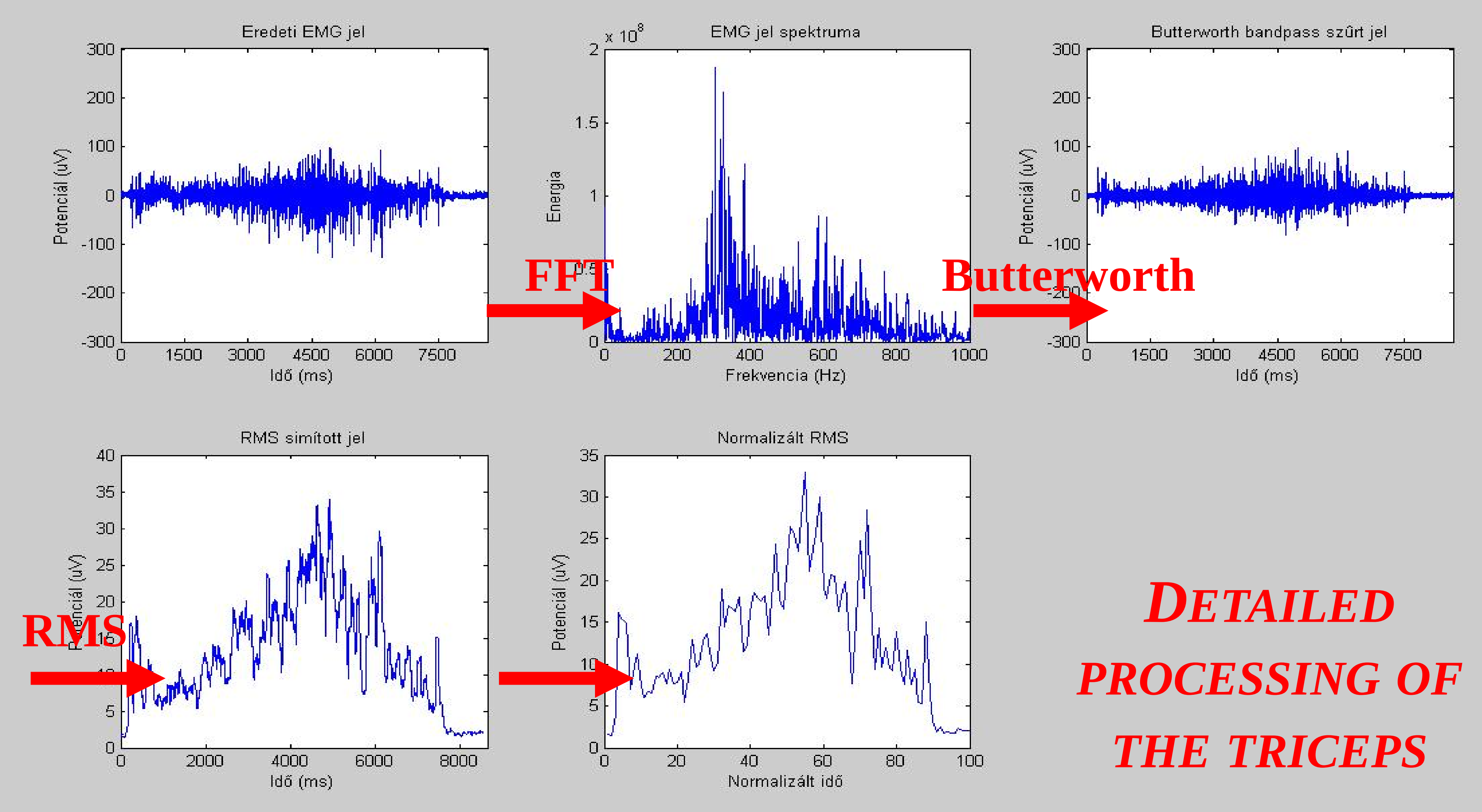
Fast Fourier Transform (FFT) – an example



Practical filtering methods




Eredeti EMG jel
Potenciál (uV)
Idő (ms)
FFT
EMG jel spektruma
x 10^8
Energia
Frekvencia (Hz)
Butterworth
Butterworth bandpass szűrt jel
Potenciál (uV)
Idő (ms)
RMS
RMS simított jel
Potenciál (uV)
Idő (ms)
Normalizált RMS
Potenciál (uV)
Normalizált idő
DETAILED PROCESSING OF THE BICEPS



Eredeti EMG jel
Potenciál (uV)
Idő (ms)
EMG jel spektruma
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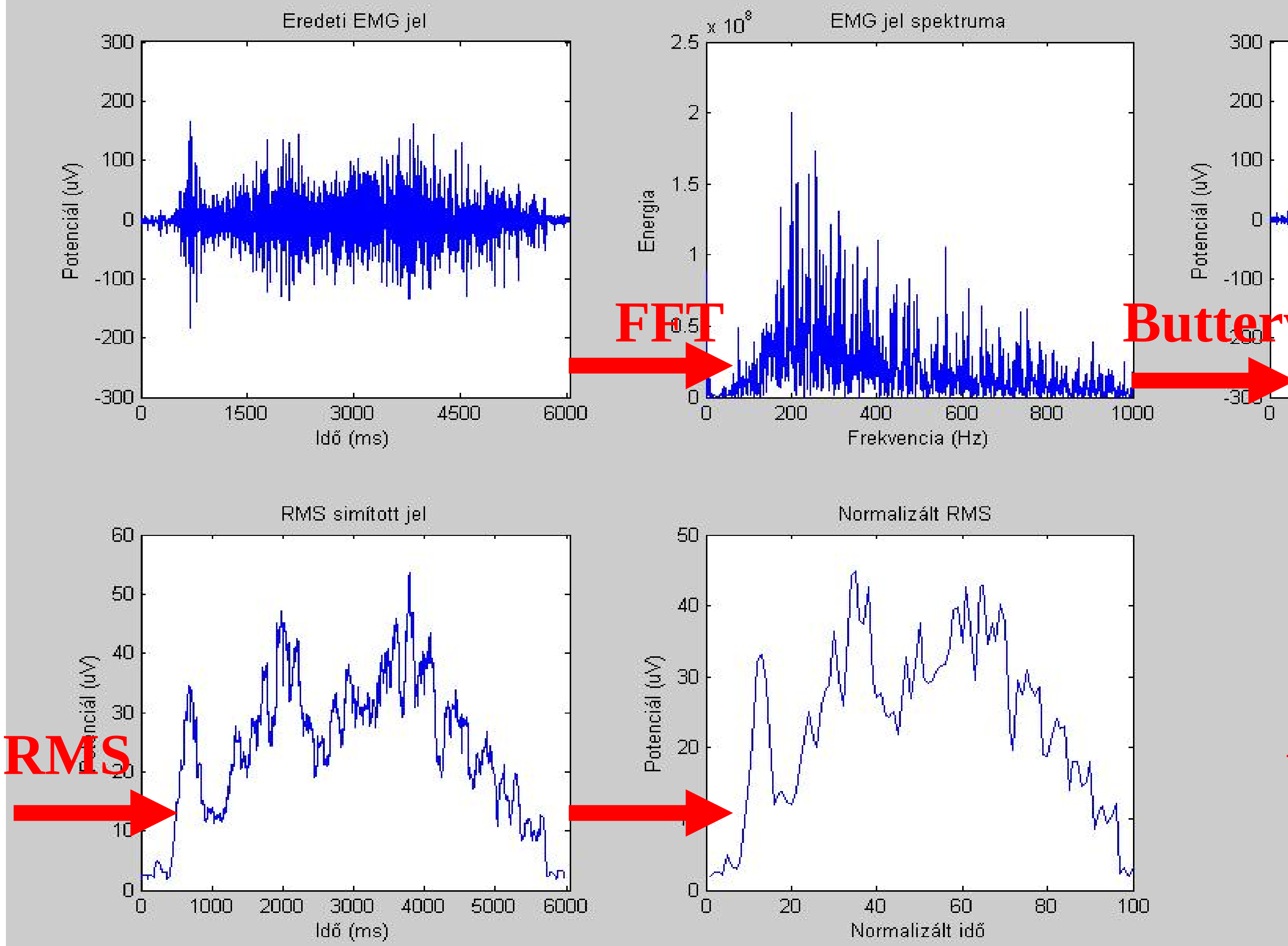
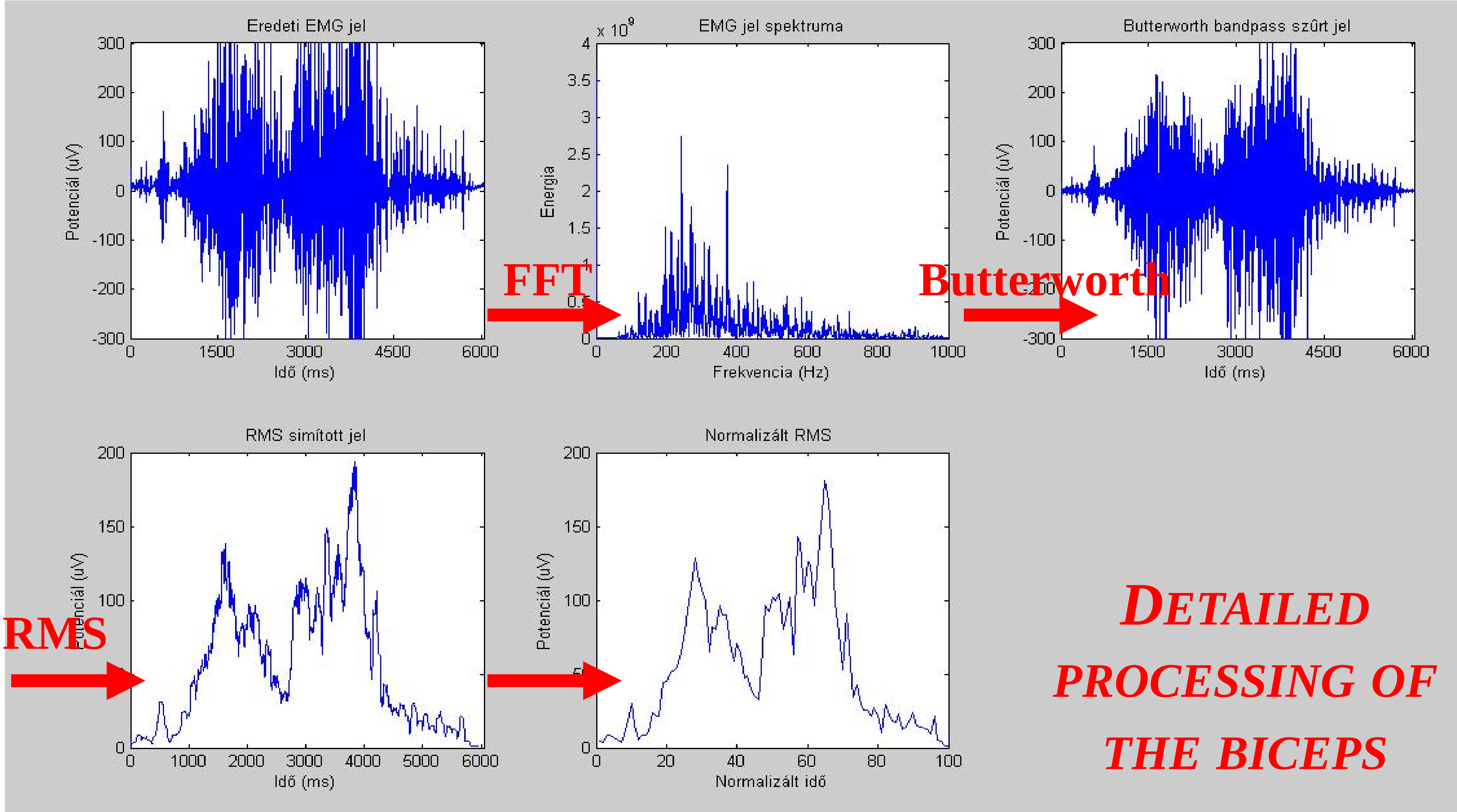
Idő (ms)
FFT
Butterworth
RMS simított jel
Idő (ms)
RMS
Normalizált RMS
Potenciál (uV)
Normalizált idő
DETAILED PROCESSING OF THE TRICEPS



DETAILED PROCESSING OF THE DELTOID POSTERIOR

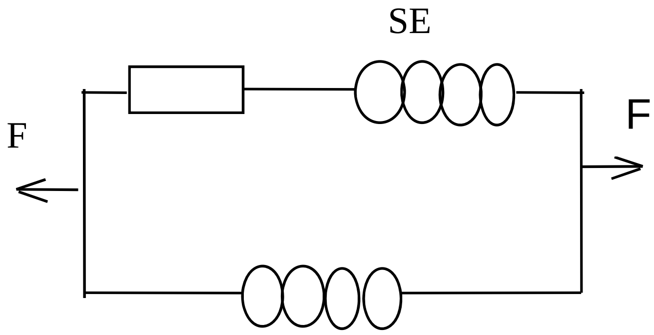
Neuromorph Movement Control:
Electromyography: signal measuring,processing



Hill model

Macroscopic muscle model (muscle=viscoelastic material, no inner stucture apriori knowledge)

elaborate the viscoelastic material:



SE serial elastic element

CE contractile element

PE parallel elastic element)

Active force (contraction) is related to the electrical activity of this struture

Summary

- Prior to muscle force production small amount of electrical current is present
- This current (low voltage) is resulted by the exchange of ions between the inner and outer cell space on the cell membrane of the muscle fibre
- This low potential is measurable: **ELECTROMYOGRAM**
- Important parameters determining EMG measurements
    - Electrodes applied (surface,invasive)
    - Sampling rate (determines the accuracy of the measurement)
    - Avoiding inaccuracy (filtering, smoothing)
        - Reducing noise (alcoholic cleaning of the skin, removing hair from the skin)

Suggested literature

- Laczko J, Pilissy T, Tibold R. (2009): Neuro-mechanical Modeling and Controlling of Human Limb Movements of Spinal Cord Injured Patients. Proc. of the 2nd International Symposium on Applied Sciences in Biomedical and Communication Technologies, ISBN 978-80-227-3216-1

- Laczko J, Tibold R., Fazekas G. (2009): Neuromuscular synergy ensures kinematic stability during 3D reaching arm movements with load. Program No. 272.2 2009 Neuroscience Meeting. Chicago, IL: Soc. for Neuroscience, 2009. Online.

- Tibold R, Poka A, Borbely B, Laczko J. (2009). The effect of load on joint- and muscle synergies in reaching arm movements. Proc. of the VII. Conference on Progress in Motor Control, Marseille, France 2009. July

Suggested literature

- Laczkó J, Pilissy T, Klauber A (2008): Neuro-mechanical factors in controlling cycling movements of spinal cord injured patients through functional electrical stimulation. Proc. of the 12th Intnl. Conference on Cognitive and Neural Systems, Boston MA., p.104.

- Pilissy T, Pad K, Fazekas G, Horváth M, Stefanik Gy, Laczkó J (2007): The role of ankle-joint during cycling movement task. Proceedings of the 9th Congress of European Federation for Research in Rehabilitation, Budapest, Aug 26-29. 2007. Int J Rehabil Res 2007;30 (Suppl 1):58-59.