Subject Name: Biomedical Instrumentation Design I_2

4^{th} Class, Second Semester

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Lecture No.: 1

Lecture Title: EMG Signal Processing.

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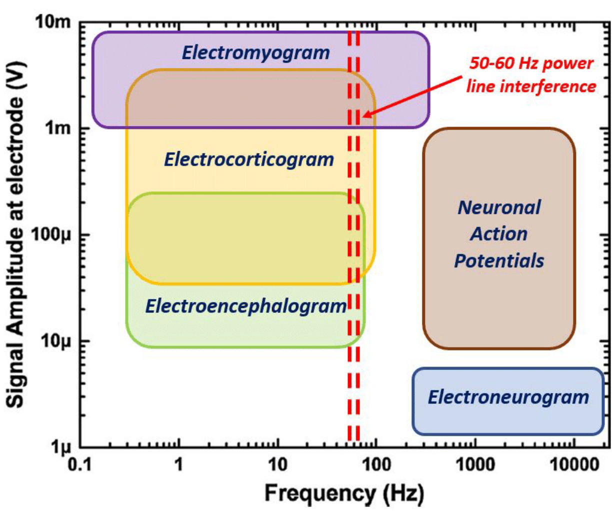
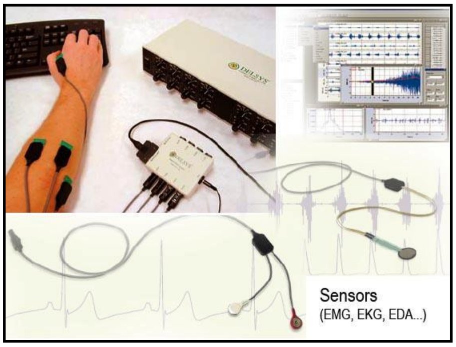
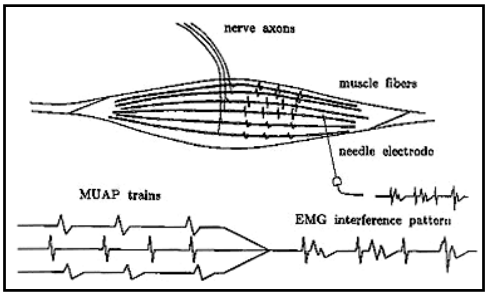
Bio-signal frequency range

Signal	Frequency range (Hz)	Amplitude range(mV)
ECG	0.01 – 300	0.05 – 3
EEG	0.1 – 100	0.001 – 1
EOG	0.1 – 10	0.001 – 0.3
EMG	**50 – 3000**	**0.001 – 100**





EMG Apparatus

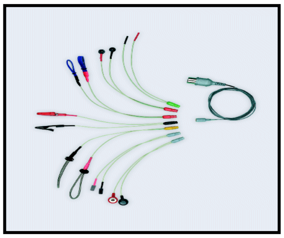


Muscle Structure/EMG

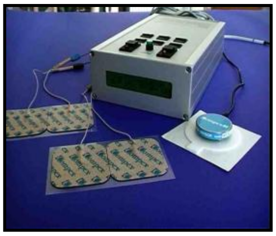
ELECTRODE TYPES

Intramuscular -

Needle Electrodes



Extramuscular - Surface Electrodes

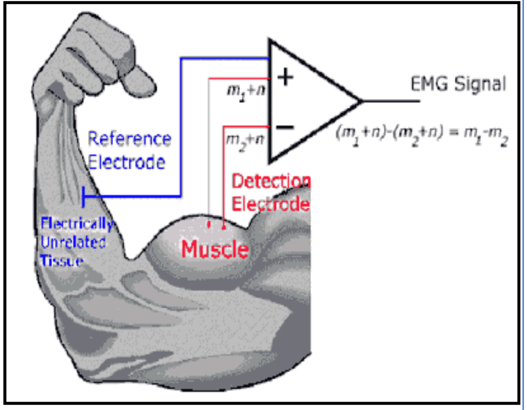


ELECTRODE TYPES

Feature	Intramuscular Electrodes (IM)	Extramuscular Electrodes (EMG)
Placement	Inserted into the muscle	Attached to the skin
Applications	Research, individual muscle fiber activity	Clinical applications, muscle rehabilitation, overall muscle activity
Advantages	High signal quality, less interference	Non-invasive, user-friendly, suitable for long-term monitoring
Disadvantages	Invasive, risk of complications, not suitable for long-term use	Lower signal quality, susceptible to interference, not ideal for deep muscles

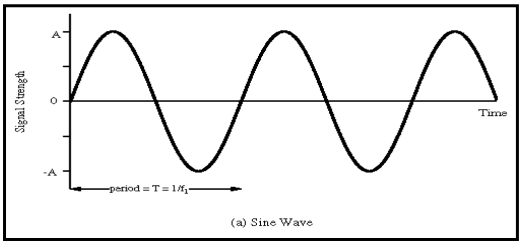
EMG PROCEDURE

- Clean the site of application of electrode;
- Insert needle/place surface electrodes at muscle belly;
- Record muscle activity at rest;
- Record muscle activity upon voluntary contraction of the muscle.



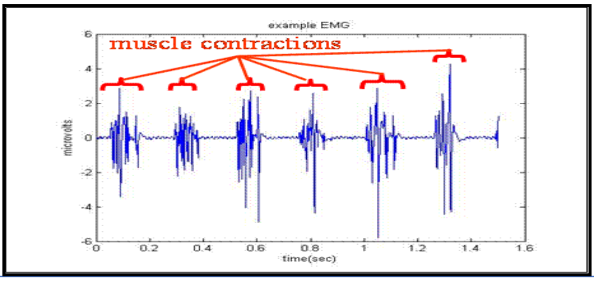
EMG Contd.

- Muscle Signals are Analog in nature.



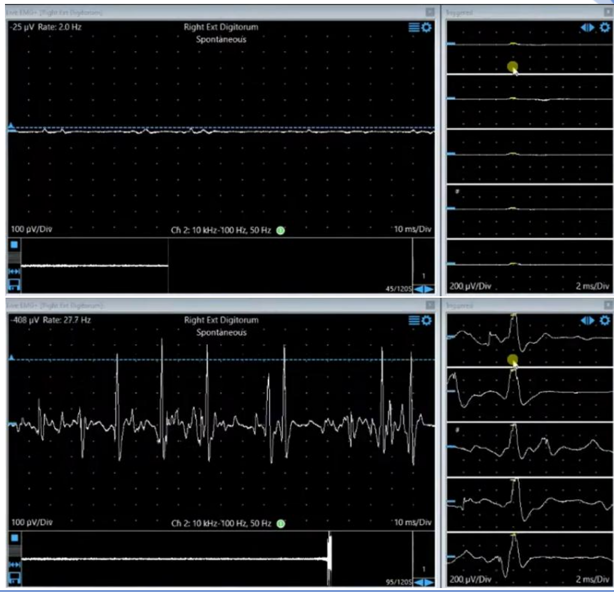
Analog Signal

- EMG signals are also collected over a specific period of time.



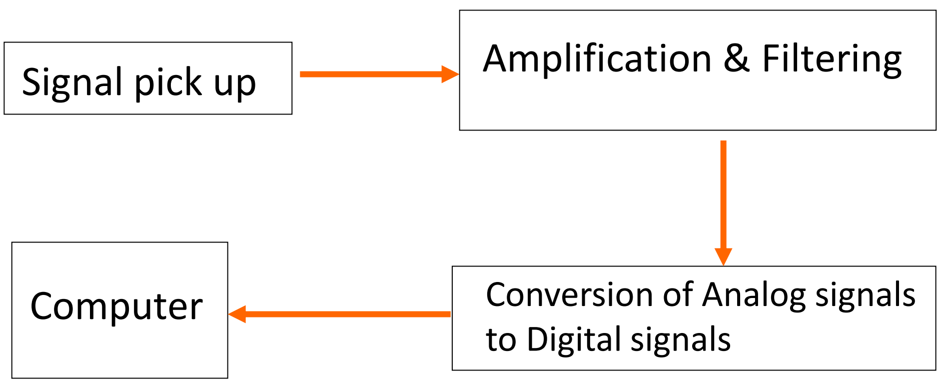
EMG recording using Needle electrode.

- Electrode Placement: the electrodes were placed on the extensor muscles, “Right Ext Digitorum,” of the fingers.
- Recording Mode: Spontaneous recording was made without specific stimulation or voluntary muscle contraction. This is often used to assess for spontaneous muscle activity, which can indicate neuromuscular disorders.
- Time Scale: 10 ms/Div indicates that each horizontal division on the screen represents 10 milliseconds of time. This gives us a rough idea of the time scale of the recorded muscle activity.
- Amplitude Scale: 200 µV/Div in the lower right corner indicates that each vertical division on the screen represents 200 microvolts of electrical activity. This gives us an idea of the amplitude of the recorded muscle signals.
- Waveform: irregular, fluctuating electrical activity typical of EMG recordings. These fluctuations suggest that the muscles are exhibiting some level of electrical activity, even at rest.



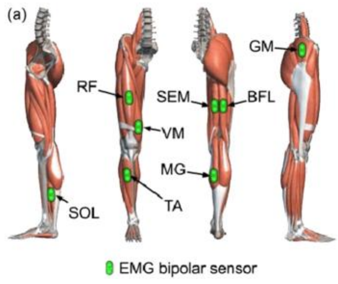
EMG Contd.

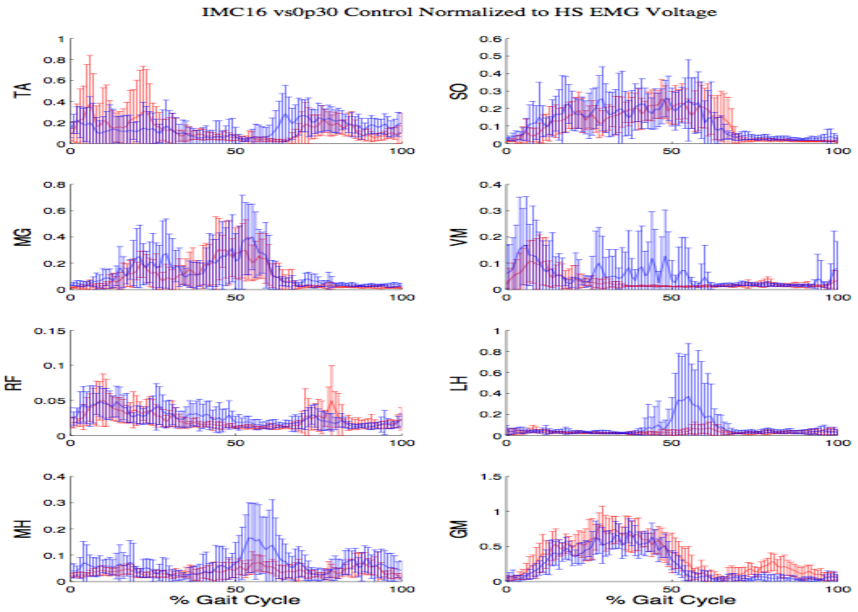
EMG processing:



SAMPLE EMG DATA

•The EMG activity from several muscle groups, including:
•TA (Tibialis Anterior), SO (Soleus), MG (Medial Gastrocnemius), VM (Vastus Medialis), RF (Rectus Femoris), LH (Lateral Hamstrings), MH (Medial Hamstrings), GM (Gluteus Medius)





EMG Signal Processing Methods

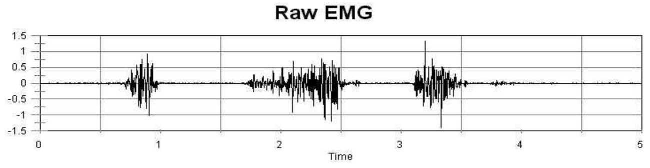
- Raw
- Half-wave rectified
- Full-wave rectified
- Filtering
- Averaging
- Smoothing
- Integration
- Root-mean Square
- Frequency spectrum
- Fatigue analysis
- Number of Zero-crossings
- Amplitude Probability Distribution Function
- Wavelet

Raw EMG

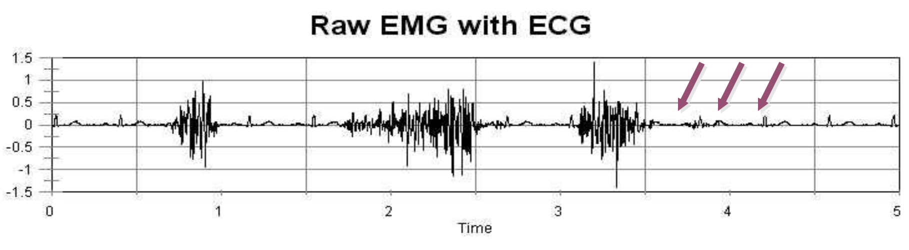
- wide frequency spectrum (20-500 Hz)
- most complete information
- needs 1000 Hz or greater sampling rates
- requires large memory storage
- difficult to determine “levels” of contraction
- bursts of activity and “onset times” may be determined from this signal
- best for examining problems with recording
- The following slides show some errors that can be detected from the raw signal

Errors when Recording EMGs

- “clean” signal



- ECG crosstalk



heart rate detected

ECG Crosstalk

- ECG crosstalk occurs when recording near the heart (ECG has higher voltages than EMG)
- EEG crosstalk when near the scalp (rare)
- difficult to resolve
    - use the right side of the body (away from the heart)
    - move electrodes as far away from the heart as possible
    - "Signal averaging" (average many trials)
    - indwelling electrodes

Muscle Crosstalk

- one muscle's EMG is picked up by another muscle's electrodes
- can be reduced by careful electrode positioning or double differential amplifier
- can be determined by cross-correlation
- difficult to distinguish crosstalk from synergistic contractions; however, biarticular muscles have "extra" bursts of activity compared to monoarticular muscles (thus, crosstalk is not a problem).
- A synergistic contraction occurs when two or more muscles (synergists) contract together to assist the primary muscle (agonist) in performing a movement. Example: During elbow flexion, *Agonist (main muscle)*: Biceps brachii, *Synergist muscles:* Brachialis and Brachioradialis.
- All these muscles may show EMG activity at the same time because they cooperate to produce the motion.

Muscle Crosstalk: Synergy Analysis

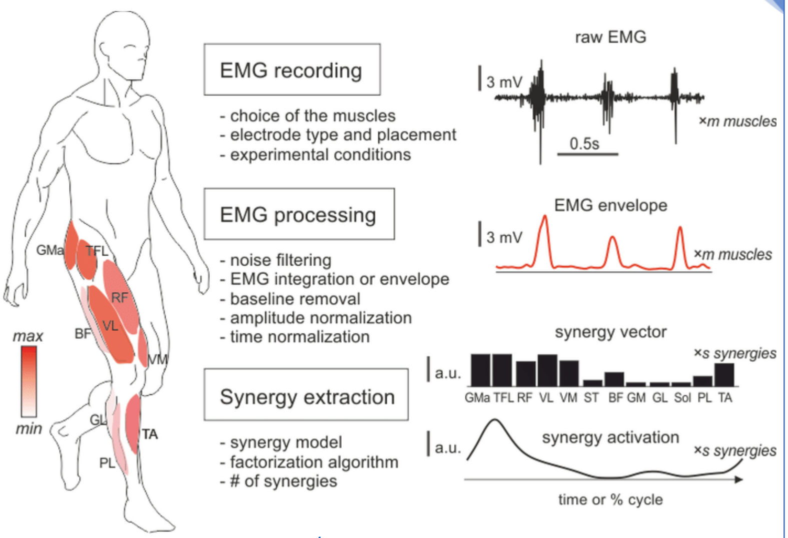
- It's a technique used to understand how muscles work together to produce coordinated movement.
- Instead of considering individual muscles acting independently, synergy analysis identifies groups of consistently activated muscles.
- Goal: To simplify the complex movement control by identifying a smaller number of functional units (synergies) representing multiple muscles' coordinated activation.
- Muscle Synergy Vectors: Each muscle synergy vector is a mathematical representation of a group of muscles that are typically activated together.
- The vector contains information about the relative activation levels of each muscle within the synergy.

Muscle Crosstalk: Synergy Analysis

- Analysis Steps:
- 1. EMG Recording: Electrodes are placed on the skin to record the electrical activity of multiple muscles during movement.
- 2. EMG Processing: The recorded EMG signals are processed to remove noise and isolate the relevant muscle activity.
- 3. Synergy Extraction: Various mathematical techniques (like non-negative matrix factorization) are used to identify the underlying muscle synergies from the processed EMG data.
- In essence, synergy analysis helps us understand how the nervous system controls movement by identifying these coordinated muscle activation patterns. This knowledge can be valuable for rehabilitation, robotics, and understanding motor control in various conditions.

Muscle Crosstalk

- Synergy analysis steps. Muscle synergy analysis identifies the structure of muscle activations, either at the spatial level, represented by muscle synergy vectors, or at the temporal level, represented by muscle synergy activations.
- The analysis requires three main steps: EMG recording, EMG processing, and synergy extraction.
- A lower limb synergy during walking is illustrated.
- The weightings of the different muscles in the synergy vector represent their relative contributions, and the synergy activation indicates how the group of muscles is activated over time.



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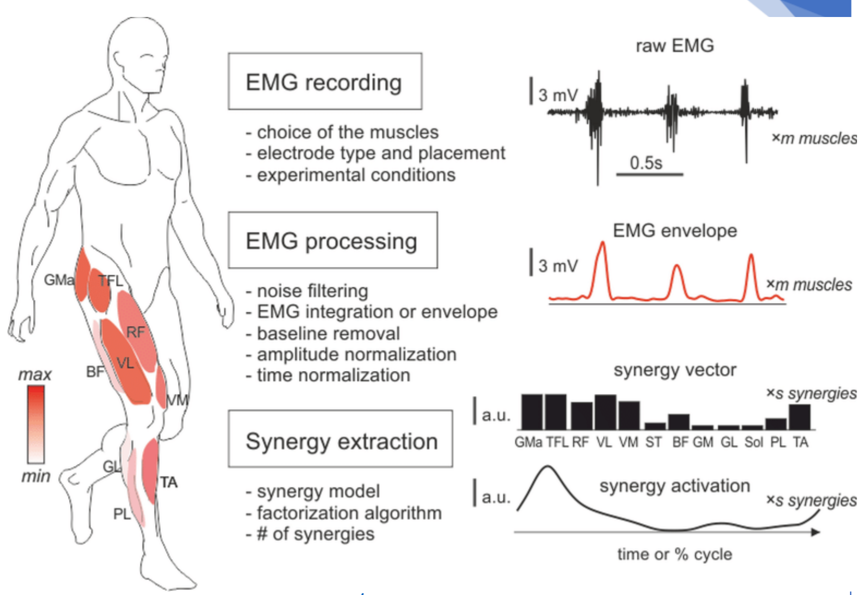
Muscle Crosstalk

- Multiplying the synergy vector by the synergy activation allows the recovery of the level of activity of the different muscles associated with a given synergy in the unit of the EMG envelopes (illustrated in color on the left of the image).
- Gma gluteus maximus, TFL tensor fasciae latae, RF rectus femoris, VL vastus lateralis, VM vastus medialis, ST semi-tendinosus, BF biceps femoris, GM gastrocnemius medialis, GL gastrocnemius lateralis, Sol soleus, PL peroneus longus, TA tibialis anterior.



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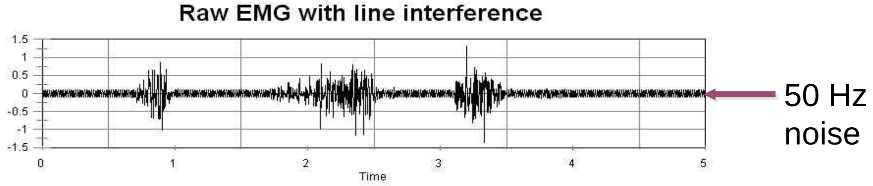
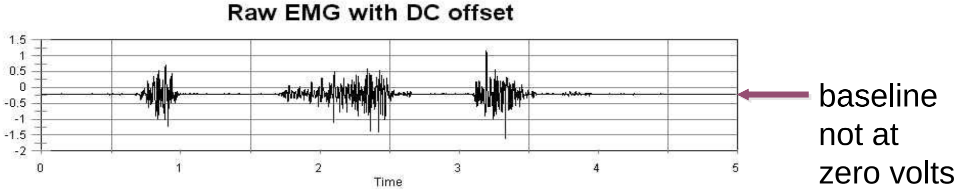
Errors when Recording EMGs

- line (AC) interference



- DC-offset or DC-bias



Solutions

To interference (line AC and radio frequency RF) Keep away from fluorescent lighting

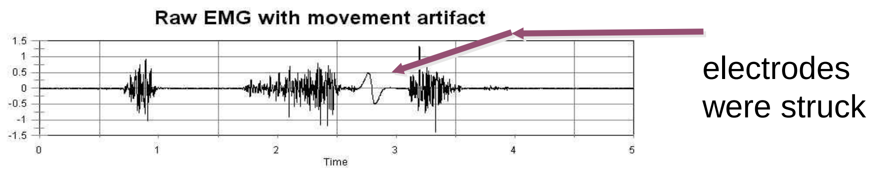
- Keep away from large electrical devices and power cords (especially leads and cabling)
- Use a room lined with grounded conductive material
- Keep leads short and braided (vs. radio)
- Use preamplified electrodes (signal is stronger)
- Use an extremely narrow notch filter in post-processing (e.g., 49.5-50.5 Hz)
  For DC (telemetry systems often have DC offsets)
- Use a good ground electrode over the electrically neutral area
- Use a high-pass filter (5–10 Hz) to remove in post-processing

Removing Bias

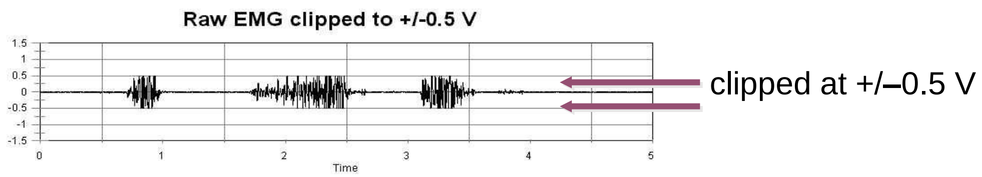
- Low amplitude voltage offset present in hardware
- Can be AC or DC
- Calculate the mean of all the data
- Subtract mean from each data point

Errors when Recording EMGs

- movement artifact



- amplifier saturation (+/–0.5 V)



Solutions

To movement artifacts

- Affix leads to the subject (tape, wrap, webbing)
- Prevent electrodes from being struck (use lateral muscles)
- Avoid rapid motions
- Use a strong high-pass filter in post-processing

Amplifier saturation

- Test with maximal contractions before recording
- Reduce gain if peaks and valleys “top out” or “bottom out.”
- Use larger range A/D converter (+/–10 V vs. +/–5 V)

Frequency Spectrum

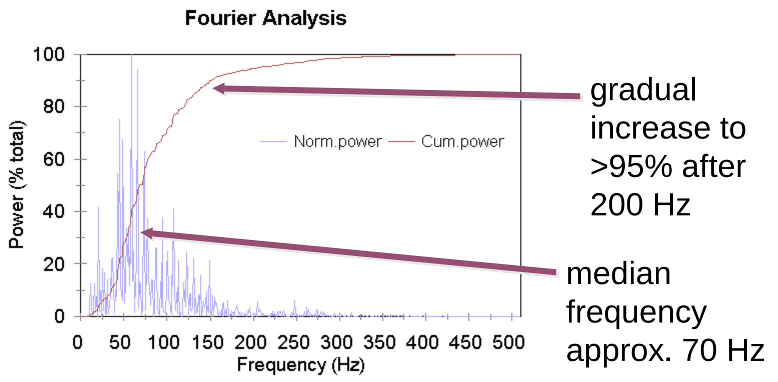
- useful for determining onset of muscle fatigue
- mean or median frequency of spectrum in unfatigued muscle is usually between 50–80 Hz
- as fatigue progresses fast-twitch fibres drop out, shifting frequency spectrum to left (lowering mean and median frequencies)
- mean frequency is less variable and therefore is better than median
- useful for detecting neural abnormalities

Frequency Spectrum

- In EMG, both median and mean frequency are used to characterize the frequency content of the EMG signal.
- **Mean Frequency:** The mean frequency is the average of all frequencies in the EMG power spectrum. The mean frequency is more sensitive to changes in the high-frequency components of the EMG signal. It is often used to assess muscle fatigue, as fatigue is associated with a shift in the power spectrum towards lower frequencies.
- **Median Frequency:** The median frequency is the frequency at which the power spectrum is divided into two equal halves. The median frequency is less affected by noise and outliers in the EMG signal than the mean frequency. It is often used as a more robust measure of muscle activation and fatigue.
- If the EMG data is noisy or contains outliers, the median frequency might be a more robust measure. If the measurement is required to be more sensitive to changes in the high-frequency components of the EMG signal, the mean frequency might be more suitable.

Example Power Spectrum

- flexor digitorum longus
  - Maximal Voluntary Contraction



Raw EMG

- Unprocessed signal
  - Amplitude of 0-6 mV
  - Frequency of 10-500 Hz
- Peak-to-Peak
  - Measured in mV
  - Represents the amount of muscle energy measured
- Onset times can be determined
- Analysis is mostly qualitative

Filtering

- **Notch filter**
- -Band reject filter; usually very narrow
- -For EMG, normally set from 49-51 Hz
- -Used to remove 50 Hz electrical noise
- -Also removes real data!
- -Too much noise will overwhelm the filter

Filtering

- **Band Pass filter**
- -allows specified frequencies to pass
- -low-end cutoff removes electrical noise associated with wire sway and biological artifacts
- -high-end cutoff eliminates tissue noise at the electrode site-often set between 20-300 Hz

Filtering

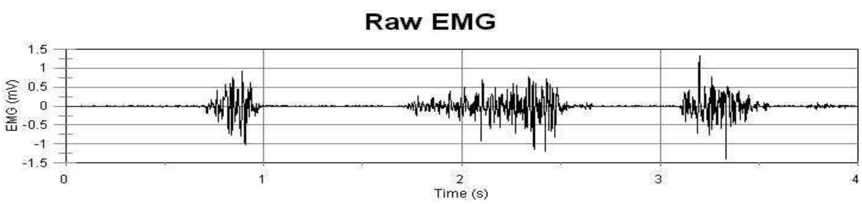
- There are no perfect filters!
- Face muscles can emit frequencies up to 500 Hz
- Heart rate artifact can be eliminated with low-end cutoffs of 100 Hz
- Filters that include 50 Hz include the noise from equipment

Rectification

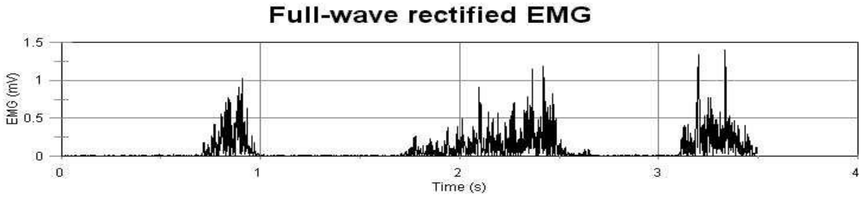
- Only positive values are analyzed
- **Half-wave rectification**
  - Only the positive half-cycles of the EMG signal are retained, while the negative half-cycles are set to zero.
- **Full-wave rectification**
  - Both positive and negative half-cycles of the EMG signal are converted to positive values. This is typically achieved by taking the absolute value of the signal.
- **Full-wave is preferred**

Sample EMGs

- raw EMG (band-passed filtered, 20-500 Hz)



- full-wave rectified

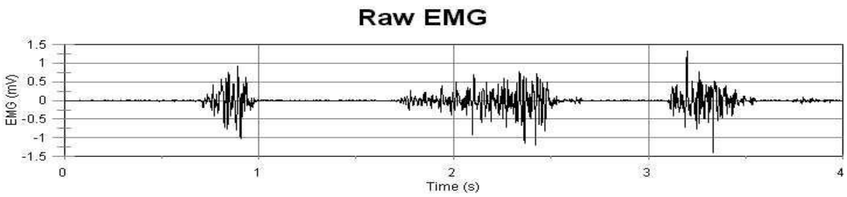


Averaged EMG

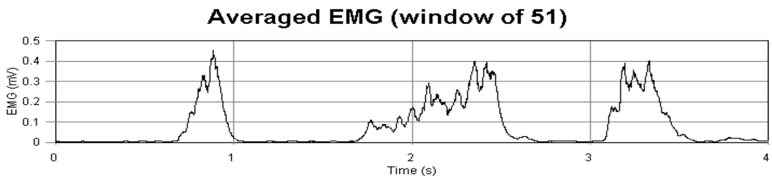
- simple to compute
- can be done in real-time
- Averaged EMG is a "moving average" of a full-wave rectified EMG
- must select an appropriate "window width" that changes with the sampling rate
- easy to determine levels of contraction

Sample Averaged EMG

- raw EMG (1010 Hz sampling rate)



- averaged EMG (moving average, 51 points)



Averaging

- Average EMG can be used to quantify muscle activity over time
- Measured in mV
- Values are averaged over a specified time window
- Window can be moved or static
- Moving windows are a digital smoothing technique
- For moving windows the smaller the time window the less smooth the data will be

Averaging

- For EMG window is typically between 100-200 ms
- Window is moved over the length of the sample
- Moving averages introduce a phase shift
- Moving averages create biased values

-values are calculated from data which are common to the data used to calculate the previous value

- Very commonly used technique

Integration

- Calculation of area under the rectified signal
- Measured in Vs
- Values are summed over the specified time and then divided by the total number of values
- Values will increase continuously over time
- The integrated average will represent 0.637 of one-half of the peak-to-peak value
- Quantifies muscle activity
- Can be reset over a specified time or voltage

Root Mean Square

- Recommended quantification method by Basmajian and DeLuca.
- Calculated by squaring each data point, summing the squares, dividing the sum by the number of observations, and taking the square root.
- Represents 0.707 of one-half of the peak-to-peak value

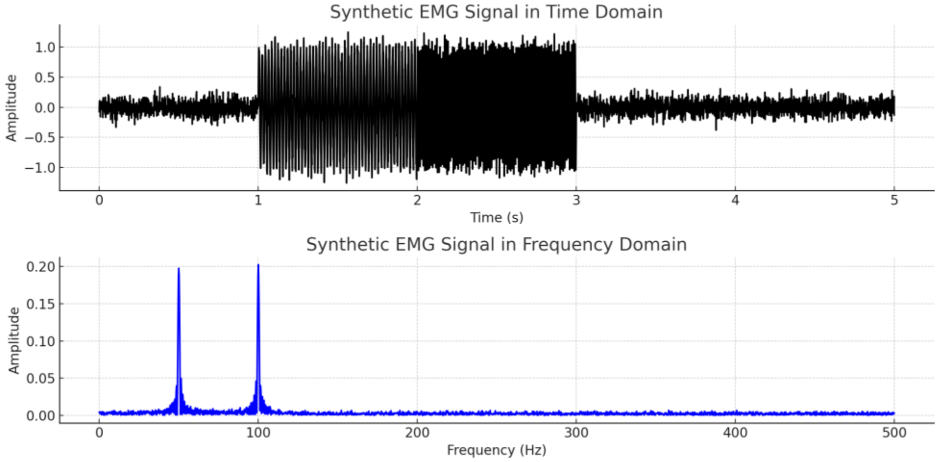
Number of Zero Crossings

- Counting the number of times the amplitude of the signal crosses the zero line
- Based on the idea that a more active muscle will generate more action potentials, which will cause more zero crossings in the signal
- Primarily used before the FFT algorithm was widely available

Frequency Analysis

- Fast Fourier Transformation is used to break the EMG signal into its frequency components.
- Frequency components are graphed as function of the probability of their occurrence
- Useful in determining cutoff frequencies and muscle fatigue

Frequency Analysis



Time-Domain Plot: The upper plot shows the EMG signal over time, where certain segments have activity (1-3 seconds) with higher amplitude due to simulated muscle contractions at 50 Hz and 100 Hz. Before and after the active segments, there is baseline noise, resembling resting EMG.
Frequency-Domain Plot: The lower plot shows the EMG signal after applying FFT. Peaks at 50 Hz and 100 Hz clearly appear, corresponding to the frequency components we added to simulate muscle activity.