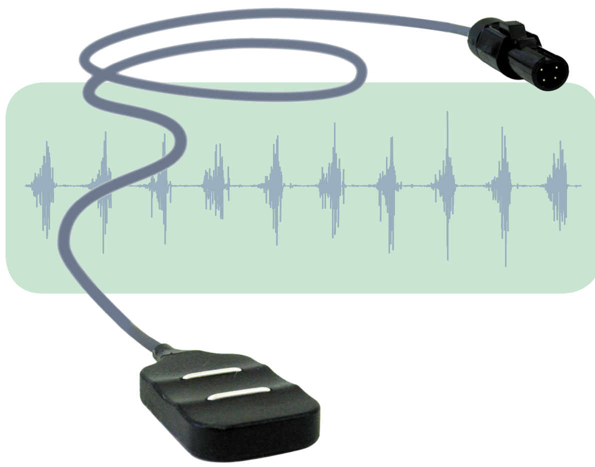
DELSYS®

Technical Note 103: EMG Signal Analysis



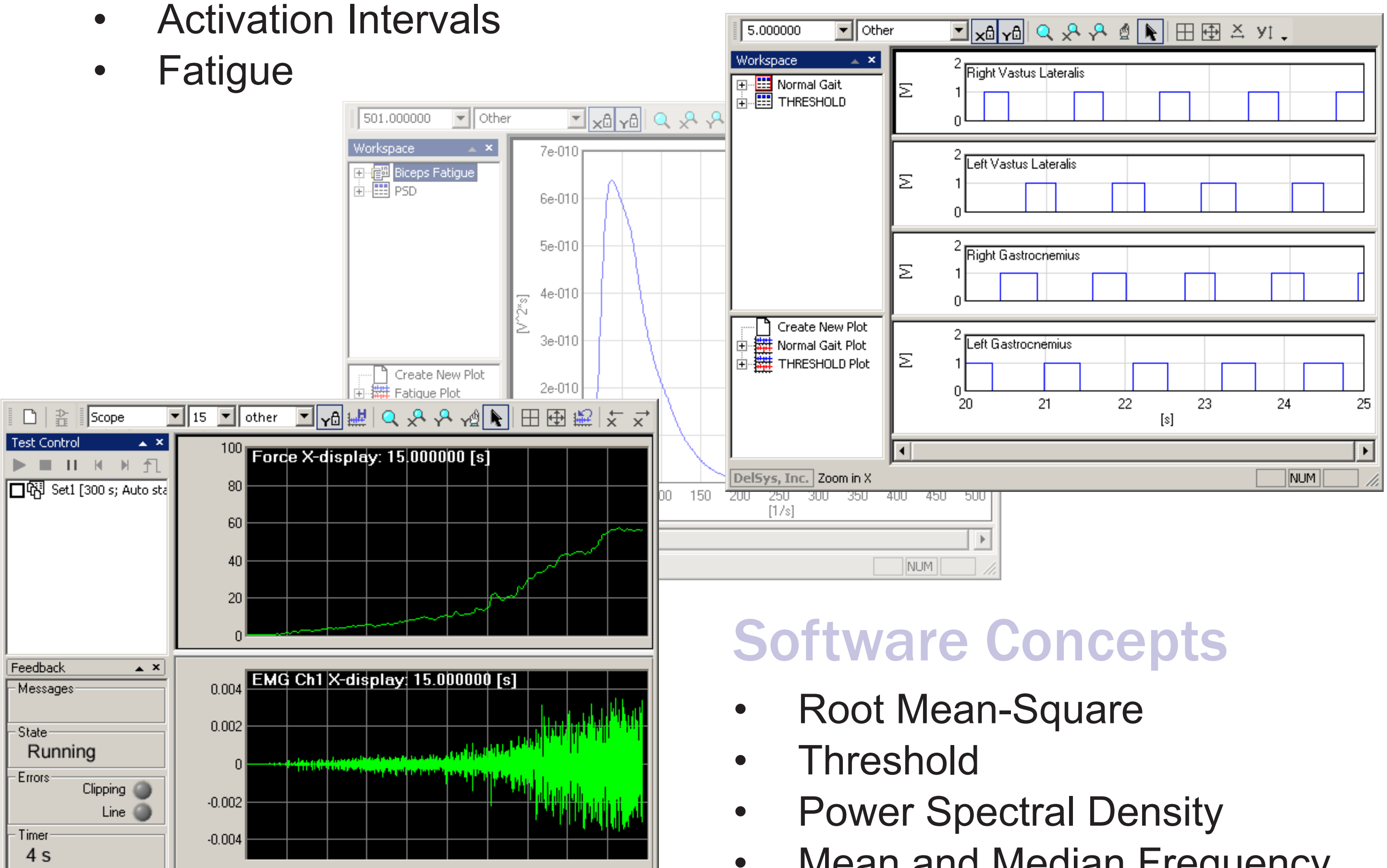
Purpose

This technical note addresses the main classes of EMG analysis. It assumes that quality EMG data has already been acquired. Please see **Technical Note 101: EMG Sensor Placement** and **Technical Note 102: EMG Signal Quality** for more details.

- Amplitude Analysis
- Timing Analysis
- Spectral Analysis

Surface EMG Concepts

- EMG Amplitude and Muscle Force
- Activation Intervals
- Fatigue



Software Concepts

- Root Mean-Square
- Threshold
- Power Spectral Density
- Mean and Median Frequency

Introduction

This document is one of a series of technical notes designed to address important concepts dealing with Delsys® hardware and software. The goal of this technical note is to introduce the three main classes of EMG signal analysis. These fundamental techniques have classically yielded the most insight into the EMG signal. Some example applications for each type of analysis will also be discussed.

Amplitude Analysis

The amplitude of the EMG signal at any instant in time is stochastic or random. In most circumstances, however, visual inspection of the gross EMG signal reveals that its amplitude is roughly proportionally to the force exerted by the underlying muscle. This relationship can be easily appreciated by viewing the EMG signal in real-time while the intensity of the muscular contraction is increased as in *Figure 1A*. There are a number of calculations that give insight into the amplitude of the EMG signal. The root mean-square (RMS) is considered to be the most meaningful, since it gives a measure of the power of the signal. *Figure 1B* shows the RMS trace for the EMG signal from *Figure 1A*.

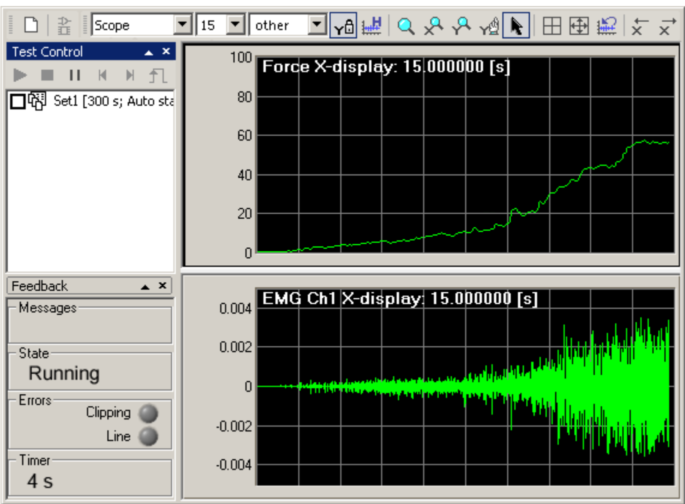


Figure 1A: Force output from the first dorsal interosseous muscle of the hand recorded with the corresponding EMG activity. It is clear visually that the amplitudes are roughly proportional.

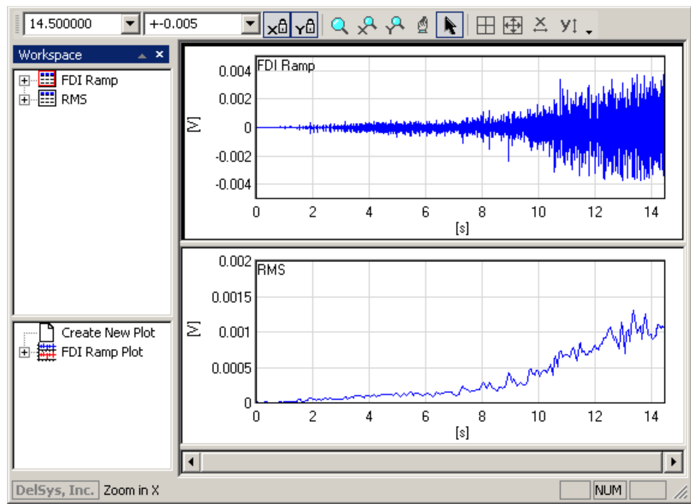


Figure 1B: EMG activity from the first dorsal interosseous muscle along with the calculated RMS for the data. The RMS trace is very similar to the force trace in Figure 1A.

It can be seen that the RMS trace from *Figure 1B* is very similar to the force trace from *Figure 1A*. They do not follow each other exactly, however. There are a number of reasons why the amplitude of the EMG signal from a muscle does not directly correlate with the force generated by that muscle. These include complex anatomical, physiological, detection, and calculation factors that will not be discussed in this document. Please refer to **www.delsys.com > Knowledge Center > Tutorials > The Use of Surface Electromyography in Biomechanics** for a detailed discussion.

Despite the fact that there is not a simple equation to correlate the muscle force with the EMG signal amplitude, the qualitative relationship between them has proved useful in many scenarios. These include biofeedback applications that are used for the training of specific muscles, ergonomic assessments that establish the degree to which muscles contract or relax, biomechanics investigations that determine the role that individual muscles have in contribution to joint torque, as well as many other applications.

Timing Analysis

The ability to correlate EMG amplitude with muscle force output allows one to determine whether a muscle is inactive (when its amplitude is effectively 0) or whether it is active (when its amplitude is greater than 0). By analyzing groups of muscles in this way, it is possible to establish muscle timing patterns for dynamic movements. This gives tremendous insight into how muscles are recruited and controlled for achieving specific movements.

Gait analysis is setting where timing analysis is helpful. *Figure 2A* shows EMG signals recorded during normal gait from the right and left vastus lateralis and the right and left gastrocnemius. The Threshold calculation was used to determine the activation intervals for each of the muscles and the results are shown in *Figure 2B*. Studying the timing of the activation intervals gives a great deal of information.

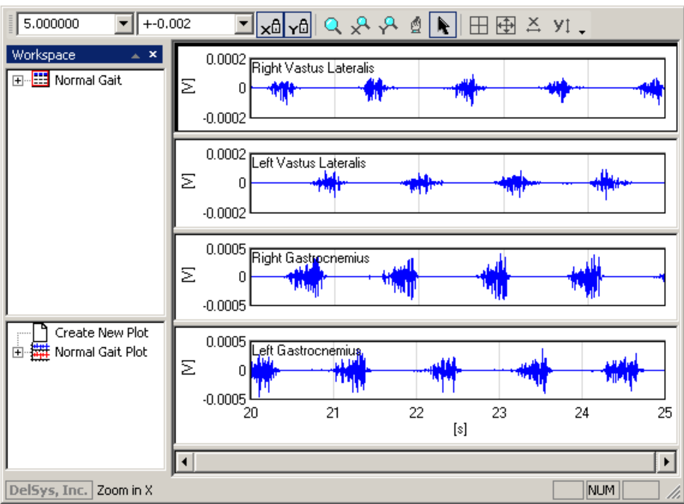


Figure 2A: EMG signals from the right and left vastus lateralis and right and left gastrocnemius during normal gait.

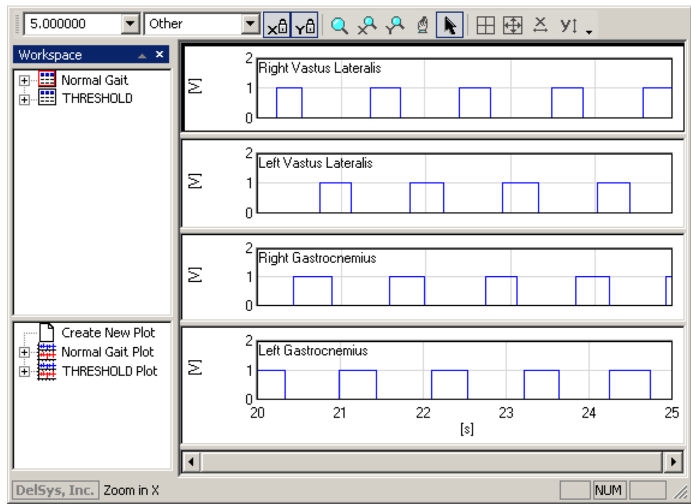


Figure 2B: Activation intervals for each of the muscles from the normal gait obtained using the Threshold calculation.

Comparing the activation intervals from normal gait with pathological gait from a limping patient in *Figures 3A* and *3B* reveals how the duration of contractions change and how the timing also changes.

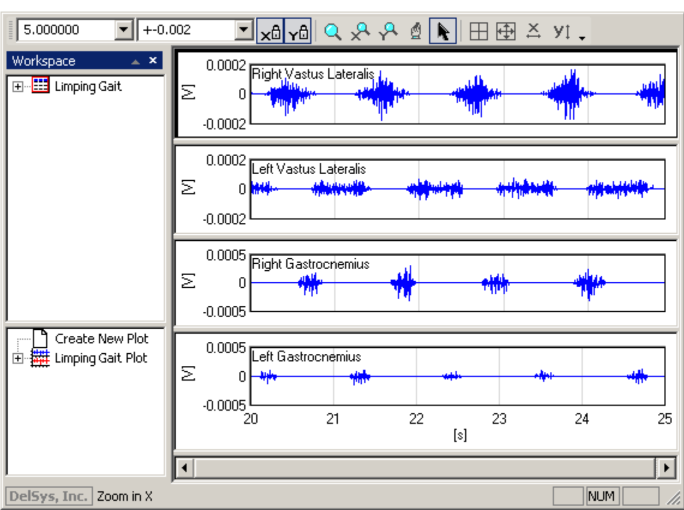


Figure 3A: EMG signals from the right and left vastus lateralis and right and left gastrocnemius during limping gait.

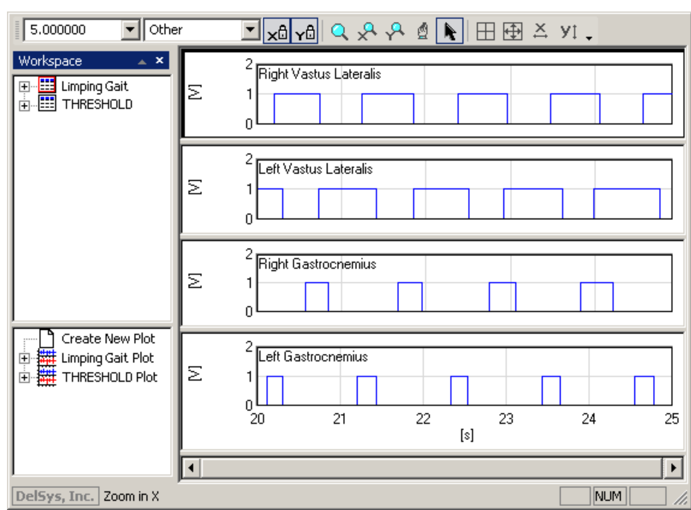


Figure 3B: Activation intervals for each of the muscles from the limping gait obtained using the Threshold calculation.

Activation intervals are helpful not only because they more clearly demarcate the beginning and end of each contraction for visual inspection as with the gait example, but they also allow for more complex quantitative analysis. The length of contractions or rest periods can be averaged for the length of a recording and variability can be examined. Statistics can be compared between different recordings and different subjects. Mathematical operations can be performed on pairs or groups of activation intervals to determine periods of muscle coactivation and periods of overall rest. The potential for different types of analysis is only limited by the imagination of the researcher.

Some other settings where timing analysis has proven useful include biomechanical assessments, sport science for muscle coordination training, and physical therapy for muscle rehabilitation and reeducation purposes.

Spectral Analysis

The previous two methods of analysis make use of the EMG signal in the time domain, as it was sampled in its original form. The third category of EMG signal analysis relies on the frequency domain. Any signal can actually be mathematically deconstructed into a collection of sine waves of different frequencies through an operation called a Fourier Transform. The result essentially gives an evaluation of what contribution each frequency has to the original signal. In order to gain meaningful information from this type of calculation, the segment of data being studied must be stationary, meaning that the statistics of the signal do not change with time. The easiest way to ensure stationarity in an EMG signal is to constrain the muscle to perform a contant-force, isometric contraction. *Figure 4A* shows EMG data from the biceps muscle during a constant-force, isometric contraction. *Figure 4B* shows the Power Spectral Density (PSD), which was calculated by squaring the Fourier Transform from each segment of data and averaging them. This gives a measure of the power that each frequency contributes to the EMG signal.

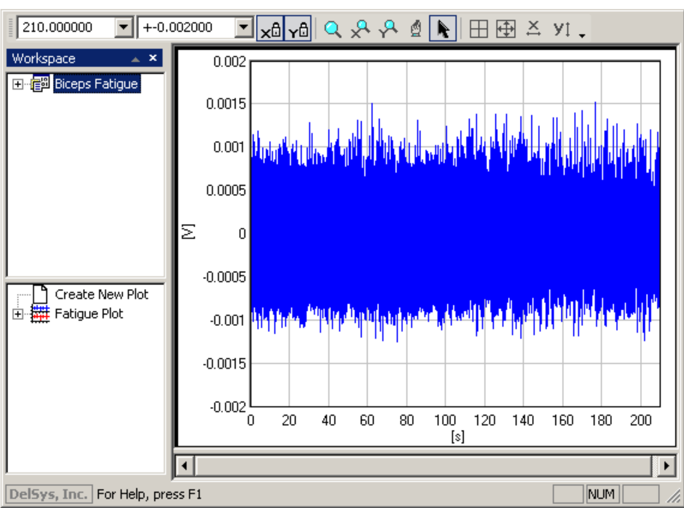


Figure 4A: EMG signal from the biceps muscle during a constant-force, isometric contraction.

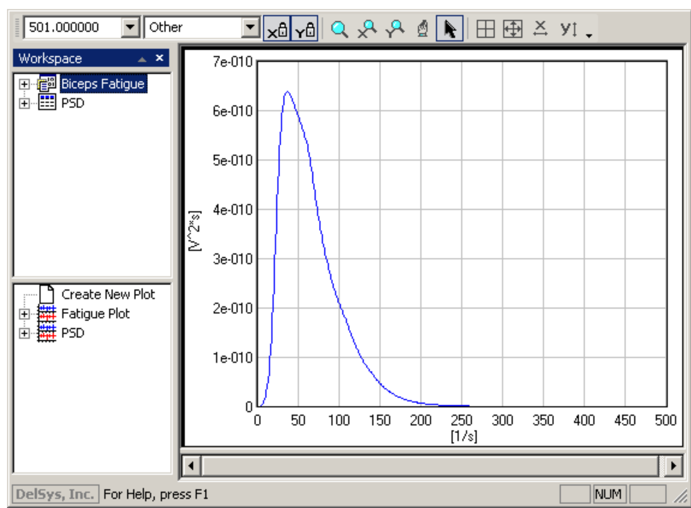


Figure 4B: PSD for the EMG data from the biceps. The contribution of power from each frequency can be visualized.

The PSD shown above summarizes the frequency components for the entire length of the EMG data. Another important part of spectral analysis relies on studying how the frequency components vary with time. Qualitative assessments can be made by calculating the PSD for each segment of data and comparing them. Quantitative assessments can be made by calculating the mean frequency or the median frequency of the PSD sequentially for epochs of EMG data.

The most important application of spectral analysis is the study of muscle fatigue. It has been shown that the mean and median frequencies of the EMG signal decrease with time during a task that induces fatigue. *Figure 5A* shows the median frequency calculated as a function of time for the data from the biceps. *Figure 5B* shows a curve fit to this data to quantify the decrease in median frequency with time.

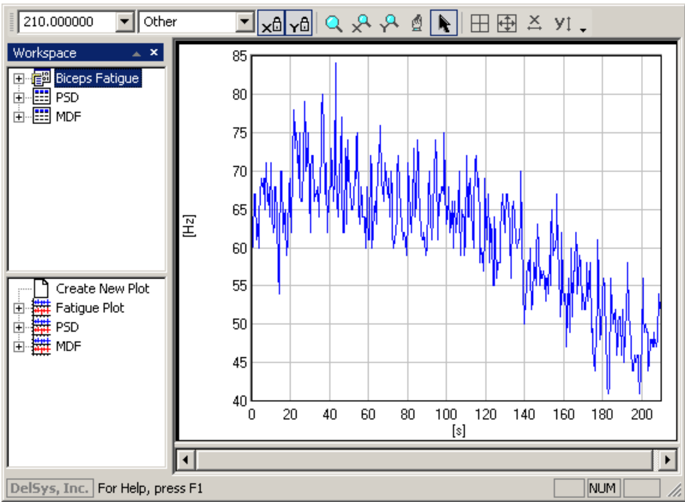


Figure 5A: Median frequency of the biceps EMG data as a function of time.

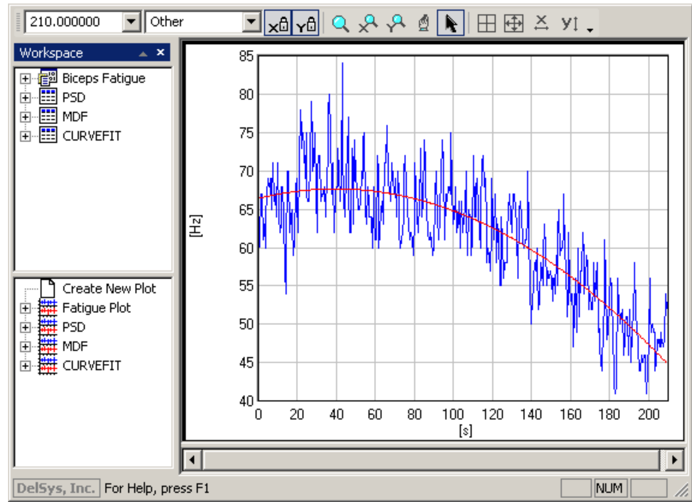


Figure 5B: Median frequency of the biceps EMG data as a function of time along with a curvefit to quantify the decrease in median frequency.