

Homework 7 - BIOEN 440 / ME 445 - Spring 2016

1. Neuromuscular System

(a) Components

In your own words describe the major functions and properties of the seven components of the neuromuscular system described in class.

(b) Pathologies

Choose one of the seven components and (using the web) research a pathology or disease that acutely effects only that component (e.g., muscular dystrophy). In one paragraph describe the mechanism of the disease, how it effects the patient, and the current treatments available.

2. Muscle Contractions

Review the *muscle contraction* reading material posted on the website. In your own words, describe two types of muscle contractions (e.g., isometric), and provide a real world example of when they occur (e.g., an exercise or movement). Do these contraction apply to dynamic movements? Why or why not?

3. Tetanic Twitch Simulation

(a) Derivation

In class we discuss how a motor unit twitch can be modeled as an impulse response of a critically damped second order system. That is, the force $F(t)$ generated by the motor unit subject to a electrical stimulation can be described as:

$$F(t) = F_0 \frac{t}{T} e^{-t/T}$$

where F_0 and T are motor unit specific constants. The general form of a second order system is:

$$\ddot{y}(t) + 2\zeta\omega_n\dot{y}(t) + \omega_n^2 y(t) = K\omega_n^2 u(t)$$

where ζ is the damping ratio, $y(t)$ is the response and $u(t)$ is the input. (Note: for our case let $y(t) \rightarrow F(t)$).

1. Write down the Laplace transform. It should be in the form:

$$\frac{F(s)}{U(s)} = \dots$$

2. Let the input be an impulse: $u(t) = \delta(t)$ (i.e., $U(s) = 1$). Take the inverse Laplace and show that it is equivalent to:

$$F(t) = F_0 \frac{t}{T} e^{-t/T}$$

(b) MATLAB Simulation

Next, you will use MATLAB to simulate the muscle twitch response. Choose $F_0 = 1$ N and $T = 79$ ms. First, define a time vector and constants:

```
dt = 1/1000;      % timestep
Tf = 1;           % total simulation time
t = 0:dt:(Tf-dt); % time vector
T = 0.079;        % T constant
F0 = 1;           % F0 constant
```

You will use the `impz` command to simulate the impulse twitch response. Use your answer in (1) to create the transfer function model:

```
s = tf('s');      % Create laplace variable
sys = ...        % Create system transfer function
```

Note: you must fill in the expression for `sys = ...` with the your solution from (1). For example, if your transfer function is $\frac{F(s)}{U(s)} = 1/(s^2 + 1)$ then

```
sys = 1/(s^2 + 1)      % Create system transfer function
```

Finally, simulate the response to an impulse:

```
[F,~] = impulse(sys,t); % Impulse response
```

Plot the simulated and analytic responses on the same plot. Are they the same? (they should be!)

(c) Tetanic Response

Next you will explore the frequency at which the motor unit must be excited in order to produce fused tetanic response. For this you must create an impulse train, that is, impulses equalling spaced in time:

```
f = 1;           % frequency (Hz) of impulse train
fs = 1/dt;       % Sampling frequency
u = zeros(size(t)); % array of all zeros, size of time vector
u(1:fs/f:end) = 1; % make every element 1 at interger multiples of f
```

Now you can simulate the twitch response to an impulse train:

```
[F,~] = lsim(sys,u,t) % simulate system
```

Do/Answer the following:

1. On the same plot, plot the twitch response for $f = [1, 25, 50, 100]$ (Hz).
2. At what frequency does the tetanus become fused?
3. Does the peak (max force) change as a function of impulse frequency?
4. Describe, in your own words, how peak force is modulated by the neuromuscular system.

4. Linear Envelope of EMG

Often researchers and clinician are interested in relating the force a muscle produces with an acquired EMG signal. One way to do this is to treat the EMG signal as the superposition of many motor unit action potentials (by full-wave rectifying) and using a critically damped low-pass filter to match the twitch response of the muscle being recorded. This is called the *linear envelope* of the EMG signal. The result is an approximation to of the muscle forces under consideration. Of course the linear envelope must be properly scaled to convert from mV to N.

In this exercise you will find the linear envelope of an EMG signal of the semitendinosus muscle (part of the hamstring) recorded during flexior of the lower leg. First download the data from the website and load the data into matlab:

```
load('st_emg.mat') % load data
```

Note, the units are in millivolts (mV) and the sampling frequency of the EMG signal is $f_s = 1$ kHz. Make a time vector:

```
fs = 1000;           % Sampling freq.
t = 0:(1/fs):(numel(st_emg)*(1/fs) - 1/fs); % time vector
```

Recall how to create and simulate transfer functions (see previous problem). Design a second order critically damped low-pass filter, with cut off frequency of $f_c = 2$ (Hz). Do the following:

1. Derive the transfer function of your filter
2. Full wave rectify the signal (absolute value)
3. Low-pass filter the result using the filter you designed
4. Plot the original and linear envelop on the same plot

Discussion:

1. This method has been shown to agree well for isometric contractions, however, for dynamic movements EMG doesn't always agree with tension/force measurements. Why?
2. What is cross-talk and how does this effect EMG?

5. Qualitative Kinematic Analysis

In this section you qualitatively compare lower limb kinematic locomotion data of a unimpaired individual and a person with a transtibial amputation. First load the data files:

```
load('S1.mat');  
load('S2.mat');
```

Each data file contains a MATLAB structure with average ankle, knee and hip saggital plane angles, for each leg, during steady gait. All units are in radians. You can view the structure with the in the command line:

```
>> S1
```

```
S1 =
```

```
RAnkleAngle: [1001x1 double]  
LAnkleAngle: [1001x1 double]  
LKneeAngle: [1001x1 double]  
LHipAngle: [1001x1 double]  
RKneeAngle: [1001x1 double]  
RHipAngle: [1001x1 double]  
gaitCycle: [1x1001 double]
```

You can access the data vector using a period: `S1.RAnkleAgle`.

Do the following:

1. Create two figures, one for each subject, with 3 vertical subplots, one for each kinematic variable (hip, knee, ankle). Plot left and right kinematic variable on same plot. You should label each plot and axis.
2. Within each subject compare the temporal and kinematic symmetry. That is to say, are the left and right limbs doing the same thing at the same time? Are the amplitudes (peak, overall shape) similar for each kinematic angle? During what range of the gait cycle is symmetry highest/lowest?
3. Now compare the subjects to each other. Repeat the analysis above.
4. Which subject has the amputation? Which side?

6. Paper Review

Read the *sensorimotor control* paper posted on the website. Give a brief one paragraph summary.

Address the following:

1. What are the experimenters trying to test?
2. How did they test this?
3. Describe the difference test conditions.
4. What were the results?
5. What are the limitations of the study?