Student names: ... (please update)

Instructions: Update this file (or recreate a similar one, e.g. in Word) to prepare your answers to the questions. Feel free to add text, equations and figures as needed. Hand-written notes, e.g. for the development of equations, can also be included e.g. as pictures (from your cell phone or from a scanner). ***This lab is graded.*** *and need to be submitted before the* ***Deadline : 03-04-2018 Midnight****.*
Please submit both the source file (.doc/*.tex) and a pdf of your document, as well as all the used and updated Python functions in a single zipped file called lab4_name1_name2_name3.zip where name# are the team member's last names. Please submit only one report per team!*

In this exercise, you will explore the different modelling techniques that can be used to control a single joint and segment. We initially start by exploring a single joint controlled by a pair of antagonist spring like muscles and then extend the model by adding dampers to it. These only represent the passive dynamics observed in a real musculoskeletal system. To make the behaviour more realistic we then study more complex hill muscle model in detail.

Exercise 1 : Pendulum model with passive elements

Mechanical behavior of muscle tissue can be described by simple passive elements such as springs and dampers. These elements, when combined properly, allow to study the behavior of muscle under compressive and tensile loads.

Explore the pendulum model with two antagonist spring elements

In this question the goal is to add two antagonist springs to the pendulum model which you are already familiar with from lab 2 exercises. For simplicity we assume the springs directly apply a torsional force on to the pendulum. Use equation 1 to develop the spring model.

Note *: The springs can only produce force in one-direction like the muscles. That is, they can only apply a pulling force and apply a zero force when compressed. You need to accomodate for this condition for springs S1 and S2 in the equation shown below*

The setup for the pendulum with a pair of antagonist springs is as shown in figure 1. Use `exercise1.py`, `lab4_pendulum.py` and `SystemParameters.py` files to complete the exercise.

$$F_s = K * (\theta_{ref} - \theta) \tag{1}$$

Where,

- F_s : Torsional Spring force
- K : Spring Constant
- θ_{ref} : Spring reference angle = angle at which the spring doesn't produce any force
- θ : pendulum angle

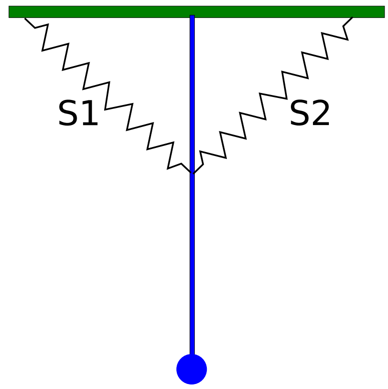


Figure 1: Pendulum model with two springs s1 and s2

1.a Does the system have a stable limit cycle behavior? Describe and run an experiment to support your answer. With different initial conditions, the circle described is different, so no, it doesn't

1.b Explore the role of spring constant (K) and spring reference angle (θ_0) in terms of range of motion, amplitude, ... Support your responses with relevant plots If we apply a reference angle to S1 of 10 and a K1 = 1000, then the whole system will oscillate around 10rad, since it is the reference position of the far strongest spring

1.c Explain the behavior of the model when you have different spring constants (K) and spring reference angles (θ_{ref}). Support your responses with relevant plots

Explore the pendulum model with two antagonist spring and damper elements

Over time muscles lose energy while doing work. In order to account for this property, let us now add a damper in parallel to the spring model. Use equation 2 to develop the damper model.

Note : *Like the previous springs, dampers can only produce force in one-direction. That is, they can only apply a damping force in the pulling direction and apply a zero force when compressed. You need to accomodate for this condition for dampers B1 and B2 in the equation shown below*

Again use `exercise1.py`, `lab4_pendulum.py` and `SystemParameters.py` files to complete the exercise. The setup for the pendulum model with a pair of antagonist spring and dampers in parallel is as shown in figure 2.

$$F_B = B * (\dot{\theta}) \tag{2}$$

Where,

- F_B : Torsional Damper force
- B : Damping Constant
- $\dot{\theta}$: pendulum angular velocity

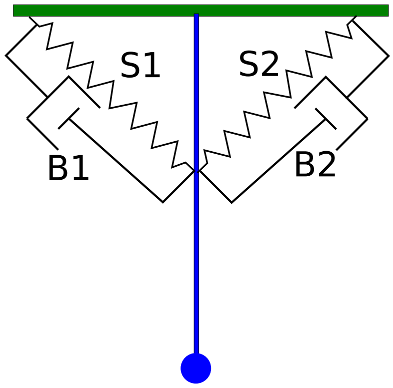


Figure 2: Pendulum model with two springs S1 and S2 and two dampers B1 and B2

1.d How does the behavior now change compared to 1.a. Briefly explain and support your responses with relevant plots

1.e Can you find a combination of spring constant (K), damping constant (B) and spring reference angle (θ_{ref}) that makes the pendulum rest in a stable equilibrium at ($\theta = \pi/6$) radians? Describe the parameters used and support your response with relevant plots.

1.f What is the missing component between a real muscle and the muscle model with passive components that you just explored? What behaviour's do you lack because of this missing component?

We don't have the contractile /active element, thus we don't have the possibility to elicit a stimulatory
response - we don't have tendons and this contractule element, therefore we lack a mean to GENERATE the force. Plus, we don't take into account pennation

==========> ANS::::::::

Exercise 2 : Hill muscle model

In exercise 1, you explored the role of different passive components and the effects of its parameters on the system. In this exercise, we try to understand the contractile or the active element of the hill muscle model. The components of the hill muscle are described in figure 3. The equations used to model the hill muscle can be found in the pdf `HillMuscleEquations.pdf`

Use `exercise2.py`, `lab4_mass.py`, `SystemParameters.py` and `Muscle.py` files to complete the exercise.

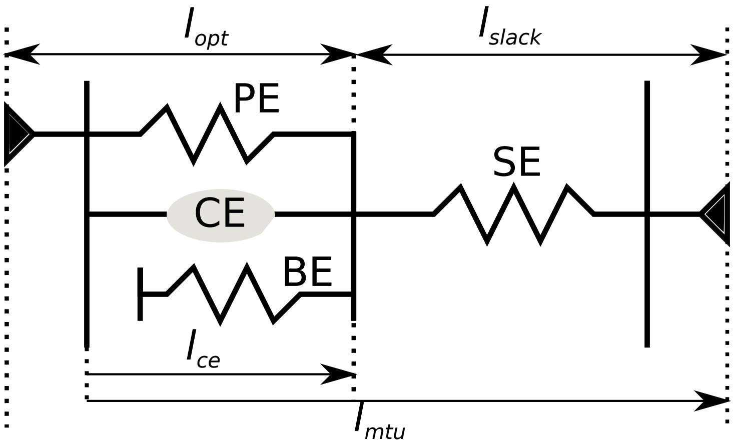
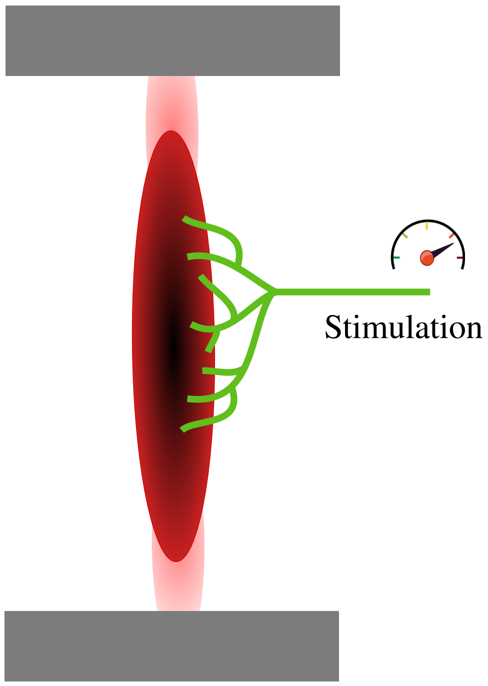
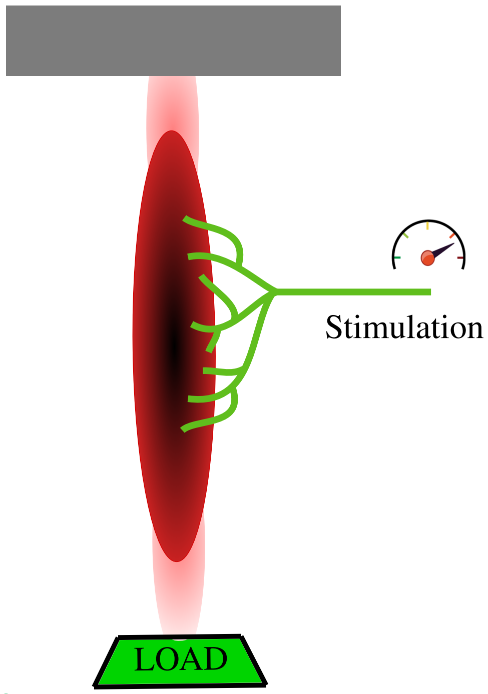


Figure 3: Hill muscle model

Where,

- PE : Parallel element (Prevents muscle from over stretching)
- BE : Muscle Belly (Prevents muscle from collapsing on itself)
- SE : Series element or the muscle tendon element
- CE : Contractile Element or the active element
- l_{opt} : Muscle optimal fiber length
- l_{slack} : Muscle tendon slack length
- l_{CE} : Contractile element length
- l_{MTC} : Muscle Tendon Complex length = Lmtu, muscle-tendon-unit





The muscle has a force depending on the position (myosin-actin coverage), so we vary the length (but fix it for the stimuli session) in order to measure the force elicited by such lengths

(a) Isometric muscle setup :
To study the relationship between Force-Length.

(b) Isotonic muscle setup :
To study the relationship between Force-Velocity.

Figure 4: Muscle Length-Velocity-Force Setup

Muscle Force-Length Relationship

In this exercise you will explore the relation between the length and velocity of the muscle. In order to do this we replicate the set-up show in figure 4.Here the length of the muscle is held constant by attaching it's tendon to two fixed points. While applying a constant stimulation, observing the force produced will give the relationship between muscle contractile element length and force.

2.a For a given stimulation, explore the relationship between active and passive muscle forces and the length of the contractile element. Plot the force-length relationship curve. Discuss the different regions in the plot

ActiveF strongly depends on the activation. passiveF is very strong because it is a sum of two squared forces

2.b In (2.a), you explored the muscle force-length relationship for a given stimulation. What happens to the relationship when the stimulation is varied between [0 - 1]? Support your response with relevant plots.

As we vary A, the active force increases more than the passive does (cf delta_plot), and the ratio totalForce/totalLength seems to evolve linearily (cf ratio_plot)

cf also general plot for varying stimulation (F_vs_length)

2.c Describe how the fiber length (l_{opt}) influences the force-length curve. (Compare a muscle comprised of short muscle fibers to a muscle comprised on long muscle fibers.) For the same activation, the curve shifts a lot to the right for suprisingly near values of fibers length. Also, it jumps far higher.

Muscle Velocity-Tension Relationship

In this exercise you will explore the relation between the force and velocity of the muscle. In order to do this we replicate the set-up show in figure 4. Here the length of the muscle is allowed to vary by attaching one of its end to a fixed point and the other to a variable external load. While applying a constant load initially and holding the muscle at constant length, a quick release is performed to let the muscle contract and pull the weight. The maximum velocity during this quick release will give us the relationship between muscle contractile velocity and the force

2.d For a stimulation of 1.0 and starting at optimal muscle length, explore the relationship between contracticle element velocity and external load. Plot the Velocity-Tension relationship curve. Include shortening and lengthening regions ???

2.e For the muscle force-velocity relationship, why is the lengthening force greater than the force output during shortening?

2.f How does the parameter muscle activation influence the force-velocity relationship. Show and explain the behavior for multiple muscle activation