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 must be submitted before the* ***Deadline : 22-04-2020 23:59****. 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 lab5_name1_name2_name3.zip where name# are the team member's last names. Please submit only one report per team!*

The file `lab#.py` *is provided to run all exercises in Python. When a file is run, message logs will be printed to indicate information such as what is currently being run and and what is left to be implemented. All warning messages are only present to guide you in the implementation, and can be deleted whenever the corresponding code has been implemented correctly.*

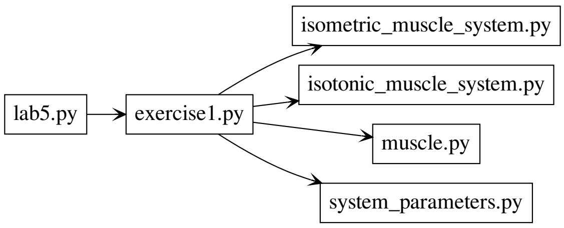


Figure 1: Exercise files dependencies. In this lab, you will be modifying `exercise1.py`*.*

Files to complete the exercises

- `lab5.py` : Main file
- `exercise1.py` : Main file to complete exercise 1
- `system_parameters.py` : Parameter class for Pendulum, Muscles and Neural Network (Create an instance and change properties using the instance. You do not have to modify the file)
- `isometric_muscle_system.py` : Class to setup your isometric muscle test experiments (You do not have to modify the file)
- `isotonic_muscle_system.py` : Class to setup your isotonic muscle test experiments (You do not have to modify the file)
- `muscle.py` : Muscle class (You do not have to modify the file)
- `mass.py` : Mass model class (You do not have to modify the file)

NOTE : '*You do not have to modify*' does not mean you should not, it means it is not necessary to complete the exercises. But, you are expected to look into each of these files and understand how everything works. You are free to explore and change any file if you feel so.

Exercise 1 : Hill muscle model

Previous week 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 2. The equations used to model the hill muscle can be found in the pdf `HillMuscleEquations.pdf`

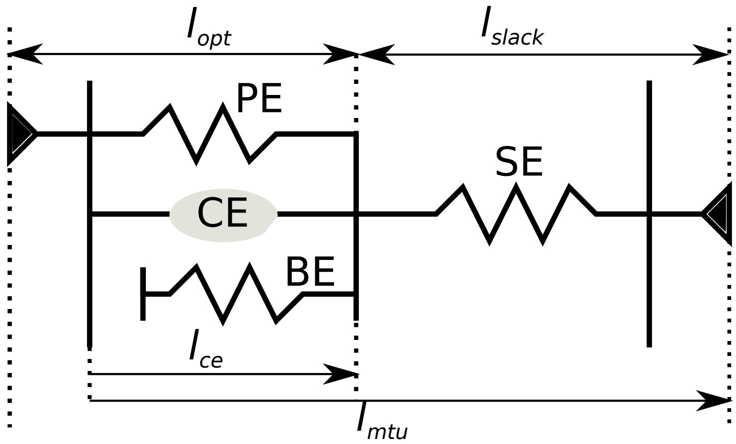
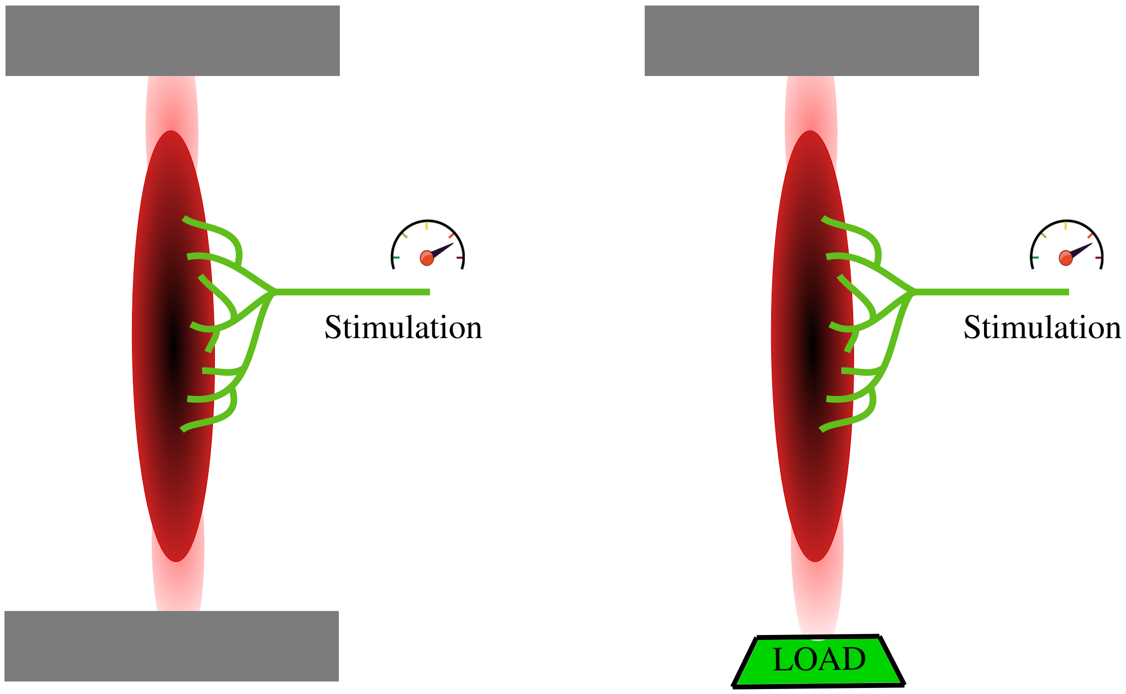


Figure 2: Hill muscle model

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_{mtu} : Muscle Tendon Unit length



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

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

Figure 3: 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 3.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.

1.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. Use the `isometric_muscle_system.py::IsometricMuscleSystem` instance to setup your experiment in `exercise1.py`

1.b In (1.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 one plot showing the different force-length relationship curves.

1.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.). To change the parameter you can use `system_parameters.py::MuscleParameters` before instantiating the muscle. No more than two plots are required.

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 3. 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.

Note : Since the velocity changes sign and you need to compute the maximum velocity accordingly by checking if the muscle was stretched or compressed at the end of the experiment.

$$V_{ce} = \begin{cases} min(v_{ce}(t)) & l_{mtu} < (l_{opt} + l_{slack}) \\ max(v_{ce}(t)) & else \end{cases} \tag{1}$$

1.d For a stimulation of 1.0 and starting at optimal muscle length, explore the relationship between contractile element velocity and external load. Plot the Velocity-Tension relationship curve. Include shortening and lengthening regions. Use the `isotonic_muscle_system.py::IsotonicMuscleSystem` instance to setup your experiment in `exercise1.py`

1.e For the muscle force-velocity relationship, why is the lengthening force greater than the force output during shortening? No plots necessary

1.f What happens to the force-velocity relationship when the stimulation is varied between [0 - 1]? Support your response with one plot showing the different force-velocity relationship curves.