HNCL Tutorial 1: Physiology

Please provide a solution with full calculations and brief explanations. Submit a Zip file (NameSurname Tutorial1.zip) containing:

- Solution for Question 1 and Question 2 (InitialsQ1Q2.pdf)
- Solution for Question 3 (Plots + explanations) (InitialsQ3.pdf)
- Your function for the pendulum muscle model: pendulum muscle equation.m
- A script that produces the plots for part 1 and part 2: pendulum sim.m

If you have any additional function you can also add them, but we must obtain all the plots as they are in the .pdf when running pendulum sim.m. We will only run pendulum sim.m!

Question 1: Neural signal transmission

The most direct signal from motor cortex to muscle involves two fast (myelinated) neurones: one from cortex to the spinal cord and one from the spinal cord to the muscle. In these fast neurones, action potentials travel at about $100m/s$. Once the action potential reaches the muscles, it spreads throughout the muscle at about $4m/s$. In addition, the time to diffuse across a synapse (between neurones and at the neuromuscular junction) takes about $1ms$.

(a) Calculate the time it takes for a neural signal from motor cortex to contract a foot muscle, assuming rough dimensions of $1m$ from the cortex to spinal cord, $1m$ from spinal cord to muscle, and a muscle fiber that is $4cm$ long.

[10 marks]

(b) Determine the percentages of the total time taken for the signal to: i) travel from the cortex to the muscle; and ii) diffuse and spread along the muscle. Explain which phase accounts for most of the signal delay.

[10 marks]

(c) How does the total travel time of the neural signal compare to the delay in an electrical signal flowing through an electrical wire of the same total length (in copper wire, electrical signals travel at approximately 68% of the speed of light)?

[10 marks]

Question 2: Muscle Model

Muscles have complex dynamic properties. For this reason, muscle modeling is used to gain insights into the structure and functioning of muscles and to improve the general understanding of contraction dynamics.

The behaviour of a single muscle can be modeled using the equations seen in class (1)-(2):

$$\mu = K_\mu(u)(\lambda_0 - \alpha u - \lambda) - D_\mu(u)\dot{\lambda}, \tag{1}$$

$$K_\mu(u) = \kappa_0 + \kappa u, \quad D_\mu(u) = (\delta_0 + \delta\sqrt{u}). \tag{2}$$

Run the script *muscle_behavior_tutorial.m* on MATLAB and describe the effect of different activation levels when you plot the behaviour of a single muscle attached to a mass after a stretch (see Figure 1).

[20 marks]

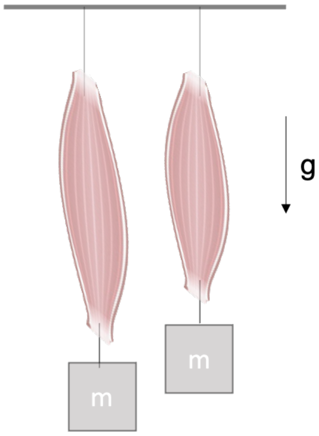

Figure 1: Single muscle attached to a mass. The muscle is strengthen and then relaxed.

Question 3: Upright forearm stabilisation

Develop a model of upright forearm stabilisation in *MATLAB*. To do this, modify the simple pendulum model (3) by integrating an antagonist muscle pair using the muscle model seen in class (equations (1)-(2)). The model should represent a pendulum attached to two symmetrical but independently activated muscles, m_1, the elbow flexor, and m_2, the elbow extensor (see figure 2). Note that θ is defined such that it is 0 when the elbow is at 90 degrees from the horizontal plane and should be positive during extension and negative during flexion. Additionally, consider that when the muscle length is smaller than the resting length $\lambda < \lambda_0 - \alpha * u$, the muscle cannot produce a tension, therefore $\mu = 0$.

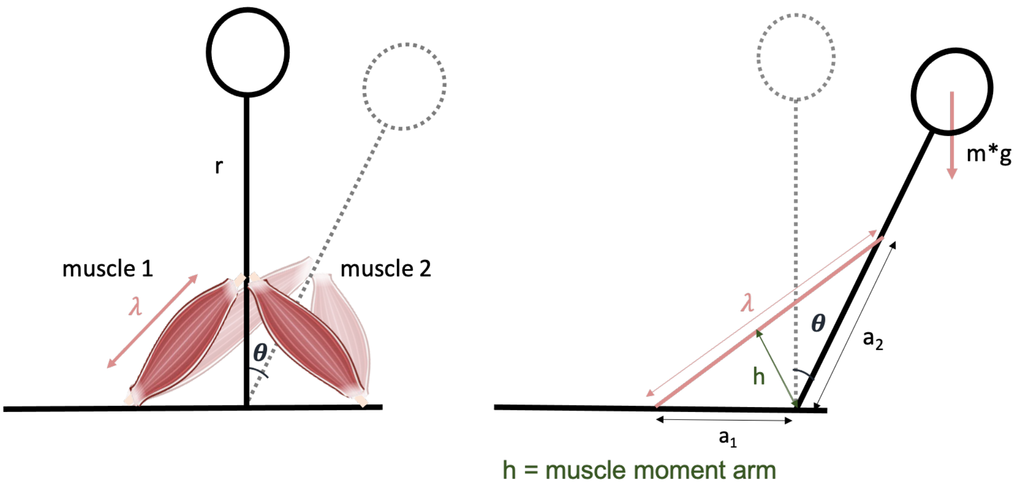

Figure 2: Left: Forearm with agonist/antagonist muscle.muscle 1: flexor, muscle 2: extensor λ: muscle length, θ,r: forearm angle and length. Right : Geometrical constraint of the pendulum model. λ: muscle length, θ: pendulum angle, m:pendulum mass, a_1: attachment point of the muscle(origin), a_2: attachment point of the muscle (insertion), h: moment arm

$$\ddot{\theta} = \frac{m * g * r * sin\theta}{m * r^2} \tag{3}$$

(a) Study how co-contraction influences the stability and position/orientation of the forearm. To do this use three values of co-contraction ($u_L = u_R \in \{0, 0.5, 1\}$). Plot the evolution of θ and $\dot{\theta}$. Choose two sets of initial values for θ and $\dot{\theta}$ such that the system:

- does not fall to the ground for both small (u = 0.5) and large (u = 1) activation levels;
- falls for a small activation (u = 0.5) and does not fall for a large activation (u = 1);

[30 marks]

Use the following set of parameters:

Parameter	Value	Unit
g	9.81	$\frac{N}{kg}$
r	0.3	m
m	1	kg
a_1	0.0436	m
a_2	0.09	m
α	0.0218	m
κ_0	810.8	$\frac{N}{m}$
κ	1621.6	$\frac{N}{m}$
ζ	0.26	NA
δ	$2 * \zeta * \sqrt{\kappa * m}$	$\frac{Ns}{m}$

(b) Simulate the behaviour of hitting a nail with a hammer. Keeping the flexor muscle relaxed, and using constant activation of the extensor, provide a plot of the pendulum angular momentum, the velocity and the position. At what minimal level of activation do you need to stimulate your muscle to hit the nail at 90° in less than 0.5 s ? [20 marks]

Hints:

1. the muscle length will be fixed by the geometrical constraint given by a_1,a_2 and θ. See figure 2.
2. $muscle_{torque} = direction * muscle_{tension} * muscle_{momentarm}$