1 Add Muscles to two-segment arm model

In the lectures, you have seen the modified Hill-type muscle model ([Haeufle et al., 2014]) shown in Figure 1 . In this exercise, we want to actuate the elbow joint by two muscles (flexor and extensor), while fixing the upper arm in space.

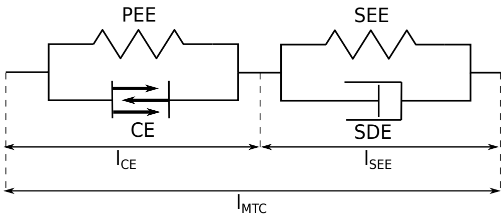

Figure 1: Hill-type muscle model (Figure taken from [Haeufle et al., 2014])

Task 1: Download the open-source muscle model from: `https://github.com/daniel-haeufle/macroscopic-muscle-model`. In this git-repo, you also find a simple example using the muscle which you can use as an orientation for this exercise. Include two muscles and their activation dynamics for the lower arm ("library_mtu_simulink.slx") of the two-segment arm model which was build up in Simscape in the last exercise (model is also uploaded to Ilias course, named: mech_armmodel).

Connecting muscles to mechanical system First, modify the shoulder joint such that it is actuated by no torque anymore and is fixed in space (modify joint limits). Second, instead of actuating the elbow joint with a constant torque, replace this by the sum of the moments of the two muscles. For example, you can simply multiply the forces $F_{\mathrm{MTU,i}}$ with a constant moment arm r_i with $i = 1, 2$. There are also more advanced methods to calculate the correct moment arms of muscles to the joints they are acting on (see Appendix [Kistemaker et al., 2007] for a function definition, or using ellipses [Hammer et al., 2019]).

Interaction between muscle-tendon unit and Hatze activation dynamics The activation dynamics models the relation between the neural stimulation signal u and the muscle activity a. It is based on the free calcium ion concentration, as well as the relative length of the contractile element (CE). For a more detailed description, read chapter 2.4.2 of [Bayer et al., 2017]. To model this interaction, you need to connect the lines a and l_{CE} of the muscle-tendon-block and the Hatze activation dynamics block in Simulink.

Changing muscle parameters If you run the init_muscle.m script, it will load the parameters for an exemplary muscle. You will need to create two of this init_muscle.m scripts, one for a flexor (MEF: monoarticular elbow flexion) and one for an extensor (MEE: monoarticular elbow extension). For that you can use Table 2 from [Kistemaker et al., 2007]. Exchange the parameters $F_{\mathrm{MAX}}, l_{\mathrm{CE,opt}}$, and $l_{\mathrm{SEE,0}}$ for both muscles. Furthermore, ensure that $l_{\mathrm{MTC,init}} = l_{\mathrm{CE,opt}} + l_{\mathrm{SEE,0}}$.

Input parameters The main input parameters to the biomechanical arm model with muscles are the control signals u_i with $i = 1, 2$. For now, you can simply set them to a constant value (between 0 and 100%). Later, you can modify these parameters to control the movement purposefully.

Notes:

- You can submit Task 1 until **27. November 2023 , 11:30 am** via email to *elsa.bunz@imsb.uni-stuttgart.de* in groups with 2-3 persons. The solution will be discussed in the exercises.
- You need to have Simscape Multibody installed. Furthermore, newer Matlab versions (tested with 2019b) have the possibility to include joint limits (if you click on Revolute Joint, you can see an additional 'Limits' option).
- Make sure that your muscle parameters (loaded by the init_muscle.m script), have the same names as your Simulink blocks. You can check this e.g. by double-clicking on the MTU block and changing the muscle parameter struct (e.g. to Param_Mus), and by double-clicking on the ActivationDynamicsHatze block and changing both the muscle parameter struct and the act parameter struct name (e.g. to Param_Mus.ActDyn).

References

[Bayer et al., 2017] Bayer, A., Schmitt, S., Günther, M., and Haeufle, D. (2017). The influence of biophysical muscle properties on simulating fast human arm movements. *Computer methods in biomechanics and biomedical engineering*, 20(8):803–821.

[Haeufle et al., 2014] Haeufle, D., Günther, M., Bayer, A., and Schmitt, S. (2014). Hill-type muscle model with serial damping and eccentric force–velocity relation. *Journal of biomechanics*, 47(6):1531–1536.

[Hammer et al., 2019] Hammer, M., Günther, M., Haeufle, D., and Schmitt, S. (2019). Tailoring anatomical muscle paths: a sheath-like solution for muscle routing in musculoskeletal computer models. *Mathematical Biosciences*, 311:68 – 81.

[Kistemaker et al., 2007] Kistemaker, D. A., Van Soest, A. J. K., and Bobbert, M. F. (2007). A model of open-loop control of equilibrium position and stiffness of the human elbow joint. *Biological cybernetics*, 96(3):341–350.