Robyn Klassen
Connor Huxman
Sam Feng

BME 355 - Assignment #1

Question 1

Using damped muscle model from the Millard et al. paper, we implemented a simplified model with beta = 0.1 and a pennation angle of 0. The plotted force-length curves for CE, PE, and SE are shown, as well as the force-velocity curve in Figure 1 below.

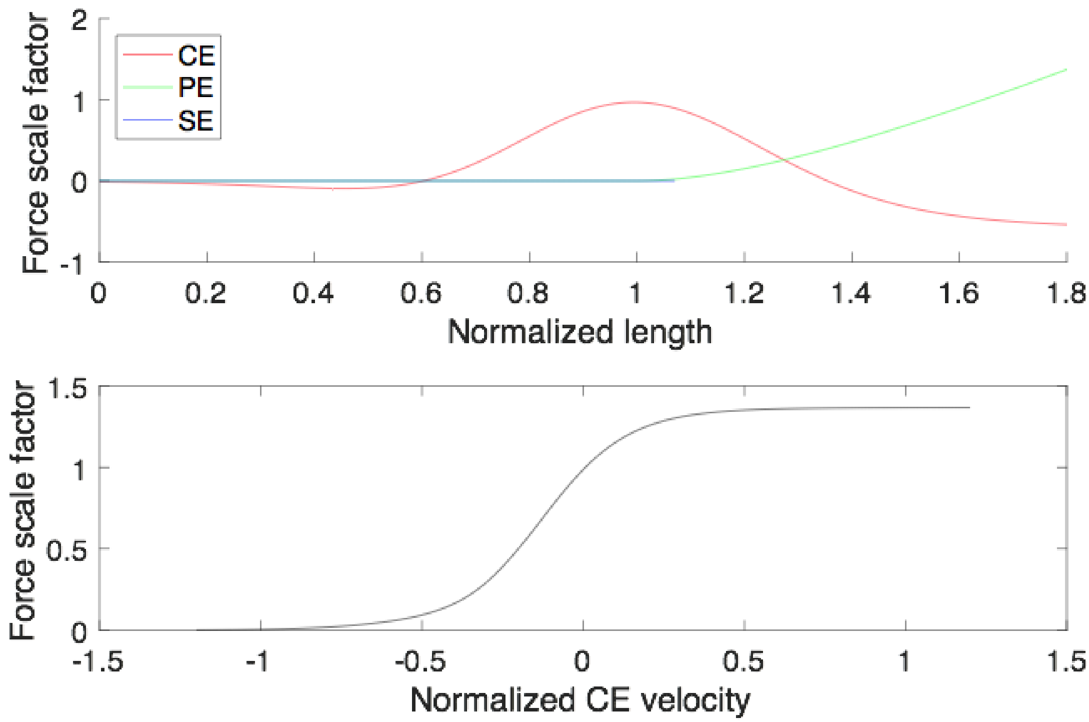

Figure 1: CE, PE, SE Force-Length Curves and CE Force-Velocity Curve

Question 2

The following normalized velocity, vM, given a = 1, lM = 1, lT = 1.01 was calculated to be -0.3944.

Question 3

A method to help visualize the behaviour of an isometric contraction for the HillTypeMuscle was written; the simulation was demonstrated over the span of 2 seconds with an activation of (t > 0.5s) and the normalized series element having an initial length of 1. Figure 2 illustrates an isometric contraction by displaying the length of the contractile element and the force produced by a HillTypeMuscle that has maximum isometric force of 100N, resting contractile element length of 1m, and resting series element length of 1.01m

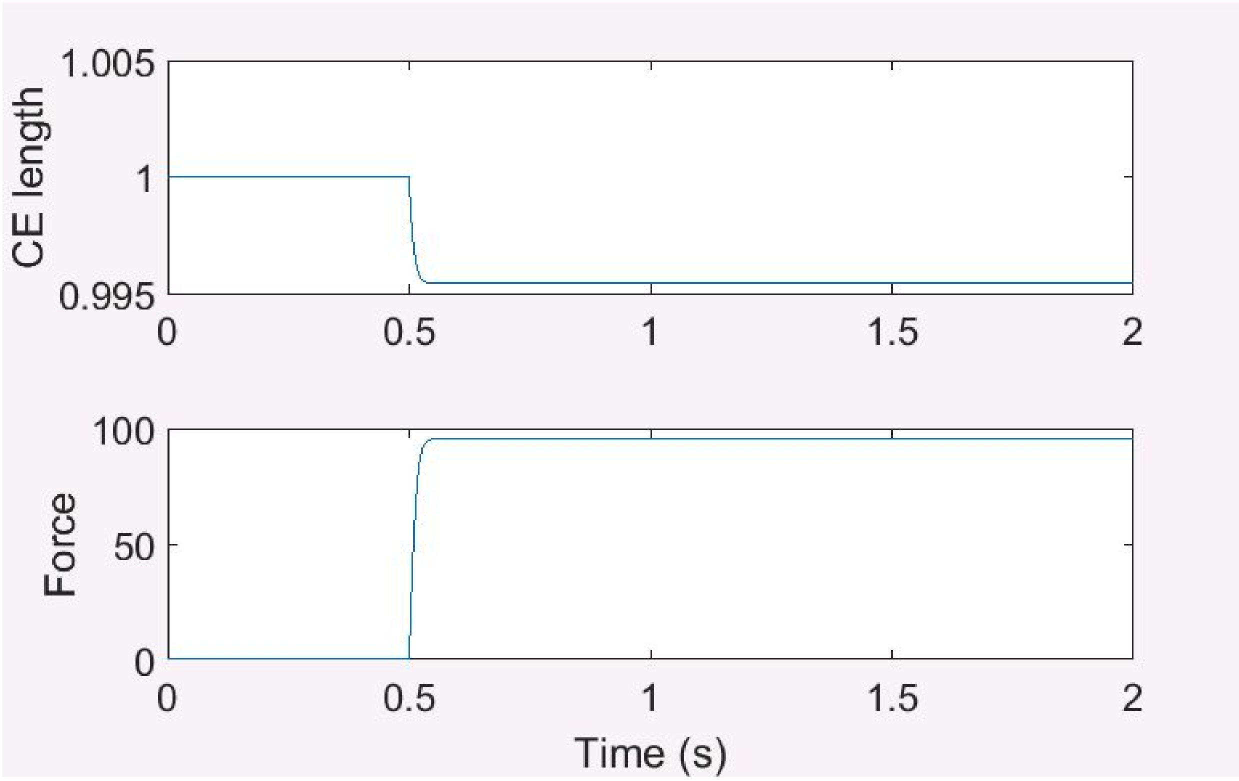

Figure 2: CE Length and Force Produced by Muscle vs Time

Question 4

Figure 3 shows the change in body angle in radians for a 5 second time duration, as well as the torques, or moments, exerted by the soleus and tibialis anterior muscles, as well as gravity about the ankle. The body angle is the angle measured counterclockwise from the ground plane towards the shank. As observed in the upper graph, the angle increases continuously with some rhythmic behaviour as time passes. In the lower graph, the torque exerted on the ankle by gravity follows an oscillatory behaviour, in conjunction with some periodic behaviour exhibited by the soleus muscle; the tibialis anterior muscle does not appear to exert any level of torque.

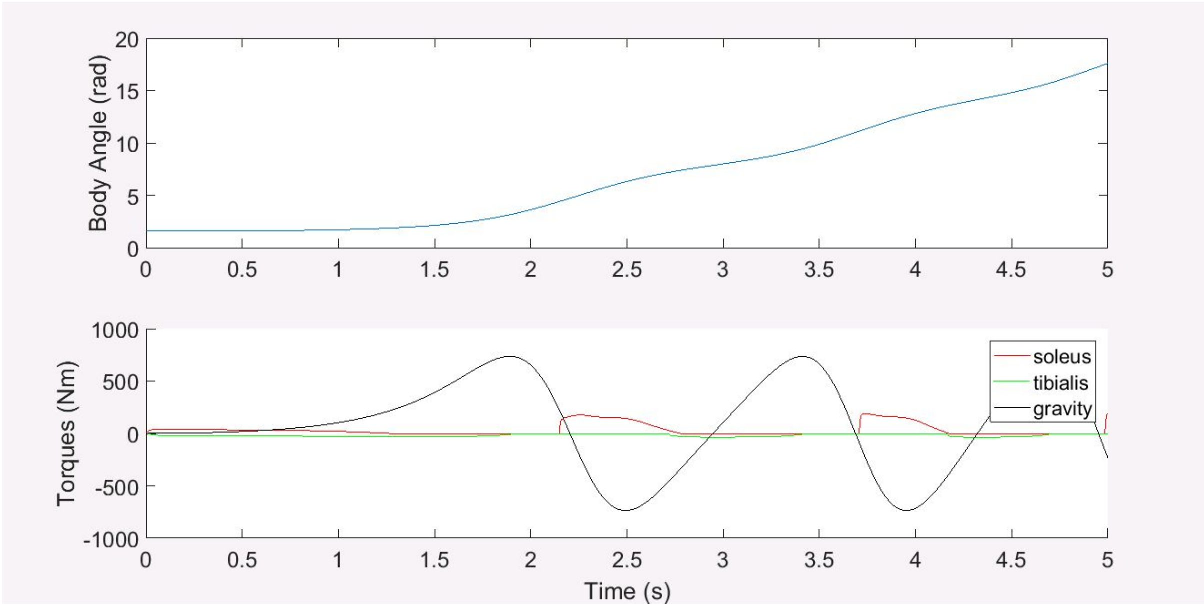

Figure 3: The angle of the body and torques about the ankle as a function of time

From a physiological perspective, this plotted behavior is, of course, physically unrealistic. To begin with, the body angle could never increase to - and certainly not beyond - pi radians as this would result in severe damage to the ankle, likely tearing the anterior talofibular ligament and extremely straining the tibialis anterior muscle. However, if we think of the system as being purely mechanical, simulating the rotation of a pendular shaft around a joint, we can interpret and physically justify the response of the torques in the lower graph to the change in the body angle. We can see that at each multiple of 2pi radians in the body angle, gravitational torque reaches its most negative value and begins to increase. This makes sense mathematically, since the gravitational moment includes the sin(theta - pi/2) term, as well as physically, since we would expect the moment's magnitude to increase sharply as the shaft initially rotates counter-clockwise from 0 rad. Furthermore, at a high level, the rotation of the body about the ankle joint necessitates that the gravity force vector likewise rotates, since this vector always acts downward (with reference to a global frame of reference). This rotation of the vector means that, for some periods of time, it generates positive or forward moment, and at others, generates a negative or backward one, thereby accounting for the oscillatory torque behaviour.

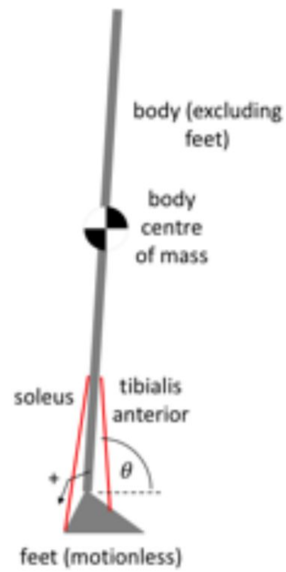

Figure 4: Musculo-skeletal model of postural stability

It is also important to note the physically unrealistic behaviour of the torques exerted on the ankle by the soleus and tibialis anterior muscles. Both these muscles are used to maintain posture, each contracting in turn depending on the location of the body's centre of mass above the foot and corresponding body angle about the ankle. With reference to Figure 4, if the body's centre of mass shifted anteriorly and decreased the body angle from pi radians, the posteriorly-located soleus muscle should contract in order to generate a greater backward torque, counteracting this forward balance; conversely, if the body's centre of mass shifted posteriorly and increased the angle from pi radians, the tibialis anterior muscle should contract to generate a greater positive torque, counteracting this backward balance. In this way, overall balance, or posture, can be maintained. As such, what would be physically expected is periodic or rhythmic torques exerted on the ankle by each of these muscles. This is in direct contrast to what is actually observed in the lower graph of Figure 3, where the tibialis anterior muscle generates no torque at all, and the soleus muscle generates a relatively smaller torque in comparison to that generated by gravity.

Question 5

To control the behaviour of the model and ensure that the model remains physically realistic, the code found in Figure 5 was implemented in the dynamics() function in the StabilityModel. The control law ensures that the ankle angle stays as consistent as possible. Essentially, the control law ensures that additional activation energy was given to the muscle that provides a torque that opposes the direction of movement and that less muscle activation occurred for the muscle that adds torque in the direction of the direction of movement. If the angular acceleration of the simulated muscle is positive, that indicates that the simulated leg is tilting backwards in reference to the previous position. To correct for this movement, the tibialis anterior activation should increase to provide additional torque and the soleus activation should increase to provide less torque. On the other hand, if the angular velocity of the ankle is negative, this implies that the shin is tilting forwards in reference to the previous position. As such, the tibialis anterior activation decreases such that the muscle provides more torque to the model under this condition. The soleus activation the decreases, and thus this muscle provides less torque when the angular velocity of the ankle is negative.

Figure 6 depicts a controlled ankle model, in which the angle of the ankle is relatively stable, simulated for 10 seconds. The torque provided by gravity is almost negligible, as the formula for this term includes sin(angle-pi/2). As the initial angle of the ankle was pi/2 and this is a controlled system, this value is close to zero consistently. The torque provided by both muscles oscillate, depending on the trajectory of the leg in reference to the ankle.

```
if control == 0
    aS = 0.05;
    aTA = 0.4;
else
    if x(2) > 0
        aS = 0.001;
        aTA = 0.9;
    else
        aS = 0.08;
        aTA = 0.05;
    end
end
```

Figure 5: MATLAB code for simple control law

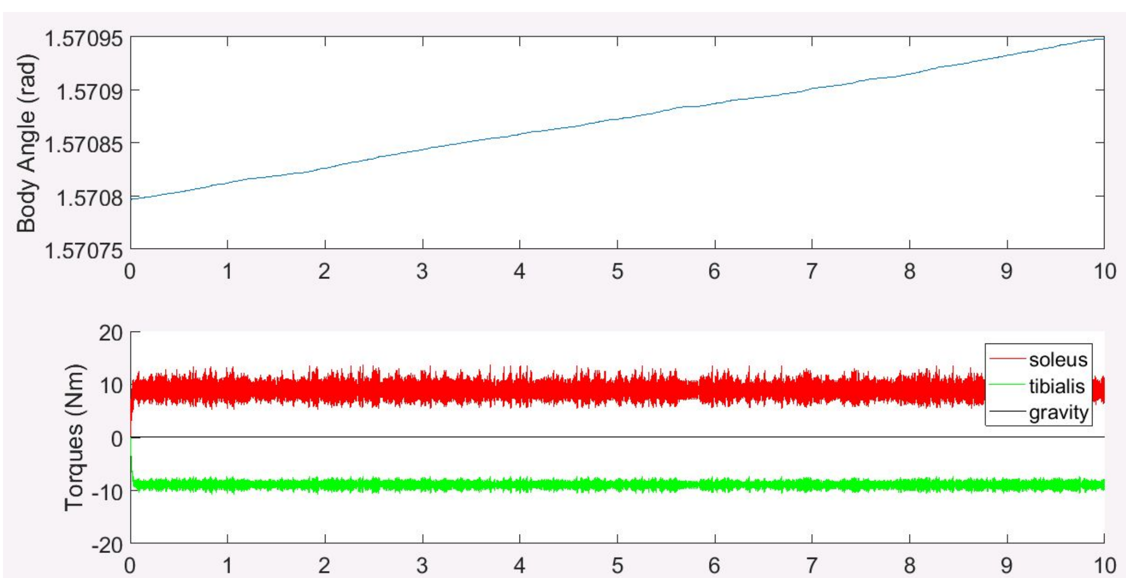

Figure 6: Controlled simulation over 10 seconds