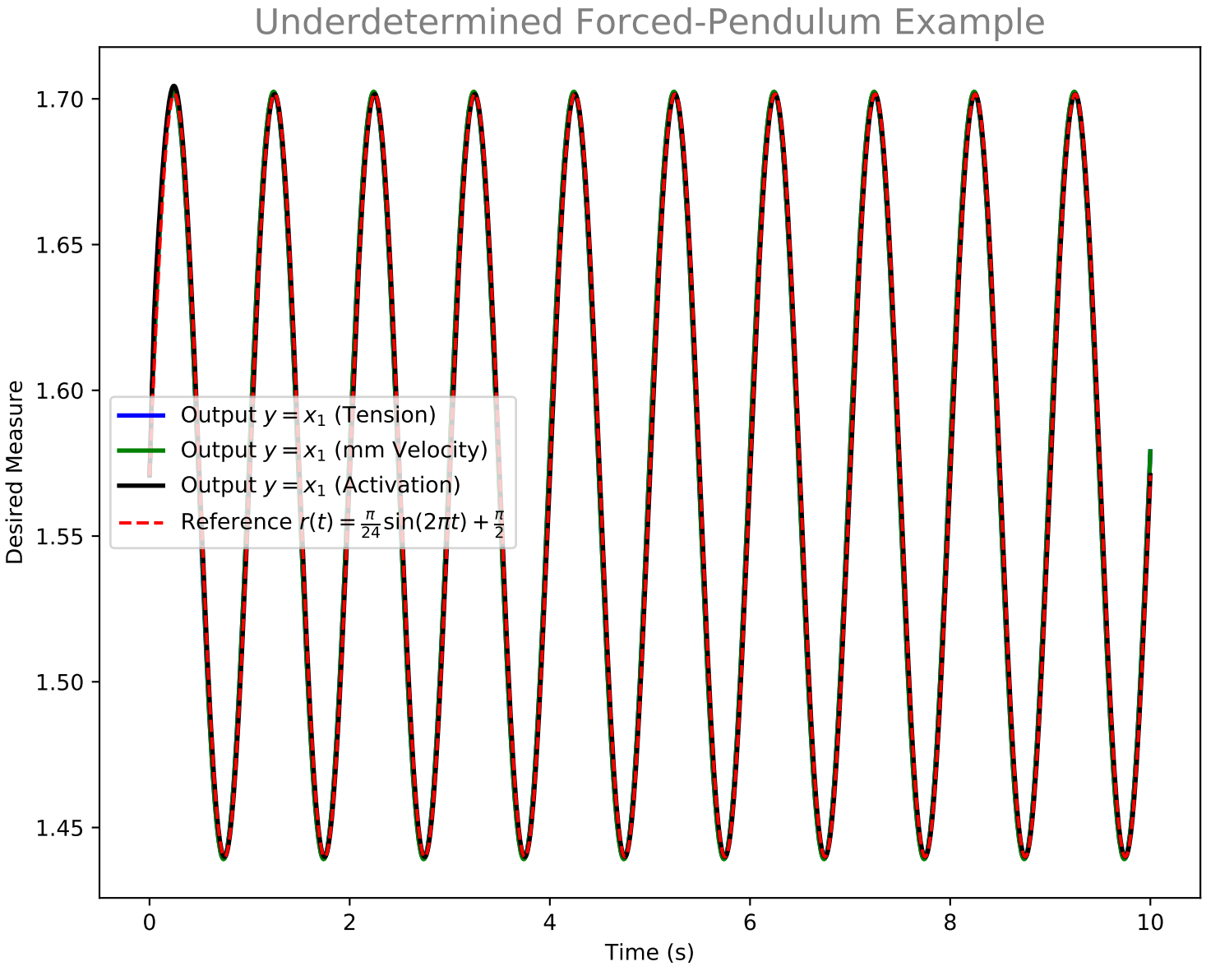
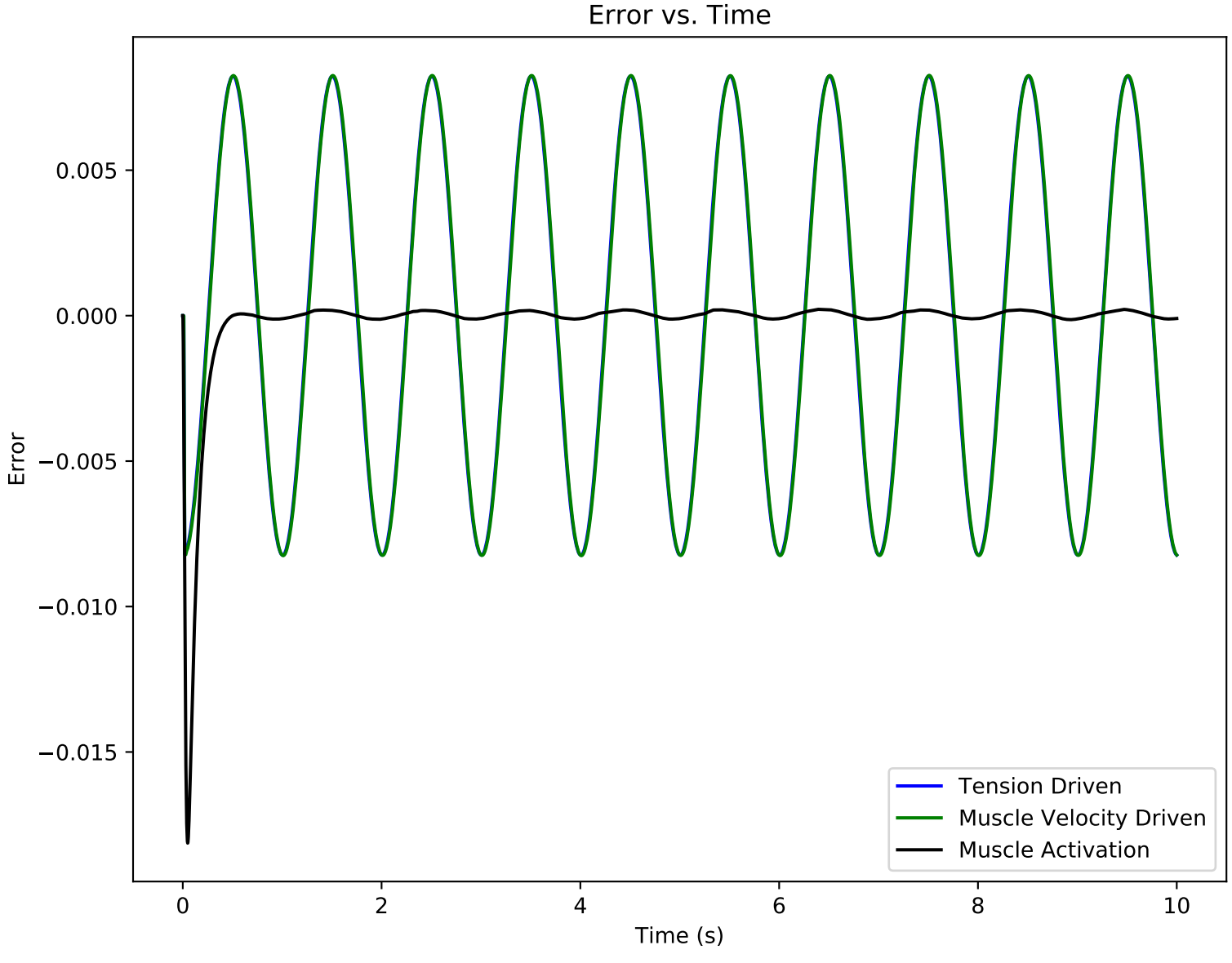
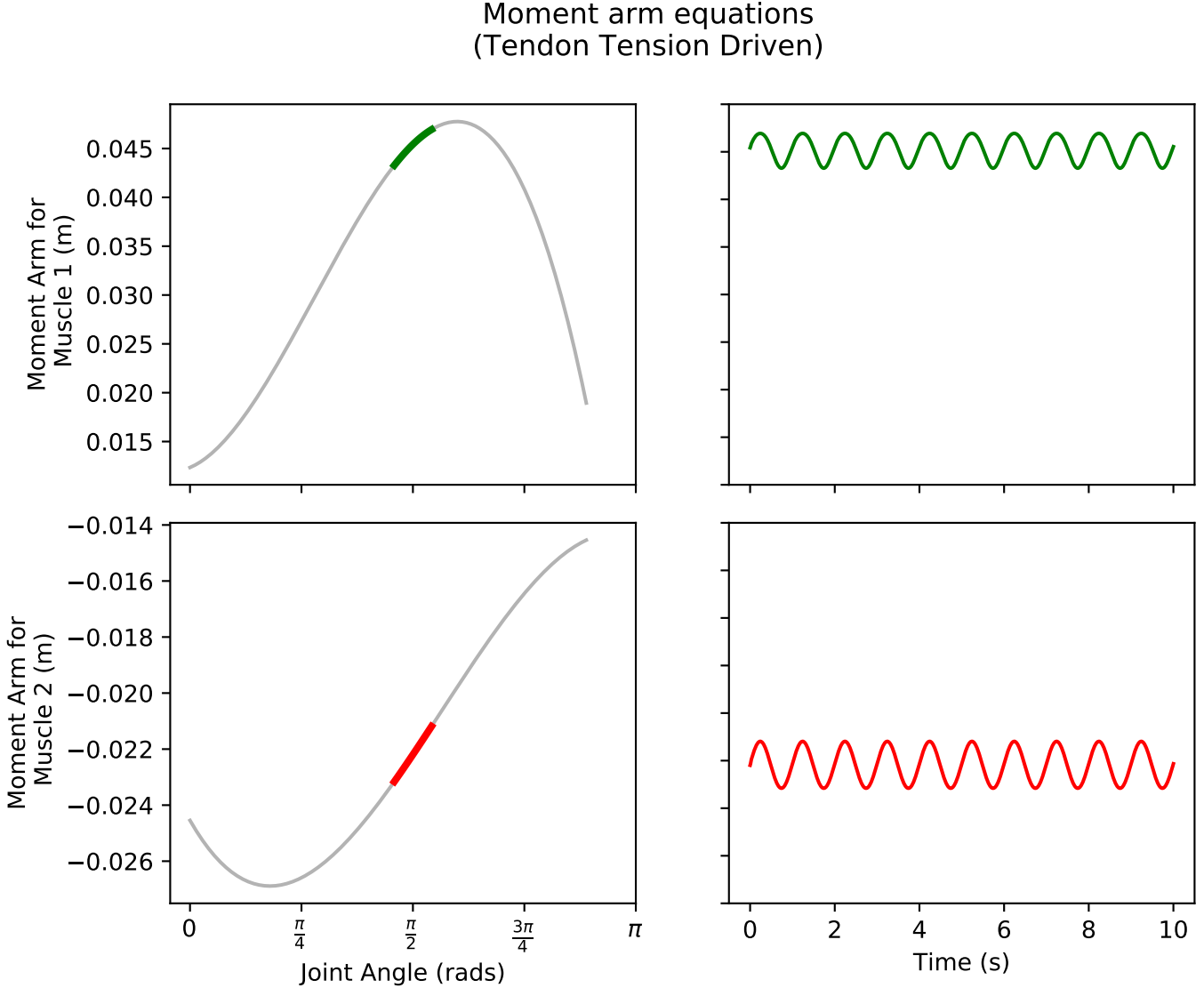
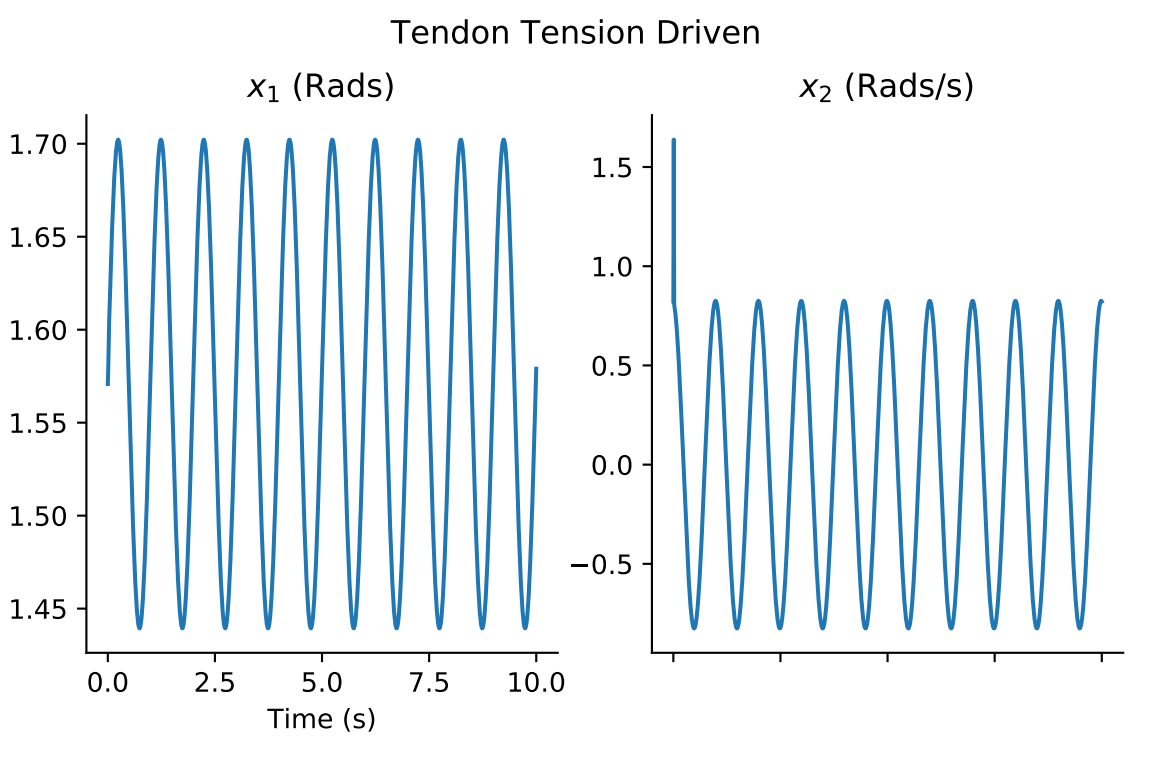
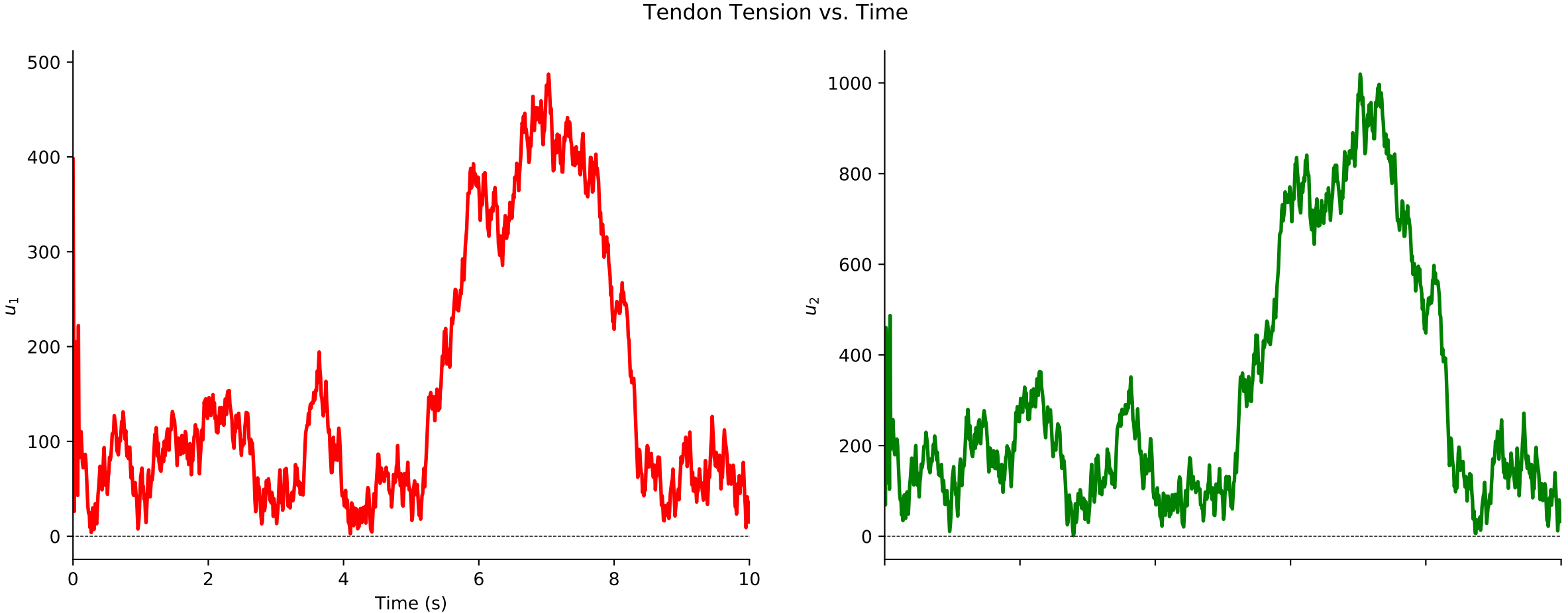
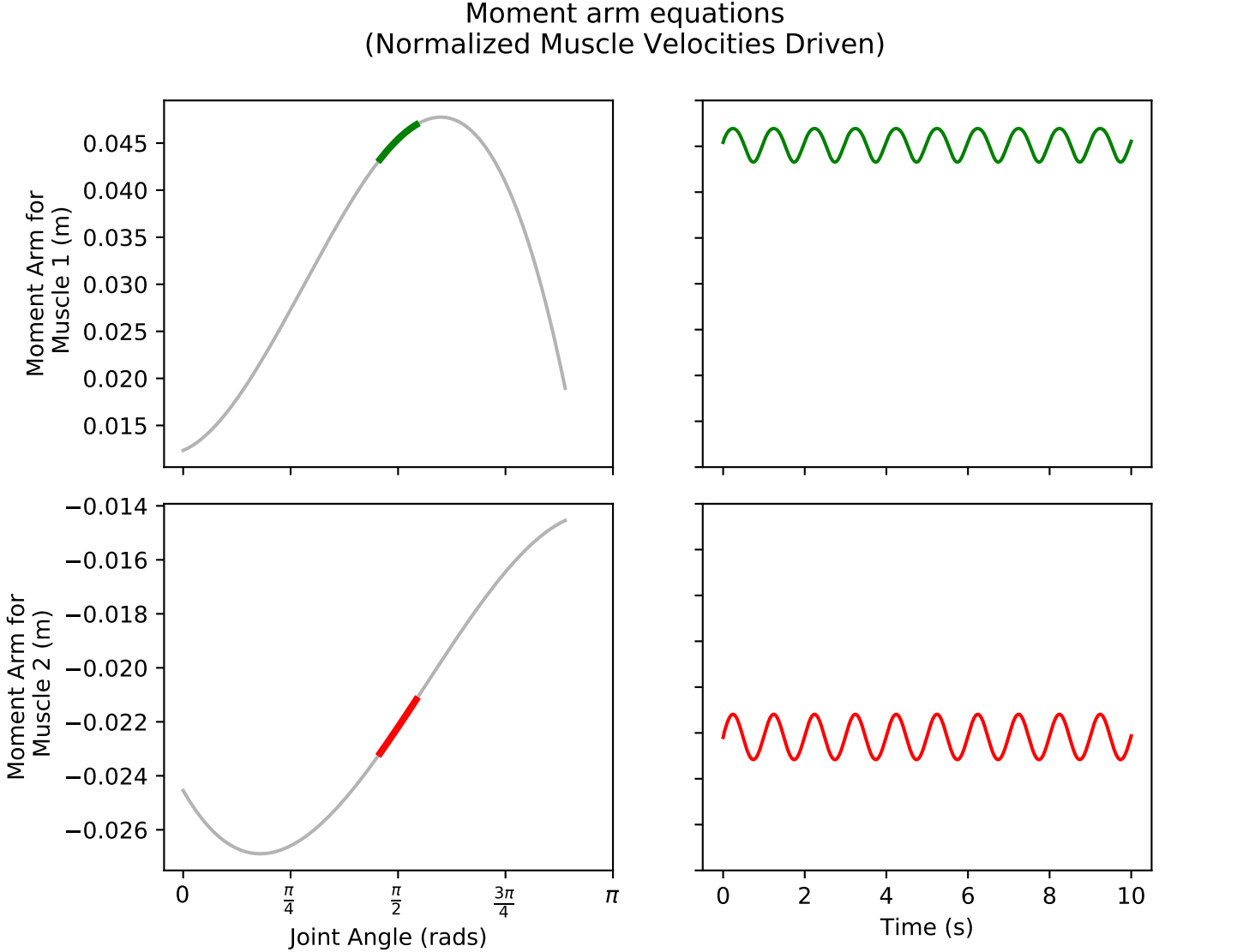

Underdetermined Forced-Pendulum Example
Desired Measure
Time (s)
1.70
1.65
1.60
1.55
1.50
1.45
0
2
4
6
8
10
Output $y = x_1$ (Tension)
Output $y = x_1$ (mm Velocity)
Output $y = x_1$ (Activation)
Reference $r(t) = \frac{\pi}{24}\sin(2\pi t) + \frac{\pi}{2}$

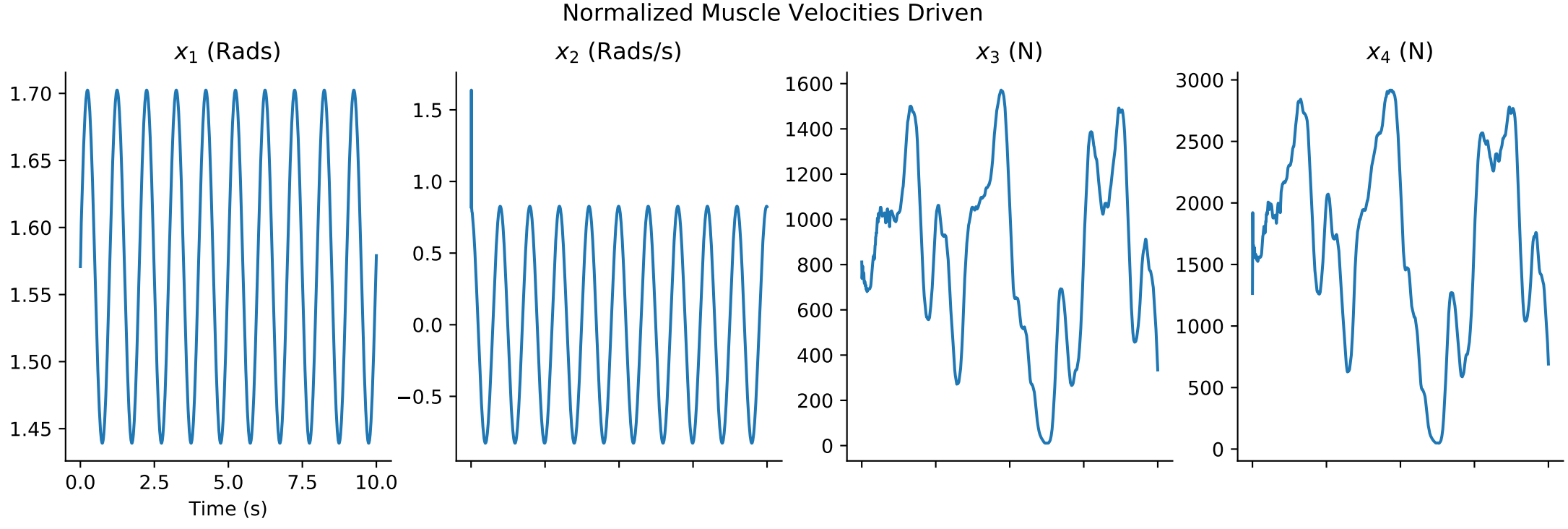

Error vs. Time
0.005
0.000
−0.005
−0.010
−0.015
Error
0
2
4
6
8
10
Time (s)
Tension Driven
Muscle Velocity Driven
Muscle Activation

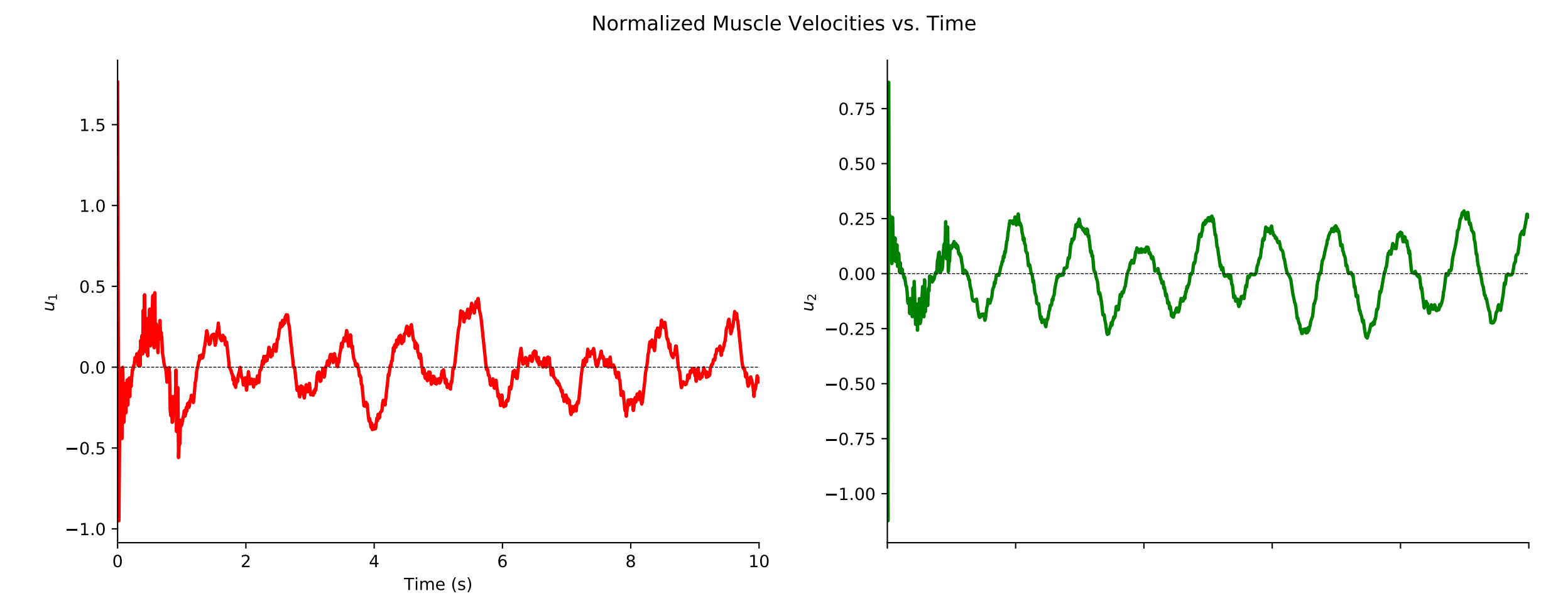

Moment arm equations
(Tendon Tension Driven)
Moment Arm for Muscle 1 (m)
0.045
0.040
0.035
0.030
0.025
0.020
0.015
Moment Arm for Muscle 2 (m)
−0.014
−0.016
−0.018
−0.020
−0.022
−0.024
−0.026
0
$\frac{\pi}{4}$
$\frac{\pi}{2}$
$\frac{3\pi}{4}$
π
Joint Angle (rads)
0
2
4
6
8
10
Time (s)

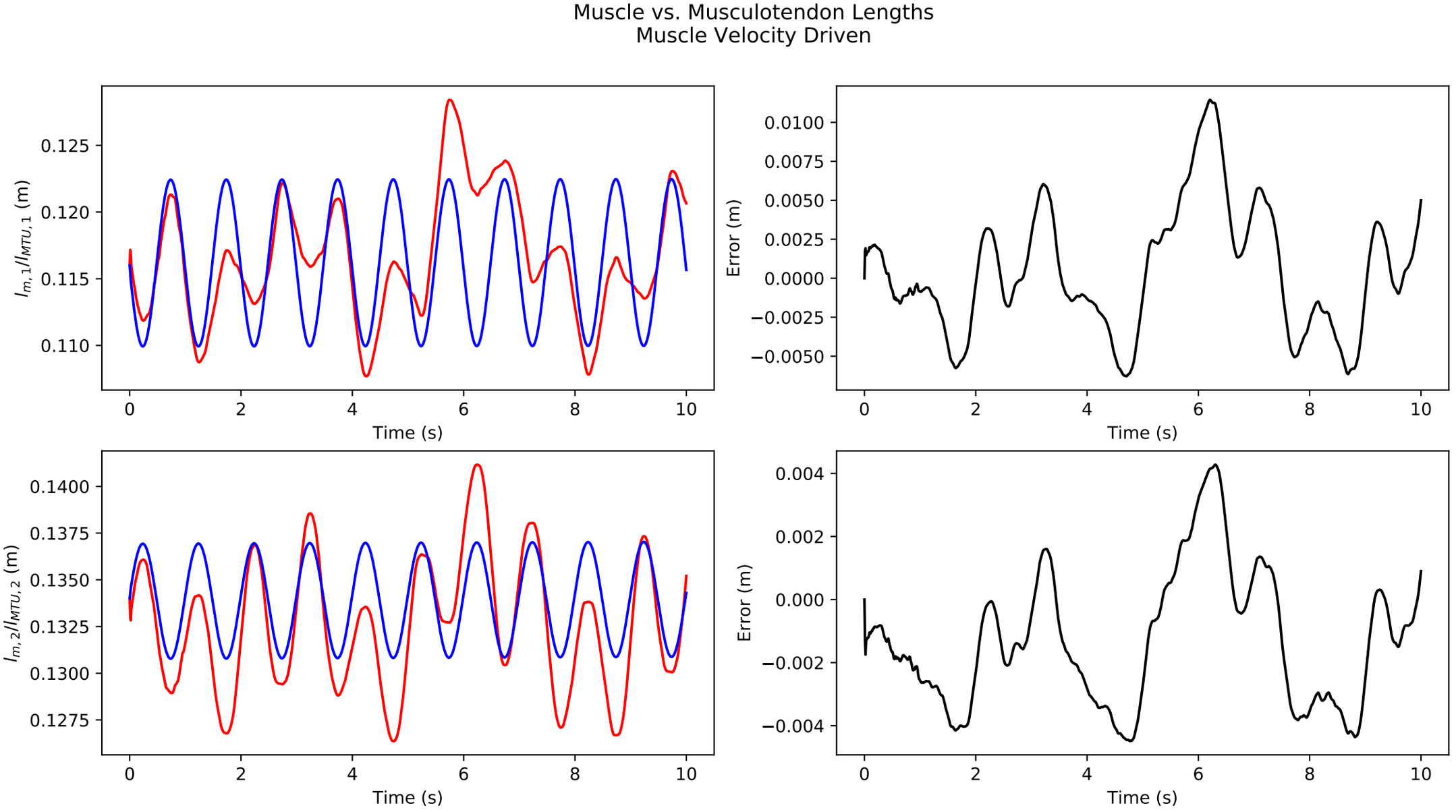

Tendon Tension Driven
x_1 (Rads)
x_2 (Rads/s)
1.70
1.65
1.60
1.55
1.50
1.45
1.5
1.0
0.5
0.0
−0.5
0.0
2.5
5.0
7.5
10.0
Time (s)

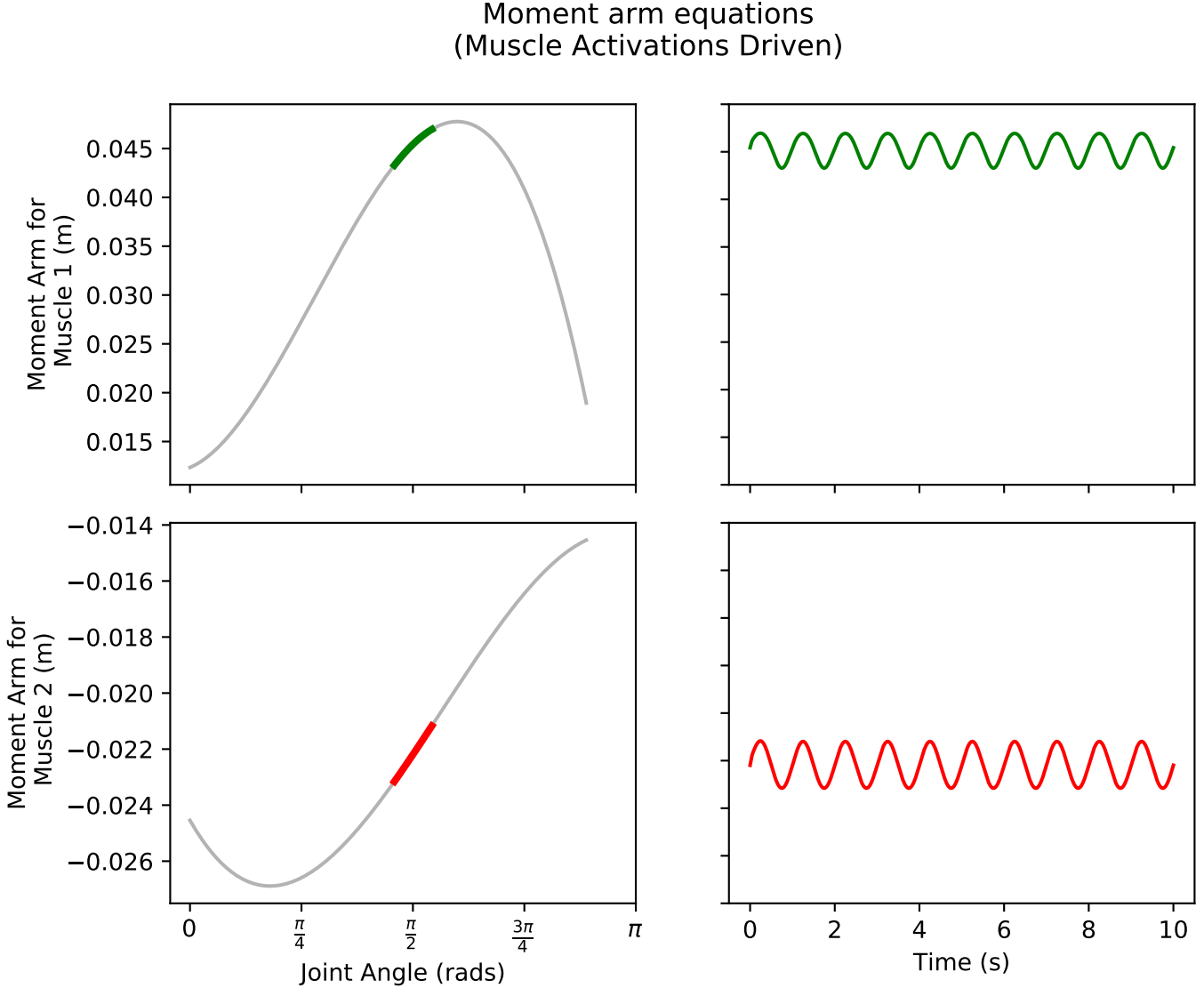

Tendon Tension vs. Time
u_1
u_2
Time (s)
0
100
200
300
400
500
600
800
1000
0
2
4
6
8
10

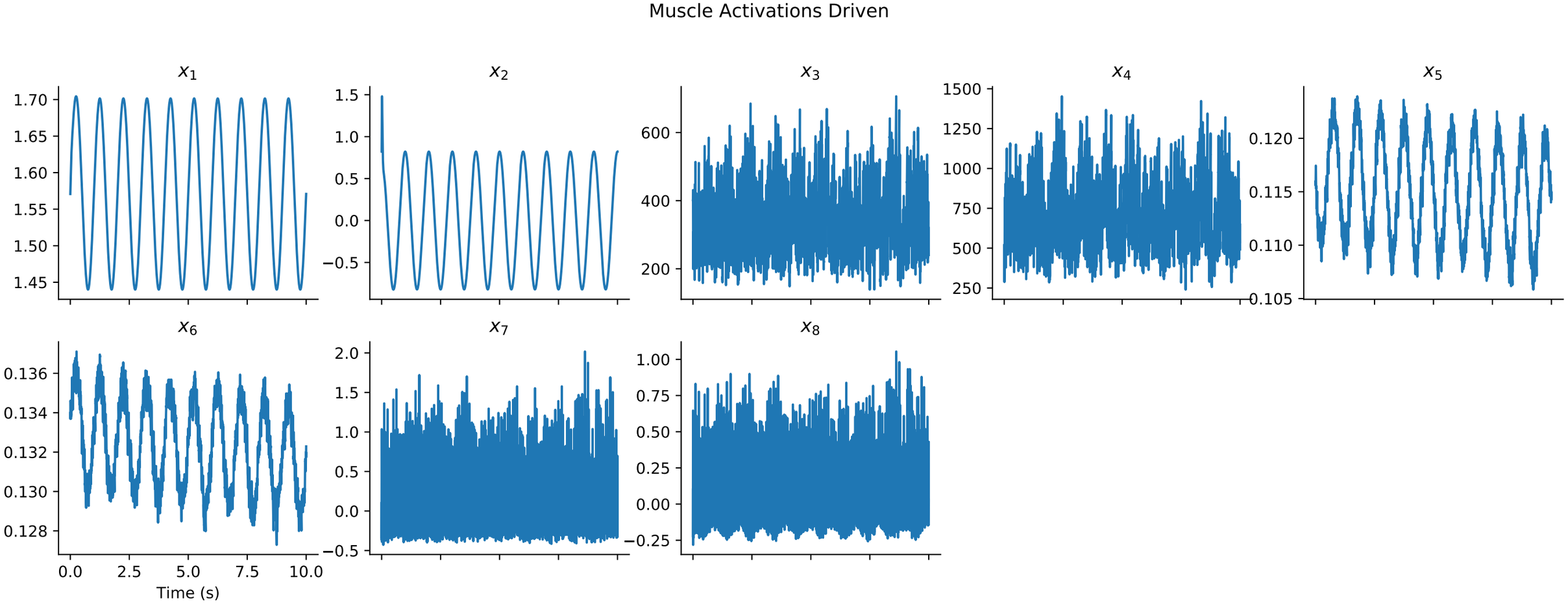

Moment arm equations
(Normalized Muscle Velocities Driven)
Moment Arm for Muscle 1 (m)
0.045
0.040
0.035
0.030
0.025
0.020
0.015
Moment Arm for Muscle 2 (m)
−0.014
−0.016
−0.018
−0.020
−0.022
−0.024
−0.026
0
$\frac{\pi}{4}$
$\frac{\pi}{2}$
$\frac{3\pi}{4}$
π
Joint Angle (rads)
0
2
4
6
8
10
Time (s)

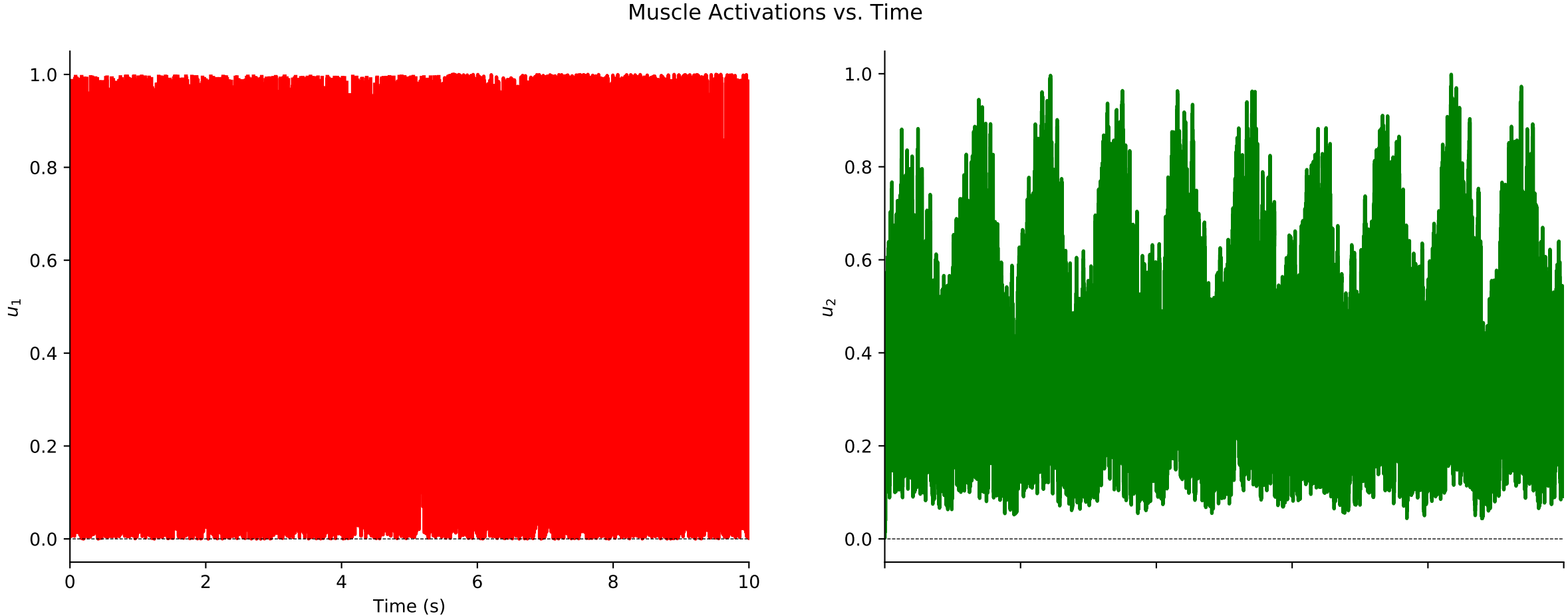

Normalized Muscle Velocities Driven
x_1 (Rads)
x_2 (Rads/s)
x_3 (N)
x_4 (N)
1.70
1.65
1.60
1.55
1.50
1.45
0.0
2.5
5.0
7.5
10.0
Time (s)
1.5
1.0
0.5
0.0
−0.5
1600
1400
1200
1000
800
600
400
200
0
3000
2500
2000
1500
1000
500
0

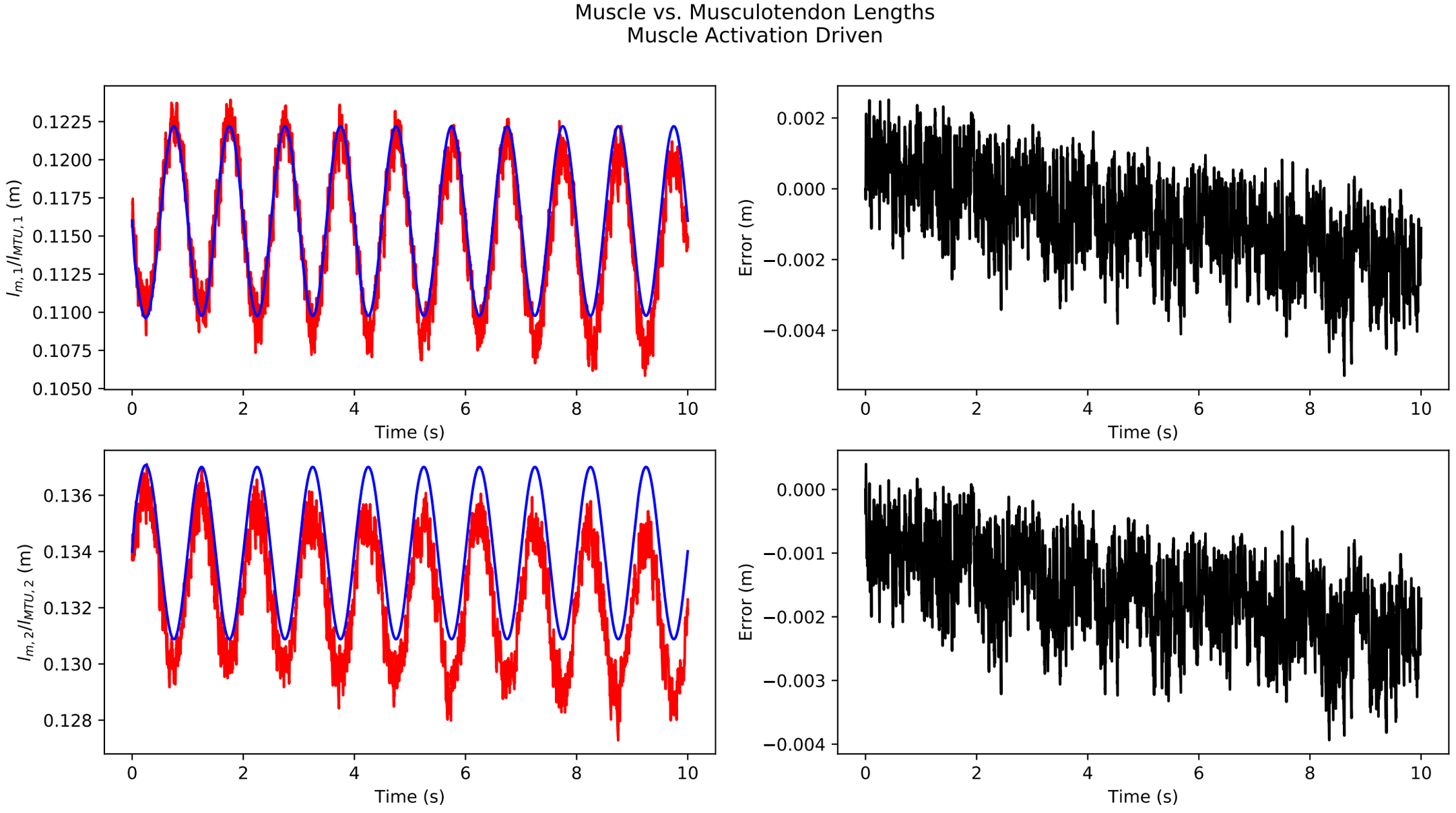

Normalized Muscle Velocities vs. Time
u_1
1.5
1.0
0.5
0.0
−0.5
−1.0
0
2
4
6
8
10
Time (s)
u_2
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
−1.00


Muscle vs. Musculotendon Lengths
Muscle Velocity Driven
$l_{m,1}/l_{MTU,1}$ (m)
0.125
0.120
0.115
0.110
0
2
4
6
8
10
Time (s)
Error (m)
0.0100
0.0075
0.0050
0.0025
0.0000
−0.0025
−0.0050
Time (s)
$l_{m,2}/l_{MTU,2}$ (m)
0.1400
0.1375
0.1350
0.1325
0.1300
0.1275
Time (s)
Error (m)
0.004
0.002
0.000
−0.002
−0.004
Time (s)


Moment arm equations
(Muscle Activations Driven)
Moment Arm for
Muscle 1 (m)
0.045
0.040
0.035
0.030
0.025
0.020
0.015
Moment Arm for
Muscle 2 (m)
−0.014
−0.016
−0.018
−0.020
−0.022
−0.024
−0.026
0
π/4
π/2
3π/4
π
Joint Angle (rads)
0
2
4
6
8
10
Time (s)


Muscle Activations Driven
x_1
x_2
x_3
x_4
x_5
x_6
x_7
x_8
Time (s)


Muscle Activations vs. Time
u_1
u_2
1.0
0.8
0.6
0.4
0.2
0.0
0
2
4
6
8
10
Time (s)


Muscle vs. Musculotendon Lengths
Muscle Activation Driven
$l_{m,1}/l_{MTU,1}$ (m)
0.1225
0.1200
0.1175
0.1150
0.1125
0.1100
0.1075
0.1050
0
2
4
6
8
10
Time (s)
Error (m)
0.002
0.000
−0.002
−0.004
0
2
4
6
8
10
Time (s)
$l_{m,2}/l_{MTU,2}$ (m)
0.136
0.134
0.132
0.130
0.128
0
2
4
6
8
10
Time (s)
Error (m)
0.000
−0.001
−0.002
−0.003
−0.004
0
2
4
6
8
10
Time (s)