Determining an Optimal Speed for a Bipedal Robot on Rough Terrain

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Introduction

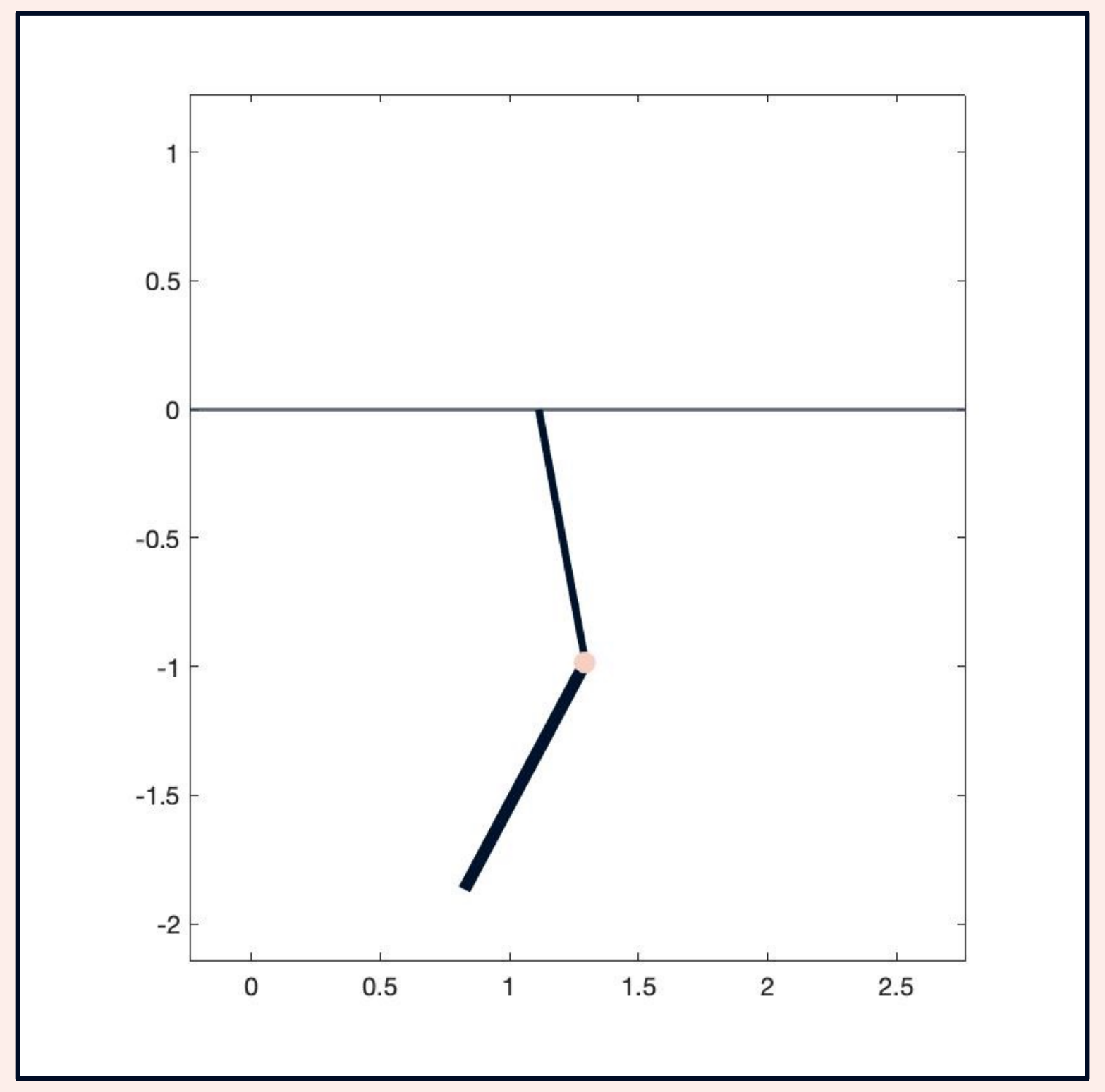

Figure 1. Image depicts a double pendulum in motion

- A double pendulum is formed by attaching a second pendulum to the end of a single pendulum, and it is very sensitive to initial conditions.
- At its core, the compass gait biped created for this project is a double pendulum, pictured above.
- This passive gait biped mimics human walking as the swing foot falls in front of the stance and the energy is transferred between the two.
- The study of bipedal robotics is important because developments in the field will allow for improvements in prosthetics, allow for robots to explore rough terrain, and allow robots to travel in conditions where humans can not.
- By studying models such as the one created for this project, we can learn much about the basics of passive dynamic walking.

Methods

- Created simulation in MATLAB
- Used dynamic equations of motion for a double pendulum given in Garcia et al.

$$\ddot{\theta} - \sin(\theta - \gamma) = 0$$

$$\ddot{\theta} - \ddot{\phi} + \dot{\theta}^2 \sin\phi \; - \; \cos(\theta - \gamma)\sin\phi = 0$$

- Used Euler's method for ordinary differential equations to solve for $\dot{\theta}, \theta, \dot{\phi}$, and ϕ.
- When heelstrike was detected, used following equation to calculate the transfer of energy from the swing and stance leg,

$$\begin{bmatrix} \theta \\ \dot{\theta} \\ \phi \\ \dot{\phi} \end{bmatrix}^{+} = \begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & \cos 2\theta & 0 & 0 \\ -2 & 0 & 0 & 0 \\ 0 & \cos 2\theta\,(1 - \cos 2\theta) & 0 & 0 \end{bmatrix} \begin{bmatrix} \theta \\ \dot{\theta} \\ \phi \\ \dot{\phi} \end{bmatrix}^{-}$$

where $-$ represents the parameters just before the heal strike, and $+$ represents them right after.

- Gamma, corresponding to slope, was increased by 50% and 100%, then new initial conditions were found to create a stable compass gait at each
- Each initial gamma was increased by 0.0001 until the compass gait walker was no longer stable

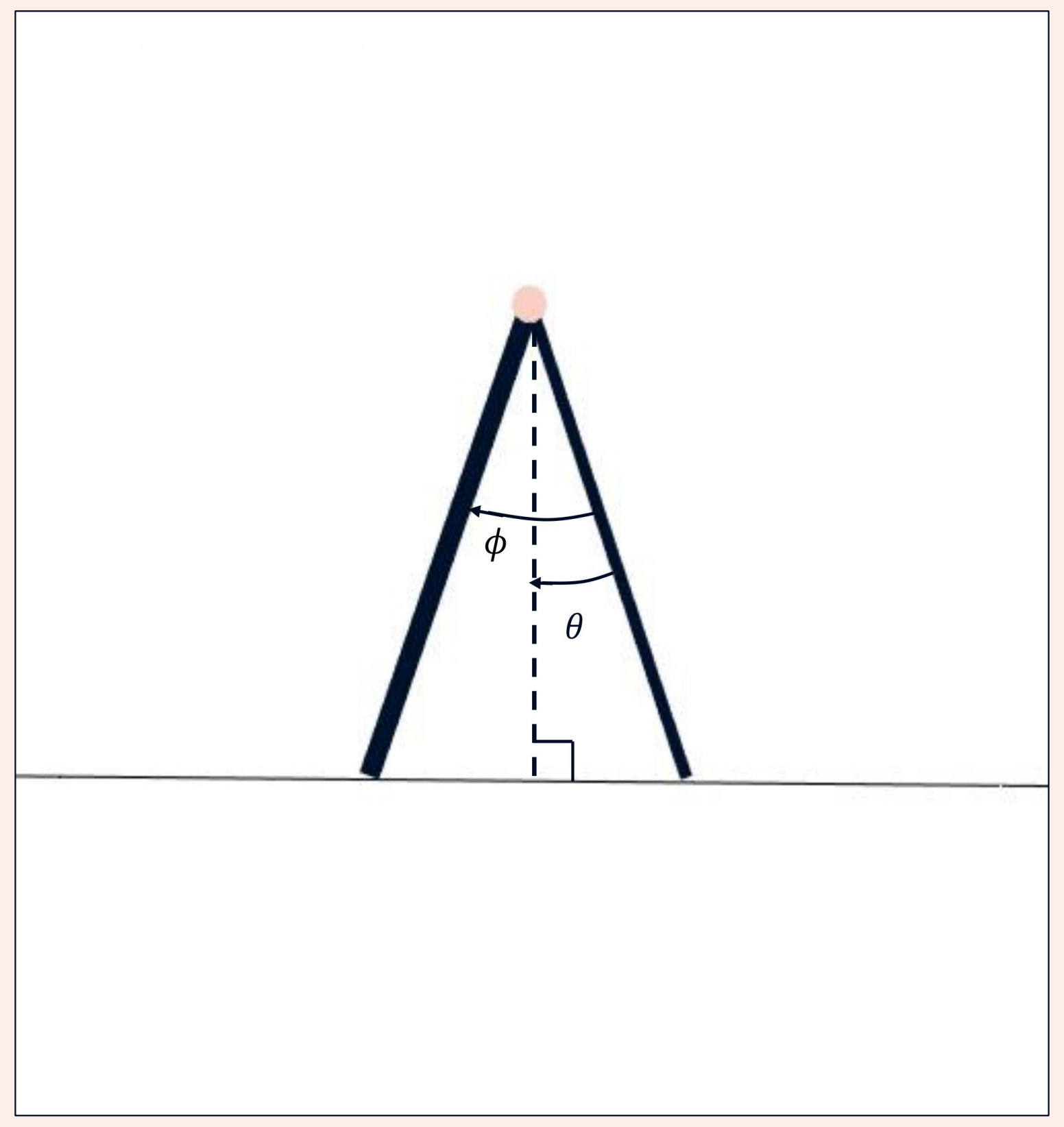

Figure 2. Image labels the angles calculated for and used in the compass gait biped simulation.

The Simulation

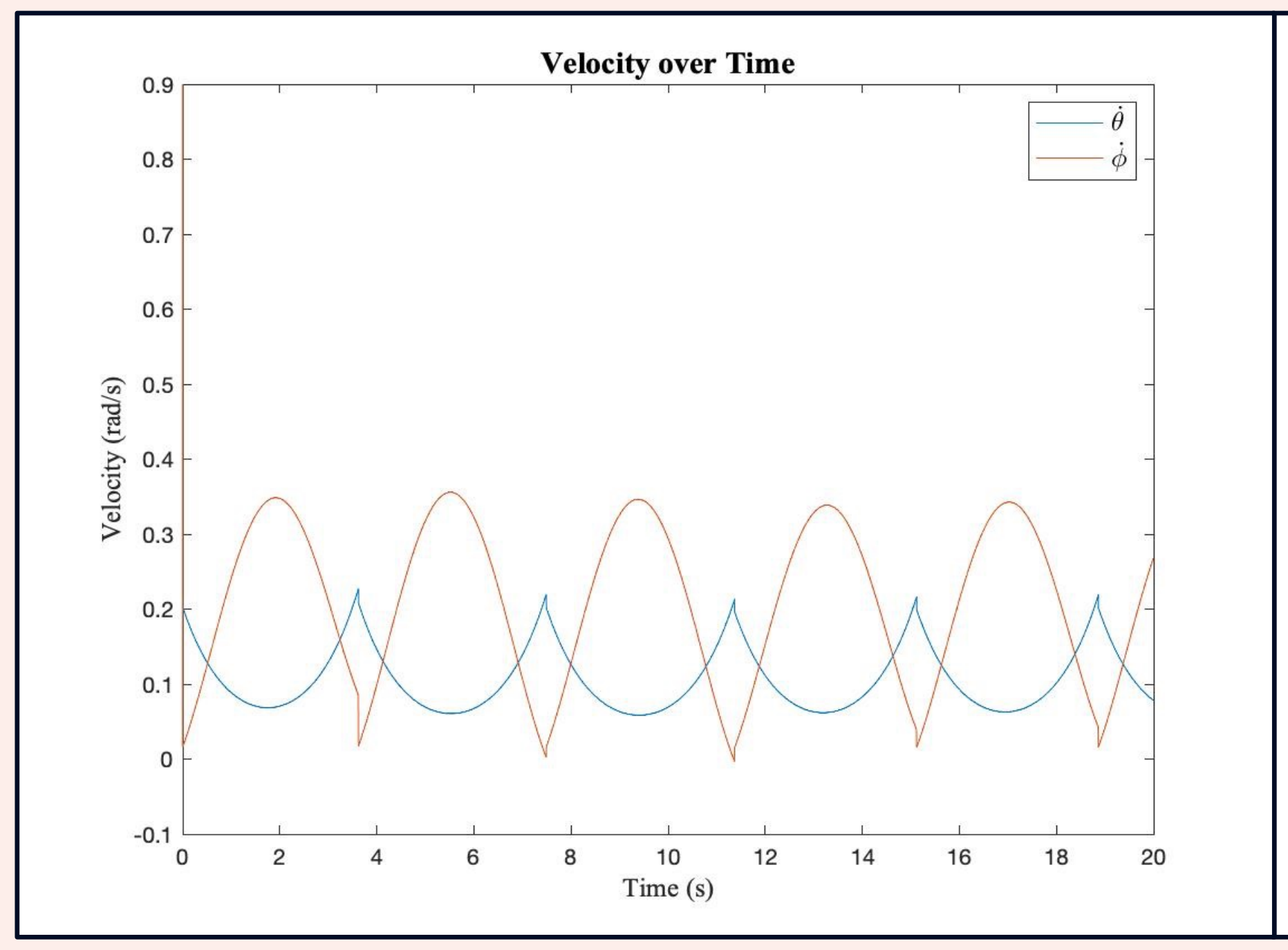

Figure 3. Graph depicts velocity of θ and ϕ over the time of the simulation.

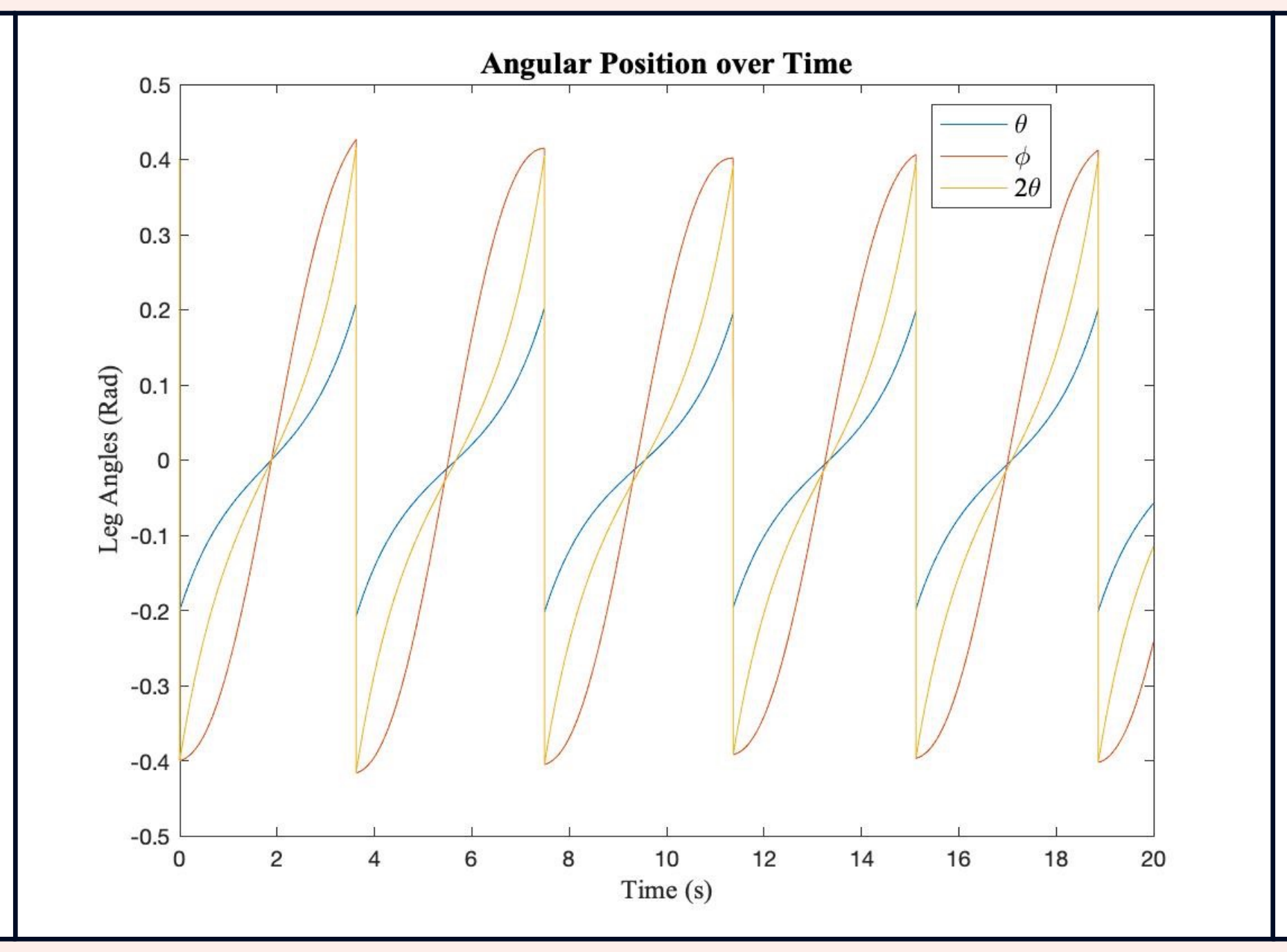

Figure 4. Graph depicts angular position of θ and ϕ over the time of the simulation.

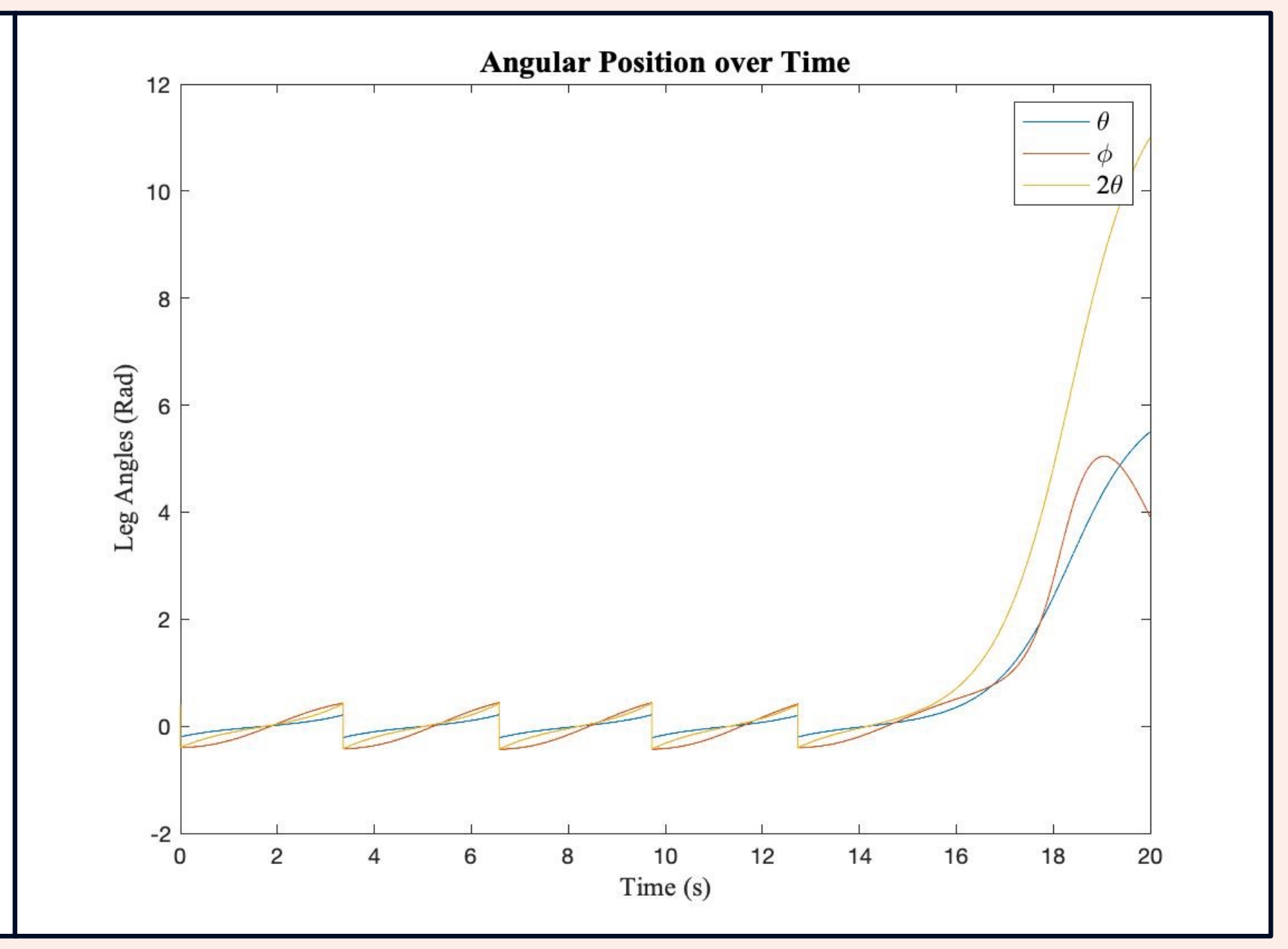

Figure 5. Graph depicts angular position of θ and ϕ during the simulation when a fall occurs

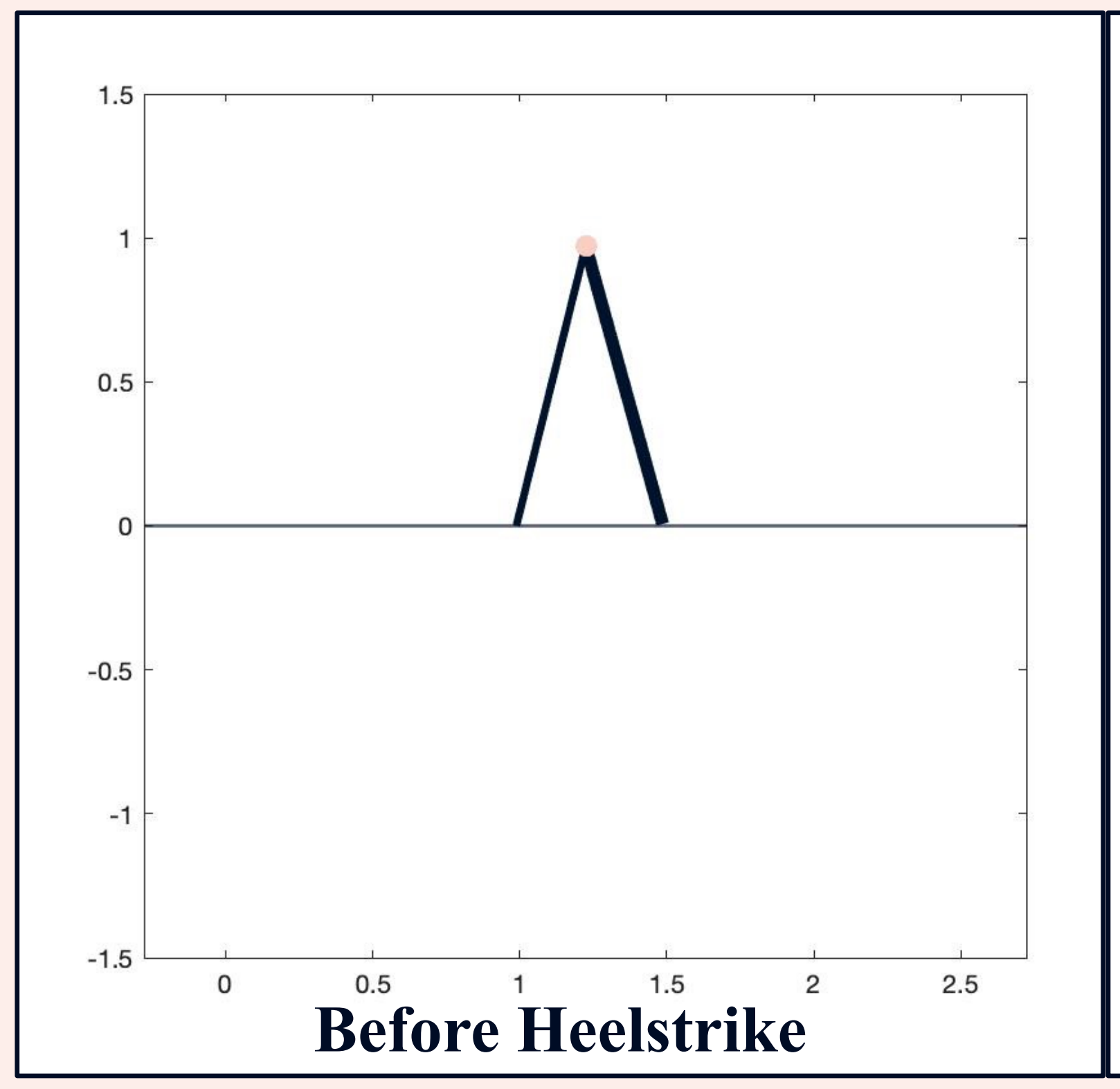

Figure 6. Image of the simulation just before a heelstrike and leg switch.

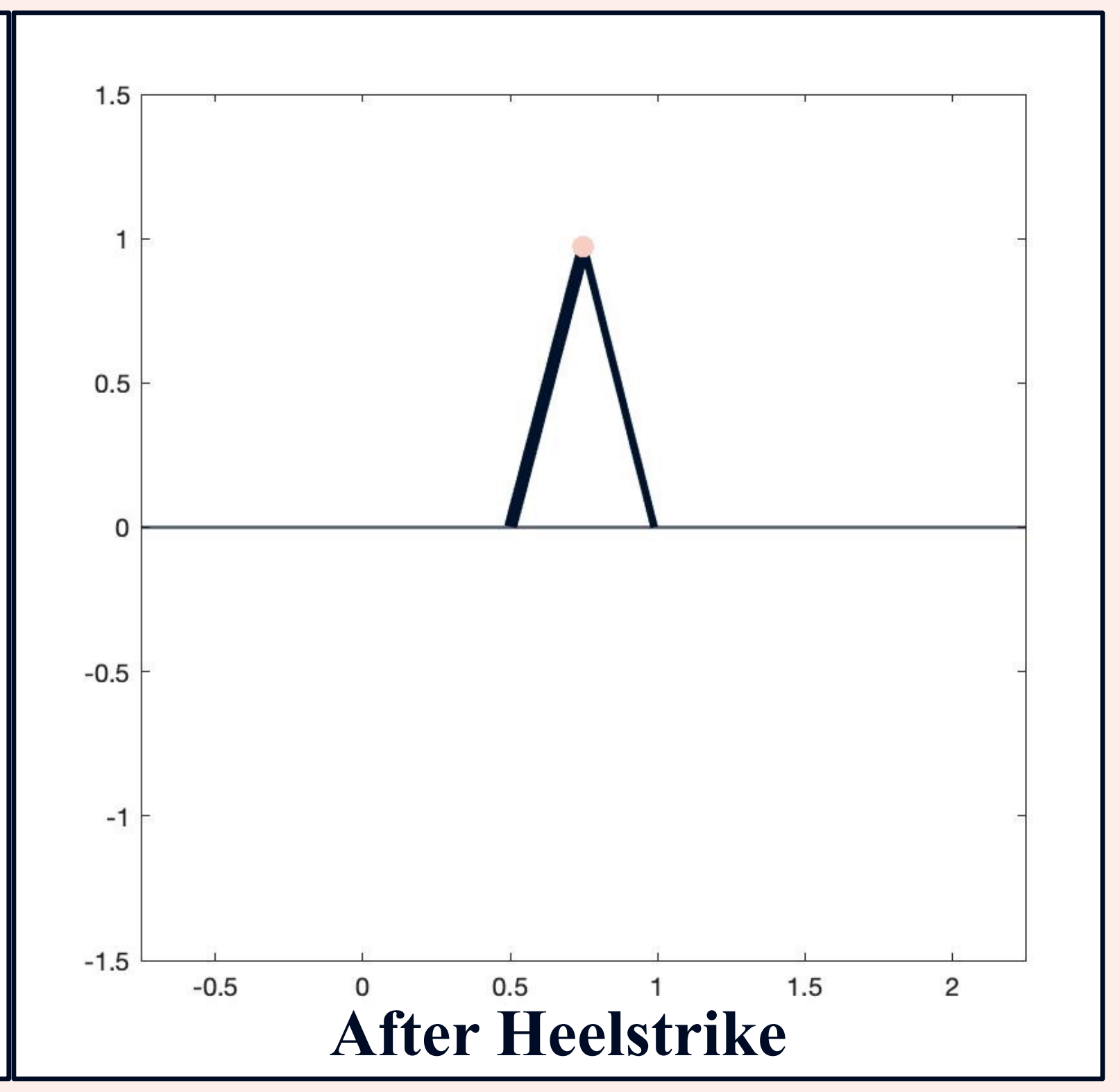

Figure 7. Image of the simulation just after a heelstrike and leg switch.

Results

Slope (γ)	θ	$\dot{\theta}$	θ	$\dot{\phi}$	Slope Range	Range Length	Speed
-0.009	0.20	0.22	0.40	0.90	-0.0090 to -0.0131	0.0041	0.2081
-0.0145	0.20	0.25	0.30	0.90	-0.0145 to -0.0167	0.0022	0.0028
-0.018	0.20	0.23	0.30	0.95	-0.0180 to -0.0230	0.0050	0.3929

Discussion

These results are significant as we can apply these speeds to true bipedal robots, that travel through rough terrain, to optimize the distance they are able to traverse through. This speed optimization will allow for improvements in bipedal robots that travel where humans can not.

Conclusion

From these results, we can conclude that speed 0.3929, is the most efficient speed. This speed was given at a γ of -0.018. This speed was stable for a range length of 0.0050 starting at -0.0018 and ending at -0.0230. This means this speed would be optimal to use for a bipedal robot on rough terrain as it is stable for the largest range of slopes. This speed was 0.0009 better than the second optimal speed, 0.2081, given at a γ of -0.009, which had a slope range length of 0.0041.

References

Garcia, M., Chatterjee, A., Ruina, A., & Coleman, M. (1998). The simplest walking model: Stability, complexity, and scaling. Journal of Biomechanical Engineering, 120(2), 281–288. https://doi.org/10.1115/1.2798313