Exploration of the Optimal Jumping Leg

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Introduction

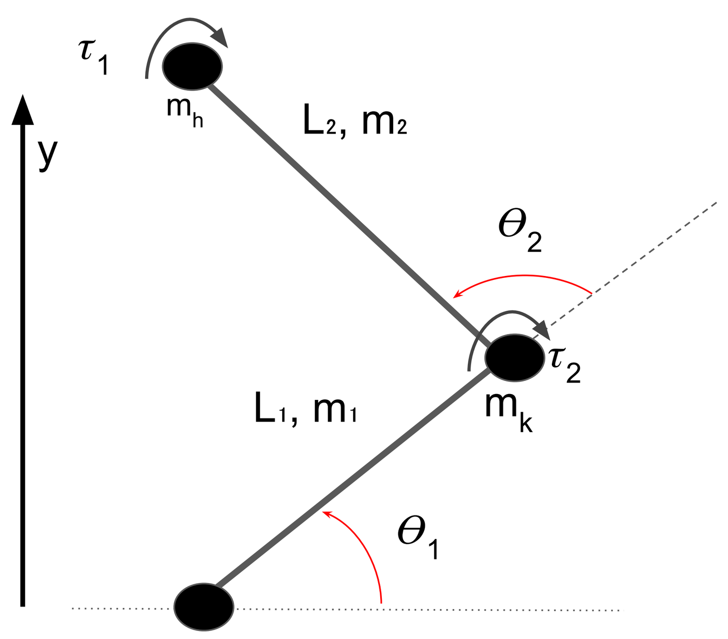
Nature provides various examples of evolved leg geometries optimized for certain performance characteristics. Kangaroos, for instance, are known for their jumping ability and have a relatively short femur, roughly half the length of their tibia[1]. The muscle distribution relating to knee and hip torques substantially varies across jumping animals. The leg muscles in frogs are densest around the hip flexor suggesting higher energy output in the hip than knee.

This experiment isolated femur and tibia length ratios in relation to vertical jump performance. The work done by each joint's motor was compared across leg geometries to identify the respective muscle group contribution towards jumping. Discovering the ideal jumping geometry and power allocation can inform athlete training and the design of future prosthetics, and robotic legs.

Simulation Methods

Lagrangian Dynamics:

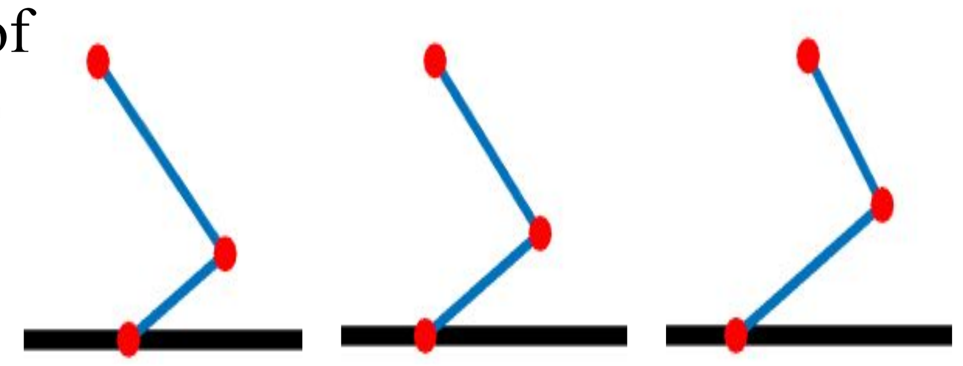
$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{q}_i}\right) - \frac{\partial L}{\partial q_i} = Q_i$$



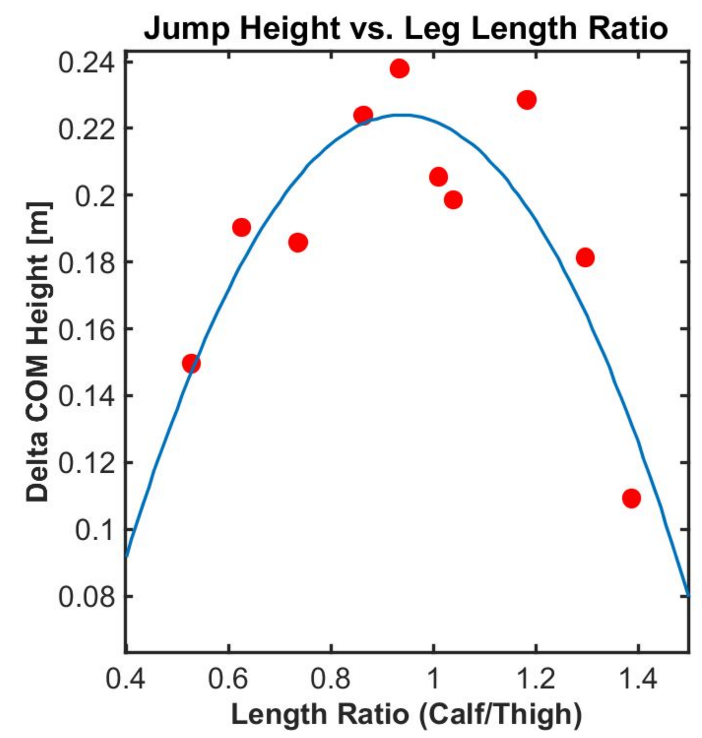
Constraints:
Hip constrained to vertical motion No hyperextension

- $0 < \theta 1 < \pi/2$
- $0 < \theta 2 < \pi$

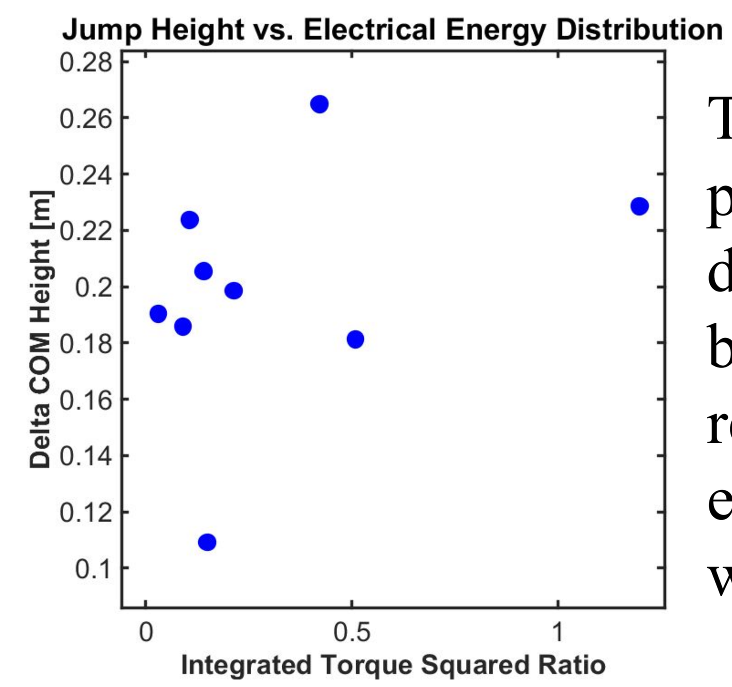
Optimized torque profile of motors at the knee and hip using MATLAB and the ode45( ) solver. Total leg length held constant.



Simulation Results



Simulations showed a parabolic relationship between leg length ratio and vertical jump height, with performance dropping off at either extreme. Peak performance occurred at a length ratio of 0.933



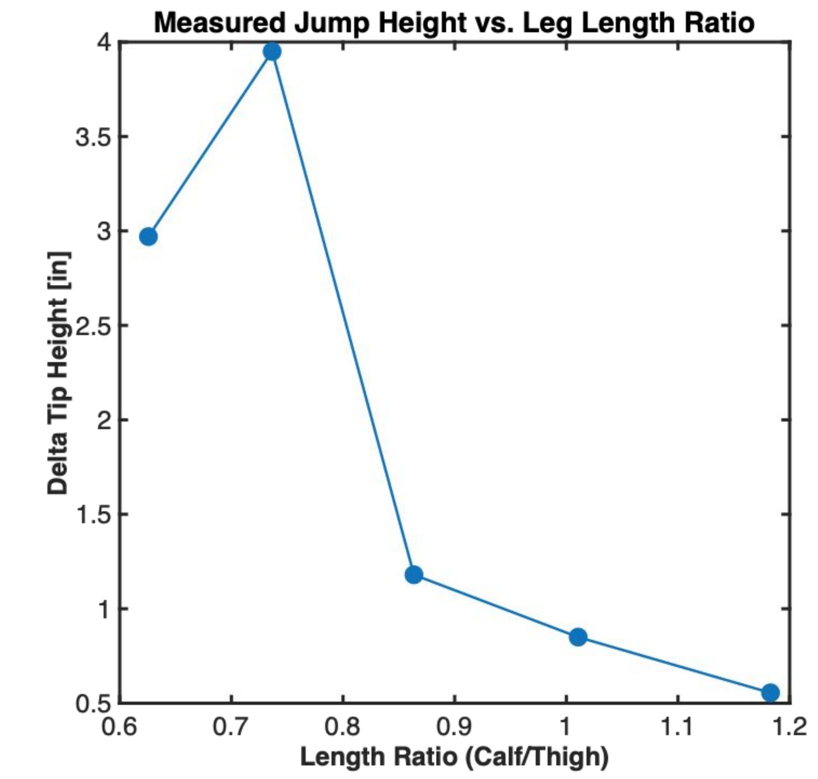
The sum of squared torque profiles was used to estimate the distribution of electrical energy between the motors. No clear relationship between distributed energy and resulting jump height was observed.

Experimental Methods

- Telescoping 2-bar, 2-motor legged jumping robot
- Counterweight + boom constraints motion to plane
- Hybrid position current PD controller

Experimental Results

Peak jump height occurred at a calf to thigh ratio of 0.754 meaning the thigh was 57% of the total leg length. .



Discussion

The simulation and experimental results were inconsistent, with the latter indicating better performance at a lower leg length ratio than the former. The simulated optimal result is fairly close to the human leg length distribution, which has an average calf to thigh ratio of 0.923.

Conclusions

- Longer femur = higher overall jump
- Performance goes to zero at extreme ratios
- No clear muscle group dominance observed
- 2-bar linkage dynamics differ greatly from 3-bar linkage jumping

References

1. Fatima, Manaal, et al. "Towards a Dynamic Model of the Kangaroo Knee for Clinical Insights into Human Knee Pathology and Treatment: Establishing a Static Biomechanical Profile." Biomimetics, vol. 4, no. 3, 2019, p. 52., doi:10.3390/biomimetics4030052.