Cornell Ranger: Computer Simulations and Experimental Fits

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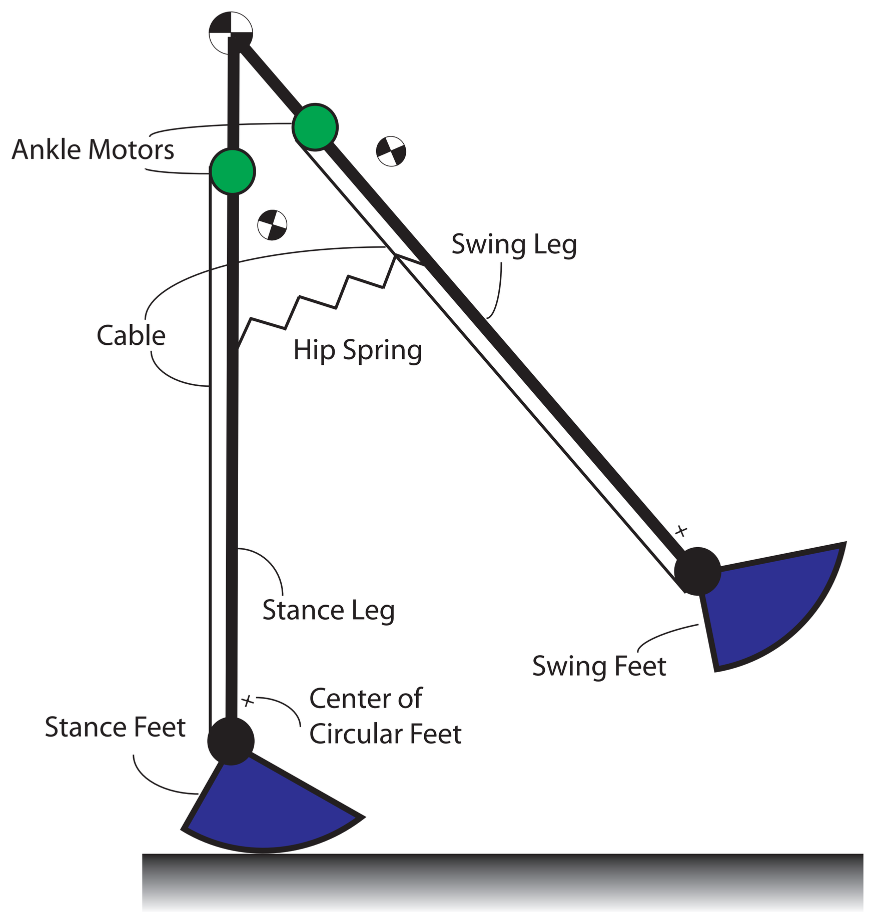
Objective

- A computer model of the Cornell Ranger that predicts the key gait parameters (step time, velocity, stride length etc).
- A DC motor model that predicts the energetics and cost of transport.

Model

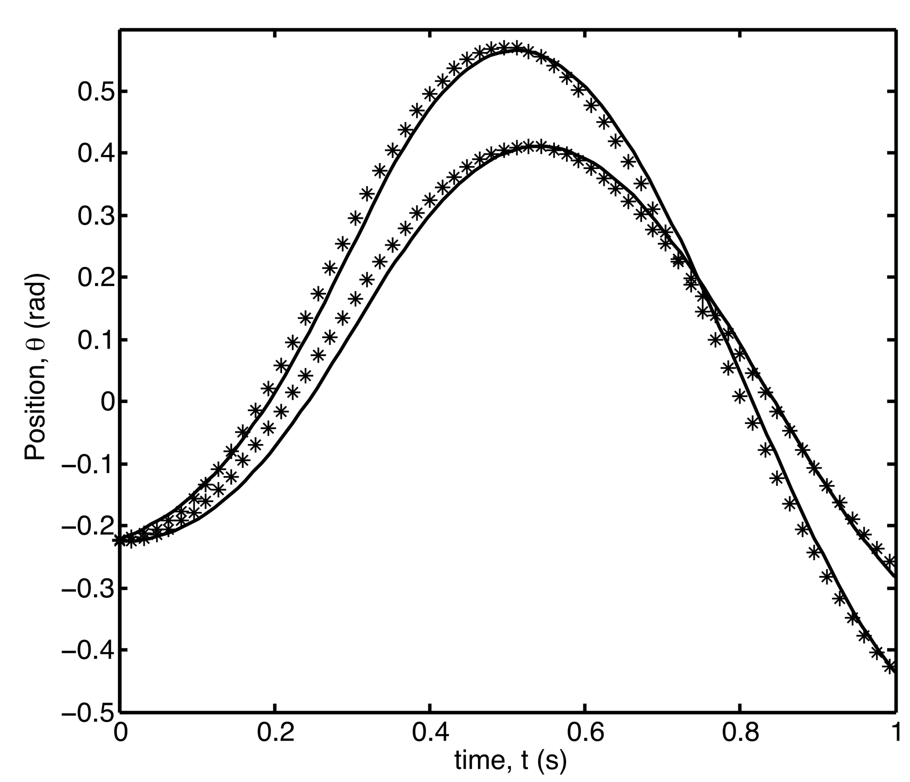
- 3 link pendulum in single stance (8 dofs in state space, 2 absolute + 6 relative)
- 4 link pendulum in double stance (10 dofs in state space, 2 absolute + 8 relative)
- Legs have mass and inertia and are symmetric. Point mass at the hip.
- Feet have no mass and are round.
- Feet Roll without slip.
- Collisions are instantaneous and hard.
- Heelstrike velocities are discontinuous while positions are continuous.
- Hip spring modeled as a linear torsional spring.
- Hip motor powers the hip.
- 2 Ankle motors connected to ankles through a finite stiffness cable. (adds 4 more dofs in state space)
- Motor model incorporates friction but ignores backlash.



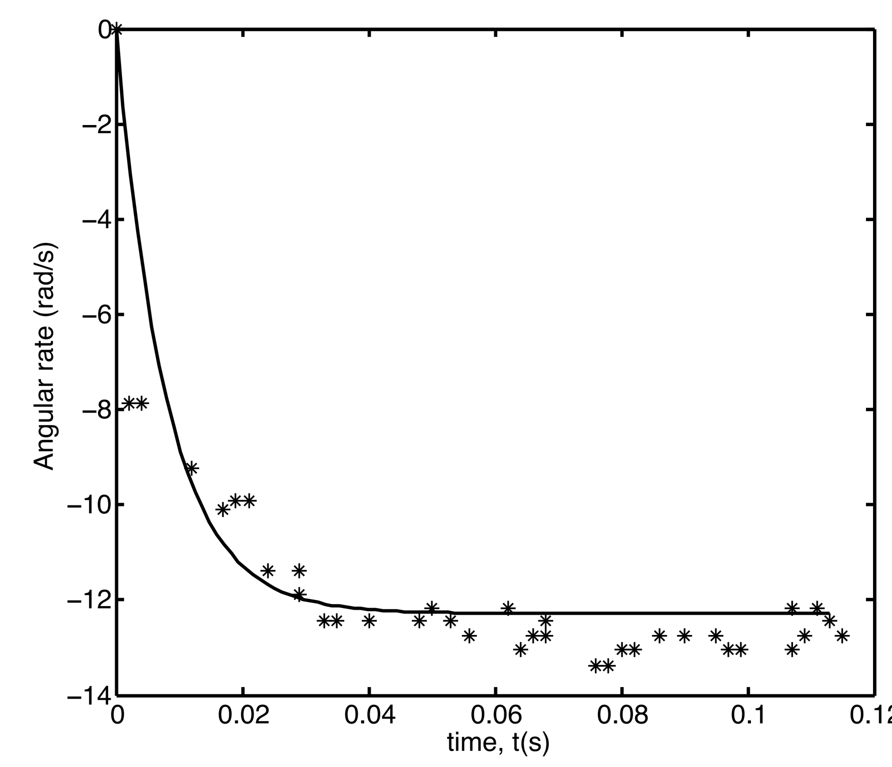
DC motor model

- The ranger is powered by 3 DC motors; one powering the hip while the other two powering the ankles.
- The energy losses in the DC motor are the friction losses in the gearbox and the resistive heat losses in the motor windings.
- Our model is based on a linear relationship between PWM (proportional to motor voltage), Torque and Speed.
- We tested the motors in bench experiments and fitted a load dependent and independent constant friction and viscous friction.
- We validated our motor model on the ranger on a hip swing and ankle lift experiment as shown in the figures below.

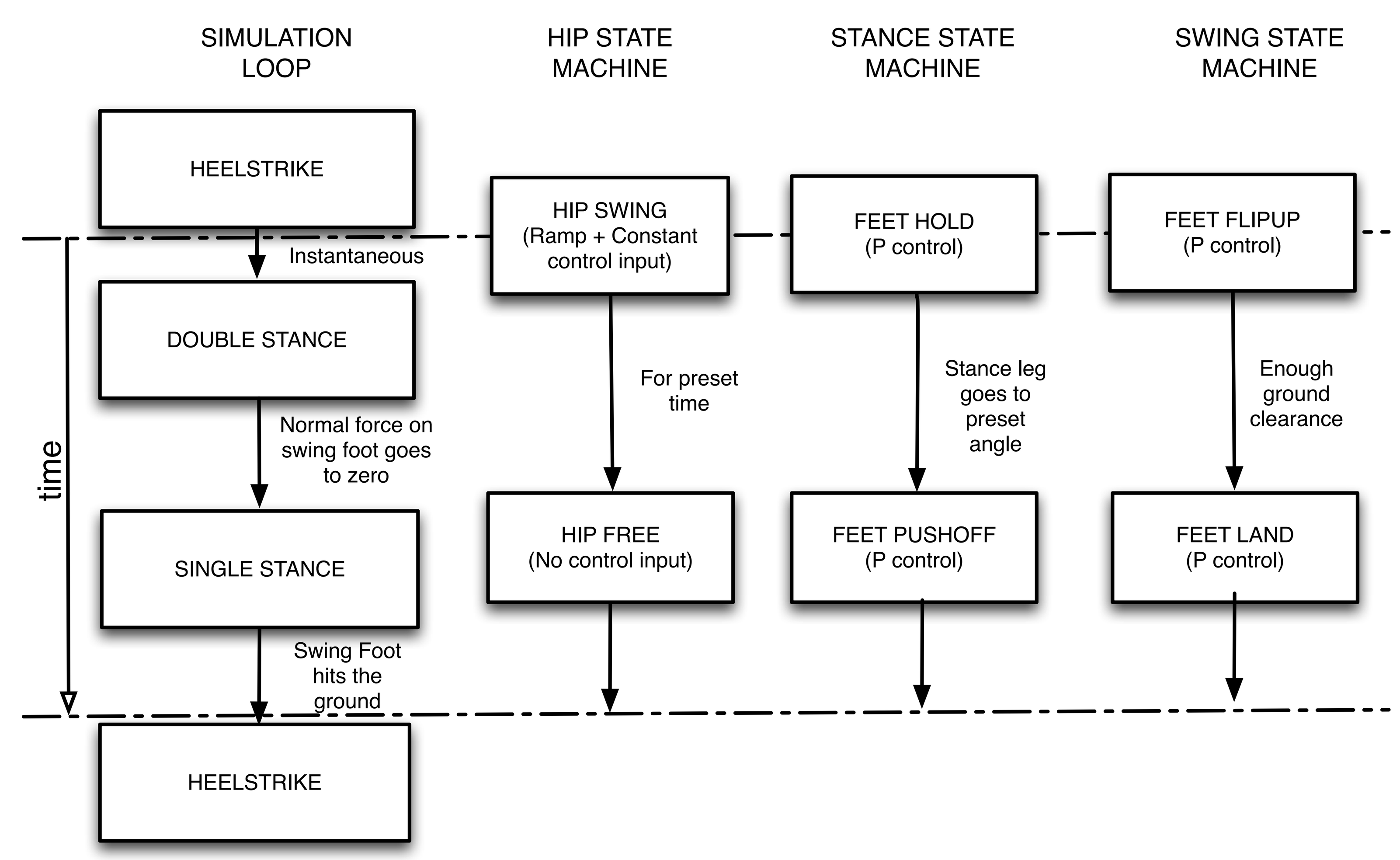
Hip Swing



Ankle Liftoff

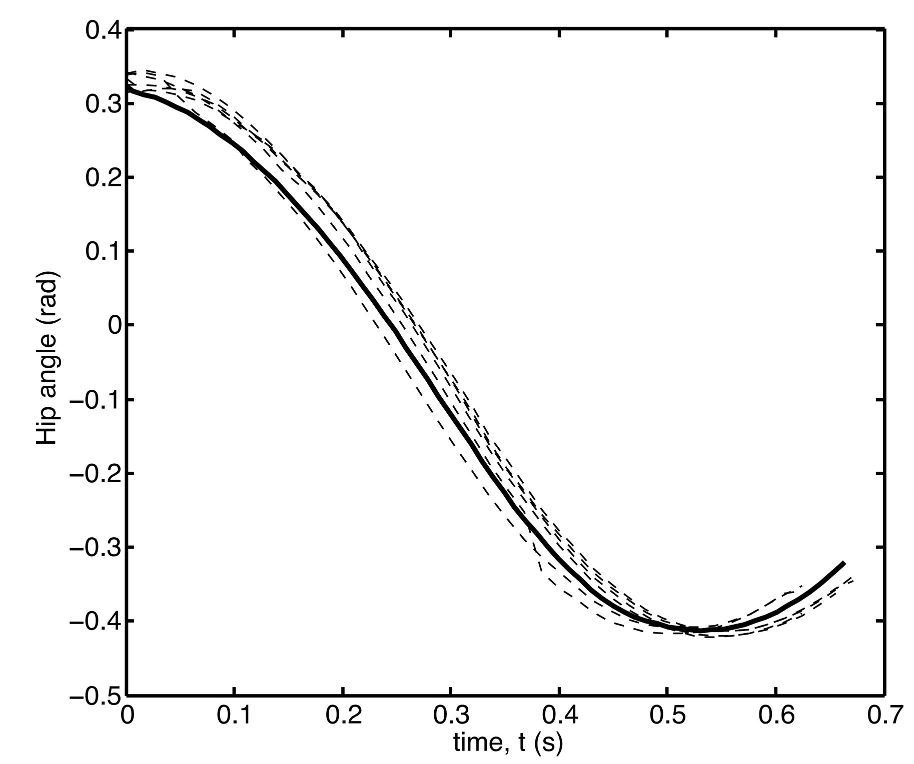


Simulation loop and Control Algorithm

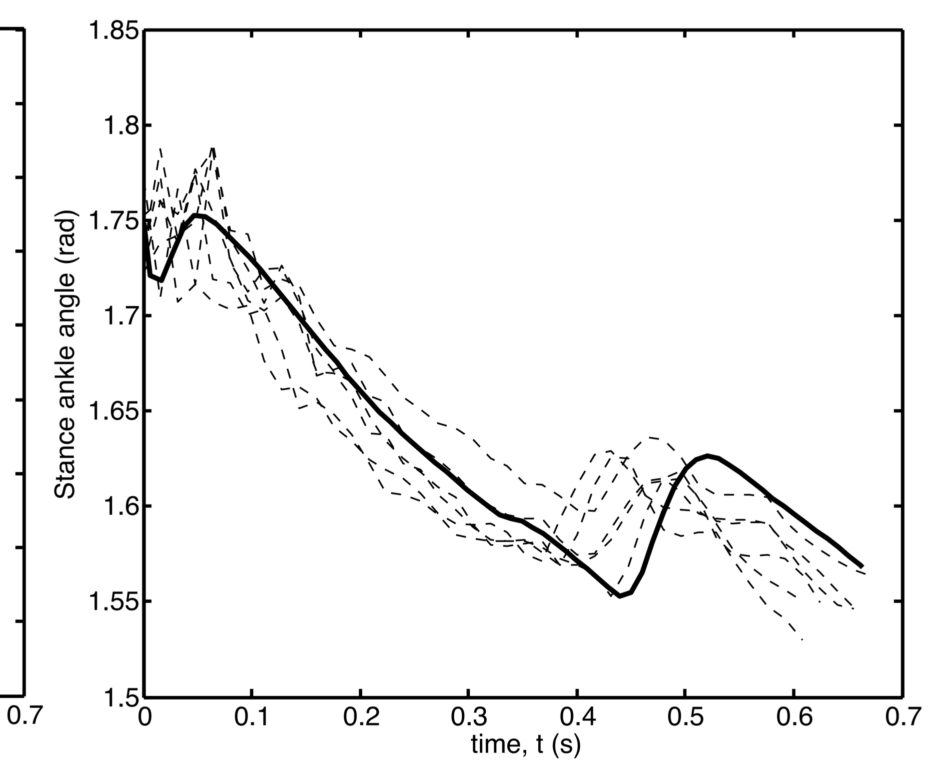


Results: Comparisons to walking trials

Hip Joint



Stance Ankle Joint



More results

- A comparison of key gait parameters.

Gait Parameter	Experiment	Simulation
Step Time (s)	0.65	0.66
Step Length (m)	0.32	0.32
Velocity (m/s)	0.49	0.48
Double Stance Time (s)	0.02	0.008

- The power consumption in the motors was experimentally found to be $17.61\ W$, which closely matched with $17.35\ W$ predicted by the model.
- The cost of transport (defined as Total Electrical Power/ (Weight $\times$ Speed)) predicted by the model matched with the experiments and was found to be 0.43. (However, the other electronics like the sensors, IMU and processors use about $8.15\ W$ and hence the actual cost of transport was about 0.62).

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