Feasibility of Achieving Standing Bipedal Balance with Small Feet

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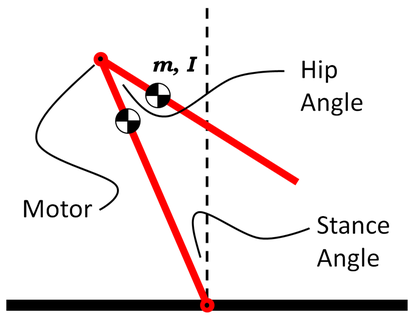
Motivation:

- Three primary means of bipedal balance:
  - 1) Foot placement 2) Ankle torque 3) Body distortion
- Question to be answered:
  - How much control authority is provided by body distortion?
- Approach:
  - Attempt to balance the Cornell Ranger using only hip torque

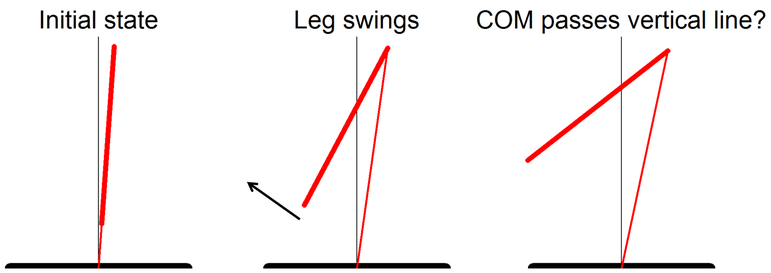
Model:

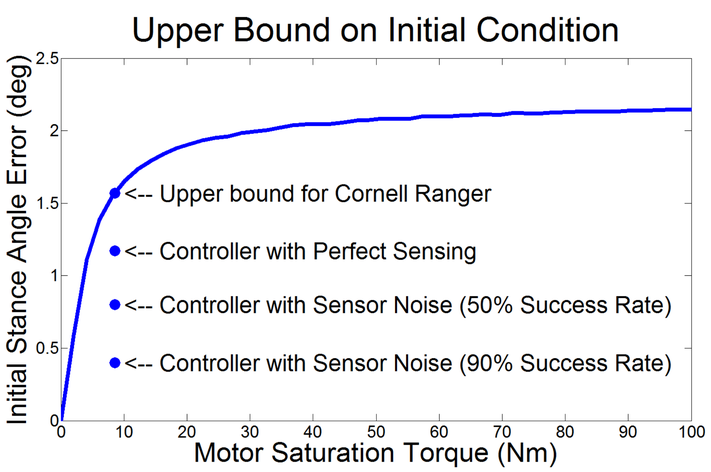
- Parameters:
  - Cornell Ranger[1]
- Dynamics:
  - Double pendulum with motor & sensor models[2]



Theoretical Bound:

- Find upper bound on controllable stance angle
  - Hip angle limited to ±40°
  - Method: full torque to swing up leg at start





Double PD Controller:

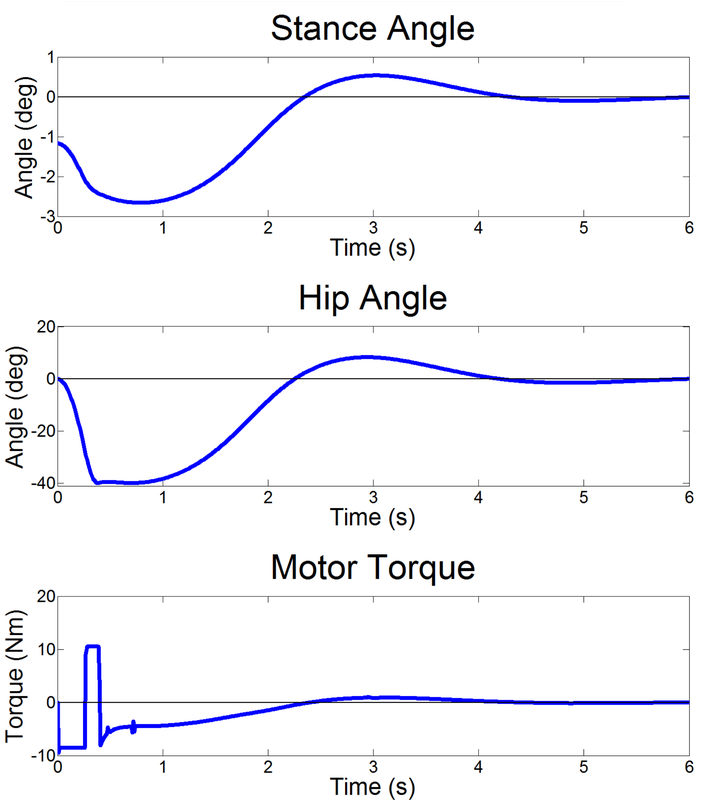
$$I_{raw} = \begin{bmatrix} K_{P1} \\ K_{D1} \\ K_{P2} \\ K_{D2} \end{bmatrix}^T \cdot \begin{bmatrix} \hat{\theta}_1 \\ \hat{\omega}_1 \\ \hat{\theta}_1 \\ \hat{\omega}_1 \end{bmatrix} \quad \begin{aligned} \hat{\theta}_1 &= Stance\ angle \\ \hat{\omega}_1 &= Stance\ rate \\ \hat{\theta}_2 &= Hip\ angle \\ \hat{\omega}_2 &= Hip\ rate \end{aligned}$$

$$T_{hip} = MotorModel\{\, Saturate(I_{raw}),\ \omega_1 \,\}$$

Particle Swarm Optimization:

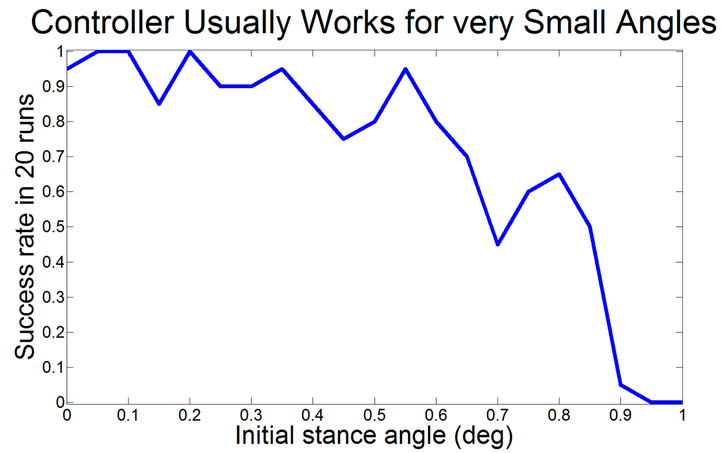
- Global optimization technique[3]
- Attempts to minimize cost function:
  1. Run simulation with a set of gains to test
  2. Cost is a function of:
     - Mean square error in stance angle
     - Ability to achieve balance
- Learn gains using a model (ideal / noisy)

Controller with Perfect Sensing:



Realistic System Model:

- Motor Model[1]:
  - Friction, Saturation
- Sensed States: noise model from data
  - Stance Angle Rate (IMU)
  - Hip Angle (Rotary Encoder)
- Estimated States:
  - Stance Angle (Integrate IMU)
  - Hip Angle Rate (Differentiate Encoder)
- Success:
  - Angles remain within bounds for 30 seconds



Key Points:

- Physical limitations: Balance only possible within 2 deg
- PD Control architecture: Balance possible within 1.2 deg
- Sensor limitations: Robust balance not possible

Future Work:

- Investigate alternative control architectures
- Improve computational efficiency of learning algorithm
- Compare control authority using:
  - Hip torque, Ankle torque, Foot placement

Acknowledgments:

- Research supported by the National Science Foundation

References:

[1] *A controller design framework for bipedal robots.* **Pranav Bhounsule.** Cornell PhD Dissertation, 2012
[2] Implemented using **Roy Featherstone's** *Spatial Vector and Rigid-Body Dynamics* Matlab library
[3] *Particle swarm optimization, an overview.* ***Riccardo Poli, James Kennedy, Time Blackwell.*** *Swarm Intell.*