Some Bipedal Control

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Introduction to Robotics 2016
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Controlling nonlinear systems

• Use tools you already know to solve interesting nonlinear problems

• For example, bipedal systems are:
  – Nonlinear (as are all real systems)
  – Underactuated
  – Hybrid Dynamic
Problems with Pendulums:
Problems with Pendulums:

How much torque do we need to get to the top?

Some times we need to think about trajectories.
Problems with Pendulums:

How much torque do we need to get to the top?

Can we get to the top with less torque?
Problems with Pendulums:

How much torque do we need to get to the top?

Can we get to the top with less torque?

Sometimes we need to think about trajectories.
Problems with Pendulums:

How much torque do we need to get to the top?

Can we get to the top with less torque?

Sometimes we need to think about trajectories

"Underactuated"
Problems with Pendulums:

Now, assume we have infinite torque, but finite foot. What happens if we apply the required gravity compensation torque?
Problems with Pendulums:

What does our system look like if we apply the required gravity compensation torque?
Problems with Pendulums:

What does our system look like if we apply the required tau?
Problems with Pendulums:

What does our system look like if we apply the required tau?

What is the effective max torque?
Problems with Pendulums:

What does our system look like if we apply the required tau?

What is the effective max torque?

What about really Large tau?
Problems with Pendulums:

Interesting systems might require path planning (or you might be doing exactly the wrong thing)
Problems with Pendulums:

Interesting systems might require path planning

Envelopes of operation
Problems with Pendulums:

Interesting systems might require path planning

Envelopes of operation

Can find ways to apply our nice linear methods in some cases
A walking system that requires no sensing, control, computer, etc.
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“Hybrid”
Another walking system

https://www.youtube.com/watch?v=dI7KUUVC-M
One way to control walking stability

For more detail, a draft of a paper on this project is available at https://dl.dropboxusercontent.com/u/19827221/2014-footYawStabilityPaperV3.pdf
More info on bicycle stability:
http://ruina.tam.cornell.edu/research/topics/bicycle_mechanics/papers.php

In particular, a very interesting bicycle that stabilizes without gyroscopic or caster effects (it uses mass distribution to couple lean with steering)
http://ruina.tam.cornell.edu/research/topics/bicycle_mechanics/stablebicycle/index.htm
(Wisse 2005)
Do people use steering to avoid falls?
Do people use steering to avoid falls?

**Model**

**Human Experiment**

- lateral foot placement
- external rotation
Walking Model

Eoms were generated analytically.

Hybrid dynamics collisions are perfectly inelastic. Constraints are enforced using constraint jacobians.

Limit cycle was found with walking down a gentle slope.

Using a sequential quadratic programming roune to enforce limit cycle constraints and anthropomorphic gait properties.

Add something technical that says I'm an irregular person.
Walking Model

Analytical EOMs
Hybrid dynamics
Inelastic collisions
Constraint jacobians
SQP $\rightarrow$ Limit cycle
Passive, down slope
Linearize Cyclic Dynamics
Unstable Lateral Falling Mode

\[ x_{k+1} = A x_k \]
Control to Stabilize Lateral Falling

\[ x_{k+1} = Ax_k + Bu \]
\[ u_k = -Kx_k \]

Stabilize lateral falling mode

Unit circle

-28.8
Stabilizing the Walking Model
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Stabilizing the Walking Model

Foot placement control
Stabilizing the Walking Model

Foot placement control

Perturb to the right
Stabilizing the Walking Model

Foot placement control

Perturb to the right

step to the right
Stabilizing the Walking Model

Foot placement control       External rotation control

Perturb to the right

step to the right
Stabilizing the Walking Model

Foot placement control

External rotation control

Perturb to the right

step to the right

Perturb to the right
Stabilizing the Walking Model

Foot placement control

External rotation control

Perturb to the right

step to the right

point foot to the right

Perturb to the right
Do people use steering to avoid falls?

Model

Human Experiment

lateral foot placement  external rotation
Do people use steering to avoid falls?

Model

Steering stabilizes mechanical model

Human Experiment

lateral foot placement  external rotation
Normal Walking
Normal Walking

- Walking Direction
- Foot Trajectory
- Normal Walking
- Rotation (rad)
- Lateral (m)
- Forward (m)

Expected plots here (or first?)

lateral foot placement, external rotation
All Stride Correlations

Rotation (rad) vs. Lateral (m)

Young

Elderly
All Stride Correlations

Rotation (rad) vs. Lateral (m)

- Young
- Elderly
All Stride Correlations

*, P < 0.05

Rotation (rad)

Rotation (rad)

Lateral (m)

Young

Elderly

lateral foot placement  external rotation
All Stride Correlations

*}, $P < 0.05$

lateral foot placement external rotation

Rotation (rad)

Young

Elderly

Rotation (rad)

Lateral (m)

Forward (m)
Simple models could be used for planning trajectories
Simple models haven't told us everything (Ruina 2005), (Kuo 2005) (Kuo 1999)
Simple models haven’t told us everything.

- Fundamental Dynamics
  - Isolate Mechanisms
    - Foot placement -> Stability
    - Pushoff -> Efficiency

(Seth 2011)
Simple models haven’t told us everything.

- Fundamental Dynamics
- Isolate Mechanisms

(Seth 2011)
Simple models haven't told us everything.

- Fundamental Dynamics
- Isolate Mechanisms
  - Stability (foot placement)

(Kuo 1999)

(Seth 2011)
• Fundamental Dynamics

• Isolate Mechanisms
  – Stability (foot placement)
  – Efficiency (Pushoff) (Kuo 1999)
  (Ruina 2005), (Kuo 2005)

(Seth 2011)