151-0653-00L
Introduction to Bio-Inspired Robotics
Tuesdays, 08-11, HG D5.2

Fumiya Iida
Hugo Marques
Utku Culha
Xiaoxiang Yu
Hung Quy Vu
## Course Overview

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**Tools:**
Classical mechanics (e.g. Eq. of Motion), Matlab (e.g. ODE, Simlink, SimMechanics), Soft robotics tool kit
Today: Tutorial
Building Bio-Inspired Robots

1. Research process overview
2. Building bio-inspired robots
3. Case study 1: Two-leg walker
4. Case study 2: Curved Beam Robots
5. Case study 3: Soft robots
6. Tutorial (ML H43)
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Biology-Robotics Loop

Bio-Inspiration, Biological Models

Biology
- Observe
- Modeling
- Experiment
- Analysis

Robotics
- Design
- Modeling
- Control
- Experiment
- Analysis

Biological Understanding
- Biological cybernetics
- Artificial life
- Adaptive behaviors

Robotics Technologies
- Bionics
- Biomimetics
- Biorobotics
- Bio-inspired robotics

Synthetic Methodology
Robotics Models
Why do we build real-world robots?
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Building Bio-Inspired Robots
Big Dog Actuation/Control System

[Buehler et al. 2005]
Salamander Robot Hardware

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Building Bio-Inspired Biped Robot

Walk and Hop in a Biped Robot

Robot Model in SimMechanics

Main Features:
- 3 limb segments
- 2 passive joints and one motor
- 4 tension springs (3 biarticular)
- Sinusoidal Oscillation with no feedback

\[ M \ddot{q} + Sp(q, \dot{q}) + GRF(q, \dot{q}) + Grav = \tau \]
\[ q = [x, y, P_1, P_2, \theta_{\text{knee}}^1, \theta_{\text{knee}}^2, \theta_{\text{ankle}}^1, \theta_{\text{ankle}}^2] \]

Tension Spring:
\[ F_{sp_{ij}} = \begin{cases} 
K_{ij}(x_{ij} - N_{ij}) - D_{ij}\dot{x}_{ij} : & x \geq 0 \\
0 : & x < 0 
\end{cases} \]

Spring-Damper Ground Interaction (with a slide-stiction switching):
\[ G_y = a|y_c|^3(1 - b \dot{y}_c) \]
\[ G_x = \begin{cases} 
\mu_{\text{slide}} G_y \dot{x}_c / |\dot{x}_c| : & \mu_{\text{slide}} G_y \dot{x}_c / |\dot{x}_c| > \mu_{\text{stick}} G_y \\
F_{xc} : & \mu_{\text{slide}} G_y \dot{x}_c / |\dot{x}_c| \leq \mu_{\text{stick}} G_y 
\end{cases} \]

Motor Control:
\[ P_1 = A \sin(2\pi \omega t) + B \]
\[ P_2 = A \sin(2\pi \omega t + \pi) + B \]
SimMechanics Simulation

Walking: $\omega=2.2$ Hz, $K_{11}=1000$, $K_{12}=100$, $K_{21}=7000$, $K_{22}=4000$
$N_{11}=0.131$, $N_{12}=0.045$, $N_{21}=0.133$, $N_{22}=0.065$ (m)

Running: $\omega=3.2$ Hz, $K_{11}=12000$, $K_{12}=8000$, $K_{21}=20000$, $K_{22}=18000$
$N_{11}=0.122$, $N_{12}=0.045$, $N_{21}=0.133$, $N_{22}=0.065$ (m)
Bipedal Walking and Running using Biarticular Springs

Motor Control:
\[ P_1 = A \sin(\omega t) + B \]
\[ P_2 = A \sin(\omega t + \pi) + B \]

Tension Spring:
\[ F_{sp_{ij}} = \begin{cases} 
K_{ij} (x_{ij} - N_{ij}) - D_{ij} \dot{x}_{ij} : & x \geq 0 \\
0 : & x < 0 
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F_{sp_{ij}} = \begin{cases} 
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\]

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0 & : x < 0 
\end{cases} \]

Robot Experiments

Motor Control:

\[ P_1 = A \sin(2\pi \omega t) + B \]
\[ P_2 = A \sin(2\pi \omega t + \pi) + B \]
Comparing Human and Robot Walking

[Seyfarth et al 2006]
Other Gait Patterns
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Building Energy-Efficient Robots

<table>
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<td>CoT: 0.2</td>
<td>3.2</td>
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<tr>
<td>Velocity: 2-10m/s</td>
<td>1.5m/s</td>
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<tr>
<td>Weight: 50-90kg</td>
<td>48-52kg</td>
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Curved Beam hopper

Weight: 0.3kg
Height: 0.45m
Cost of Transport: 0.44

Modeling of Curved Beam Hopper

Robot

2D Model

1D Models


Modeling of Curved Beam Hopper

Model III is the best 1D model

Design Principle of Curved Beam Hopper

Cost of Hopping

Hopping height

Curved Beam Runner

Diverse gait patterns

Simulation

Experiment

Design Principle of Curved Beam Runner

Other Curved Beam Robots

Oliver Walchli, 2012

Yafeng Shu, 2013

Fabio Giardina, 2013
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Building a Functioning Prototype

1. **Design Concept**
   - Start with a general concept

2. **Design**
   - Generate construction dependent designs (CAD, etc.)

3. **Fabrication**
   - Produce custom design parts, purchase items

4. **Assembly**
   - Get the robot together; joints, cables, circuits...

5. **Controller**
   - Turn on the controller system to get the robot to function

6. **Experiments/Optimization**
   - Turn on the controller system to get the robot to function

7. **Repeat for better results**

---

**Building Model**
- Analysis

**Building Robot**
- Analysis
Building a Prototype *Quickly*

Hot Melt Adhesives (HMAs)

- Design Concept
- Design
- Fabrication
- Assembly
- Controller
- Experiments/Optimization

Sculpture by Carlyle Micklus

 Courtesy: Liyu Wang [Wang 2013]
Sample HMA Based Robots

Tendon Driven HMA Hand Robot

Courtesy: Melissa Lee, BIRL, 2013

HMA Based Tool Construction

Courtesy: L. Brodbeck, L. Wang, BIRL, 2013
Building a Prototype *Quickly*

Hot Melt Adhesives (HMA)

- Intuitive thinking for design process,
- Easy & fast fabrication of robot parts,
- Straightforward assembly / disassembly,
- Quick test of proof of concepts,
- Faster optimization & redesign
Case Study 3: Amoeboid

Courtesy: Steven Rich, BIRL, 2013
Case Study 3: Amoeboid

Completing the circle: \textit{from robot to model}
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Problem Set 3

Building Bio-Inspired Robots

Part 1: Robot Construction

Location: ML H 43
Morning Session: 09:15 – 11:15
Afternoon Session: 14:15 – 16:15

Part 2: Modeling & Simulation

Due: 12.11.2013
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