CDC Workshop

# Feedback Control of Bipedal Walking Robots

**Organizers**

**Jessy W. Grizzle (University of Michigan, USA)**
**Carlos Canudas-de-Wit (CNRS, Grenoble, France)**

**Additional Participants**

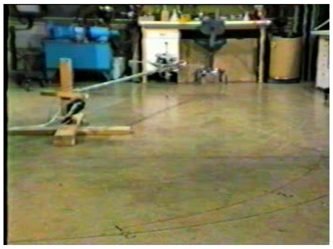
**Eric R. Westervelt (The Ohio State University, USA)**
**Mark Spong (Univ. of Illinois at Urbana-Champaign, USA)**
**Anton Shiriaev (University of Umea, Sweeden)**



# Rigorous Stability Analysis

Model of Running

Raibert's Hopper (1984)



1991 Koditschek & Beuhler
1998 Francois & Samson

Model of Efficient Human Walking

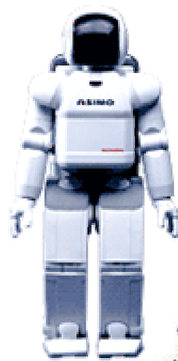
Passive Walkers

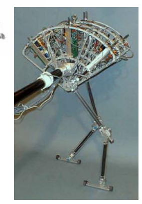
(Collins, Wisse and Ruina, 2001)

McGeer 1990
Espiau & Goswani 1994
Ruina et al. 1997
Howell & Baillieul 1998
Kuo et al. 1999

# Most Powered Biped Robots use Heuristics for Controller Design

- ZMP (Zero Moment Point)
  - Asimo [Honda ’96 →], >$150,000,000 [dev. cost] and
    $1,000,000 per robot
  - SDX-3x [Sony, 2001]
- Intuition
  - Spring Flamingo [MIT Leg Lab’96-’00]
- Other Approx. Notions
  - Many





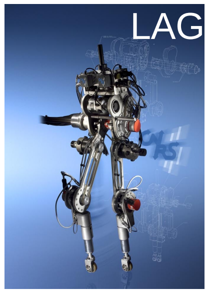
# Why This Workshop?

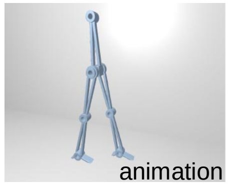
## Obvious Drawbacks of Heuristics

- When models are ignored, each aspect of the feedback design looks like a special case
- Many trials on hardware before success
- Impossible to know performance limitations
- Difficulty in generalizing to other platforms

# Workshop Outline

- Nonlinear control methods for an underactuated planar biped
  - Walking motions
    - Modeling
    - Feedback design theory
    - Feedback experiments
  - Dynamic balancing
- Passivity based control of bipedal locomotion
  - 3D & Fully actuated (feet)






# Holy Grail of Feedback Control:

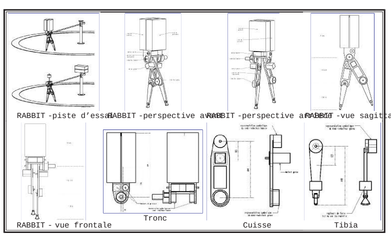
## Hardware Construction & Control Design Proceed in Parallel

RABBIT -Proposition de géométrie et des masses

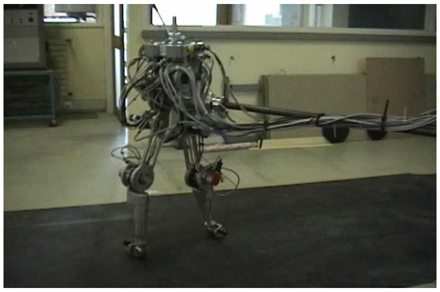
ENSEMBLE

hauteur 1.425 m
masse totale 40 kg

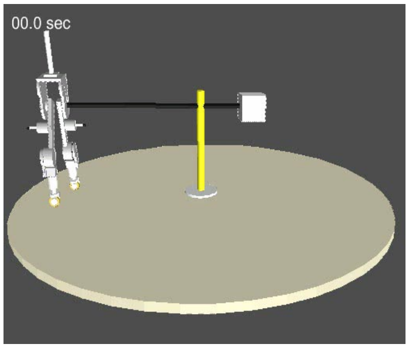
| TRONC | CUISSE | TIBIA | MOTO -REDUCTEUR |
|---|---|---|---|
| longueur L=0.625 m | longueur L=0.400 m | longueur L=0.400 m | Irotor = 2.45 kg10m2 |
| masse m=20 kg | masse m=6.8 kg | masse m=3.2 kg | Ireducteur = 1.07 kg10 |
| centre de masse yG=0.010 m et zG=0.200 m | centre de masse zG=0.163 m | centre de masse zG=0.127 m | |
| inertie Iox=2.22 kg m2 | inertie Iox=0.25 kg m2 | inertie Iox=0.10 kg m2 | Irot+Ired = 3.32 kg10m2 |
| (premiers moments MY=0.20 kg m et MZ= | (premier moment MZ=1.11 | (premier moment MZ=0.41 | |
| CUISSE CORRIGEE | | TIBIA CORRIGEE | |
| Inertie corrigee = 1.08 kg m2 | | Inertie corrigee = 0.93 kg m2 | |
| avec rapport de reduction tronc/cuise =50 | | avec rapport de reduction tronc/cuise =50 | |



## Partially Achieved in RABBIT
(Preview: Experiment vs Simulation with essentially no tweaking)



LAG: Laboratoire Automatique de Grenoble




GeomView Animation by Evan Leung



## Workshop Schedule

- **8:10 to 8:20** Welcome & Introduction
- **8:20 to 9:00** Background & Modeling of Planar Bipeds (Grizzle)
- **9:00 to 10:00** Feedback Control of Rabbit (Westervelt)
- **10:00 to 10:15** Break
- **10:15 to 11:05** Orbital Stabilization (Shiriaev & Canudas-de-Wit)
- **11:05 to 11:10** Pause
- **11:10 to 12:00** Passivity Based Control of 3-D Walking (Spong)