Research on Animals and Vehicles

Chapter 8 of Raibert

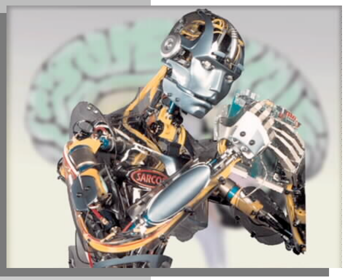
By Rick Cory

Animal Locomotion

- Design experiments to probe mechanisms of biological systems
- Each experiment arises in the course of studying legged machines
- Allow research of biological systems to stimulate developments in robotics

Experiments in Animal Locomotion

- Algorithms for Balance
- Symmetry in Balance
- Algorithms for Foot Placement
- Distribution of Body Mass
- Yaw Control
- Conserving Angular Momentum
- Virtual Legs



Balance

Raibert's Method:

- Uses linear feedback servo to calculate foot placement

$$x_f = T_s \dot{x}/2 + k_{\dot{x}}(\dot{x} - \dot{x}_d).$$

- Respect to body's center of mass
- Based on symmetric tipping behavior of inverted pendulum

Animals Experiments:

- Changes in forward running speed
- Angular momentum during flight phase
- Actual foot placement

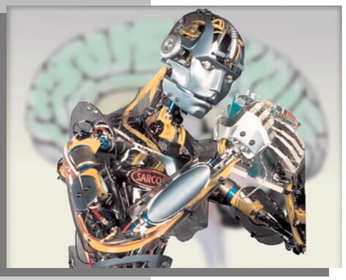
Symmetry in Balance

Raibert's Method:

- Motion of the body and feet are even and odd functions of time
- Independent of the number of legs
- Provides Sufficient but not necessary conditions

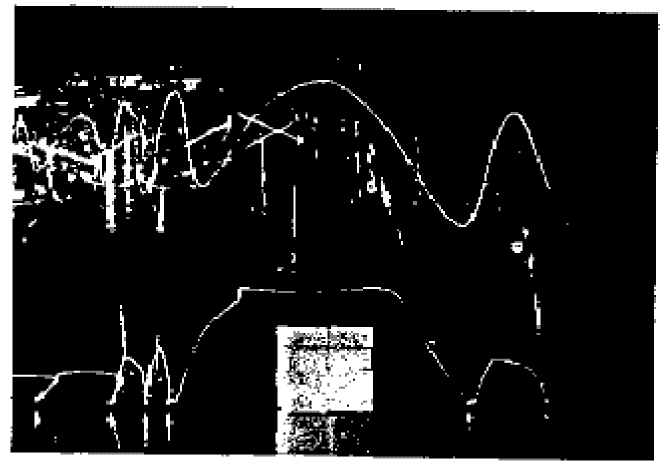
Further Questions:

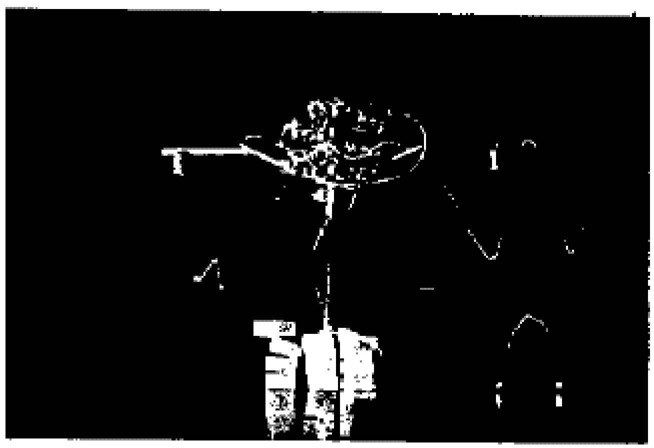
- How universal is symmetrical balance in humans and animals?
- What is the precision of the symmetry?
- Does is extend to angular body motion?
- How do asymmetries in the body structure influence the symmetry in observed motion

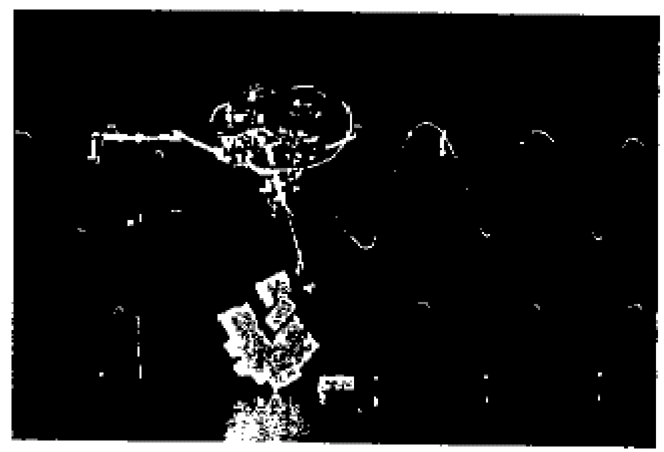


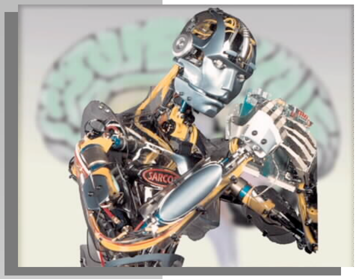
Foot Placement

- Critical In Traversing Irregular Terrains
- Subject must choose footholds with respect to variations and obstacles



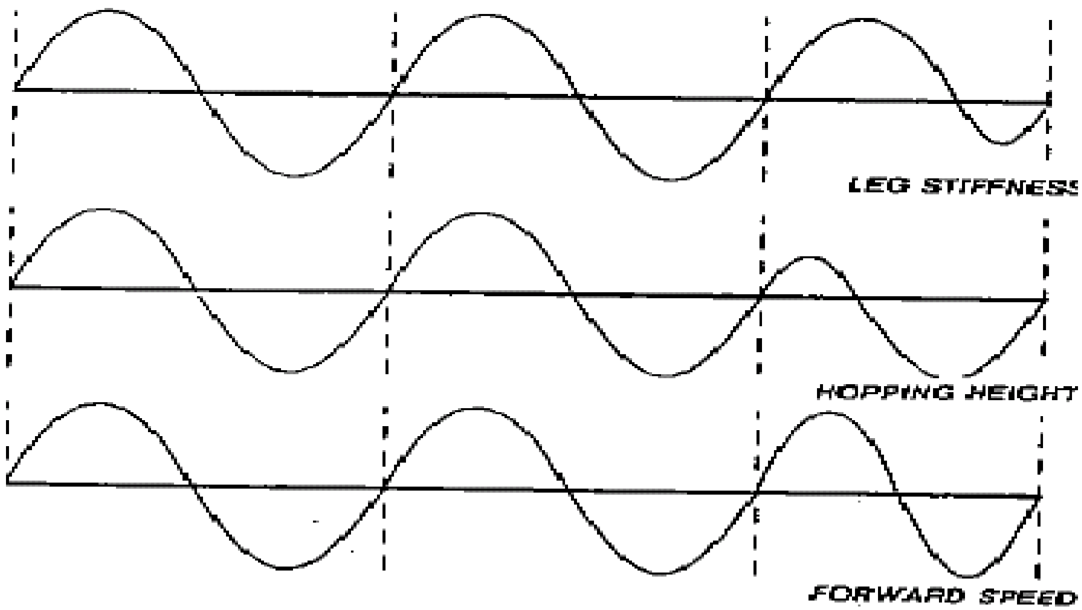


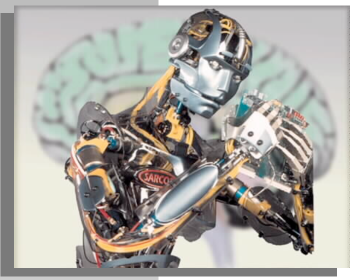




Other Foot Placement Strategies

- Leg Stiffness
- Hopping Height
- Forward Speed





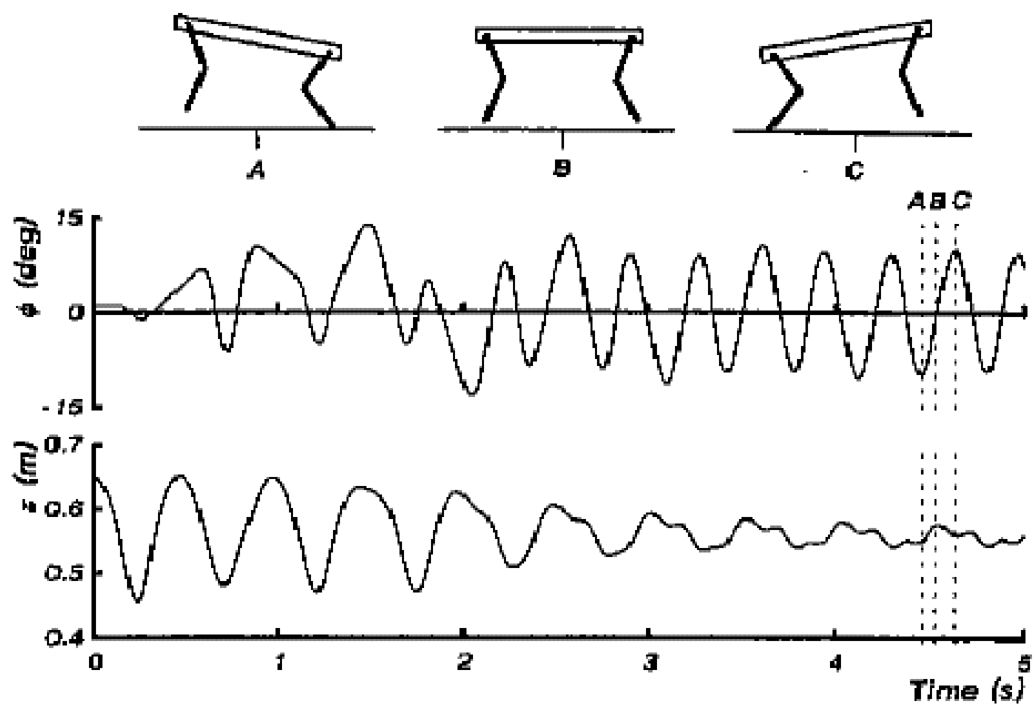
Body Mass Distribution

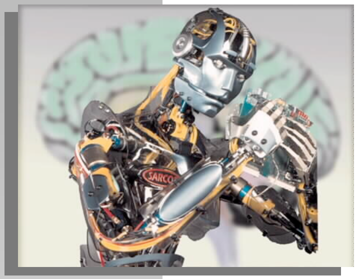
Normalized moment of inertia: $j = J/(md^2)$

J – Body moment of Inertia

m – mass of the body

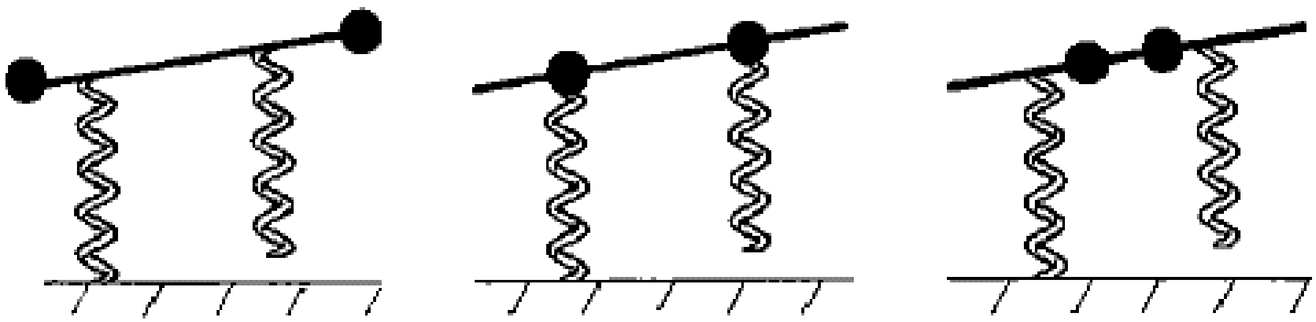
d – half the hip spacing





Normalized Moment of Inertia

- j > 1
  - An upward force on the left leg causes the right hip to accelerate upward
- j = 1
  - System acts as two separate oscillators with neutral stability
- j < 1
  - An upward force on the left leg causes the right hip to accelerate downward



Yaw Control

- Yaw Control
  - Difficult for one legged machines (no foot to exert torsional torque on the ground)
  - Humans, in principle, develop torsional traction on the ground about the yaw axis
  - Experiments to measure torsional torque during running and relate the results to yaw motions

Conservation of Angular Momentum

- A legged system must conserve its angular momentum during flight phase
- Conserving angular momentum in stance phase
  - Not required because legs exert forces on ground
  - However, keeping angular momentum constant can achieve higher efficiency
  - How precisely is angular momentum preserved?

Virtual Legs

Raibert's Method:

- Divide quadruped running problem into two simpler problems
  - Algorithms to control virtual Legs
  - Control physical legs to achieve desired virtual leg behavior

Animal Experiments:

- Make measurements on the ground force during trotting and pacing
- Disturb one or both feet and measure force response

Developing Useful Legged Robots

- Variety of Difficult Problems to be solved in order to develop USEFUL legged machines
  - Walk and Run on Flat Floor [1]
    - Essentially solved given desired direction and speed
  - Travel on Rough Terrain [3]
  - Speed and Position Measurement [2]
  - Terrain Sensing and Perception [4]
  - Self-Contained Power [3]
  - Optimize Payload, Range, and Speed [1]
    - Optimization problem for mechanical engineering

Travel on Rough Terrain

- Control and planning algorithms must be solved to negotiate difficult terrain
- Several ways terrain becomes rough
  - Not Level
  - Limited traction (slippery)
  - Areas of poor or nonexistent support (holes)
  - Vertical variation in available footholds (steps)
  - Obstacles
  - Intricate footholds (ladder)

Speed and Position Management

- Provide a mobile system with information about
  - Where it is
  - Direction of Motion
  - Speed of Motion
- Band width needed for legged systems is large!
  - Fine grain information needed

Terrain Sensing and Perception

- Single most important barrier to achieving useful legged systems
- Problems involve
  - Sensing
  - Perception
  - Spatial Representation
- Difficulty is related to generality of situations

Self Contained Power

- Real legged systems need to provide their own power
- Not a problem for carrying power for large scale systems
- Smaller scale (human size) is a difficult engineering problem

Conclusion

- Combine work in the study of animals and the construction of machines
- Biological systems provide motivation but are extremely complicated to study
- Laboratory Robots are easily built and studied but have poor performance as compared to biological systems
- Robotics contributes to robotics and biology Biology contributes to biology and robotics