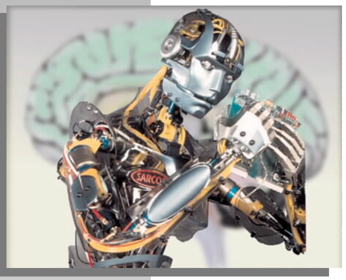
Alternatives for Locomotion Control

Chapter 6 presented by Peyman Mohajerian

Motivation

Alternative to control of algorithm by changing some of the design and implementation decisions, e.g.:

- Three-part decomposition
- Use of foot placement and symmetry
- Virtual Legs



Fixed Hopping Height

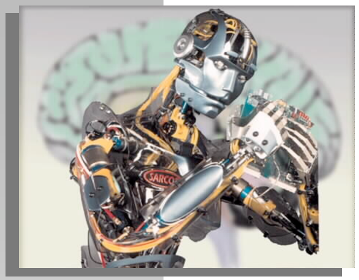
Instead of fixed thrust, adjust the energy injected on each hop.

Advantages:

- Less susceptible to frictional variations
- Correct for sweeping of the leg

Disadvantage:

- More complicated control

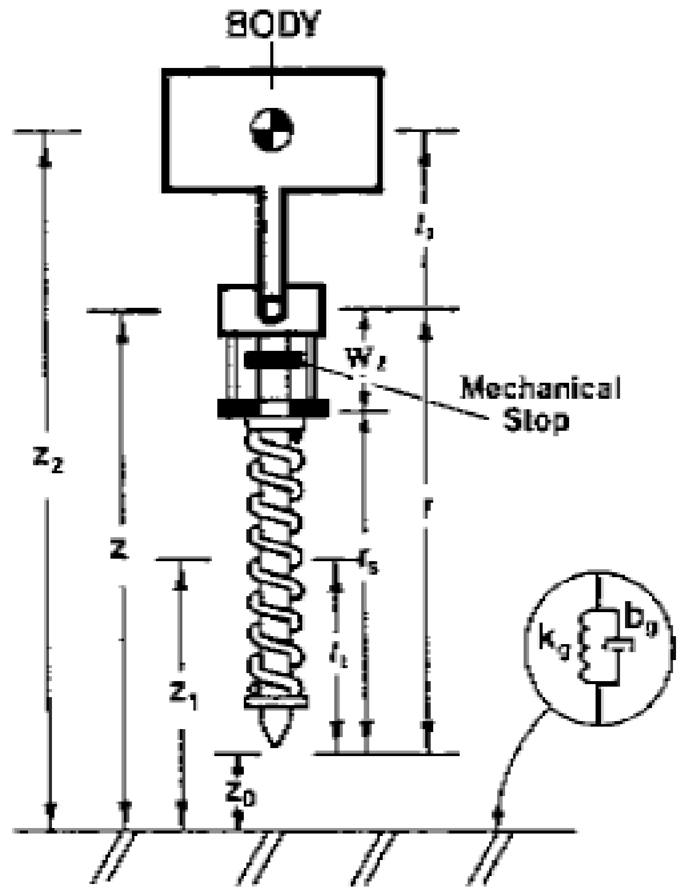


Fixed Hopping Height- Schematic

Leg:

- Sliding joint
- Spring
- Actuator
- Mechanical stop

Actuator and spring act in series to lengthen and shorten the leg



Fixed Hopping Height- Principle

Positive Work:
Support: lengthening actuator
Flight: shortening actuator

Negative Work:
Support: shorting actuator
Flight: lengthening actuator

Fixed Hopping Height- Model

During leg support, spring-mass oscillator:

$$\omega_n = \sqrt{\frac{k_\ell}{m}}.$$

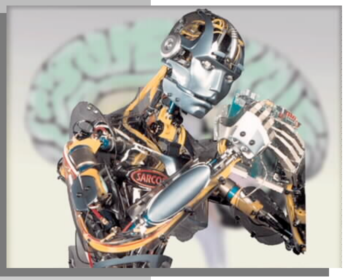
$$T_s = \frac{\pi}{\omega_n} = \pi\sqrt{\frac{m}{k_\ell}}.$$

Parabolic trajectory during flight:

$$T_f = \frac{2\dot{z}}{g} = \sqrt{\frac{8H}{g}},$$

Period of a full hoping cycle:

$$T = \pi\sqrt{\frac{m}{k_\ell}} + \sqrt{\frac{8H}{g}}.$$



Fixed Hopping Height- Energy

The total vertical energy at any time:

$$E = m_\ell g z_1 + m g z_2 + \frac{1}{2} m_\ell \dot{z}_1^2 + \frac{1}{2} m \dot{z}_2^2 + \frac{1}{2} k_\ell (r_{s0} - r + w_\ell)^2 .$$

Touchdown energy lost:

$$\Delta E_{td} = \frac{1}{2} m_\ell \dot{z}_{1,td-}^2 ,$$

Equating linear moment:

$$m \dot{z}_{2,lo-} = (m + m_\ell) \dot{z}_{2,lo+} ,$$

$$\dot{z}_{2,lo+} = \frac{m}{m_\ell + m} \dot{z}_{2,lo-} .$$

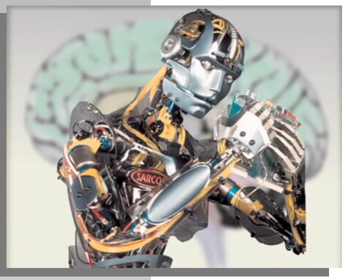
Fixed Hopping Height- Energy

Energy lost during liftoff:

$$\Delta E_{lo} = -\frac{m_\ell m}{2(m_\ell + m)} \dot{z}^2_{2,lo-}.$$

During stance total hopping energy for next flight:

$$E_f = \frac{m}{m_\ell + m}\left(m_\ell g z_1 + m g z_2 + \frac{1}{2} m_\ell \dot{z}_1^2 + \frac{1}{2} m \dot{z}_2^2 + \frac{1}{2}(k_\ell r^2_{s\Delta}) + \frac{1}{2} k_g \dot{z}_0^2\right).$$



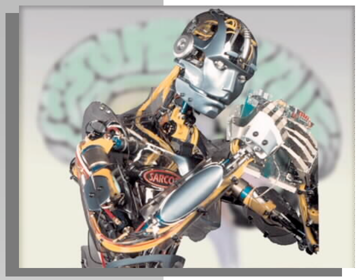
Fixed Hopping Height- Energy

Total vertical energy to hop to H:

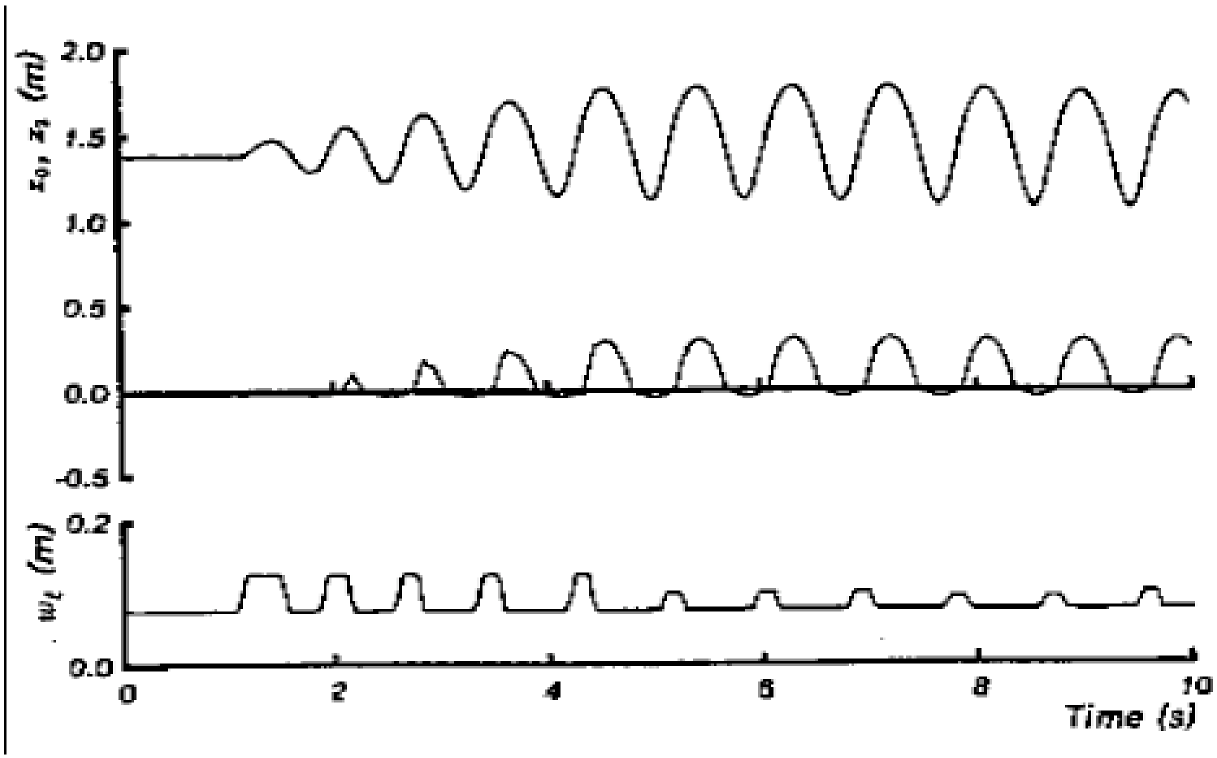
$$E_H = m_\ell g(H + l_1) + mg(H + r_{s0} + l_2).$$

The leg actuation must be:

$$\Delta w_\ell = -r_{s\Delta} + \sqrt{r_{s\Delta}^2 + \frac{2\,\Delta E}{k_\ell}}.$$



Fixed Hopping Height- Simulation



Hopping Strategies

1- Leg shortening at lift-off

- Ground clearance- uneven train
- Reduces leg's moment of inertia

2- Leg shortening at top

- Slower actuator, increase time between vertical actuation

3- Leg shortening at touchdown

- Ground impact force to foot reduced- period of acceleration to ground speed increase.

Human apply items 1 and 3 at the expense of extra lengthening and shorting!!!

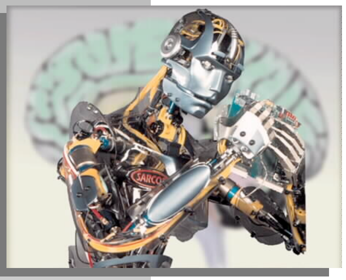
Alternative Three-part Control

So far assignment of control action to variable of control:

- Forward foot placement - forward velocity
- Hip torque - body attitude
- Leg thrust - hopping height

Alternative, leg sweeping algorithm:

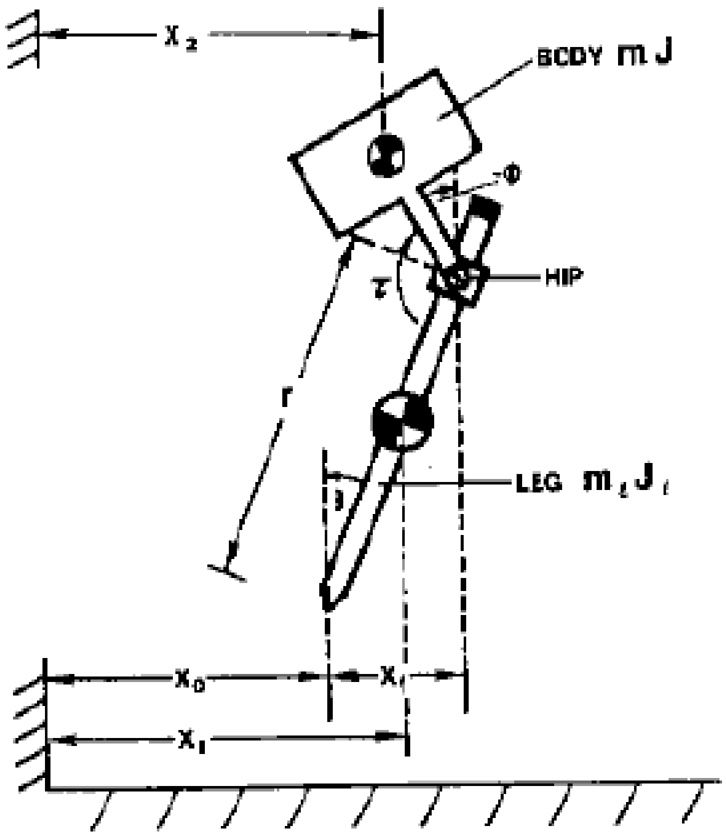
- Forward foot placement - body attitude
- Hip torque - forward velocity

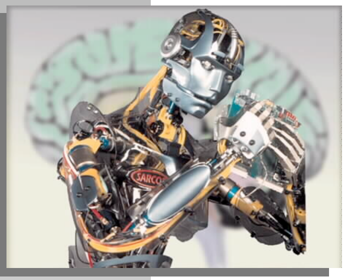


Leg Sweeping Algorithm

To keep hopping at a desired constant speed, no net horizontal force.

Using hip torque sweep leg and foot backward During stance for a specific speed.





Leg Sweeping Algorithm

Hip servo:

$$\tau = -k_p(\gamma - \gamma_d) - k_v(\dot{\gamma}),$$

Forward position of center of mass:

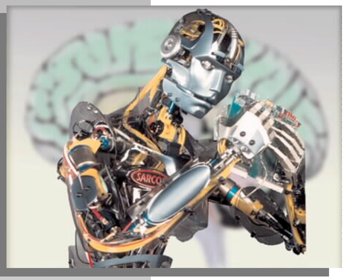
$$x_{cg} = \frac{(l_1 - r)m_\ell \sin(\theta) + l_2 m \sin(\phi)}{m_\ell + m}.$$

Neutral point:

$$x_{f0} = \frac{\dot{x}T_s}{2}.$$

To accelerate attitude, foot displacement:

$$x_{f\Delta} = k_\phi(\phi - \phi_d) + k_{\dot{\phi}}\dot{\phi},$$



Leg Sweeping Algorithm

At touchdown, forward position:

$$x_f = x_{cg} + x_{f0} + x_{f\Delta}.$$

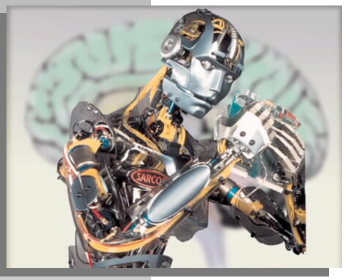
During stand, foot should move backward with respect to the center of mass, horizontal trajectory:

$$x_f(t) = x_{cg} + x_{f0} + x_{f\Delta} - \dot{x}_d(t - t_{td}),$$

The kinematics of the leg: $x_f = -r\sin\theta,$

Eliminate dependence on leg angle:

$$-r\sin\theta = \frac{(l_1 - r)m_\ell \sin(\theta) + l_2 m \sin(\phi)}{m_\ell + m} + x_{f0} + x_{f\Delta} - \dot{x}_d(t - t_{td}). \quad (6.22)$$



Leg Sweeping Algorithm

Leg, body, and hip angle are related: $\gamma = \phi - \theta.$

Based on forward speed of body, duration of stance, and geometry of the system, hip angle is:

$$\gamma_d = \phi + \arcsin\left(\frac{l_2 m \sin(\phi) + (m_\ell + m)(x_{f0} + x_{f\Delta} - \dot{x}_d(t - t_{td}))}{l_1 m_\ell + r m}\right).$$

Quadruped Running- Coordinates

Machine Coordinate for quadruped:
- Preferred direction of travel
- Asymmetry in forward and lateral behavior

World coordinates for hopping:
- No orientation preference

Quadruped Running- Hopping Cycle

Tight coupling of leg sequences.

Alternatives:

- Treat each leg independently
- Legs coupled for vertical thrust only
- Velocity control based on independent leg but position based on the coupled overall velocity of the body

Quadruped Running- Coordinating Leg Thrust

Simultaneous trust delivery to all legs on ground- avoid tipping.

- Servo leg length during flight
- Servo leg length during support-same axial force
- Servo leg length during support- keep body level
- Thrust independently according to separate state of each leg similar to single leg hoping

Quadruped Running- Velocity Control

Velocity Control Algorithm:
- Sweep control- Use hip torque
- Foot positioning

Coupling or Not:
- Couple position of leg- velocity of center of gravity
- Independent positioning of leg- velocity of each hip for yaw rotation

Quadruped Running- Attitude Control

- Hip Torque-
- Leg Thrust- Modulate differential thrust of legs providing support.
- Limit-cycle- Seesaw in a limit cycle, trusting legs act at different times in the hopping cycle

Leveling Control- Hip Torque, Leg Thrust

Rocking Control- Limit-cycle