Raibert Ch 2: Hopping on 1 Leg in the Plane

Running is like:

- Bouncing ball
  - falling due to gravity
  - elastic deformation, Ek absorbed
  - passive bouncing oscillation
  - control system excites oscillation and regulates amplitude

- Inverted pendulum system
  - support point moved in response to tipping
  - BUT.. legs change length when loaded by body
  - .. instantaneous point changes during tipping

Control System Tasks

Control System regulates, through a Finite State Machine:

- Hopping (thrust motion to the body)
- Forward speed (forward foot position so that the required net acceleration is provided)
- Body attitude (hip torque to hold the body upright during the stance)

1 Leg: Planar Hop

Leg composed of:

- Body (with sensors, valves, actuators)
- Springy leg (air cylinder with switch at bottom of foot; air flow controlled by 4 solenoid valves)
- Hinge-type hip (air cylinders driven by proportional pneumatic pressure-controlled valve)
- Movement: front & back, up and down, pitch rotation

1 Leg: Leg Component

Control sytem operates the 4 solenoid valves to sustain hopping:

- Close solenoid valve in upper chamber to trap air in upper chamber of leg
- As foot leaves the ground, exhaust the air (through valve in lower chamber) until desired pressure is reached
- Leg shortens under load
- Trapped air compresses (like 1/r spring, r = leg length) => thrust

Phases during Hop:

- liftoff (no ground contact)
- top (maximum altitude, moving from up to down)
- touchdown (ground contact)
- bottom (minimum altittude, moving from down to up)

Control Task 1: Hopping Height

- 2 phases: passive oscillation (loaded) & ballistic flight (unloaded)
- Thrust determines hopping height
- Thrust is fixed (chosen by designer)
  - At fixed thrust, reach equilibrium at the hop height so E(thrust) = E(friction) + E(unsupported leg mass)
  - Unique height for each thrust value
  - Leg spring acts like 1/r spring

Control Task 2: Forward Speed I

- v_f , $v_{vertical}$, axial leg force affect accelerations
- Control system choses a forward foot position before landing
- Net fwd acceleration = acc @ liftoff - acc @ touchdown
  - At neutral point, net fwd acc = 0
  - For non zero fwd speeds, neutral point is in front of the body
  - Center of mass travels symmetric trajectory if foot is @ neutral point

Control Task 2: Forward Speed II

- Approaches to determine foot placement
  - From equations of motion, determine state variables as a function of time and invert the solution so foot position = f(state, desired behaviour)
  - Simulate large set of situations so results can be used to approximate solutions
  - Closed form approximations to solutions --> used
- Measure v_f and use to approximate the neutral point
- Use $v_{f,error}$ to calculate displacement from neutral point needed to accelerate the system

Control Task 2: Forward Speed III

- Centre of Gravity-print (CG-print): locus of points over which C.O.G will travel
  - Center of CG-print = neural point
  - CG-print = $v*T_s$ (v = speed, T_s = stance period)
  - If place foot at $(v*T_s) / 2$ in front of the hip, this places foot at the neutral point so it can provide acceleration
- Control system equation for foot displacement:
  - $x_{f,\ delta} = k_v*(v - v_d)$ = foot displacement
  - $x_f = (v*T_s)/ 2 + k_v*(v - v_d)$ = foot placement
- Control system equation for hip angle
  - $gamma_d$ = pitch angle of body - $\arcsin(x_f / 2)$

Control Task 3: Body Attitude

- Angular momentum is conserved during flight
- Change angular momentum during stance phase
- Control system equation for hip torque (to servo the body to the desired attitude)
  - $T = -k_p*(p- p_d) - k_v(p')$ (where p = pitch angle of body)

Improvements & Limitations

- Ground speed matching
- Folding of natural legs vs. telescoping leg
- 3-part control system: separate dynamics?
- Purpose of 1 Leg planar hop:
  - to identify framework for algorithms
  - to focus on active balance in dynamic legged locomotion --> generalization to multilegged