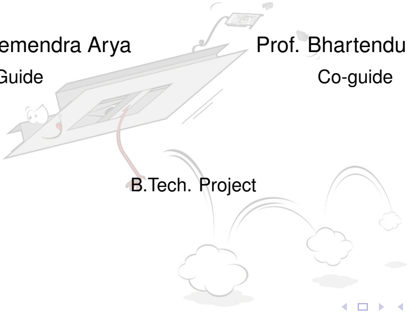
Design and Stabilization of a One Legged Hopper

Pratik Chaudhari

06D01015

Prof. Hemendra Arya
Guide

Prof. Bhartendu Seth
Co-guide



B.Tech. Project

Outline

Springy Leg Offset Mass

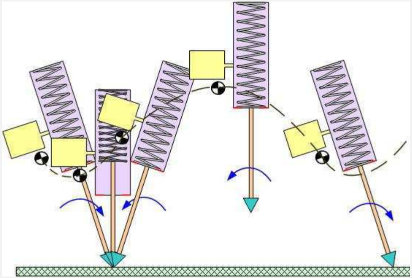


Figure: SLOM motion

Stages

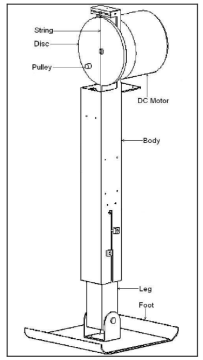
- Lift-off
- Free fall
- Touch-down
- Stance

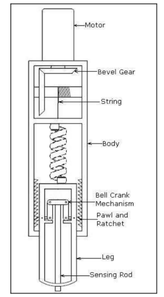
Terms

- Energy Pumping Mechanism
- Constraint
- Energy Release

Outline

Previous Work





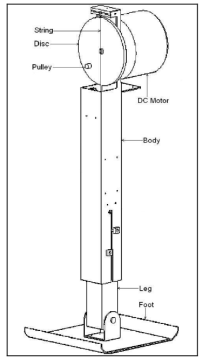
SLOM hopper

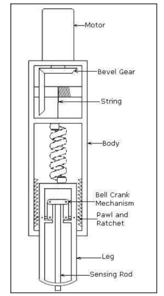
- Compression spring
- Ratchet and paul activated by voice coil
- Large leg mass : Small hopping height
- In-place hopping : Feed forward control law

1D hopper

- Spring compressed by a motor
- Bell-crank constraint mechanism
- Use of impact to release energy

Previous Work





SLOM hopper

- Compression spring
- Ratchet and paul activated by voice coil
- Large leg mass : Small hopping height
- In-place hopping : Feed forward control law

1D hopper

- Spring compressed by a motor
- Bell-crank constraint mechanism
- Use of impact to release energy

Outline

Problem Definition

Features

- SLOM concept, 2D / 3D hopping
- Tension springs instead of compression spring
- Reduce leg mass, higher hopping heights
- Reaction wheel
  - Necessary for inplace hopping
  - Stable running gait
- Onboard embedded system

Design 1

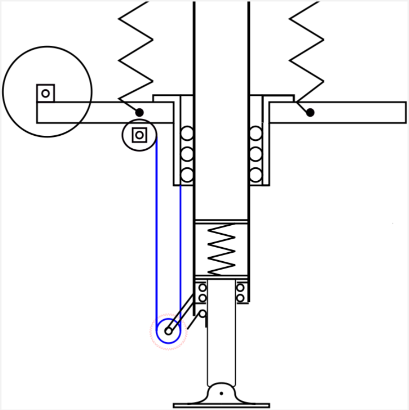


Figure: Winch pulley design

Features

- EPM :
  - Motor pulls itself down
  - Moves twice the extension
- Constraint :
  - Toothed pulley constrained by the hatch
  - Impact pushes hatch inside
  - Momentum transfer

Design 1

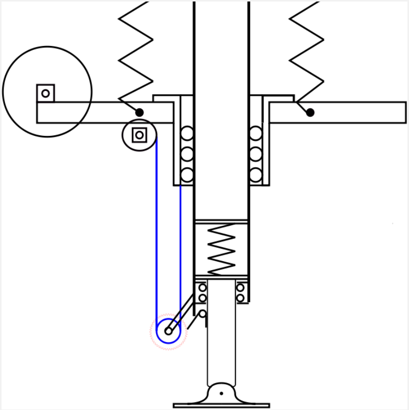


Figure: Winch pulley design

Evaluation

- Pros :
  - Simple constraint mechanism
  - Easier to make a light leg
- Cons :
  - Winch can slide off the pulley
  - Torsion spring : potentional point of failure
  - Torques on roller bearings

Design 2

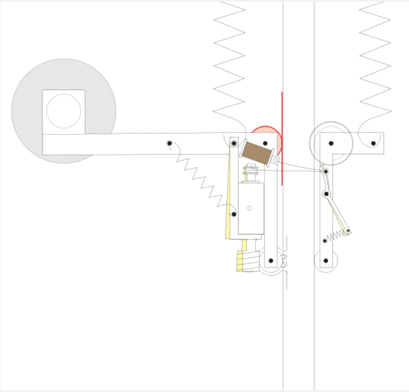


Figure: Rack and pinion design

Features

- EPM :
  - Rack worm-worm wheel
  - Band drive
  - Main spring can push the worm onto the rack
- Constraint :
  - Friction pulley
  - Ratchet with paul
  - Motor sleeve moves left

Design 2

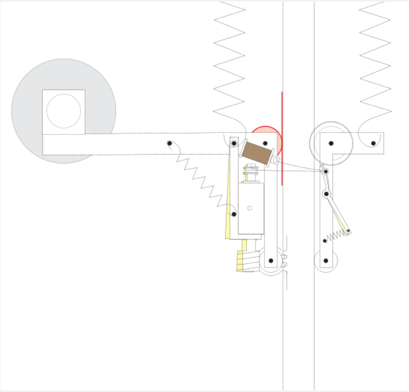


Figure: Rack and pinion design

Evaluation

- Pros :
  - Mechanical advantage
  - Less moving parts, easier to build
- Cons :
  - Friction pulley
  - Lower resolution

Outline

Objectives

Objective

- Estimate masses, dimensions
- Choose motors and electronics

Design 1

- Reaction wheel
- Springs
- Winding motor
- Platform
- Lower leg, main leg masses

Design 2

- Reaction wheel
- Springs
- Rack-pinion drive and motor
- Platform and leg mass

Objectives

Objective

- Estimate masses, dimensions
- Choose motors and electronics

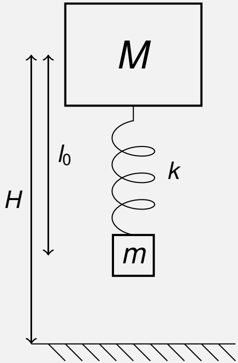
Design 1

- Reaction wheel
- Springs
- Winding motor
- Platform
- Lower leg, main leg masses

Design 2

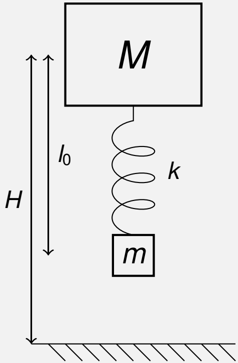
- Reaction wheel
- Springs
- Rack-pinion drive and motor
- Platform and leg mass

Two Mass Problem

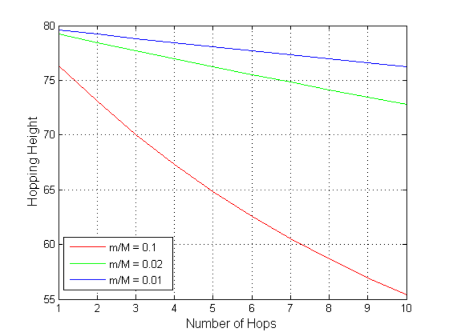


- $$h_n = \frac{Mh_{n-1} + ml_0}{M + m}$$
- $$E_{loss} = \frac{Mg\,(H - l_0)}{1 + M/m}$$

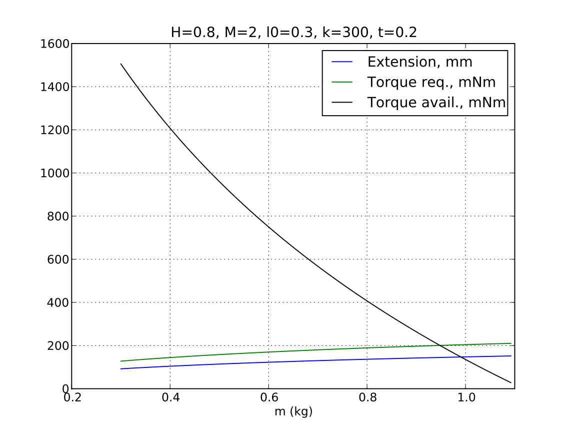
Two Mass Problem



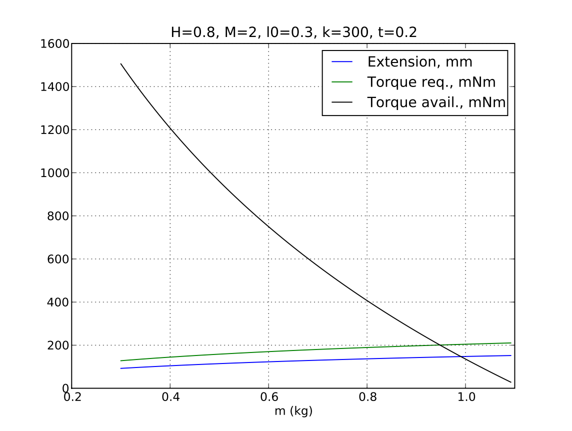
- $$h_n = \frac{Mh_{n-1} + ml_0}{M + m}$$
- $$E_{loss} = \frac{Mg\,(H - l_0)}{1 + M/m}$$



Torque Requirements



Torque Requirements



Results

- m $\sim$ 0.5 kg
- k $\sim$ 300 N
- M $\sim$ 2 kg
- Lower leg $\sim$ 12 cms
- Standard rack-pinion
- Faulhabeur 2342 motor
- 43 : 1 gearbox

ReWac : Idea and Advantages

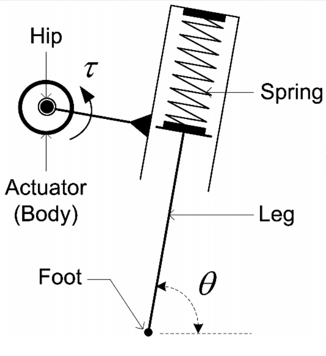


Figure: ReWac : Schematic

Inertia Wheel Assembly

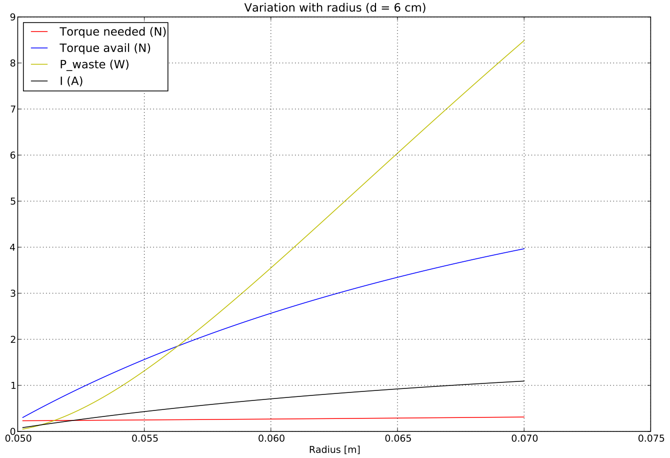
Conserve angular momentum

$$\dot{\theta}_b = -\frac{J_w}{J_b + J_w}\dot{\theta}_w$$

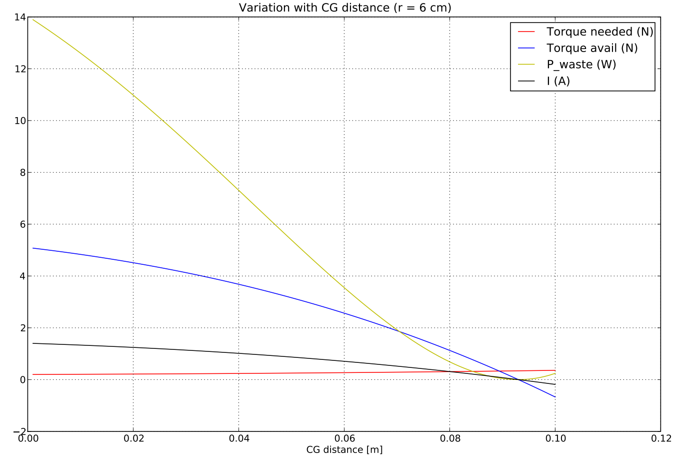
Uses

- Initial condition
- Changing hopping height online
- Change from an arbitrary pitch to steady state pitch within one hop

ReWac : Radius



ReWac : CG distance



Impact Analysis

Concept

- Desired hopping height dictates impact frequency
- Masses dictate energy loss
- Natural frequency of the system should be much higher than hopping frequency

Results

- Hopping frequency is a weak function of hopping height and M
- A large dependence on leg mass

Impact Analysis

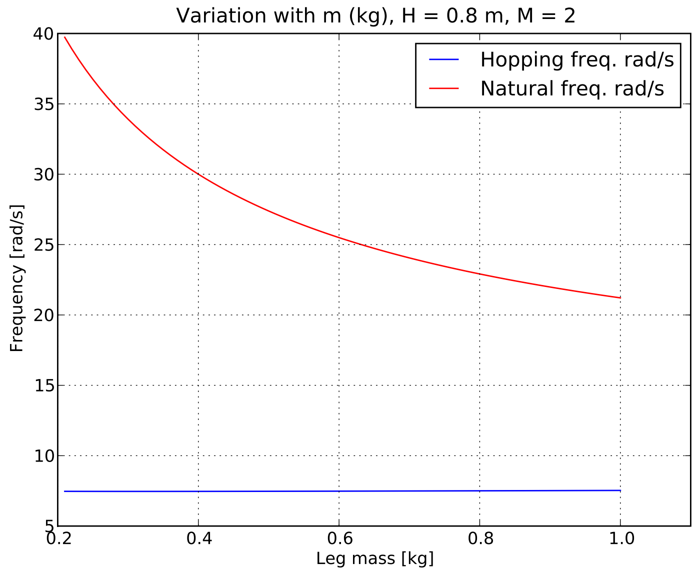
Concept

- Desired hopping height dictates impact frequency
- Masses dictate energy loss
- Natural frequency of the system should be much higher than hopping frequency

Results

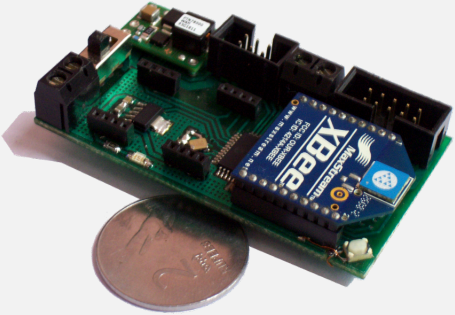
- Hopping frequency is a weak function of hopping height and M
- A large dependence on leg mass

Impact : Leg mass



Outline

ReWac Board Hardware



- Microchip dsPIC33F
  40 MIPS
- Accelerometer
  2.162 LSB/mg
- Gyroscope (50 Hz)
  0.07326 $^{o}/s/$LSB
- Quadrature Encoders
- XBee module

Kalman Filter

Why

- Pitch attitude estimate
- Computing power

How

$$\boldsymbol{x} = [x_1 \quad x_2]^T = [\theta \quad \dot{\theta}]^T$$

$$\boldsymbol{x}_{k+1} = \boldsymbol{A}\,\boldsymbol{x}_k + \boldsymbol{B}\,\boldsymbol{u}_k + \boldsymbol{w}_k$$

$$y_{k+1} = \boldsymbol{C}\,\boldsymbol{x}_{k+1} + z_{k+1}$$

Tricks

- Sparse covariance matrix
- Remove matrix operations
- Fixed point arithmetic

Attitude Estimation

Accelerometer

- Slow, absolute reading
- Body accelerations - Noise
- High frequency noise

Gyroscope

- Fast
- Drifts slowly, randomly

- After liftoff $\sim$ 250 ms
  - Only force is gravity
  - Both sensors used
- Free fall $\sim$ 250 ms
  - No accelerometer reading
  - Propagate using rate only
- Stance $\sim$ 150 ms
  - Ankle potentiometer

High Frequency Input sampled at 50 Hz