Design and Stabilization of a One Legged Hopper

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Guide

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B.Tech. Project

Outline

Springy Leg Offset Mass

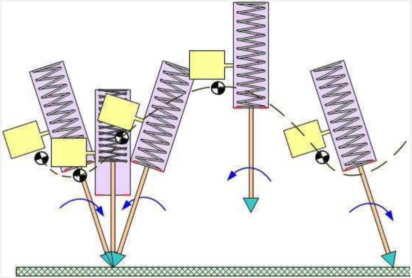

Figure: SLOM motion

Stages

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

Terms

- Energy Pumping Mechanism
- Constraint
- Energy Release

Design of robot

- Efficient EPM
- Reaction wheel
- Onboard electronics

Theory

- Non-linear model
- Initial conditions
- In-place hopping
- Running gait

Experiments

- Attitude estimation
- Fabrication and interfacing of electronics

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Final Design

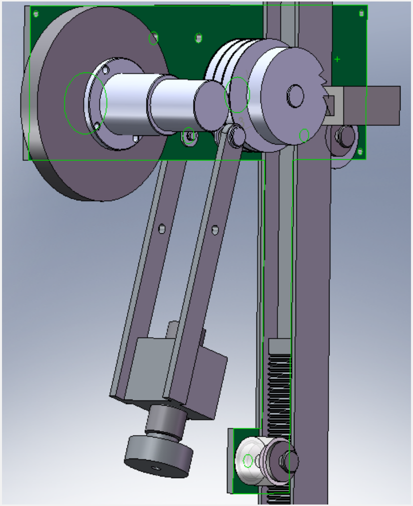


Figure: Detached motor sleeve

Features

- EPM :
  - Motor travels down on rack
  - Dual springs, helical gears and slant rack
- Constraint :
  - Ratchet and Paul
  - Band drive
  - Disengage motor sleeve

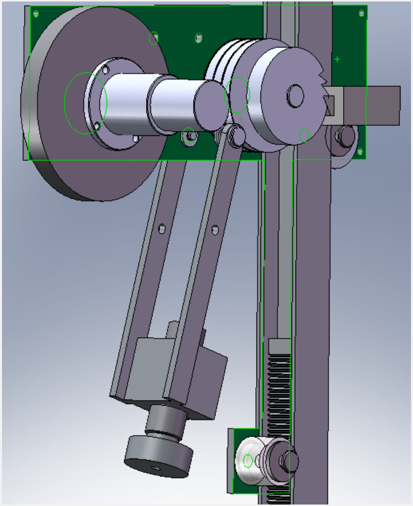


Figure: Detached motor sleeve

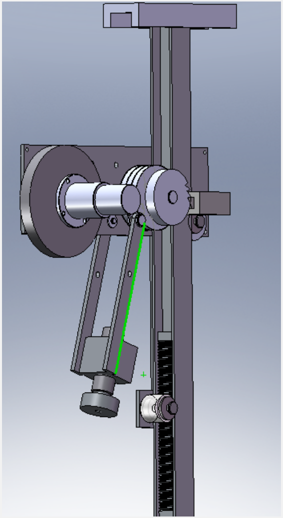


Figure: Full Robot

Final Design

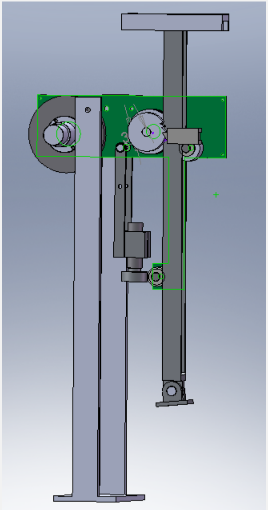


Figure: Test Rig

Features

- Test-rig :
  - Pivoted near the C.G.
  - Attitude re–orientation
  - Simulated hopping
- Overall :
  - Height : $\sim$ 500 mm
  - Leg $\sim$ 0.7 kg
  - Total $\sim$ 4.7 kg
  - Disengage motor sleeve

Outline

Equations of motion

Euler–Lagrangian equations

$$T = \frac{1}{2}\left[m_w(\dot{x_w}^2 + \dot{y_w}^2) + m_p(\dot{x_p}^2 + \dot{y_p}^2) + m_l(\dot{x_l}^2 + \dot{y_l}^2) + J_w(\dot{\phi} + \dot{\theta})^2 + J_b\dot{\theta}^2\right]$$

$$V = g\,[\,m_l\,y_l + m_w\,y_w + m_p\,y_p\,] + \frac{1}{2}K\,(l - l_0)^2$$

$$L = T - V$$

$$q = [\,x \quad y \quad l \quad \theta \quad \phi\,]$$

$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{q}_A}\right) - \frac{\partial L}{\partial q_A} = Q_A$$

$$Q_A = \sum_{r=1}^{m} \lambda_r \frac{\partial \psi_r}{\partial q_A}$$

Stance Phase

Stance Phase

- Foot touches the ground when,

$$y(t) = (\ l_{impact} - l_0\ )\ \cos\theta_{impact} + d\sin\theta_{impact}$$

- Constraint equations,

$$y(t) = (\ l(t) - l_0\ )\ \cos\theta + d\sin\theta$$
$$x(t) = x_{f-impact} - (\ l(t) - l_0\ )\ \sin\theta - d\cos\theta$$

  where

$$x_{f-impact} = x_{impact} + (\ l_{impact} - l_0\ )\ \sin\theta_{impact} + d\cos\theta_{impact}$$

- Phase ends when

$$l(t) = l_0$$

Flight Phase

Spring Controller

- $$\ddot{l}(t) = \begin{cases} 0 & l(t) \leq (l_0 - \epsilon) \;\; OR \;\; l(t) \geq (l_{max} + \epsilon) \\ l_{accel} & l_0 \leq l(t) \leq \frac{(l_{max}+l_0)}{2} \\ -l_{accel} & \frac{(l_{max}+l_0)}{2} \leq l(t) \leq l_{max} \end{cases}$$
- Convert $\ddot{l}(t)$ control law to implementable $\dot{l}(t)$ form
- Sense $\omega(t)$ with encoders,

$$e(t) = \omega(t) - \omega_d(t)$$

$$U_l(t) = K_w \, \omega_d(t) + K_p \, e(t) + K_d \, \frac{d \; e(t)}{dt} + K_i \int e(t) \, dt$$

Spring Phase

Constrainted flight phase

- Constraint is,

$$l(t) = l_{max}$$

- Solver stops when,

$$y(t) = (\ l(t) - l_0\ )\ \cos\theta + d\sin\theta$$

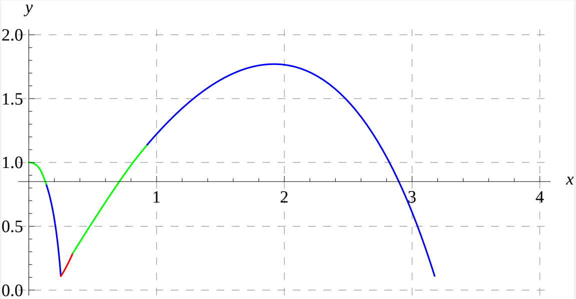


Figure: Equations of motion propagation

Initial Conditions

- Topmost point of the trajectory,
  i.e. $x = 0$, $\dot{x} = 1$, $\dot{y} = 0$, $y = 1$, ϕ is constrained
- Calculate the amount of energy lost in the impact to give $l_{max} = 0.37m$
- Vary θ_0 and $\dot{\theta}_0$ to minimize norm
- Define norm as,

$$norm = \sum_{i=1, i \neq 1,5,10}^{10} ||q_{A_i} - q_{B_i}||$$

  Remove $x(t)$, $\phi(t)$ and $\dot{\phi}(t)$ from the norm
- Problems with optimizing algorithm, hence manual search
- $\theta_0 = 0$ and $\dot{\theta}_0 = -0.5$ rad/s

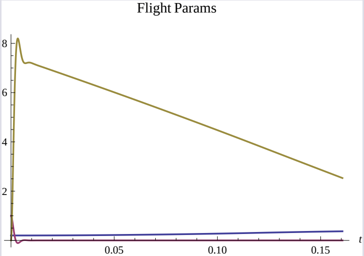
Outline

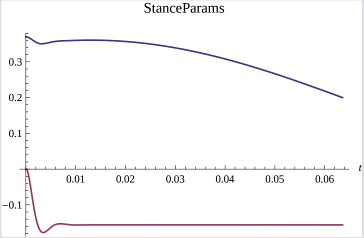
In-place hopping

Controller

- Impact torque destabilizing, control robot attitude
- Flight, spring phases : $\theta_d = 0$
- Stance phase,

$$\theta_d = \tan^{-1}\left(\frac{x_{impact}}{h_{max}}\right)$$





- $l(t)$ - Blue, $\theta(t)$ - Pink, $\phi(t)$ - Yellow, t = secs

Inplace : Trajectory

- Start at $y = 1$m, $\theta = 1$ rad, $\dot{\theta} = -1$ rad/s

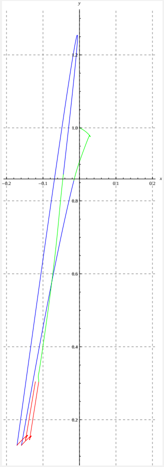


Figure: Inplace : Trajectory

Stance controller

Details

- Most important phase for control
- Generate $\theta_G(t)$ using good initial conditions
- PID torque controller for $e = \theta - \theta_G$

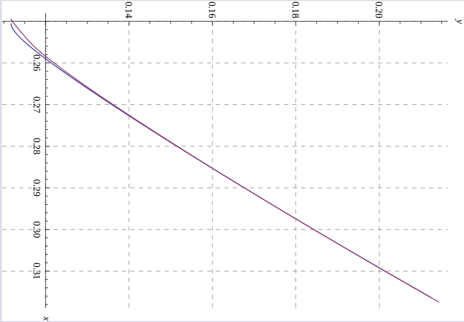


Figure: Good - Blue, Perturbed - Pink, distances in meters

Flight, Spring phases

Control

- Large time–scales
- Solve attitude reorientation to impact attitude

$$\Delta\ \theta(t) = \theta_{impact} - \theta(t)$$

$$\ddot{\phi}_d(t) = \left(\frac{-2\ J_b}{J_w}\right)\left(\frac{\Delta\ \theta - \dot{\theta}(t)\ t_{left}}{t_{left}^2}\right)$$

$$e(t) = \ddot{\phi}(t) - \ddot{\phi}_d(t)$$

$$U_\phi(t) = \ddot{\phi}_d(t) + K_p\ e(t) + K_d\ \dddot{\phi}(t) + K_i\ \int \phi dt$$

Controlled trajectory

- Perturb attitude at liftoff

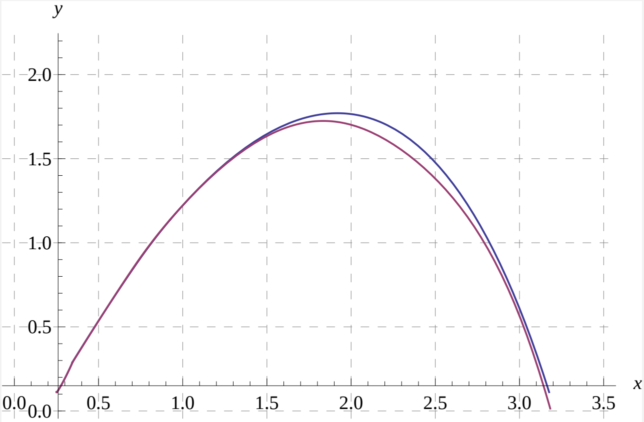
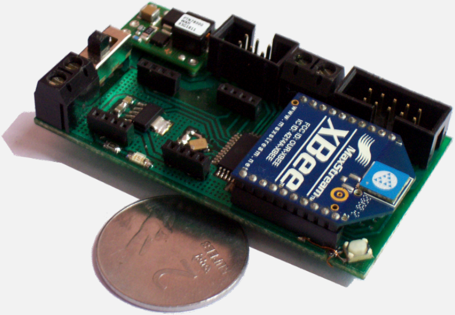


Figure: Trajectory Controller : Good - Blue, Perturbed - Pink

Outline

ReWac Board Hardware



- Microchip dsPIC33F
  16 bit, 40 MIPS
- Accelerometer
  2.162 LSB/mg
- Gyroscope (50 Hz)
  0.07326 $^o/s/$LSB
- Self-made MOSFET motor driver
- XBee module

Kalman Filter

Why

- Pitch attitude estimate
- Computing power

How

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

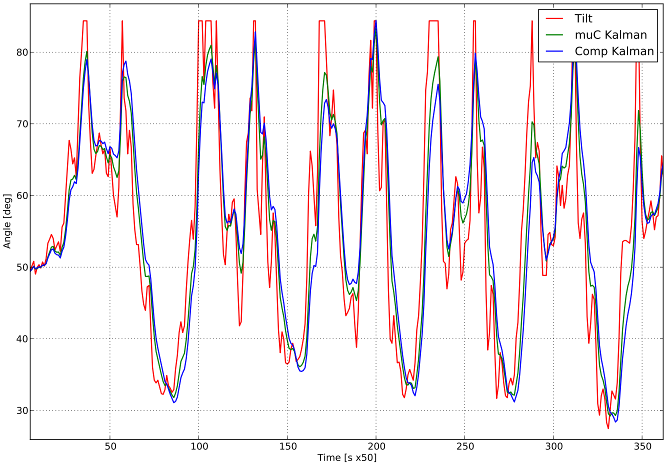
$$\boldsymbol{x}_{k+1} = \boldsymbol{A}\,\boldsymbol{x}_k + \boldsymbol{B}\,\boldsymbol{u}_k + \boldsymbol{w}_k$$

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

Tricks

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

High Frequency Input sampled at 50 Hz



Outline

Summary

Fabrication

- Robot fabrication almost done
- Electronics ready

Controller

- In-place hopping solved
- More work on trajectory following

Future Work

- Assisted test-rig control
- Running on treadmill