

Case Studies Nonlinear Optimization

Open Cast Mining

Midterm Presentation

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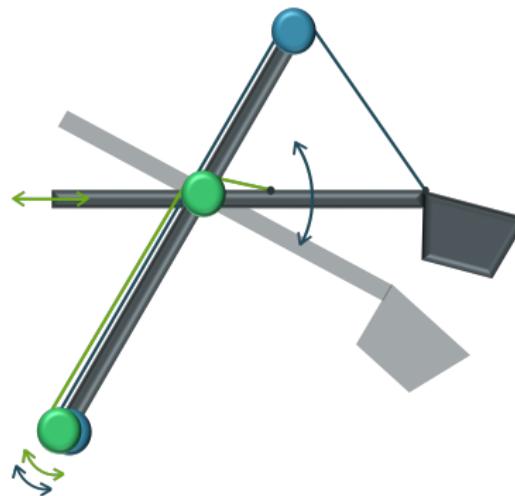
5 Summary



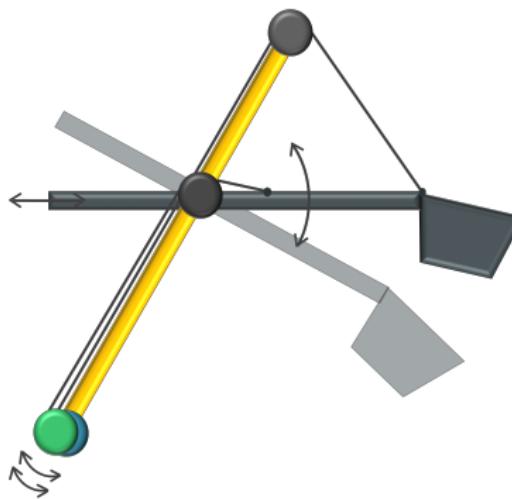
originally posted to Flickr by FAndrey at <http://flickr.com/photos/43301444@N06/4141786255>

- Goal: **optimization of model parameters**
- Models of technical system = physical properties + control properties

Problem Setting

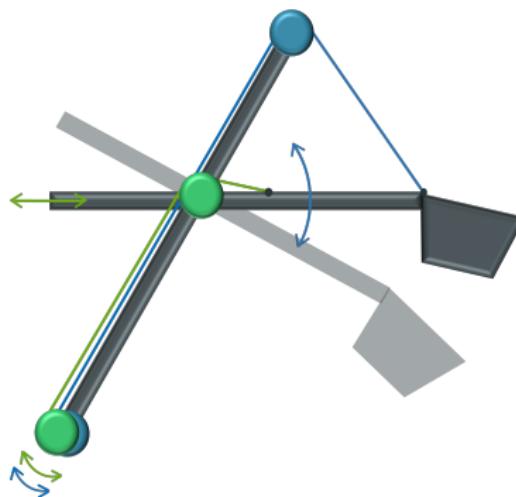


Problem Setting



- arm element fixed to base
- cannot be moved w.r.t. the base

Problem Setting



green shovel motion **back** and **forth**
blue shovel motion **up** and **down**

Main Problems

1. Physical Modelling

- modelling rope properties
- determining information needed for calibration of model

2. Parameter Optimization

- optimizing parameters for a complex, unknown model (black box)

Physical Modelling

Why?

building an accurate
model



better visualization of
control and motion

to consider:

- friction in cable reels
- deformation of ropes

Parameter Optimization

What are parameters?

- friction coefficients
- mass
- inertia

Why?

accurate and realistic
parameters



better prediction and
planning of motion

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1 Problem Setting

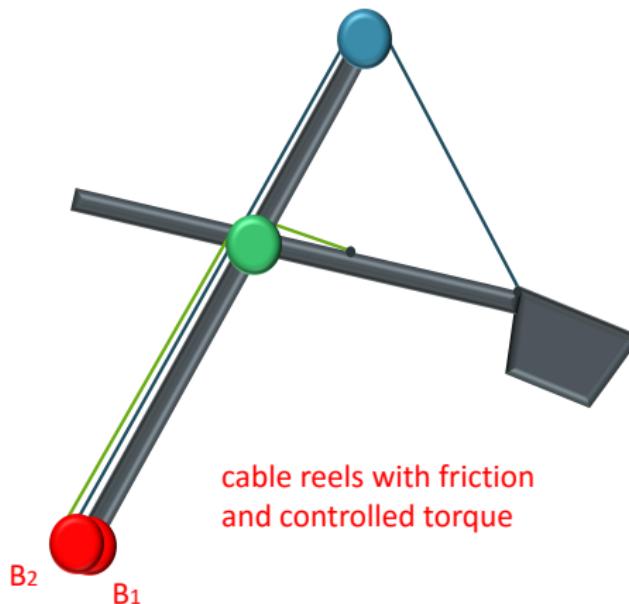
2 Physical Model

3 Visualization

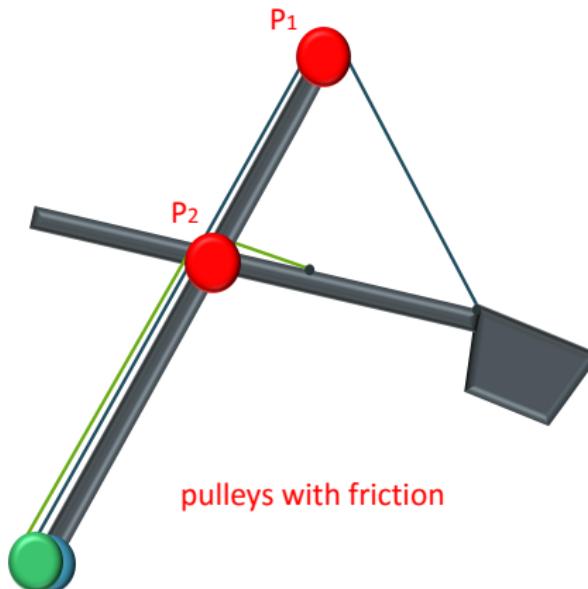
4 Parameter Optimization

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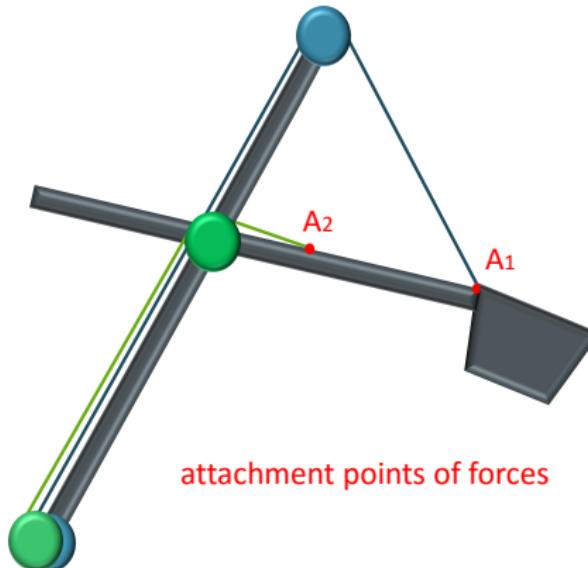
Involved Forces



Involved Forces



Involved Forces



Generalized Forces Q

Example: force at A_2 :

$$F_{A_2} = \left[\frac{\tau_{B_2}}{r_{B_2}} - \mu_{B_2} \frac{\dot{s}}{r_{B_2}} - \mu_{P_2} \frac{\dot{s}}{r_{P_2}} \right] \begin{pmatrix} \cos(\theta) \\ \sin(\theta) \end{pmatrix}$$

all generalized forces:

$$Q_s = \left(\frac{\partial r_{A_1}}{\partial s} \right)^T F_{A_1} + \left(\frac{\partial r_{A_2}}{\partial s} \right)^T F_{A_2}$$

$$Q_\theta = \left(\frac{\partial r_{A_1}}{\partial \theta} \right)^T F_{A_1} + \left(\frac{\partial r_{A_2}}{\partial \theta} \right)^T F_{A_2}$$

Parameters

masses M_1, M_2

inertia of pulleys $I_{B_1}, I_{B_2}, I_{P_1}, I_{P_2}$

friction coefficients $\mu_{B_1}, \mu_{B_2}, \mu_{P_1}, \mu_{P_2}$

Lagrangian Formalism

$$\frac{d}{dt} \left(\frac{\partial T}{\partial \dot{s}} \right) - \frac{\partial T}{\partial s} + \frac{\partial V}{\partial s} = Q_s$$

$$\frac{d}{dt} \left(\frac{\partial T}{\partial \dot{\theta}} \right) - \frac{\partial T}{\partial \theta} + \frac{\partial V}{\partial \theta} = Q_\theta$$

Resulting ODE

Second order ODE from Lagrange formalism:

$$A(x, p) \begin{pmatrix} \ddot{s} \\ \ddot{\theta} \end{pmatrix} = b(x, u, p)$$

Transformed into first order ODE:

$$\frac{d}{dt} \begin{pmatrix} s \\ \theta \\ \dot{s} \\ \dot{\theta} \end{pmatrix} = \begin{pmatrix} \dot{s} \\ \dot{\theta} \\ A^{-1}(x, p)b(x, u, p) \end{pmatrix} = f(x, u, p)$$

state $x = (s, \theta, \dot{s}, \dot{\theta})^T$

control $u = (\tau_1, \tau_2)^T$

parameters $p = (p_1, \dots, p_k)^T$

Discretization of the ODE

Discretize time interval:

$$[0, T] = [t_0, t_1] \cup \dots \cup [t_{m-1}, t_m]$$

Discretize state and control:

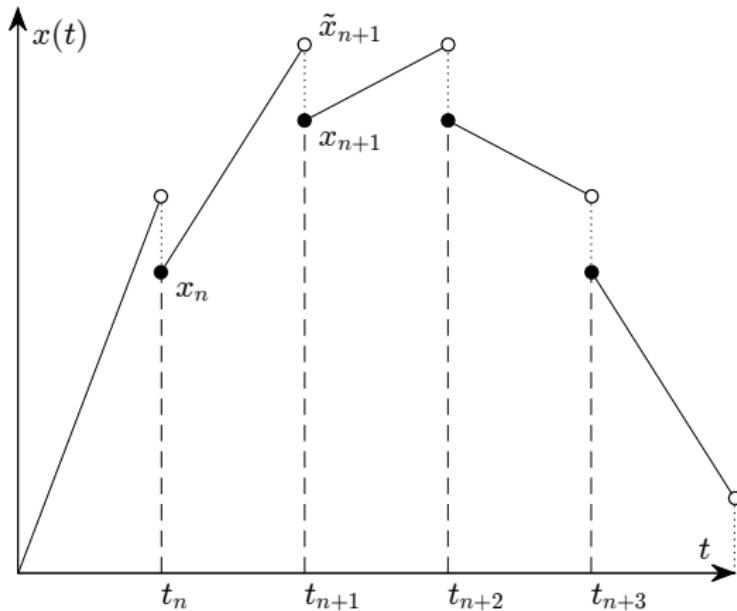
$$x_n = x(t_n)$$

$$u_n = u(t_n)$$

Solve ODE for every time step $h_n = t_{n+1} - t_n$ (Forward Euler):

$$\tilde{x}_{n+1} = x_n + h_n f(x_n, u_n, p)$$

Multiple Shooting



Lagrange Formalism

Method to describe dynamics of an accelerated system

T kinetic energy

V potentials

F non-conservative external forces

r vector pointing to origin of force F

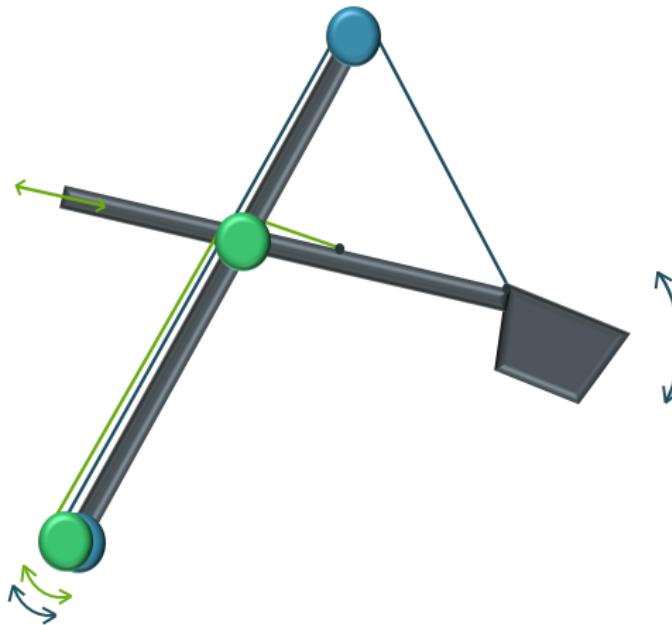
q free variables

Q generalized forces

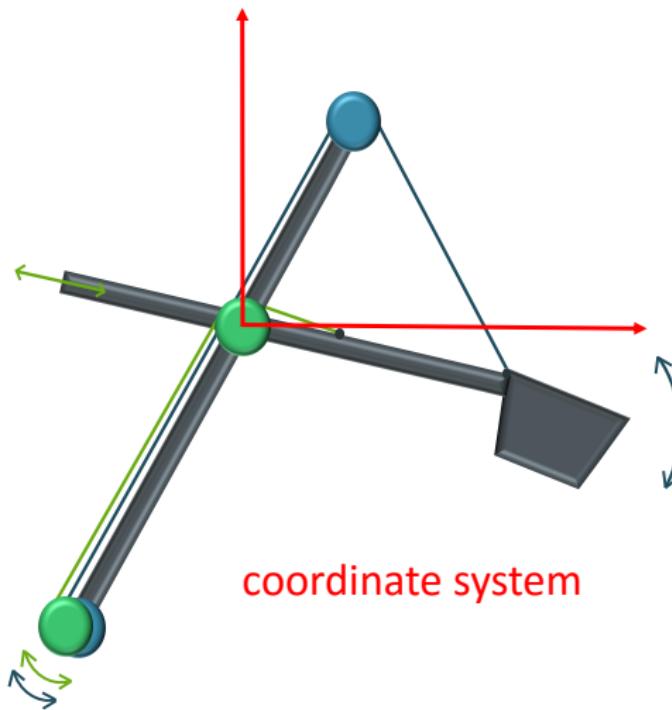
$$\frac{d}{dt} \left(\frac{\partial T}{\partial \dot{q}_i} \right) - \frac{\partial T}{\partial q_i} + \frac{\partial V}{\partial q_i} = Q_i$$

$$Q = \left(\frac{\partial r}{\partial q} \right)^T F$$

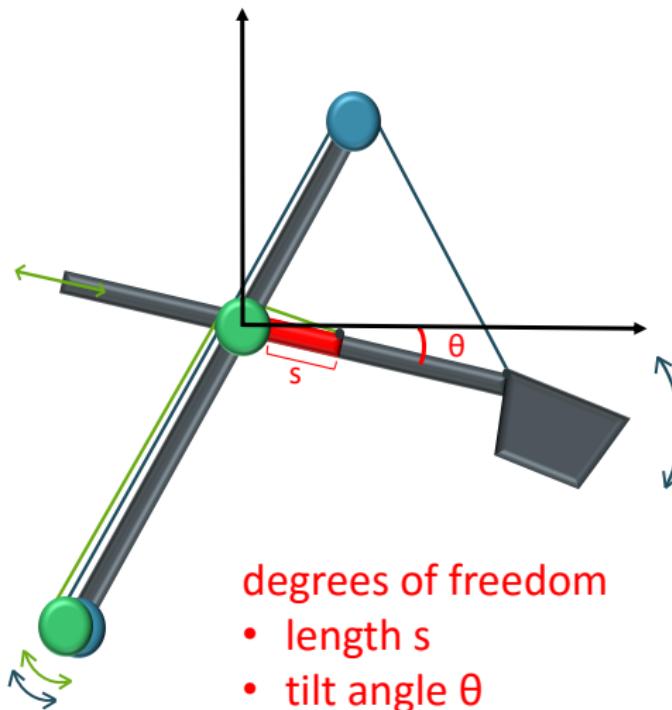
Physical Model of Excavator



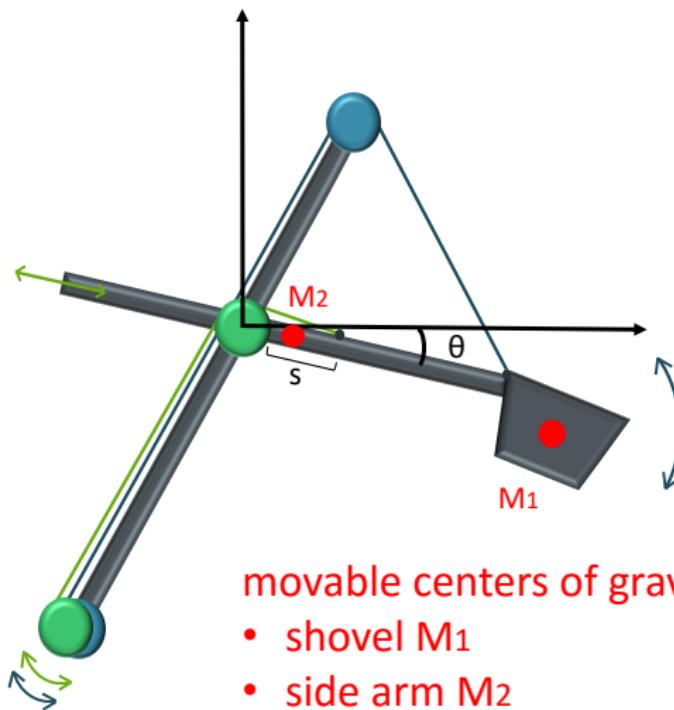
Physical Model of Excavator



Physical Model of Excavator



Physical Model of Excavator



movable centers of gravity of

- shovel M_1
- side arm M_2

Physical Model of Excavator

Assumptions to the model:

- ropes do not have masses
- consider shovel as point mass
- no slack between ropes and cable reels

Kinetic Energy T

Example: energies of M_2

$$E_{\text{kin},M_2} = \frac{1}{2} M_2 \|v_{O,M_2}(s, \theta, \dot{s}, \dot{\theta})\|^2$$
$$E_{\text{rot},M_2} = \frac{1}{2} I_{M_2}(s) \dot{\theta}^2$$

all kinetic energies:

$$T = E_{\text{kin},M_1} + E_{\text{kin},M_2} + E_{\text{rot},M_2} \\ + E_{\text{rot},B_1} + E_{\text{rot},B_2} + E_{\text{rot},P_1} + E_{\text{rot},P_2}$$

Potential V

Example: potential of M_2

$$V_{M_2} = M_2 \ g \ h(s, \theta)$$

all potentials:

$$V = V_{M_1} + V_{M_2}$$

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Visualization

- MatLab/Simulink
- verification of system's behaviors by simulating the motions for characteristic inputs

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Parameters

Examples:

- friction
- inertia
- mass of sidearm

Why do we need parameter optimization?

- hard to measure
- may change over time

Blackbox Model

- contains a realistic model from Siemens
- content valuable

Input

- control
- parameters

Output

- motion

Optimization

- no information about blackbox
 ⇒ derivative-free optimization
- need own model for testing

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Results