Case Studies Nonlinear Optimization

Open Cast Mining

Midterm Presentation

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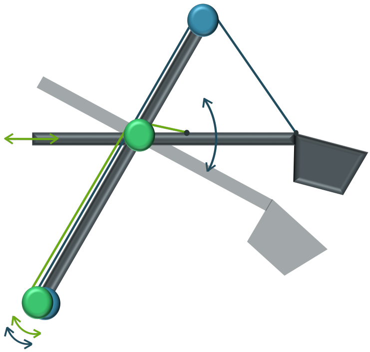
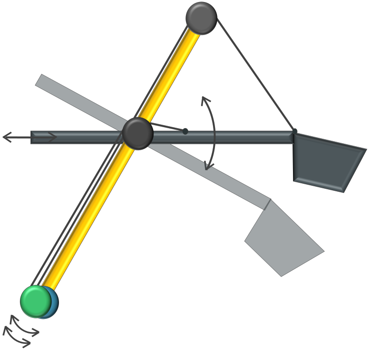
originally posted to Flickr by FAndrey at http://flickr.com/photos/43301444@N06/4141786255

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

Problem Setting

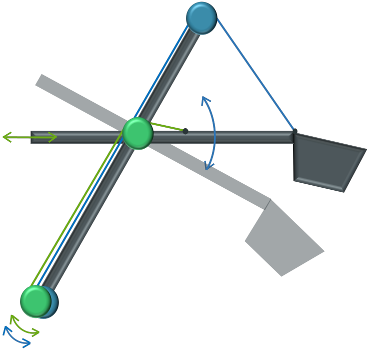


Problem Setting



- 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. Phyiscal 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	$\Rightarrow$	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	$\Rightarrow$	better prediction and planning of motion

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Lagrange Formalism

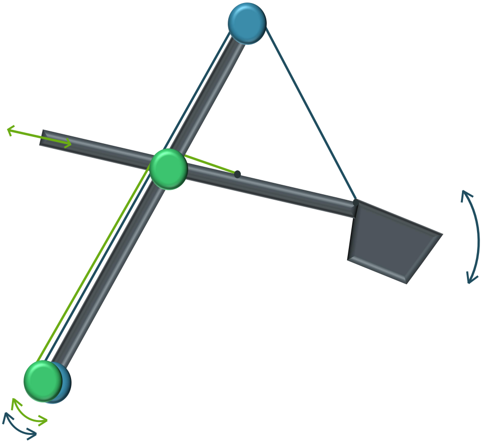
Method to describe dynamics of an accelerated system

T	kinetic energy
V	potentials
F	non-conservative external forces
r	vector pointing to origin of force F
q	free variables
Q	generalized forces

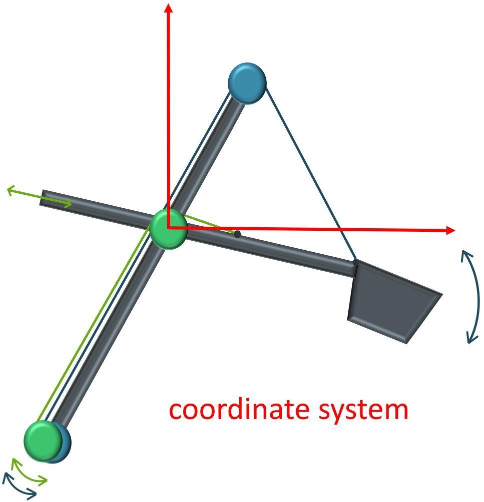
$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{q}_i}\right) - \frac{\partial T}{\partial q_i} + \frac{\partial V}{\partial q_i} = Q_i$$

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

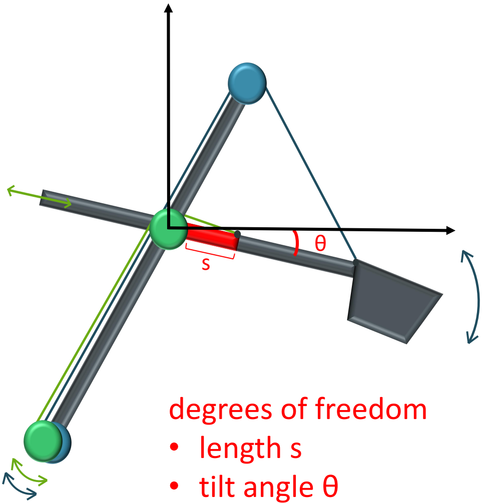
Physical Model of Excavator



Physical Model of Excavator



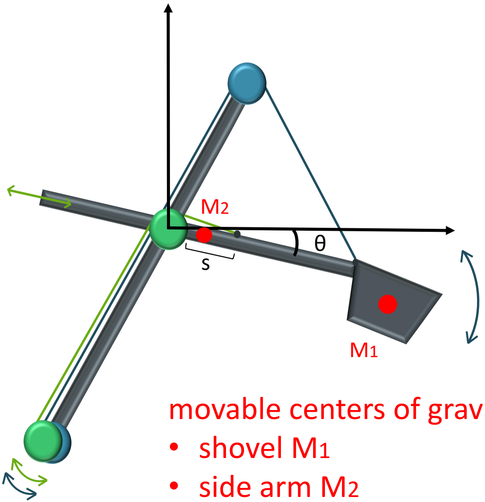
Physical Model of Excavator



degrees of freedom

- length s
- tilt angle θ

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:

$$\begin{aligned} T \;=\; & E_{\text{kin},M_1} + E_{\text{kin},M_2} + E_{\text{rot},M_2} \\ & + E_{\text{rot},B_1} + E_{\text{rot},B_2} + E_{\text{rot},P_1} + E_{\text{rot},P_2} \end{aligned}$$

Potential V

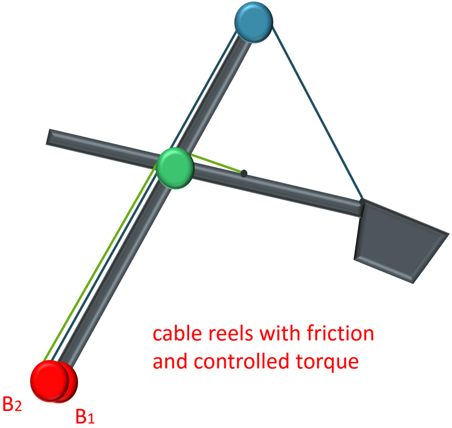
Example: potential of M_2

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

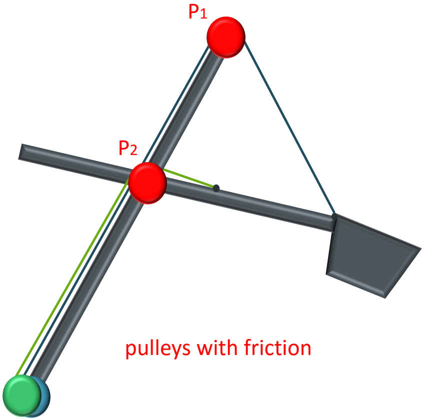
all potentials:

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

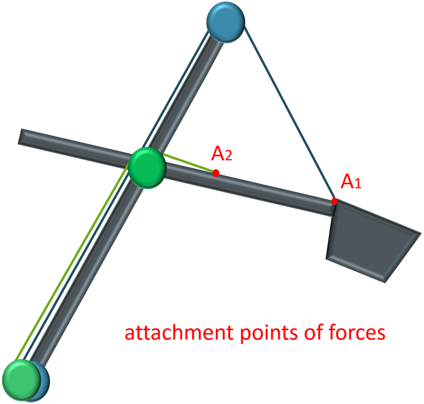
Involved Forces



Involved Forces



Involved Forces



attachment points of 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	$\mu_{B_1}, \mu_{B_2}, \mu_{P_1}, \mu_{P_2}$

Lagrangean 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	$p = (p_1, ..., p_k)^T$

Discretization of the ODE

Discretize time interval:

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

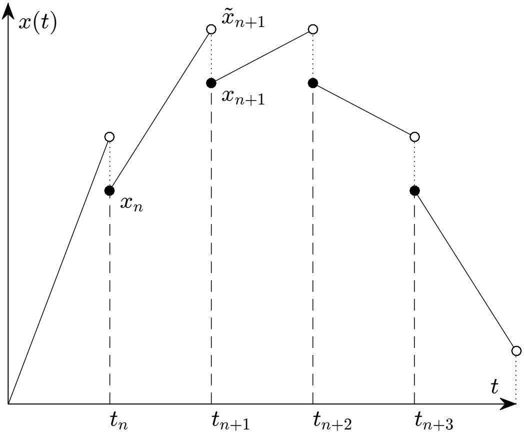
Discretize state and control:

$$x_n = x(t_n)$$
$$u_n = u(t_n)$$

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



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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
  $\Rightarrow$ derivative-free optimization
- need own model for testing

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Results