Case Studies Nonlinear Optimization

Open Cast Mining

Midterm Presentation

May 30, 2016

InYoung Choi, Olivia Kaufmann, Martin Sperr, Florian Wuttke

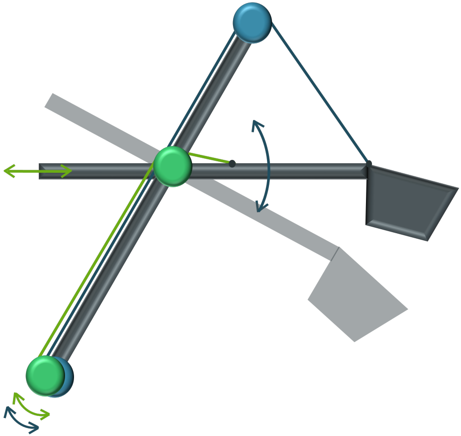
Table of Contents

Table of Contents

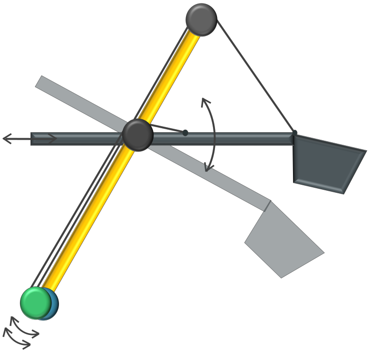
originally posted to Flickr by FAndrey at http://flickr.com/photos/43301444@N06/4141786255

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

Problem Setting

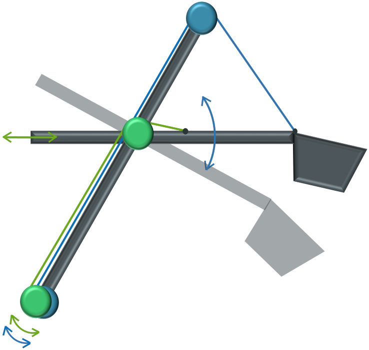


Problem Setting



- 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

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 $\Rightarrow$ Good description of the effects of control and motion

Physical Modelling

Why?

Building an accurate model

$\Rightarrow$

Good description of the effects of control and motion

To consider:

- Friction in cable reels
- Deformation of ropes
- etc.

Parameter Optimization

What are parameters?

- Friction coefficients
- Mass
- Inertia

Parameter Optimization

What are parameters?

- Friction coefficients
- Mass
- Inertia

Why?

Accurate and realistic parameters	$\Rightarrow$	Better prediction and planning of motion

Table of Contents

Lagrange Formalism

Method to describe dynamics of an accelerated system

T	kinetic energy
V	potentials
F	non-conservative external forces
r	points of actions of forces
q	free variables
Q	generalized forces

Lagrange Formalism

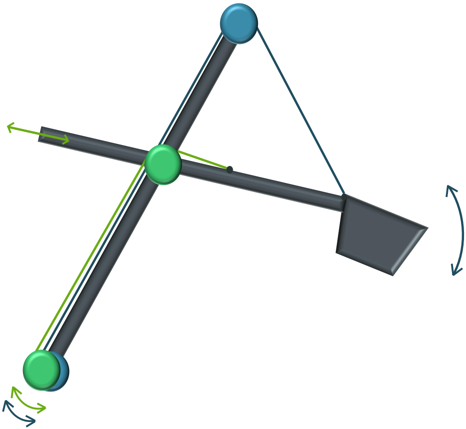
Method to describe dynamics of an accelerated system

T	kinetic energy
V	potentials
F	non-conservative external forces
r	points of actions of forces
q	free variables
Q	generalized forces

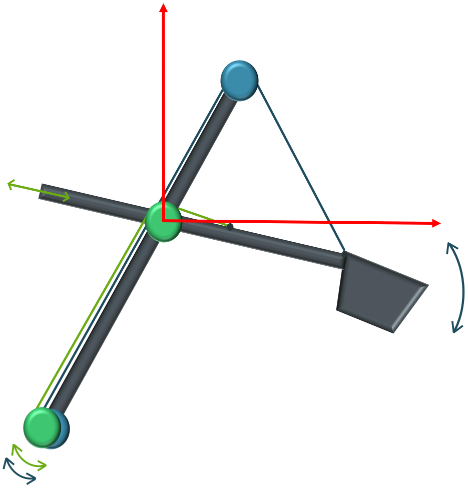
$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{q}_i}\right) - \frac{\partial T}{\partial q_i} + \frac{\partial V}{\partial q_i} = Q_i$$

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

Physical Model of Excavator

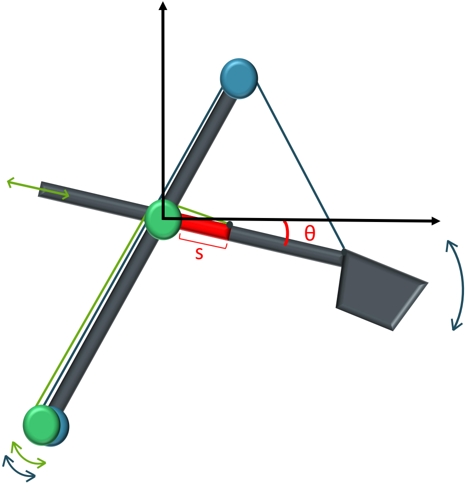


Physical Model of Excavator



coordinate system

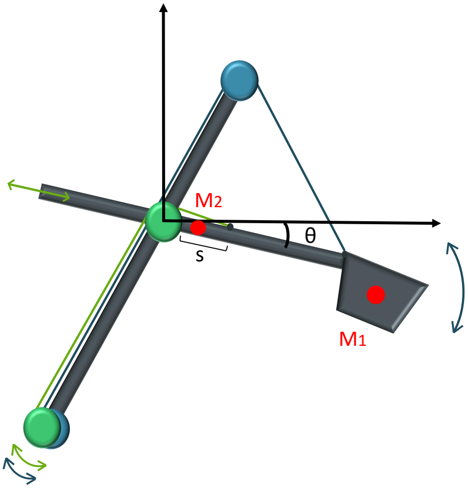
Physical Model of Excavator



degrees of freedom

- length s
- tilt angle θ

Physical Model of Excavator



movable centers of gravity of

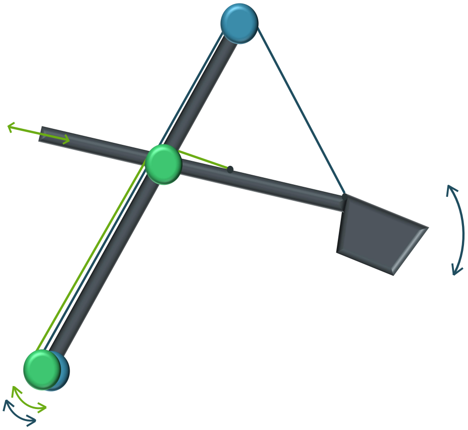
- shovel M_1
- arm M_2

Physical Model of Excavator

Assumptions to the model:

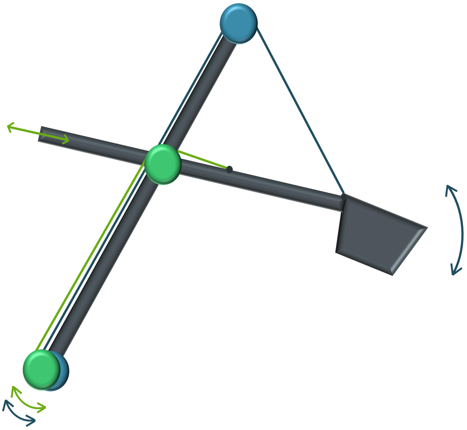
- no mass for the ropes
- shovel as point mass
- no slack/friction between ropes and cable reels

Kinetic Energy



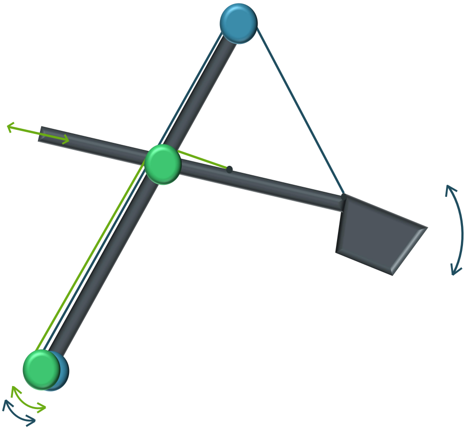
- movement of mass
- rotation of cable reel

Potential Energy



gravitational potential energy

Generalized Forces



- torque on cable reel
- friction of cable reel

Lagrange 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:

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

Discretize state and control:

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

Discretization of the ODE

Explicit Euler for every time step $h_n = t_{n+1} - t_n$:

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

Discrete constraint:

$$0 = x_{n+1} - \tilde{x}_{n+1} \quad \forall n = 0, \ldots, m-1$$

Discretization of the ODE

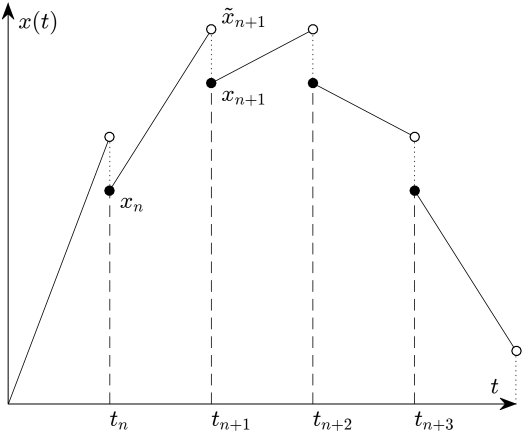


Table of Contents

Parameters

Examples:

- Friction coefficients $\mu_{B_1}, \mu_{B_2}, \mu_{P_1}, \mu_{P_2}$
- Masses M_1, M_2
- Inertia $I_{B_1}, I_{B_2}, I_{P_1}, I_{P_2}$

Parameters

Examples:

- Friction coefficients $\mu_{B_1}, \mu_{B_2}, \mu_{P_1}, \mu_{P_2}$
- Masses M_1, M_2
- Inertia $I_{B_1}, I_{B_2}, I_{P_1}, I_{P_2}$

Why do we need parameter optimization?

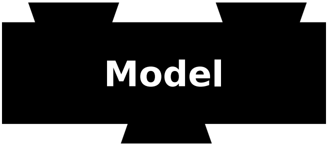
- Hard to measure
- May change over time

Blackbox Model

- Contains a realistic model from Siemens
- Confidential information

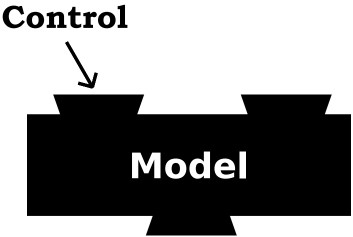
Blackbox Model

- Contains a realistic model from Siemens
- Confidential information



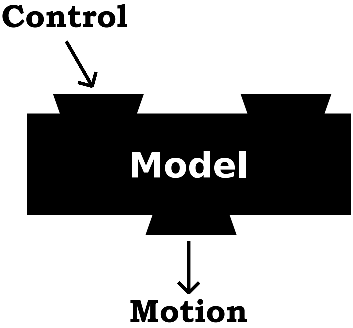
Blackbox Model

- Contains a realistic model from Siemens
- Confidential information



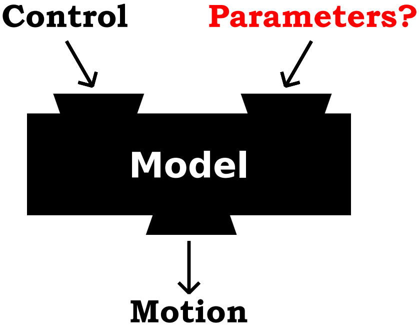
Blackbox Model

- Contains a realistic model from Siemens
- Confidential information



Blackbox Model

- Contains a realistic model from Siemens
- Confidential information

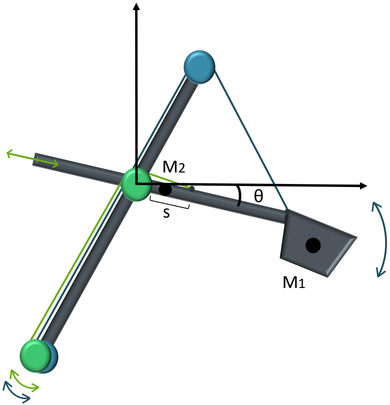


Parameter Optimization

- Black box $\Rightarrow$ derivative-free optimization
- Need own model for testing

Table of Contents

Results



Results