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Exercise Sheet 6

Presentation during exercises in calendar week 26

Exercise 6.1 – Optimization of a rocket car

This exercise can only be compiled and run on the CIP Pool!!!

In the following we will investigate the rocket car given in

`/RocketCar_Template/doc/setup_rocket_car.pdf`

as a (min energy) optimal control problem:

$$\min_{T,x(t),u(t)} \int_0^T u^2(\tau)\,\mathrm{d}\tau \tag{1a}$$

subject to: (1b)

$$\dot{x}(t) = \begin{bmatrix} \dot{q} \\ u \end{bmatrix} \tag{1c}$$

$$r(0) = \begin{bmatrix} q(0) \\ \dot{q}(0) \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix} \tag{1d}$$

$$r(T) = \begin{bmatrix} q(T) \\ \dot{q}(T) \end{bmatrix} = \begin{bmatrix} L \\ 0 \end{bmatrix} \tag{1e}$$

$$\underline{t} \leq t \leq \overline{t} \tag{1f}$$

$$\underline{u} \leq u \leq \overline{u} \tag{1g}$$

$$\underline{x} \leq x \leq \overline{x} \tag{1h}$$

a Familiarize yourself with the code template given in

`/RocketCar_Template/`

and fill in the gaps.

b Now, the car has an engine problem - maximal acceleration goes down to $0.8\frac{m}{s^2}$ - what happens to the solution? make a second trial with maximal acceleration at $0.5\frac{m}{s^2}$

c Reformulate problem **a** such that it is solved for minimum lap-time (use the `mfcn` function). Use $\underline{t} = 0.0$s and $\overline{t} = 40s$ for time box constraints (1f) (`h_min, h_max`). What does happen?

d Now the engine goes to serious overheat and the maximal acceleration goes down to $0.5\frac{m}{s^2}$. What happens now?

Notes:

- In order to run muscod with one of your `DatFileName.dat` files, go to your build folder - `/SRC/`, `/DAT/` as well as your libraries (`.so` files) should be there - and execute

  `muscod DatFileName`
- If you want to maintain multiple source files, compile multiple libraries by adding additional lines

  `ADD_LIBRARY ( LibName SRC/SrcName.cc)`

  to your `CMakeLists.txt`. After that you have to run `cmake` again (from inside your build folder).
- Dont forget to link your `.dat` file to a library by modifying the following lines inside the `.dat` file:

  `libmodel`

  `libLibName` ← your library will have the `lib` prefix once compiled!

Exercise 6.2 – Cart Pendulum

Imagine the given cart pendulum from figure 1. The cart pendulum consists of two rigid bodies, the *Cart* and the *Pendulum*. The pendulum itself consists of two elements, a spherical mass and a massless link. The model has two degrees of freedom:

- q_0: the x-translation of the body *Cart*.
- q_1: the rotation around the y axis of the body *Pendulum*.

The movement of the pendulum can be controlled by a force u_0 acting in horizontal direction on the cart.

Cart:

- Cuboid
- x-length= 0.5m, y-length = 0.2m, height = 0.2m
- mass = 10.0kg

Pendulum:

- Massless link: length = 0.5m
- Sphere: radius = 0.1m, mass = 1.0kg

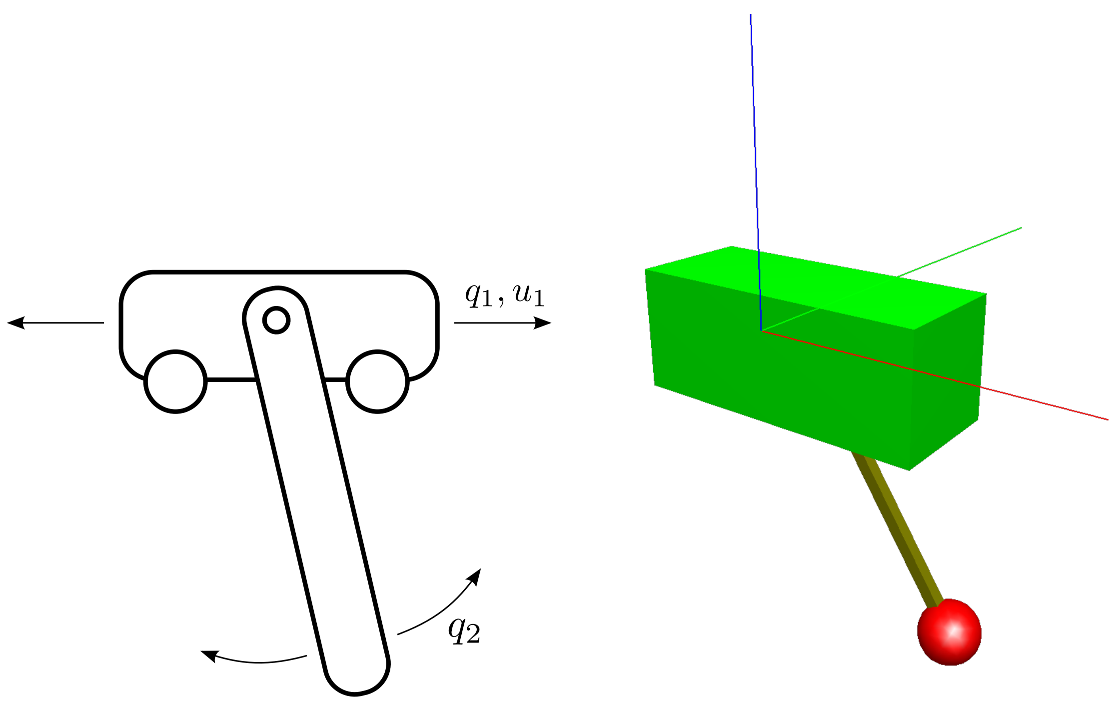

Figure 1: Cart pendulum and MeshUp model

Formulate an optimal control problem to find a *swing-up* trajectory $x(t)$ with minimal energy consumption from the static initial state $q(0) = \begin{bmatrix} 0 & \pi \end{bmatrix}$ towards the final static state $q(T) = \begin{bmatrix} 0 & 0 \end{bmatrix}^T$. The *swing-up* should be performed in $5s$ and the force characteristics on the cart are given with:

$$-150N \leq u \leq 150N \tag{2a}$$

$$-50\frac{N}{s} \leq \dot{u} \leq 50\frac{N}{s} \tag{2b}$$

- Implement the problem formulation for minimum energy based on the template from the following folder:

  `/Cart_Pendulum_Template/`

- Unfortunately, the actuation-system was not well assembled and overheats again. Force-output drops to $100N$ - how fast can the pendulum now swing up? (change `of_sca` to 1.0 and `u_sca` to 10.0)