# Trajectories

## Input

- Joystick commands: `cmd_hst_pt, cmd_crd_pt`

## Output

- Torques: `u_hst, u_crd`
- Positions: `y_hst, y_crd`

Currently we have:

- `n_tra` different trajectories of size `n_sim`
- `n_tra = 9; n_sim = 1000`
- each of them is a matrix of size `(n_sim, n_tra)`

# Objective Function

Parameters that are optimized:

`hst_inertia_engine, inertia_yy, hst_friction, crd_mass`

$$\begin{aligned} \min_{p \in \mathbb{R}^4} f(p) = \quad & \frac{1}{n_{\text{tra}}} \cdot \left( \alpha_1 \cdot \|\overline{U}_{\text{hst}} - U_{\text{hst}}(p)\|_{\text{F}}^2 + \ldots \right) \\ \text{s.t.} \quad & p_i \geq 0 \end{aligned}$$

where

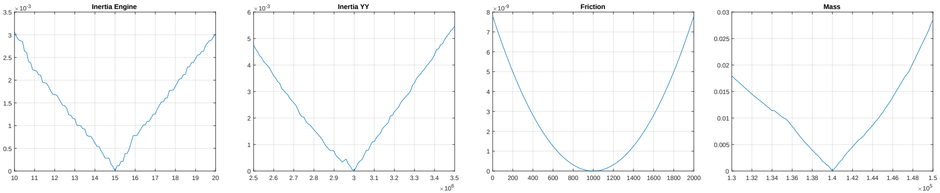
$$\alpha_1 = \frac{1}{\|\overline{U}_{\text{hst}}\|_{\text{F}}^2} \qquad \|\overline{U}_{i,j}\|_{\text{F}}^2 = \sum_{j=1}^{n_{\text{tra}}} \sum_{i=1}^{n_{\text{sim}}} |\overline{U}_{i,j}|^2$$

$\| \cdot \|_{\text{F}}$ is the Frobenius norm

# Influence of the Parameters

$10\%$ deviation of parameter . . . cause in the objective function:

| | | |
|---|---|---|
| ■ `hst_inertia_engine` | $1 \cdot 10^{-3}$ | linear |
| ■ `inertia_yy` | $3.3 \cdot 10^{-3}$ | linear |
| ■ `hst_friction` | $7.8 \cdot 10^{-11}$ | quadratic |
| ■ `crd_mass` | $52 \cdot 10^{-3}$ | linear |



# Solvers

Conditions:

- Starting values: $X \sim \mathrm{N}\left(\bar{x}, \bar{x}/2\right)$, where $\bar{x}$ is the given value
- Smarm Size: $10$
- Function Tolerance: $10^{-9}$
- Time Limit: 15 min
- Max Iterations: $\infty$

| | penalty | evaluations | time |
|---|---|---|---|
| Particle Swarm | $10^{-13}$ | $2500$ | 3 min |
| Pattern Search | $10^{-3}$ | $6000$ | 8 min |
| Genetic Algorithm | $10^{-2}$ | $7500$ | 15 min (time limit) |
| Simulated Annealing | $10^{-1}$ | $3000$ | 4 min |

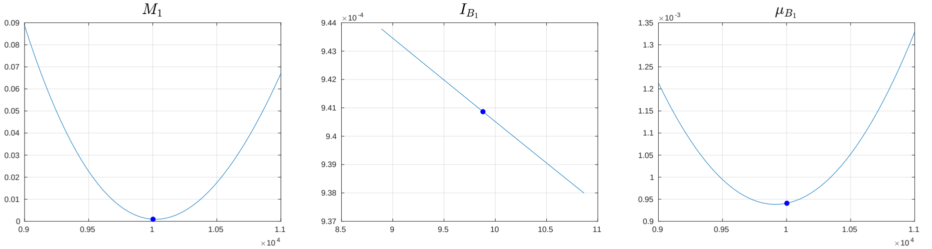
# Optimization Problem

$$\min_{p \in \mathbb{R}^{10}} f(p) = \frac{1}{2} \|x_{\text{ref}} - x(p)\|^2$$
$$\text{s. t.} \quad p_i \geq 0$$

- state $x = (s, \theta, \dot{s}, \dot{\theta})^T$
- $x_{\text{ref}}$ reference trajectory
- $x(p)$ approximation using Runge-Kutta methods of Order 1/2/3/4

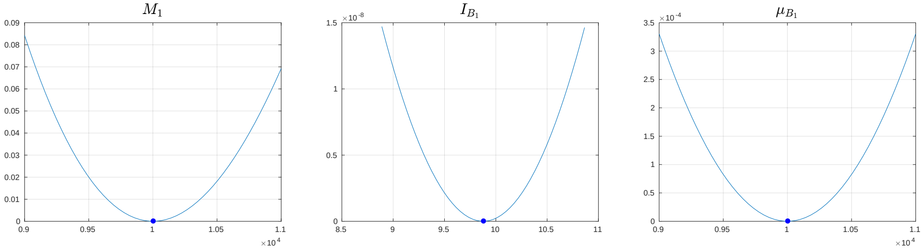
# Influence of the Parameters

Using $x_{\text{ref}} = x_{\text{real}}$, the real trajectory:



# Influence of the Parameters

Using $x_{\text{ref}} = x(p_{\text{real}})$, the approximation from the real parameters:



# Solvers

Conditions:

- Supporting Points: 100
- Runge-Kutta Order: 1
- Reference Trajectory: $x_{\text{real}}$
- $\frac{1}{2}\|x_{\text{real}} - x(p_{\text{real}})\|^2 = 9.4 \cdot 10^{-4}$
- Optimality Tolerance: $10^{-10}$

| | iterations | feval | $\frac{1}{2}\|x_{\text{real}} - x(p)\|$ | $\frac{1}{2}\|x(p_{\text{real}}) - x(p)\|$ |
|---|---|---|---|---|
| SQP | $219$ | 241 | $1.8 \cdot 10^{-4}$ | $7.6 \cdot 10^{-4}$ |
| Interior Point | $218$ | 228 | $1.8 \cdot 10^{-4}$ | $7.6 \cdot 10^{-4}$ |
| Trust Region | $25$ ($112$ cg) | 26 | $1.8 \cdot 10^{-4}$ | $7.6 \cdot 10^{-4}$ |
| Active Set | $244$ | 501 | $2.0 \cdot 10^{-4}$ | $8.3 \cdot 10^{-4}$ |

# Solvers

Conditions:

- Supporting Points: 100
- Runge-Kutta Order: 4
- Reference Trajectory: $x_{\text{real}}$
- $\frac{1}{2}\|x_{\text{real}} - x(p_{\text{real}})\|^2 = 9.4 \cdot 10^{-5}$
- Optimality Tolerance: $10^{-10}$

| | iterations | feval | $\frac{1}{2}\|x_{\text{real}} - x(p)\|$ | $\frac{1}{2}\|x(p_{\text{real}}) - x(p)\|$ |
|---|---|---|---|---|
| SQP | $225$ | 248 | $8.9 \cdot 10^{-5}$ | $5.4 \cdot 10^{-6}$ |
| Interior Point | $262$ ($37$ cg) | 280 | $8.9 \cdot 10^{-5}$ | $5.4 \cdot 10^{-6}$ |
| Trust Region | $27$ ($123$ cg) | 28 | $8.9 \cdot 10^{-5}$ | $5.4 \cdot 10^{-6}$ |
| Active Set | $231$ | 469 | $1.2 \cdot 10^{-4}$ | $5.0 \cdot 10^{-5}$ |

# Visualization with Simulink

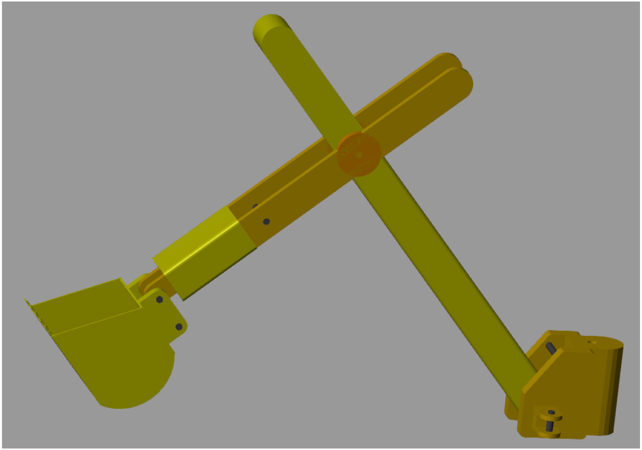


Figure : Current state