# Power consumption identification for time and energy trade-off in cranes

Filipe Barbosa


## Summary

**Objective:** Trade-off time and energy when loading a container ship.

**Challenge:** Incorporate electromechanical dynamics to the power dynamics model.

**Method:** Data collection and standard system identification.


## Preliminaries

Taking regeneration into account, the energy consumed is

$$E(t) = \int_0^t \max(P(\tau), \gamma P(\tau)) d\tau.$$

1. The mechanical power produced by an electric motor is

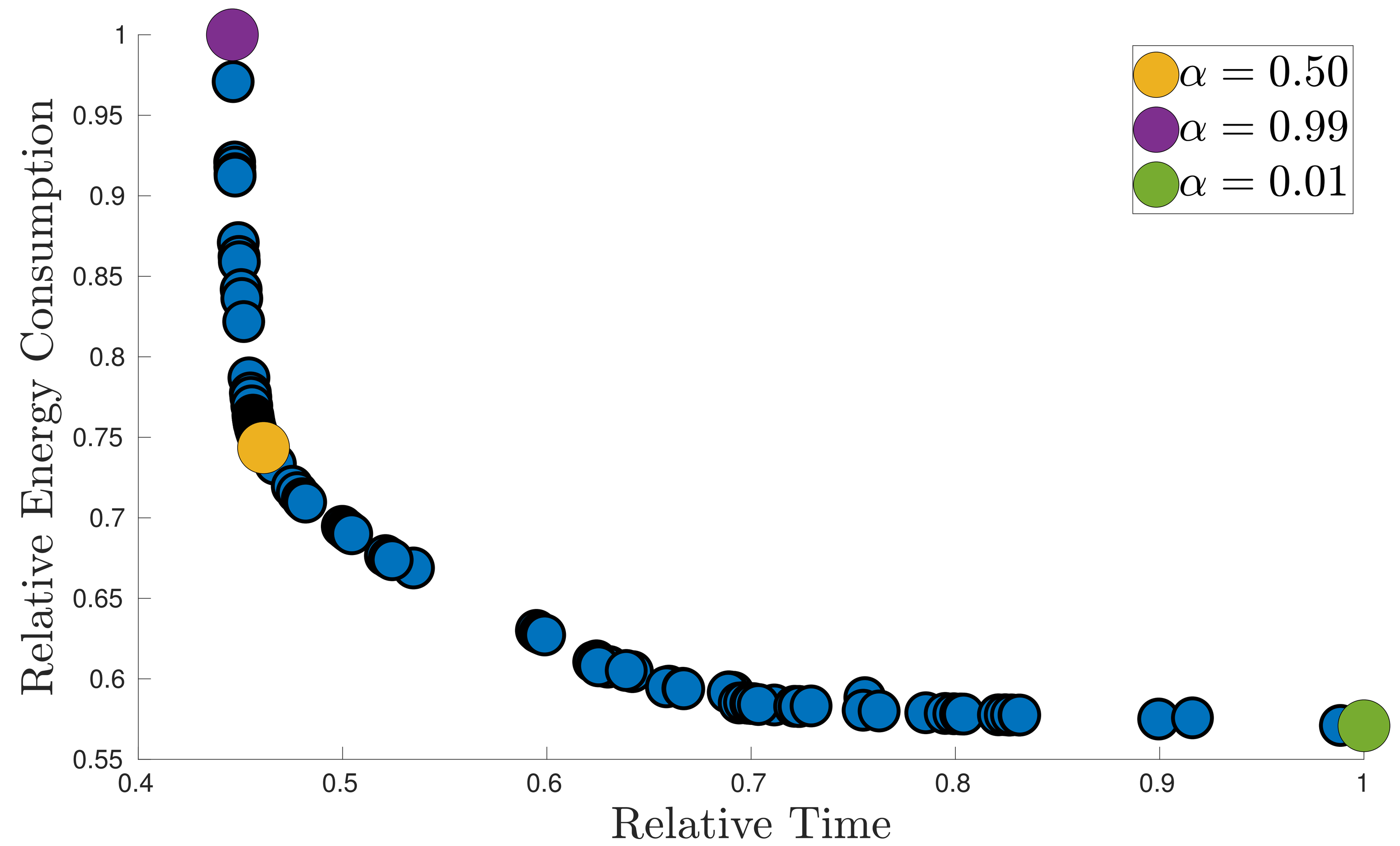
$$P_m = T\,\omega$$

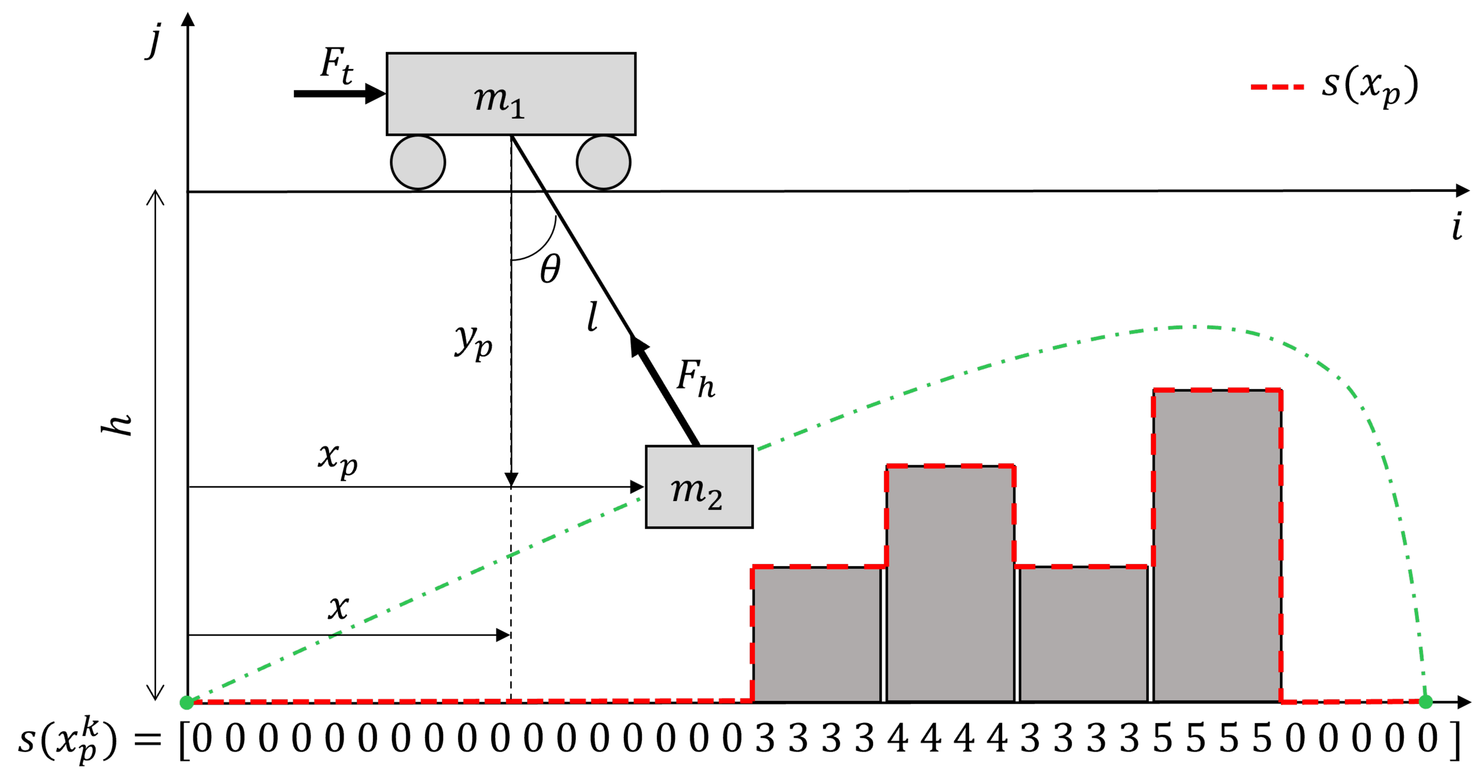
where $T$ is motor output torque and $\omega$ the rotor speed.

2. The electrical power consumed by a $3\phi$ motor is

$$P_{in} = \sqrt{3}\,U I \cos(\phi)$$

where $U$ is the voltage, $I$ the current and $\cos(\phi)$ the power factor.



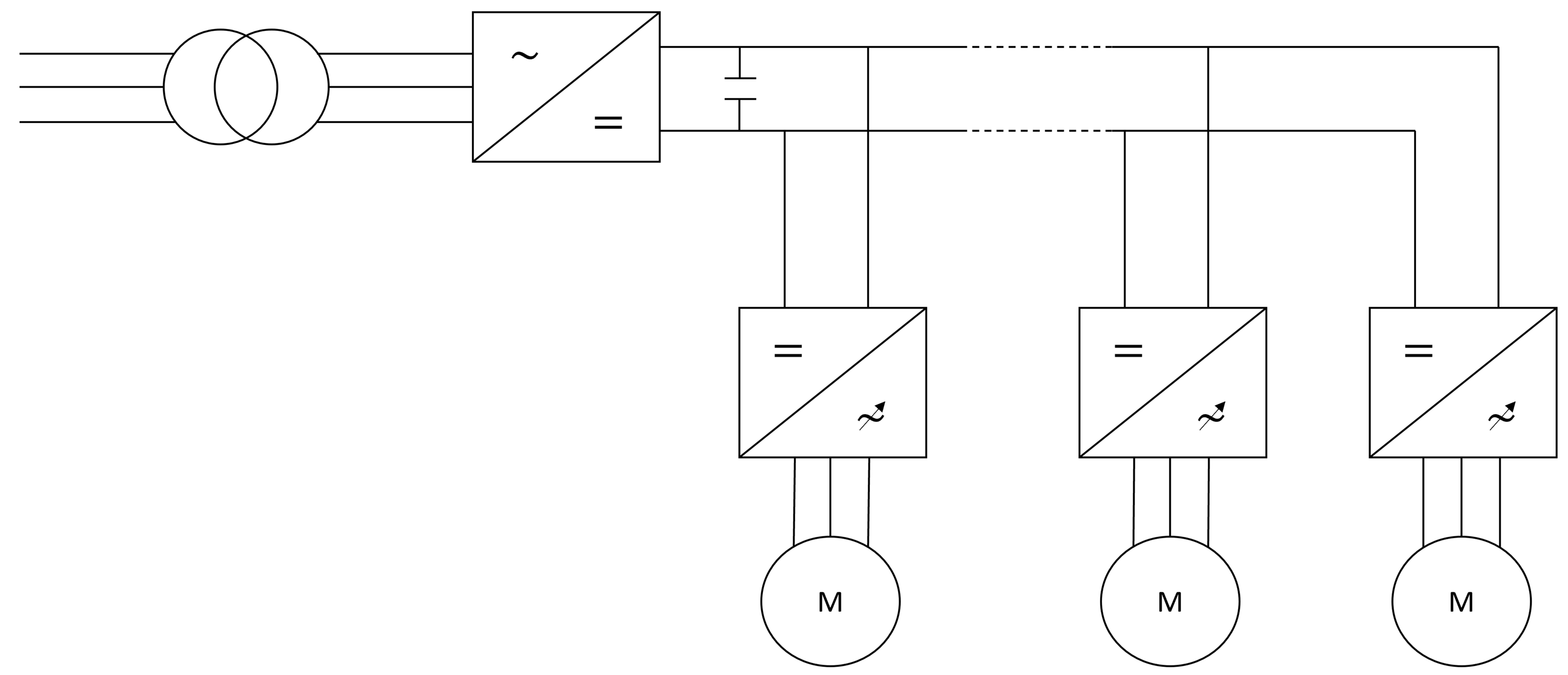




$$\begin{aligned}
\underset{u}{\text{minimize}}\quad & J = \Psi(E, t_f) \\
\text{subject to}\quad & x_2\dot{x}(x_p) = f(x_p, x(x_p), u(x_p)) \\
& 0 \le y_p(x_p) \le h - s(x_p) \leftarrow \text{container constraints} \\
& z_t(t) \ge P_t(x_p) \\
& z_t(t) \ge \gamma_t P_t(x_p) \\
& z_h(t) \ge P_h(x_p) \\
& z_h(t) \ge \gamma_h P_h(x_p) \\
& \vdots \\
& \text{other constraints}
\end{aligned}$$

## Identification

1. We have access to the motor's speed and torque as well as the power consumption at the drive.
2. We also have access to $U$ and $I$, so the identification can also be done at the motor input. This may help to model the losses.
3. Then we find the relationship between the motor speeds and torques, and the power consumption given by the drive

$$P = f(\omega, T).$$




## The optimization problem

1. To deal with a non-smooth integrand in the cost function:

$$\begin{aligned}
\min_u \quad & \int_0^{t_f} z(t)dt \\
\text{subject to}\quad & z(t) \ge P(t) \\
& z(t) \ge \gamma P(t)
\end{aligned}$$

with $z(t)$ as an upper bound in an epigraph formulation.

2. Time discretization would lead to

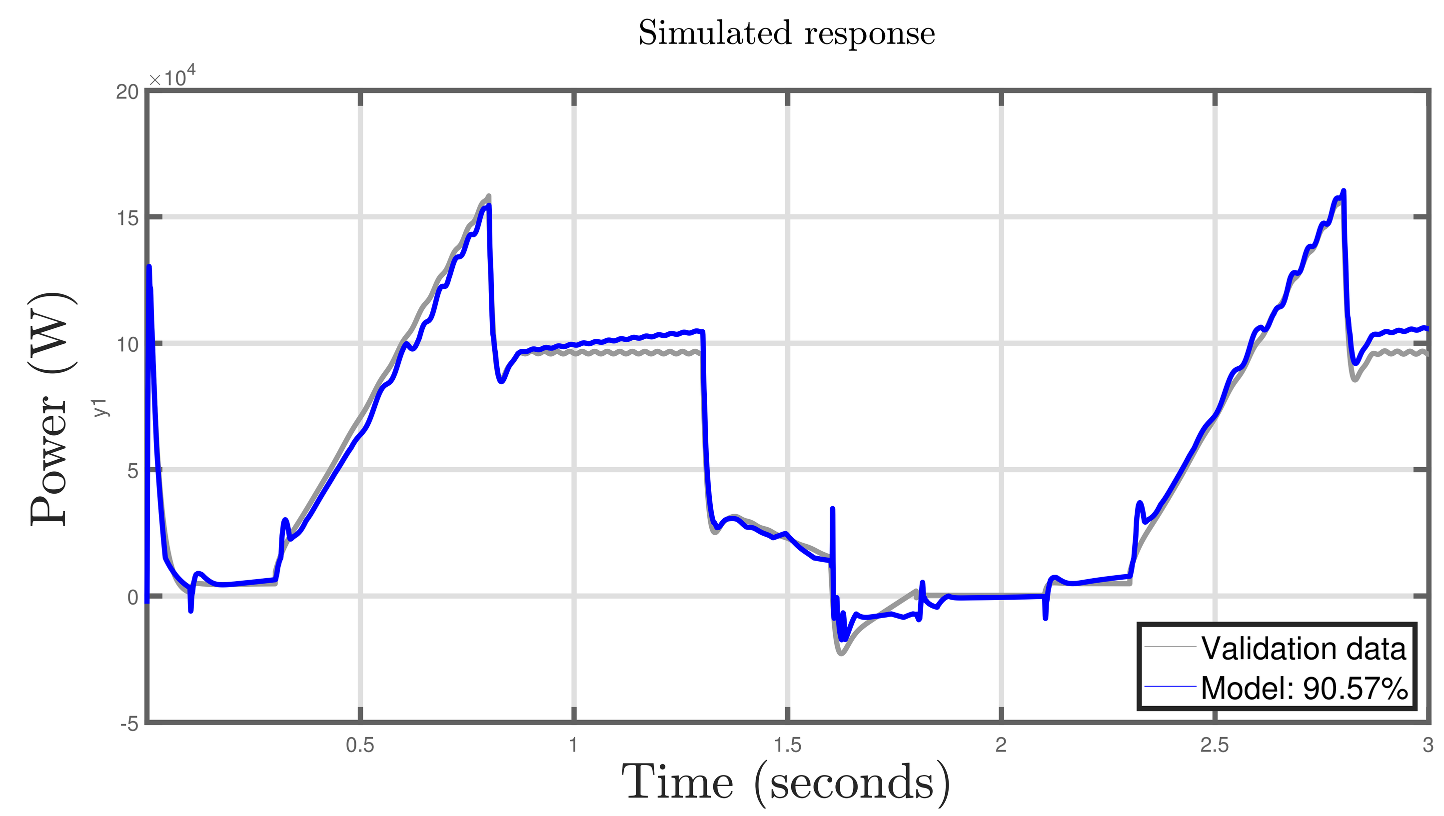
$$0 \le y_p(t^k) \le h - s(x_p(t^k)).\quad ✗$$

So, use spatial derivatives deal to with the collision avoidance

$$\dot{x}_1 = \frac{dx_1}{dt} = x_2 \implies \frac{dt}{dx_1} = \frac{1}{x_2}, \frac{dx_2}{dx_1} = \dots$$

and the collision avoidance becomes

$$0 \le y_p(x_p^k) \le h - s(x_p^k).\quad ✓$$




LINKÖPING UNIVERSITY

LINK-SIC