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POLITECNICO DI TORINO

Model Predictive Control of a Hydraulic Power Take-Off for Wave Energy Converter

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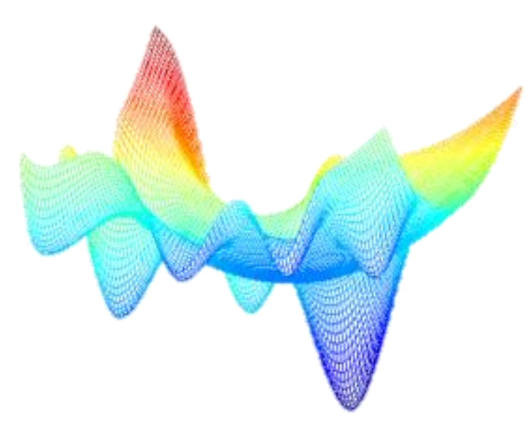
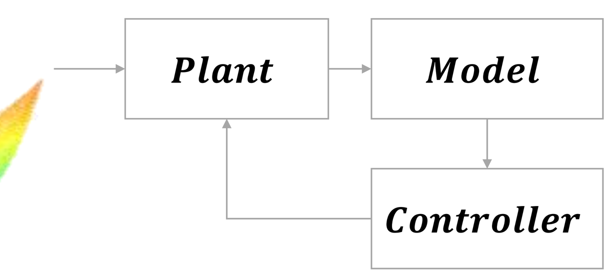
Project aim

Design of a Model Predictive Controller for a high efficiency PTO system for the management of renewable sources in isolated grids. The application of the MPC overcome the problem of the power extraction maximization in renewable sources performing a constrained optimization basing on the future knowledge of the plant behaviour.

Model Predictive Control (MPC)



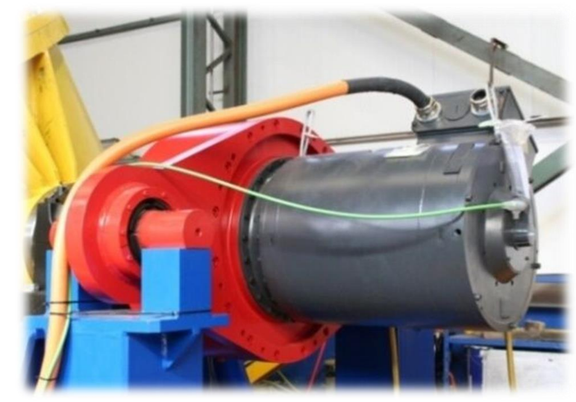


$$E(t) = -\int_0^t \langle u(t)|y(t)\rangle dt$$

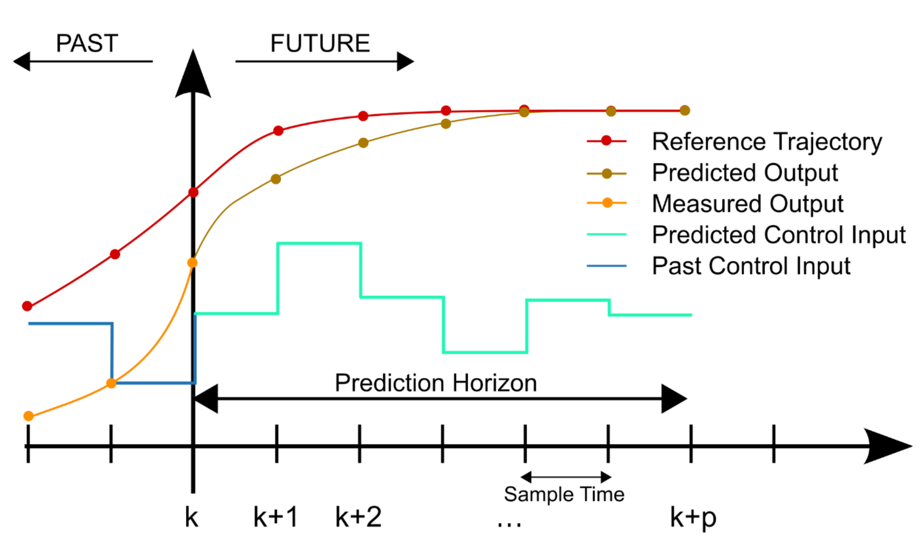
Power extraction optimization

- Model based optimization
- Optimal control of the plant
- Energy extraction and efficiency optimization

Wave Energy Converter



MPC philosophy



- At time k the controller solve an optimal control problem over the horizon $[k, k+p]$
- Only the first control action u(k) is applied to the plant
- At time k+1, given new measurements, a new optimization is performed over the horizon $[k+1, k+p+1]$

Input estimation | **Plant evolution prediction** | **Constrained optimization**

Unknown input estimation

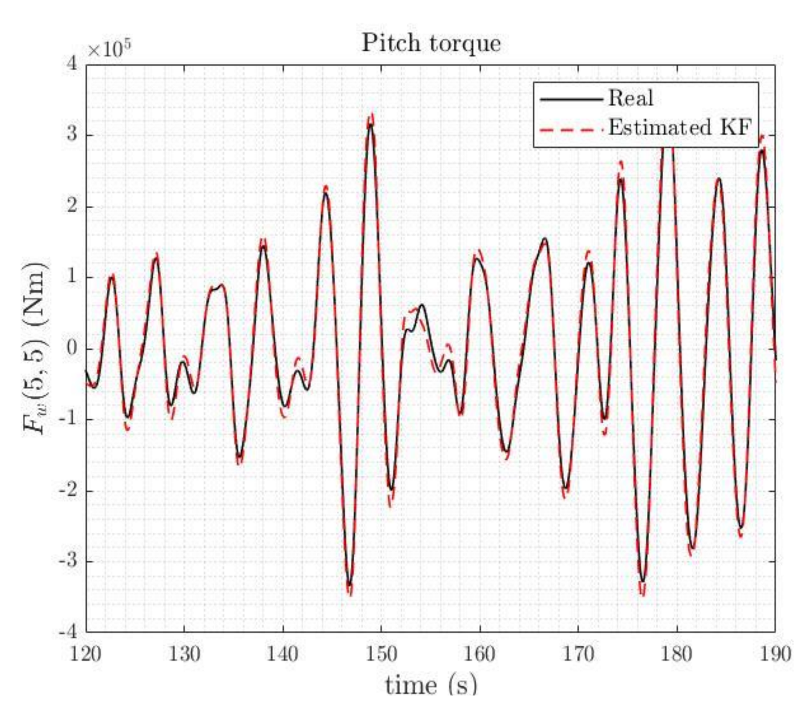
Kalman Filter Observer

- Time Update step:

$$P_{k+1}^- = AP_kA^T + Q$$
$$S_{k+1}^- = AS_k$$

- Measurement Update step:

$$K_{k+1} = P_{k+1}^- C(CP_{k+1}^- C^T + R)^{-1}$$
$$P_{k+1} = (I - K_{k+1}C)P_{k+1}^-$$
$$S_{k+1} = S_{k+1}^- + K_{k+1}(Y_{k+1} - CS_{k+1}^-)$$

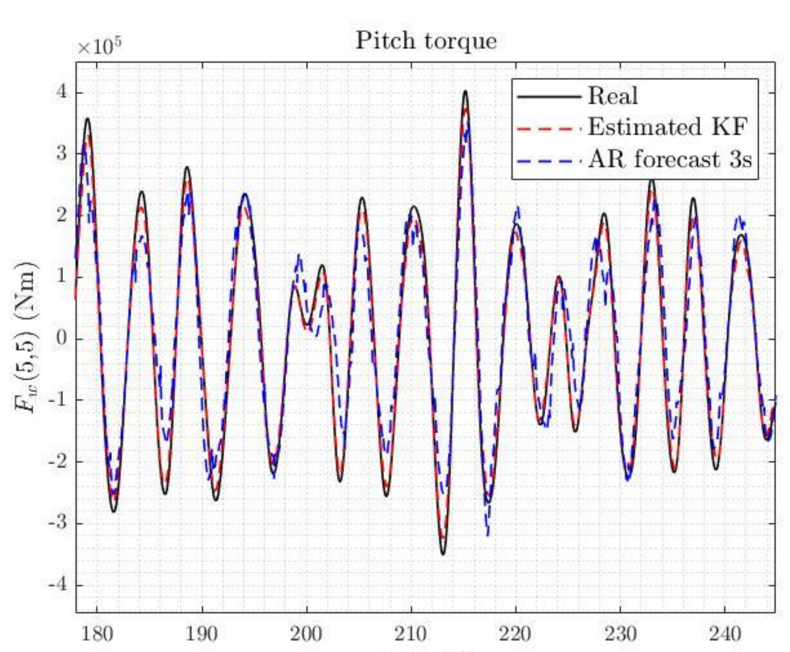


Wave Force prediction

Autoregressive Model

$$F_t = \sum_{i=1}^{p} a_i \cdot F_{t-p} + \varepsilon_t \quad : \; t \; value$$

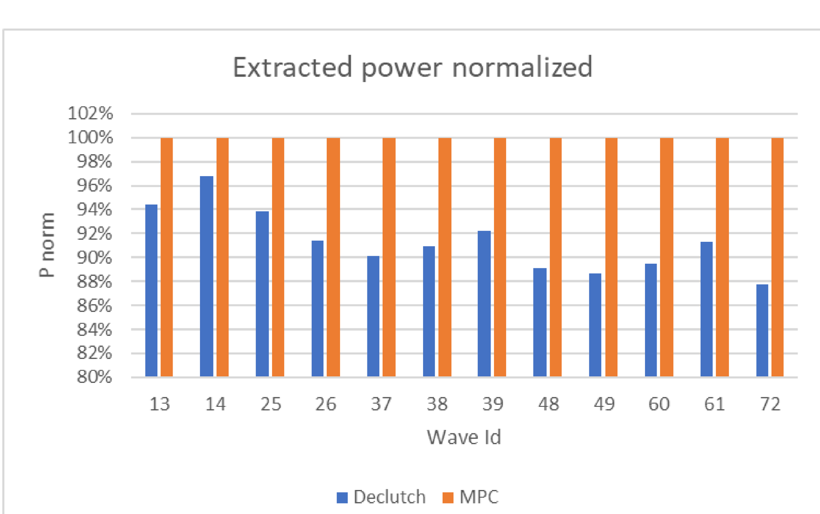
$$F_{t+n} = \sum_{i=1}^{p} a_i \cdot F_{t-p+n} + \varepsilon_t \quad : \; t+n \; values$$

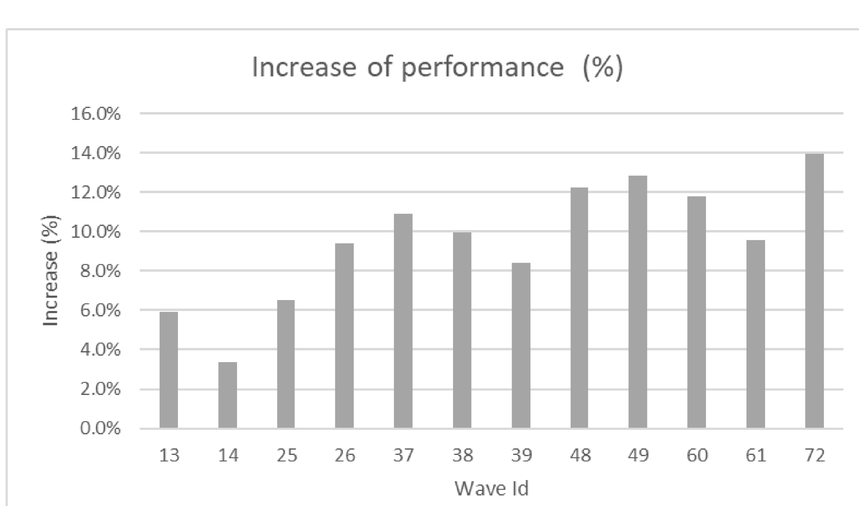


MPC optimization

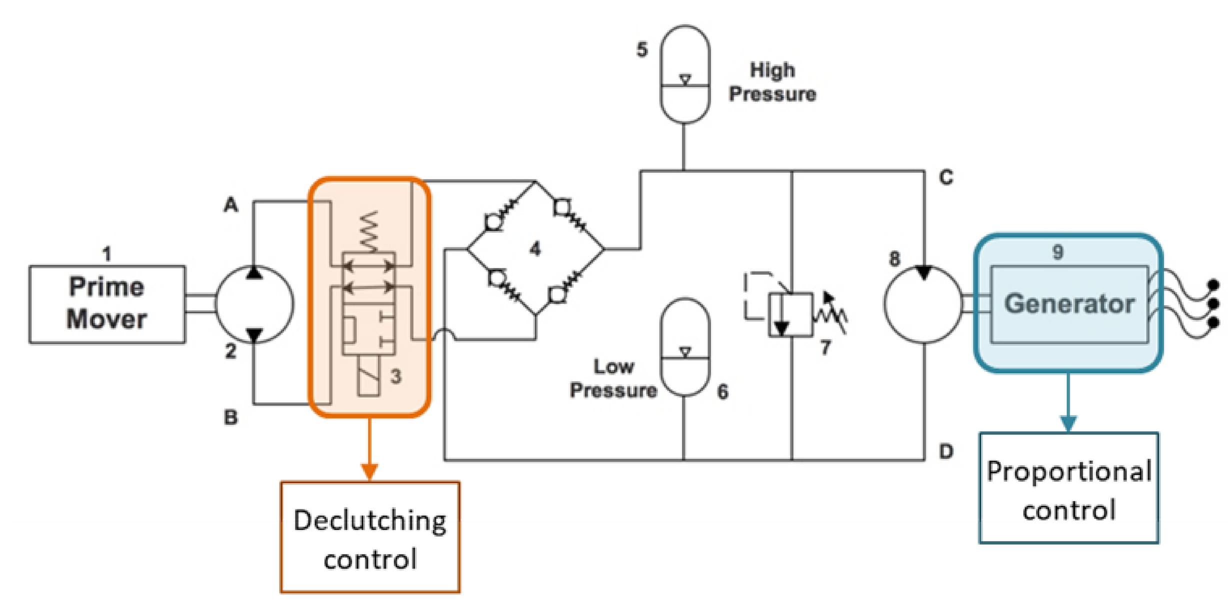
Non convex – constrained optimization

Comparison between a simple declutcing control and MPC





PTO architecture and control framework



- **Dynamic equations:**

$$\dot{X}(t) = f(X(t)) + b(X(t))u(t) + Gv(t)$$
$$y(t) = CX(t)$$

The system is linear in respect of the control u

- **Cost function:**

$$J(X(t), u(t), v(t), t) = -\int_0^{t_f} \langle u(t), y(t)\rangle dt$$

- **Pontryagin's maximum principle:**

$$H(X, u, v, \lambda, t) = \left(y(t) + \lambda^T b(X(t))\right)u(t) + \\ +\lambda^T\left(f(X(t)) + Gv(t)\right)$$

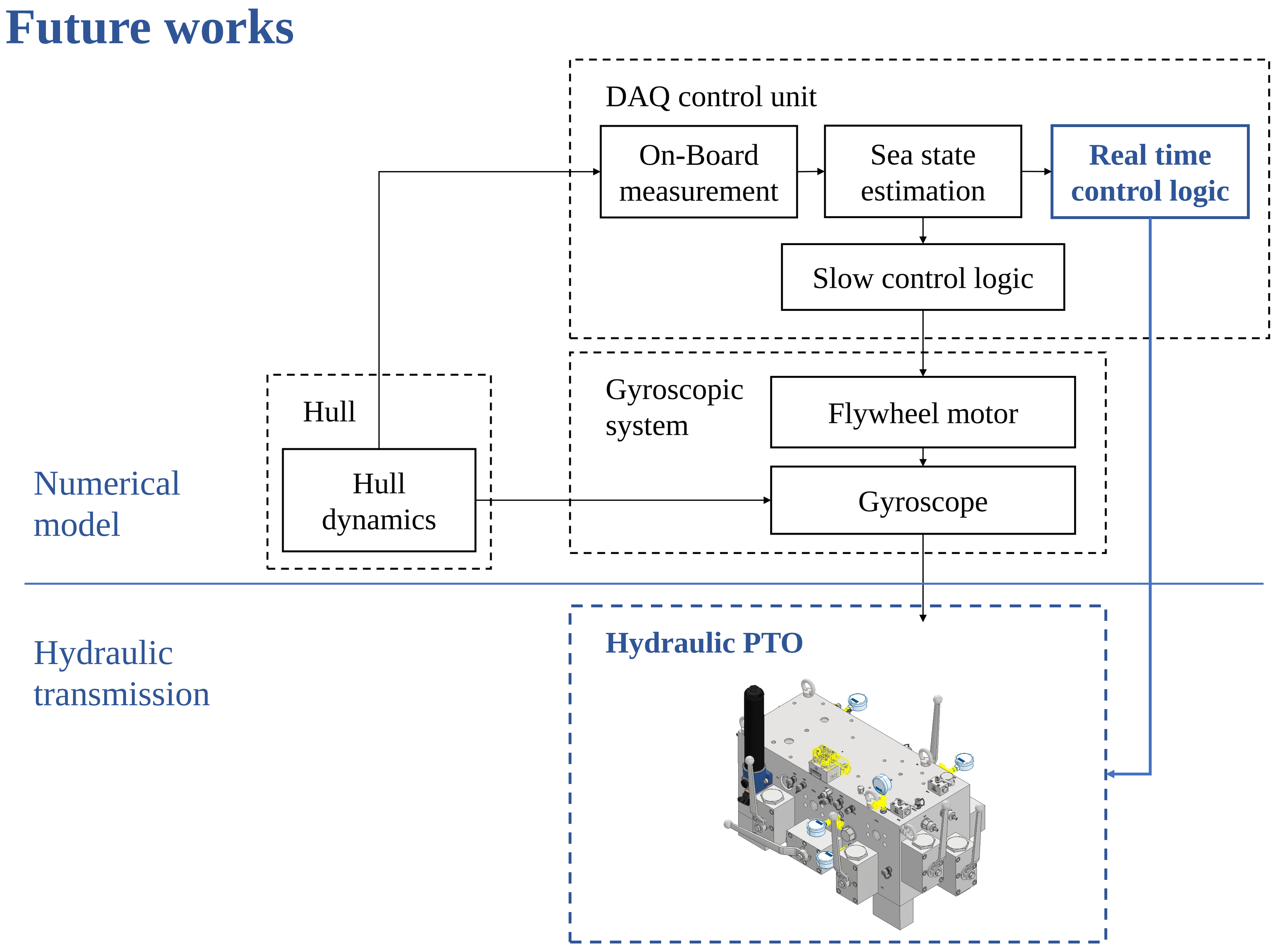
We obtain $\rightarrow$ $H(X, u, v, \lambda, t) = \Phi u + \lambda^T \Theta$

The Hamilatonian is linear in respect of the control u

Optimal control problem

$$H(X, u, v, \lambda, t) = \Phi u + \lambda^T \Theta$$
$$X(0) = X_0$$
$$\lambda(t_f) = 0$$
$$\frac{\partial \lambda}{\partial X} = \dot{\lambda}$$
$$\frac{\partial H}{\partial u} = \Phi$$
$$u = \begin{cases} u_{max} & if \; \Phi < 0 \\ u_{sing} & if \; \Phi = 0 \\ u_{min} & if \; \Phi > 0 \end{cases}$$

Future works



HIL test rig simulations | **Performance assessment** | **Numerical model validation**