Main results: distributed MPC techniques applied to the HD-MPC four tank benchmark

The objective of the benchmark is to test and compare centralized, decentralized, and distributed predictive controllers under similar operation conditions. To this end the following experiment is defined in which the controllers must regulate the levels of tanks 1 and 2 to follow a set of reference changes by manipulating the inlet flows $q_a$and q_b based on the measured levels of the four tanks:

- The first set-points are set to s_1 = 0.65 m and s_2 = 0.65 m. This first reference is aimed to steer the plant to the operation point. Once the plant is in the operation point the test begins maintaining the operation point during 300 seconds.
- In the first step, the reference is changed to s_1 = 0.3 m and s_2 = 0.3 m during 3000 seconds.
- Then, the reference is changed to s_1 = 0.5 m and s_2 = 0.75 m during 3000 seconds.
- Finally, the set-points are changed to s_1 = 0.9 m and s_2 = 0.75 m during 3000 seconds. To perform this change tanks 3 and 4 have to be emptied and filled respectively.

The set-point signals are shown in the figure. The total control test takes 9300 seconds.

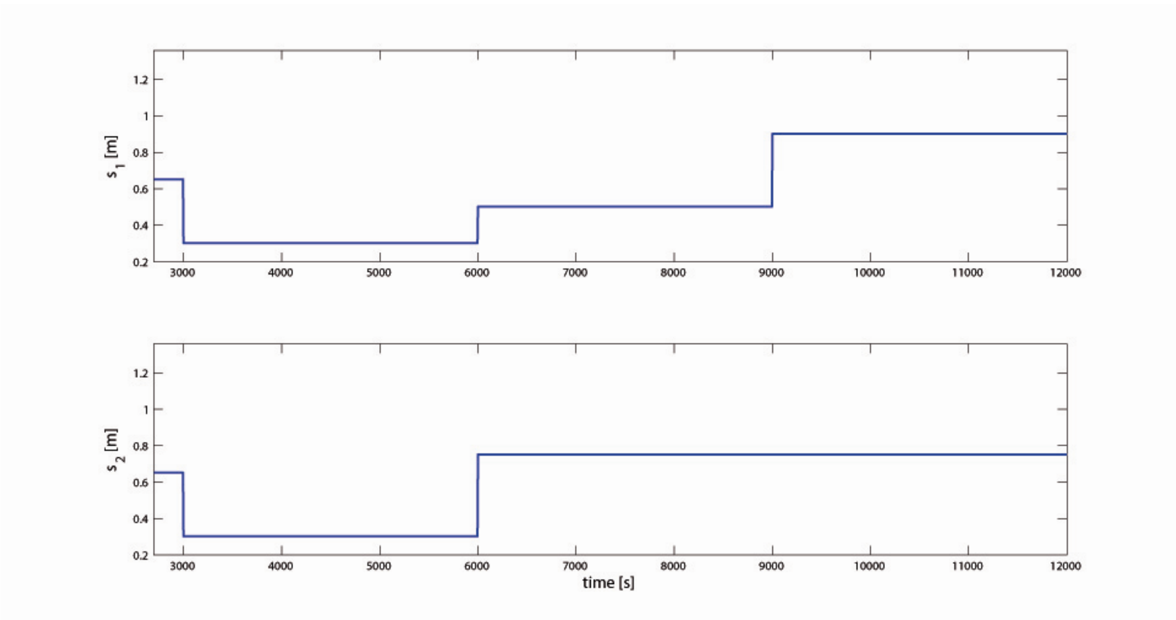

Figure 1. Set-point signals for the benchmark

The objective of the benchmark is to design the distributed MPC controllers to optimize the following performance index:

$$J = \sum_{i=0}^{N_{sim}} \left(h_1(i) - s_1(i)\right)^2 + \left(h_2(i) - s_2(i)\right)^2 + 0.01\left(q_a(i) - q_a^s(i)\right)^2 + 0.01\left(q_b(i) - q_b^s(i)\right)^2$$

where q^s_a and $q^s_b$are the steady manipulable variables of the plant for the set-pointss_1 and s_2 calculated from steady conditions of the proposed model of the plant.The sampling time is 5 seconds, that is, $N_{sim} = 1860$ samples.

Centralized MPC for tracking

A centralized predictive controller based on the linearized prediction model has been tested on the plant. Since the reference is changed throughout the control test, the MPC for tracking proposed in [1] has been chosen.

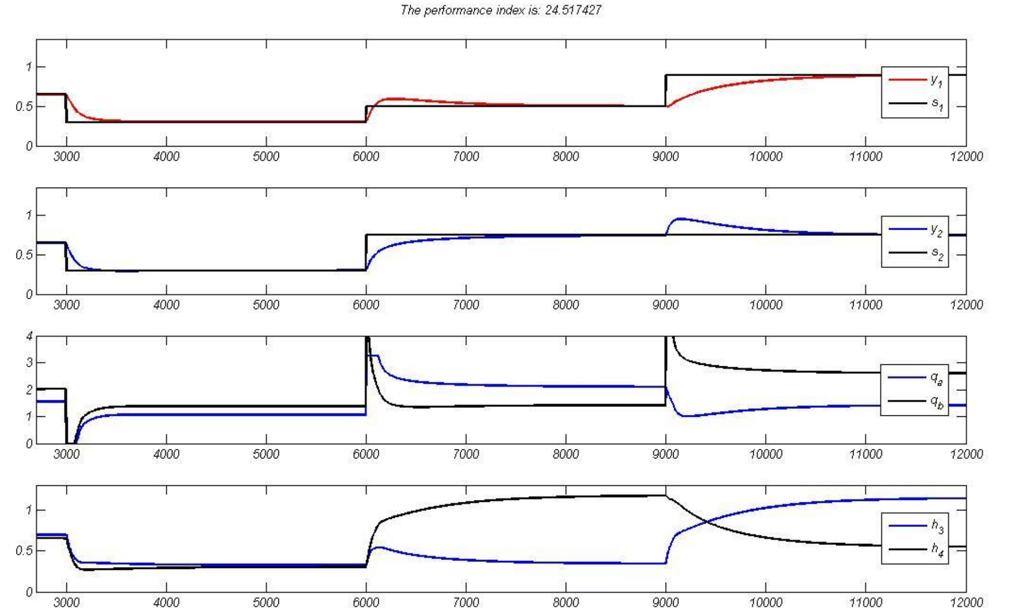

Figure 2. Centralized MPC for tracking. Simulation results

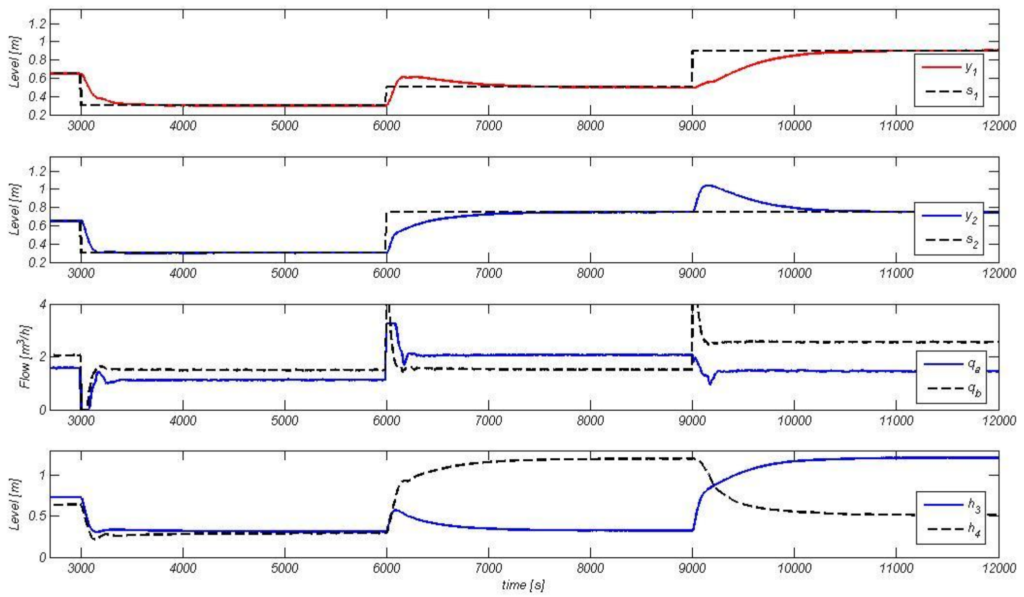

Figure 3. Centralized MPC for tracking. Real results

The performance index for the real experiment is 28.4 and 24.52 for the simulation case.

Centralized MPC for regulation

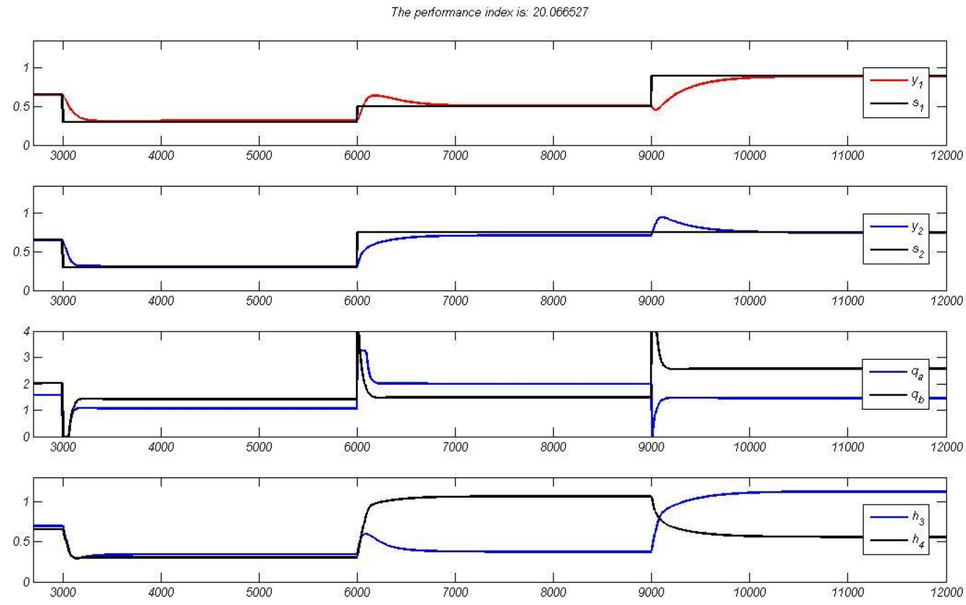

Figure 4. Centralized MPC for regulation. Simulation results

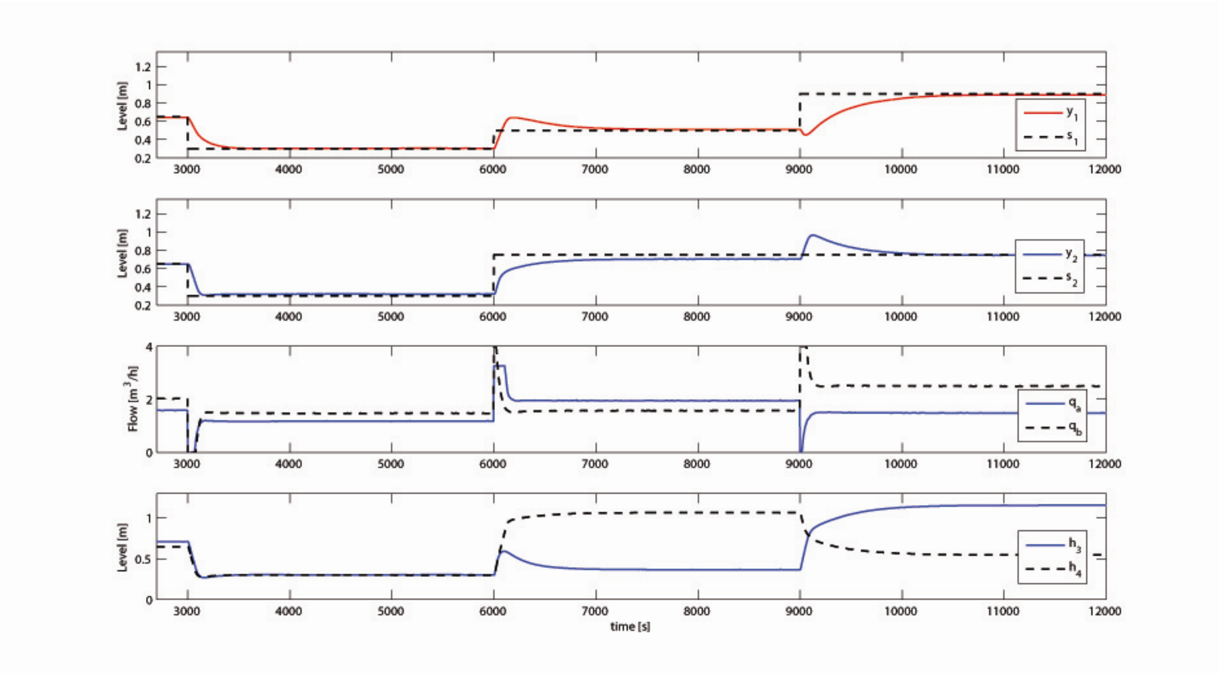

Figure 5. Centralized MPC for regulation. Real results

The performance index for the real experiment is 25.46 and 20.07 for the simulation case.

Decentralized MPC for tracking

The next control technique tested has been a decentralized predictive controller. The considered subsystems have been chosen according to the pairings derived from the relative gain array (RGA) analysis.

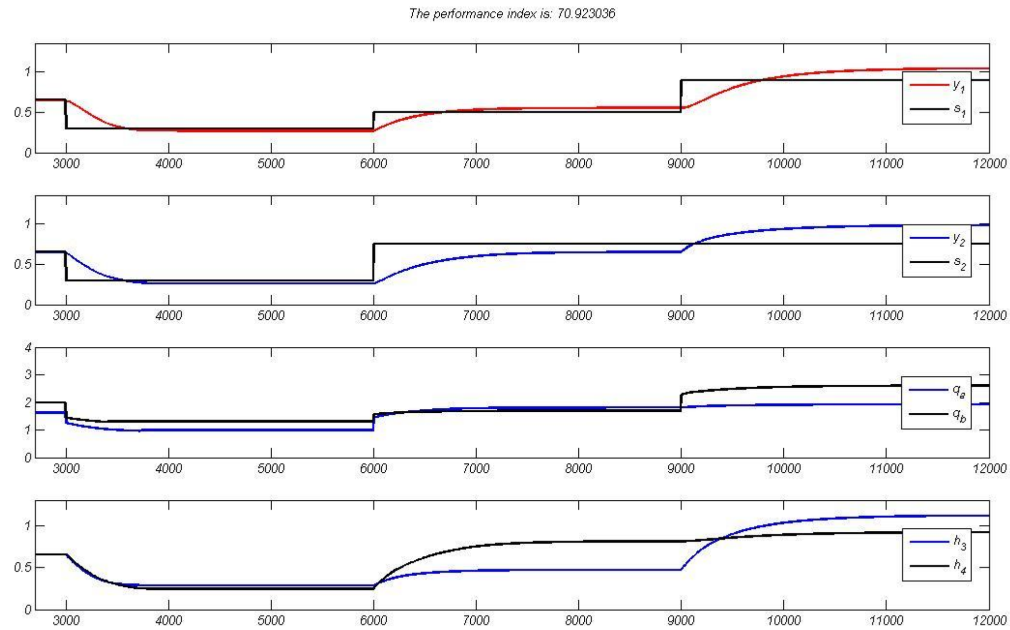

Figure 6. Decentralized MPC for tracking. Simulation results

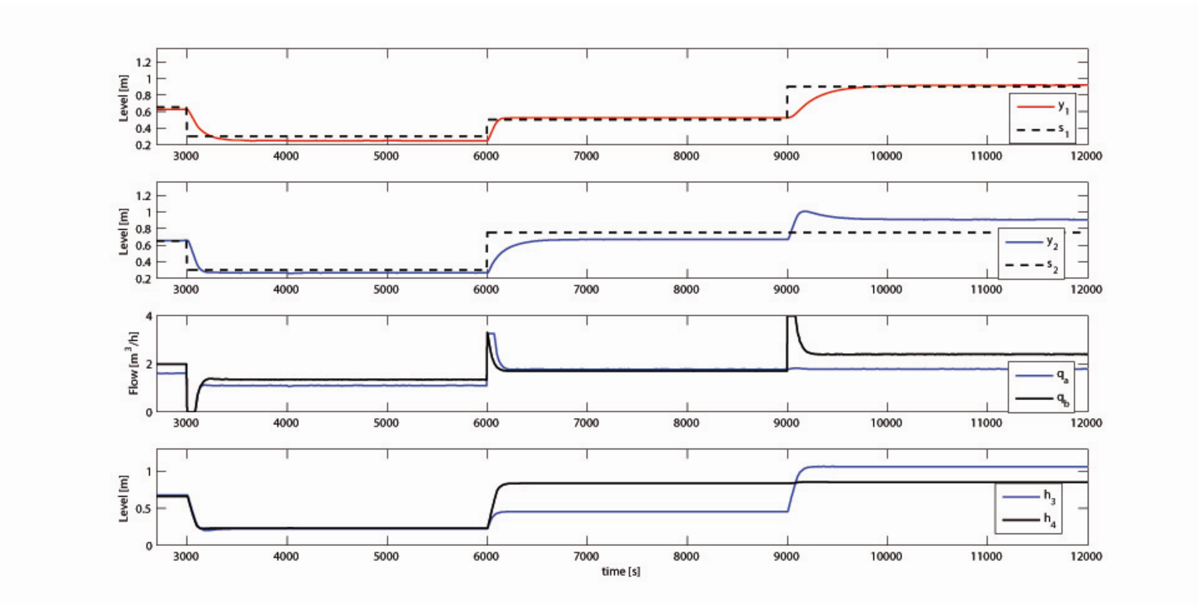

Figure 7. Decentralized MPC for tracking. Real results

The performance index for the real experiment is 39.54 and 70.92 for the simulation case.

Distributed MPC based on a cooperative game

In this section we present the distributed MPC scheme based on a cooperative game scheme presented in [2].

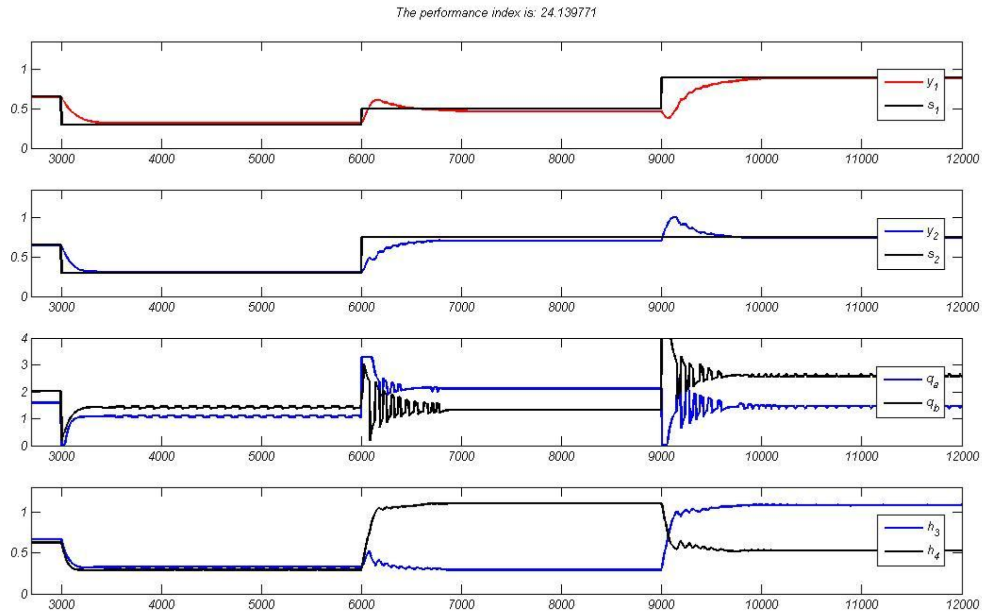

Figure 8. Distributed MPC based on cooperative game. Simulation results

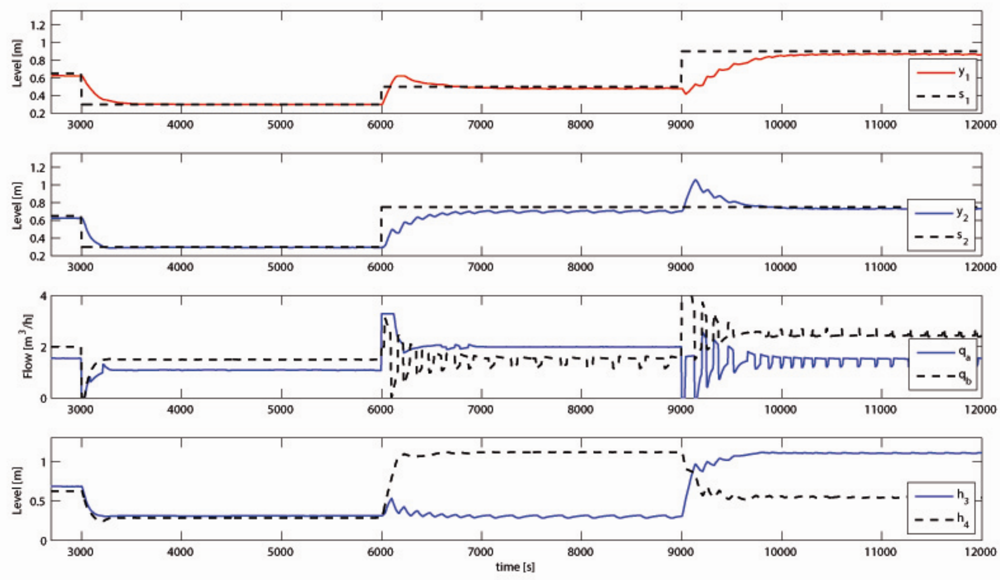

Figure 9. Distributed MPC based on cooperative game. Real results

The performance index for the real experiment is 30.71 and 24.14 for the simulation case.

Sensitivity-Driven Distributed Model Predictive Control

The results of a novel sensitivity-driven distributed model predictive control (SD-DMPC) scheme [3] are considered in this section.

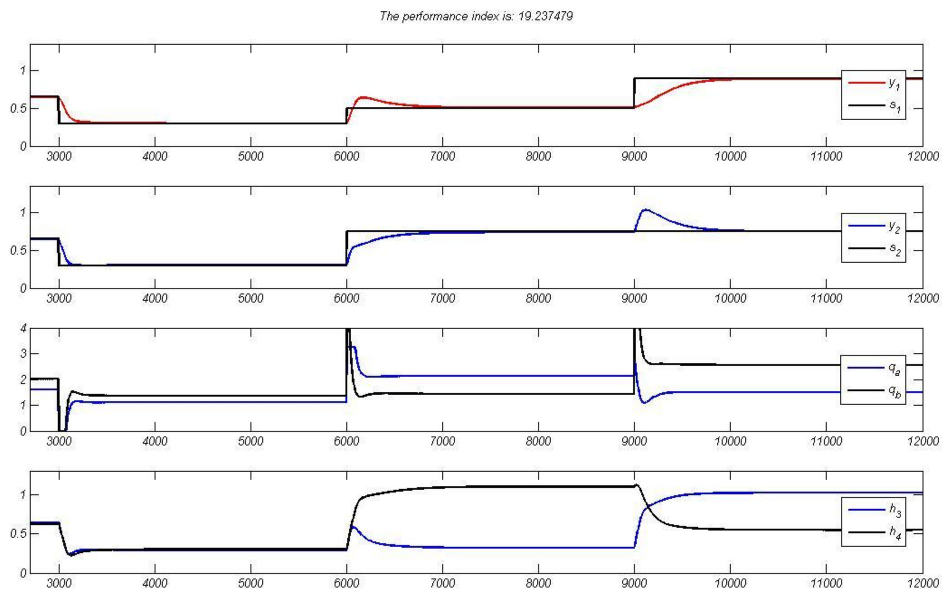

Figure 10. Sensitive-driven DMPC. Simulation results

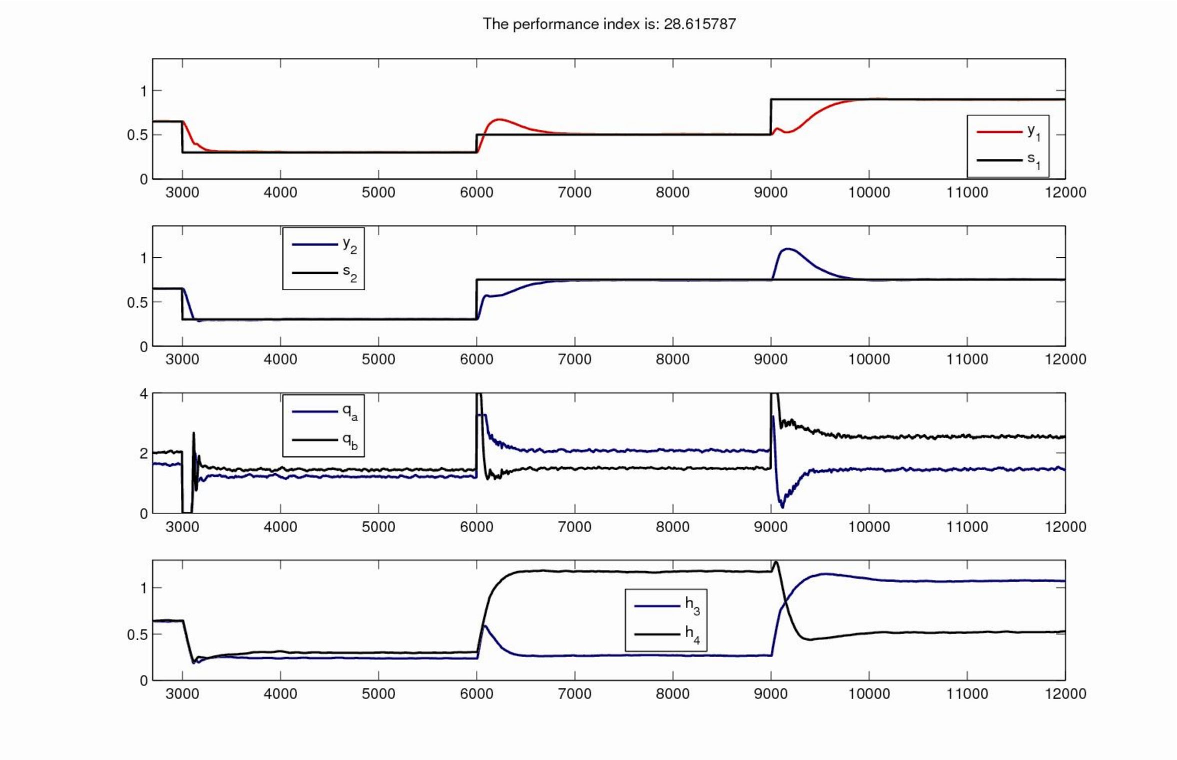

Figure 11. Sensitive-driven DMPC. Real results

The performance index for the real experiment is 28.61 and 19.23 for the simulation case.

Feasible-cooperation distributed model predictive controller based on bargaining game theory concepts

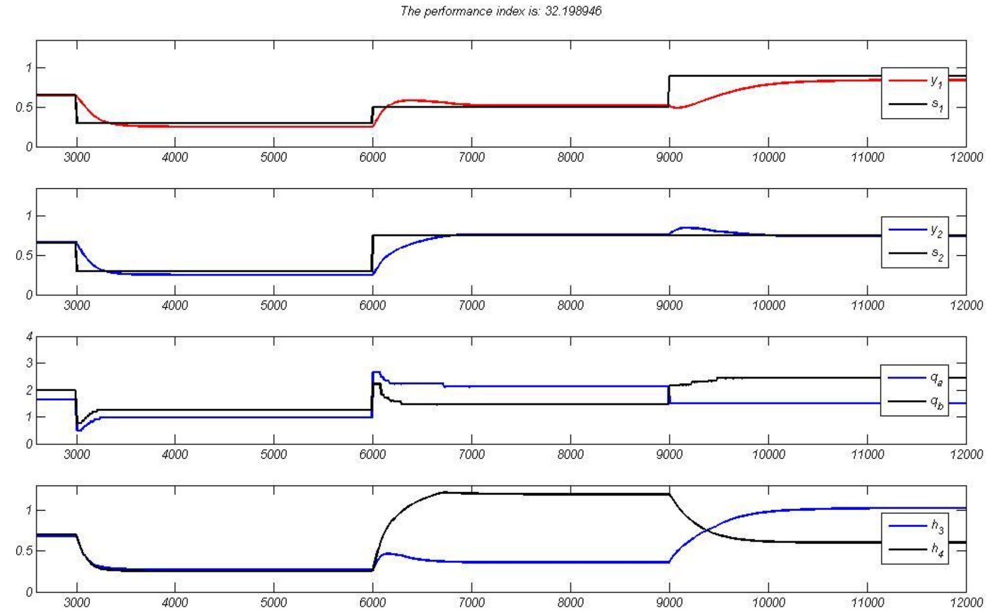

Figure 12. Feasible-cooperation DMPC. Simulation results

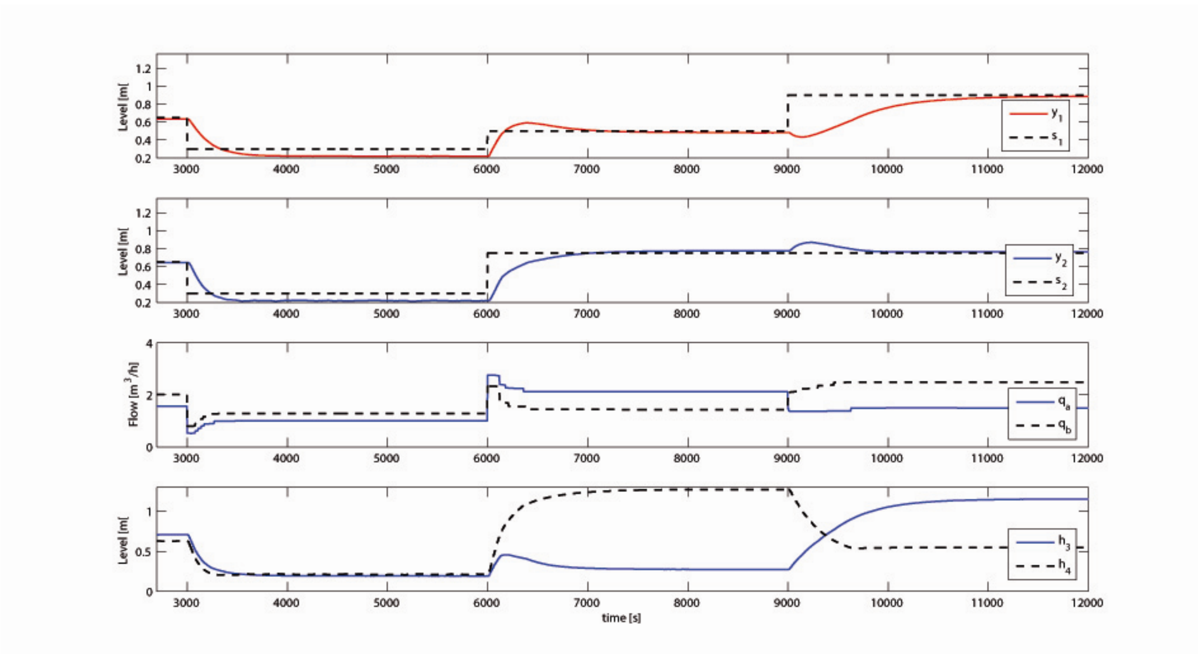

Figure 13. Feasible-cooperation DMPC. Real results

The performance index for the real experiment is 46.32 and 32.19 for the simulation case.

Serial DMPC scheme

We have implemented the scheme proposed in [4, 5] for the four-tank system. This scheme is derived from a serial decomposition of an augmented Lagrangian formulation of the centralized overall MPC problem.

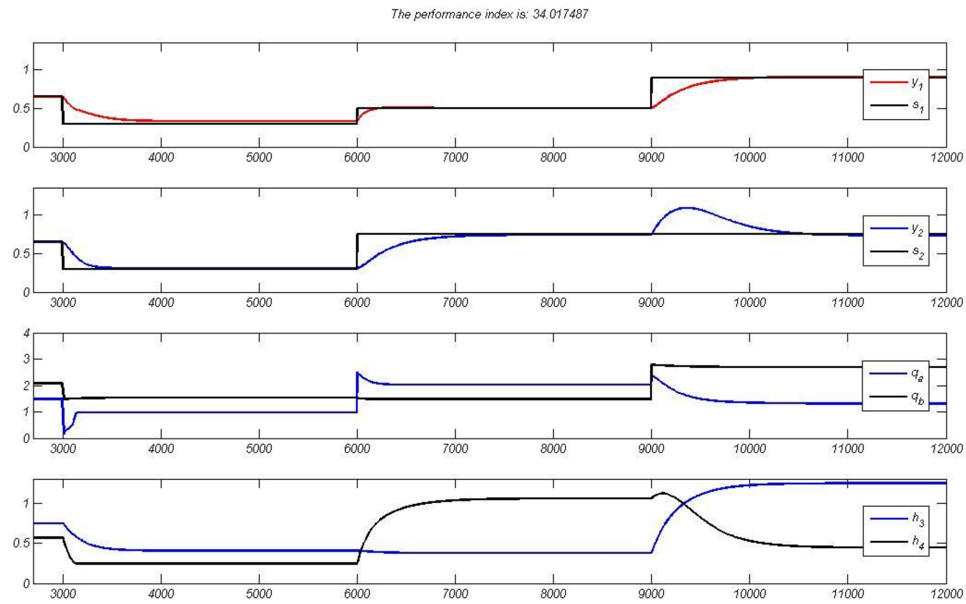

Figure 14. Serial DMPC. Simulation results

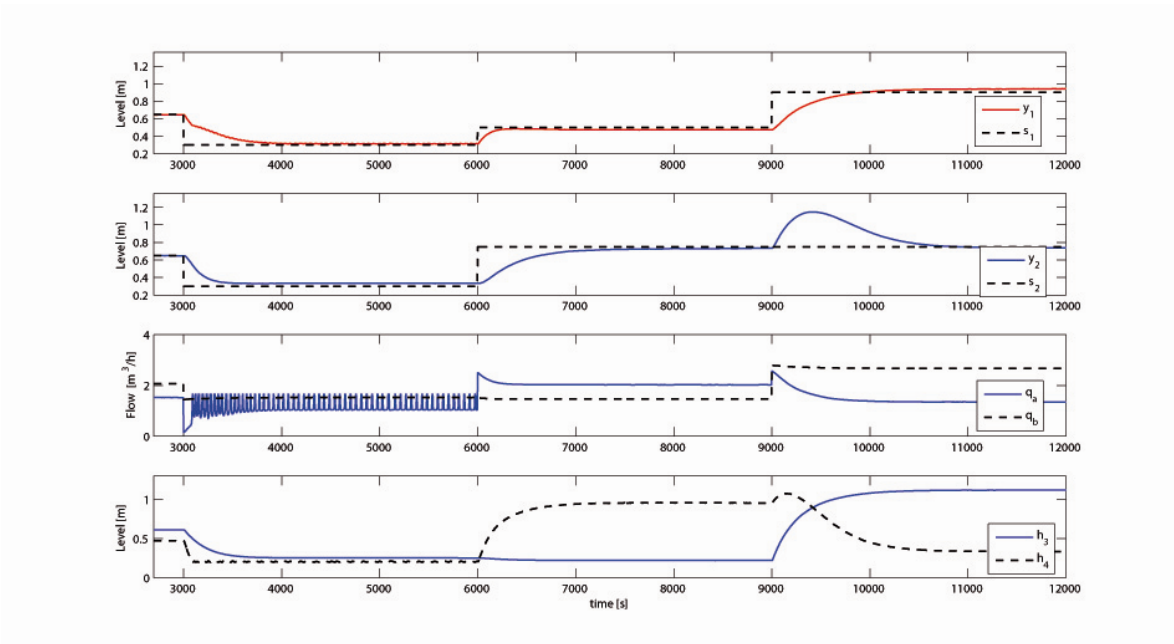

Figure 15. Serial DMPC. Real results

The performance index for the real experiment is 44.59 and 34.01 for the simulation case.

References

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[2] J. M. Maestre, D. Mu˜noz de la Pe˜na, and E. F. Camacho. Distributed model predictive control based on a cooperative game. *Optimal Control Applications and Methods, Accepted for publication*, 2010.

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[4] R. R. Negenborn, B. De Schutter, and J. Hellendoorn. Multi-agent model predictive control for transportation networks: Serial versus parallel schemes. *Engineering Applications of Artificial Intelligence*, 21(3):353–366, 2008.

[5] R. R. Negenborn, P. J. van Overloop, T. Keviczky, and B. De Schutter. Distributed model predictive control for irrigation canals. *Networks and Heterogeneous Media*, 4(2):359–380, 2009.