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Nonlinear inversion-based control of a distributed parameter heating system

László Richárd Tóth*, Lajos Nagy, Ferenc Szeifert

University of Pannonia, Department of Process Engineering, 10 Egyetem street, 8200 Veszprém, Hungary

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ABSTRACT

In this work the control of a pilot-scale water heating equipment was studied. The water flows through a tube, in which it was heated by electric power. The outlet temperature was controlled by the flow rate, compensating heat duty and inlet temperature disturbances. This device shows resemblance to solar collectors and heat exchangers, thus making it a useful tool to carry out controller experiments for similar objects.

The method of constrained inversion was applied. This control strategy is based on the first principle model of the process and feed-forward control. Two different approaches were compared in handling the distributed parameter system. To eliminate steady-state error, a feedback compensation was needed, which was implemented in an IMC structure. Experimental results showed that both controllers were superior to the conventional PI controller. Compensation of dead time, nonlinearity and measured disturbances are the key factors in the success of the model-based controller.

1. Introduction

In this article the control of a pilot-scale water heating equipment was studied. It can be modeled as a DPS, which makes the design of the controller difficult, as most times lumped parameter models are used, and many times linearity is also assumed. In the early attempts in controlling DPSs the greatest task was to reduce the models of the process to a set of ODEs, and if possible, linearization of these equations [1].

Our device shows similarities with solar collectors, whose control is heavily studied. In Camacho et al. [2,3] a thorough review summarizes the achievements in the control of industrial solar collectors. The problem in this field is that measurements are affected by the weather conditions, they are expensive and last long. It would be beneficial to find a golden mean between physical measurements and simulation.

To achieve satisfactory control, the first step is modeling the controlled process. The main problem with solar collectors is that they are DPSs and have nonlinear behavior. Our approach is first principle modeling, but black box models are also common. Examples for handling nonlinear characteristics with neural networks are in Tan et al. [4] and in Aggelogiannaki et al. [5]. The latter one is also an example for using the nonlinear model for predictive control.

Roca et al. [6] applied a filtered Smith-predictor technique for the control of a solar collector field. This technique makes use of dead time compensation, and they use filtering to reduce effects of model mismatch. They also utilize feedback linearization, that could be regarded as the predecessor of our method, the constrained inversion.

Another interesting idea is switching control, where linear controllers are used parallel, and only one is active at a time. Pasamontes et al. [7] provided a framework for switching control, where switches are performed without major disturbances on the process. The method has been tested on a solar collector field successfully.

The water heater also shows resemblance to heat exchangers. In Vasičkaninova et al. [8] a very popular approach, the MPC and neural networks are presented in the simulation study of a co-current tubular heat exchanger. Using a neural network model, the MPC approach outperformed conventional PID controllers both in terms of controller performance indicators and in energy saving. Özkan et al. [9] also used nonlinear model predictive control for a similar object, a jacketed batch reactor.

Our approach is different from the common control studies in the sense that we use first principle models for control. Although neural networks and other nonlinear techniques are getting much attention, first principle models can be simpler and more adequate

Abbreviations: CV, controlled variable; DPS, distributed parameter system; IMC, internal model control; MPC, model predictive control; MV, manipulated variable; ODE, ordinary differential equation; OPC, OLE for process control; OLE, object linking and embedding; PDE, partial differential equation; PWM, pulse width modulation; SP, setpoint.

* Corresponding author. Tel.: +36 88 624295.
E-mail address: tothl@fmt.uni-pannon.hu (L.R. Tóth).

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