IDENTIFICATION FOR CONTROL

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Contents

Summary

Control systems are generally designed on the basis of a quantitative model of the dynamical system or plant to be controlled. When identifying dynamical models for this particular purpose on the basis of experimental data, care has to be taken that the model is particularly accurate in those aspects that are most relevant for the model application (See *Model-Based Control Design*).

In order to design control systems with manageable complexity, many advanced control design algorithms require models of limited order. This stresses the necessity of identifying reduced order models that are control-relevant. For the identification of such models, closed-loop experiments have particular advantages.

Additionally, the interplay between modeling and control has led to a wide variety of iterative modeling and control approaches; in which control-relevant identification is interleaved with control analysis and design, aiming at the gradual improvement of controller performance.

1. Introduction

1.1 Relation between modeling and control

When designing a feedback control system for a dynamical process, model information on the dynamical process generally plays a crucial role. The control system is basically designed and analyzed on the basis of a model of the process at hand. Dependent on the particular design procedure, different types of model information are required. Controller tuning methods as: e.g. PID, and frequency domain loop shaping methods are often based on non-parametric (graphical) representations as e.g. step responses, frequency responses, disturbance spectra, etc. However more advanced design strategies, which typically also apply to systems having multiple input and multiple output signals, require a full parametric dynamic model of the underlying process, together with a model of the disturbances acting on the measurement signals.

In the identification problem, as schematically depicted in Figure 1, measurement data of particular experiments are used to identify a dynamical model. In the control design stage, this model information is used to design a feedback control system, as schematically depicted in Figure 2, aiming at typical control performance properties as stability, disturbance rejection, tracking of particular reference inputs, etc.

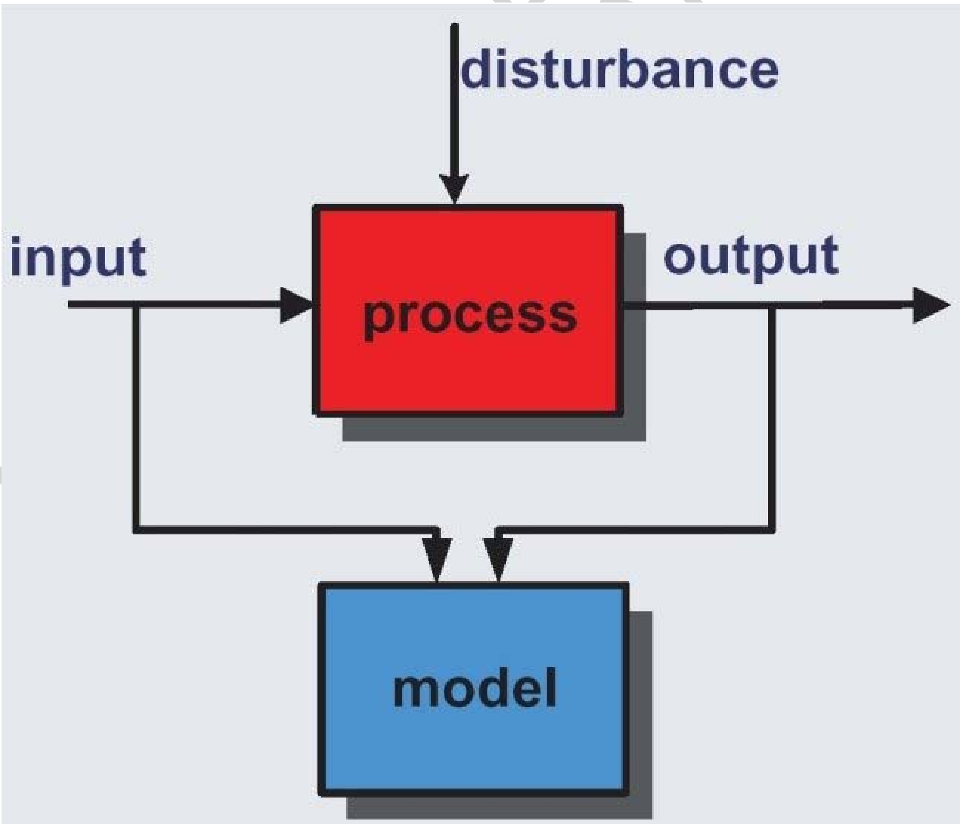

Figure 1: Identification on the basis of input-output data.

When considering the question, which identified model would be best suited to serve as a basis for subsequent control design, there is one obvious answer. If the model exactly represents the process under consideration, including the disturbances acting on the process, then this model process will be optimal for all model applications, including model-based control design. This principle of certainty equivalence that requires that an exact model be constructed and then used for control design, is hard to justify when the model has to be identified from measurement data. In this latter situation, the identified model will contain uncertainties due to e.g.

- disturbances acting on the measurement data
- finite observation times
- limited excitation of input signals
- the approximate character of the class of models used

Practically, it is often impossible to exactly characterize all phenomena that describe the dynamical behavior of the process. Therefore, models will necessarily be approximate. Additionally, many control design methods provide controllers whose order is essentially determined by the order of the underlying process model. In this way, a high-order process model will also lead to a high order controller, which may be infeasible from an implementation point of view. Therefore, low order-approximate-models are needed for the control design. On the other hand, many complex industrial processes are controlled satisfactorily by low order (PID) controllers. This suggests that limited order models should suffice when serving as a basis for control design. When identifying these models from data, dedicated experiments and well-chosen identification methods are required for control-relevant modeling.

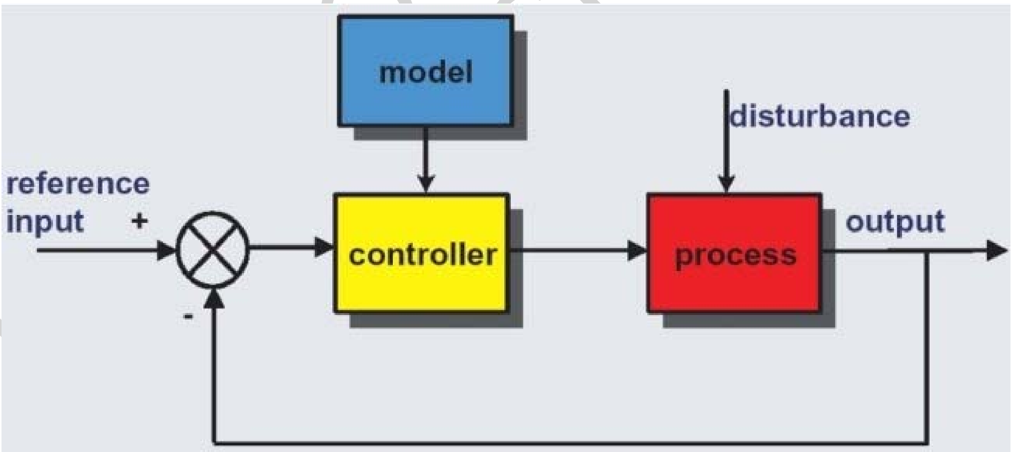

Figure 2: Feedback control system

1.3. When is a model good for feedback control?

Models that accurately describe the open-loop frequency response of the process are not necessarily good for control, and models that seem bad from an open-loop frequency response point of view, can be good as a basis for control design. As a brief illustration of this, we consider the following example.

In Figure 3, the frequency response of a dynamical process is given in black, together with two candidate models (red and blue curves). The blue model is very accurate in the lower frequency range ($\omega < 0.2\ rad/s$), but shows moderate deficiencies in the higher frequencies. The red model has a very poor low-frequent behavior, but is accurate in the frequency range $0.2\ rad/s \leq \omega \leq 1\ rad/s$. The poor open-loop quality of the red model is also clearly visible in Figure 4 (left) where the open-loop step response of the process and the two candidate models is shown.

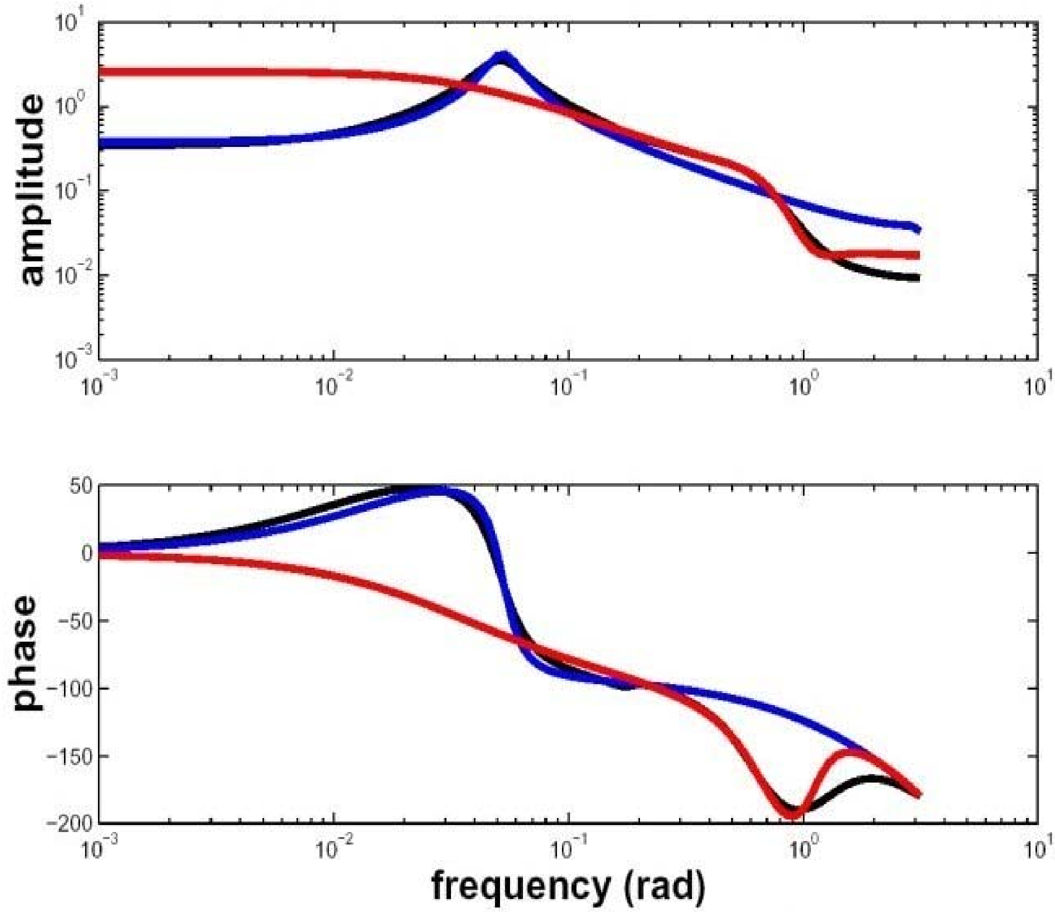

Figure 3: Frequency response of dynamical process (black) and two candidate models (red and blue).

When evaluating the properties of process and models in a closed-loop configuration, determined by a feedback controller achieving a closed-loop bandwidth of 0.7 rad/s, the red model appears to exhibit a closed-loop step response that is very similar to the response of the process, whereas the blue model deviates considerably from this. The closed-loop step responses are depicted in Figure 4 (right).

As a general rule-of-thumb it can be stated that for model-based control design, the process model should be particularly accurate around the bandwidth of the closed-loop system. However, the required accuracy at other frequencies can not be specified on beforehand.

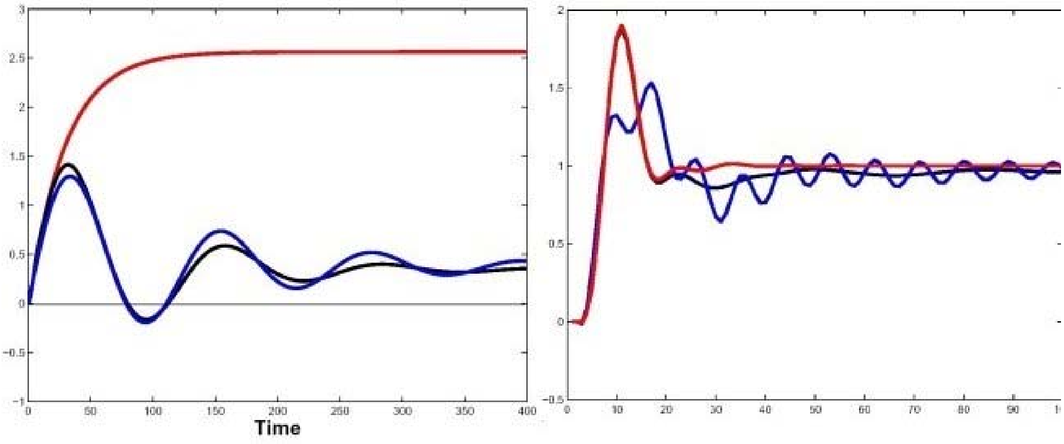

Figure 4: Open loop step response (left) and closed-loop step response (right) of the dynamical process (black) and of two candidate models (red and blue).

A simple experiment that will reveal plant information in the important frequency region is given by a relay feedback experiment, as depicted in Figure 5. A nonlinear feedback switch will cause the output of the closed-loop system to oscillate when the reference signal is held constant.

The frequency and amplitude of the oscillating signal carries the necessary information on the plants amplitude and frequency at which its phase shift is –180 degrees, being the crossing of the Nyquist curve of the plant with the negative real axis. For many industrial plants, this provides knowledge on the maximum controller gain that can be allowed while guaranteeing stability of the closed-loop system.

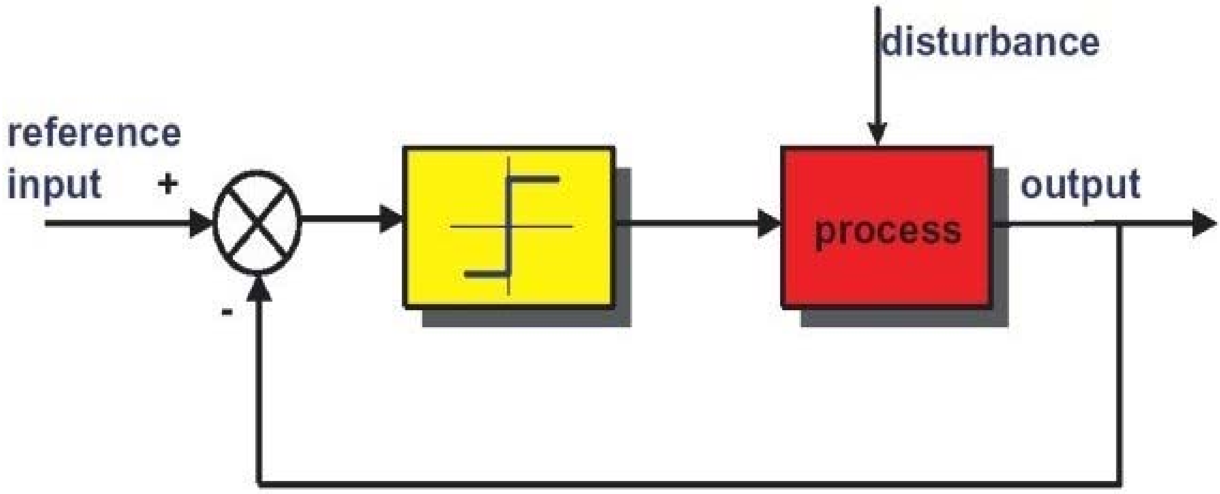

Figure 5: Relay feedback system

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Biographical Sketches

Paul M. J. Van den Hof was born in 1957 in Maastricht, The Netherlands. He received his M.S. and Ph.D. degrees from the Department of Electrical Engineering, Eindhoven University of Technology, The Netherlands in 1982 and 1989, respectively. From 1986 to 1999 he was an assistant and associate professor in the Mechanical Engineering Systems and Control Group of Delft University of Technology, The Netherlands. Since 1999, he has been a full time professor in the Signals, Systems, and Control Group of the Department of Applied Physics at Delft University of Technology. Currently he is Co-Director of the Delft Center for Systems and Control. He is acting as IPC/NOC chairman of the 13th IFAC Symposium on System Identification, Rotterdam, The Netherlands in 2003. His research interests include, system identification, parametrization, signal processing and robust control design, with applications in servomechanical systems, physical measurement systems, and industrial process control systems. He is a member of the IFAC Council, a Senior Member of IEEE, and Automatica Editor for Rapid Publications.

Raymond de Callafon was born in 1968 in Rotterdam, The Netherlands. He received his M.Sc. and Ph.D. degrees in Mechanical Engineering from Delft University of Technology, the Netherlands in 1992 and 1998, respectively. Since 1997 he has been employed at the Department of Mechanical and Aerospace Engineering of the University of California at San Diego. He was first employed as a research assistant, and then, in 1998, joined the faculty as an assistant professor in the Dynamic Systems and Control Group. His current research interests lie in the theory of modeling using system identification techniques and the interaction between modeling and control. He is interested in modeling and control applications that involve mechanical, servo and structural systems.