Chapter 1
Introduction

Generally in control systems and particularly in process control applications the *feedback control* scheme or *closed-loop control system* depicted in Fig. 1.1 is the control structure that solves most of the control problems faced.

For a given process P' there is a characteristic or variable that needs to be "controlled." The information about this controlled variable is obtained with a measurement instrument, the sensor/transmitter T. The transmitter output signal Y is sent to the controller C that also receives the desired value or set-point R for the controlled variable. The controller control algorithm processes these two inputs and the computed control effort or controller output U is sent to the actuator or final control element A in order to modify a process internal quantity, a manipulated variable, or to affect the variable of interest. The disturbances D are all other process variables that affect the controlled variable in an undesired fashion.

From the *controller* point of view the actuator/process/transmitter group represents the *controlled process* P. The controller and the controlled process share information through the control effort (U) and the controlled variable (Y) signals. Then, for an external viewer the feedback control system has two inputs: the *set-poin*t (R) and the *disturbances* (D), and one output, the *controlled variable* (Y) as depicted in Fig. 1.2.

The controller is designed to *restrict* the controlled variable response to a change in the input signals according to the design specifications. As there are two input signals of very different kind and entering at different points of the control system, the problem of dealing with each one of them (either the disturbance D that should be attenuated or the reference R that must be tracked) is not trivial. The control design problem is then to adjust ("tune") the parameters of the selected controller control algorithm in order to achieve the desired controlled variable performance.

A natural way to adjust or correct the behavior over time of a controlled process output, the controlled variable, is by using an actuating input computed on the basis of the comparison of the process actual output and the measured controlled variable with its desired or set-point value; this is based in the closed-loop system feedback error. To compute the control action information about the feedback error evolution is required. Normally its current value, its past evolution, and a prediction of its future

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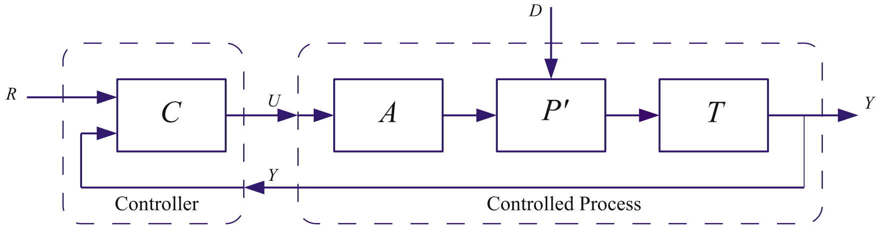

Fig. 1.1 General feedback control system structure

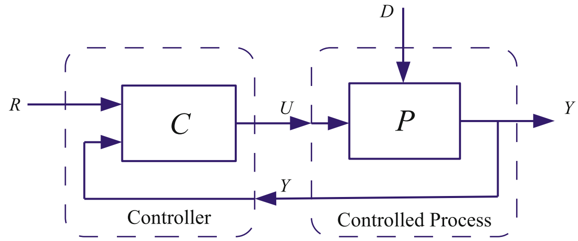

Fig. 1.2 Simple feedback control system

behavior are used. The way we use this information to deliver the control action constitutes the controller control algorithm.

The feedback control structure has been used for a long time, but if we restrict ourselves to the industrial process control area, the proportional (present error information), the integral (past error accumulated) and the derivative (future error prediction) or the PID control algorithm age starts in 1940 with the introduction of the Taylor Fullscope 100 pneumatic PID controller [1]. It was the first controller with knobs and calibrated dials for all three responses [2]. The original simple three-term PID control algorithm has evolved to the actual four- or five-term two-degree-of-freedom (2DoF) PID implementations [3].

To guarantee a stable and successful operation of the control system the controller must be matched with the controlled process, using information of the dynamic characteristics of the process usually represented by a low-order linear *model*. This matching essentially captures the process information and translates into a suitable selection for the controller parameters either by application of a direct tuning procedure (usually based on optimization or analytical derivations) or by means of a tuning rule. Tuning rules have the advantage of ease of calculation of the controller parameters (when compared to more analytical controller design methods), on the one hand; on the other hand, the use of tuning rules is a good alternative to trial and error tuning.

At the beginning, controller tuning took into consideration only the control system *performance* [4, 5], the output signal dynamic characteristics, to step changes in its inputs. Most of the developed research works that have emerged over the years, take the form of design proposals based on simple models and generally give rise to tuning rules that link the parameters of the process model, with the controller ones in a direct and simple way. The need for such simple and model-based tuning rules is also encouraged from several control engineering books; some of them specific on PID control. A common point that can be found in all of them is the need to incorporate a good understanding of the control problem and its relationship with modeling and knowledge of the process to be controlled. It was noticed that if only the performance is considered in the design it leads to control systems with very low robustness [6], this is to say low capability to deal with changes in the controlled process dynamic characteristics. Then, *robustness* was introduced into the controller design [7]. The performance/robustness trade-off in PID control system design is a well-known issue [8]. Even in case that this trade-off be resolved at the design stage [9–12], it is important to evaluate the controller *fragility*: the effect of a change in the controller parameters, at its final fine-tuning [13].

In most of the industrial process control applications, the desired value of the controlled variable, or set-point, normally remains constant and a good load disturbance rejection is required [14], which is usually known as regulatory control. However, due to variations in the process operating conditions, the controlled variable set-point may eventually need to be changed and then a good transient response to such change is required, which is known as servo-control operation. Satisfying these two operating conditions simultaneously is not possible by using a one-degree-of-freedom (1DoF) PI/PID controller, but using a two-degree-of-freedom (2DoF) PI/PID allows tuning of the controller in order to do so. The extra parameter it provides is used to improve its servo-control behavior while considering the regulatory control performance and the closed-loop control system robustness. This second degree of freedom; introduced by Araki [15–17]; is aimed at providing additional flexibility to control system design with PI/PID controllers [18, 19].

On the other hand, we have a variety of controlled processes dynamics, from the most common self-regulating overdamped to integrating and unstable processes.

Nowadays, the proportional integral and proportional integral derivative are the most used control algorithms in industry. Although, it is reported elsewhere that there are many loops with very poor performance, badly tuned or not tuned at all. Considering the huge number of PI and PID controllers in service at present in the process industry any improvement in their performance will produce a big overall revenue. Since the introduction of the seminal tuning rules of Ziegler and Nichols [20] a great number of tuning rules have been developed as revealed in [21]. Most of them take into account only one design criteria (performance, robustness) and are oriented to a specific controlled process model structure (overdamped, integrated, or other).

A different path is followed here. A general design procedure for 2DoF PI and PID controllers is proposed based on the specification of the corresponding control system closed-loop transfer functions that include parameters that affect the *performance/robustness trade-off*. The control system robustness requirement is controlled process dependent, and more importantly it cannot be avoided the robustness level, measured with the maximum sensitivity, is used as the design target. Besides this, the design methodology is the same for all considered processes and controllers. The specification of the closed-loop transfer functions also takes into account obtaining smooth *control effort*, controller output, signals.

One of the objectives of the work has been to develop a design methodology for robust control systems independent of the controller, PI or PID, and on the controlled process avoiding appealing to ad hoc design procedures for each particular case (controller/process combination). The controlled process model specific characteristics are incorporated only into the closed-loop target response specifications. The proposed controller design methodology denoted as *Model-Reference Robust Tuning* (MoReRT) is applied to tune 2DoF PI and PID controllers for first- and second-order overdamped, integrating, inverse response, and unstable controlled processes, being the accomplishment of the robustness target level for all the controlled process models considered (overdamped, integrated, and unstable) one of the distinctive characteristics of the proposed design method.

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