Fundamentals of Control Theory

This chapter is dedicated to the reader with no prior knowledge in control theory. On the one hand, we will explain the fundamentals of control theory, which are necessary to understand a fuzzy controller or any advanced problems related to them. On the other hand, we will present an overview of the possibilities that classical control theory offers in order to enable the reader, when confronted with real applications, to judge whether to solve the problem using a fuzzy controller or a classical controller. A complete introduction to the fundamentals of control theory, however, will not be given, as the chapter would then exceed the proportions of the book. More thorough introductions can be found in the basic literature of classical control theory.

2.1 Basic Concepts

Control theory is concerned with influencing systems in order to achieve that certain output quantities take a desired course. These can be technical systems, like the heating of a room with the output quantity temperature, a ship with the output quantities course and speed, or a power plant with the output quantity electrical power. The systems could as well be social, chemical or biological, as, for instance, the system of a national economy with the output quantity rate of inflation. The nature of the system does not matter. Only its dynamic behavior is of importance to the control engineer. We can describe this behavior by differential equations, difference equations or other functional equations. In classical control theory, which is mostly concerned with technical systems, the system that will be influenced is called the (controlled) plant.

In what kinds of ways can we influence the system? Every plant consists not only of output quantities, but as well of input quantities. For the heating of a room, these will, for example, be the position of the valve, for the ship the power of the engine and the angle of the rudder. These input variables have to be adjusted in a way that the output variables take the desired course, and they are called actuating variables. In addition to the actuating variables, the
disturbance variables affects the plant, too. For example, a heating system, where temperature will be influenced by the number of people in the room or an open window, or a ship, whose course will be affected by water currents.

The desired course of the output variables is defined by the reference variables. They can be defined by humans, but they can also be defined by another system. For example, the autopilot of an aeroplane computes the reference values for the altitude, course, and speed of the plane. But we do not want to discuss the generation of the reference variables here. In the following, we take them for granted. We just have to take into account, that reference variables do not necessarily have to be constant, they can also be time-varying.

What information do we need to calculate the actuating variables to make the output variables of the system follow the reference variables? Obviously the reference values for the output quantities, the behavior of the plant and the time-dependent behavior of the disturbance variables have to be known. With this information, we can theoretically compute the values for the actuating variables, which then will influence the system in a way that the output quantities will take the desired course. This is the principle of a steering mechanism (Fig. 2.1). The input variable of the steering mechanism is the reference variable $w$, its output quantity the actuating variable $u$, which again - together with the disturbance variable $d$ - forms the input value of the plant. $y$ stands for the output value of the system.

The disadvantage of this method is obvious. If the behavior of the plant is not in accordance with the assumptions that we made about it, or if unforeseen disturbances occur, then the output quantities will not continue to take the desired course. A steering mechanism cannot react to this deviation, as it does not know about the output quantities of the plant.

One improvement that can immediately be made is the principle of an (automatic) control (Fig. 2.2). Inside the automatic control, the reference variable $w$ is compared to the measured output variable of the plant $y$ (control variable), and a suitable output quantity $u$ of the controller (actuating variable) is computed inside the control unit from the difference $\Delta y$ (control error). In former times the control unit itself was called controller, but modern controllers, including, among others, the fuzzy controllers, show a structure where the calculation of the difference between actual and desired output value and the computations of the control algorithm cannot be distinguished in the way