

# Chapter 2

## Theory and Background

In this chapter we present some basic concepts about the work in order to understand the idea and the context of this book better.

### 2.1 Fuzzy Inference System

Fuzzy logic in contrast to Boolean logic is similar to real life, because fuzzy logic concepts defined in varying degrees of membership follow reasoning patterns similar to those of human thought.

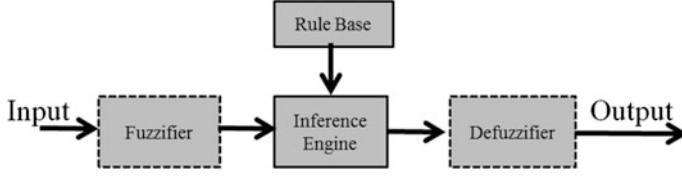
Fuzzy logic has acquired a great reputation for a variety of applications ranging from the control of complex industrial processes to the design of electronic control devices for home use and entertainment, as well as in diagnostic systems [1]. Fuzzy logic is essentially a many-valued logic and an extension of classical logic. The latter sets only impose their values true or false, however, much of human reasoning is not as deterministic [2].

#### 2.1.1 Type-1 Fuzzy Logic Systems

A Type-1 fuzzy set in the universe  $X$  is characterized by a membership function  $\mu_A(x)$  taking values on the interval  $[0,1]$  and can be represented as a set of ordered pairs of an element and the membership degree of an element to the set and is defined by Eq. (2.1) [3–6]:

$$A = \{(x, \mu_A(x)) | x \in X\} \quad (2.1)$$

where  $\mu_A : X \rightarrow [0, 1]$ .



**Fig. 2.1** Type-1 fuzzy logic system

In this definition  $\mu_A(x)$  represents the membership degree of the element  $x \in X$  to the set  $A$ . In this book we use the following notation:  $A(x) = \mu_A(x)$  for all  $x \in X$ . Figure 2.1 shows a Type-1 fuzzy logic system.

### 2.1.2 Interval Type-2 Fuzzy Logic Systems

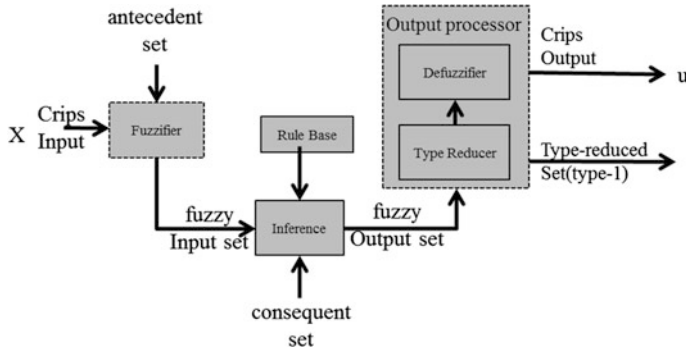
Based on Zadeh's ideas, Mendel et al. presented the mathematical definition of a Type-2 fuzzy set, as follows [7, 8].

An Interval Type-2 fuzzy set  $\tilde{A}$ , denoted by  $\underline{\mu}_{\tilde{A}}(x)$  and  $\tilde{\mu}_{\tilde{A}}(x)$  is represented by the lower and upper membership functions of  $\mu_{\tilde{A}}(x)$ , where  $x \in X$ . In this case, Eq. (2.2) shows the definition of an IT2FS [9–14].

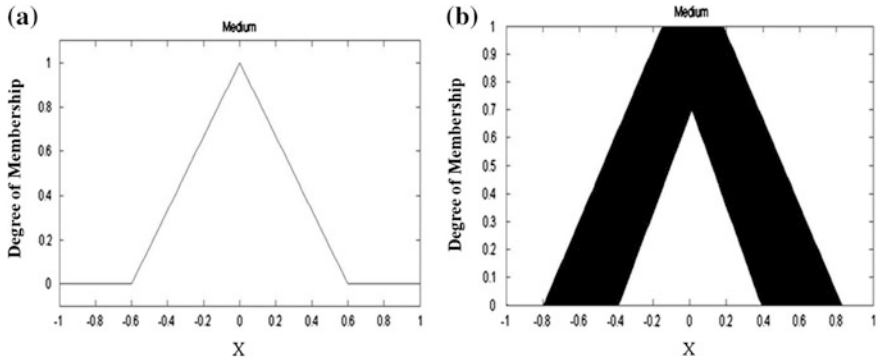
$$\tilde{A} = \{((x, u), 1) | \forall x \in X, \forall u \in J_x \subseteq [0, 1]\} \quad (2.2)$$

where  $X$  is the primary domain and  $J_x$  is the secondary domain. All secondary degrees  $(\mu_{\tilde{A}}(x, u))$  are equal to 1. Figure 2.2 shows the representation of an Interval Type-2 fuzzy logic system.

The output processor includes a type-reducer and defuzzifier that generates a Type-1 fuzzy set output (from the type-reducer) or a crisp number (from the defuzzifier) [15–18]. An Interval Type-2 FLS is also characterized by if–then rules,



**Fig. 2.2** Interval Type-2 fuzzy logic system



**Fig. 2.3** Triangular membership function of the Type-1 FLS (a), and triangular membership function of the interval Type-2 FLS (b)

but their fuzzy sets are now of Interval Type-2 form. The Type-2 fuzzy set can be used when circumstances are too uncertain to determine exact membership degrees, as is the case when the membership functions in a fuzzy controller can take different values and we want to find the distribution of membership functions that show better results in the stability of the fuzzy controller.

Figure 2.3 shows a representation of the triangular membership function for the Type-1 FLS (a) and Interval Type-2 FLS (b). For the IT2FLS the footprint uncertainty (FOU) is determined by the distribution of the six values that define the design of the triangular membership function (See Fig. 2.3b). According to the literature, if the size of the FOU is larger then the evaluation of uncertainty presented in IT2FLS will be more accurate.

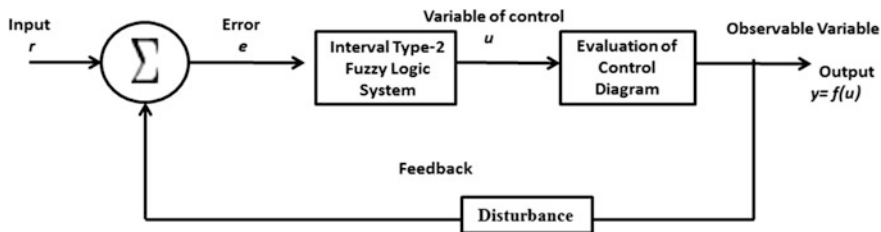
## 2.2 Fuzzy Controllers

Fuzzy control is a control method based on fuzzy logic. Just as fuzzy logic can be described simply as “computing with words rather than numbers” fuzzy control can be described as “control with sentences rather than equations” [19].

The collection of rules is called a *rule base*. The rules are in the familiar if–then format, and formally the if side is called the *antecedent* and the then side is called the *consequent*.

Fuzzy controllers are used in various control schemes; the most used is *direct control*, where the fuzzy controller is in the forward path in a feedback control system. The process output is compared with a reference, and if there is a deviation, the controller takes action according to the control strategy.

In *feed forward control* a measurable disturbance is being compensated; it requires a good model, but if a mathematical model is difficult or expensive to obtain, a fuzzy model may be useful. Fuzzy rules are also used to correct tuning parameters. If a nonlinear plant changes the operating point, it may be possible to



**Fig. 2.4** General representation of a FLC

change the parameters of the controller according to each operating point. This is called *gain scheduling* because it was originally used to change process gains.

A gain scheduling controller constrains a linear controller whose parameters are changed as a function of the operating point in a preprogrammed way. It requires thorough knowledge of a plant, but is often a good way to compensate for non-linearities and parameter variations. Sensor measurements are used as *scheduling variables* that govern the change of the controller parameters, often by means of a table lookup.

Early on, a fuzzy logic controller (FLC) was designed only using Type-1 fuzzy sets in representing the input–output uncertainties. However, these are uncertainties in the meaning of words in the antecedents and consequents of the rules, the histogram value of the consequents extracted from a group of experts, and the noisy data as well as measurements [1, 20–31]. Type-1 fuzzy sets have a limited ability to handle such uncertainties because they apply crisp membership functions. The generic representation of the FLC is illustrated in Fig. 2.4.

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