Chapter 3

Design of Interval Type-2 Fuzzy Logic Controllers

Uncertainty is an inherent part of intelligent systems used in real-world applications [42]. The use of new methods for handling incomplete information is of fundamental importance [13]. Type-1 fuzzy sets used in conventional fuzzy systems cannot fully handle the uncertainties present in intelligent systems. Type-2 fuzzy sets that are used in type-2 fuzzy systems can handle such uncertainties in a better way because they provide us with more parameters [42]. This chapter deals with the design of intelligent systems using interval type-2 fuzzy logic for minimizing the effects of uncertainty produced by the instrumentation elements, environmental noise, etc. Experimental results include simulations of feedback control systems for non-linear plants using type-1 and type-2 fuzzy logic controllers; a comparative analysis of the systems’ response is performed, with and without the presence of uncertainty [68, 69].

3.1 Introduction

Uncertainty affects decision-making and appears in a number of different forms. The concept of information is fully connected with the concept of uncertainty. The most fundamental aspect of this connection is that the uncertainty involved in any problem-solving situation is a result of some information deficiency, which may be incomplete, imprecise, fragmentary, not fully reliable, vague, contradictory, or deficient in some other way. Uncertainty is an attribute of information. The general framework of fuzzy reasoning allows handling much of this uncertainty; fuzzy systems employ type-1 fuzzy sets, which represent uncertainty by numbers in the range [0, 1]. When something is uncertain, like a measurement, it is difficult to determine its exact value, and of course type-1 fuzzy sets make more sense than using sets. However, it is not reasonable to use an accurate membership function for something uncertain, so in this case what we need is another type of fuzzy sets, those which are able to handle these uncertainties, the so called type-2 fuzzy sets. So, the amount of uncertainty in a system can be reduced by using type-2 fuzzy logic because it offers better capabilities to handle linguistic uncertainties by modeling vagueness and unreliability of information [11, 12].
Recently, we have seen the use of type-2 fuzzy sets in Fuzzy Logic Systems (FLS) in different areas of application [13, 28]. A novel approach for realizing the vision of ambient intelligence in ubiquitous computing environments (UCEs), is based on embedding intelligent agents that use type-2 fuzzy systems which are able to handle the different sources of uncertainty and imprecision in UCEs to give a good response [30]. There are also papers with emphasis on the implementation of type-2 FLS and in others, it is explained how type-2 fuzzy sets let us model and minimize the effects of uncertainties in rule-base FLS [30, 75, 76]. There is also a paper that provides mathematical formulas and computational flowcharts for computing the derivatives that are needed to implement steepest-descent parameter tuning algorithms for type-2 fuzzy logic systems. Some research works are devoted to solve real world applications in different areas, for example in signal processing, type-2 fuzzy logic is applied in prediction of the Mackey-Glass chaotic time-series with uniform noise presence [20, 56]. In medicine, an expert system was developed for solving the problem of Umbilical Acid-Base (UAB) assessment [63]. In industry, type-2 fuzzy logic and neural networks was used in the control of non-linear dynamic plants; also we can find interesting studies in the field of mobile robots [28].

In this chapter we deal with the application of interval type-2 fuzzy control to non-linear dynamic systems [22, 23, 47, 51]. It is a well known fact, that in the control of real systems, the instrumentation elements (instrumentation amplifier, sensors, digital to analog, analog to digital converters, etc.) introduce some sort of unpredictable values in the information that has been collected [68]. So, the controllers designed under idealized conditions tend to behave in an inappropriate manner. Since, uncertainty is inherent in the design of controllers for real world applications; we are presenting how to deal with this problem using type-2 Fuzzy Logic Controller (FLC), to reduce the effects of imprecise information [35, 61]. We are supporting this statement with experimental results, qualitative observations, and quantitative measures of errors. For quantifying the errors, we utilized three widely used performance criteria, these are: Integral of Square Error (ISE), Integral of the Absolute value of the Error (IAE), and Integral of the Time multiplied by the Absolute value of the Error (ITAE).

3.2 Fuzzy Logic Systems

In this section, a brief overview of type-1 and type-2 fuzzy systems is presented. This overview is considered as necessary to understand the basic concepts needed to understand the methods and algorithms presented later in the chapter [13].