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A review on interval type-2 fuzzy logic applications in intelligent control

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ABSTRACT

A review of the applications of interval type-2 fuzzy logic in intelligent control has been considered in this paper. The fundamental focus of the paper is based on the basic reasons for using type-2 fuzzy controllers for different areas of application. Recently, bio-inspired methods have emerged as powerful optimization algorithms for solving complex problems. In the case of designing type-2 fuzzy controllers for particular applications, the use of bio-inspired optimization methods have helped in the complex task of finding the appropriate parameter values and structure of the fuzzy systems. In this review, we consider the application of genetic algorithms, particle swarm optimization and ant colony optimization as three different paradigms that help in the design of optimal type-2 fuzzy controllers. We also mention alternative approaches to designing type-2 fuzzy controllers without optimization techniques.

1. Introduction

Uncertainty affects decision-making and emerges in a number of different forms. The concept of information is inherently associated with the concept of uncertainty [112,117]. 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 [168]. The general framework of fuzzy reasoning allows handling much of this uncertainty and fuzzy systems employ type-1 fuzzy sets, which represent uncertainty by numbers in the range $[0,1]$. When an entity is uncertain, like a measurement, it is difficult to determine its exact value, and of course type-1 fuzzy sets make more sense than traditional sets [168]. However, if we have a higher degree of uncertainty in the problem, in this case another type of fuzzy sets that are able to handle this higher degree of uncertainty could be used, the so called type-2 fuzzy sets [26]. The amount of uncertainty in a system can be reduced by using type-2 fuzzy logic because this logic offers better capabilities to handle linguistic uncertainties by modeling vagueness and unreliability of information [149,162]. A higher degree of uncertainty in control applications means that there is noise in the control process mainly due to a changing environment for the plant or when information is transmitted (like in the feedback process in the control loop). Of course, there is always some degree of this uncertainty, but if this is in a low level then type-1 fuzzy logic may be sufficient to manage it. However, in many real situations the noise or dynamically changing environment can be viewed as with a higher degree of uncertainty and then we can expect that type-2 fuzzy logic can do a better job in handling it.

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Type-2 fuzzy models have emerged as an interesting generalization of fuzzy models based upon type-1 fuzzy sets [26,57]. There have been a number of claims put forward as to the relevance of type-2 fuzzy sets being regarded as generic building constructs of fuzzy models [47,140,152]. Likewise, there is a record of some experimental evidence showing some improvements in terms of accuracy of fuzzy models of type-2 over their type-1 counterparts [31,48,104]. Unfortunately, no systematic and comprehensive design framework has been provided and while improvements over type-1 fuzzy models were evidenced, it is not clear whether this effect could always be expected. Furthermore, it is not demonstrated whether the improvement is substantial enough and fully legitimized given the substantial optimization overhead associated with the design of this category of models. There have been a lot of applications of type-2 in intelligent control [22,27,57,60,113], pattern recognition [119], intelligent manufacturing [48,115,170], and others [9,30]. Similarly, optimization methods have also been applied in the design of optimal type-1 fuzzy systems in diverse areas of application [5,13–15,41,63,65,73,136]. However, no general design strategy for finding the optimal type-2 fuzzy model has been proposed, and for this reason bio-inspired algorithms have been used to try in find these optimal type-2 models.

In general, the methods for designing a type-2 fuzzy model based on experimental data can be classified into two categories. The first category of methods assumes that an optimal (in some sense) type-1 fuzzy model has already been designed and afterwards a type-2 fuzzy model is constructed through some sound augmentation of the existing model. The second class of design methods is concerned with the construction of the type-2 fuzzy model directly from experimental data. In both cases, an optimization method can help in obtaining the optimal type-2 fuzzy model for the particular application.

Recently, bio-inspired methods have emerged as powerful optimization algorithms for solving complex problems [46]. In the case of designing type-2 fuzzy controllers for particular applications, the use of bio-inspired optimization methods have helped in the complex task of finding the appropriate parameter values and structure of the fuzzy systems. In this review, we consider the application of genetic algorithms, particle swarm optimization and ant colony optimization as three different paradigms that help in the design of optimal type-2 fuzzy controllers. We also mention some hybrid approaches and other optimization methods that have been applied in problem of designing optimal type-2 fuzzy controllers in different domains of application. The main thing that a reader can learn from this review is the importance of using bio-inspired optimization methods in designing optimal type-2 fuzzy logic controllers. Of course, the use of type-2 fuzzy logic in the area of control has been receiving recently considerable attention, but the main problem is the difficulty in the designing the type-2 fuzzy controllers because these controllers have more parameters than their type-1 counterparts. For this reason the use of bio-inspired optimization techniques has been gaining popularity in solving the problem of designing optimal type-2 fuzzy controllers, which is the main theme of the paper.

2. Type-2 fuzzy logic systems

In this section, a brief overview of type-2 fuzzy systems is presented. This overview is intended to provide the basic concepts needed to understand the methods and algorithms presented later in the paper [23,26].

If for a type-1 membership function, we blur it to the left and to the right, as illustrated in Fig. 1, then a type-2 membership function is produced. In this case, for a specific value x', the membership function (u'), takes on different values, which are not all weighted the same, so we can assign membership grades to all of those points.

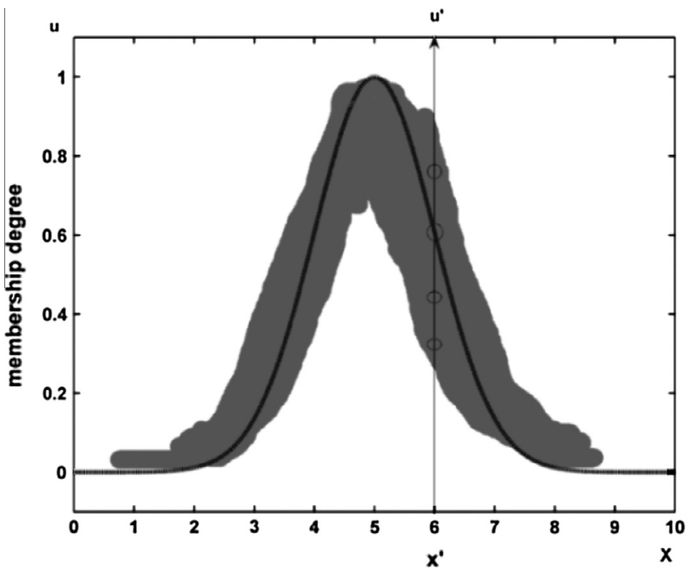

Fig. 1. Type-2 membership function as a blurred type-1 membership function.