A New Framework With Similarity Reasoning and Monotone Fuzzy Rule Relabeling for Fuzzy Inference Systems

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Abstract—**A complete and monotonically-ordered fuzzy rule base is necessary to maintain the monotonicity property of a Fuzzy Inference System (FIS). In this paper, a new monotone fuzzy rule relabeling technique to relabel a non-monotone fuzzy rule base provided by domain experts is proposed. Even though the Genetic Algorithm (GA)-based monotone fuzzy rule relabeling technique has been investigated in our previous work [7], the optimality of the approach could not be guaranteed. The new fuzzy rule relabeling technique adopts a simple brute force search, and it can produce an optimal result. We also formulate a new two-stage framework that encompasses a GA-based rule selection scheme, the optimization based-Similarity Reasoning (SR) scheme, and the proposed monotone fuzzy rule relabeling technique for preserving the monotonicity property of the FIS model. Applicability of the two-stage framework to a real world problem, i.e., failure mode and effect analysis, is further demonstrated. The results clearly demonstrate the usefulness of the proposed framework.**

Keywords-Fuzzy inference system; monotonicity property; fuzzy rule relabeling; application frameworks, failure mode and effect analysis

I. INTRODUCTION

The importance of the monotonicity property in Fuzzy Inference System (FIS) modeling has been highlighted in a number of recent publications [1-6]. To maintain the monotonicity property of an FIS model, a *monotonically ordered* and *complete* fuzzy rule base is necessary [1-6]. In order to maintain a *monotonically ordered* fuzzy rule base obtained from domain experts, a monotone fuzzy relabeling technique was introduced in our previous work [7]. It attempts to relabel a non-monotone fuzzy rule base gathered from domain experts. It searches for a new fuzzy rule base that is monotone (as the first priority), with the minimum number of relabeled rules (as the second priority), and with the minimum loss measure (as the third priority). A Genetic Algorithm (GA) was adopted in [7]. However, the use of the GA could not guarantee an optimal solution. It also might require a relatively high computation complexity. As a solution to these shortcomings, the first aim of this paper is to develop a new fuzzy rule relabeling technique.

To maintain a *monotonically ordered* and *complete* fuzzy rule base, we also proposed an optimization based similarity reasoning (SR) scheme previously [7-8]. A search in the literature reveals that various SR schemes (e.g., analogical reasoning [9], fuzzy rule interpolation [10-11], and qualitative reasoning [12]) are available to allow the conclusion of an observation (in the form of a fuzzy set) to be deduced or predicted, based on a fuzzy rule base (database). Even though these approaches are useful, it is difficult to ensure that a *monotonically ordered* fuzzy rule base is always produced [7-8, 13-14]. Thus, we argue that the deduced conclusions need to be optimized, before implementing them in practice [7-8, 13-14].

To the best of our knowledge, there are relative few papers addressing practical implementation of SR. It is worth mentioning that in our previous investigations, applications of SR to Failure Mode Effect Analysis (FMEA) [13] and education assessment [14] have been investigated. Thus, the second aim of this paper is to propose a new framework as an alternative to preserve the monotonicity property in an FIS model, whereby its fuzzy rules are incomplete and non-monotonically ordered. The two-stage framework encompasses a GA-based rule selection scheme, an optimization based-SR scheme, and the proposed monotone fuzzy rule relabeling technique. It systematically reduces the number of fuzzy rules that needs to be gathered from domain experts. In stage 1, the GA is used to search for a small set of fuzzy rules (namely *stage-1 fuzzy rules*) that needs to be gathered from human experts. The monotone fuzzy rule relabeling technique is used to relabel *stage-1 fuzzy rules*. In stage 2, the remaining fuzzy rules (namely *stage-2 fuzzy rules*) are deduced using the optimization-based SR scheme. This framework is important in practice, because it always is difficult and laborious to obtain a complete and yet monotonically ordered fuzzy rule set from domain experts in the real environments [13-15]. The proposed framework allows a monotonicity-preserving FIS model to be constructed with the minimum number of fuzzy rules, even when the rule base is incomplete and the rules are non-monotone.

Traditional SR schemes usually focus on reasoning and/or interpolation of two neighbouring fuzzy rules within a relatively small local region [9-12]. This approach may not efficient for the whole domain, or even a relatively large region, for real-world applications. The proposed optimization-based SR scheme includes the (local) monotonicity property as an additional piece of qualitative information. The inclusion of such additional qualitative information is important, because it increases the accuracy of reasoning for a relatively large range of operating region. In addition, the idea of the two-stage framework is to search for a set of evenly-distributed *stage-1 fuzzy rules* in the whole domain such that reasoning and/or interpolation for a relatively large region can be avoided or minimized. In short, this study contributes to a practical solution for overcoming