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Linguistic truth-valued intuitionistic fuzzy reasoning with applications in human factors engineering

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ABSTRACT

It is useful to process information expressed by linguistic terms under uncertain environment. This paper proposes a layered reasoning algorithm of the linguistic truth-valued intuitionistic fuzzy lattice. Based on linguistic truth-valued intuitionistic fuzzy algebra (LTV-IFA), some concepts and properties of a new intuitionistic fuzzy layered aggregation (IFLA) operator and its inverse operator are discussed. By using IFLA operators, we present two types of implication operators and a LTV-IFA-based reasoning algorithm. The proposed method can express not only positive evidence, negative evidence and indeterminacy at the same time, but both comparable and incomparable information as well. We carried out a case study based on 10 LTV-IFA, where a human factors engineering analysis in the area of safety management of marine engineering is considered. Comparative results using two implication operations demonstrate that the proposed reasoning approach performs better.

1. Introduction

Decision making problems play an important role in artificial intelligence. Many of these decision problems are under uncertain environments with vague and imprecise information [8], the attribute values involved in the decision problems are not always expressed as numbers, and some of them are more suitable to be described by fuzzy numbers, linguistic variable, intuitionistic fuzzy numbers, etc. Since the concept of fuzzy sets had been proposed, fuzzy numbers have become a common format of information studied in decision-making [10,17]. In the subsequent decades, the theory of fuzzy sets has been developed and improved, and has been applied to many fields. Intuitionistic fuzzy sets (IFSs) being characterized by a membership function and a non-membership function are useful in providing a model to elaborate uncertainty and fuzziness involved in decision making [1,2]. They have attracted increasing attention since their appearance, and have been utilized and expanded in describing the uncertain or imprecise knowledge. Chen et al. proposed a new similarity measure between Atanassov's intuitionistic fuzzy sets based on some transformation techniques [4]. Two new aggregation operators based on the Łukasiewicz triangular norm are proposed, which are monotonous with respect to the total order of interval-valued intuitionistic fuzzy set [15]. Recently, a new extension of fuzzy sets so-called hesitant fuzzy sets has attracted very quickly the attention of many researchers that have proposed diverse extensions, several types of operators to compute with such types of information, and eventually some applications have been developed. Luis et al. present a multicriteria linguistic decision-making model in which experts provide their assessments by means of linguistic expressions based on comparative terms close to the expressions used by human beings. The

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linguistic expressions are represented by hesitant fuzzy linguistic term set [9]. They present an overview on hesitant fuzzy sets with the aim of providing a clear perspective on the different concepts, tools and trends related to this extension of fuzzy sets [11]. On the other hand, there exist many alternative methods in lattice-valued logic, such as gradational lattice-valued logic with truth-values in a logical algebra called lattice implication algebra (LIA) by introducing the definition of generalized clause, generalized conjunctive normal form and generalized Skolem standard form [16]. As residuated lattices provide the algebraic semantic frameworks to related fuzzy logic formal systems, Zhang et al. investigated the filter theory of residuated lattices [20]. Zou et al. proposed a kind of linguistic truth-valued intuitionistic fuzzy lattice based on the point view of intuitionistic fuzzy set and linguistic truth-valued LIA [24]. The linguistic-valued credibility was then modeled based on the lattice ordered logical algebra and then used in linguistic-valued approximated reasoning [25,26].

Fuzzy reasoning approaches have been widely used in many fields, such as control engineering and information technology. There have been many improvements and extensions of fuzzy reasoning approaches in different ways, such as, an interpretation of intuitionistic fuzzy values in the framework of Dempster–Shafer theory [7], an approach based on interval belief degrees and fuzzy evidential reasoning analytical algorithm for the evidential reasoning and so on [14]. Many approximate reasoning and interesting results have been reported [19,22]. In addition, there are some other improved fuzzy reasoning methods. For example, Deng et al. presented a new fuzzy reasoning method by optimizing the similarity of truth tables [6]. Chen et al. proposed a method to construct a polygonal rough-fuzzy set from a set of polygonal fuzzy sets [5]. Zhang et al. proved that the union and intersection operations of rough fuzzy approximation pairs are closed and a bounded distributive lattice can be constructed [21]. Zhou et al. proposed the Quintuple Implication Principle [23].

With the development of the shipping industry, a large number of automated and professional ships are put into operation. Ship safety management in order to improve the economic and social benefits of the ships becomes an important issue, that must be solved in the shipping industry and people begin to address those problems with mathematical modeling approaches [12]. Zeng et al. built an evaluation model of inland river shipping enterprises' safety management based on triangular fuzzy numbers [18]. A measurement method based on small sample is reported in [3]. By analyzing system structure, designing function modules and data management, Su et al. proposed a framework to integrate, manage, and analyze the seabed information comprehensively [13].

The methods mentioned above provide new ways for human factors engineering; however, in real world applications, people are more likely to describe things with linguistic values for analysis and evaluation of people's behavior and psychological factors in the management of the marine engineering. Moreover, in many cases, in addition to the positive comments, there are a lot of negative comments and uncertainties. Therefore, it is necessary and meaningful to study advanced reasoning techniques by the linguistic truth-valued intuitionistic fuzzy sets. In this paper, we present IFLA operators and its inverse operators on LTV-IFA. Using these operators, the linguistic truth-valued intuitionistic fuzzy lattice can be layered and the linguistic truth-valued intuitionistic fuzzy pair can be aggregated as an IFLA number, which has an index with a subscript. For the intuitionistic fuzzy reasoning, two kinds of implication with IFLA number are discussed. By using IFLA inverse operators, the reasoning results can be restored to a linguistic truth-valued intuitionistic fuzzy pair.

The remainder of this paper is organized as follows: Section 2 reviews some relevant concepts of intuitionistic fuzzy sets, and introduces 10 LTV-IFA. Section 3 presents an IFLA operator and analyzes properties of IFLA numbers, and an associated 10 LTV-IFA based reasoning algorithm is proposed. An illustrative example on human factors engineering analysis is given to show the applicability of the proposed method. We conclude this paper in Section 4.

2. 10 LTV-IFA

Based on linguistic truth-valued lattice implication algebra, linguistic truth-valued intuitionistic fuzzy algebra has been established. We consider five common linguistic hedges and form 10 linguistic truth-values.

In this section, we briefly review generic concepts of intuitionistic fuzzy set and LTV-IFA.

Definition 1. ([2]). Intuitionistic fuzzy set is defined in the following form:

$$A = \{(x, \mu_A(x), \nu_A(x))|x \in U\},$$

where U is a discourse space, $\mu_A(x)$: $U \to [0,1]$ and $\nu_A(x)$: $U \to [0,1]$ are respectively the membership degree and nonmembership degree of the object $x \in U$ belonging to $A \subseteq U$ which satisfy the following condition $0 \le \mu_A(x) + \nu_A(x) \le 1$ for any $x \in U$.

In the intuitionistic fuzzy set A, the expression $\pi_A(x) = 1 - \mu_A(x) - \nu_A(x)(\forall x \in U)$ is called the degree of indeterminacy of x in A. In fuzzy sets, if $\mu_A(x)$ is the membership degree of x to A, then $1 - \mu_A(x)$ is the non-membership degree, i.e., $\pi_A(x) = 1 - \mu_A(x) - \nu_A(x) = 0$. Hence, the intuitionistic fuzzy set arises as a useful extension of fuzzy set [2].

For any intuitionistic fuzzy sets $A = \{(x, \mu_A(x), \nu_A(x))|\ x \in U\}$ and $B = \{(x, \mu_B(x), \nu_B(x))|\ x \in U\}$, the operations of union ($\cup$), joint ($\cap$) and complement ($'$) are defined as follows [2]:

$$A \cup B = \{(x, \max(\mu_A(x), \mu_B(x)), \min(\nu_A(x), \nu_B(x)))|x \in U\},$$

$$A \cap B = \{(x, \min(\mu_A(x), \mu_B(x)), \max(\nu_A(x), \nu_B(x)))|x \in U\},$$

$$A' = \{(x, \nu_A(x), \mu_A(x))|x \in U\}.$$