Linguistics and Fuzzy Control

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Abstract

In this paper, we turn attention to the linguistic side of approximate reasoning and fuzzy control. Some concepts and problems rising from modelling of linguistic semantics and pragmatics are outlined. Their impact on fuzzy control is also shortly discussed. We claim that fuzzy control could be improved if the development of the theory of approximate reasoning could proceed in direction to greater linguistic richness. In the last section of the paper, a software tool for Linguistic Fuzzy Logic Controller is shortly introduced.

1 INTRODUCTION

Fuzzy control became a hit of the last several years and it is the most successful application of fuzzy logic. Hence, a big effort is now devoted to improve its performance. However, the problem of improvement is somehow shifted to technics and nobody cares very much for basic ideas which stood in the beginning of fuzzy control.

The main idea of fuzzy control, if I understand it well, is to find a tool for translation of human operator's experiences in control of some process into a form of a working algorithm whose performance would be at least as good as that of human. Since these experiences are mostly expressed in natural language, it is necessary to find proper translation of natural language into the "language of numbers". This task has been fulfilled by genial L. A. Zadeh's, and later on, by E. H. Mamdani's ideas. Their idea to formulate control process in a form of IF–THEN rules with presence of vague terms and to interpret them as fuzzy sets and relations has won.

The aim of this paper is to turn the attention to the linguistic side of the problem of fuzzy control. This question is somewhat neglected and for example, all fuzzy controller softwares known to me postpone this problem to the user forcing him to specify his own fuzzy sets representing the meaning of natural language words, or even expressions by himself. Moreover, tuning of fuzzy controller consists in a direct modification of the shape of membership functions. But this may lead to fuzzy sets not expressing the meaning of the original words at all. Summarizing together, the original idea of fuzzy control is suppressed though the resulting behaviour may be acceptable. However, if the behaviour of the controller has to be modified, then it seems to us that the necessary effort to do it would be significantly smaller if the control were designed on the basis of linguistic consideration without direct influence of the fuzzy sets hidden inside. In other words, we should try to find a way of linguistic formulation of fuzzy control without specification of more things than are necessary.

In the following sections of this paper we will comment some of the problems of linguistic semantics and pragmatics and their connection with fuzzy control. Finally, we mention a concrete realisation of the idea of a linguistic fuzzy logic controller (LFLC) that is already available and proved its ability to work also in the practical applications.

2 LINGUISTIC SEMANTICS AND PRAGMATICS

Fuzzy set theory became popular, besides other, by its ability to model some parts of linguistic semantics. This idea was first elaborated in [25]

In general, a sentence $\mathscr{S}$ of natural language is ambiguous and it can be represented by a set $Mean(\mathscr{S})$ of labelled trees which is a set of meanings of $\mathscr{S}$. Each node of the tree corresponds to a certain word and edges correspond to relations among words (for details see [21]. Hence, modelling of linguistic semantics needs first to model meaning of words, then their grammatically formed connections (so called, ***syntagms***) and last, to model the meaning of the whole sentences. Furthermore, vagueness and many logical and even philosophical aspects must be taken into account. A possible approach to this task is presented in [15] where the so called *Alternative Mathematical Model of Linguistic Semantics and Pragmatics* (AML) has been formulated. Its mathematical frame is the *Alternative Set Theory* (AST) presented e.g., in [23].

Words of natural language have several basic roles: they denote properties, make some relations among words more precise, or have quite auxiliary, elucidating function. A fundamental role in our lexical supply is played by ***nouns***.

A meaning of a noun $\mathscr{N}$ can be understood to be a certain property $\varphi_{\mathscr{N}}$ and a grouping $X_{\mathscr{N}}$ of elements that have the property $\varphi_{\mathscr{N}}$. In symbols, we may write

$$M(\mathscr{N}) = \langle \varphi_{\mathscr{N}}, X_{\mathscr{N}} \rangle$$

where

$$X_{\mathscr{N}} = \{x;\ \varphi_{\mathscr{N}}\}. \tag{1}$$

The $\varphi_{\mathscr{N}}$ is called an ***intension*** and $X_{\mathscr{N}}$ and ***extension*** of the noun $\mathscr{N}$.

The meaning of an ***adjective*** $\mathscr{A}$ is a property $\varphi_{\mathscr{A}}$. The meaning of simple syntagms such as "small man", "beautiful flower", etc. is a certain kind of conjunction of $\varphi_{\mathscr{N}}$ and $\varphi_{\mathscr{A}}$. This is constructed on the basis of some ***features*** of the elements x. There may be many features of each x. Thus, their character is important for the construction of syntagms since not every adjective can be joined with every noun (e.g. "sour table" has no sense). Some features, however, have an outstanding role and they are present almost in every element, for example "size" (many things can be "small" or "big"). All these considerations concern deep properties of natural language and we have no place here to discuss them in detail.

A special group of words is formed by adverbs. This group is somewhat heterogenous. The most important adverbs are so called ***intensifying*** adverbs ("very", "strongly", etc.). These lead to certain operations on the extensions of words, or syntagms.

In AML, the extensions $X_{\mathscr{N}}, X_{\mathscr{A}}, \ldots$ are modelled by semisets (see [23]) and a transition from semisets to fuzzy sets is proposed. The problem, however, is not so simple since alternative set theory represents a significant departure from classical mathematics and thus, fuzzy sets may serve rather as proper approximation of some notions and not a tantamount partner. On the other hand, it seems that this is a good way for explication of many, by other means inexplicable, phenomena. Fuzzy sets appeared to be a good tool if we want to deal empirically with the meaning.

Let us, for simplicity and with some objections, consider all the extensions to be fuzzy sets, or fuzzy relations.

A special and very important problem is the problem of modelling of the meaning of conditional statements. In fuzzy logic, the simpliest form of conditional statements called IF–THEN rules are considered:

$$\text{IF } \mathscr{P} \text{ THEN } \mathscr{Q} \tag{2}$$

where $\mathscr{P}, \mathscr{Q}$ are syntagms of natural language. We argue that in natural language, IF–THEN rules are logical implications in an imprecise environment. This fact, however, has impact on the kind of operations used in generalised modus ponens. The syntagms $\mathscr{P}, \mathscr{Q}$ may contain words of various kinds including verbs and thus, they can be very complicated. In the simpliest case, they have the form

$$\mathscr{N} \text{ is } \mathfrak{m}\mathscr{A} \tag{3}$$

where $\mathscr{N}$ is a noun, $\mathscr{A}$ is an adjective, and $\mathfrak{m}$ is an intensifying adverb.

However, for more sofisticated applications, more complex form of syntagms $\mathscr{P}$ and $\mathscr{Q}$ is necessary. Especially important are ***linguistic quantifiers.*** These are pronouns ("every"), indefinite numerals ("several"), adverbs ("many, few, most") and others. Unfortunately, it is very difficult to model the meaning of these kinds of words though much work in this respect has been done e.g., [24, 28, 5]. The problem consists in classical understanding to infinity. Since the classical notion of infinity does not allow reasonable solution, all the mathematical considerations are based on finite sets. However, this is unsatisfactory. In AST, this problem is overcome since the notion of the so called ***natural infinity*** is well elaborated and thus, the formulas may work.

At the end of this section, we mention the problem of pragmatics, i.e. use of words in a concrete context. Pragmatics concerns substitution of concrete objects (people, things) on places represented by certain words. For example, "I am glad to meet you" contains two pragmatic items: "I" and "you". Other pragmatic item is "now".

Very important problem connected with pragmatics is the problem of context. For example, "small man" has different meaning in Europe in compare with various parts of Africa. It can be demonstrated that the context also concerns the mentioned notion of infinity. Natural infinity of AST can help to solve our problems. This concept in connection with modelling of natural language semantics is elaborated in [15] as well.

3 FUZZY LOGIC, LINGUISTIC SEMANTICS, AND CONTROL

In this section, we outline what is the impact of the problems and notions presented in the previous section to fuzzy controllers.

We are convinced that the development of the theory of approximate reasoning (an thus, of fuzzy control) should proceed in direction to greater *linguistic* richness. Taking this point of view leads to reevaluation of some mathematical concepts and approaches. First of all, we must accept a logical frame in many considerations of us since logic is inseparably connected with natural language. This concerns, besides other, the concept of implication.

There are many works dealing with various kinds of implication functions, e.g., [2, 6] and many others. We think, however, that we should take a well behaved formal apparatus to be a logical frame and origin. Such a frame is for us *many valued fuzzy logic* based on residuated lattices (see [20, 10, 11, 22]). Many good properties of this logic have been proved and demonstrated. Due to it, the Lukasiewicz implication

$$a \rightarrow b = 1 \wedge (1 - a + b), \qquad a, b \in \langle 0, 1 \rangle$$

should be taken as fundamental. This logic influences also the use of other operations and connectives (see [10, 15] for the reasons).

Thus, conditional statement of the form 2 is translated into a formula

$$A \Rightarrow B$$

where A, B are formulas in the language of fuzzy logic.

In [13, 12], it was demonstrated that the reasoning process can be explicated by means of many–valued rules of inference. Thus, taking the above formalisation of IF–THEN (conditional statements) rules into account, the inference can be realised using the rule

$$r_{CMP} : \frac{A_k(x), \bigwedge_{j=1}^{m}(A_j(x) \Rightarrow B_j(y))}{B_k(y)} \left(\frac{a, b}{a \otimes b}\right) \qquad 1 \leq k \leq m. \tag{4}$$

where $\bigwedge$ denotes conjunction. In brackets on the right hand side, the method for computation of truth degrees with the respective concrete formulas is given. The operation $\otimes$ is a bold product operation adjoined with the residuation and given by

$$a \otimes b = 0 \vee (a + b - 1), \qquad a, b \in \langle 0, 1 \rangle.$$

The rule (4) can be extended by special unary connectives representing adverbs.

The type of syntagms used in linguistic description of control process is quite simple since the syntagms (3) contain a noun "error", "change of error", or casually, "action". In all cases, the corresponding extensions $X_{\mathscr{N}}$ in (1) can be represented by fuzzy sets (semisets) in a real line $\mathbb{R}$. Our task is then to find suitable models of the adjectives $\mathscr{A}$ and adverbs $\mathfrak{m}$. The meaning of the syntagms of the form "$\mathscr{N}$ is $\mathscr{A}$" in this case leads to fuzzy sets of the well known S^-, S^+, and Π shapes (cf. [10]).

The first step to increase the linguistic richness is to introduce various kinds of adverbs $\mathfrak{m}$. We may consider intensifying adverbs with narrowing effect (***very, highly, extremely***) making the meaning more precise (though still vague), and widening affect (roughly, more or less, quite roughly, etc.) making the meaning even more vague. In syntagms of the form "$\mathscr{N}$ is $\mathfrak{m}\mathscr{A}$" the adverb $\mathfrak{m}$ modifies the extension $X_{\mathscr{N}\mathscr{A}}$. If it is considered to be a fuzzy set then the meaning of adverbs becomes a couple of functions

$$\langle \zeta_m, \nu_m \rangle$$

where $\zeta_m : U \longrightarrow U$ is a shifting function and $\nu_m : \langle 0, 1 \rangle \longrightarrow \langle 0, 1 \rangle$ is a modification function. Models of several kinds of intensifying adverbs have been proposed in [10, 27, 8, 1] and elsewhere. The possibility to use these adverbs has great impact on the effectiveness of fuzzy control (see the next section).

Greater linguistic richness can be reached by extending the repertoire of adverbs and introducing some other types of them, e.g. focusing (***only, simply***) or time adverbs (***regularly, often***). A special and important field that could significantly increase linguistic richness and effectivenes of fuzzy control are the mentioned linguistic quantifiers.

A still unknown field are verbs. Note that the verb "is" in the above considered syntagms is used as an assignement rather than as a pure verb since the latter must have its frame, temporal and other characteristics. The model of the meaning of verbs has also been proposed in [15].

We have no place to discuss these questions in detail. Let us, however, stress that the proclaimed linguistic richness is not the end in itself. A classical fuzzy controller is based on linguistic motivation. However, as has already been stressed, the practical realization of it cares neither linguistics nor logic very much. It uses Max–Min rule of inference that has been demonstrated to be non-sound from the logical point of view. A simple counterexample can be contructed demonstrating that the non-soundness may lead also to wrong control action (cf. [17]). Nevertheless, in practice it often works. The rule (4) always works correctly. An analysis of this discrepancy needs more detailed elaboration and it will be done elsewhere.

What we advocate for is the need to focus more strongly to the logic and linguistics. Logical implication is the most general expression of a directed relation, and natural language is the most general tool for the description of our world and events in it. Thus, we have the most general tools at our disposal and thus, we may make the following hypothesis.

Hypothesis 1 *If it is physically possible to control a process then it is possible to describe the control using natural language. Hence, if a fuzzy controller is consistently based on the use of natural language then the process is controllable by fuzzy controller.*

This hypothesis is similar to Church thesis for algorithms and it will be difficult to prove it. However, we are on a way to demonstrate its rightfulness. We have good reasons for the statement that consitent keeping of logical and linguistic basis will significantly increase effectiveness of the design and performance of fuzzy controller including a simple way to its adaptivity and learning capability. This presupposition is partly verified by the Linguistic Fuzzy Logic Controller presented in the next section.

4 LINGUISTIC FUZZY LOGIC CONTROLLER

On the basis of the linguistic and logical principles discussed above we have began to develop a *Linguistic Fuzzy Logic Controller* (LFLC). This controller can be considered to be the first stage on a way to get as close as possible to the capability to transform directly a free linguistic description of the control process provided by a human operator into a form of an effective control algorithm and thus, to demonstrate Hypothesis 1.

LFLC realises inference on the basis of a set of conditional linguistic statements that may contain quite rich variety of the discussed syntagms. Also the concept of linguistic context appeared to be very useful. Practical experiences have shown us that rich linguistic variety is enough to express quite precisely the control strategy, and no other information except for linguistic context is necessary. Tuning of a linguistic description for LFLC proved to be simple and quick. Moreover, we may also demonstrate a good deal of adaptation ability by means of the linguistic context. We may finally remark that LFLC has also a working real application in a control of a plaster kiln, and further applications are in preparation.

LFLC is available as a software for education (*LFLC-edu* — see [18]). For professional use it is in preparation. We continue the development of LFLC in agreement with the concepts discussed above.

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