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Address: Univerzitetski trg 2, 18000 Niš,YU, Tel. +381 18 547-095, Fax: +381 18 547-950
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INTELLIGIBILITY SPEECH ESTIMATION USING FUZZY LOGIC INFERENCING

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Miloš Manić, Dragan Cvetković, Momir Praščević

University of Niš, Faculty of Occupational Safety, Čarnojevića 10a, 18000 Niš, Serbia, Yugoslavia, e-mail: misko@ieee.org

Abstract. *Ambiental information intelligibility represents an ever growing problem because of an evident growing acoustic load in case of various halls. Fuzzy eXPert Systems represent an extension of existing expert systems and are featuring some qualitative improvements, tending to solve problems, previously approached only in a crisp manner. The example given in this paper refers to an speech recognition estimation, by application of proposed mechanisms.*

Key words: *fuzzy logic, soft computing, intelligibility speech, knowledge base*

1. INTRODUCTION

Fuzzy logic along with the concept of neural networks and probabilistic reasoning, represents one of the main computer methodologies that enable imprecise, incomplete and uncertain information treatment, as also as work with the complex, non-linear problems. These methodologies are commonly named by **soft computing** [1, 2, 3].

This theory is based on the fact that human thinking consists of linguistic terms but only numbers, and that human reasoning logic is not 2-valued or multiple-valued, but logic of not exact, incomplete (fuzzy) information, operation and rules of inferencing. The extension of Boolean two-valued into a multiple-valued i.e. infinitely valued logic leads to fuzzy logic [4, 5].

Fuzzy logic theory originates from revolutionary work of Lofti Zadeh "Fuzzy sets" [6], as an extension of multi-valued logic. An unique consideration of as also numeric data as linguistic knowledge by non-linear mapping of input vector of characteristic into a scalar output, i.e. by mapping of discrete inputs into discrete outputs, that enables approximative reasoning upon imprecise, incomplete information [1, 2, 3, 6, 7].

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2. Fuzzy Expert Systems

Fuzzy logic experiences growing practical application in industrial and commercial systems (especially in Japan). Frequent practice of this way of inferencing, assuming **fuzzy logic systems** for decision support and different systems control, one can find in literature. This was the original idea, exploited in this paper. Such system could be exploited for an speech estimation because of non-numerical parameters for speech recognition. Such system could be further extended into a fuzzy expert system for acoustic load control, in order to preserve wanted ambiental comfort level (depending on comprehensibility of acoustic information – speech).

Conceptual extension of classic inferencing and control systems consists of absence of analytic description of such systems. First approaches to an extension of control systems based on Zadeh's concept of fuzzy sets origin from Mamdani [8], who has introduced a fuzzy logic controller which contained control algorithm based on simple rules. Aproximative reasoning of such fuzzy system converts knowledge represented by incomplete (fuzzy) information and fuzzy rules into a non-fuzzy (numeric) outputs.

In order to model human reasoning mechanisms, Lofti Zadeh has introduced the fuzzy extension of conventional inferencing systems (fuzzy logic systems - **FLS**) [1, 6, 7] that, besides quantitative aspects, have included the logic of inexact, incomplete information, operation and inferencing rules, also. In order to combine with heuristic formulation inside such systems, so called. **if-then** rules, numerical values of mathematical descriptions had to be symbolically interpreted.

Fuzzy e***XP***ert ***S***ystems (**FXPS**) appeared as the fuzzy extension of existed expert systems and feature some differences in contrast to fuzzy controller (**FC**). They can use **different techniques of knowledge representation** beyond rules, can have **more than one step of inferencing**, are **hybrid** (as also numerical as fuzzy), solve so called **off-line** problems in spite of fuzzy controller that often operate in real time, not exclusively meant for control, but for **diagnostics**, **decision support**, **optimization**, **simulation**, **failure detection**, **pattern recognition**, **maintenance**, etc., [5].

2.1. Operating stages of FES

Diagram of fuzzy logic system functioning by phases is given by Fig. 1.

First stage includes fuzzification, i.e. translation of the input, numerical values into fuzzy variables. Characteristics of interest – linguistic terms, are associated by adequate membership functions with certain linguistic variables. In contrast to traditional systems, fuzzy systems for every input variable generate membership function that takes the numerical value from the interval [0,1] and represents degree of membership (compatibility) of the input value to an adequate fuzzy subset - linguistic term. Qualitative interpretation of different available values of input variables is achieved by fuzzification.

The choice of adequate membership function is one of the most critical step in constructing fuzzy logic models of inferencing and control systems, because the shape of the fuzzy set determines the correspondence between the input data and linguistic terms, upon further fuzzy inferencing is done. As basic predicates of the fuzzy production rules, linguistic terms i.e. their fuzzy sets have to be defined before the system modeling by fuzzy logic rules.

Many applications over the fuzzy sets include aggregation operation. Classic aggregation operators are used with fuzzy numbers and fuzzy values (fuzzy value is the fuzzy set in domain of real numbers whose membership function does not have to fulfill conditions of convexity, normality and continuity of universal set – does not have to be a fuzzy number). Basic examination in fuzzy operators defining is that in reducing onto classical sets, they do not have to be reduced to classic set operators.

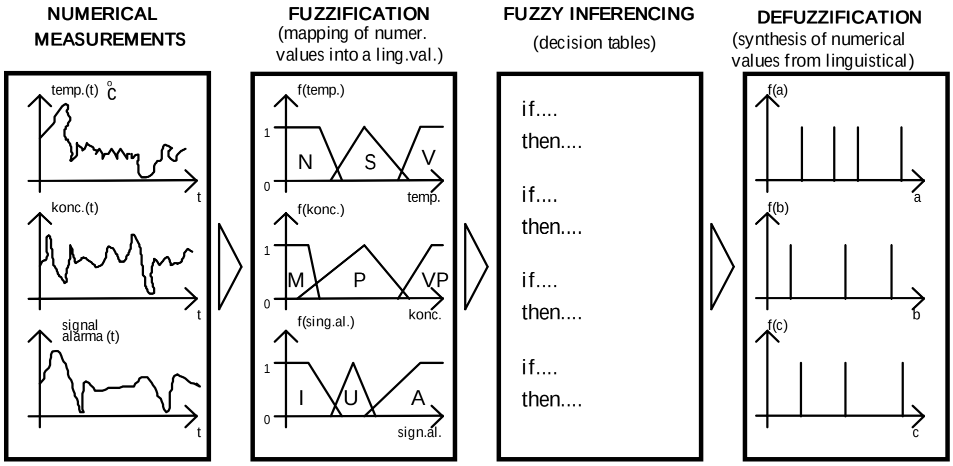


Fig. 1. Four stages of fuzzy logic inferencing

Finalized fuzzification follows the central stage of fuzzy system functioning – **fuzzy inferencing**. This phase (Fig. 1) understands usage of **knowledge base** i.e. execution of the aggregation of fuzzy production system fuzzy premises – **rule application**, adequate to context of fuzzy inferencing system model.

Defuzzification represents an essential functional part of any fuzzy logic system and understand a mapping of fuzzy values into numerical outputs. By application of some method of aggregation while inferencing over fuzzy rules, a **fuzzy solution area** is obtained, over which process of defuzzification is needed. By this last stage of operating fuzzy system, fuzzy solution area is transformed into a discrete value. At the same Fig. 1, conversion of symbolic into a numerical domain during this stage of fuzzy logic system operating is illustrated.

During this process, predefined threshold or decomposition logic of fuzzy solution area is used, in accordance with the problem context. Deffuzification criterion reflects the interpretation logic of different linguistic variables constellation and can be realized in different ways [9]. Among different techniques, the one that responds with the best representation of the information contained in the resulting set, has to be chosen.

Evaluation of the premises of every fuzzy rule responds the fuzzy set associated with the correspondent rule conclusion. Aggregation of obtained sets gives the final fuzzy set over which some of the deffuzification techniques is further executed.

3. KNOWLEDGE REPRESENTATION FORMALISMS

Effective reasoning inside expert systems is based upon the adequate specific knowledge representation, concerning certain area of interest. Every such system has the expertise of narrow knowledge domain. In order to be used for inferencing, knowledge has to be represented in certain knowledge structures. Various knowledge representation formalisms, accepted as standards arouse by data representation methods evolution, and are namely [10, 11]: predicate logic, semantic networks, production rules, frames and scenarios, object-oriented approach, etc.

3.1. Rules

Widest use among all the knowledge representation formalisms experienced systems based on rules, by which various mechanisms of inferencing are realized. Rule based systems use the non-procedural way of inferencing. They are not based on typical algorithms but on simple facts connected by some inferencing mechanism. These systems simulate the expert "on work" and bring the conclusions like human way of reasoning instead of procedural programs, more adequate for structural environments. They are characterized by intuitive inferencing over the knowledge contained inside the system. Important concepts of such systems refers to knowledge base development, rules firing and executing, and searching for rules in situation where more than one rule application corresponds to [10].

Rule based systems contain **knowledge base** which consists of **set of fact** and **rule set**. The set of facts describes the state of considered domain (existence of certain objects and their mutual relationships). These systems contain **working memory** i.e. initial and derived facts during the inference process. Rules have unique **if_then** structure:

If *<premise>*
and *< premise >* ***and****...*
then *<conclusion>.*

The inherent part of the system is the **rule interpreter** which applies them by embedded mechanism of inferencing, and adds new, derived facts to the set of already known ones.

3.2. Objects

Object-oriented methods of knowledge representation ensures the alternative but very similar knowledge representation methodology to **frames** and **semantic networks**. Knowledge is referred to as the **set of objects**, of which every demonstrates certain characteristics. Objects are characterized as by structures as also by functional features of the modeled domain. Every object is situated in network or hierarchy and can access the characteristics and object's information of the higher level.

In object oriented system the **system decomposition** is based on the concept of the **object**. Object mutually communicate by sending and receiving of messages. Receiver upon message reception checks its own database and decides upon the action to be done. Every further action is executed in a form of message. In context of programs based on knowledge, an opportunity of **problem structure encapsulation and its solving strategy** inside the same entity – object.

3.3. Fuzzy knowledge types

The problem of human alike reasoning is mostly based on representation of incomplete, subjective and imprecise information i.e. statements that prevail in everyday usage of natural language. Classic theory of probability and conventional techniques represent the artificial intelligence knowledge based on predicates, is not adequate for representation of such knowledge, because they do not enable work with uncertainties nor the ability of truth granularization (in predicate logic premises and conclusions are either truth or false).

Fuzzy logic approach extends the traditional formalisms of knowledge representation, leaning on the idea of imprecise knowledge describing. For instance, in statement "if the car is old and cheap, then probably is not in a good shape", there are five sources of uncertainty: time uncertainty (fuzzy predicate "old"), fuzzy predicate uncertainty ("cheap" and "not in a good shape"), event uncertainty ("car are not in a good shape") and uncertainty in fuzzy characterization of the event ("probably") [12].

Absence of classical expert systems representation and reasoning over inexact knowledge compensate fuzzy logic expert systems, enabling the form of representation and inferencing over human knowledge that origins form human inherent fuzzy concepts, unreliable and incomplete information, similar but not identical pattern recognition, etc.

4. RULE BASED FUZZY INFERENCING

Typical fuzzy logic system could be illustrated by Fig. 1. It consists of four main components:

- **fuzzification interface** that contains predefined set of linguistic values. It converts non-fuzzy (deterministic) inputs of fuzzy system into a fuzzy inputs for inferencing mechanism.
- **knowledge base** that consists of two parts: **database** that defines linguistic variables fuzzy sets, and **rule base** that represents the mapping of fuzzy input set into a fuzzy output set. Rules are fuzzy conditional statements (implications).
- **decision logic** that simulates human decision making based on fuzzy concepts. Conclusion of certain condition is derived by decision making logic.
- **defuzzification interface** that converts rule base fuzzy outputs into non-fuzzy (numerical) values.

Central mechanism of knowledge base and decision making logic considers the fuzzy extension of conventional rule inferencing concept to **fuzzy rules inferencing**. Premises and conclusions of rules now contain fuzzy i.e. inexact facts. These facts by definition describe practically continual input set of characteristics. In this manner, one rule can replace more conventional rules.

Fuzzy inferencing rules generally connect **m** conditional variables $X_1,..., X_m$ to **n** consequent variables $Y_1,..., Y_n$ in form of:

if X_1 is A_1 and ... X_m is A_m
then Y_1 is B_1 and ... Y_n is B_n

where $A_1,..., A_m$ and $B_1,..., B_n$ are linguistic terms of linguistic variables $X_1,..., X_m$ and $Y_1,..., Y_n$, respectively.

5. KNOWLEDGE BASED FUZZY LOGIC SYSTEM OBJECT IMPLEMENTATION

Fuzzy inferencing expert system can be viewed as the fuzzy extension of classical system with inferencing mechanism over entirely defined data. Therefore the development of such system can be set as traditional inferencing mechanism implementation with the explaining possibility at first, which could be further upgraded in order to exploit fuzzy knowledge and fuzzy inferencing. Such a concept is applied in this paper.

5.1. Inferencing production system

On the basis of known (assigned) facts, using rule set of the assigned knowledge base, production system reaches the conclusion which truth value is examined (existence of the fact in the working memory, if it does not, is it possible to be derived from the known facts). This mechanism is known as the forward chaining mechanism (production system).

When the inferencing mechanism ran into a applicable rule (the rule where premises could be satisfied), upon rule execution conclusion has to be added to working memory (set of initial and drawn facts). That is how the system can "learn" i.e. enlarge the existing knowledge base. That means that the goal, not necessarily of the first level (consequence of the first passing through the rules), can be concluded, but also the other goal, by multiple going through rule base and inferencing over conclusions already executed rules. Inferencing mechanism should enable the rules that input of the one be the premise of some other rule. For correct describing of the real system model, hierarchical decision structure is needed, i.e. using of the complex inference tree.

Production system based on the preassigned inference tree, represented by production rule set, is realized in this paper. Drawing of conclusions is performed on the basis of certain, predefined facts.

System is tested on the complex inference tree, from the Fig. 2, with inter rules that in multiple level represent the process of conclusion drawing, concerning source of certain car.

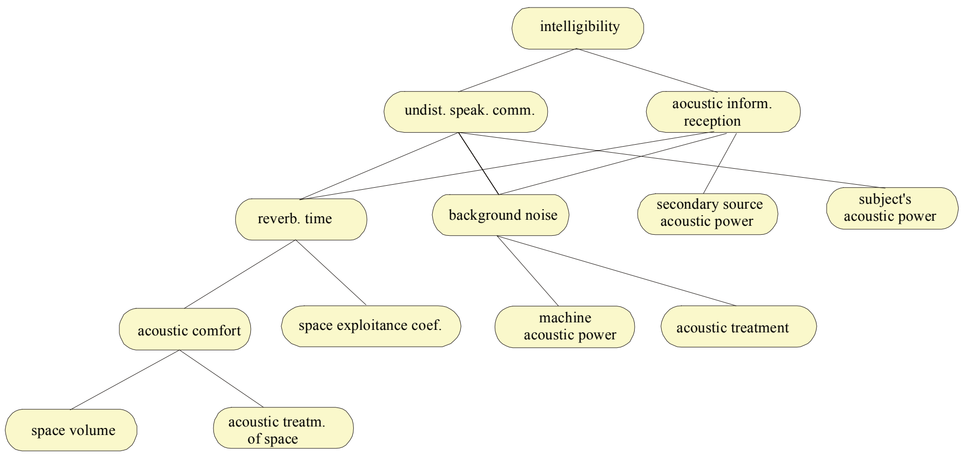


Fig. 2. Inferencing tree of test example production system

Upon predefined inference tree, production rules should be made, and determine if some conclusion, based on certain predefined initial facts, could be withdrawn.

Embedding of new classes, methods and other parameter of production rules is performed by the main steps of object oriented development and by exploiting the fountain model for object development of software system.

For the purpose of production rule system, existing class hierarchy of some object environment could be upgraded by implementation of 3 new classes: **Expert**, **Rule** and **Fact**. That is how the entity (along with corresponding attributes – instance variables) is identified, and represent the **expert** that uses **facts** and **rules** for drawing the conclusion (Fig. 3). Instance of **Expert** class fires all available rules and calculates parts of the rule with the conclusion, generating concluded facts, until final goal fact is achieved, or all rules based on known facts of the knowledge base, are fired/searched through.

Goals are achieved by adequate message sending, and the system could provide an explanation of the way of achieving certain conclusion.

5.2. Knowledge based, object fuzzy logic system

Fuzzy inferencing mechanism could be implemented as the fuzzy extension of classical production system which uses classes and methods for inferencing over conventional data. Production fuzzy system uses preimplemented messages of the fact of interest's checking authenticity. The system contains messages that check if the fact exists in base of facts, messages for inferencing over recently concluded fact (for multiple firing of the rules), as also as the mechanism of describing of performed inferencing.

The existing mechanism could be further expanded for premises and rule conclusions to contain as also classical as fuzzy facts (linguistic terms). Objects that are involved in inferencing could be classic objects and objects that contain fuzzy terms.

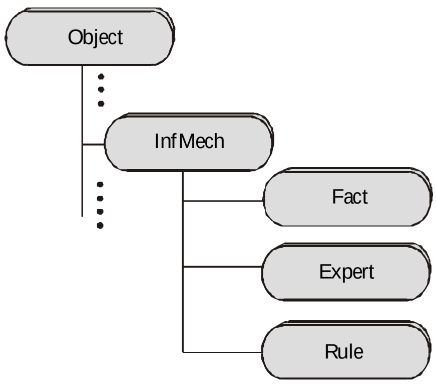


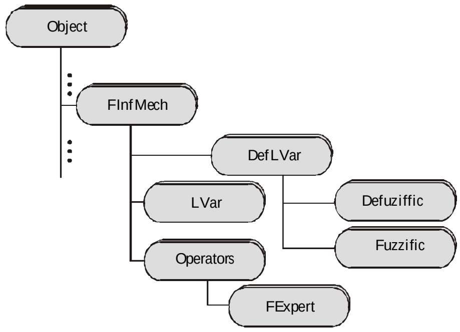
Fig. 3. Class hierarchy of production system

The aim of this fuzzy system model was to unite both fuzzy set concept and fuzzy logic inferencing with object knowledge representation. System uses the knowledge base (fuzzy rules) and working memory (fuzzy facts), that are implemented by objects, accomplishing the advantages of the object approach.

Such object approach to the fuzzy system realization, enables **simple modification** of all the model parameter.

5.2.1. Object implementation of the fuzzy logic system

Fuzzy inferencing system can be implemented as an extension of the existing forward chaining system and that way exploit for that purpose already embedded classes. In order to achieve fuzzy model of such mentioned system, the existing hierarchy is upgraded by hierarchy from Fig. 4 and thus obtained the class hierarchy from Fig. 5. Therefore, realized fuzzy expert system is hybrid, enabling treatment of as also numerical as fuzzy terms [13].



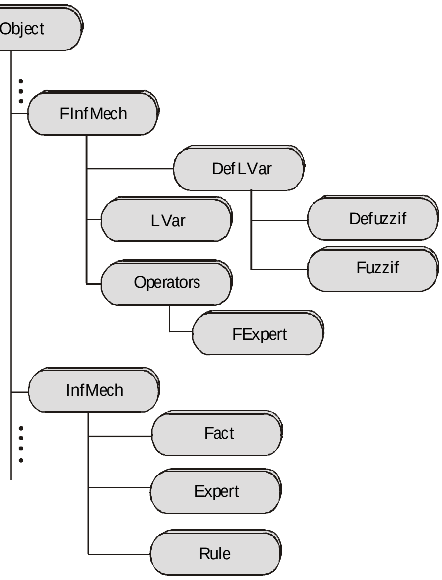


Fig. 4. Class hierarchy of the fuzzy inference system

Fig. 5. Final hierarchical structure of fuzzy inference engine

5.2.2. Test example

For the purpose of the experiment, the test example of ambiental comfort estimation depending on following parameters:

1. **Good speech intelligibility** (logatom intelligibility by speech reproduction)
2. **Acoustic information reception** (expert evaluation)
3. **Undisturbed speaking communication** (signal level by 10 dB greater then general noise)

Other parameters of interest are: **sensation without acoustical disturbances** (conversation without the tension), **reverberation time** (Fig. 6), **background noise**, **secondary source acoustic power** (phone, etc.), **subject's acoustic power**, **acoustic comfort**, **space exploitance coefficient**, **machine acoustic power**, **acoustic treatment** (absorption, barriers, etc.), **space volume** and **acoustic treatment of space**.

Identified parameters are expressed by if-then rules.

Giving names to fuzzy subset of linguistic variables is of great importance for intelligibility, maintaining and validation of fuzzy system models. Since fuzzy models are based on linguistic approach to a representation of real model, the name of the fuzzy set has to be chosen to represent the adequate meaning of the certain term as near as it is possible. In this example, names **communication without disturbances, intelligibility, information reception, undisturbed speaking communication and reverberation time**, are used to illustrate linguistic variables in speech intelligibility estimation model.

The rule set created to represent the fuzzy system model, can be represented in form of the Tables 1. and 2. (Table 2. is 3×3 FAM matrices), and can be symbolically represented by coordinate system (Fig. 7).

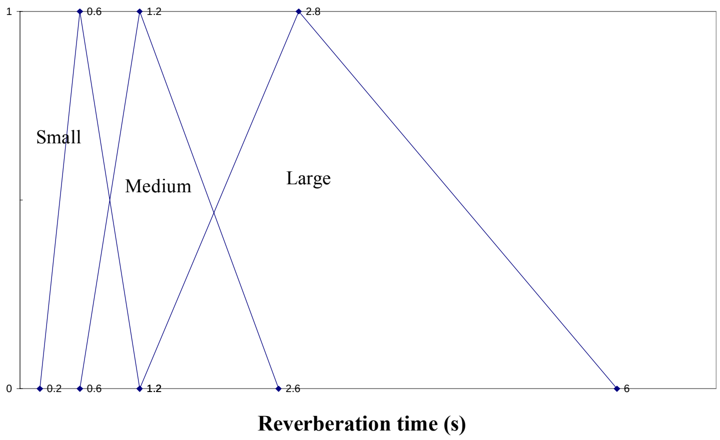


Fig. 6. Linguistic variable Reverberation time

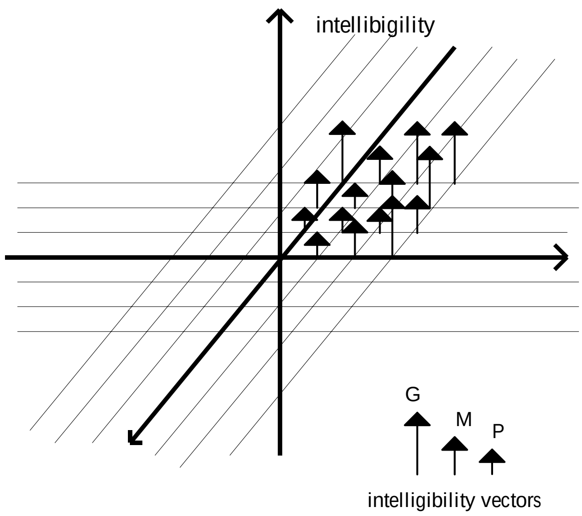


Fig. 7. Fuzzy rules of simulated system

Table 1. Inference table example

rule no.	inf.rec.	sp.com	intell.
1	S	S	S
2	S	M	M
3	M	S	M
4			
5			
6			
:	:	:	:

Table 2. Inference table example

		ac. inf. recept.		
s		S	M	L
p	S	S	M	M
c	M	M	M	M
m.	L	M	M	L

Diversity of defuzzification methods is fully expressed at the systems with rule aggregation (systems where situations with simultaneous multiple applicable rules arise).

In the above test example such examples have not been considered (input variables are without overlapping membership functions), but for certain parameter values and for certain end-cuts, trend of deffuzified, numerical values at implemented methods is examined.

Ultimate fuzzy logic system should enable inference over linguistic variables with overlapping membership functions, too. A step toward this is achieved. The procedure of fuzzification such variables has been realized. A modification of the main message for returning defuzzified valued of the concluded alarm state (membership degree, linguistic term and its description) has been done. By implemented and tested operators of membership function aggregation, an inferencing should be performed.

The original hierarchical structure, after some successive modification has resulted in structure from Fig. 5.

6. Conclusion

Fuzzy systems based on knowledge, that find an useful practical application in situations difficult to be described by mathematical models (due to incomplete, imprecise information and conceptual complexity of the problem), have been considered in this paper. The problem of intelligibility speech information due to increase acoustic load in certain ambient, was exactly explained in this paper.

An identification of basic acoustic parameters, established FES and the way of its realization, are all illustrated in this paper.

Approximate approach is based on qualitative evaluation of state parameters of certain complex system, using linguistic descriptions (linguistic variables and linguistic terms).

References

1. Zadeh, A.L., "Fuzzy Logic", *IEEE Computer*, vol.21, no.4, pp.83-93, April 1988.
2. Zadeh, L.A., "Fuzzy Logic and the Calculus of Fuzzy If-Then Rules", *IEEE 0195-623X/92*, 1992.
3. Zadeh, A.L., "Soft Computing and Fuzzy Logic", *IEEE Software*, pp.48-56, November 1994.
4. Kandel, A., "On the Decomposition of Fuzzy Functions", *IEEE Trans. on Computers,* vol.C-25, no.11, pp.1124-1130, November 1976.
5. Temme, K.,H., "Applications of Fuzzy-Logic", *Course on Intelligent Technologies and Soft Computing*, Romania 1995.
6. Zadeh, L.A., "Fuzzy sets", *Information and Control*, vol.8, pp.338-353, 1965.
7. Zadeh, A.L., "Appendix", Proc. of the U.S.-Japan Seminar on Fuzzy Sets and Their Application, Berkeley, Ca., pp.27-39, July 1974.
8. Mamdani, E.H., "Application of fuzzy algorithms for control of simple dynamic plant", *Proceedings IEE*, vol.121, no.12, pp.1585-1588, December 1974.
9. Runkler, T.,A., Glesner, M.. "A Set of Axioms for Defuzzification Strategies - Towards a Theory of Rational Defuzzification Operators ", *Proccedings of IEEE Int.Conf. on Fuzzy Systems*, 1993.
10. Parsaye, K., Chignel, M., *Expert System For Experts*, John Wiley & Sons, Inc. 1988.
11. Brachman, R.J., Levesque, H.J., *Readings in Knowledge Representation,* Morgan Kaufmann, Los Altos, Ca., 1985.
12. Zadeh, L.A., "Commonsense Knowledge Representation Based on Fuzzy Logic", *IEEE Computer*, pp.61-65, Oct., 1983.
13. Manic M., Fuzzy logic based on an object representation of knowledge Master's thesis, Faculty of Electronic Engineering, Oct. 1996.

PROCENA RAZUMLJIVOSTI GOVORA KORIŠĆENJEM FAZI LOGIČKOG ZAKLJUČIVANJA

Miloš Manić, Dragan Cvetković, Momir Praščević

Razumljivost ambijentalnih informacija predstavlja rastući problem zbog evidentno sve većeg akustičkog opterećenja u slučaju različitih hala. Fazi ekspertni sistemi predstavljaju proširenje postojećih ekspertnih sistema i karakterišu se nekim kvalitativnim poboljšanjima, koja nastoje da reše probleme kojima se do tada pristupalo na kvantitativan, numerički način. Primer dat u ovom radu, odnosi se na procenu prepoznavanja govora primenom predloženih mehanizama.