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Modelling of Fuzzy Expert Information in the Problem of a Machine Technological Adjustment

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Abstract. The paper considers the problem of stating fuzzy expert information for intelligent systems of decision support. The application of such systems is worthwhile when complex agricultural machines operate under the changing field conditions, characterized by fuzziness of information concerning external environment and parameters of a machine. One of the important stages of making expert systems for agricultural machines is modelling of fuzzy information regarding input and output parameters of the system and also their interrelations. The paper presents the problem solution of linguistic representation of the adjustable parameters of a combine harvester: speed of the combine movement, rotational speed of the threshing drum, and rotational speed of the separator fan. These parameters are most important for providing qualitative indices of technological process in combine harvesting, and they are characterized by efficiency of control and accessibility of updating. As a result of the analysis, linguistic variable, basic and extended term-sets have been determined. On the basis of the information, obtained from four experts, membership functions have been constructed with the use of standard functions of triangle and trapezoidal types. The indices of consistency of the expert models have been calculated, and the optimal models have been selected on the basis of their analysis.

1 Introduction

Intelligent information systems of decision support are widely used while performing control of complex technical systems. An urgent character of the development of such systems for providing control of harvesting agricultural crops is specified by complexity, inertia, diversity of external factors and parameters of the technical system, multiple connections and insufficient study of interrelations of the object domain attributes, difficulty of decision-making when eliminating abnormal situations connected with substandard quality of harvesting. Thereby, the problem of making machines of new, intelligent type is distinguished in the strategy of developing agricultural engineering in our country as one of the most important. Grain combine is the main machine used for harvesting many crops. Efficiency and high quality of harvesting directly depend on optimal solution of the control problem of combine harvesting technological process.

For harvesting machines, working in changing external conditions, the problem of setting optimal values of adjustable parameters is especially urgent. It is rather difficult under field conditions to assess certain values of external factors influencing the technological process, and find out their change in due time. Estimation of external factors has an approximate, frequently qualitative (subjective) character; this stipulates reference for the mathematical apparatus of the theory of fuzzy sets [1, 2]. In [3, 4] there is a review of the available approaches to the problem of a combine harvester technological adjustment; among the considered approaches there are regression models, experimental and statistical methods, automated facilities for control and management. The first two represent tedious mathematical constructions that don't always adequately reflect reality, their use in real time and complex conditions is difficult; the last one mainly solves the problems of a combine harvester movements control and doesn't provide decision support while carrying out technological adjustment of the combine harvester working tools. Complexity and low efficiency of the conventional mathematical models of a combine operation, and also fuzzy character of information concerning external factors and their interrelations with technological parameters stipulate the use of mathematical apparatus of the theory of fuzzy sets [1, 2] as the main one for describing the process of decision-making in complex multilevel hierarchic systems that grain combine harvesters refer to. The suggested approach of fuzzy modeling of decision-making processes, when performing technological adjustment and updating the parameters of the combine harvester

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working tools, meets the requirements of the system analysis. It provides integrity of consideration of the complex hierarchy system (combine harvester) on the basis of accounting basic elements and processes in the system and relations between them. It also has sufficient degree of simplification when modelling, allowing to reflect adequately a real process and take into account the determining factors in this system.

Intelligent information systems of decision support on the basis of fuzzy control [5] are at present used in agricultural industry. But, as a rule, they are connected with the analysis of patterns, weather conditions, sorting or processing products, yield checking, they are applied for identification of weeds, definition of the combine harvester location in the field, its monitoring and movements etc. [6-13]. The problems of automatic setting some parameters of the combine operation on the basis of quality factors when using production rules are also considered [14, 15].

2 Problem definition

In fuzzy models for formalizing real systems a linguistic approach is applied, and the dependency between the sets of input and output variables is described on the qualitative level in the form of statements by means of production rules. The mechanism of fuzzy logic inference in fuzzy models is significantly based on expert knowledge. Authenticity and correspondence of expert information to real conditions essentially influence the accuracy of solution; this establishes high requirements to organization of the base of expert information.

Modelling of decision-making in fuzzy expert systems consists of three stages: fuzzification, composition and defuzzification. Generation of the expert information unit takes place at the stage of fuzzification. At this stage, an object domain is studied, significant factors are determined and the conditions of the problem solution are presented in a linguistic form. In accordance with the logic-linguistic approach, the models of input and output attributes are developed in the form of semantic spaces and the corresponding them membership functions (MFs).

In the problem of technological adjustment of the grain combine harvester parameters the input parameters include crop yield, humidity, content of impurities, haulm density and some others. In [16-17] we considered the problem of setting optimal parameters of the models of the mentioned linguistic variables (LVs) that characterize external factors.

The output LVs for the problem under consideration are adjusting parameters. For technological adjustment of the main units of the grain combine harvester (header, grain separator) 54 adjustable parameters are used.

The most important ones with regard to operational efficiency, accessibility and degree of impact on the quality of harvesting are speed of the combine movement, rotational speed of a threshing drum and rotational speed of a separator fan. The present paper considers establishment of fuzzy expert information for the indicated adjusting parameters.

3 Problem solution

The performed analysis of the object domain "Combine harvester technological adjustment" made it possible to set up basic and extended term-sets of the linguistic variables Speed of a harvester (SH) (for the crop yield of approximately 40 q/ha), Rotational speed of a threshing drum (RSTD) (for the crop yield of approximately 50 q/ha) and Rotational speed of a separator fan (RSSF) (for harvesting barley). To provide assessment, four experts were given 5-term and 7-term models. Typical functions of trapezoidal and triangle types have been applied for describing the terms [18]. To choose the optimal quality of terms we applied the technique [16, 17] which is based on the analysis of indices of general and pair consistency of models.

General consistency of models of expert estimation of an attribute is determined by additive k and multiplicative $\tilde{k}$ indices [18, 19].

$$k = \frac{1}{m}\sum_{l=1}^{m}\frac{\int_0^1 \min\limits_{\forall i=1,2,\dots,n} \mu_{il}(x)dx}{\int_0^1 \max\limits_{\forall i=1,2,\dots,n} \mu_{il}(x)dx};\ \tilde{k} = \sqrt[m]{\prod_{l=1}^{m}\frac{\int_0^1 \min\limits_{\forall i=1,2,\dots,n} \mu_{il}(x)dx}{\int_0^1 \max\limits_{\forall i=1,2,\dots,n} \mu_{il}(x)dx}} \qquad (1)$$

where l=1,2,...,m - is the term number, i=1,2,...,k - is the expert number, $\mu_{il}(x)$ - is MF which was assigned by the i -th expert for the l-th term.

The index of difference d_{ij}^l between the models of two experts, i-th and j-th, within the framework of l-th term is determined as a linear distance (by Hemming) between fuzzy sets with MF $\mu_{il}(x)$ and $\mu_{jl}(x)$ [20].

$$d_{ij}^l = \int_0^1 \left|\mu_{il}(x) - \mu_{jl}(x)\right| dx \qquad (2)$$

The values d_{ij}^l form a matrix of fuzziness indices D^l for l-th term.

The index of consistency between the models is determined by the value k_{ij}^l [18].

$$k_{ij}^l = \frac{\int_0^1 \min[\mu_{il}(x), \mu_{jl}(x)]dx}{\int_0^1 \max[\mu_{il}(x), \mu_{jl}(x)]dx} \qquad (3)$$

Then we construct the pair consistency matrix K^l of the models of i-th and j-th experts within the framework of l-th term. It is evident that on the main diagonal of the matrix D^l there are nulls, and on that of the matrix K^l there are unities and symmetric matrices.

On the basis of matrix of fuzziness indices and matrix of pair consistency of the models for all terms, matrix of fuzziness indices D and matrix of consistency K of the models for all terms are determined. Their elements are determined by the formulae [18, 19].

$$d_{ij} = \frac{1}{m}\sum_{l=1}^{m} d_{ij}^{l}, \quad k_{ij} = \frac{1}{m}\sum_{l=1}^{m} k_{ij}^{l} \qquad (4)$$

A subsystem of obtaining and updating of intelligent information systems knowledge has been developed for computations automation on estimating consistency of fuzzy expert information [21]. When introducing new and updating available linguistic variables a computation of additive and multiplicative indices of common consistency among the models is performed.

Results of calculations of additive k and multiplicative $\tilde{k}$ indices by the formulae (1) for all the models are given in table 1.

Table 1. Results of calculations of indices *k* and $\tilde{k}$.

LV	Model	***k***	$\tilde{k}$
SH	5-term	0,721	0,716
	7-term	0,892	0,890
RSND	5-term	0,697	0,692
	7-term	0,765	0,753
RSSF	5-term	0,734	0,727
	7-term	0,729	0,728

The analysis of consistency of expert models made it possible to choose optimal models of the linguistic variables: 7-term models for Speed of a harvester and Rotational Speed of a threshing drum and a 5-term model for Rotational speed of a separator fan. As a result we obtained the following linguistic description of the adjustable parameters under consideration.

The tuple of the output LV "Speed of the harvester-40" (i.e. for the crop yield of approximately 40 q/ha) has the following form:
< SPEED OF HARVESTER, km/h {Very low, Low, Lower than nominal, Nominal, Higher than nominal, High, Very high}, [2,5 – 5,5] > SH = {VLSH, LSH, LNSH, NRTH HNSH, HSH, VHSH, km/h}.

The tuple of the output LV "Rotational speed of the threshing drum for wheat-50" (i.e. for the crop yield of approximately 50 q/ha) has the following form:
<ROTATIONAL SPEED OF THRESHING DRUM, rev/min {Very low, Low, Lower than nominal, Nominal, Higher than nominal, High, Very high}, [620 – 940] >
RSTD = {VL, L, LN, N, HN, H, VH, rev/min}.

The tuple of the output LV "Rotational speed of the separator fan - barley" (i.e. for barley harvesting) has the following form:
<ROTATIONAL SPEED OF SEPARATOR FAN, rev/min {Low, Lower than nominal, Nominal, Higher than nominal, High}, [550 – 800] >
RSSF = { L, LN, N, HN, H, rev/min}.

For the selected optimal models the parameters of the generalized MFs have been calculated. When averaging, we used equal weighting factors, and the reason for this was rather high indices of pair consistency (3) for all experts. As an example we provide matrix K (4) of pair consistency for all terms for the optimal model of the LV Rotational speed of the separator fan.

$$K = \begin{pmatrix} 1 & 0,992 & 0,735 & 0,907 \\ 0,992 & 1 & 0,795 & 0,832 \\ 0,735 & 0,795 & 1 & 0,813 \\ 0,907 & 0,832 & 0,813 & 1 \end{pmatrix}$$

The graphs of the generalized MFs in question are presented in figures 1 - 3.

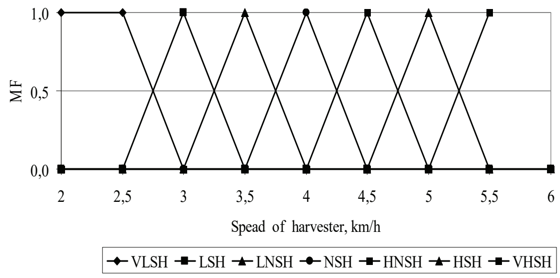

Fig. 1. Membership functions of LV terms Speed of the harvester-40.

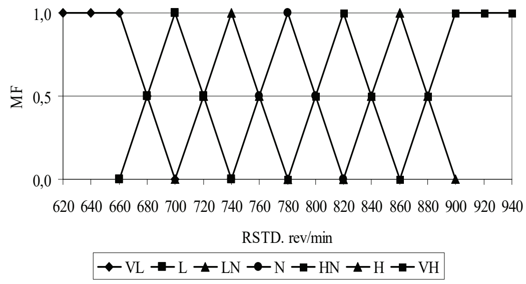

Fig. 2. Membership functions of LV terms Rotational speed of the threshing drum for wheat.

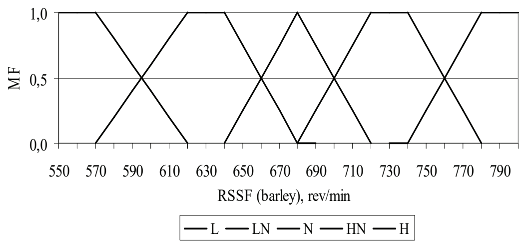

Fig. 3. Membership functions of LV terms Rotational speed of the separator fan.

The generalized membership functions are applied further in the system of fuzzy logical inference [22] for the determination of exact values of adjustable harvester parameters.

4 Conclusion

The analysis of the published papers on theoretical and applied aspects of the theory of fuzzy sets illustrates that the application of fuzzy models allows us to represent correctly the properties of the initial system and simplify the process of its analysis. The adopted degree of

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abstraction is the most reasonable as more sweeping generalization will be fruitless from the point of view of practice, and insufficient degree of abstraction will result in infeasibility of the problem solving – it will be too complicated.

The application of the mentioned approach to the problem of technological adjustment of the combine harvester in the field made it possible to formalize the object domain, obtain linguistic description of the adjustable parameters, select optimal term-sets, and to construct the generalized membership functions of the linguistic variables. Therefore, the unit of fuzzy expert information has been prepared for realizing fuzzy logical inference of the expert system, which provides setting-up optimal adjustable parameters of the combine harvester. The application of such expert systems in the field environment makes it possible to increase output of the combine harvester and reduce grain losses.

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