Generalized scheme of fuzzy control of grain harvester in field conditions

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Abstract. The article discusses the issues of modeling the process of managing the combine in the field. A generalized scheme for solving important practical problems of technological adjustment of the working bodies of the units of a combine harvester based on fuzzy expert data on the input factors (external environment) and output parameters (adjustable parameters of the machine) is proposed. The architecture of the knowledge base of the information intelligent system is given, as well as the relationships between the individual structural elements. The main semantic spaces of the considered subject area are highlighted. This is a group of environmental factors, a group of adjustable parameters, a group of quality indicators of the cleaning process, a group of possible violations of the quality of the cleaning process. The characteristic features of the output of solutions during technological adjustment and, accordingly, adjustments of technological adjustments are considered. Models of subject areas are presented.

1. Introduction

Making decisions on setting the parameters of the technological adjustment of the combine operating in the field conditions for harvesting a specific grain crop under changing environmental factors is one of the urgent tasks for maintaining and ensuring the quality of the crop. The difficulty in choosing the values of technological parameters is due to a number of factors, including a significant and ambiguous dependence of the regulated parameters on external factors of cleaning. Another important factor is the variability of external factors and the approximate estimated nature of their values. As a result, even a skilled operator may have difficulty making decisions about the assignment of kinematic and other parameters of the working parts of the machine. Insufficiently competent decisions lead to significant financial losses, which are caused by: direct grain losses, mechanical damage to grain, increased machine downtime, increased consumption of fuels and lubricants, etc.

Currently, active research is underway on the digitalization of agricultural technological processes and the implementation of the concept of "precision farming" [1-2]. Combine combines actively use modern automatic control and management systems for the operation of the machine. With the undoubted efficiency of the use of such systems, one cannot fail to note the inadequacy and efficiency of some of them. In addition, the existing automatic and information systems mainly solve the following tasks: controlling the movement of the combine, adjusting the engine parameters, the frequency of rotation of the main working bodies, controlling the losses (intensity) of grain, etc. and to a much lesser extent provide the operator with information support in complex (often changing) field conditions when there is a deviation of the quality indicator of the technological process of combine harvesting from the permissible value [3-8].
Earlier it was shown that the combine is a multilevel hierarchical system, for the control of which (in particular, for the process of making decisions on technological regulation) it is advisable to use information support based on a linguistic approach [9-10]. This is due to the fact that the processes of technological adjustment of the combine and troubleshooting do not have adequate mathematical descriptions that could be used in the operational control system in real time.

One of the promising directions for the implementation of timely decision-making in the operation of agricultural machines in real time is the creation of intelligent information systems (IIS-ES), based on the methodology of fuzzy knowledge. Currently, fuzzy expert systems are successfully used in various fields of agriculture [11-19], such as processing and sorting agricultural products, determining the yield, identifying weeds, positioning the combine in the field, controlling its movement, etc. Along with the methodology of fuzzy sets and fuzzy logic in expert systems use image analysis, genetic algorithms. Systems for selecting the values of the combine parameters based on the quality indicators of the technical process using production rules [12-13], predicting malfunctions [18], and evaluating the reliability of machines [19] have become widespread.

Formulation of the problem. The complexity of the tasks of managing the combine harvesting process is due to the complexity of the design of the mechatronic system (combine) itself, which interacts with representatives of wildlife (grain, soil, stem, etc.). By its nature, the external environment is characterized by fuzzy information about its parameters. Currently, there are no traditional mathematical models that represent the relationship between harvesting factors and the parameters of the machine itself. Most of them are of an approximate nature and are practically not used in the field.

For example, the standard procedure for helping the operator in modern combines when adjusting the working tools is to assign an interval of values for a specific kinematic parameter of the working tool (for example, a threshing drum), depending on the type of crop. When a deviation of the quality indicator of a technological process appears, a prompt when searching for the cause of this deviation from the set value consists in a ranked list of possible causes.

The improvement of the methods of technological regulation determines the appeal to fuzzy modeling and the development of decision-making information systems (expert systems) based on the use of fuzzy expert knowledge and rules of fuzzy logic [20].

The creation of a knowledge base of such systems is based on a domain model. The problem of defining a formal language for describing decision-making processes in the field is prevalent. The fuzzy (linguistic) presentation of information objectively reflects the approximate nature of the available information about the parameters of the environment and the machine and adequately characterizes the essence of the process, and also allows taking into account, both with fuzzy goals, and fuzzy restrictions.

2. Materials and methods

Identification and analysis of the studied process of technological adjustment of the combine made it possible to substantiate the methodology for constructing domain models based on the methodology of fuzzy sets [10-11]. This technique includes the stages of fuzzification, composition and defuzzification.

For the problem of finding the initial values of the adjustable parameters of the combine, production-type models are used:

\[
\text{IF } A1 \text{ and } A2 \text{ and } \ldots \text{ and } A_n \text{ THEN } P1 \text{ and } P2 \text{ and } \ldots \text{ Pm} \quad (1)
\]

As A1, A2 ... An, there are many values of the parameters of the external environment (crop, yield, moisture of the stand, weediness, etc.) As P1, P2, ... Pm, there are many permissible values of the kinematic and geometric parameters of the working bodies.

To solve the inverse problem - adjusting the adjustments (if there is a deviation of the value of the quality indicator from the permissible, for example, grain crushing is higher than the permissible), the production type model has the form:
IF P, THEN B or C or ...

As P, there are many external signs of deviation of the quality indicator from the permissible value, and as the values of the parameters of the working bodies of the combine, signs B, C. When solving this problem, the assumption is made that at the same time only one deviation of the quality indicator from the permissible value can be observed.

On the basis of the considered logical-linguistic approach, we have proposed models of the semantic spaces of the system under study: X - the space of cleaning factors; Y - spaces of adjustable parameters; V - spaces of quality indicators, as well as the corresponding membership functions µ:

\[
\mu_k(x_1, x_2, ..., x_i) \in (0; 1)
\]

\[
\mu_k(y_1, y_2, ..., y_j) \in (0; 1)
\]

\[
\mu_k(y_1, y_2, ..., y_k) \in (0; 1)
\]

Compositions of fuzzy relations of the specified semantic spaces is a mathematical model of the subject area "setting the combine":

\[
R = X \rightarrow Y
\]

Where R - is the fuzzy relationship between the harvesting factors and the kinematic and geometric values of the parameters of the individual working bodies of the combine, which must be assigned when changing the harvesting factors:

\[
R \{X, T(X), U, G, M\} \times \{Y, T(Y), U, G, M\} \quad \forall (x, y) \in X \times Y
\]

The relation R is a fuzzy set on the direct product of the considered constituents of the rules-productions: premises and conclusions, that is, X×Y.

The composition of fuzzy relations of all considered semantic spaces is a model of the problem of "adjusting technological adjustments":

\[
R_1 \circ R_2 ~ \forall x \in X \quad \forall y \in Y \quad \forall v \in V
\]

\[
\mu_{R_1 \circ R_2}(x, v) \lor (\mu_{R_1}(x, y) \land \mu_{R_2}(y, v))
\]

Where R_1 is the fuzzy relation "cleaning factors - kinematic and geometric parameters of the working bodies":

\[
R_1 \{X, T(X), U, G, M\} \times \{Y, T(Y), U, G, M\} \quad \forall (x, y) \in X \times Y
\]

\[
R_2 \{Y, T(Y), U, G, M\} \times \{V, T(V), U, G, M\} \quad \forall (y, v) \in Y \times V
\]

3. Results

The analysis of the considered processes of combine harvesting revealed that, in accordance with their characteristic features, it is advisable to use both deductive and inductive methods for deriving the desired solutions. Figure 1 shows a generalized scheme for solving the problems under consideration.
Figure 1. Generalized decision making scheme based on the proposed approach (here premise A and corollary B - there are fuzzy statements related to specific tasks).

Figure 2 shows the structural components of the knowledge base containing information about the main semantic spaces of the studied subject area. This is a group of environmental factors, a group of adjustable parameters of the working bodies of the combine aggregates, a group of quality indicators of the harvesting process, a group of possible violations of the quality of the harvesting process.

The expert system, in contrast to the traditional method of adjusting the combine, offers the opportunity to make the so-called "fine tuning", which takes into account the characteristic uncertainties in setting the values of the harvesting factors. In fig. 3 shows a diagram of the formation of production rules and the conclusion of decisions, i.e. obtaining a specific value of the combine parameter. In this case, the traditional scheme for determining the initial value of the controlled parameter, which is incorporated in the automated system of the combine and is used by the operator (machine operator), consists in setting the interval of parameter values. The knowledge base, built in...
accordance with the proposed scheme, allows the initial adjustment of the working bodies to be more adequate to the external conditions of the environment.

The presence of this procedure can significantly reduce the time to find the cause of the disruption of the technological process, which necessarily occurs when the harvesting conditions change (changing weather conditions, moving to another field, changing factors depending on the time of day, etc.).

Figure 3 shows that taking into account all factors in the rules of the knowledge base of the expert system makes it possible to initially determine the initial value of the controlled parameter adequate to the cleaning conditions. For example, instead of a single-digit value of 840 rpm (coarse setting), it is possible to set the value as close as possible to specific harvesting conditions [820, 860, 900] rpm.

![Scheme "fine tuning" using an expert system](image)

**Figure 3.** Scheme "fine tuning" using an expert system "(UR40 - yield 40 c/ha; CHVMB - threshing drum rotation frequency).

4. Conclusion
The efficiency and effectiveness of combine harvesting in difficult field conditions are determined by the optimal solutions to the tasks of setting and adjusting the technological adjustments of the working bodies. Finding optimal solutions to these problems is complicated by the fact that they belong to the class of non-formalized decision-making problems.
For an adequate description in a formalized form of the real process of finding solutions, it is advisable to use the methodology of fuzzy sets. The use of this methodology makes it possible, with a sufficient degree of simplification, to build models that are adequate to external conditions, take into account all the semantic spaces of the system's features (both quantitative and qualitative), and display the relationships between them. As a result, we can talk about the creation of an integral model of subject areas, which fully corresponds to the real conditions of the functioning of combines, based on a single formalism of signs of the system under consideration.

As a result of modeling, a knowledge base was formed for each of the regulated parameters, which includes 60 production rules, taking into account five input factors (crop, yield, moisture, straw content, weeding). Only for the considered conditions, the knowledge base is 2400 production fuzzy rules.

The use of this approach in the implementation of an intelligent information system will significantly increase the shift time ratio of the combine and, as a result, increase the efficiency of harvesting.

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