Development of an Approach to Adaptive Construction of Individual Educational Trajectories for Students of Massive Open Online Courses Based on the Methods of the Fuzzy Set Theory

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Abstract

The issue of the emergence of individual educational routes and their application in the practice of modern education is associated with the introduction of the principle of an individual approach to the development of students' abilities and knowledge. The purpose of the research is to study the application of the theory of fuzzy sets in the problem of intelligent control of individual educational trajectories, depending on the level of achievement of the planned learning outcomes in the online environment. In the presented study, a comparison is made of various ways of assessing educational achievements, expressed both numerically and qualitatively, using fuzzy numbers. Also, we have constructed a model and describe a methodology for integrated assessment of the results of mastering the contents of the curriculum of an experimental online course based on fuzzy estimates. It is established that intelligent control of trajectories will be effective if the mathematical apparatus of fuzzy logic and the theory of fuzzy sets are used. The leading methods to the study of the problem are the methods of fuzzy logic, the classical method of average values. In our research we were revealed that the fuzzy logic method is more flexible and accurate in the integrated assessment of the results of mastering an online course. The materials presented in the paper can be used as the basis for the design of an adaptive recommender system that functions as part of an online learning platform.

Keywords [1]

adaptive recommender system, individual educational trajectory, Mamdani method, fuzzy logic, fuzzy sets, online course, assessment, learning outcomes

1. Introduction

The specificity of the adaptive recommender system that operates as part of the online learning platform is to take into account the educational capabilities of the student when selecting the content of the curriculum [6, 7]. The proposed system offers the student a specific online course in a timely manner to dynamically adjust the individual educational trajectory depending on the level of achievement of the planned learning outcomes. However, the complexity of its design and creation lies in the fact that it is necessary to ensure the issuance of the right solutions in the context of incomplete, inaccurate, ambiguous, and vague information coming from the subjects of the educational process [14, 15]. To solve this problem, it is proposed to use the mathematical apparatus of the theory of fuzzy sets when constructing a model for integrated assessment of the results of mastering an online course.

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Pedagogical control, implemented in an online learning platform, is characterized by the following most important features:

(1) a change in the approach to the assessment system, which involves a transi-tion to a criteria-based, substantive assessment;

(2) assessment of the dynamics of educational achievements of students;

(3) involvement in the evaluation activities of both teachers and students;

(4) a combination of various types of control: external, mutual and self-control;

(5) providing an integrated approach to assessing all planned results of mastering the content of curricula;

(6) focus on achieving the result of education;

(7) the expansion of forms of control and methods of assessment procedures.

An individual integral assessment of the results of mastering the online course by students should be as objective and transparent as possible. Learning achievements of students should be aggregated in a timely manner in an intelligent system integrated into the online learning platform. The information received will be available to both the student and the teacher. The confidence of students that within the framework of one online course equal conditions are provided for a fair assessment of the results of educational activities, there are the same evaluation criteria and the maximum possible exclusion of subjective attitude on the part of the teacher is guaranteed, is a significant incentive to master the full content of the curriculum.

2. Related work

In the study [8], the authors use an approximate algorithm to find a solution to the vertex coverage problem that is close to the optimal one. The paper presents a greedy search algorithm for almost optimal coverage, which provides a search for a solution in polynomial time. The proposed approximation algorithm gives an optimal solution in most cases.

To construct educational path, several researchers use data on the individual char-acteristics of students. In the study [9], the authors propose two approaches to solving this problem, one of which is based on the use of methods based on neural networks.

In the study [10], the authors propose a new method for the formation of the educational path, based on assessing the effectiveness of the already studied disciplines using a dynamic control model. At the heart of the proposed model, the authors use a competency-based approach in combination with the use of modern information technologies for the analysis of learning outcomes.

In a study [11], the authors in practice propose to apply the concept of individuali-zation of educational activity, taking into account the characteristics of various types of cognitive processes that occur in the process of mastering educational programs.

Zoja Raud et al. used the ontological design of educational path [12]. The method proposed by the authors allows us to determine the basic set of competencies for the chosen field of knowledge of the student. Based on the data obtained, the authors propose to form a consistent plan for studying the cycle of disciplines.

The main task of constructing an individual educational path for the student is to reduce the risks of not completing the selected courses, as well as forecasting the time of their development [13].

A review of the studies showed that at the moment there are many algorithms for constructing educational path, but some modifications are needed to apply them to particular optimization problems.

3. The online course model

The structure of the online course is represented by n topics, each of which provides monitoring of the results of educational activities (Fig. 1) [7]:

- self-control (carried out by students over their own activities, provides for the mandatory performance of tests);
- external (carried out by the teacher over the student’s activities, involves checking mandatory assessment tasks in accordance with predetermined criteria);

- mutual (carried out by students of the course over the student's activities, involves (at the discretion of the teacher) participation in the mutual evaluation of the submitted works).

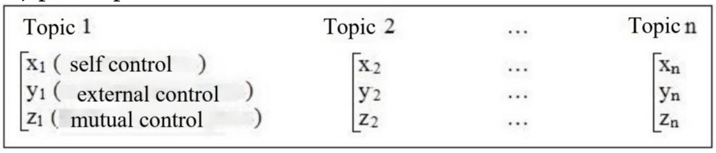

Figure 1: Evaluation procedures in the online course

For the X.Test group ("Tests (self-control)"), the input variables are (x1, x2, ..., xn), where x1 is the result of the test control in topic 1; x2 - in topic 2; ...; xn - in topic n. For the Y.Instructor group ("Activity tasks (external control)"), the variables (y1, y2, ..., yn) are defined as input, where y1 is the result of the teacher evaluating the task in topic 1; y2 - in topic 2; ...; yn - in topic n. Accordingly, for the Z. Listeners group ("Work Mutual Evaluation (Mutual Control)") - (z1, z2, ..., zn), where z1 is the result of the criteria for students to evaluate the work performed in topic 1; z2 - in topic 2; ...; zn - in topic n.

Each group has a certain weight (significance relative to each other) when calculating the integral score.

The output variable is Result, which determines the integrated evaluation of the learning outcomes of the online course curriculum.

When using the classical method of average values, Result is made up of estimates obtained for different types of phased educational work, and is calculated as follows:

Result = $\mu 1\ X + \mu 2 Y + \mu 3\ Z$,

where X is the average result of all tests; Y - the average result of the teacher checking all activity tasks (homework, essays, essays, etc.); Z is the average result of the mutual evaluation of all the submitted works by the course participants; μ1, μ2, μ3 - weighting factors that determine the significance of the respective types of valuation tools relative to each other, and the sum of which is one.

4. The use of fuzzy logic and the theory of fuzzy sets in decision making and management of individual educational trajectories

Fuzzy logic methods make it possible to carry out an integral assessment in conditions of uncertainty, for example, in cases where there is no complete information on the learning outcomes, or when evaluating, qualitative indicators are used that reflect the subjectivity of judgments or point estimates [5].

Consider the mathematical apparatus of the theory of fuzzy sets, which contributes to the construction of a fuzzy model of integrated assessment of the results of mastering the contents of the curriculum of an online course.

A fuzzy conclusion was made using the Fuzzy Logic application of the MATLAB mathematical package (Figure 4).

Linguistic variables with the names X.Test, Y.Instructor, Z.Listeners, Result were introduced. The term sets of linguistic variables are defined as follows: X.Test {Poor, Fair, Good, Excellent}, Y. Instructor, Z. Listeners, Result {Poor, Fair, Good, Very Good, Great}. The domain of linguistic variables was the set of real numbers [0; 100], since the assessment used a 100-point scale.

Input of input and output linguistic variables is shown in Fig. 2.

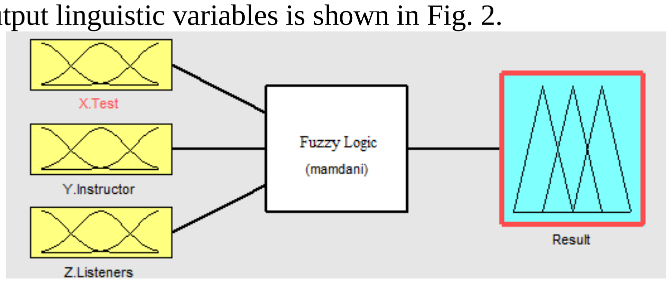

Figure 2: Input and output variables in the editor of the fuzzy output system of the Fuzzy Logic Toolbox application of the MATLAB package

The diagnostics of mastering the curriculum of the online course reflected the dynamics of achieving the planned learning outcomes and was the basis for management decisions by the teachers and tutors of the course. The results of the integrated assessment and their interpretation were used by the adaptive recommender system to give suggestions for further adjustment of the individual educational trajectory, namely:

1. if the level turned out to be “Poor”, then the student was recommended to take the course again;
2. if the level turned out to be “Satisfactory”, then the student was asked to re-examine those topics on which significant gaps were identified;
3. if the level turned out to be “Good”, then the student was recommended to study the expanded content of those for which difficulties were identified;
4. if the level turned out to be “Very Good”, then it was believed that the development of the program was completed, and it was recommended to study some additional sections that expand and deepen the program of the current course;
5. if the level turned out to be “Excellent”, then it was believed that the development of the program was completed in full, and it was recommended to study new courses in a related field or take a professional intensive course in this field of knowledge.

By using this approach, we prepared an algorithm for managing individual educational trajectories, based on an integrated assessment of the results of mastering the contents of the curriculum of an online course using fuzzy grades.

5. The fuzzy model and methodology for the integrated assessment of the results of mastering the contents of the curriculum of an online course

Modeling was carried out on the example of the data of the experimental online course "Information Technologies", the structure of which is presented by five topics.

The application of the constructed fuzzy model occurred in several stages [1, 2, 4].

Stage 1. Fuzzification of input values.

On the basis of fuzzification, a numerical value was converted into a symbolic fuzzy value. When testing the tests, a 100-point rating scale was used. When assessing the results of students completing activity tasks, the teacher was guided by pre-developed assessment criteria, in accordance with which points were set and levels were identified. Similarly, there was an mutual evaluation of the submitted works by the course participants.

The linguistic variable X.Test had four meanings - linguistic terms that correspond to given qualitative assessments: “Poor” - 0-59; “Satisfactory” - 60-75; “Good” - 76-89; “Excellent” - 90-100. Accordingly, the linguistic variables Y. Instructor, Z. Listeners and Result could take five values: "Poor" - 0-49; “Satisfactory” - 50-64; “Good” - 65-74; "Very good" - 75-84; “Excellent” - 85-100.

Stage 2. Definition of application rules and fuzzy inference algorithm.

Fuzzy reasoning - fuzzy inference using unions and intersections. Fuzzy inference was performed using the Mamdani algorithm [3]. Linguistic terms of input variables were determined by trapezoid membership functions. The values of membership functions corresponding to certain gradations were set by experts in this subject area. The result of adding five membership functions for one input variable X.Test of the fuzzy inference system is shown in Fig. 3.

The rules determined the input and output membership functions that were used in the inference process. The process of forming the base of rules for fuzzy inference was a formal representation of the empirical knowledge of an expert in this problem area.

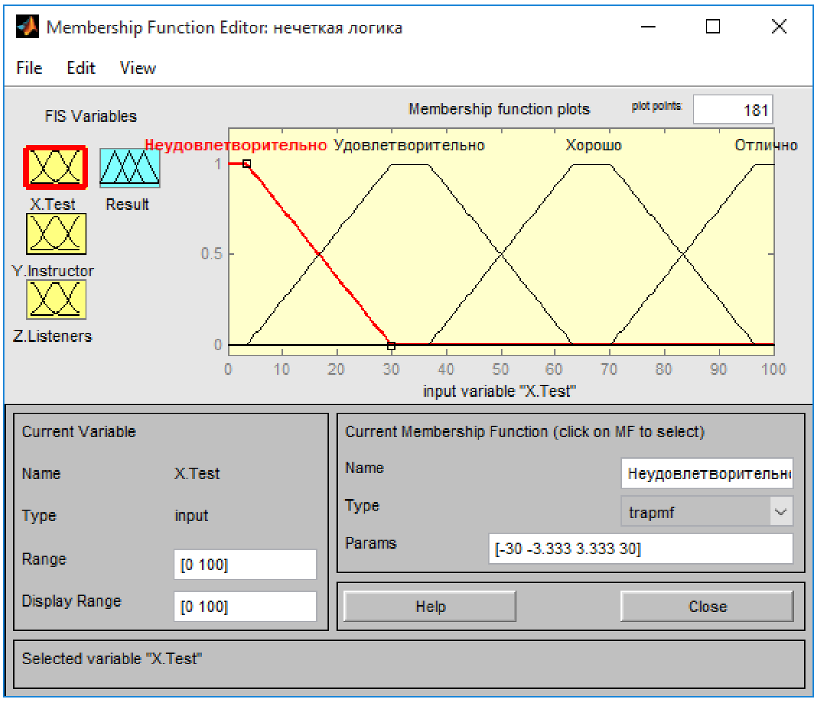

Figure 3: Indication of membership function values

An example of writing rules that look like structured text:

Rule 1: If X.Test is “Unsatisfactory” and Y. Instructor is “Unsatisfactory” and Z.Listeners is “Unsatisfactory”, then Result is “Unsatisfactory”

Rule 2: If X.Test is “Unsatisfactory” and Y. Instructor is “Unsatisfactory” and Z.Listeners is “Satisfactory”, then Result is “Unsatisfactory”

Rule 3: If X.Test is “Good” and Y.Instructor is “Very Good” and Z.Listeners is “Very Good”, then Result is “Very Good”

These rules were linguistic and made up the rule base (Fig. 4).

Stage 3. Defuzzification of the output value Result.

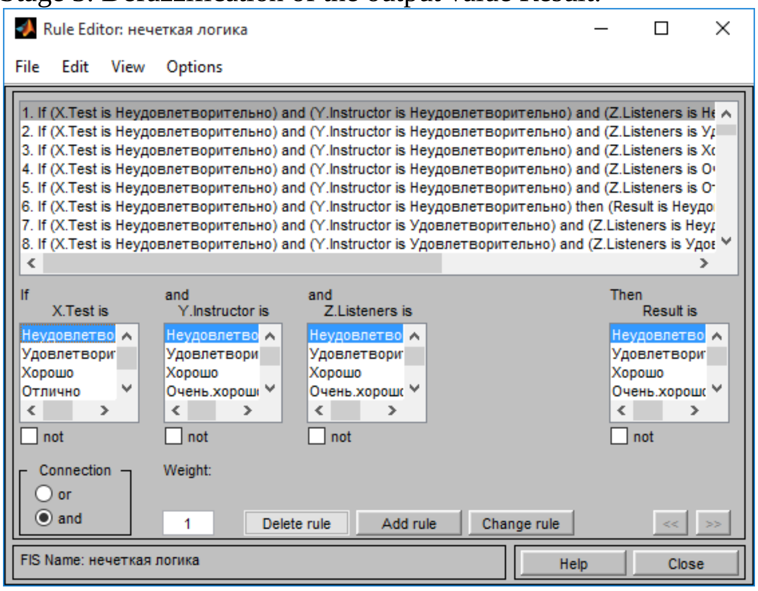

Figure 4: The window for creating the rule base

Clear decision-making - defuzzification, which was the conversion of a fuzzy symbolic value into a number.

Next, a surface graph of the solutions of the fuzzy inference system was constructed, which is a three-dimensional curve. A window for viewing the surface of solutions in the implementation of a fuzzy model of integrated assessment of the results of mastering an online course is shown in Fig. 5.

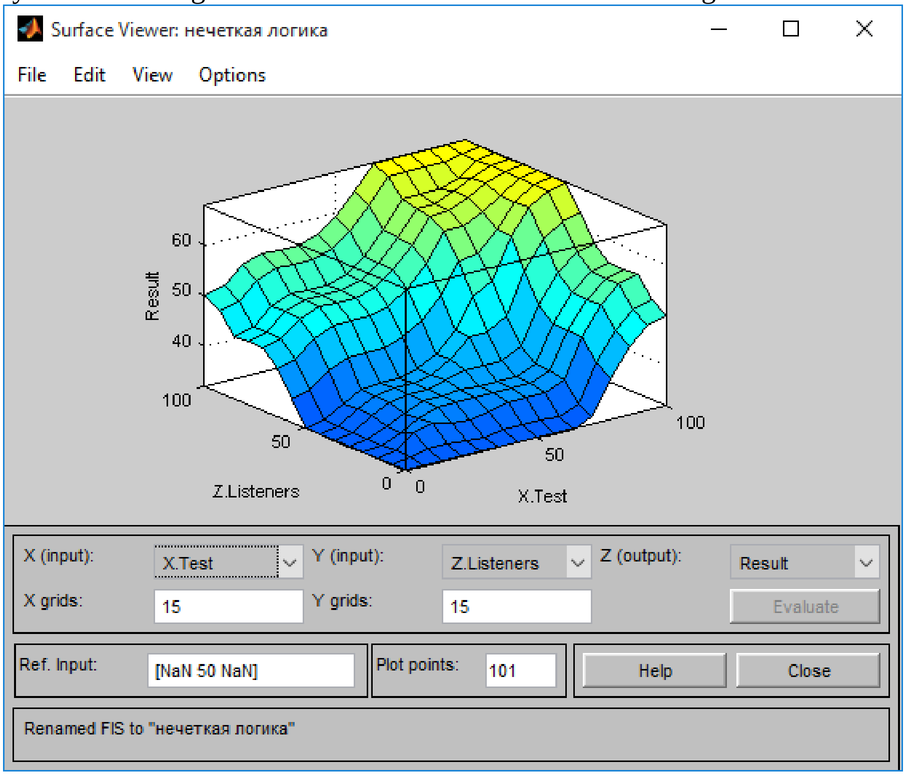

Figure 5: The window for creating the rule base

6. Experimental results

Table 1 shows a fragment of the results of applying two methods: fuzzy logic methods and the classical method of average values. The initial data for a sample consisting of five subjects (n = 5) are shown in Table 1-2.

Table 1

The results of applying two methods

No. of student	X.Test	μ_1	Y.Instructor	μ_2	Z.Listeners	μ_3
1	59		50		50	
2	74		68		85	
3	48	0.3	59	0.5	62	0.2
4	51		73		69	
5	87		75		82	

Table 2

The results of applying two methods

No. of student	Fuzzy conclusion (score)	Result	Weighted average (point)	Result
1	50.6	Satisfied	52.7	Satisfied
2	67.8	Good	73.2	Good
3	51.7	Satisfied	56.3	Satisfied
4	62.8	Satisfied	65.6	Good
5	78.4	Very well	80	Very well

The Pearson correlation criterion rxy was used to determine the presence or absence of a linear relationship between two quantitative indicators, as well as to evaluate its strength and statistical significance. The Cheddock scale was used to qualitatively evaluate the strength of the correlation relationship. The statistical significance of the correlation coefficient was estimated using the t-test (tr). An analysis of the results showed that the value of the Pearson correlation coefficient was 0.99, which corresponds to a very high tightness of the relationship between the quantitative indicators obtained by two different methods. This correlation was statistically significant ($p < 0.01$).

Therefore, using the fuzzy logic method can provide the same results as the classical method of average values. However, in some cases, differences were found in the results of the application of the two methods, namely, in the absence of data on educational achievements achieved by a number of assessment tools. Due to the fact that the fuzzy model provides the possibility of processing incomplete, inaccurate, and vague information, the fuzzy logic method is more flexible and accurate when integrating the results of mastering the contents of the curriculum of an online course.

7. Conclusions

Thus, the work presents a fuzzy model and methodology for the integrated assessment of the results of mastering the contents of the curriculum of an online course. The implementation of the desired model in the MATLAB environment required the use of a set of fuzzy logic tools with a logical inference system. The advantages of the proposed model based on fuzzy logic are as follows:

(1) the fuzzy model is more understandable for the teacher than a similar mathematical model (the teacher can edit the ranges of membership functions and the base of the rules of the fuzzy inference system, allowing a heterogeneous, but flexible and objective assessment of the results of mastering the online course);
(2) the method of fuzzy sets allows you to include qualitative variables in the analysis, operate with fuzzy input data and linguistic criteria, estimates formulated in a natural language;
(3) the fuzzy models are easier to implement than other algorithms and methods of intelligent data processing.

The main disadvantage, which is the subjectivity of the opinions of experts when choosing membership functions and the formation of fuzzy input rules, can be partially eliminated by attracting a larger number of experts in this subject area.

The proposed algorithm can be used as the basis for the design of an adaptive recommender system that functions as part of an online learning platform and offers the course participant to dynamically adjust the learning path for the curriculum content.

Prospects for further research in this area of research will be to expand the forms of control and methods of assessment procedures for the modernization of the fuzzy model for integrated assessment of the results of mastering the contents of the curriculum of the online course, as well as in the design of an adaptive model of fuzzy inference, which allows for parameterization in the learning process based experimental data.

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