INTELLIGENT MODEL FOR CONTROLLING THE TEMPERATURE AND HUMIDITY OF THE BAKING OVEN

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Abstract. The relevance of the study is the need to introduce automated control systems in Kazakhstan. As world experience shows, a promising direction of this task is to improve the quality of food enterprises and reduce production costs. The article is devoted to the problem of automated control of the bread baking process in production. As an example of the development of a fuzzy control model, the process of controlling the temperature and humidity in the bread baking chamber is taken, which is an urgent task. An intelligent control scheme based on a fuzzy controller is proposed.The input and output variables are defined, the formation of decision-making rules by experts is considered, and an example of setting the membership functions of fuzzy variables is given.

Keywords: Automated control, bakery oven, intelligent system, fuzzy model, rule base.

Introduction

The fourth industrial revolution is developing at a new pace in the world. Reacts to optimize production in the real world. A long-term program that provides automation and intellectualization of all industrial production processes from digital product design, creating a digital copy of it to an individualized approach to working with customers. The State program of industrial and innovative development of the Republic of Kazakhstan for 2020-2025 sets 4 tasks for domestic enterprises [1]

The fourth industrial Revolution means greater automation of all production processes and stages. The development of this industrial revolution is an important direction of automation in various types of production. Automation leads to increased productivity, freeing people from the production process, improving the quality of products and fully meeting the needs of society [2,3.].

The introduction of innovative technologies improves the quality of baking and consumer properties of bread, mainly contributes to the competitiveness of enterprises [4]. Information technologies in the bakery industry contribute to changing the relationship between consumption and production, but their interaction requires the exchange of information. [5-7].

A relatively recent approach to data analysis that uses information processing, statistics, and data visualization techniques to find patterns and relationships in large datasets is data mining. Finding their main application in the world of finance and marketing, the methods used have been applied in the processing industry, and more recently in the baking industry [8, 9].

An important factor that can lead to a rethinking of today's achievements and make new theories and practices is data mining, which is a sharp expansion of the capabilities of computer technologies, including hardware implementation of logic and other artificial intelligence tools [10].

Artificial intelligence includes reasoning, natural language processing, and even various algorithms that are used to incorporate intelligence into the system. [11, 12].

In the field of system automation technology development, the potential of various machine learning methods and statistical methods in predicting product quality in production baking processes has been studied [13].

Bread baking and control methods in industrial furnaces

Currently, there are several dozen approaches that are being developed specifically for the study of the management of technical systems. Modern control theory has become a leading science not only in the field of technical, but also in social, economic, environmental, food and other systems [14, 15].

The method of automatic control theory is one of the classical control methods. Disadvantages of this method: when creating a control system, it requires building an accurate mathematical model and taking into account all the constituent factors [16].

With the development of technology, the number of artificial neural networks in various areas of production increases every year. With the help of the neural network, many complex real-world production problems can be solved as a management tool in food technology. [17].

However, they require significant computing power and a relatively longer time for the initial training period [18]

The most optimal method of managing technical objects is the method of artificial intelligence based on fuzzy logic. [19]. It is advisable to use fuzzy logic in cases of a small amount of information about control objects and it is possible to develop effective control systems. [20].

The solution to this problem is the use of fuzzy control methods. [21].

Since fuzzy logic simulates human behavior and decision – making, models and methods based on modeling human thinking and behavior processes are used to describe it, as well as the ability to regulate and change the source data, the measurement range without completely recalculating the regulator. The advantage of fuzzy logic systems over other systems:

- do not require precise mathematical models to perform their functions.
- in complex issues, they can find a quick solution.

Development of a fuzzy control system for temperature and humidity in the baking chamber

Bread baking is a very complex process, consisting of microbiological, colloidal, biochemical, and physical compex processes [22, 23].

The temperature of the test piece changes gradually from the outer layers to the inner layers, and the nature of the processes occurring in it also changes [24]. In the working area, the use of forced heat exchange between the heat carrier and the bread allows you to redistribute the heat flows and ensure a uniform temperature distribution throughout the working area of the baking chamber. To ensure the required heat exchange and humidity in the baking chamber, it is proposed to include a control unit for automatically increasing the heat of the heating element, redistributing the heat flow and turning on the steam humidifier. The required humidity level inside the furnace chamber is provided by the steam supply from the steam humidifier. The temperature in the baking chamber is brought to 240-250 °C (depending on the stages of baking bread). To maintain the set temperature range, temperature sensors are placed in the baking chamber, which are regulated through the control unit (at a temperature difference of ± 10 °C), the inclusion of forced heat exchange fans. To improve the quality of finished products and reduce the baking of bread, you need to adjust the temperature and humidity inside the baking chamber during the baking process. Baking of bread blanks consists of three main stages: moistening, roasting, and baking.

Table 1 shows the technological characteristics of the baking process, taking into account the stages, humidity and temperature.

Table 1. Stages of bread baking in the baking chamber

Allowable limit	Stage 2 Moistening	Stage 2 Roasting	Stage 3 Baking
Baking time	2-3 minute	3 minute	33 minute

Humidity in the chamber	Lower limit	30-35%	11-18%	5%
	Acceptable limit	40-70%	18-24%	5-7%
	High limit	70-80%	24-30%	7-10%
Temperature	Lower limit	100°C	220°C	140°C
	Acceptable limit	110-120°C	240-250°C	150-180°C
	High limit	130°C	260°C	190°C

To create a model for controlling the temperature and humidity in the baking chamber, you need to perform: set the parameters of the fuzzy control model; form the rule bases; set and build the FP; output the solution. [25]. The input and output data are shown in Figure 1.

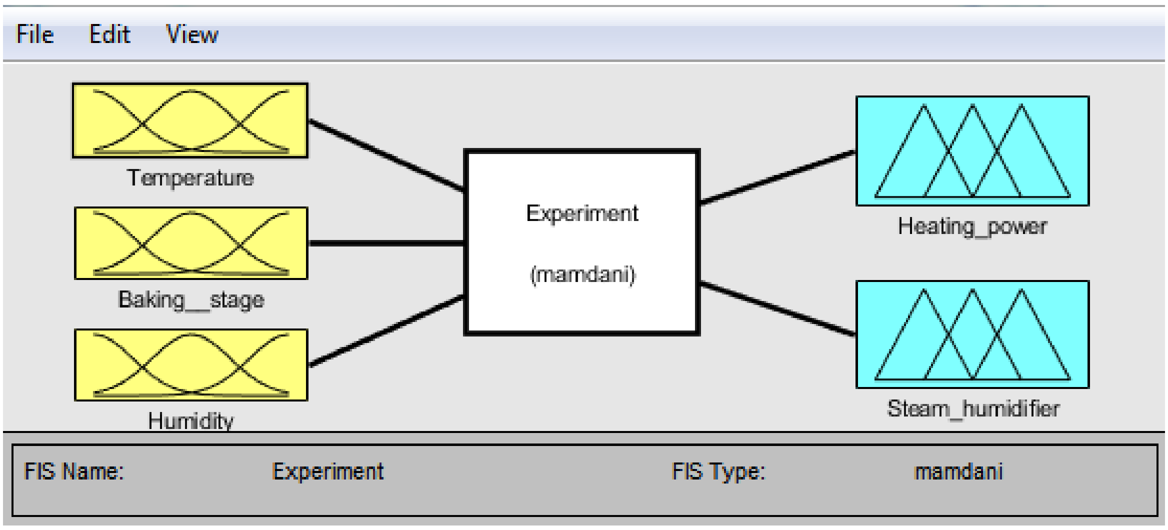

Figure 1-Input and output data

To control the temperature in the baking chamber, we define a set of input fuzzy variables: the temperature in the chamber is 100-300 C, the humidity level is 0-100%, and three stages of baking bread: moistening,roasting, and baking.

We define the set of output linguistic variables by two elements: the regulation of the input power of the heating element of the baking oven and the switching on and off of the steam humidifier.

Based on the qualitative characteristics formulated by experts, you can set a rule base that describes the operation of the control object (OU). "If..., then...", assume to use in the condition of the rule information about the OP-amp, its current state, from the conclusion a control signal is output that brings the OP-amp to the desired state. For example: Rule 1: If in the first stage the temperature in the baking chamber is high and the humidity is low, then the power of the heating element is low and the steam humidifier is turned on. Thus, the rule base of the fuzzy temperature control system in the baking chamber is formed, Table 2.

Table 2. The base of rules of a fuzzy control system

Stage	Temperature	Humidity	Heating power	Steam humidifier
1	Low	Low	Average	Turn on

1	Average	Low	Average	Turn on
1	High	Low	Low	Turn on
1	Low	Average	Average	Switch off
1	Average	Average	Average	Switch off
1	High	Average	Low	Switch off
1	Low	High	Average	Switch off
1	Average	High	Average	Switch off
1	High	High	Low	Switch off
2	Low	Low	High	Switch off
2	Average	Low	Average	Switch off
2	High	Low	Low	Switch off
2	Low	Average	High	Switch off
2	Average	Average	Average	Switch off
2	High	Average	Low	Switch off
2	Low	High	High	Switch off
2	Average	High	Average	Switch off
2	High	High	Low	Switch off
3	Low	Low	High	Turn on
3	Average	Low	Average	Turn on
3	High	Low	Low	Turn on
3	Low	Average	Average	Switch off
3	Average	Average	Average	Switch off
3	High	Average	Low	Turn on
3	Low	High	High	Switch off
3	Average	High	Average	Switch off
3	High	High	Low	Switch off

The fuzzy inference system was developed using Matlab software, will allow the user to continuously adjust three inputs, and the outputs will change according to changes in the input signals:MF

$$\mu(x) = \begin{cases} L\left(\frac{n_1 - x}{\alpha}\right), & x \le n_1 \\ 1, & n_1 \le x \le n_2 \\ R\left(\frac{x - n_2}{\beta}\right), & x \ge n_2 \end{cases} \quad (1)$$

where n is a number called (mode) the mean value of a fuzzy number A ($\mu_A(n)$),

α - is a real positive value of a number or left-handed scatter, β is a right-handed scatter. By increasing the dispersion, we get an even more fuzzy number$A$. Let's write down the fuzzy number L-R:

$$\mu(x) = \frac{1}{1+\left(\frac{x-c}{a}\right)^{2b}} \quad (2)$$

In the Matlab system, the MF is called gbellmf - a generalized bell-shaped MF.

$$\mu(x) = \frac{1}{1+\left(\frac{x-c}{a}\right)^{2b}} \quad (3)$$

For TS "Low" we use z - similar MF zmf
nonlinear approximation

$$\mu(x) = \begin{cases} 1, & x \le a \\ \text{nonlinear approximation}, & a < x < b \\ 0, & x \ge b \end{cases} \quad (4)$$

TS "High" let us describe Smf - s - similar MF

$$\mu(x) = \begin{cases} 1, & x \le a \\ \text{nonlinear approximation}, & a < x < b \\ 0, & x \ge b \end{cases} \quad (5)$$

The output of the "Heating Power" model uses the trapezoidal shape of the trampf accessory for the "Low" and "High" term sets [26]:

$$\begin{cases} 0, & x \le a \\ \frac{x-a}{b-a}, & a \le x \le b \\ 1, & b \le x \le c \\ \frac{d-x}{d-c}, & c \le x \le d \\ 0, & d \le x \end{cases} \quad (6)$$

and triangular MF trimpf for the term-set "Average"

$$\begin{cases} 0, & x \le a \\ \frac{x-a}{b-a}, & a \le x \le b \\ \frac{c-x}{c-b}, & b \le x \le c \\ 0, & c \le x \end{cases} \quad (7)$$

For the problem being solved, the number of rules in the rule base is 27.

Table 3. Shows the results of testing the model

№ п/п	Stage	Temperature	Moisture	Heating power	Steam humidifier	Error
1	1	136	81,3	0,175	0,708	0,41
2	1	124	72	0,522	0,711	0,63
3	1	116	35	0,522	0,274	0,53
4	1	97	57	0,846	0,712	1,01
5	1	114	37	0,521	0,273	0,53
6	1	102	37	0,522	0,275	0,57
7	1	90,2	60,8	0,846	0,71	1,03
8	1	27,6	79,9	0,5	0,5	0,93
9	1	119	38,4	0,52	0,49	0,64
10	2	234	16,7	0,5	0,5	0,40
11	2	263	23	0,175	0,276	0,16
12	2	225	18	0,845	0,276	0,46
13	2	256	22	0,35	0,275	0,22
14	2	244	21	0,52	0,275	0,30
15	2	263	20,9	0,175	0,273	0,16
16	2	275	23	0,175	0,273	0,15
17	2	251	18,3	0,521	0,272	0,29
18	2	230	18,3	0,5	0,5	0,40
19	3	179	16,7	0,845	0,267	0,57

20	3	189	12,9	0,523	0,253	0,38
21	3	150	13	0,523	0,253	0,48
22	3	161	12,9	0,523	0,253	0,45
23	3	200	12,5	0,175	0,249	0,20
24	3	143	14	0,517	0,739	0,80
25	3	184	12,3	0,52	0,25	0,39
26	3	1163	11	0,517	0,248	0,07
27	3	182	12	0,519	0,249	0,40

The calculation of the root mean square deviation (RMSD) is made according to the formula

$$\delta = \sqrt{\frac{1}{N}\sum_{i=1}^{m}\left(G_{\text{зад}} - G_{\text{тек}}\right)^2} \quad (8)$$

where n is the number of simulations;
m is the number of hits in the selected interval;
G_{set} – set value of the output variable
G_{cur} is the received value of the output variable.
RMSD does not exceed 5%, which indicates the adequacy of the constructed model.

Conclusion

The standard deviation (RMS) does not exceed 5%, which indicates that the model is built correctly. Thus, it is possible to obtain numerical values of the intelligent control of the cooking chamber using the Mamdani fuzzy logic machine. The correspondence of the constructed model and the influence of the input variables on the output variables were proved using the program for viewing the surface of the blurred model.

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