SYNTHESIS OF A FUZZY INTELLIGENT CONTROL SYSTEM FOR A DYNAMIC OBJECT BASED ON FUZZY LOGIC

Abstract. This article discusses the synthesis of a fuzzy dynamic object-driven intelligent control system using a fuzzy mathematical apparatus. If the exact description of the control object is rather complicated and there is no a priori information about the operation of the system, it is considered more important to apply fuzzy intelligent control systems to control objects. Unlike classical models, fuzzy models are more flexible and allow taking into account the experience and intuition of specialists in a particular field. The fuzzy model of control and diagnostics is more adequate to the simulated reality, and the correct solution is obtained due to the accuracy of the initial data.

Operating principle A fuzzy model of a fuzzy intelligent control system based on a fuzzy logical statement of the type "If A..., then B" has been created.

Keywords: fuzzy controllers, linguistic variables, physicalizing, production rules, logic, defuzzification.

Introduction. At present, the theoretical basis for the use of fuzzy approaches in modeling a control system under conditions of inaccurate information or fuzzy goals and restrictions is a fuzzy mathematical apparatus, including fuzzy algebra, fuzzy and linguistic logic, and probability theory. The fuzzy mathematical apparatus makes it possible to form and describe fuzzy qualitative and quantitative concepts used by experts to describe their ideas about the real system, their wishes and suggestions, and management goals.
Unlike classical models, fuzzy models are more flexible. These models allow taking into account the experience and intuition of specialists in a particular field. The fuzzy model of control and diagnostics is more adequate to the simulated reality, and the correct solution is obtained due to the accuracy of the initial data. Fuzzy models require less time to obtain results and allow you to increase the speed of processing quality information when using relatively simple specialized devices. Fuzzy models are created when it is impossible or difficult to build smooth models.

The fuzzy approach to modeling control systems has the following features: in fuzzy models, instead of numerical variables, “linguistic” variables are used; relationships between variables are described using fuzzy judgments; complex relationships are described by fuzzy algorithms [1,2].

In modern times, intelligent systems for processing and describing knowledge are being developed through the integration of symbolic and figurative descriptions of scientific knowledge. These areas are of great practical importance for the connection of engineering knowledge with the development of multimedia equipment and software, especially at the stages of converting paper documents into computer equivalents.

1. **The principle of organizing a fuzzy intelligent control system**

Currently, intelligent control systems based on fuzzy logic, founded by L. Zadeh, are widely used. In particular, the application of fuzzy intelligent control systems to control objects is more efficient if the exact description of the control object is rather complicated and there is no a priori information about the system operation.

The principle of operation of the fuzzy intelligent control system is based on a fuzzy logical statement of the type "If A ..., then B". Fuzzy systems have a knowledge base and elements of artificial intelligence [3].

The functional diagram of a simple control system shown in Figure 1 implements a rising output. This scheme can be described in logical-mathematical form as follows:

**Knowledge:** &lt;&lt; If there will be $X = A$, Then they will $Y = B &gt;&gt; $

**Fact:** &lt;&lt; $X = A'$ &gt;&gt;
Conclusion: \(<\!< Y = B' >\>\)

Here \(A, A', B, B' - m(A), m(B)\) is a descriptive form of linguistic variables given as fuzzy sets.

The relationship between the input variable \(X\) and its linguistic variable \(A\) can be described as a characteristic function of the "ascending" linguistic variable, as shown in Figure 2.

\[
\text{Fig. 2. The affiliation function of the "ascending" linguistic variable}
\]

Here \(A = \{(x_i, a_i)\}, x_i \in X\) – is a fuzzy set, where \(X\) is a universal set; \(-\) the degree of belonging to the majority of the element. A discrete representation of a fuzzy set can be viewed as a vector:

\[
\text{In a similar way, } B = (b_1/y_1, b_2/y_2, ..., b_i/y_i, ..., b_m/y_m), 0 \leq b_i \leq 1.
\]

In fuzzy logic, A-cause and B-result are related to each other by a relationship matrix \(R\). \(R\) is a matrix representing a fuzzy causal relationship between \(A\) and \(B\).

The matrix \(R\) can be described as follows [4,5]:

\[
R = \begin{bmatrix}
    r_{11} & \cdots & r_{1n} \\
    \vdots & \ddots & \vdots \\
    r_{m1} & \cdots & r_{mn}
\end{bmatrix}
\]

(1)

For L. Zadeh, the fuzzy ascending result was defined as follows:
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\[ B = (b_1 / y_1, b_2 / y_2, ..., b_n / y_n) = \]
\[ = (a_1 / x_1, a_2 / x_2, ..., a_n / x_n) \circ \left[ \begin{array}{ccc} r_{11} & \cdots & r_{1n} \\ \vdots & \ddots & \vdots \\ r_{n1} & \cdots & r_{nn} \end{array} \right] = A'R \]

(2)

From (2) it follows that

\[ b'_j = \cup_i (a'_i \circ r''_i), \]

(3)

where, \( \circ \) is the logical multiplication (minimum); \( \cup \) is logical complement (maximum).

For continuous logic, logical multiplication is minimal, and logical addition is equivalent to finding the maximum value.

Mamdani proposed the following fuzzy approach, which is widely used in practice:

\[ r''_i = a'_i \cap b'_i, \]

(4)

here \( \cap \) - logical multiplication (minimum).

Fig. 3. Functional diagram of a fuzzy extractor

The structure of the fuzzy control system can be implemented using a special fuzzy controller based on the fuzzy extractor shown in Figure 3. This machine implements the fuzzy statement of formula (5) “If this is A, then this is B”.

The block that performs the C-minimum function performs the intersection of clusters \( A \) and \( A' \). The block that implements the e-maximum function extracts elements of the maximum value from the set \( A \cap A' \), which intersects the set B. Transforms the resulting set of elements of the maximum value into the set \( B' \).
The basic architecture of a fuzzy controller that performs multiple fuzzy extract (FO) consists of a fuzzy inference engine (FIE) as shown in Figure 4. The basic fuzzy controller consists of a fuzzy memory that contains an additional knowledge base from NFC and a maximum result pooling scheme. Fuzzy control can be implemented using conventional or specialized logic algebra controllers [7].

![Diagram of basic architecture of fuzzy controllers](image)

**Fig. 4. Basic architecture of fuzzy controllers**

2. Development of a fuzzy control algorithm

The logical algebra controller carries out the output of logical formulas using the logical operations "AND", "OR" by calculating the characteristic values of linguistic variables. The transition from different linguistic values - linguistic variables that take terms - is carried out using the corresponding characteristic function - the membership function shown in Figure 5. To implement a simple fuzzy control algorithm, it is advisable that each linguistic variable consists of 3-7 terms.

Consider an example of the synthesis of a fuzzy crane control system, the functional diagram of which is shown in Figure 6. The input variables of the dynamic object are the distance \( d[m] \) from the drum to the wall and the angle of inclination of the load from the vertical \( \varphi \), and the output variables are the power supplied to the engine from the drum m. The development of a fuzzy control algorithm consists of three stages.

At the first stage, the transition from physical variables to linguistic variables
and their characteristic functions - the classification operation can be performed based on the following steps:

Step 1. Find the numerical value of the physical quantity for each member of the taken linguistic variable. At best, the characteristic data values of this term are "1".

Step 2. If the value of the characteristic function for each term is "0", the range of values of the physical variable is selected.

Step 3. After determining the extreme values, the intermediate values of the characteristic function are determined by choosing the typical functions shown in Figure 5.

Suppose that each of these variables (Fig. 6) has three terms corresponding to its characteristic values: zero, medium and large:

\[ D_0 \quad \text{zero (or less) distance}; \quad D_{\text{average}} \quad \text{average distance}; \quad D_{\text{long}} \quad \text{long distance}; \]

\[ \varphi_0 \quad \text{is zero (or small) angle}; \quad \varphi_{\text{orta}} \quad \text{is the mean angle}; \quad \varphi_{\text{boyuk}} \quad \text{large angle}; \]

\[ M_0 \quad \text{zero (or less) power}; \quad M_{\text{average}} \quad \text{of average power}; \quad M_{\text{big}} \quad \text{big power}; \]

During phasing, the input variables of a dynamic object take values in fractions [0,1]. At this stage, for each of the three variables, the degrees of affiliation are calculated from the triangular (function \( \sigma \)) affiliation function:

\[ \mu(d_i) = 1 - \frac{d_i - \bar{d}_i}{\bar{d}_i - d_i}, \quad q = 1/\sigma \quad (\text{where} \quad \sigma = d - \bar{d}, \quad \mu(d) = \mu(\bar{d}) = 0.5 \quad \text{is the transition point}), \]

as shown in Figure 7.
Second phase. Most fuzzy systems use production rules to describe relationships between linguistic variables. Typical production rules consist of an antecedent (if...) and a consonant (...then...). A predecessor may consist of more than one state. These conditions are connected by "AND", "Or", i.e. logical connections.

The process of calculating fuzzy rules, called fuzzy logic, is divided into two stages: generalization and inference. In this case, one of the production rules could be:

If distance = medium and angle = small, then power = medium.

Using the above notation, this rule can be represented as a logical formula:

\[ M_{\text{orta}} = D_{\text{orta}} \varphi_0 = \min[D_{\text{orta}}, \varphi_0] \]

All possible combinations of input variables can be specified as follows:

\[ D_0 \varphi_0, D_0 \varphi_{\text{orta}}, D_0 \varphi_{\text{boýuk}}, D_{\text{orta}} \varphi_{\text{boýuk}} - M_0, D_{\text{orta}} \varphi_0, \varphi_0, \varphi_{\text{boýuk}} - M_{\text{orta}}, D_{\text{boýuk}} \varphi_0, D_{\text{boýuk}} \varphi_{\text{orta}} - M_{\text{boýuk}} \]

3. System modeling

Divide them into three groups according to the member of the output variable,
for example, as shown above. The calculation of the output variable for these sections can be given by the following formulas in accordance with the production rules [5-8]:

\[ M_0 = D_0 \cup D_{orta} \varphi_{boyük} = \max\{D_0, \min(D_{orta}, \varphi_{boyük})\} \]

\[ M_{orta} = D_{orta} \varphi_{orta} \cup D_{boyük} \varphi_{boyük} = \max[\min(D_{orta}, \varphi_{orta}), \min(\varphi_0, \varphi_{boyük})] \]

\[ M_{boyük} = D_{boyük} (\varphi_0 \cup \varphi_{orta}) = \min[D_{boyük}, \max(\varphi_0, \varphi_{orta})] \] (6)

Let us assume that the distance \( d = 55m \) from the drum to the wall is equal to the angle \( \varphi = 5^\circ \) of the load from the vertical (Table 1).

### Table 1

<table>
<thead>
<tr>
<th>( \varphi_0 )</th>
<th>( \varphi_{average} )</th>
<th>( \varphi_{max} )</th>
<th>( D_0 )</th>
<th>( D_{average} )</th>
<th>( D_{max} )</th>
<th>( M_0 )</th>
<th>( M_{average} )</th>
<th>( M_{max} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.91</td>
<td>0.94</td>
<td>0.88</td>
<td>0.25</td>
<td>0.55</td>
<td>0.1</td>
<td>0.55</td>
<td>0.88</td>
<td>0.1</td>
</tr>
</tbody>
</table>

\( M_0 = \max\{0.25; \min(0.55; 0.88)\} = 0.55 \)

\( M_{orta} = \max[\min(0.94; 0.55); \min(0.94; 0.88)] = 0.88 \)

\( M_{boyük} = \min[0.1; \max(0.91; 0.94)] = 0.1 \)

For the operation of the actuator, it is necessary to move from the degree of membership to the output value of a physical quantity (in this example, the output quantity is power (M)). This process is called defability.

The third stage is the stage of defabulation. The most common defacing methods are:

- By the method of maximum average (MA) is the average value of the values obtained after calculating the degrees of membership of the output value, \( \mu_m(m_0), \mu_m(m_{orta}), \mu_m(m_{boyük}) \), i.e.

\[ \mu_m(m) = 1/3(\mu_m(m_0) + \mu_m(m_{orta}) + \mu_m(m_{boyük})) \]

- When using the maximum value method (MV), the largest value is selected from the obtained output values \( m_0, m_{orta}, m_{boyük} \), i.e.

\[ m = \max(m_0, m_{orta}, m_{boyük}) \]

- the value of the output quantity, sought by the center of gravity (CG) method of the output quantities.
\[
m = \frac{\mu_m(m_0) m_0 + \mu_m(m_{\text{orta}}) m_{\text{orta}} + \mu_m(m_{\text{boyuk}}) m_{\text{boyuk}}}{\mu_m(m_0) + \mu_m(m_{\text{orta}}) + \mu_m(m_{\text{boyuk}})}
\]

is the coordinate of the center of gravity of the figure, obtained from the intersection of the characteristic functions.

While the MA strategy provides the best transition process, the CG strategy provides the best static accuracy [8].

CG-based fuzzy controllers give better results than MA-based fuzzy controllers.

– CG = 3.54 kW according to the CG method;
– m = 0.88 kW according to the MV method;
– According to the MA method, m = 0.51 kW is obtained.

In this case, the average power is assigned to the engine with the accepted values of the input variables \( d \) and \( \varphi \). Because this term has a higher degree of affiliation.

Conclusions. The stages of synthesis of a fuzzy intelligent control system for a dynamic object (crane) based on fuzzy logic are considered. The characteristic membership functions of parameters of a dynamic object are established, fuzzy values are calculated. It turned out that when assigning values to input variables, the average coefficient of power membership \( M_{\text{orta}} = 0.88 \) is higher than the rest. In order for the actuator to work, a defascification operation was performed to transfer from the degree of belonging to the output value of the physical quantity (where the power of the crane was taken as the output value). The most optimal solution was considered to be the assimilation of the average power (m = 3.54 kW) obtained by the engine center of gravity method. That is, with high engine power, durability and high performance of the crane are achieved.

References:


