MODELS AND FUZZY MICROCLIMATE CONTROL SYSTEM IN THE STORAGE OF ARCHIVAL DOCUMENTS

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Erratum
there was a small change

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Abstract: In this article, the main object of research is the creation of appropriate microclimatic conditions to ensure reliable and high-quality storage of archival documents, as well as automatic control of the optimal values of the main parameters of the external and internal environment that directly affect the quality of storage. To control the microclimate, three categories of models for automatic control of these parameters are considered separately in the archives: the “white box”, “black box” and “gray box" models. The results of the analysis of the advantages and disadvantages of the considered models are presented. The generalized structure of the microclimate management system is also given, as well as a list of controlled and changeable parameters of the microclimate management system of archives. It is proposed to use the fuzzy logic apparatus to create microclimate control systems in archival repositories, which allows synthesizing stable algorithms for its functioning in conditions of uncertainty. The specific steps that need to be performed when designing and using fuzzy inference systems and which are implemented based on the rules of fuzzy logic are listed. When designing and using fuzzy inference systems, it is necessary to observe certain stages that are implemented based on the rules of fuzzy logic. A generalized algorithm for implementing the fuzzy inference procedure is presented. The tasks that need to be solved when designing a fuzzy control system are indicated. A system of automatic temperature control in archival repositories with a fuzzy logic controller is presented.

Keywords: microclimate in archival storages, influencing factors in storages, fuzzy control, fuzzy analysis, fuzzy logic, fuzzification, fuzzy regulator, fuzzy logic controller.

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Abstract: In this article, the main object of research is the creation of appropriate microclimatic conditions to ensure reliable and high-quality storage of archival documents, as well as automatic control of the optimal values of the main parameters of the external and internal environment that directly affect the quality of storage. To control the microclimate, three categories of models for automatic control of these parameters are considered separately in the archives: the “white box”, “black box” and “gray box" models. The results of the analysis of the advantages and disadvantages of the considered models are presented. The generalized structure of the microclimate management system is also given, as well as a list of controlled and changeable parameters of the microclimate management system of archives. It is proposed to use the fuzzy logic apparatus to create microclimate control systems in archival repositories, which allows synthesizing stable algorithms for its functioning in conditions of uncertainty. The specific steps that need to be performed when designing and using fuzzy inference systems and which are implemented based on the rules of fuzzy logic are listed. When designing and using fuzzy inference systems, it is necessary to observe certain stages that are implemented based on the rules of fuzzy logic. A generalized algorithm for implementing the fuzzy inference procedure is presented. The tasks that need to be solved when designing a fuzzy control system are indicated. A system of automatic temperature control in archival repositories with a fuzzy logic controller is presented.

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INTRODUCTION. In archival institutions, the object of close attention is archives, where archival documents are stored, transferred to state storage.

At the same time, a main factor of attention is maintaining optimal values of air parameters and a stable microclimate in the storage.

For productive functioning of the microclimate control system, regular adaptation to unstable requirements of the internal state and the external environment is required with ability to short-term and medium-term prediction of the status of controlled object under the influence of changing environmental factors.

It is possible to predict the state of microclimate by control system using a variety of models capable of detecting changes in the parameters of the external and internal environment. Many models, due to their originality, take into account only a small number of parameters affecting the feeling of comfort, and their use is considered narrowly focused. The most widespread model is PMV model because of its flexibility and complexity, considering a huge number of parameters, (The Predicted Mean Vote) introduced by Ole Fanger and taking into account the influence of microclimate parameters (temperature, humidity, ambient temperature, etc.) [1; 2].

MATERIALS AND METHODS. Traditional management methods (“white box” models) are used constantly at this time due to their relative ease of implementation. However, when these methods are applied, costs associated with maintaining the system and energy consumption are relatively high.

Therefore, nowadays there are more and more so-called “black box” models, which are based on methods of intellectual calculus (fuzzy logic, genetic algorithms, neural networks, etc.) [2].

Most indoor climate control models can be divided into 3 categories (Fig. 1):

1. So-called white box models are based on the physical foundations of thermodynamics, hydrodynamics and gas dynamics. All these models are calculated from the order of complex differential equations, in which numerous coefficients are applied, considering the geometry of the room, thermal characteristics of enclosing structures, insolation, etc. All parameters and coefficients of the models are known, they are either calculated or measured.

Such models are cumbersome, computationally intensive and time consuming. Some types of models take into consideration the susceptibility of documents and humans to thermal and humidity requirements on the principle of a comfort index (PMV / PDD values). And the last type of models is
based on electrothermal similarity, which is determined by the identity of the equation of electrical conductivity and the equation of thermal conductivity [2; 3; four].

Black box models - Do not explicitly exploit physical principles when developing a model. Only the input and output parameters of the model are defined. This model is a separate approximation of controlled processes. These models include various models based on artificial neural networks, models based on fuzzy logic and neuro-fuzzy modeling.

Gray box models - Created partly on physical bases. Not all parameters of such a model are known, they cannot be calculated or measured. They are hybrid models, combining the characteristics of the first and second types.

A choice of calculation model and dataset may depend on specific tasks and conditions of use. Control in heating, ventilation and air conditioning (HVAC) systems is mainly carried out according to the parameters shown in Fig. 2.
ANALYSIS OF MODELS. Analysis showed that the modeling of the influence of illumination and air pollution (CO2) is taken into account in the models less often than such factors as temperature, humidity, energy consumption [4; 5]. Table 1 provides a brief analysis of the advantages and disadvantages of the considered models.

Table 1. Analysis of the advantages and disadvantages of microclimate control models

<table>
<thead>
<tr>
<th>Model</th>
<th>Model advantages</th>
<th>Model disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Classic differential room heat balance equations</td>
<td>Reliability and validity of the results, the possibility of taking into account additional factors (humidity, etc.)</td>
<td>Complexity and cumbersomeness of calculation, need to identify a large number of parameters</td>
</tr>
<tr>
<td>model PMV</td>
<td>Uses a large number of parameters, take metabolic factors into account</td>
<td>Cannot be used when fluctuating many variables. Main parameters must fit in the specified intervals</td>
</tr>
<tr>
<td>Models ET-DISC and SET</td>
<td>Models emulate the thermoregulation system of the human body</td>
<td>Do not take into account the habituation of the body, apply the established factors</td>
</tr>
<tr>
<td>Models TS, PD, PS</td>
<td>Allows you to discover the comfort conditions for factors affecting the quality of life in a building</td>
<td>Local convenience models, low accuracy, difficult to explain results</td>
</tr>
<tr>
<td>Adaptive model</td>
<td>Consider outdoor climate variation, good resistance</td>
<td>Complexity and laboriousness during implementation</td>
</tr>
<tr>
<td>Control on base of fuzzy logic</td>
<td>High accuracy, stability, speed, makes it possible to control nonlinear systems with dynamically changing parameters</td>
<td>Complexity of the formation and configuration of the base of fuzzy rules.</td>
</tr>
<tr>
<td>Artificial neural network control</td>
<td>BigData processing, good prediction, no preliminary building or climate information required</td>
<td>A large sample is required for high-quality forecasting, training process time</td>
</tr>
<tr>
<td>Artificial neural network control</td>
<td>Control of complex nonlinear dynamic objects and synthesis of nonlinear control rules for them</td>
<td>Long learning process</td>
</tr>
</tbody>
</table>

Microclimate of the premises during the changing climatic seasons, depending on the weather and day-night changes, and its parameters can have a detrimental effect on health and well-being. In this regard, the task of automatically maintaining comfortable and safe values of climatic parameters in the premises of buildings becomes urgent. A list of monitored and changeable parameters of the indoor climate control system as shown in Fig. 3.

Fig. 3. Generalized structure of the microclimate control system.

To control and change the parameters shown in Fig. 3, appropriate measuring and actuating devices are needed, an approximate layout of which is shown in Fig. four.
Management of such objects is a difficult task in the applied sense, since the construction of a traditional control system requires a formal description of the control object, as well as the refinement of control criteria formed on the basis of a mathematical apparatus operating in quantitative categories.

In practice, such objects are controlled by an operator, using experience, he makes decisions that do not have a rigorous mathematical description. Therefore, the construction of models of procedures, close to the reasoning of a specialist, and their subsequent use in automatic control systems is one of the most important areas of automation of production processes.

When managing processes that do not have an exact mathematical description, fuzzy control systems, as compared to traditional ones, have higher indicators in terms of such criteria as speed, stability, noise immunity and accuracy due to a more adequate description of real environment in which they operate. Therefore, to create microclimate control systems in archival storages, it is proposed to use the apparatus of fuzzy logic, which allows synthesizing stable algorithms for its functioning under conditions of uncertainty (Fig. 4).

Fuzzy control is carried out in two variables: deviation \( e \) and \( \frac{de}{dt} \) rate of change of the deviation \( e \) and \( \frac{de}{dt} \) of the desired output variable \( y \) in control object from its actual value \( y_{in} \).

Fuzzy inference is a procedure for making conclusions, in the so-called fuzzy form, about the characteristics of control actions on executive devices, formed with the participation of linguistic variables, which are based on information about the current state of the microclimate. When designing and using fuzzy inference systems, specific stages must be observed, which are implemented on the basis of the rules of fuzzy logic (Fig. 5) [6; 7; 8, 11, 12, 13].

**Fig. 4. Control system with a fuzzy controller for deviation from the set parameters.**

**Fig. 5. Principle for formation of Fuzzy inference.**
A rule base is a linguistically formalized experience of experts in the form of fuzzy production rules. A rule base includes the experience of experts on methods and algorithms for controlling a control object under conditions of unpredictable disturbances. A specific approach to the implementation of a separate stage of fuzzy inference describes a certain algorithm of actions. Criteria for choosing a certain algorithm for the implementation of fuzzy inference technology are the formulated technical problems.

Generalized algorithm for generating the rule base and the methodology for the implementation of the fuzzy inference procedure is shown in Fig. 6.

![Generalized algorithm for forming the base of rules and methodology for implementing the procedure of fuzzy inference.](image)

Fig. 6. Generalized algorithm for forming the base of rules and methodology for implementing the procedure of fuzzy inference.

When designing a fuzzy control system, the following problems were solved [9; 10, 14, 15]:

- transition from the numerical value of the input data mismatch estimate to its verbal representation in terms of fuzzy logic (fuzzification);
- formation of a base of rules for a fuzzy regulator based on expert opinions, data from monitoring and procedures for determining control actions, "processing" of a set of linguistic rules, taking into account the adopted preferences and assumptions (through the mechanism of the membership function);
Converting the weighted result back to numerical form (defuzzification).

When solving fuzzification problems in relation to the regulation of the climatic parameters of the management/control object (MO), it is necessary:

- Determination of linguistic variables and the composition of their terms in order to determine the current state of the control object, its characteristics, necessary control actions, taking into account internal and external disturbances and specific features of the control object;
- Determination of the FP of physical quantities and terms corresponding to linguistic variables, based on the opinions of experts and the conclusions of the forecasting system from the data of observation processing.

Consider a system for automatic temperature control in archive storage with a fuzzy logic controller (FLC) (Fig. 7).

![Image of a system for controlling the temperature regime in archival storages with a fuzzy logic controller.]

**Fig. 7. A system for controlling the temperature regime in archival storages with a fuzzy logic controller.**

Fuzzy controller is assigned the task of developing a control action in the range of changes in the dynamic control error and its derivative with respect to its threshold values.

According to this scheme, the input vector of the FLC is fuzzed form \( E^* = (e_1^*, e_2^*) \) using a fuzzification block \( F \), then the fuzzy inference is performed in the rule base, resulting in a fuzzy output variable \( u^* \). The translation of the values of the control vector \( u^* \) from the fuzzy region to the crisp one \( u \) is carried out by the defuzzification unit DF.

Block N is intended for preprocessing the input signal of the regulation error and its derivative:

\[
e^N_i = \begin{cases} e_i, & |e_i| < e_i^{max} \\ e_i^{max} \text{sign}(e_i), & |e_i| \geq e_i^{max} \end{cases}
\]  

(1)

Post-processing of the output control signal \( u \) is carried out by the DN block, where the denormalization tasks \( u \) are solved:

\[
u = u_{max}^{DN} = u_N \left| u_{max} \right|,
\]

(2)

where \( u_{max} \) - is maximum value of the control supplied to the object.

As a rule, the NLR knowledge base contains a description of the terms of linguistic variables (LV), which must be defined in advance for each input and output variable.

**Conclusion.** As a result of the analysis of external factors affecting the high-quality storage of information on paper, as well as the study of microclimate control models in storages, a fuzzy system for controlling the microclimate of archival document storages was proposed.

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