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Automatization of Temperature Control in Specialized Industrial Facilities by Means of Microprocessor System

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Abstract: The study suggests a scientific approach to development of automatic system of prescribed temperature parameters maintenance in industrial facilities by means of designing mathematical support and software for a microprocessor system to enable the solution of a range of information processing tasks. A mathematical model has been developed as well as algorithms and programmes implementing the concept of autonomic temperature control in specialized industrial facilities based on artificial intelligence method with the use of fuzzy knowledge base, subsystems of logic output, adaptation and self-training. Its application allows to control prescribed temperature parameters in uncertain and quickly changing environment. The results of conducted optimization calculations ensure increased efficiency of soft and hardware tools being developed.

Key words: Temperature control, intelligent energy-saving system, individual adaptation, training and self-training, draft and production project, mathematical modelling, approval testing, conservation of fuel, electricity and thermal energy

INTRODUCTION

Energy efficiency and conservation are courses of highest priority in science, technology and engineering development. With growing deficit of fuel and energy resources the issues of its effective usage and creating conditions for transferring Russian economy to the energy conserving course are becoming increasingly relevant.

In Russia, the level of thermal and electrical power transportation, distribution and consumption systems as well as of buildings and constructions engineering systems being equipped with new home-produced tools of technological and commercial accounting, local and complex automation is extremely inadequate.

Therefore, development and introduction of new home-produced energy-saving tools, equipment, systems and electronic component base ensuring essential economical effect in energy and resources conservation are relevant.

The development of energy-saving system of temperature control for specialized industrial facilities and manufacturing sections has been currently an important issue. The system should be able to work in an autonomous mode independent of central heating abilities, thus, ensuring operation self-sufficiency and the possibility of manufacturing areas arrangement at any convenient place.

MODERN TENDENCIES IN TH EDEVELOPMENT OF AUTOMATIC TEMPERATURE CONTROL SYSTEMS FOR INDUSTRIAL FACILITIES

With growing deficit of fuel and energy resources in developed countries the issues of its effective usage and creating conditions for transferring economies to the energy conserving course are becoming increasingly relevant (Morozova *et al*., 2013b; Akimov and Morozova, 2013; Strakhov, 2014).

It is a well-known fact that in developed countries automatic temperature and humidity control systems for indoor spaces are extensively used in buildings construction and operation. However, complex mathematical modelling of building current thermal condition with non-steady heat transfer through enclosing constructions is not applied as there are no adequate mathematical models.

The analysis of existing hard and software tools as well as of energy-saving system of temperature control

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based on them within the concept •smart building• (Ostroukh *et al*., 2014a, c) has shown that systems in the market have the following drawbacks:

- No possibility of environment identification and decision-making on-line as well as individual adaptation through self-training
- Necessity of special equipment for system installation
- Difficulty of installation and use
- Highest price

Therefore, development and introduction of new energy-saving tools, equipment, systems and electronic component base ensuring essential economical effect in energy and resources conservation are relevant.

The development of energy-conserving system of temperature control for specialized industrial facilities and manufacturing sections has been currently an important issue. The system should be able to work in an autonomous mode independent of central heating abilities, thus, ensuring operation self-sufficiency and the possibility of manufacturing areas arrangement at any convenient place (Ostroukh *et al*., 2014b; Morozova *et al*., 2013c).

MATHEMATICAL MODEL OF ENERGY-SAVING SYSTEM OF TEMPERATURE CONTROL IN INDOOR SPACE

Mathematical model is developed for the control of thermal envelope valving system through control command. Methods used by building of the mathematical model in question are of general character and can be applied in accomplishing tasks of the same kind for automatic control of systems of various functioning.

Mathematical model of a decision-making system is based on the information about present situation and designed to ensure energy conservation by its application in systems of temperature control in industrial facilities (Morozova and Akimov, 2013; Morozova *et al*., 2013a).

The mathematical model is built on artificial intelligence method with the use of fuzzy knowledge base, sub-systems of logic output, adaptation and self-training. The application of the method allows to control prescribed temperature parameters in uncertain and quickly changing environment which is of high importance by its use in models of temperature parameters control for industrial and other facilities, sensitive to temperature changes. Mathematical model adaptation is based on the adjustment of coefficients of rules and facts atoms. Coefficients change according to the environment by means of modified group method of data handling.

By using fuzzy rules description of system operation is carried out through modusponens and modustollens rules with their form being determined on the base of the following composition:

$$B' = A'(A \to B)$$

where A, A'ϵF(X); B, B'ϵF(Y) are fuzzy numbers, i.e., subsets of universal sets XϵR and YϵR correspondingly. It should be noticed that instead (sup-min) composition (sup-T) one has been considered, where T is a triangular norm, μ_B' and μ_A' are membership functions. In such case:

$$\forall y \in Y(\mu_B \times (y) = \sup T\{\mu_A \times (x) \mu_A \to B \in^{x,y}\})$$

where, T is independent of implication operator. The formula in question determines fuzzy inference algorithm by temperature settings. As long as composition and implication operations can be defined ambiguously and must be specified in a certain way, the choice of particular representations is determined by the algorithm of fuzzy inference. In fuzzy production systems knowledge base of temperature modes contains the following set of rules (Ostroukh *et al*., 2011c):

$$\begin{array}{c} R_1\text{: if x then } A_1\text{, there is y then } B_1 \\ R_2\text{: if x then } A_2\text{, there is y then } B_2 \\ \dots \\ \underline{R_n\text{: if x then } A_n\text{, there is y then } B_n} \\ \text{x then } A' \\ \text{y then } B' \end{array}$$

Each rule R_i has a corresponding implication $A_i \to B_i$. Aggregation is used for uniting items in one system. First of all, aggregation of all rules is carried out by means of relevant aggregation operator A_{gg} with resultant generalized rule of a certain kind $R = A_{gg}(R_1, R_2, ..., R_n)$, then composition operator $B' = A'$, $R = A' = A_{gg}(R_1, R_2, ..., R_n)$ is applied.

Conclusion is built for each inference rule $\forall i = 1, ..., N(N'_i = A'R_i)$, then aggregation operator is applied to obtained components B'_i, i.e., $B' = A_{gg}(B_1, B_2, ..., B_n)$. After obtaining fuzzy sets defuzzification procedure is applied to each of them with aggregation being carried out thereafter. Fuzzification trasforms real values of input variables (temperature) into fuzzy sets which are used by fuzzy inference system as well as the base of rules.

This procedure is described in the following way: A' = fuzzy(x0) where x0 is the value of input variable X, fuzzy is fuzzification operator, A' is a fuzzy subset from input variable X domain. The following possibility of defining fuzzy operator is used: each x0 is correlated with a membership function of the following form (Ostroukh *et al*., 2011a):

$$\mu_{Ai}(x) = \begin{cases} 1, \text{ if } x = x0 \\ 0, \text{ if } x \neq x0 \end{cases}$$

Thus, defuzzification establishes connection between a fuzzy set and the temperature numeric value belonging to the domain of membership function of fuzzy set.

ALGORITHM OF INDOOR ENVIRONMENT TEMPERATURE CONTROL FOR AN ENERGY-SAVING SYSTEM IN AN INDUSTRIAL FACILITY

For temperature control the programme should implement management of the data coming from external sensors to make the decision about changes of thermal energy supply into a heating system of facilities with special function. In that process a special algorithm of getting control command ("Slightly open", "Open", "Close" etc.) is used. Data stream is determined through the input process and fixing information in the database.

The algorithm of software system of microcontroller operation can be represented in the following way (Fig. 1).

Within the algorithm operation at the primary stage initialization of data gathering system is performed and input of current environment data from external sensors as well as from internal ones is carried out. The obtained information is transferred to the database containing system operation rules. There rules fuzzification, i.e., bringing the obtained data to the formal state is performed. Further on by means of fuzzy output block control command is issued to the management sub-system of valves of heat supply controller which in its turn changes the level of thermal energy supply into the heating system of an industrial facility.

With the operations being accomplished, the current environment conditions are compared with those at the moment of measuring. If current measurements are lower than ones taken at the beginning of algorithm operation, then tact of control is terminated, otherwise, the system returns to the mode of collecting information from sensors and the algorithm is repeated again.

The essential element of the algorithm correct performance is the base of knowledge containing rules necessary for obtained sensor data adequate interpretation. During its operation the system goes through self-training, i.e., adding into the knowledge base new rules and facts based on the data from sensors (Ostroukh, 2008).

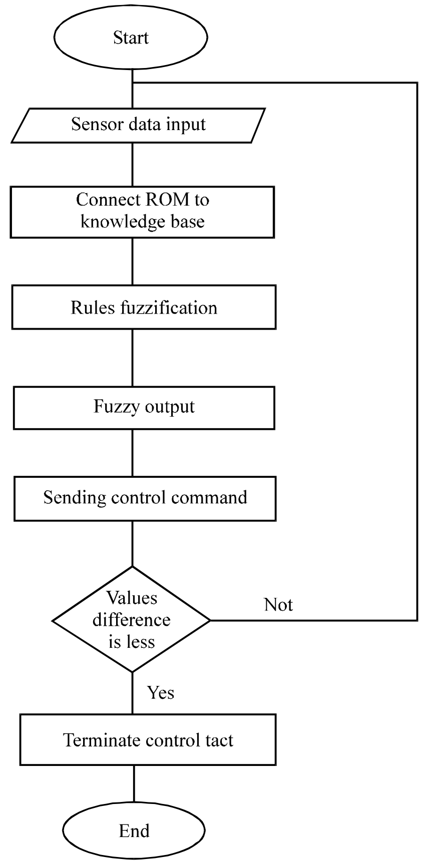

Fig. 1: The scheme of microprocessor operation algorithm

The knowledge base of control system is on the cloud service, thus, it is necessary to connect to it before starting work. With successful connection to the cloud service being established, data transfer to the knowledge base is performed. The obtained data is going through verification procedure on the service side with following aggregation of knowledge base rules. If the commands mentioned above are executed the process of knowledge output is conducted through net classifier. Hereafter, comes the process of coefficients change in the knowledge base, so called system adaptation process. With the adaptation process being finished, new rules obtained during the previous stages are added to the system and all the steps mentioned above result in update of microcontroller knowledge base (Fig. 2) (Ostroukh *et al*., 2011b).

Operation algorithm of the kind allows to unify the decision and self-training processes of distantly located systems and to ensure its applicability not only in one particular industrial facility but in an industrial system of distantly located facilities as well (Ostroukh, 2012) (Fig. 3).

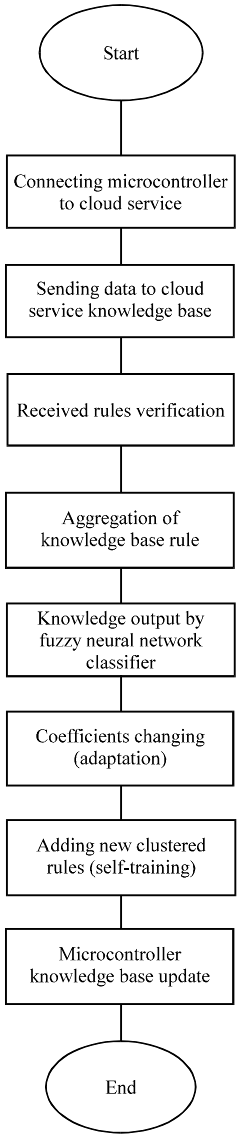

Fig. 2: Scheme of self-training algorithm

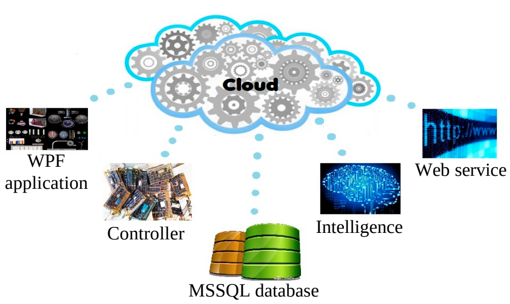

Fig. 3: Structure of temperature control system based on cloud service

Based on the developed algorithms the structure of the system being developed was built. The principal operations are realized through the following programme procedures and functions:

- Get_customers_using_Soap12ServiceClient()-getting parameters through SOAP protocol
- Get_customers_using_XmlServiceClient()-getting parameters through XML
- Get_customers_using_JsonServiceClient()-getting parameters through JSON

For system correct operation an Intelligent Temperature Control Scheme (ITCS) has been developed as well (Morozova, 2014) (Fig. 4). ITCS also contains the switching on device of the standby power battery for turning on the thermal envelope valve if primary power supply is down. The ITCS principal task is maintenance of the temperature mode determined by technological process being performed in the industrial facility as well as by the user regardless of inside and outside temperature measurements and thermal energy evolved by manufacturing objects and the staff present in the facility.

ITCS operation principle is based on the converting of thermal energy into electrical signals by temperature sensors with following signal processing by master device, data output on the LED digital display and control signals production.

ITCS master device sends packet of signals to TS1, receives signal responses, adds to them data stored in memory and sends the packet to the next TS. After going through all TSs, the master device receives packet of signals with data from all TSs stored in it.

The master device performs comparative analysis of each TS temperature, compares it with stored temperature model of the facility and switches on/off performing devices in one or another part of facility, if necessary.

After temperature summarizing and analysis, the master device builds data packet with all commands for each performing device, then the packet is sent to PD1 and goes through all PD involved.

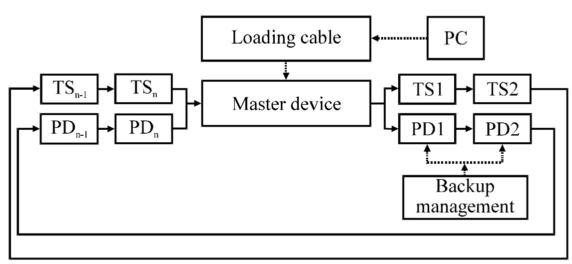

Fig. 4: Structure of intelligent temperature control system; TS: Temperature Sensor; PD: Performing Device; PC: Personal Computer

ITCSs operate in a 24 h mode receive data from temperature sensors trough communication channels according to the protocol IEC/EIARS-485:

- Temperature sensors fulfill functions of environment parameters indicators
- The number of connected temperature sensors is up to 30 items

ITCS power source is external single-phase alternating current network with voltage of 220 V. Each ITCS device is immediately connected to the electrical network trough adapter. Power supply of temperature sensors should be provided according to their types. Power consumption is defined as the sum from the number of involved ITCS functional units (master device, TS and PD).

Based on the data obtained during the environment conditions analysis the principal rules have been formulated allowing to formalize the comparison processes of external factors and thermal sensors valve state in industrial facilities. Principal criteria affecting temperature mode of an industrial facility:

- External temperature
- External temperature in the sun
- Internal temperature
- Number of people in the facility
- Total capacity of working equipment in the facility

KNOWLEDGE BASE OF TEMPERATURE CONTROL SYSTEM FOR AN INDUSTRIAL FACILITY

Rules of obtained data processing are stored in a knowledge base which is a file in hexadecimal format and determine system's behaviour depending on external parameters. A developed knowledge base has the following form (Morozova and Soumkin, 2013). Knowledge base is an array of prescribed temperature values and the set of rules.

Addresses 1-30 (Fig. 5) are filled with prescribed temperatures (i.e., the temperatures to be maintained) for addresses 1 and 2 values are entered formally as they are external sensors monitoring outside temperature and thus having no crucial value.

Addresses 1-30 are filled with values 0×19 which makes 25 degrees in decimal system and is the prescribed temperature for all rooms. Further on for addresses from 32-38 cells are filled with values 0×FF. These are check values necessary for the programme to work in PLD:

	00	01	02	03	04	05	06	07	08	09	0A	0B	0C	0D	0E	0F
00000	00	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19
00010	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	00
00020	FF	FF	FF	FF	FF	FF	FF	03	D8	3C	D8	3C	FF	01	03	D8
00030	3C	D8	3C	00	00	03	D8	3C	D8	3C	FE	02	03	D8	3C	D8
00040	3C	FD	03	03	D8	3C	D8	3C	FC	04	03	D8	3C	D8	3C	01
00050	05	04	00	3C	00	3C	01	05	00	00	00	00	00	00	00	00
00060	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
00070	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00

Fig. 5: Knowledge base structure of temperature control system

- From address 39 on the rules begin
- Format of a rule. A rule consists of 7 bytes
- D(0) is a number of the sensor to which the rule is applied
- D(1) is temperature in the sun 1
- D(2) is temperature in the sun 2
- D(3) is temperature in the shadow 1
- D(4) is temperature in the shadow 2
- D(5) is deviation from prescribed temperature
- D(6) mode

The following rule is specified in PLD:

```
if mas_temp_real(1)>D(1) and mas_temp_real(1)<D(2) and
mas_temp_real(2)>D(3) and mas_temp_real(2)<D (4) and (mas_temp_
real(D(0))-mas_temp_zad(D(0))) = D(5)
then
    kom_iu(D(0))<= D(6);
end if;
```

where mas_temp_real(1) is actual measured temperature in the sun, mas_temp_real(2) is actual measured temperature in the shadow. Example of knowledge base data processing. From the address 39 on the rule has the following form:

- 03 D8 3C D8 3C FF 01
- 03 is a sensor number
- D8 is temperature in the sun ((neg. temp. in two'' complement) -40 in dec. system)
- 3C is temperature in the sun (60 in dec. system)
- D8 is temperature in the shadow ((neg. temp. in two's complement) -40 in dec. system)
- 3C is temperature in the shadow (60 in dec. system))

FF is deviation from the prescribed temperature. In such case the number is negative and is in two's complement. If converted into one's complement in decimal system it makes (-1). 01 is number of the mode to be turned on if the situation coincides. As a result, the rule in question can be interpreted in the following way.

IF measured temperature in the sun is higher than -40 AND measured temperature in the sun is <60 AND measured temperature in the shadow is >-40 AND measured temperature in the shadow is <60 AND actual temperature from the 3d sensor is 1 degree lower than prescribed, THEN command 1 is sent to PD 3. Thus, the following rule format allows to simulate any kind of situation.

SOFTWARE SYSTEM STRUCTURE FOR TEMPERATURE CONTROL IN INDUSTRIAL FACILITIES

The software system implements structure necessary for two variants of efficient control. With local server can be applied for operating in autonomous conditions (without internet connection). With cloud services can be applied in bakery manufacturing network with developing infrastructure (using internet). Software system is represented in Fig. 6. The principal nodes of software system are:

- Knowledge base, responsible for knowledge editing, adaptation and self-training
- Block of request service is a subsystem of data streams management
- Task list is the system ensuring real time operation

If system works according to the cloud services variant, the general structure can be shown as client-server architecture operation. Client part is a controller management system. It is installed on the central controller block having internet access. Server part is a web-service. F connection to the server part is established through the internet. By software system operation advanced software is used capable of ensuring determined processor speed. Platform Microsoft.NET Framework 4.0 was chosen for the project software implementation as it uses operating systems potential most fully and allows to create software of most advanced technological level.

The development of kernel is supposed to be carried out in MicrosoftVisualStudio 2010 environment. At the moment MicrosoftVisualStudio 2010 is the most productive tools for creation of high quality programmes with c visualization systems. In modern commercial projects programme design plays not the last part, especially when it concerns interface. The chosen platform and development environment allows us to use Windows Presentation Foundation (WPF) technology making creation of programmes of utmost quality and convenience possible.

Development for the other platforms can be implemented by means of corresponding programming languages and SDK. For storing data of various kinds system of databases management Microsoft SQL Server 2008 R2 was used. Combined with platform Microsoft.NET Framework 4.0 this ensured the utmost productivity in data receiving and storage.

By means of developed mathematical model thermal condition parametric analysis of industrial facility where ITCS (Morozova *et al*., 2013c; Morozova and Akimov, 2013) approval testing was conducted has been carried out. The obtained calculation results were used for estimation of gas consumption reduction in office facilities heating with various outside temperatures, shown in Table 1 (Morozova *et al*., 2013a).

We can see gas consumption reduction growing with the increase in outside temperature, it depends on water temperature in radiator. With low outside temperatures (-30 to -20°C) maximum gas consumption reduction falls at

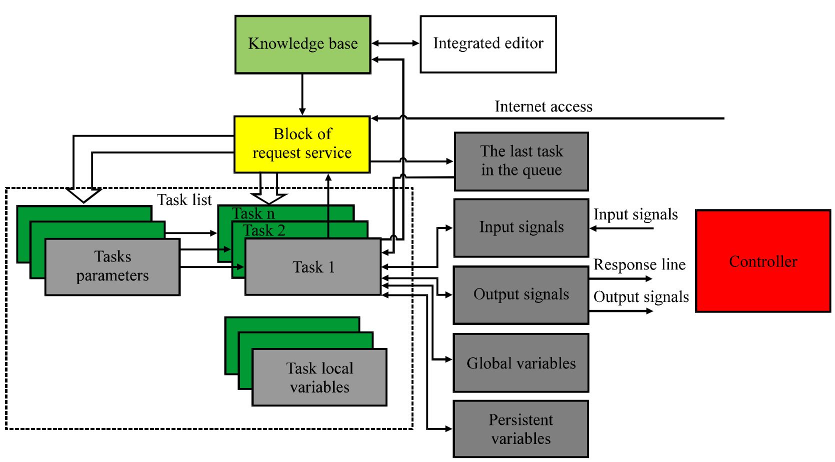

Fig. 6: Structure of temperature control software system

Table 1: Results of calculations for consumption reduction of the gas used for standard industrial facility heating with automatic hot water consumption control in heating system radiators

Temperature of water in heating system radiator (°C)	Power value of heating system radiators (W)	Gas consumption reduction (%) with outside temperature (°C)			
		-30	-20	-10	+7
45	1027	29	42	55	77
50	1280	37	43	52	62
60	1840	35	37	42	47
70	2480	30	31	34	37

water temperature in radiator of 50-60°C. With growing outside temperature maximum reduction moves towards relatively low water temperatures in radiator.

Thus, using ITCS for temperature mode moderation in a facility we can reach from 37-77% gas saving for industrial facilities heating (depending on outside temperature).

CONCLUSION

Thus, the analysis of modern soft and hardware as well as of intelligent energy-saving systems of indoor environment temperature control in industrial facilities based on it has been carried out showing the following drawbacks of existing systems:

- Impossibility of increase in connected devices number because of lower operation speed of the system as a whole
- High price of sensors and systems
- There are no systems of common intelligent heart

The advantages of the system being developed are the following:

- Use of a unique intelligent system of real time environment recognition and decision-making
- Individual adaptation by means of self-training
- Cross-platform software solution based on cloud technology
- User-friendly interface
- Software system does not require special equipment
- Simple installation and usage (doesn't require special knowledge)
- Complexity (all functions are integrated in a single module)
- Considerably lower price than that for systems of the same class

A mathematical model, algorithms and programmes have been developed to implement the concept of indoor environment temperature control system for industrial facility. The model in question is of great interest for various industrial facilities with autonomous heating.

A mathematical model has been created for customization of system of indoor environment temperature control in industrial facility describing non-steady thermal condition of an industrial building.

Software system for automatic temperature regulator control is based on artificial intelligence method with fuzzy knowledge base, sub-system of logic output, adaptation and self-training. Its application allows to control prescribed temperature parameters in uncertain and quickly changing environment which is impossible with standard analytical mathematical model.

Self-training is carried out by adding new consistent rules to knowledge base or by old rules deletion. Self-training is based on hyperresolution method with neural-like structures. New knowledge is generated through previous situations recognition by neural-like structures and is corrected by statistic analysis algorithm.

The combination of expert knowledge, adaptation and self-training allows to solve the task of energy efficiency and temperature adjusting in real time. The project of Intelligent System of Temperature Control (ITCS) for industrial facility indoor environment has been developed with the following testing.

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