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SMART HOME CLIMATE CONTROL SYSTEM BASED ON FUZZY LOGIC CONTROLLER

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The system of smart home climate control based on fuzzy logic and the Raspberry Pi microcomputer that ensures the operation of the heater, conditioner and humidifier of air has been developed. As a result of presenting input data using linguistic variables and fuzzy production rules for current values of temperature and relative humidity, output signals to control the functional devices of the smart home are obtained. The proposed approach is implemented using the Mamdani algorithm that includes the stages of fuzzification of input variables, aggregation of the truth of each rule sub-conditions, activation of conclusions and defuzzification of output variables. The application of fuzzy logic in the smart home climate control system makes it possible to take into account the individual characteristics and preferences of residents.
Keywords: smart home, climate control system, fuzzy logic controller, production rules, fuzzy inference, Raspberry Pi.

1. Introduction

The development of information technology (IT) and the home automation industry through the creation of many smart devices such as the Internet of Things (IoT) has revolutionized our living environment. Improving the quality of life of residents of smart homes is ensured by integrating a variety of appliances into an intelligent system that provides safety, comfort, and resource savings [1-3]. Due to the integration of advanced IT in the home environment, all systems and electronic devices in Smart-home projects coordinate the performance of functions without human intervention [4]. The intelligent smart home system provides not only continuous monitoring of many living environment parameters but also centralized control of electronic devices [5-7]. As the subsystems become more complex and the number of functions they perform increases, their management becomes more and more difficult. Therefore, the development of systems and algorithms designed to meet the specific needs of smart home residents or to respond to situations related to environmental change or security is one of the current areas of research in the field of Smart solutions & IoT.

An important indicator of the smart home quality is the level of comfort that is determined by the compliance of values of basic home parameters to optimum conditions of the residents in the system “human – living environment”. These parameters include temperature, humidity and indoor air pollution, light level, etc. Climate control is one of the most requested features of intelligent systems of the smart house that provides the optimal combination of a high comfort level of residents and balanced use of resources [8,9].

A feature of the climate control system is the need to take into account approximate and subjective information for the control of household appliances that create an atmosphere of coziness and comfort. Comprehensive coverage of different criteria of comfortable living involves the use of linguistic variables and rules, which are close to spoken language by structure presentation. These requirements need the use of specific approaches, which include fuzzy modeling methods [10,11]. Fuzzy modeling is a classic artificial intelligence technology that is successfully used in many control systems for industrial and household appliances, where traditional modeling methods and controllers usually do not provide the required level of efficiency or productivity. In particular, the use of linguistic variables to describe complex and weakly structured processes, establish the correlation between concepts, and implement a formal description of fuzzy rules make fuzzy algorithms for managing technical systems relatively easy to develop and implement [12-14].

In this paper, the climate control system with two inputs and three outputs based on fuzzy inference is proposed. It has been demonstrated that fuzzy logic controller provides reliable control of the modes of heating, conditioning, and humidification of air using current temperature and relative humidity data.

2. Design of fuzzy logic controller

The architecture of fuzzy logic controller for climate control system consists of fuzzification block, the base of fuzzy production rules, and defuzzification block, which generates output signals that control the operation of the heater, conditioner, and humidifier of air. The values of temperature and relative humidity indoor are used as input signals. Fig. 1 illustrates the architecture of the climate control system based on fuzzy inference.

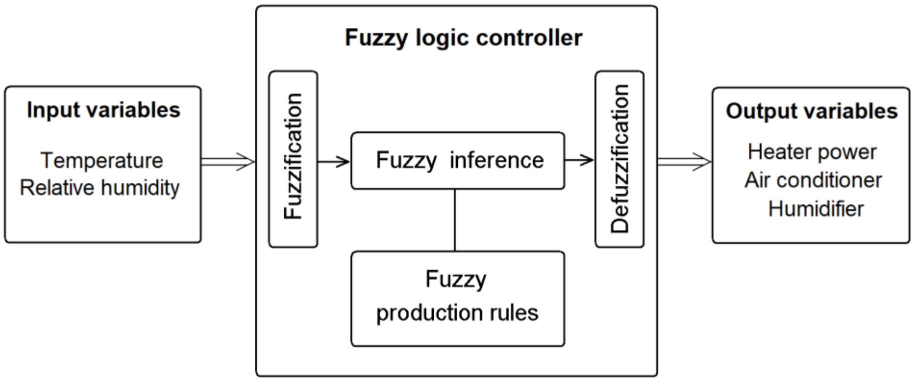
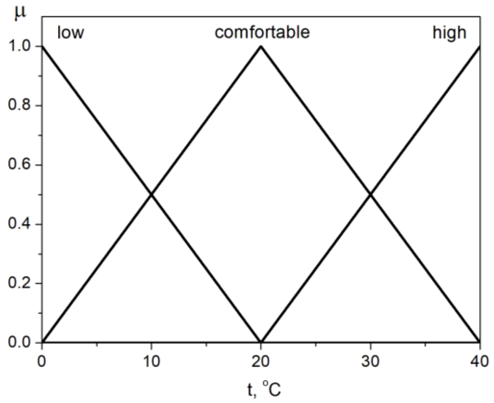


Fig. 1. Scheme of the climate control system based on the fuzzy logic controller.

The input linguistic variables "temperature" and "humidity" contain the terms "low", "comfortable" and "high". They are set on the scales of temperature and relative humidity respectively. The terms of the output linguistic variables correspond to the control signals that ensure the operation of the heater, air conditioner and humidifier. That is, the output linguistic variables are "heater power", "air conditioner" and "humidifier". In particular, the power of the heater can be high (P_H high), medium (P_H middle), or the heater can be turned off (P_H off). The modes of air conditioning (C) and humidification (H) can be turned on or off. The membership functions of fuzzy sets characterizing the terms of input and output linguistic variables were set by piecewise linear functions, as shown in Fig. 2 and Fig. 3. It should be noted that the parameters of the membership functions of fuzzy sets can be adjusted according to the individual preferences of the smart home residents.



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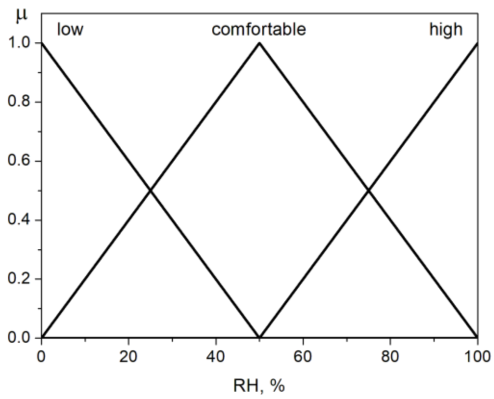


b)

Fig. 2. Membership functions of fuzzy sets characterizing the input variables “temperature” (*a*) and “humidity” (*b*).

To implement the smart home climate control functions, the algorithm of fuzzy inference proposed by Mamdani was used [15]. The mechanism for obtaining a fuzzy inference is based on information of various origins, including experimental data, expert opinions, and the preferences of residents. This information is represented by fuzzy production rules.

The proposed climate control system is based on fuzzy rules in the form of IF (sub-condition 1) AND (sub-condition 2) - THAT (action). Sub-condition 1 establishes affiliation of current value temperature to fuzzy sets characterizing the terms of the linguistic variable "temperature". Sub-condition 2 is associated with the affiliation of the current value of relative humidity to terms of the linguistic variable "humidity". Table 1 shows the base of fuzzy rules formed in accordance with the proposed model.

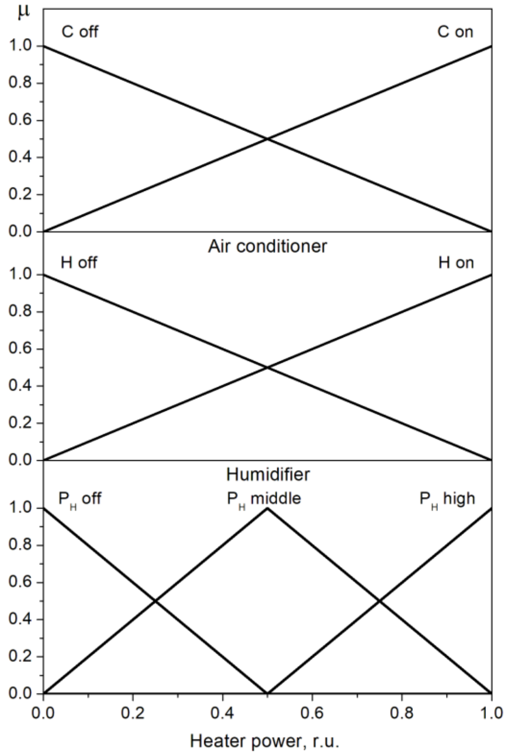


Fig. 3. Membership functions of fuzzy sets characterizing the output linguistic variables "air conditioner", "humidifier" and "heater power".

The algorithm for generating signals controlling climatic household appliances contains the following stages of fuzzy inference:

1. The truth degree of the statements of each of the terms of linguistic variables that form the conditions of the production rules is determined using the fuzzification procedure for given values of temperature and relative humidity (RH). It should be noted that the truth degree of the statement is defined as the value of the membership function of the corresponding fuzzy set for a quantitative value of the selected input parameter.

2. The truth of the condition of each of the fuzzy rules is obtained by aggregation of the truth degrees of the sub-conditions of this rule by the operation of the fuzzy conjunction.

3. The truth of the conclusion of each of the fuzzy production rules is determined by the operation of min-activation. Only active production rules are involved in the conclusion activation procedure. The truth degree of their conditions is different from zero.

4. Accumulation of conclusions of fuzzy production rules for each of the output linguistic variables is carried out by means of fuzzy disjunction operation.

5. Output signals to control the functional devices of the climate system are obtained using the defuzzification procedure by the center of gravity method [16].

Table 1. The base of fuzzy rules of the smart home climate control system.

Temperature	Humidity		
	Low	Comfortable	High
Low	P_H high C off H on	P_H high C off H off	P_H high C on H off
Comfortable	P_H off C off H on	P_H off C off H off	P_H middle C on H off
High	P_H off C on H on	P_H off C on H off	P_H off C on H off

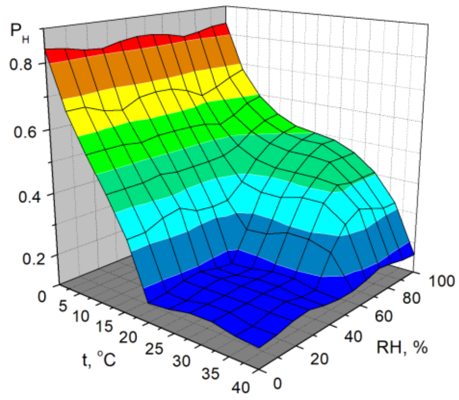
The application of this algorithm for a pair of temperature and relative humidity values makes it possible to obtain output control signals that provide a comfortable living environment for smart home residents.

3. Software and hardware implementation of climate control system

Test results of the climate control system based on fuzzy inference are illustrated in Fig. 4, which shows the dependence of the output control signals of "heater power" (P_H), "air conditioner" (C), and "humidifier" (H) on room temperature and relative humidity.

The obtained results demonstrate that output signals, which control the heater power and the air conditioner, depend on both the value of temperature and relative humidity. The climate control system significantly increases the power of the heater in case of low room temperature. In addition, the air conditioner is turned on together with a low-power heater in the case of high humidity even at high room temperature. However, the power of the heater decreases as much as possible with increasing temperature. The combined action of the air conditioner and the heater provides an effective reduction in humidity. Unlike the operation of the air conditioner, the activation of the humidification mode is determined mainly by the value of relative humidity regardless of room temperature.

The setting of the output linguistic variable P_H on the set [0, 1] allows getting the value of the output signal as a percentage of the maximum power of the heater. This approach is versatile for rooms that differ in size and shape, with various thermally conductive properties of the walls, for different heat sources. To enable air conditioning and humidification modes, it is necessary to select the threshold values of the output variables "air conditioner" and "humidifier" in the range [0, 1]. Fig. 5 shows diagrams for the threshold values of the output variables C and H as a function of temperature and relative humidity. The use of fuzzy modeling methods makes it possible to take into account approximate and subjective information on the comfort of living spaces and adjust the climate control system to the individual preferences and needs of residents.



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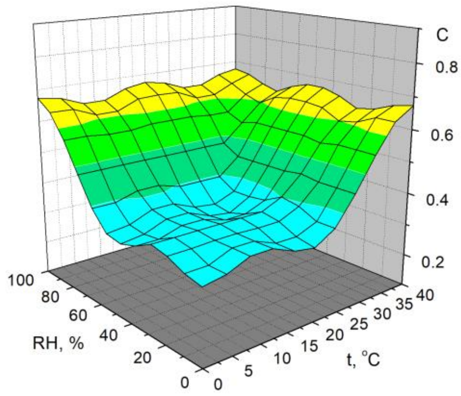

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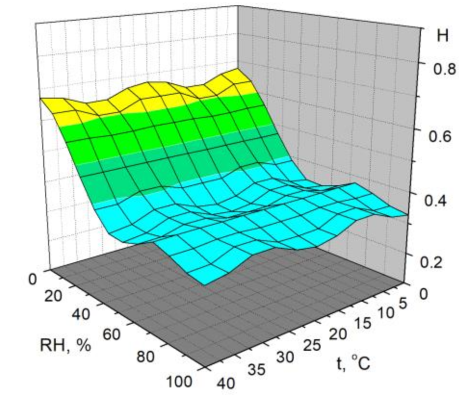
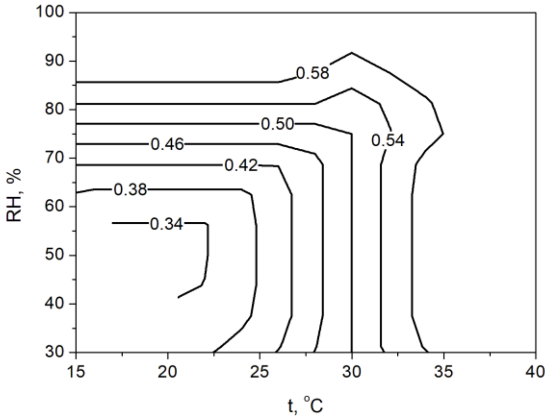


c)

Fig. 4. Dependences of the output control signals of "heater power" (*a*), "air conditioner" (*b*), and "humidifier" (*c*) on room temperature and relative humidity.

In particular, if residents prefer a warm and humid climate, the threshold value of the control signal, which turns on the air conditioning and humidification modes, should be increased. Conversely, the threshold value of these output signals should be reduced in the case of preference for dry and cool living conditions.



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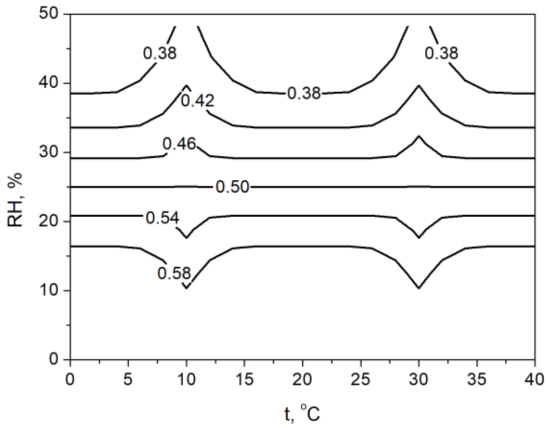

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Fig. 5. Threshold values of the output signals that turn on/off the air conditioning (*a*) and humidification (*b*) modes as a function of temperature and relative humidity.

It should be noted that the accuracy of the proposed climate control system based on the fuzzy logic controller can be increased by a smaller partition of the subject area, the introduction of additional fuzzy sets and the corresponding fuzzy production rules. An increase in the model complexity (i.e. increasing the number of rules or fuzzy sets) increases the adequacy of the model and its ability to accurately describe the real system. However, with increasing complexity, the amount of information about the system needed to model increases significantly. This information is often insufficient to determine the parameters of the model. Therefore, it is advisable to find a reasonable compromise between the accuracy and complexity of the fuzzy model. In many practical tasks, even simple fuzzy models provide effective control of various devices.

The smart home climate control system is implemented on the basis of the Raspberry Pi microcomputer using the RPi.GPIO module [17]. The DHT11 temperature and relative humidity sensor [18] was used to determine both current values of the fuzzy logic controller input variables. The software is developed in Python using the libraries necessary for fuzzy modeling and work with the DHT11 sensor. The output signals of the fuzzy logic controller were fed to the electronic unit to amplify and control the operation of climate devices. Pulse-Width Modulation was used to control the power of the heater. The value of the output variable P_H was used as the Duty Cycle parameter.

4. Conclusions

Thus, the considered climate control method in smart homes based on the fuzzy logic controller enables to obtain the quantitative values of heater power and output signals that turn on/off air conditioning and humidification modes. Control signals are obtained as a result of the implementation of procedures of fuzzification of temperature and relative humidity input variables, aggregation of the truth of each fuzzy rule sub-conditions, activation of conclusions and defuzzification of output variables.

The proposed approach makes it possible to take into account the individual preferences and needs of smart home residents and does not require complicated calculations. This leads to the simplification of the climate control process in smart homes.

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СИСТЕМА КОНТРОЛЮ КЛІМАТУ РОЗУМНОГО БУДИНКУ НА ОСНОВІ КОНТРОЛЕРА НЕЧІТКОЇ ЛОГІКИ

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У роботі розроблено систему контролю клімату розумного будинку на основі контролера нечіткої логіки та мікрокомп'ютера Raspberry Pi. Запропонована система контролю клімату забезпечує роботу обігрівача, кондиціонера та зволожувача повітря. У результаті представлення вхідних даних у вигляді лінгвістичних змінних і бази нечітких продукційних правил для поточних значень температури та відносної вологості повітря отримано вихідні сигнали для управління функціональними пристроями, що забезпечують комфортні кліматичні умови мешканцям розумного будинку.

Запропонований підхід реалізовано на основі алгоритму Мамдані, який містить етапи фазифікації вхідних змінних, агрегування істинності підумов кожного з нечітких продукційних правил, активації висновків та дефазифікації вихідних змінних. Застосування нечіткої логіки у системі контролю клімату розумного будинку дає змогу врахувати індивідуальні особливості та уподобання мешканців і не вимагає складних розрахунків. Це забезпечує спрощення процесу керування кліматом у розумних будинках.

Система контролю клімату реалізована на основі мікрокомп'ютера Raspberry Pi з використанням модуля RPi.GPIO і бібліотек мови програмування Python, необхідних для нечіткого моделювання та роботи з сенсором DHT11, який було використано для визначення температури та відносної вологості повітря.

Ключові слова: розумний будинок, система клімат-контролю, контролер нечіткої логіки, продукційні правила, нечіткий висновок, Raspberry Pi.

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