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APPLICATION OF ARTIFICIAL NEURON NETWORK AND FUZZY INFERENCE IN THE HOUSEPLANT WATERING INTELLIGENT SYSTEM

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ABSTRACT

Background. The automation of modern technologies and the widespread adoption of smart Internet of Things (IoT) devices not only provide an opportunity to optimize routine processes but also offer innovative solutions within intelligent smart home systems, enhancing the daily comfort of residents. In particular, the integration of artificial intelligence (AI) technologies can expand the functionality of embedded smart home systems and improve their efficiency. Consequently, the development of hardware and software tools for such systems represents a pertinent area of research in the field of smart solutions.

Materials and Methods. The automatic indoor plant irrigation system is implemented using the Raspberry Pi 4 microcomputer and the SEN0308 soil moisture sensor. Control of the irrigation system is achieved through an artificial neural network with two hidden layers and fuzzy logic inference methods. These methods determine the required water volume for irrigation based on soil relative moisture and air temperature.

Results and Discussion. The system operates by periodically analyzing the soil's relative humidity and indoor air temperature, making decisions regarding the activation of the irrigation mechanism based on the collected data. It has been established that implementing artificial intelligence algorithms and fuzzy logic enables automatic regulation of water usage according to environmental conditions, preventing excessive soil moisture. The proposed approach ensures an optimal soil moisture level of 50–60%, suitable for plant growth and development, while also reducing the average monthly water consumption by 25–27%.

Conclusion. The results indicate the high efficiency of using artificial intelligence and fuzzy logic methods for the rational utilization of water resources. Moreover, the proposed algorithms can be implemented on low-power computational platforms commonly used in automation and IoT systems. The proposed intelligent irrigation system demonstrates the potential for functional expansion and the integration of innovative technologies for indoor plant care.

Keywords: Smart home, IoT, embedded systems, irrigation system, artificial neural network, fuzzy logic.

INTRODUCTION

The technological revolution of recent decades has profoundly transformed daily life. Among the key trends driving this progress is the automation of modern technologies, which not only optimizes routine processes but also, through the widespread adoption of the Internet, offers innovative solutions for everyday comfort in intelligent smart home systems [1-3].

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Examining contemporary models of embedded smart home systems reveals key technological components, including centralized control systems and smart sensors. Popular systems such as Google Home, Amazon Alexa, and Apple HomeKit utilize voice control to activate and manage various home devices [4-6]. Integrated solutions encompass intelligent automation systems that regulate lighting, heating, ventilation, and air conditioning. Notably, smart home systems from Crestron or Control4 allow users to schedule and create scenarios for different situations [7,8]. Smart thermostats can automatically adjust home temperatures based on residents' schedules and habits. Continuous monitoring of all smart home systems optimizes energy consumption and enhances energy efficiency. Security systems frequently incorporate video surveillance, motion and door sensors, and technical tools for identification and access control. For instance, Google's Nest Secure provides an integrated system of video surveillance and security sensors with remote control capabilities via smartphone [9]. Furthermore, embedded smart home systems employing unified platforms for integration and management can interact seamlessly with various household devices under the IoT paradigm [10,11].

Most IoT household devices in smart homes are designed to perform single functions, such as watering plants at a predetermined time or raising blinds at sunrise. However, the rapid advancement in microcomputer technology, edge computing, and the availability of tools like TensorFlow Lite, which enables neural network deployment on mobile phones, tablets, televisions, and other embedded systems, opens new possibilities for the development of intelligent smart home systems [12].

This study aimed to explore the integration of artificial intelligence (AI) and fuzzy logic technologies in automatic indoor plant irrigation systems to ensure the efficient use of natural resources. Special attention was given to investigating the potential of low-power computational technologies and artificial neural networks in advancing innovative smart home systems.

MATERIALS AND METHODS

To investigate the efficiency of using artificial intelligence and fuzzy logic technologies in smart home systems, an automatic indoor plant irrigation system was developed based on a Raspberry Pi 4 microcomputer [13] and a SEN0308 soil moisture sensor [14]. The schematic diagram of the irrigation system is shown in Fig. 1.

The system operates by periodically analyzing the relative humidity (RH) of the soil and air, as well as the air temperature, every 8 hours. Based on the collected data, decisions are made regarding the activation of the irrigation mechanism. Since the experimental studies were conducted using a ficus plant, the proposed irrigation system aimed to maintain optimal conditions for this plant. Specifically, in the simplest implementation, automatic watering with 150 ml of water occurred when the soil moisture at a depth of 6–7 centimeters fell below 50% (Fig. 2).

The application of artificial intelligence technology and fuzzy logic algorithms not only determines the necessary volume of water for irrigation but also adapts it to changing environmental conditions, maintaining optimal soil moisture for the ficus within the range of 50–60%. In the initial implementation, the plant irrigation system was controlled using a neural network with two hidden layers, trained on historical data of soil moisture and water usage over 100 epochs. Mean Squared Error (MSE) was employed as the loss function, and the weights of the neural network were optimized using the backpropagation algorithm with an adaptive gradient optimizer [15,16]. Model validation was performed through cross-validation using independent datasets.

Another approach involved using a fuzzy logic inference system with two inputs and one output. This system determined the required water volume for irrigation based on the soil relative moisture and indoor air temperature. The input linguistic variables were *"Soil moisture"* = {"Low" (L), "Moderate" (M), "High" (H)} and *"Indoor temperature"* = {"Cold" (C),

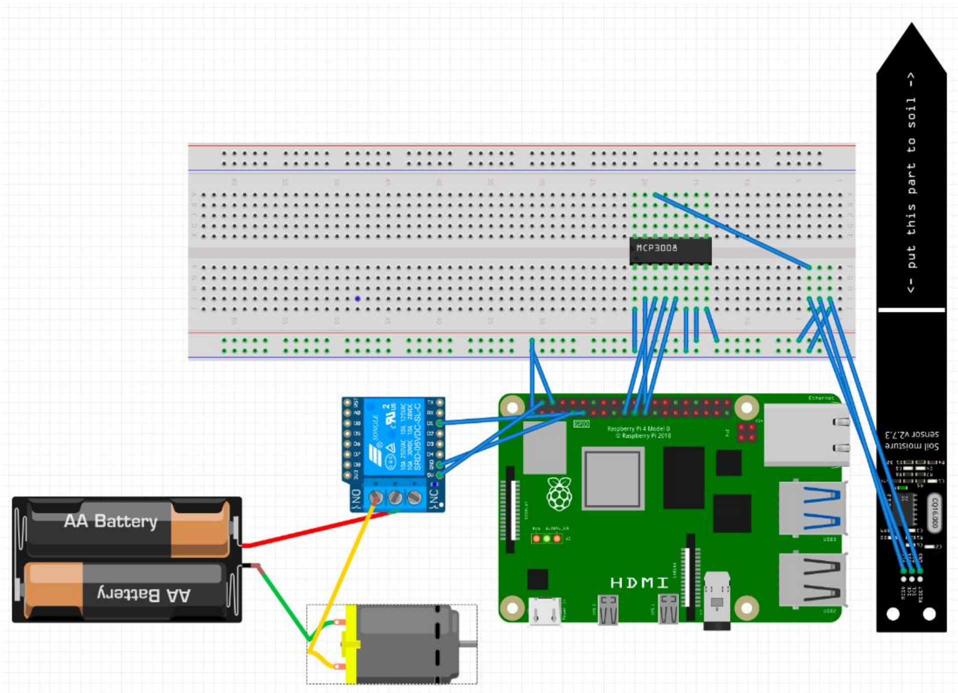


Fig 1. Schematic diagram of the automated indoor plant irrigation system.

"Warm" (W), "Hot" (H)}. The terms of the output linguistic variable *"Used water volume"* characterized the need for very low (LL), low (L), moderate (M), high (H), and very high (HH) levels of soil hydration. The membership functions of the fuzzy sets corresponding to the terms of these linguistic variables are shown in *Fig 3*.

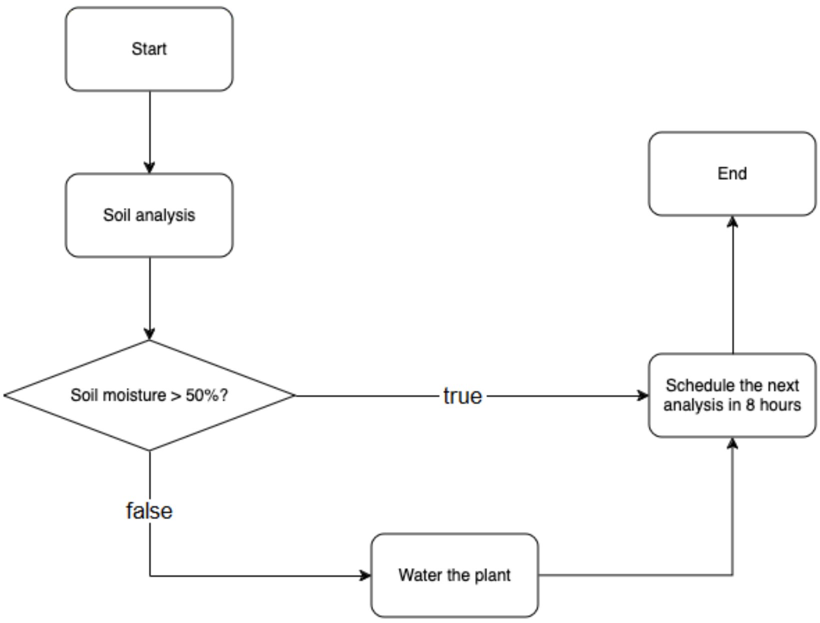


Fig 2. Algorithm of automated irrigation system operation.

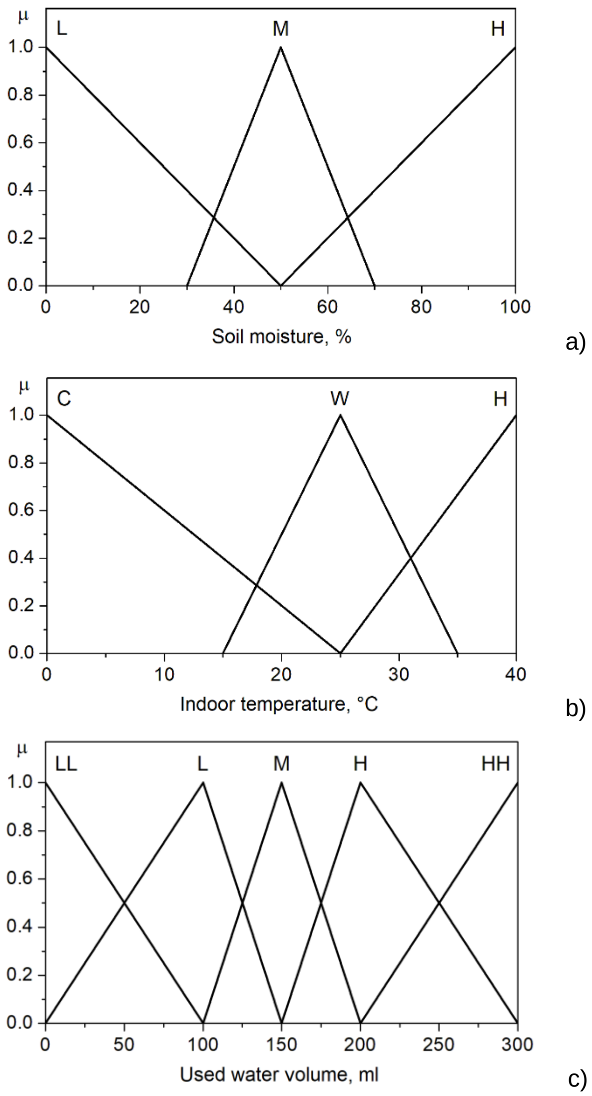


Fig. 3. Membership functions of fuzzy sets characterizing the input linguistic variables "Soil moisture" (a) and "Indoor temperature" (b) as well as output linguistic variable "Used water volume" (c)

The fuzzy rule base was formed in the form IF (sub-condition 1) AND (sub-condition 2) THAT (action). Sub-condition 1 establishes the affiliation of the current value of the soil relative moisture to fuzzy sets characterizing the terms of the linguistic variable "Soil *moisture*". Sub-condition 2 is associated with the affiliation of the current value of temperature to terms of the linguistic variable *"Indoor temperature"*. The fuzzy sets of the corresponding terms of the output linguistic variable *"*Used *water volume"* are the rule conclusions.

The base of fuzzy rules for the houseplant watering system is given in Table 1. In general, the fuzzy rules accumulate information from various sources, including experimental data, simulation results, and expert opinions.

The fuzzy logic-based irrigation system was implemented using the Mamdani algorithm, whose main stages include the fuzzification of input variable values, min-activation and max-accumulation of the conclusions from fuzzy production rules, and the defuzzification of the output variable using the centroid method [17,18].

Table 1. **The base of fuzzy rules of the houseplant watering system**

Soil Moisture	Indoor Temperature		
	L	M	H
L	M	H	HH
M	L	M	H
H	LL	L	M

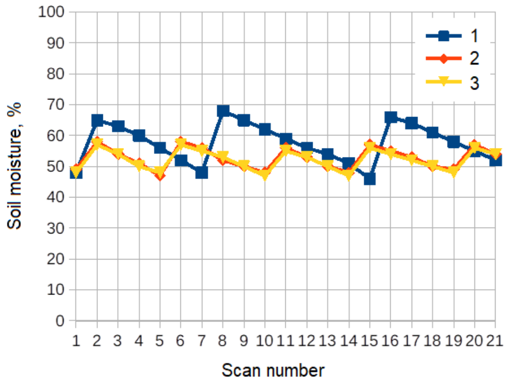
RESULTS AND DISCUSSION

The primary objective of the developed system is to ensure efficient irrigation of indoor plants while minimizing water consumption and preventing potential harm to the plants. Considering that environmental conditions such as temperature and humidity vary throughout the year, the effectiveness of irrigation can also fluctuate. Therefore, experimental studies were conducted in two stages under different indoor climatic conditions. In the first stage, the relative humidity and air temperature were approximately 60% and 20°C, respectively. During the second stage, the plant was subjected to warmer and drier conditions – with a relative humidity of about 45% and an air temperature of 25°C.

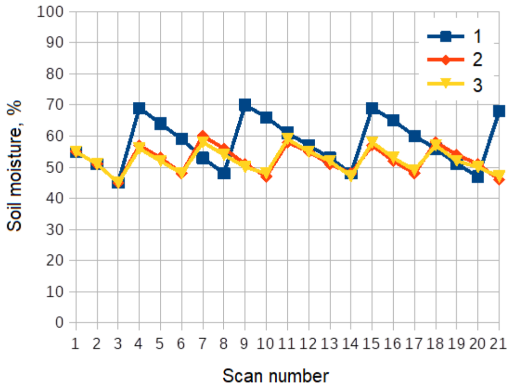
An important parameter for the functioning of the irrigation system is the soil moisture at the time of each watering, as it is essential to maintain the optimal soil moisture level for the plant – approximately 55% for ficus. The temporal variations of soil moisture under different indoor climatic conditions and various irrigation methods are illustrated in *Fig. 4*.

Integrating artificial intelligence technologies into the irrigation system enables automatic regulation of the water volume used based on environmental conditions, preventing excessive soil moisture. As a result, this approach not only provides optimal conditions for plant growth and development but also ensures rational water consumption (see Table 2). Specifically, a reduction of 25% in average monthly water usage was observed during the first stage of the studies, and a 27% water savings during the second stage.

The intelligent indoor plant irrigation system based on fuzzy logic inference demonstrates similar water usage and soil moisture levels to those of the neural network system (see *Fig. 4*). The results of testing the irrigation system with fuzzy inference are illustrated in *Fig. 5*. Based on the analysis of the input–output surface of the fuzzy controller, it was established that the volume of water used for irrigation depends on both soil moisture and air temperature. Specifically, the irrigation system requires a significantly larger volume of water when soil moisture is low and indoor air temperature is high.



a)



b)

Fig. 4. Time dependence of soil moisture during the first (a) and second (b) stages of the study using the automated irrigation system (1) and one with an integrated artificial neural network (2) and fuzzy inference (3)

Table 2. **Average monthly mater volume used for irrigating an indoor plant (ficus) under different indoor climatic conditions**

Irrigation system type	Used water volume, ml	
	Stage 1 RH=60%, *t*=20°C	Stage 2 RH=45%, *t*=25°C
Automated	2228	3085
Integrated AI	1688	2260
Fuzzy inference	1663	2243

Unlike more complex machine learning algorithms, fuzzy logic methods can be effectively implemented on low-power platforms such as the Raspberry Pi Pico or Arduino, which are widely used in automation and IoT systems. The low cost and low energy consumption of microcontrollers make them an ideal choice for use in budget-friendly and energy-efficient irrigation systems. Moreover, fuzzy logic algorithms allow for the consideration of a wide range of input parameters and enable decision-making that mimics human reasoning.

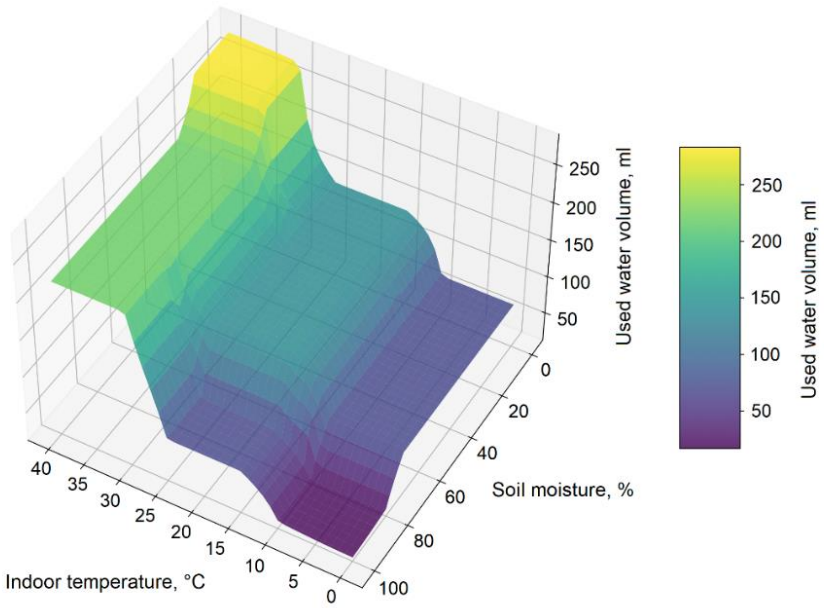


Fig 5. Dependence of used water volume on soil *moisture* and indoor temperature

CONCLUSION

In this work, an automated indoor plant irrigation system was developed using IoT technologies. The proposed irrigation system enables periodic monitoring of soil moisture and waters the plant as needed. Soft computing methods were employed to determine the necessary amount of water under varying air temperatures and relative soil moisture levels. It was established that integrating an artificial neural network and fuzzy logic inference into the irrigation system allows for maintaining an optimal moisture level in the range of 50–60% and reducing water consumption by 25–27%. An additional advantage of using fuzzy logic inference algorithms is their ability to be implemented on low-power computing devices, aligning with the IoT paradigm. By integrating new sensors, the proposed intelligent irrigation system has the potential to expand its functionality and implement innovative technologies for indoor plant care.

COMPLIANCE WITH ETHICAL STANDARDS

The authors declare that they have no competing interests.

AUTHOR CONTRIBUTIONS

Conceptualization, [R.K., I.O.]; methodology, [R.K., I.O.]; validation, [R.K.]; investigation, [R.K.]; writing – original draft preparation, [R.K.]; writing – review and editing, [I.O.]; visualization, [R.K., I.O.].

All authors have read and agreed to the published version of the manuscript.

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ЗАСТОСУВАННЯ ШТУЧНОЇ НЕЙРОМЕРЕЖІ ТА НЕЧІТКОГО ВИСНОВКУ В ІНТЕЛЕКТУАЛЬНІЙ СИСТЕМІ ПОЛИВУ КІМНАТНИХ РОСЛИН

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АНОТАЦІЯ

Вступ. Автоматизація сучасних технологій і широке впровадження розумних пристроїв Інтернету речей дає змогу не тільки оптимізувати рутинні процеси, але й запропонувати інноваційні рішення в інтелектуальних системах розумного будинку, які забезпечують повсякденний комфорт мешканців. Зокрема, використання засобів штучного інтелекту може розширити функціональність вбудованих систем розумного будинку і підвищити їх ефективність. Тому розробка програмно-апаратних засобів для таких систем є одним із актуальних напрямків досліджень у галузі розумних рішень.

Матеріали та методи. Система автоматичного поливу кімнатних рослин реалізована на основі мікрокомп'ютера Raspberry Pi 4 та сенсора вологості ґрунту SEN0308. Для керування іригаційною системою було використано штучну нейромережу з двома прихованими шарами та методи нечіткого логічного висновку, які на основі значень відносної вологості ґрунту та температури повітря визначають об'єм води для поливу.

Результати. Функціонування системи полягає у періодичному аналізі відносної вологості ґрунту та температури повітря у приміщенні і прийняті рішення про активацію механізму поливу на основі отриманих даних. Встановлено, що реалізація алгоритмів штучного інтелекту та нечіткої логіки дає змогу автоматично регулювати об'єм використаної води залежно від умов навколишнього середовища та уникати надмірного зволоження ґрунту. Запропонований підхід забезпечує не тільки оптимальний для росту та розвитку рослин рівень зволоження ґрунту у діапазоні 50–60%, але й зменшення середньомісячного об'єму використаної води на 25–27%.

Висновки. Одержані результати свідчать про високу ефективність використання методів штучного інтелекту та нечіткої логіки для раціонального використання водних ресурсів. Крім того, запропоновані алгоритми можуть бути реалізовані на малопотужних обчислювальних платформах, які широко використовуються в системах автоматизації та Інтернету речей (IoT). Запропонована система інтелектуального поливу має потенціал для розширення функціональності та впровадження інноваційних технологій для догляду за кімнатними рослинами.

Ключові слова: Розумний будинок, інтернет речей, вбудовані системи, іригаційна система, штучна нейромережа, нечітка логіка.

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