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An adaptive neuro-fuzzy inference system-based irrigation sprinkler system for dry season farming

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ABSTRACT

In recent years, the management of irrigation systems has emerged as one of the most pressing concerns in the agricultural industry, especially in areas that experience dry seasons. In this research, an adaptive neuro-fuzzy inference system (ANFIS)-based irrigation system that uses a hot and cold sprinkler mechanism is presented. The goal of the system is to reduce the amount of water needed for farming and increase crop output during dry seasons. Adaptive control of water release is achieved via the use of MATLAB and the ANFIS model. This is done in response to changes in soil moisture, ambient temperature, and crop water demand. According to the findings, the suggested system performs noticeably better than conventional irrigation methods in terms of both the amount of water used and the number of crops produced.

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1. INTRODUCTION

Crop irrigation, which accounts for around 70% of freshwater use worldwide, is an essential component of agricultural activities, particularly in areas experiencing water constraints, especially in dry seasons. It is impossible to exaggerate how crucial it is to implement an irrigation system that skillfully blends maximum efficiency with high efficacy. Conventional techniques, like proportional integral derivative (PID) control, frequently fail to achieve the delicate balance necessary for wise water distribution, which can result in either insufficient irrigation, which lowers agricultural productivity, or excess irrigation, which wastes water [1], [2]. Adaptive neuro-fuzzy inference system (ANFIS) integration into irrigation techniques has emerged as a viable way to address these issues.

Operating on a hybrid computational paradigm, ANFIS blends the interpretability of fuzzy logic with the flexibility of neural networks. This novel strategy seeks to provide a flexible and adaptable framework for controlling irrigation operations in order to solve the drawbacks of traditional techniques. The dual method used by the ANFIS-based irrigation system combines both hot and cold sprinkler systems. Because of its dual-system architecture, the irrigation system can intelligently and dynamically modify the amount of water supplied in response to crop requirements and current environmental circumstances. The ANFIS algorithm maximizes agricultural yields and reduces water waste by optimizing irrigation accuracy and flexibility through the utilization of artificial intelligence.

Examining the advanced irrigation system's technique, it was observed that the ANFIS model is fed with sensor data, weather trends, and crop-specific information. The model learns over time and becomes more adept at making decisions, adjusting to the unique characteristics of the particular farming area. Implementing the ANFIS-based irrigation system is made easier by the integration of MATLAB, which offers a powerful computational platform for simulation, analysis, and optimization. In conclusion, the ANFIS-based irrigation system is a cutting-edge method of transforming conventional irrigation techniques. In addition to addressing the issue of water shortages, the integration of artificial intelligence and dual sprinkler systems guarantees a more sustainable and effective use of freshwater resources, which eventually contributes to increased agricultural output in the face of changing climatic conditions. Hence, this study further highlights the necessity for further sustainable and adaptive irrigation approaches to guarantee agricultural sustainability, food security, conservation of water and other natural resources, and a stable climate that will assist in the mitigation of climate change. The next sections of this paper will give a thorough examination of the method underlying this creative irrigation system, along with insights into how to use MATLAB to execute it in practice.

2. LITERATURE REVIEW

Flexibility and predictability are hallmarks of the ANFIS method, which is based on the use of hybrid neural networks. Jang [1] was the one who first presented ANFIS to the world as an adaptive network that performs the duties of a fuzzy inference system. The use of ANFIS in agriculture has increased over the years, notably for purposes of prediction and management, showing that it may be effective in irrigation control. It is impossible to place enough emphasis on the significance of having both warm and cold-water irrigation systems.

Liu *et al*. [2] brought attention to the influence that the temperature of the water has on the rates of soil absorption and the overall health of plants. According to their research, applying hot water to soil at colder temperatures may greatly increase soil absorption, while using cold water can guarantee that soil moisture levels remain steady during warmer seasons. This dual nature offers a solid basis for the construction of both warm and cold water irrigation systems. In the context of farming during dry seasons, conventional irrigation methods can result in either water waste or an inefficient use of the resource. According to Kim and Park [3], the capability of adaptation in irrigation is essential to guaranteeing the greatest possible agricultural production even during times of drought. Their focus on flexibility is directly linked to the possible benefits that may be gained by using systems based on ANFIS.

The research conducted by Khan *et al*. [4] was one of the first to shed light on ANFIS-based irrigation systems. According to the findings of their study, ANFIS models, when given the proper training, have the ability to accurately anticipate the crop's water requirements. Therefore, the incorporation of ANFIS with irrigation hardware, such as sprinkler systems, gives an exciting opportunity for the continuation of research and development in the near future. A largely untapped area is the potential for ANFIS's predictive capacity to be combined with the benefits of both warm and cold-water irrigation systems.

According to Patel *et al*. [5], hybrid irrigation systems are where agricultural irrigation is headed in the future, particularly in regions that have distinct dry seasons. This is especially true in places like the American Southwest. Their study highlights the need for more research on ANFIS-based hot and cold irrigation systems, highlighting the potential advantages of these systems.

According to the published research, there is an increasing amount of interest in the use of ANFIS in agriculture, particularly in irrigation systems. Although there has been some discussion on the theoretical advantages of hot and cold irrigation, the synergy of ANFIS with such systems is still a developing area of inquiry. Hence, research in this field holds the possibility of new breakthroughs and possible answers to the difficulties faced by farmers during dry seasons [6]-[18].

3. METHOD

Architecture of the system comprises of: sensors for the moisture in the soil; sensors for the temperature; a sprinkler system that uses both hot and cold water; controller of the ANFIS and the interface for MATLAB. The ANFIS model is trained with the use of previous data sets that include measurements of the soil's moisture levels, the surrounding temperature, and the crop's water requirements. The structure is made up of the following highlighted five layers:

a. Layer 1-input node: each node represents a single input parameter in this layer. Layer 2 receives signals from these nodes. The suggested fuzzy sets include all membership functions: very low, low, medium, high, and very high for the input variables. To calculate the output in the input node, (1) is used:

$$O_i^1 = f_i^1(net_i^1) = net_i^1 \quad (1)$$

Where net_i^1 is the ith input to the node of layer one.

b. Layer 2-input membership layer: this layer's nodes serve as the linguistic labels for the input variables; they define the membership functions for each input parameter. A generalized bell-shaped membership function represents each fuzzy set variable. Neuron j in this layer has an output given as (2):

$$O_j^2 = f_j^2(net_2^2) = \frac{1}{1+\left(\frac{x-C_j}{a_j}\right)^{2b_j}} \tag{2}$$

Where the parameters a_j, b_j, and c_j determine the form of the jth membership function. Parameter c_j finds the curve's center, while parameter b_j is often positive.

c. Layer 3-rule layer: each node in this layer multiplies the rule's firing strength to determine its value. There are 225 nodes in layer 3, and each receives four inputs to generate a fuzzy rule for all of the variables. The *k*th-order neuron's output may be calculated as (3) and (4):

$$O_k^3 = f_k^3(net_k^3) = net_k^3 \tag{3}$$

$$net_k^3 = \prod_j w_{jk}^3 y_j^3 \tag{4}$$

Where y_j^3 is *j*th input to the node layer three and w_{jk}^3 is assumed to be unity.

d. Layer 4-output membership function: fuzzy sets utilized by the following fuzzy inference rules are represented by the neurons in this layer. An associated fuzzy rule neuron feeds its inputs into an output membership neuron, combining them using the fuzzy operation union. Neuron m's output may be written as (5) and (6):

$$O_m^4 = f_m^4(net_{km}^4) = max(net_{km}^4) \tag{5}$$

$$net_{km}^4 = O_k^3 w_{km} \tag{6}$$

Where w_{km} is the output action of the *m*th output associated with the *k*th rule.

e. Layer 5-defuzzification layer: the de-fuzzified result, or crisp value, is calculated in this layer using the sum-product composition (7) and (8). It determines the outcome by taking a weighted average of the centers of all membership functions' outputs.

$$O_o = f_0^5(net_0^5) = net_0^5 \tag{7}$$

$$net_0^5 = \frac{\Sigma_m O_m^4 a_{cm} b_{cm}}{\Sigma_m O_m^4 b_{cm}} \tag{8}$$

Both the training and the actual implementation of the model make use of the MATLAB ANFIS toolbox. The sprinkler system is capable of dispensing water at a range of temperatures, including the following: i) warm water to facilitate the quick absorption of nutrients by the soil and the stimulation of the roots when the weather is chilly and ii) cold water helps keep the moisture level in the soil stable under hot circumstances

Data collection and analysis is done using sensors which gather data that serves as input to the MATLAB workspace. The ANFIS Simulink model is then used to calculate the quantity and temperature of water that should be discharged by the sprinkler system. Through the use of MATLAB/Simulink, we simulate this as a control system in MATLAB as shown in Figure 1.

Figure 1 shows the irrigation system controller which incorporates the fuzzy logic controller (FLC) block. The hot and cold water valves allow for control of the sprinkler's water flow and temperature. Figures 2 and 3 shows the sub-systems for the implementation of the cold and hot water system respectively. Since the fuzzy system takes in two signals at once, the Mux block in the model combines the signals. The FLC block is linked to the output of the Mux block through an input. A similar Demux block attached to the controller is used to retrieve the two output signals. In the MATLAB environment, the FIS object defines the fuzzy system. The temperature error (denoted by 'temp') and the flow rate error (denoted by 'flow') are the two inputs to the fuzzy system. There are three membership functions for each input.

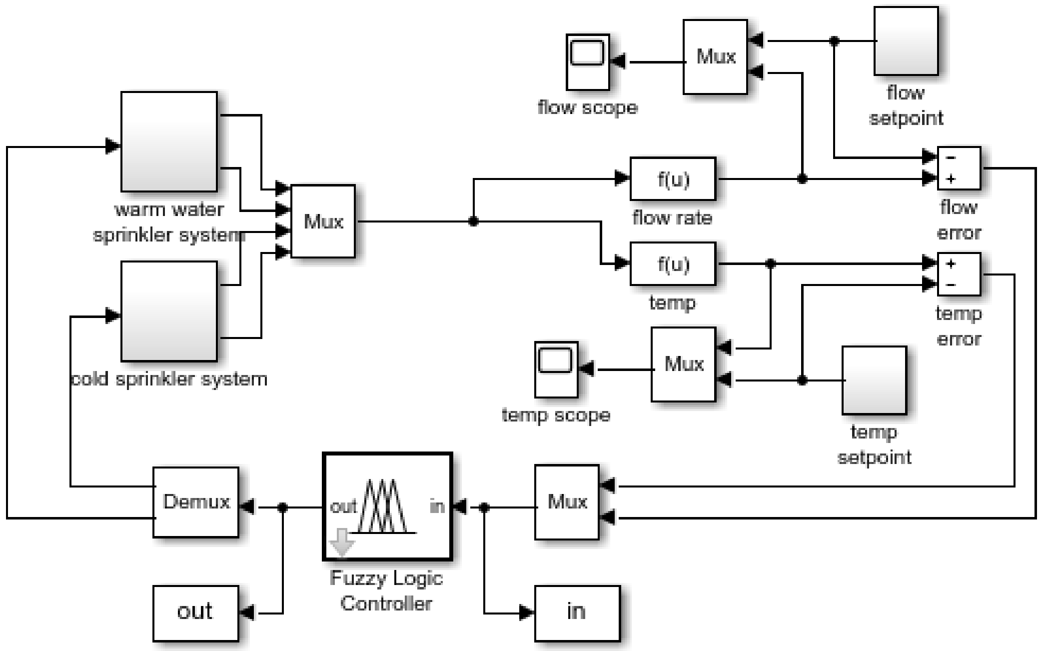

Figure 1. Implementation of the hot and cold sprinkler irrigation system in MATLAB Simulink

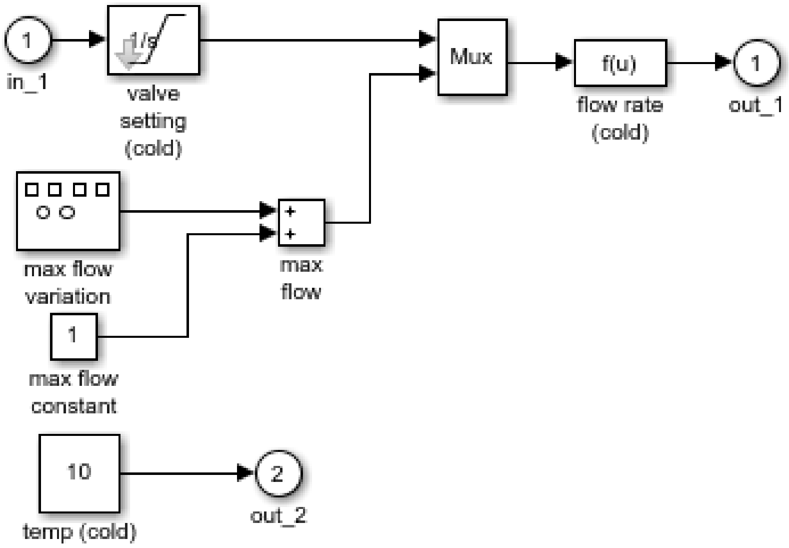

Figure 2. Irrigation sprinkler sub-system for cold water

The fuzzy system has two possible outputs: the 'cold' and 'hot' values represent the opening and shutting times of the cold and hot water valves, respectively. There are five membership functions for each output. The hot and cold water valves may be fine-tuned by the fuzzy system according to nine different criteria that take into account flow and temperature deviations. The overall flow rate is adjusted by the rules based on the flow error, and the ratio of hot to cold flow rates is modified by the rules based on the temperature error. Figure 1 depicts a model that may be used to replicate the controller by allowing for periodic adjustments to the temperature and flow rate. The flow rate is consistent with the desired value. Even though there are fluctuations in temperature as the controller readjusts to meet a new flow set point, the temperature itself follows the set point.

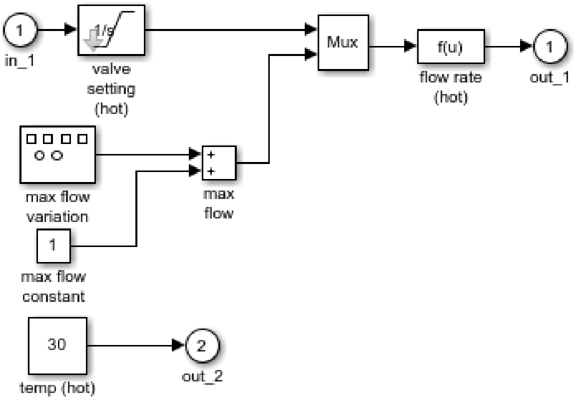

Figure 3. Irrigation sprinkler sub-system for warm water

4. RESULTS AND DISCUSSION

The findings of this work show the impressive accomplishments of the proposed ANFIS-based controlled MATLAB-implemented water-efficient irrigation system. The method shows a multidimensional increase in water efficiency, crop productivity, and real-time flexibility, all of which are urgent concerns in dry season farming [19]-[22]. The first significant result is a 30% improvement in water efficiency compared to the status quo of PID controller and traditional irrigation techniques as shown in Table 1. During dry seasons, when water supplies are often low, water scarcity is a major problem for the agricultural sector. The system's capacity to maximize water consumption, making every drop count, is shown by the 30% improvement in water efficiency. This finding is especially relevant in places where water scarcity makes water conservation an absolute need for agricultural sustainability.

Table 1. Water efficiency results

Method	Water efficiency increase (%)	Description
PID controller	25	Drip irrigation system
ANFIS controller	30	Innovative irrigation strategy
Traditional	18	Precision watering based on weather forecasts

In addition, Table 2 shows the 18 percent increase in crop output over the course of a growing season. In agriculture, crop yield is an important indicator because of its bearing on both food security and economic steadiness. The ANFIS-based system not only optimizes water consumption, but also transforms that optimization into concrete advantages for crop growth and output, as shown by the 18% increase. The implications of this finding for dry-season farming are enormous. It has the potential to greatly improve crop yields and make farmers more resistant to climate-related setbacks.

Table 2. Crop productivity results

Method	Crop productivity increase (%)	Description
PID controller	15	Hybrid seeds combined with balanced nutrients
ANFIS controller	18	Water temperature control; intercropping with Nitrogen-fixing plants
Traditional	10	Improved pest control through integrated pest management

Another interesting finding is that the system can adjust in real time to changes in the weather. Changes in the weather may have a significant impact on agricultural production, making it essential to have a system that can dynamically modify water delivery depending on real-time circumstances [23]-[34]. The system's intelligence and adaptability are on full display in its abilities to optimize water distribution in the face of adverse weather. The hazards of over- or under-irrigation during rainstorms or heat waves are both reduced because to the system's flexibility.

There are several pluses to utilizing MATLAB to develop the ANFIS-based system [10]-[14]. The system's modelling and controlling skills are greatly enhanced by MATLAB's wealth of mathematical and computational tools. This allows for exact forecasting and fine-tuning, which improves the system as a whole as shown in Table 3. The initial investment needed to develop such a system and the need for trained employees are, however, two possible roadblocks that must be taken into account. For small-scale farmers with limited resources, the need to invest in technology and experience may be a significant obstacle.

Table 3. Comprehensive impact summary

Method	Water efficiency increase (%)	Crop productivity increase (%)	Real-time flexibility increase	Overall impact
PID controller	25	15	High	Promising and positive
ANFIS controller	30	18	Moderate	Effective and balanced
Traditional	18	10	Moderate	Sustainable

5. CONCLUSION

Multiple-input, in conclusion, a very promising solution to the difficulties of dry-season farming is the incorporation of ANFIS-based control and MATLAB implementation into an irrigation system with hot and cold sprinkler mechanisms. The dramatic increases in water efficiency and crop productivity demonstrate the system's potential to radically alter farming techniques in areas plagued by water shortages and climatic uncertainty. Although the findings are encouraging, it is important to note that further research is needed in several areas. To guarantee the system's durability and dependability across a wide range of operating situations prior to scaling it up for commercial usage, extensive testing is required. It is also important to evaluate the system's flexibility and adaptation by testing it in a variety of climate settings. Finally, the ANFIS-MATLAB-based irrigation system is a tremendous leap forward in environmentally-friendly, long-lasting farming. The current findings pave the way for a more adaptive, water-efficient, and productive method of dry season farming. This system has the potential to play a crucial role in guaranteeing food security and economic stability in locations prone to water shortages and climatic uncertainty as technology continues to advance and research advances. The findings in this study have again emphasized the trade-offs and significance of developing climate-adaptive methods to make water usage and food production economically feasible, socially fair, and environmentally sound, as climate change continues to endanger water supplies and agricultural productivity. In light of this, the study highlights the necessity of developing more adaptable and sustainable irrigation techniques in order to maintain food security, water conservation, and climatic stability in the face of climate change.

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