A Novel Approach for an Outdoor Oyster Mushroom Cultivation using a Smart IoT-based Adaptive Neuro Fuzzy Controller

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***Abstract*—An automatic environment control systems for greenhouses are turning to be very significant because of food demand, and rise in temperature and population of the world. This article proposes to design and implement a low cost, robust and water efficient autonomous smart internet of things (IoT) system to monitor and control the temperature, and humidity of an outdoor oyster mushroom growing unit. The IoT-based control system involves DHT22 sensors, ESP32 controller and actuators (water pump and cooling fan) to facilitate the adequate amount of air for circulation to maintain temperature and water to maintain humidity inside an outdoor oyster mushroom growing unit as per its requirement. A real working prototype is developed and implemented on integrating fuzzy inference system (FIS) in ESP32 controller using Arduino C with the help of its integrated design environment. The FIS is designed to calculate the switching on/off time of water pump and cooling fan on sensing current temperature, and humidity inside oyster mushroom unit with respect to ambient temperature, and humidity respectively. The prototype provides inside temperature, humidity, ambient temperature, ambient humidity, water pump time and fan time on Thing-speak platform in real time. Furthermore, the data is used for design and simulation of Adaptive Neuro Fuzzy Inference Controller for an outdoor oyster mushroom growing unit in MATLAB/Simulink to improve the performance of the system. The practical applicability of the proposed ANFIS controller over FIS Controller and industrial PID Controller is shown by simulation findings with use of experimental data. The system reduces water use as well as an extremely extraordinary administration required for monitoring the mushroom unit. In addition, it increases robustness of the system.**

Keywords—Precision agriculture; adaptive neuro fuzzy inference system; fuzzy inference system; oyster mushroom cultivation; internet of things

I. Introduction

Agricultural practices are utmost essential ways of subsistence over the period of human evolution. Henceforth, human beings depend on broad scale of agricultural goods in nearly every facet of life. However, today the changes in climatic conditions are affecting the growth of greenhouses drastically. In addition, increase in food demand with increasing world population, the traditional agricultural practices are transforming into artificial and smart practices. This study aims to address the problem of controlling the environment conditions in an oyster mushroom crop and watering it without contamination, by providing sensor and actuators based smart autonomous controller, thereby removing much of efforts required by farmer.

The advent of new species of mushrooms for commercial growing during the past two decades has caused the mushroom industry worldwide to expand very quickly. Despite having a plenty of agricultural waste, and a rich fungal biodiversity, India's rise has received only unresponsive support. Presently, 0.13 million tons of mushrooms are produced in India [1]. From 2010 to 2017, the Indian mushroom market experienced an average annual growth of 4.3% (www.indiastat.com). This shows that the` mushroom industry is expanding day by day and has potential to generate more money in the future. Since maintaining essential environmental conditions is necessary for mushroom growth, the key challenge is how to add value to the mushroom cultivation process. In order to link data to productivity gains, the Internet of Things (IoT) era is essential to the information technology revolution. The use of the IoT has the potential to help farmers to overcome a number of challenges, such as water shortages, a lack of adequate land for plantations, maintaining crucial parameter for crop growth, difficulty in managing costs, and meeting the global demand for food resources [2]. In order to help farmers to improve the quality, quantity, sustainability, and cost-effectiveness of agricultural production, smart agriculture uses IoT applications.

Oyster Mushroom has many advantages, including being high in proteins and having medicinal uses. These mushrooms can only grow in upland regions with specific humidity and temperature levels. Because it is more economical than other agricultural practices, the government encourages farmers to grow oyster mushrooms in lowland areas. Misting oyster mushrooms with clean water will keep them at the right humidity and temperature. It can develop normally in controlled environments where the temperature ranges from 24 to 27°C and the relative humidity ranges from 70 to 85% [3]. However, because it requires a significant financial commitment, farmers typically find it challenging to build air-conditioned farms. When growing mushrooms manually, humidity is maintained by hanging coir mats or gunny sheets along the walls, and it is kept moist by periodic watering during the cropping phase. It is also more difficult to maintain the proper humidity and moisture in the substrate during the summer because more water is lost due to evaporation. Watering the mushrooms extensively twice or three times a day is the solution, but this has the drawback of making the mushrooms overly wet and producing unusable, low-quality product. Therefore, proper controlling mechanism is needed.

A smart oyster mushroom growing unit is an enclosed structure that offers mushrooms an environment that is properly controlled using IoT and Soft computing technology Fuzzy Inference System (FIS) to regulate mushroom growing conditions, to lower production costs and increase the revenues. The IoT-based control system involves DHT22 sensors, ESP32 controller and actuators water pump and cooling fan to facilitate the adequate amount of air for circulation to maintain the temperature and water to maintain the humidity inside the oyster mushroom growing unit as per its requirement. The real working prototype is developed and implemented on integrating FIS in ESP32 controller using Arduino C, and its integrated design environment. The FIS is designed to calculate the switching on/off time of water pump and cooling fan on sensing current temperature and humidity inside oyster mushroom unit with respect to ambient temperature and humidity respectively. The prototype provides inside temperature, humidity, ambient temperature, ambient humidity, water pump time and fan time on Thing-speak platform in real time. Furthermore, the data is used for design and simulation of Adaptive Neuro Fuzzy Inference Controller for an outdoor oyster mushroom growing unit in MATLAB/Simulink.

This research examines the modelling and controlling of inside temperature and humidity for an outdoor oyster mushroom growing unit with respect to ambient temperature and humidity. In addition, Proportional Derivative and Integrated (PID), Fuzzy logic control (FLC), and ANFIS are the control techniques that are discussed, compared and validated. The remainder of this article is presented as follows: literature review is discussed in Section II, all three controllers modelling are covered in Section III, a real time implementation of IoT prototype using FIS controller and all three controllers Simulink modelling is covered in Section IV, the experimental findings and discussions are included in Section V, and the conclusion of the work and future scope are covered in Section VI.

II. LITERATURE REVIEW

The adaptive neuro-fuzzy inference system (ANFIS) combines the concepts of neural networks and fuzzy logic. It is frequently used to solve engineering problems when traditional methods are unable to provide a quick and reliable solution [4]. Numerous academics have focused on the control design of the climate of smart mushroom houses over the last decade. A smart mushroom house environment was developed using a smart controller by MSA Mahmud et al [5] Thong-un, N. et al. [6], Ariffin, M. A. M. et al. [7], Sihombing, P. et al. [8], Chieochan, O. et al. [9], Marzuki, A. et al. [10], and Yin, H. et al. [11].

For controlling various green houses, a fuzzy system and neural network techniques were used by researchers Koutb, M. et al. [12], Lafont, F. et al. [13], Marquez-Vera et al. [14], Mote, T et al. [15], Revathi, S et al. [16], Xu, F. et al. [17], Fourati, F. et al. [18], Coelho, J. [19], Mohamed, S. et al. [20], Atia, D. M. et al. [21], Oubehar, H. et al. [22], Hernández-Salazar et al. [23], Qiuying, Z. et al. [24], Khuntia, S. R. et al.[25], and Hamidane, H.et al.[26].

The significant contribution of the presented work is as follows:

- Designing of FIS system in MATLAB as per oyster mushroom cultivation requirement, includes input and output variable membership function design, setting fuzzy inference rules, and choosing a suitable defuzzification method.
- Design and implementing a low cost, autonomous IoT based monitoring, controlling FIS integrated system prototype that controls inside temperature and humidity of an outdoor oyster mushroom growing unit.
- Design and simulating an ANFIS controller in Simulink using real time data collected by IoT prototype.

III. PROPOSED AUTOMATIC ENVIRONEMNT CONTROLLERS FOR AN OUTDOOR MUSHROOM GROWING UNIT

A. Fuzzy Inference System

Fuzzy inference system (FIS) has three steps, fuzzification, inference engine and defuzzification. In fuzzification, the membership functions (MFs) are designed for input and output values. MFs are used to convert crisp value into fuzzy values. Trapezoidal MF is designed for input variables temperature, as shown in Fig. 1. The range of temperature considered is 0 to 50°C and the membership values are decided as Cold, Suitable, and Hot. Another input variable is humidity varying from 0 to 100%. Its membership values are considered as Dry, Suitable, and Wet with trapezoidal MF as shown in Fig. 2. The triangular MFs are designed for output variables water pump time, as well as fan time. Their range is considered from 0 to 60 seconds with Off, Slow, Medium, and Long membership values as shown in Fig. 3 and Fig. 4. The inference engine is the set of if-then rules, designed using expert suggestion and trial and error method as shown in Table I. In defuzzification, the fuzzy value is converted back into crisp value using center of gravity method.

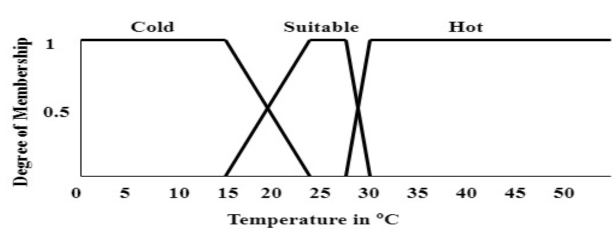

Fig. 1. Membership function for input temperature.

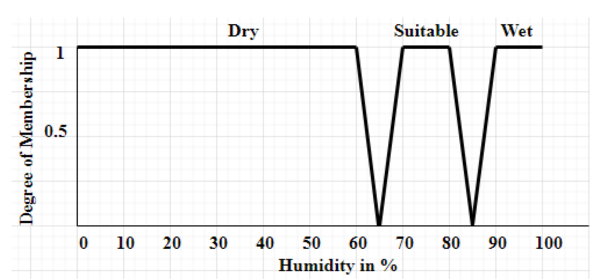

Fig. 2. Membership function for input humidity.

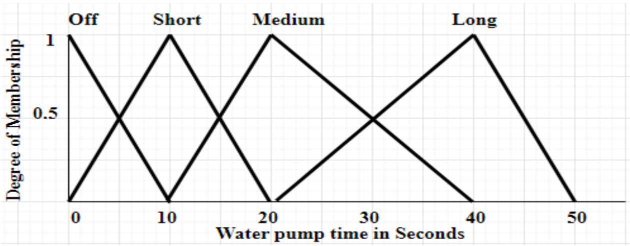

Fig. 3. Membership function for water pump time.

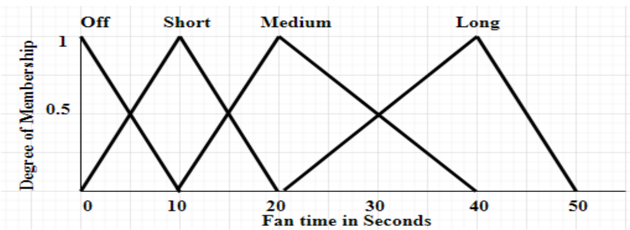

Fig. 4. Membership function for fan time.

TABLE I. FUZZY RULE BASE

Rule	Input Variables				Output Variables	
	Temperature		***Humidity***		***Water Pump Time***	***Fan Time***
1	Cold	AND	Dry	THEN	Short	Short
2	Suitable	AND	Dry	THEN	Medium	Medium
3	Hot	AND	Dry	THEN	Long	Long
4	Cold	AND	Suitable	THEN	Off	Off
5	Suitable	AND	Suitable	THEN	Off	Off
6	Hot	AND	Suitable	THEN	Off	Medium
7	Cold	AND	Wet	THEN	Off	Off
8	Suitable	AND	Wet	THEN	Off	Off
9	Hot	AND	Wet	THEN	Short	Short

The designing of FIS is done in MATLAB/Simulink to generate .fis file. It is converted into Arduino C code to upload into ESP32 controller of IoT prototype for real time implementation.

B. Adaptive Neuro Fuzzy Inference System

ANFIS is an adaptive network consisting of fuzzy logic and neural network. The fuzzy controllers developed by Takagi-Sugeno are simulated using an adaptive network. With a given input/output data set, ANFIS modifies all the parameters using the back propagation gradient descent methodology for non-linear parameters and the least squares kind of method for linear parameters. This section presents the five-layered ANFIS architecture and the learning process for the neural fuzzy network.

- Layer 1: Each node i in first layer is functional adaptive.

$$O_i^1 = \mu_{Ai}(x) = \frac{1}{1+[(\frac{x-c_i}{a_i})^{17}]^{bi}} \text{ , } i = 1, 2,..,17 \quad (1)$$

Where, x is the input to adaptive node i, A_i is the fuzzy variable associated with node i. O_i^1 is the membership function provides the degree of membership to which A_i given x satisfy the quantifier A_i. The $\{a_i, b_i, c_i\}$ are the parameter set with changing values to get best bell-shaped function.

- Layer 2: Every node in this layer is a circle node labeled Π, which multiplies the incoming signals and sends the product out. For an instance,

$$w_i = \mu_{Ai}(x) * \mu_{Ai}(y), \ i = 1,2,\ldots,17 \quad (2)$$

- Layer 3: Each node in this layer is a circle node labeled N. The i^{th} node calculates the ratio of the i^{th} rule is firing strength to the sum of all rules firing strengths.

$$\overline{w} = \frac{w_i}{w_1+\cdots+w_{17}}, i = 1, \ldots, 17 \quad (3)$$

- Layer 4: Every node in this layer is a square node with a node function.

$$O_i^4 = \overline{w_i} f = \overline{w}(p_i x + q_i + r_i) \quad (4)$$

Where w_i is the output of layer 3, and $\{p_i, q_i, r_i\}$ is the parameter set. Parameters in this layer will be referred to as consequent parameters.

- Layer 5: The single node in this layer is a circle node labeled Σ that computes the overall output as the summation of all incoming signals.

$$O_1^5 = \sum \overline{w_i} \ f = \frac{\sum_i w_i f}{\sum_i w_i} \quad (5)$$

C. PID Controller

To validate the performance of the study, we compared ANFIS, FIS with a standard industrial controller Proportional, Integral, and Derivative (PID) control system. We have used an Ideal PID controller using the equation (6) [27].

$$\mu(t) = K_p \ e(t) + K_i \int_0^t e(t)dt + K_d \frac{d \ e(t)}{dt} \quad (6)$$

Here K_p is the proportional gain, K_i is the integral gain and K_d is the derivative gain along with time t. The values of K_p and K_i are tuned using self-tuning App in Simulink and K_d is adjusted to zero initially.

IV. IMPLEMENTATION OF AUTOMATIC ENVIRONEMNT CONTROLLERS FOR AN OUTDOOR OYSTER MUSHROOM GROWING UNIT

A. Experimental Setup

The studied smart autonomous outdoor oyster mushroom growing unit is illustrated in Fig. 5. It is a small outdoor unit with dimensions 6 x 4 x 6 feet and designed and implemented at the Mushroom Lab, Indian Institute of Horticulture Research, ICAR, Hessaraghatta Lake Post, Bengaluru, India. It is loaded with 70 oyster mushroom bags each of weight 1kg and spawned with 50g of oyster mushroom spawns. It is covered with two layers of gunny sheets, which must be wet to keep the required climate inside the mushroom unit.

A smart IoT based climate control system is designed, implemented and deployed in an outdoor oyster mushroom growing unit. It has two parts, an applied environment system and an internet of things (IoT) node as shown in Fig. 6. An applied environment system consist of AC cooling fan, a DC water pump and 6 mm diameter plastic pipe with length 25m. The water pump flows the water through the plastic pipe, which is positioned around gunny sheets to sprinkle water on it to maintain humidity inside the unit. The other part of system is an IoT node as shown in Fig. 7. It consists of two DHT22 sensors, ESP32 controller, and two relays. DHT22 sensors used to sense inside and outside temperature and humidity of the unit. The ESP32 controller is used to control the inside temperature and humidity on actuating water pump and cooling fans using FIS system. FIS is integrated with the ESP32 controller and used to calculate the water pump and cooling fan times. It helps ESP32 controller to trigger the actuator relays to turn them on and off. A built in Wi-Fi module of ESP32 controller is used to collect data in ThingSpeak platform after every 30 seconds. The data is collected from 17th, January 2023 to 31st, January 2023. The platform logs the temperature, ambient temperature, humidity, ambient humidity, water pump time, and cooling fan time. This experimental data is utilized for further implementation of ANFIS controller to control temperature and humidity of an outdoor oyster mushroom growing unit.

B. Implementation of ANFIS Controller

The ANFIS approach creates a FIS using a collected primary data. A backpropagation algorithm either alone or in conjunction with a least squares approach is used to tune (change) the membership function parameters. The FIS structure works alike a neural network that converts inputs into outputs by first mapping input membership functions and associated parameters to outputs.

As ANFIS is multiple input single output (MISO), two ANFIS models are generated. ANFIS-1 predicts the water pump time and ANFIS-2 predicts fan time. In both models, humidity and temperature are the input variables. In this study, the five-layered ANFIS simulates the operation of a fuzzy inference system as shown in Fig. 8. The input and output linguistic variables are represented by the fuzzy nodes in layer one and four, respectively. The term nodes in second layer serve as membership functions for input variables. The third layer's neurons represent a fuzzy rule, with input connections standing in for its prerequisites and output connections for its results. All of these layers are initially fully connected, signifying every potential rule.

The membership functions assigned to two input variables temperature and humidity is Gaussian as shown in Fig. 9 and Fig 10. The closed-loop control mechanism in the ANFIS model is dependent on the prior expert data. In this system, the humidity, temperature, and water pump time training data (with data points 14668) are used to train the ANFIS to obtain the membership function (MFs), which enables the ANFIS to estimate an accurate correlation between inputs and outputs. The expert data is used in the system input-output trial to design the controller with the least degree of error. Throughout 1,000 epochs, the training error is reduced until it is less than 1.9986. This implies that the ANFIS-1 system output is close to the desired training values.

Fig. 5. Internal and external view of experimental setup of a mushroom unit.

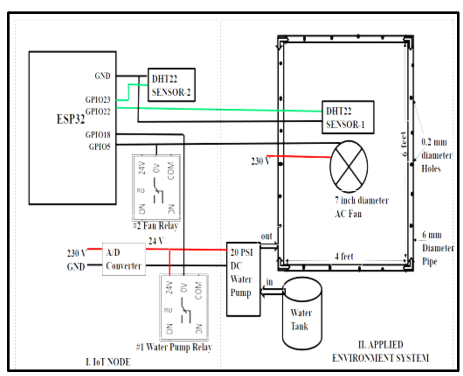

Fig. 6. IoT Node for installation.

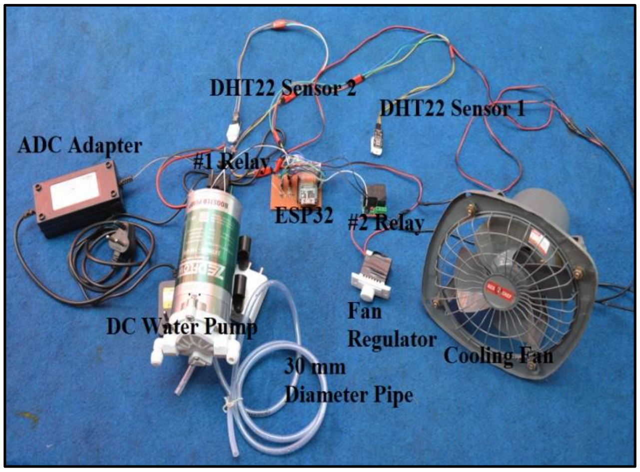

Fig. 7. IoT node for installation (model).

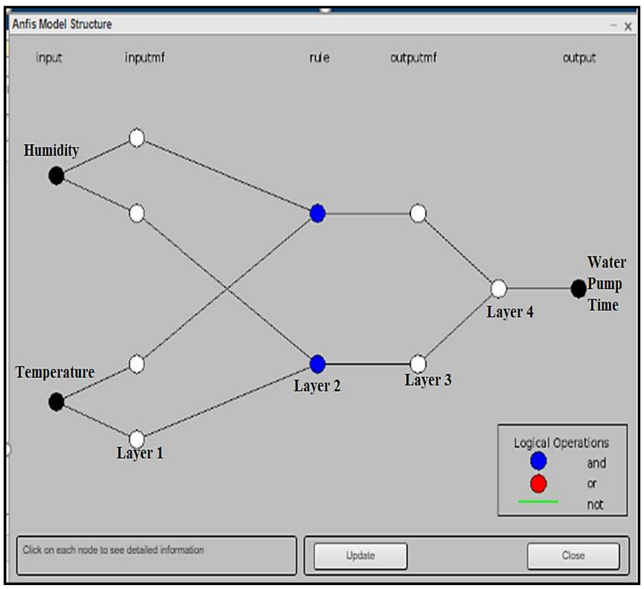

Fig. 8. ANFIS-1 architecture to predict water pump time.

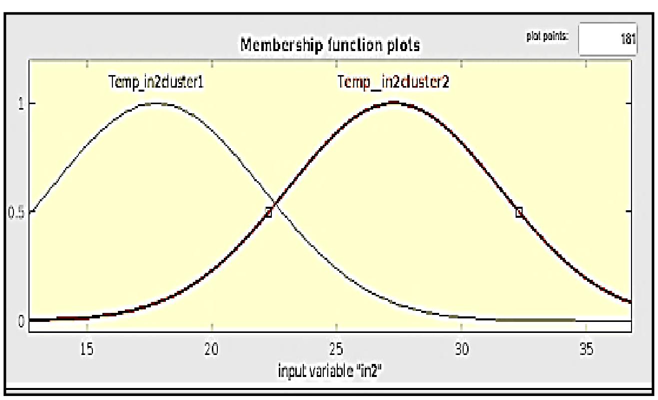

Fig. 9. ANFIS-1 membership fuction for input temperature.

Similarly, ANFIS-2 is implemented in the same way as ANFIS-1, with an expert dataset (with data points 14668) containing temperature, humidity, and fan time. The training error is reduced throughout 1,000 epochs until it is less than 2.28817. This implies that the ANFIS-2 system output is close to the desired training values.

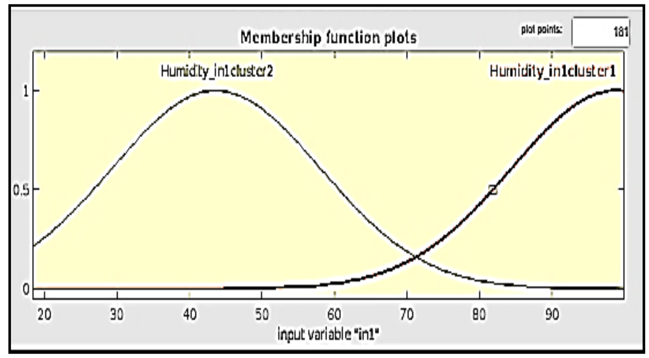

Fig. 10. ANFIS-1 membership fuction for input humidity.

C. Simulink Models for FIS, ANFIS and PID Controller

The dynamic models of PID, FIS and ANFIS controllers are designed in MATLAB/Simulink environment to control inside temperature and humidity of an oyster mushroom growing unit, as shown in Fig. 11. A primary dataset is collected while experimenting IoT prototype to control its temperature and humidity in real time. It is consisting of temperature, humidity, water pump time and fan time. It is used as an input to all Simulink models. In Simulink, first, the FIS Simulink model is implemented as per the required design details discussed. Secondly, the ANFIS Simulink model is implemented as discussed in previous section. Thirdly, PID Simulink model is implemented as per equation (6).

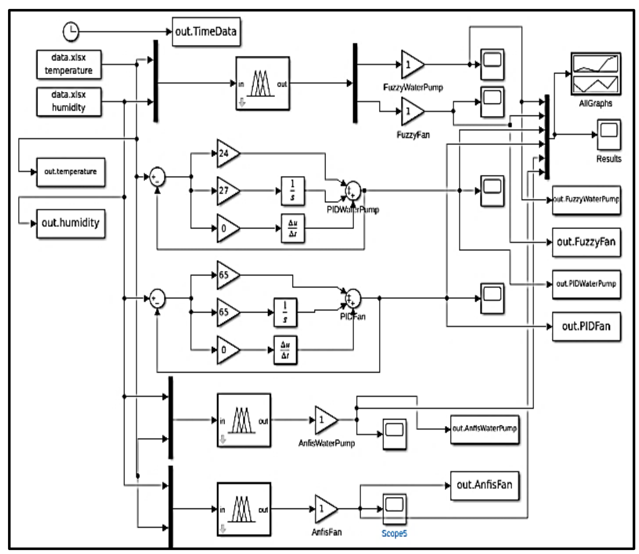

Fig. 11. Simulink models for FIS, ANFIS and PID Controller.

V. Results and Discussion

In this section, firstly the results are presented and discussed for IoT based real time FIS controller, secondly the comparative study of FIS controller, ANFIS controller, and PID controller is discussed and presented, and lastly the cost analysis of IoT prototype is presented.

A. FIS Experimental Results and Discussion

The experimental results are obtained on implementing the IoT based prototype in an outdoor mushroom growing unit. To show the viability of the suggested FIS System, several experiments were carried out. The outcomes are the outputs of DHT22 sensor reading for temperature, humidity, ambient temperature, ambient humidity, and FIS calculated water pump time and fan time, transferred and updated on the website, www.thingspeak.com as shown in Fig. 12, Fig. 13, and Fig. 14. The date and timestamp for reading showed on website for user information. The real time results show the robustness of FIS based IoT prototype, which is able to maintain the required temperature, and humidity in an outdoor mushroom growing unit.

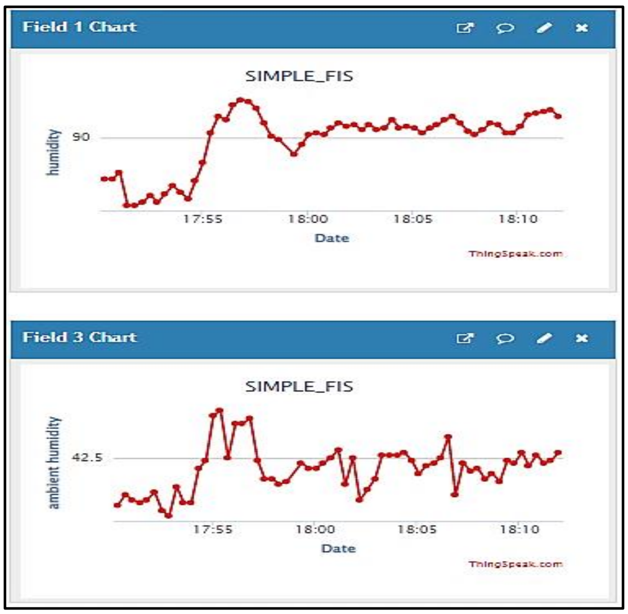

Fig. 12. Online visualization of humidity, and ambient humdity against time.

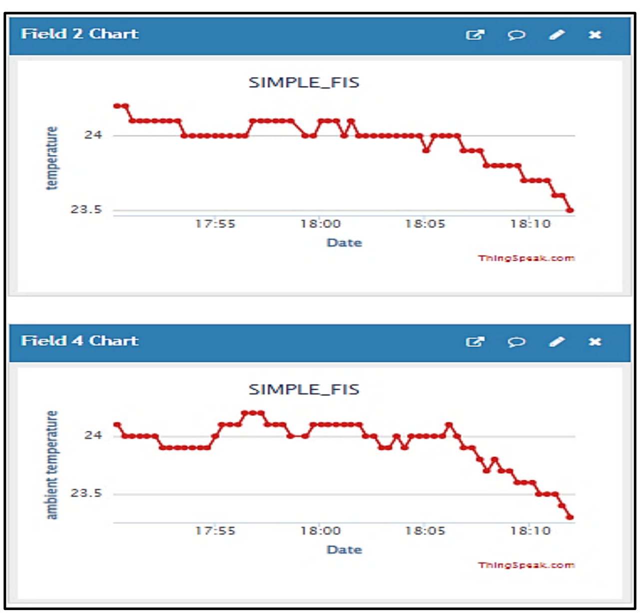

Fig. 13. Online visualization of temperature, ambient temperature against time.

Fig. 15 illustrates the calibrated humidity and ambient humidity sensor reading along with water pump time values of applied prototype obtained from the website, www.thingspeak.com in real time. It shows that, when humidity is below 70%, the water pump and fan switches ON, on the other hand when humidity rises above 70%, both remains off mode. This shows the water is used on requirement and playing a vital role in improving the water use as well. Similarly, Fig. 16 illustrates the calibrated temperature and ambient temperature sensor reading along with fan time values of applied prototype obtained from the website, www.thingspeak.com in real time. It shows that when temperature of an outdoor mushroom growing unit is not in range (above 27°C), then the FIS controller switches on the fan, until it comes in range. In addition when temperature is below 27°C, fan remains in switched off mode. This proves the robustness of the system.

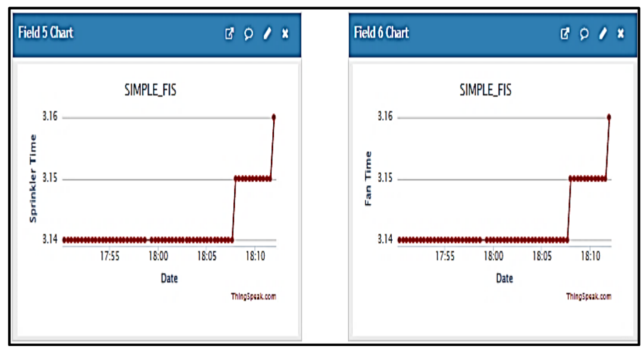

Fig. 14. Online visualization of water pump time, fan time against time.

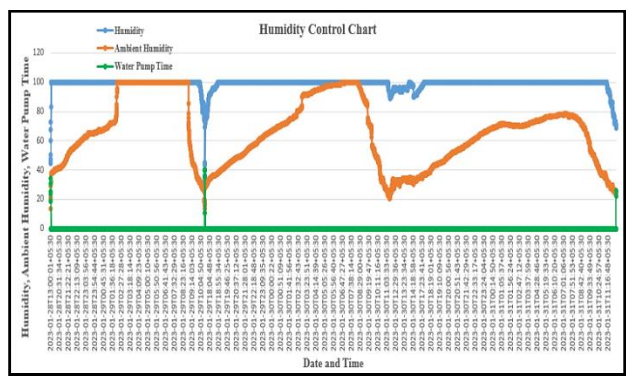

Fig. 15. Calibrated humidity and ambient humidity sensor reading along with water pump time values.

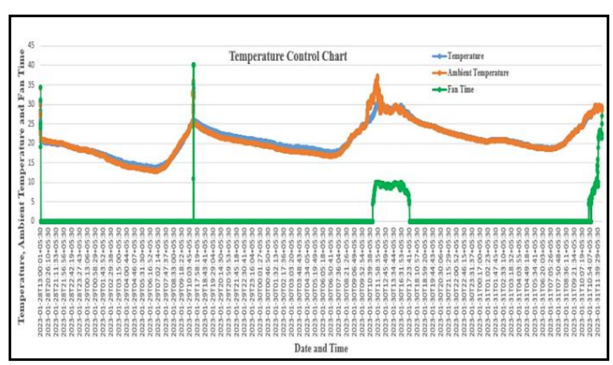

Fig. 16. Calibrated temperature and ambient temperature sensor reading along with fan time values.

B. Performance Evaluation of Simulink Models

ANFIS controller has the capability that can deal with nonlinear systems on the self-learning data. It is compared with FIS designed with human expertise knowledge and with a standard industrial PID controller with same system parameters. In PID controller there are only three parameters to adjust, whereas FLC has a lot of parameters to select like membership functions and its parameters, correct choice of rule base. The ANIFS controller self learns the data and designing neuro fuzzy system on training the data. The input data used is experimental data collected on implementing the IoT prototype for an outdoor oyster mushroom growing unit. It has timestamp, inside temperature and humidity value fields. The output of all Simulink models is water pump time and fan time, plotted in the graph shown in Fig 17.

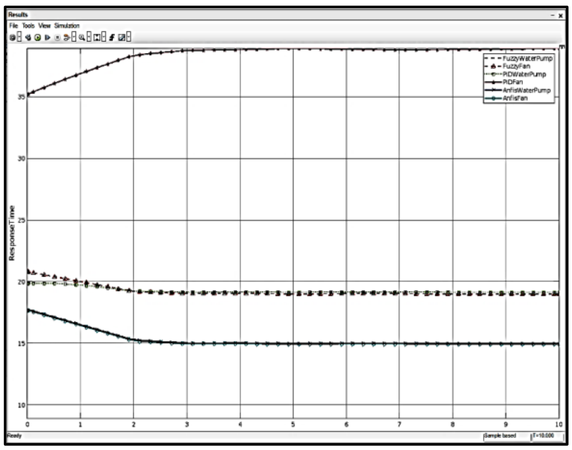

Fig. 17. Output of Simulink models.

All three Simulink models are compared and evaluated using four performance matrices, transient time, settling time, overshoot and peak time. The transient time is the output characteristic of a control system. After applying an input to the control system, the output takes a specific time to reach a steady state. Transient time is the length of time that the control system must respond in order for the transient state to stabilize. While calculating transient time, the parameters considered are settling time, maximum overshoot, and peak time, rise time [28]. Table II and III shows that ANFIS controller has performed better than the FIS and PID controller in terms of transient time, settling time, maximum overshoot and peak time on achieving optimum values.

TABLE II. PERFORMANCE EVALUATION FOR FIS, ANFIS AND PID CONTROLLER FOR WATER PUMP TIME

Performance Parameters	**Parameter Values**		
	FLC Controller	***ANFIS Controller***	***PID Controller***
Transient Time	2.9693	2.9441	7.2451
Settling Time	19.917	16.3742	19.5115
Settling Min	19.0171	14.9875	19.1456
Settling Max	20.8169	17.7610	19.8772
Overshoot	9.4640	8.5054	23.8212
Peak	20.8169	17.7610	19.8772

TABLE III. PERFORMANCE EVALUATION FOR FIS, ANFIS AND PID CONTROLLER FOR FAN TIME

Performance Parameters	**Parameter Values**		
	FLC Controller	***ANFIS Controller***	***PID Controller***
Transient Time	2.9693	8.7821	2.9441
Settling Time	19.917	37.0608	16.3742
Settling Min	19.0171	35.1824	14.9875
Settling Max	20.8169	38.9393	17.7610
Overshoot	9.4640	20	8.5054
Peak	20.8169	38.9393	17.7610

C. Cost Analysis

The list of components and their descriptions used in implementing the IoT prototype are shown in Table IV. Dollars are used to express the cost analysis. Because of variation in the exchange rate of the world market, these cost patterns may change time-to-time. It includes the cost of labor, value added tax, or delivery cost. It can be seen that the full prototype cost 40.46$. This suggests an inexpensive gadget that can be used by farmers with minimum, available resources efficiently [29].

TABLE IV. COST ANALYSIS OF IMPLEMENTED DEVICE PROTOTYPE

Sr. No.	**Component Name**	**Specifications**	**Quality**	**Price per Item**	**Total Price**
1	ESP32	DC Power Source, built in Wi-Fi & Bluetooth	1	4.62$	4.62$
2	DHT22 Sensor	Operating Voltage- 5V, Temperature, Range: -40 to 80 °C error: +-0.5°C, Humidity Range: 0 to 100% error: +-2%	2	2.42$	4.84$
3	Relay Optocoupler	Operating Voltage: 5 to 12V, 1 channel with optical coupler	2	2.42$	4.84$
4	FAN	7 inch diameter AC 230 V Fan	1	8.51$	8.51$
5	PMDC Diaphragm Motor	Operating Voltage: 12V to 24V, RPM: 40 to 3000rpm, Inlet PSI:20, Nominal Flow>=2 LPM, Working pressure: 100PSI, Power:80 Watt.	1	20.06$	20.06$
6	White Pipe	Plastic material, diameter=6mm	1	0.36$	2.19$
7	4 Elbow connectors	Plastic material	4	0.073$	0.29$
8	T connector	Plastic material	1	0.073$	0.073$
Total Price of IoT Prototype in Dollars			**40.46$**		

VI. Conclusion

A novel Internet of Things-based smart environment monitoring and control system for an outdoor oyster mushroom growing unit is presented in this paper along with a low-cost autonomous sensor prototype. A real working prototype was developed using fuzzy inference system (FIS). The purpose of this effort was to empower farmers to monitor and control temperature and humidity automatically for an oyster mushroom, to increase its yield. The applied prototype used two DHT22 sensors to measure inside and outside temperature and humidity of unit, a water pump to sprinkle the adequate amount of water to maintain humidity, a cooling fan to maintain temperature, and a Wi-Fi module to make internet access to the collected data. The data, collected on the web server, were thoroughly observed and analyzed. The FIS controller is reliable and robust. The data is used to design and implement adaptive neuro fuzzy inference system (ANFIS) in MATLAB/Simulink to improve the performance of controller.

The ANFIS controller is compared with FIS and PID controller in MATLAB/Simulink. The performance evaluation results of ANFIS controller is better than FIS and PID controller in terms of transient time, settling time, maximum overshoot and peak time. In future, the applied low-cost system can be studied, observed, and analyzed with ANFIS controller design. In addition, the presented study focused on small-scale mushroom cultivation, the proposed ANFIS controller can be studied for large-scale mushroom production.

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