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Greenhouse Environmental Variables Subjugation by Fuzzy Controller

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Abstract: The Greenhouse system is a complex system. Any significant changes in one environmental variable could have an adverse effect on another variable as well as development process of the plant. One of the fundamental challenges in greenhouse is that the environmental variables subjugation is a difficult task to maintain as some of the variables such as temperature and humidity are related in a way that when the temperature increases the humidity decreases. To achieve better enhancement of the growth of plants in greenhouse, the greenhouse environmental variables mathematical model is established and data acquisition via Atmega 328p microcontroller-based circuit is employed to monitor and record the values of temperature and humidity of the natural environment and are continuously modified by fuzzy controller in order to optimize them for maximum plant growth and yield. Both the software and hardware implementations were carried out and the results of physically constructed work were obtained under observations for temperature and humidity.

Keywords: Greenhouse environmental variables, fuzzy controller, micro-climate parameters, temperature and humidity, subjugation

1. Introduction

Agricultural production is to be increased to assure food security for the growing population. This can be achieved by developing and adopting technologies which can maximize agricultural production. For plant of given genetic makeup, the factors that affect the plant growth are light, temperature, humidity and nature of the growing medium. Hence the crop growing environment is to be suitably modified to maximize production. The environmental factors to be modified include light, temperature, relative humidity, carbon dioxide concentration and nature of growing environment. In the case of open field cultivation, only the growing medium can be controlled and the environmental factors which affect crop growth cannot be controlled manually, whereas in greenhouses all the environmental variables can be suitably controlled or modified. We can cultivate any crop, anywhere during any season inside a greenhouse by modifying crop growing environment. Greenhouses are framed structures covered with transparent material, in which crops can be grown under the conditions that the environmental variables are partially or fully controlled and are large enough to allow a person walk within them to carry out agricultural operations. A greenhouse protects plants from wind, precipitation, excess solar radiation, temperature extremes, pests and diseases.

Continuous monitoring and subjugation of the environmental variables give relevant information pertaining to the individual effects of the various factors towards obtaining maximum crop production [1].

Basically, there are two different methods for computing the models. One is based in terms of the physical laws involved in the process and the other one is based on an analysis of the input/output of the process. The interdependence of temperature and humidity requires a control strategy which takes into account the relationship between these two parameters, thus approach proposed in this work is oriented in the synthesis of an intelligent climatic controller based on fuzzy logic. The use of fuzzy logic in this work is due to the benefit of exploiting the tolerance of impression, uncertainty and partial truth, the use of human contribution and low solution cost. In this work, the model of the greenhouse environmental variables (temperature and humidity) is presented and fuzzy logic control algorithm is applied to subjugate these variables.

2. Related work

The assemblage of climatologically parameters forming around living plants inside a greenhouse is termed as greenhouse microclimate. Greenhouse climate is the major driving force influencing fruit quality and productivity of greenhouse crops [2] – [3]. The microclimate of greenhouse is nonlinear and multivariate with strong coupling system that it is impossible to carryout ventilation management accurately if only controlled manually. In recent years, investigation about smart control, where fuzzy control theory is used to control temperature and solve other problems has been carried out in [4] – [6]. Fuzzy rules are usually set under personal experience and the control result is always affected by subjectivity as studied in [7]. Researches on microclimate of greenhouses so far studied, focused on the analysis of temperature and humidity separately but lacked integral analysis of the combined effects [8] – [9]. This model is not widely used in resolving comprehensively, the problems of environmental variables subjugation in greenhouses.

Temperature and humidity concentration control in greenhouses by means of simultaneous ventilation and heating using Takagi-Sugeno (T-S) fuzzy models and the parallel Distributed Compensation conditions was studied in [10]. Using this T-S fuzzy model, the stability analysis and control design problems can be reduced however; more sensors are required for monitoring environmental parameters.

An automatic control of greenhouse climate using a fuzzy interface system was constructed in [11]. The operation of the designed fuzzy interface system is inflexible and not easy to manipulate within the greenhouse. The contribution of this research focuses on modeling and control of temperature and humidity in the greenhouse environment which is realized through real-time and precise control of air vent's open degree based on fuzzy system.

3. Methods

System design of the smart greenhouse and modeling of its environmental microclimatic variables is illustrated in Figure 1. The temperature and the humidity serve as simultaneous variables of the Fuzzy Logic Controller (FLC) design and are presented together with graphical representation as input and output variables.

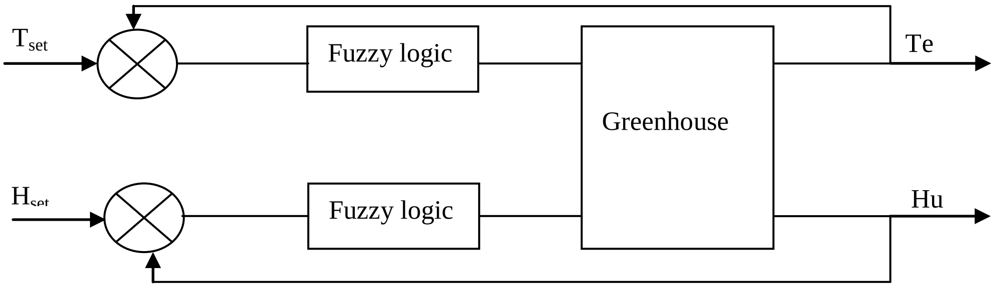

Figure1: Block diagram of the system

Figure 1, illustrates the block diagram of greenhouse automation system with its hardware components involved and connections. Four sensors were used to feed the input parameters into FLC. It reads the sensor output and can generate output according to the program written into it. It can read both digital and analog inputs and can generate digital output. The developed FLC reads analog data from humidity sensor and then generates digital high/low output according to the threshold value which is written in the program, if it reads digital data from the moisture sensor then it can generate digital high/low output according to the internal logic written into the program. The FLC constantly monitors the microclimate parameters of the various sensors and verifies them with the predefined threshold values and checks if any corrective action is to be taken for the condition at that instant. In case if such a situation arises, it activates the actuators to perform a control operation. An array of actuators can be used in the system such as relays, contactors, and change over switches, etc. They are used to turn on AC devices such as motors, coolers, pumps etc.

3.1 Modeling of Greenhouse Microclimate

In a greenhouse, the state climate can be represented by two variables, namely, inside air temperature and absolute humidity. A simplified greenhouse climate model adequate for control purposes describes the dynamic behavior of the state variable with the following two difference equations [12].

a) Energy balance

The energy fluxes affecting the greenhouse air are due to the exchanges with outside air by ventilation (E_v), and through the cover (E_c), to the energy supply (E_h) by a heating system and the energy contribution by a solar radiation (E_s). This balance can be written as follows:

$$T_a(k+1) = \frac{t_s}{C_{cap,q}}(E_h - E_v - E_c + E_s) + T_a(k) \quad \ldots(1)$$

$E_v = C_{cap,q,v} V (T_a - T_0)$, $E_c = h_T(T_a - T_0)$, $E_s = \tau S_0$ and the symbols are described in table I. The two control variables that appear in this balance are the heating supply (E_h), and the ventilation rate (V).

b) Water vapour balance

The greenhouse air exchanges water with the outside air by ventilation (W_v) and through the cover (W_c), following the dynamic model:

w_a (k+1) = $t_s(-W_v - W_c)$ + w (k)

…(2)

Where $W_v = \frac{V}{C_{cap,h}}(W_a - W_0)$ and $W_c = \frac{V_h}{C_{cap,h}}(W_a - W_0)$.

The model presented above is a discretized model with several simplifications, and the use of such a model is justified by the fact that its main usage is for control design.

3.2 Exact fuzzy modeling of the greenhouse

The objective of this section is to derive a T-S fuzzy model by applying the model-based fuzzy control design methodology described in [13] based on nonlinear equations (1) and (2).

T_a (k+1) = $\frac{t_s h_T}{C_{cap,q}}(T_0 - T_a) + \frac{t_s C_{cap,q,}}{C_{cap,q}} V(T_0 - T_a) + \frac{t_s}{C_{cap,q}} E_h + \frac{t_s \tau}{C_{cap,q}} S_0 + T_a(k)$,

T_a (k+1) =(1−a_1) T_a + a_2V$(T_0 - T_a)$ + $a_3 E_h$ + $a_1 T_0 + a_4 S_0$

…(3)

w_a (k+1) = $\frac{t_s}{C_{cap,h}} V(w_0 - w_a) + \frac{t_s h_w}{C_{cap,h}}(w_0 - w_a) + w_a$(k),

w_a(k+1)=$a_5 V(w_0 - w_a) + (1 - a_6)w_a + a_6 w_0$(k),

…(4)

Where: $a_1 = \frac{t_s h_T}{C_{cap,q}}$, $a_2 = \frac{t_s C_{cap,q,v}}{C_{cap,q}}$, $a_3 = \frac{t_s}{C_{cap,q}}$, $a_4 = \frac{t_s \tau}{C_{cap,q}}$, $a_5 = \frac{t_s}{C_{cap,h}}$, $a_6 = \frac{t_s h_w}{C_{cap,h}}$.

Equations (3) and (4) can be written as:

$$\begin{bmatrix} T_a(k+1) \\ w_a(K+1) \end{bmatrix} = \left[\begin{bmatrix} 1-a_1 & 0 \\ 0 & 1-a_6 \end{bmatrix}\right] \begin{bmatrix} T_a(k) \\ w_a(k) \end{bmatrix} + \begin{bmatrix} a_3 & a_2(T_0 - T_a) \\ 0 & a_5(w_0 - w_a) \end{bmatrix} \begin{bmatrix} E_h \\ V \end{bmatrix} + \begin{bmatrix} a_1 & a_4 & 0 \\ 0 & 0 & a_6 \end{bmatrix} \begin{bmatrix} T_0(k) \\ S_0(k) \\ w_0(k) \end{bmatrix}$$

… (5)

Considering the solar radiation, outside temperature and absolute humidity as disturbances, the model without disturbances is as follows:

$$\begin{bmatrix} T_a(k+1) \\ w_a(k+1) \end{bmatrix} = \begin{bmatrix} 1-a_1 & 0 \\ 0 & 1-a_6 \end{bmatrix} \begin{bmatrix} T_a(k) \\ w_a(k) \end{bmatrix} + \begin{bmatrix} a_3 & a_2(T_0 - T_a) \\ 0 & a_5(w_0 - w_a) \end{bmatrix} \begin{bmatrix} E_h \\ V \end{bmatrix}$$

…(6)

In this model, there are two nonlinear terms: $a_2 V(T_0 - T_a)$ and$a_5 V(w_0 - w_a)$. Thus, to prevent the control system from working in unfavorable conditions, for crop growth and development, it was imposed some limitations on the inside temperature T_a and absolute humidityw_a. These bounds are represented by the linear inequality constraint, $T_{a,min} \le T_a \le T_{a,max}, w_{a,min} \le w_{a,max}$. Then, for the nonlinear terms, we define z_1(k) = $a_2(T_0 - T_a)$ and z_2(k) = $a_5(w_0 - w_a)$, which can be written as:

z_1(k) = $M_1 \underline{\beta}$ + $M_2 \overline{\beta}$ and z_2 (k) = $N_1 \underline{\alpha}$ + $N_2 \overline{\alpha}$, where:

$\underline{\beta} \le z_1$ (k) $\le \overline{\beta}$, $\underline{\alpha} \le z_2$ (k)$\le \overline{\alpha}$, $M_1 + M_2 = 1$, and $N_1 + N_2 = 1$. In the end, we arrive at the following T-S fuzzy model:

If z_1 (k) is M_1 and z_2 (k) is N_1 Then x(k+1) = A_1 x (k) + B_1u,

$A_1 = \begin{bmatrix} 1-a_1 & 0 \\ 0 & 1-a_6 \end{bmatrix}$, $B_1 = \begin{bmatrix} a_3 & \underline{\beta} \\ 0 & \underline{\alpha} \end{bmatrix}$. If z_1 (k) is M_1 and z_2 (k) is N_1 Then;

x(k+1) = A_2x(k) + B_2u, $A_2 = A_1$, $B_2 = \begin{bmatrix} a_3 & \underline{\beta} \\ 0 & \overline{\alpha} \end{bmatrix}$.

If z_1 (k) is M_2 and z_2 (k) is N_1,

Then, x(k+1) = A_3x(k) + B_3u,

$A_3 = A_1$, $B_3 = \begin{bmatrix} a_3 & \overline{\beta} \\ 0 & \underline{\alpha} \end{bmatrix}$.

If z_1(k) is M_2 and z_2(k) is N_2,

Then, x (k+1) = A_4x(k) + B_4u, and $A_4 = A_1$, $B_4 = \begin{bmatrix} a_3 & \overline{\beta} \\ 0 & \overline{\alpha} \end{bmatrix}$.

The closed loop system is given by:

X(k+1)= $\sum_{i=1}^{4}\sum_{j=1}^{4} h_i(k))\, h_j\big(z(k)\big)\big(A_i + B_i K_j\big)x(k)$

…(7)

To ensure an optimal climate in greenhouses, we propose considering constraints on the outputs. For this, the following conditions are added to ensure the optimal climate in the greenhouse.

Theorem 1: Assume that the initial condition x (o) is known. The constraints $\|y(t)\|_2 \leq \lambda$is enforced at all times t$\geq$ 0 if the LMIs

$$\begin{bmatrix} 1 & x(0)' \\ x(0) & X \end{bmatrix} \geq 0, \begin{bmatrix} X & XC_i' \\ C_iX & \lambda_i^2 I \end{bmatrix} \geq 0, \text{ Hold, where } X=P^{-1}.$$

In this work, we consider air temperature T_a and humidity concentration w_a as outputs:

$$\begin{bmatrix} y_1(k) \\ y_2(k) \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} T_a \\ w_a \end{bmatrix}$$

3.4 Fuzzy controller and linguistic input/output variables.

The input and output variables within a greenhouse system under control are represented by linguistic variables. These are two input linguistic variables, error and change in error; the three output linguistic variables are heater, fan and humidifier. Each linguistic term this represents categories for the values of a linguistic variable. The linguistic variables error and change in error include the linguistic terms (NB, NS ZE. PS and PB). The output linguistic variables include the linguistic terms (ONB, ONS, OZE OPS and OPB).

The positive of error shows that the plant under vision need for cooling while negative values represent that the desired temperature is greater than the feedback or measured temperature of the plants hence, the system calls for heating action. The $T_{set\text{-}point}$ is the desired temperature value while T_f is the measured value of the temperature inside the plant. The error function response, settling time, overshoot can be optimized based on system requirements. Normally, as the time increases, the system tries to hunt for more stability.

The relationships between input and output linguistic variables based on their linguistic terms are defined in rules. The set of rules for a fuzzy system is equivalent to the control strategy of FLC; this set of rules is known as the rule base with the fuzzy concept. The total number of rules base is equal to the product of the numbers of set of each input variables. Linguistic terms are represented graphically by membership functions. A membership function represents the degree of membership of linguistic variable within their linguistic terms. The range of membership degree is incessant between 0 and 1, where 0 is equal to 0% membership and 1 is equal to 100% membership. Table 1 and 2 show the rule matrix of linguistic variables for both temperature and humidity errors and their change in errors where the rules are mapped into the matrix inputs.

Table 1: Rule matrix of the linguistic variable for temperature

T_{ERR}/T_{CERR}	N	NS	ZE	PS	PB
PB	Z	NS	NB	N	NB
PS	PS	ZE	NS	NB	NB
ZE	PB	PS	ZE	N	NB
NS	P	PB	PS	ZE	NS
NB	P	P	P	PS	Z

Table 2: Rule matrix of linguistic variable for humidity

H_{ERR}/H_{CERR}	NB	NS	ZE	PS	PB
NB	PB	PB	PL	PS	ZE
NS	PB	PB	PS	ZE	NS
ZE	PB	PS	ZE	NS	NB
PS	PS	ZE	NS	NB	NB
PB	ZE	NS	NB	NB	NB

Fuzzy rules are collection of linguistic statements that describe how the fuzzy controller should make a decision regarding classifying an input or controlling an output. The combined fuzzy rules for temperature and humidity are written in the following form:

1. IF ‘Temperature’ IS ‘High’ AND ‘Humidity’ IS ‘High’ THEN ‘Command ‘FAN’ IS ‘HIGH’ ALSO ‘Command Pump’ IS ‘OFF’
2. IF ‘Temperature’ IS ‘HIGH’ AND ‘Humidity’ IS ‘Normal’ THEN ‘Command FAN’ IS “HIGH’ ALSO ‘Command Pump’ IS ‘OFF’
3. IF ‘Temperature’ IS ‘HIGH’ AND ‘Humidity’ IS “Low’ THEN ‘Command ‘FAN’ IS ‘HIGH’ ALSO ‘Command Pump’ IS ‘HIGH’
4. IF ‘Temperature’ IS ‘Normal’ AND ‘Humidity’ IS ‘HIGH’ THEN ‘Command ‘FAN’ IS ‘OFF’ ALSO ‘Command Pump’ IS “OFF’

5. IF ‘Temperature’ IS ‘Normal’ AND ‘Humidity’ IS ‘Normal’ THEN ‘Command FAN’ IS ‘OFF’ ALSO ‘Command Pump’ IS ‘OFF’
6. IF ‘Temperature’ IS ‘Normal’ AND ‘Humidity’ IS ‘Low’ THEN ‘Command FAN’ IS ‘OFF’ ALSO ‘Command Pump’ IS ‘HIGH’
7. IF ‘Temperature’ IS ‘Low’ AND ‘Humidity’ IS ‘High’ THEN ‘Command HEATER’ IS ‘HIGH’ ALSO ‘Command Pump’ IS ‘OFF’
8. IF ‘Temperature’ IS ‘Low’ AND ‘Humidity’ IS ‘Normal’ THEN ‘Command HEATER’ IS ‘HIGH’ ALSO ‘Command Pump’ IS ‘OFF’
9. IF ‘Temperature’ IS ‘Low’ AND ‘Humidity’ IS ‘Low’ THEN ‘Command HEATER’ IS ‘HIGH’ ALSO ‘Command Pump’ IS ‘HIGH’

3.5 Hardware design

The System hardware was designed and implemented on the printed circuit board (PCB), which initialized the system, reads the sensors, displays the values on LCD and take action according to the algorithm. The temperature and humidity sensor modules was used for sensing the inside temperature and humidity of the greenhouse. The sensor modules require +5 volts supply. The temperature transmitting range is -60℃ to 75℃ while the humidity transmitting range is 30 to 90% RH with accuracy of ±5 % RH. Figure 2 and Figure 3 show the circuit design in Proteus environment and the hardware implementation respectively.

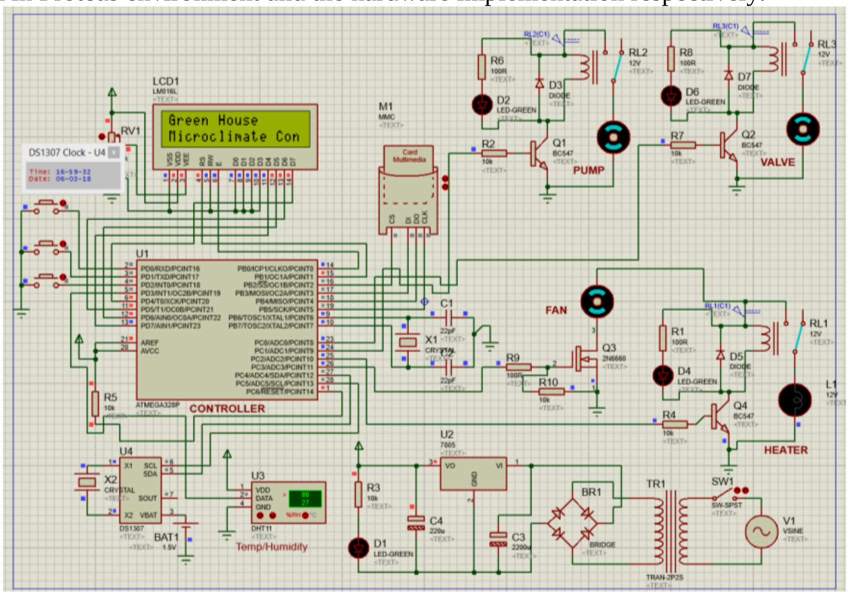

Figure 2: Circuit design

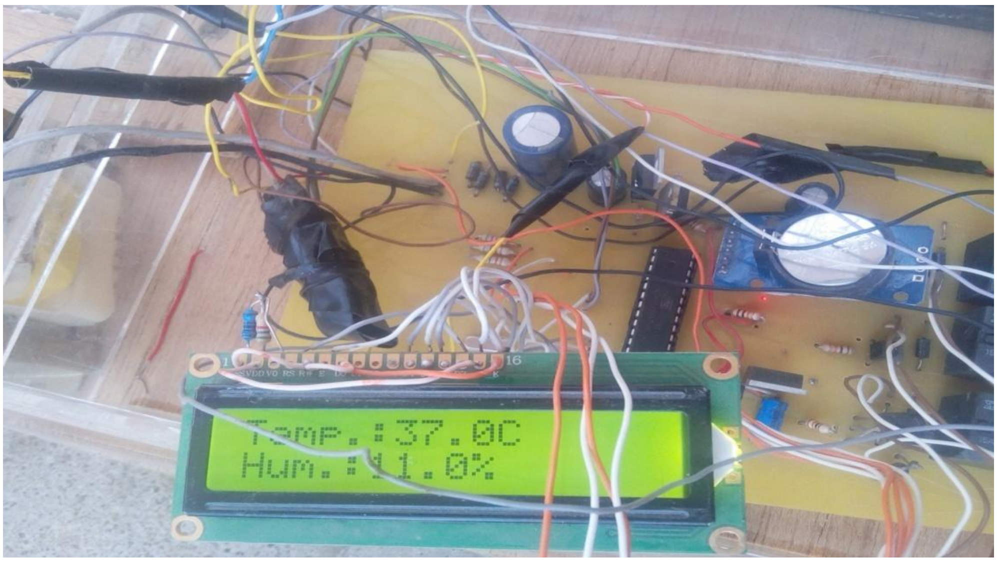

Figure 3: Hardware implementation of the circuit

4. Results

An experiment has done to record the temperature and humidity readings in the greenhouse developed model. The reason of this experiment is to make sure that the designed system is functioning well and the data can be recorded correctly.

More than one experiments were carried out to test the reliability and feasibility of the system designed. The developed greenhouse system has the following dimensions:

Length = 50cm
Width = 30cm
Height = 60cm

The experiment consists of two tests, the two tests were carried out to obtain the data from the prototype for the period of eleven hours from (8am to 6pm) by using the control procedure to see the effect of the developed FLC, and show how the system keeps the parameters inside the system smaller than outside. The tests were done to ensure the ability of the system work without any problems and the results show how the system works with simple possibility to achieve the proposed goals. Figure 4, 5, 6 and 7 show the general required responses for the error and the change in error of both temperature and humidity control system. The temperature and humidity set-points are considered to be 27℃ and 60% respectively. The feedback responses are satisfied because there are no much significant difference between the set-points of both temperature and humidity with their measured values. From the results shown in figure 4, 5, 6 and 7 it can be concluded that the overall performance of the fuzzy controller in maintaining the temperature and humidity within a given range around the set-points is satisfactorily. It was also observed that the temperature in the greenhouse is maintained in the desired range of [25-30°C] during the day. It can also be shown that the relative humidity under greenhouse is influenced by the inside temperature and varies in the interval of [55%, 61%].

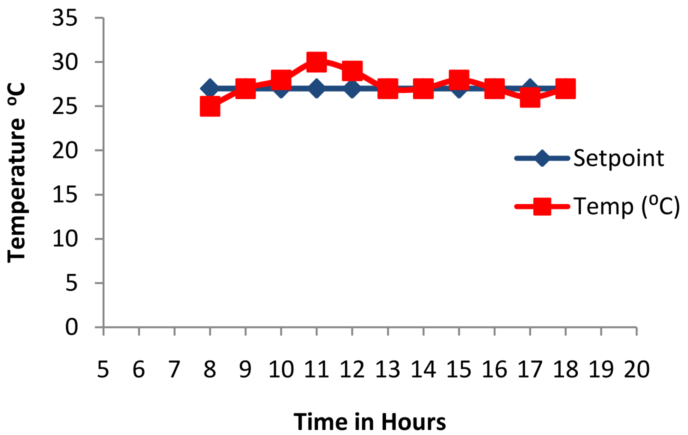

Figure 4: Temperature readings for day1

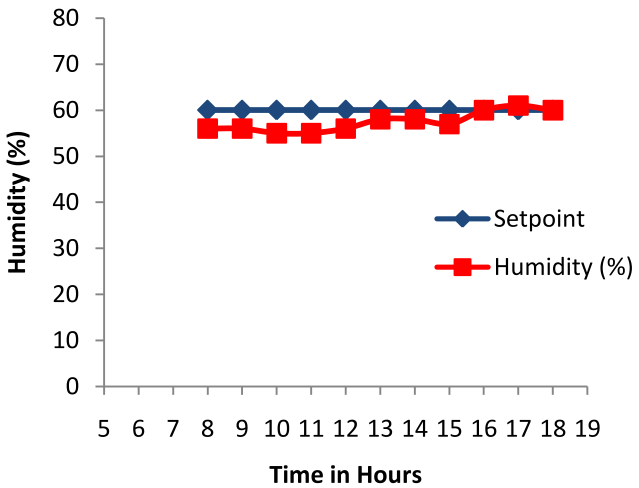

Figure 5: Humidity readings for day1

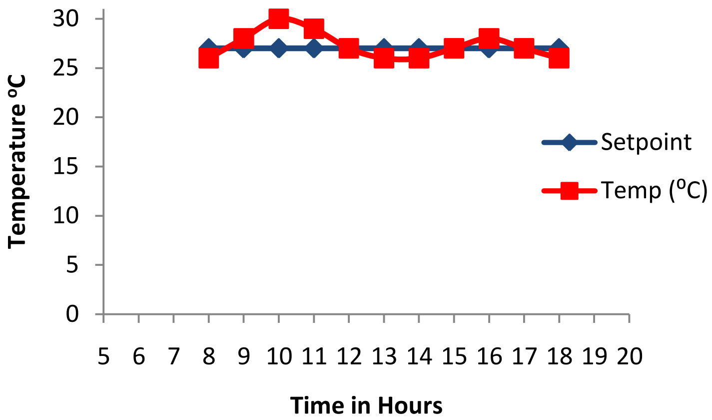

Figure 6: Temperature readings for day2

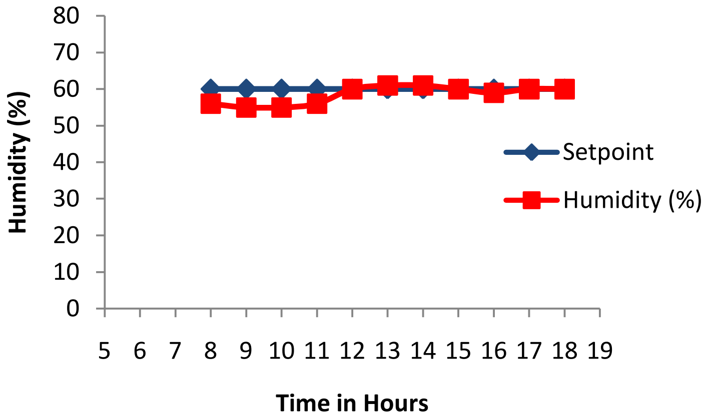

Figure 7: Humidity readings for day 2

5. Conclusion

This research has successfully showed that the design of a fuzzy logic controller capable of regulating temperature and humidity inside greenhouse was achieved; and fuzzy logic controller can be applied to develop a system for monitoring and control of climate parameters under greenhouse.

The experimental tests performed and the results obtained showed that the robust fuzzy logic controller effectively achieves the desired climatic conditions in a greenhouse. It can also be concluded that the overall performance of the fuzzy controller to maintain temperature and humidity within a given range around the set-points is satisfactory. There is however, a need for further study to improve the system reliability and capability by improving the model and adding more sensors.

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