Remote Monitoring and Controlling of Enhanced Greenhouse Using Web Application

Dr. Bassim Abdulbaki Jumaa[1], **Amna Muath Mohammed**[2]

Abstract: ***In this paper a smart greenhouse management system is developed using web application for remote monitoring and controlling. The system uses SMS notification to notify the user and the support team when there is something wrong. The aim of this system is to control five important micro-climate parameters which are temperature, humidity, light, soil moisture, and Co_2 which significantly affects crop quality and yield. The system use fuzzy logic to make all the important decisions to control the greenhouse environment.The obtained results from testing the prototype show thatfuzzy logic is a quick and accurate tool for making decisions to control the greenhouse environment. Moreover, it shows that the operation of the proposed system verifies the suggested desired states for the proposed smart greenhouse.***

Keywords: Fuzzy, Greenhouse, Rpi3, Web application

1. Introduction

The greenhouse provides shelter from extreme weather conditions and allows desired micro-climate conditions for plant growth through constant controlling [1]. The control of the micro-climate in the greenhouse is a complicated procedure because of the number of involved variables and the fact that they aredependent on each other. Thus, the greenhouse is considered as a complex multivariable non-linear system [2].The idea of growing in a controlled environment has been around since 30 A.D in Roma. Since that time techniques and technology in greenhouses have evolved and are still evolving to this day. However, the principle still the same which is providing a controlled environment in such a way that optimal growing conditions are acquired so as to produce high-quality crops, high yields, and year-round production, which otherwise cannot be achieved in the open field[3].An IoT (Internet of Things)fuzzy-based smart greenhouse system enhanced with remote monitoring and controlling web application is proposed. The proposed system can be divided into two parts. The first part is related to a fuzzy-based control system that controls microclimate inside the greenhouse so as to optimize the growth conditions and automate the growing process. The second part of the proposed system is related to the design of a web application for remote monitoring and controlling of the greenhouse. The web application consists of two interfaces, one for admin which is the oneresponsiblefor adding or updating plant information records stored in the database. The second interface is for the operator to initialize the system by selecting the plant being planted in the greenhouse and setting other important information. Also, it allows the operator to select whether the greenhouse is controlled manually or automatically, and allow him to analyze and view the important system variables (temperature, humidity, light, Co_2, and irrigation) that are stored in the database. Moreover, the proposed system provides SMS notification to keep the operator informed if something goes wrong with the system.

2. Smart Greenhouse Control

a) The Prototype System

The overall system block diagram is shown in Fig 1 and the actual prototype is shown in fig 2. The proposed system software is written in Python programming language by the Python IDEL (integrated development and learning environment). The main prototype system algorithm is shown in fig 3.

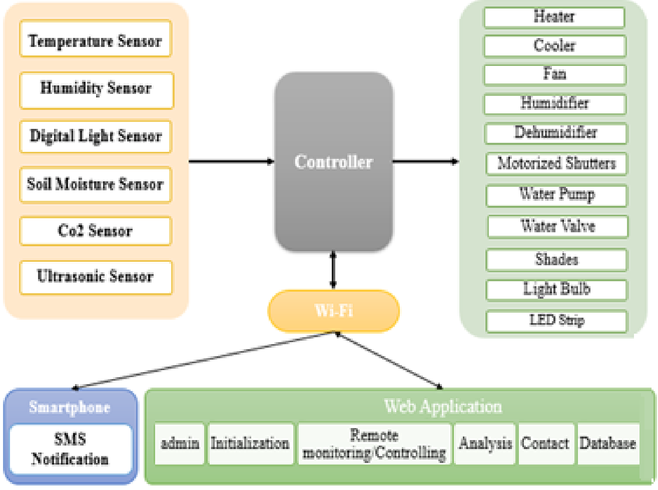


Figure 1: The general system block diagram

Figure 2: The greenhouse

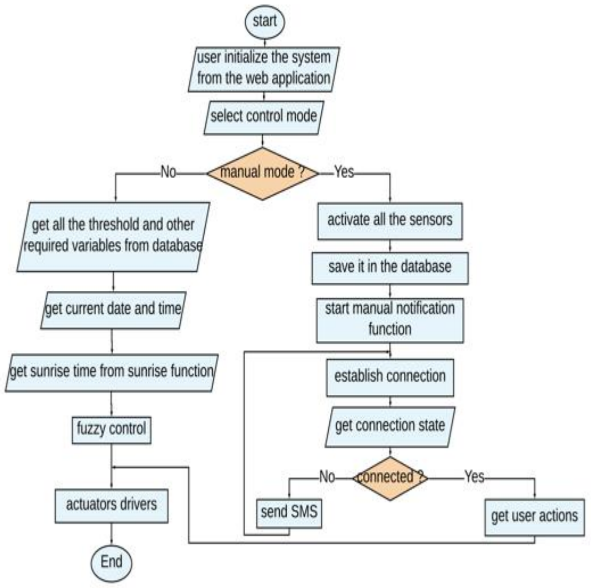


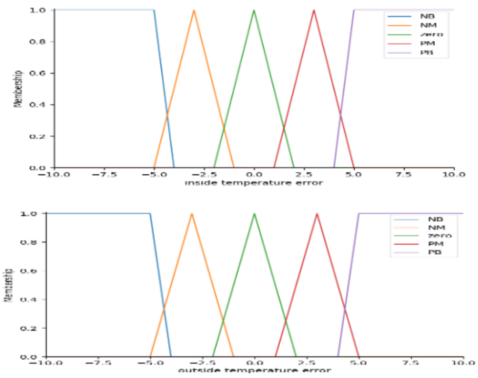
Figure 3: The flowchart of the proposed system algorithm

a) Fuzzy Logic Control (FLC)

This section describes the proposed solution. To control the greenhouse microclimate type-2 fuzzy logic is used. The inside greenhousemicroclimate control system is based on fuzzy controller that manages the various decisions to achieve a desired greenhouse climate depending on weather meteorological data and user instructions. The FLC control system proposed will be detailed in the following paragraphs of this section.

b) Temperature FLC

The input variables are inside and outside temperature error. The output variable of this system is the decision to turn on/off the heater/cooler and at what PWM. It is important to mention that the universes of the discourse of input variables were set to suitable values for the area of study (Baghdad), using new-locCLim software. Input and output membership functions are shown in Fig 4 and they were built with triangular and rectangular membership functions. Inside and outside temperature error universes of discourse are [-5, -3, 0, 3, 5] and their fuzzy linguistic values are [**NB** (negative big), **NM** (negative medium), **zero**, **PM** (positive medium), **PB**(positive big)]. Heater and cooler PWM and their universes of discourse are [0, 10, 25, 50, 75, 90] and their fuzzy linguistic values are [**off, Very_low, low, med, high, very_high].**



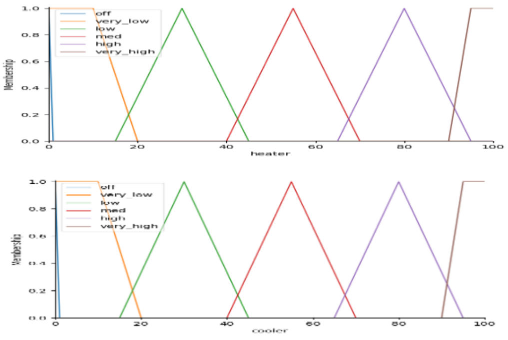


Figure 4: Temperature FLC input and output membership

c) Humidity FLC

The input variable is inside humidity error. The output variable of this system is a decision to turn on/off the humidifier/dehumidifier. The input and output membership functions are shown in Fig 2. Inside humidity error universes of discourse are [-10, 0, 10] and its fuzzy linguistic values are [**NEG** (negative), **ZERO,POS** (positive)]. Humidifier and dehumidifier universes of discourse are [0.5, 1.5] and their fuzzy linguistic values are [**OFF, ON**]. It is worth mentioning that the weirdly shaped output membership functions in Fig 5 are because the used fuzzy library (sci-kit fuzzy) does not support the singleton membership function. Therefore, triangular membership functions were used and manipulated to give approximate results to singleton membership functions.

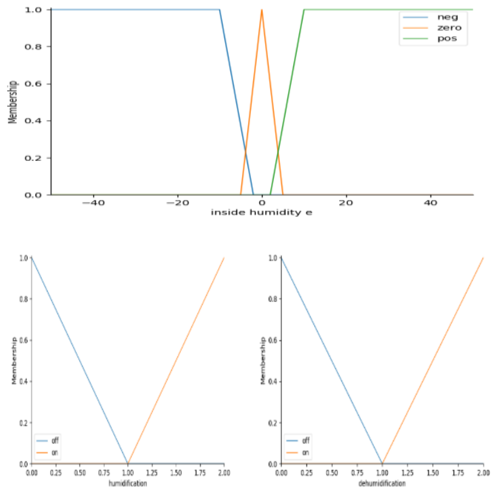


Figure 5: Humidity FLC input and output membership functions

d) Light FLC

The inputs to the system are inside light intensity error, outside light intensity and outside temperature. Inside light intensity is used to control the brightness of the lighting system. Outside light intensity and outside temperature, on the other hand, are used to control the shading system. Input and output membership functions are shown in Fig 6. Inside light intensity error universe of discourses are [4,0,-4,-5,-6,-7,-8,-9] and their fuzzy linguistic values are [**P** (positive), **Z** (zero), **N** (negative), **NS** (negative small), **NM** (negative medium), **NB** (negative big), **VN** (very negative), **EN** (extremely negative)]. Outside light intensity universe of discourses are [2,1,0.2] and their fuzzy linguistic values are [**clear, cloudy, dark**]. Outside temperature universe of discourses are [20,25,30] and their fuzzy linguistic values are [**cold, warm, hot**]. The output of the system is light PWM with the universe of discourses [192, 172, 137, 102, 57, 22, 0] and their fuzzy linguistic values are [**ON, VB** (very bright), **B** (bright), **M** (medium), **D** (dim), **VD** (very dim), **OFF**]. Shades universe of discourses are [0.5, 1.5] and their fuzzy linguisitic values are [**ON, OFF**].

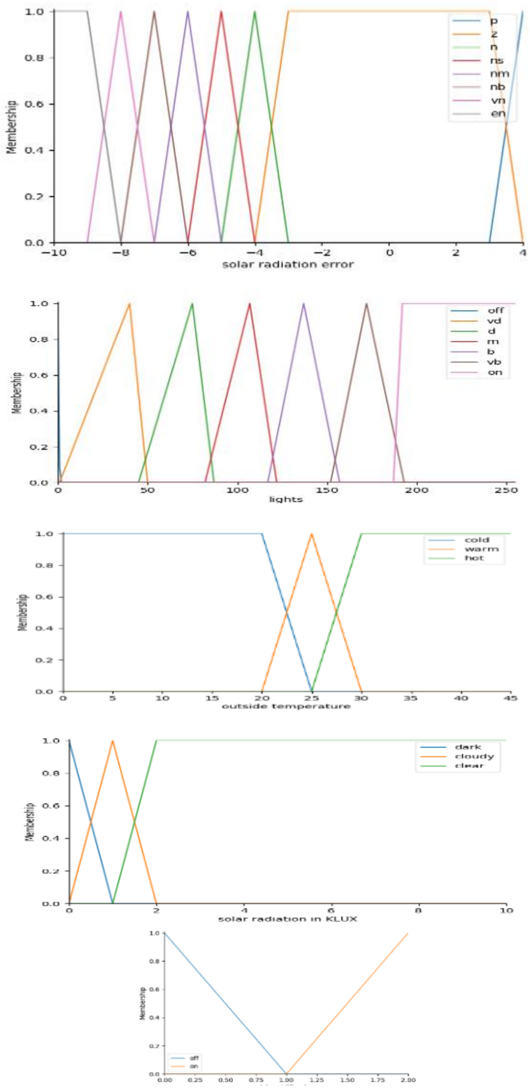


Figure 6: The light FLC input and output membership functions

e) Co_2 FLC

The inputs to the system are outside temperature and humidity error and inside Co_2 level. The output of the system is the ventilation fan speed. Input and output membership functions are shown in Fig 7. Outside temperature error universe of discourses are [-5,-3,0,3,5] and their fuzzy linguistic values are [**NB** (negative big), **NM** (negative medium), **zero**, **PM** (positive medium), **PB** (positive big)]. Outside humidity error universe of discourses are [-30,-16,0,16,30] and their fuzzy linguistic values are [**NB** (negative big), **NM** (negative medium), **zero**, **PM** (positive medium), **PB** (positive big)]. Inside Co2 error universe of discourses are [-230,0,230] and their fuzzy linguistic values are [**NEG** (negative), **ZERO**, **POS** (positive)]. Ventilation (the output) universe of discourses are [0,30,51,72,82] and their fuzzy linguistic values are [**off, low, med, high, very_high].**

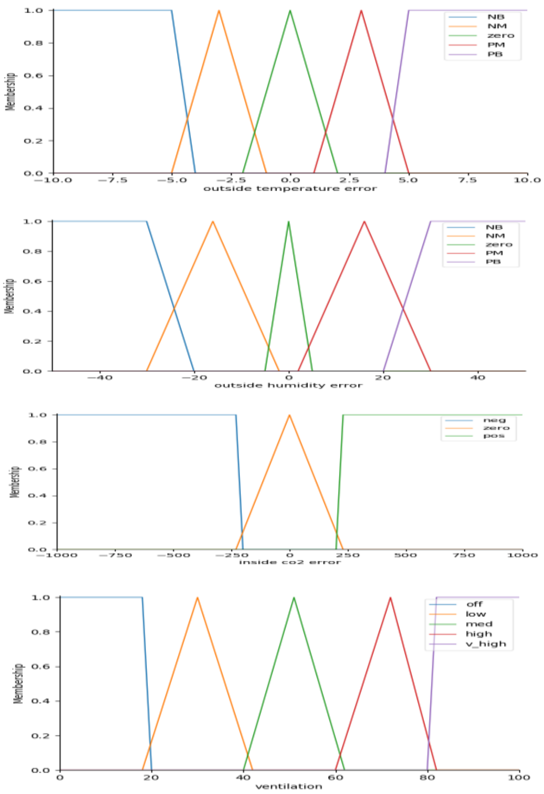
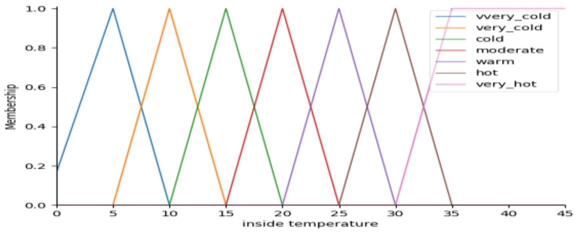


Figure 7: Co_2 input and output membership functions.

f) Irrigation FLC

Inputs to this system are inside temperature, humidity, and light intensity, the output of the system is an estimation of ET0. Input and output membership functions are shown in Fig 8. Inside temperature universe of discourses are [5, 10, 15, 20, 25, 30, 35] and their fuzzy linguistic values are [**vvery_cold, very_cold, cold, moderate, warm, hot, very_hot].** Inside humidity universe of discourses are[0, 37, 48, 60, 71, 83, 94] and their fuzzy linguistic values are [**very_dry, dry, relatively dry, moderate, relatively wet, wet, very_wet**]. Inside light intensity universe of discourses are [0, 34.5, 43.2, 51.8, 60.5, 69.1, 77.8] and their fuzzy linguistic values are [**NL** (negative large), **NM** (negative medium) **NS** (negative small), **ZERO**, **PS** (positive small), **PM** (positive medium) **PB** (positive big)]. Output universes of discourse are [**0, 1, 2, 3, 4, 5, 6, 7, 8**] and their fuzzy linguistic values are [**EL** (extremely low), **VVL** (very very low), **VL** (very low), **L** (low), **M** (medium), **H** (high), **VH** (very high), **VVH** (very very high), **EH** (extremely high)]. It is important to mention that the irrigation FIS was trained with over 2000 datasets calculated with ET0Clac software.



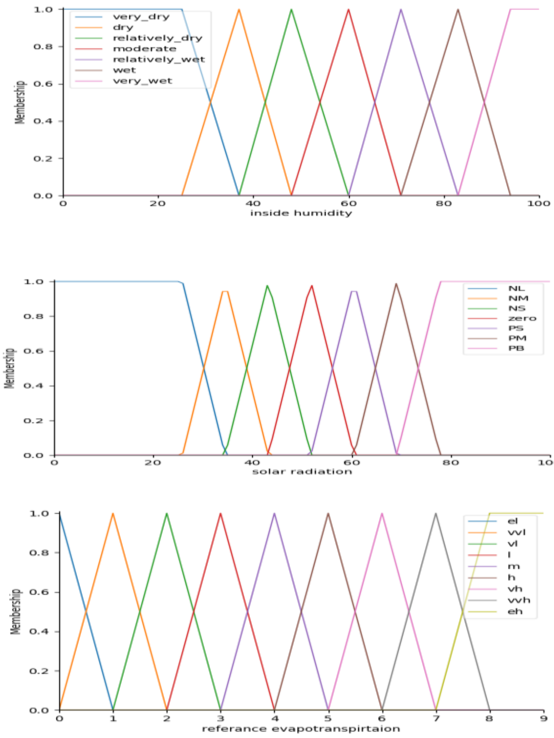


Figure 8: Irrigation system input and output membership function

g) User Interface

A website application has been developed to initialize, remotely monitor and/or manually controlling the greenhouse. The web application consists of two interfaces, the *admin interface* whichconsists of two pages (admin and contact).The admin person who is responsible for providing all the information of the crops to be growing inside the greenhouse enters the required data and saves them in the database to be used whenever required.Admin webpage is where the admin inserts all of the required crop information such as the crop name, total growing period. Initial stage, mid-stage, development stage, and late-stage growing periods, root depth and crop coefficient of each stage. Moreover, the admin inserts other information regarding the crop desired microclimates of temperature, humidity, Co_2 level, light level, and photoperiod. The contact page is for the admin to contact the user or the support team if there is something wrong in the system. The *user/operator interface* consists of four web pages (initialization, monitoring/ controlling, analysis, and contact) used to initialize the system.In the initialization page the user initializes the system by selecting the crop to be growing in the greenhouse from the crop selecting list. Also select the stage of the crop (initial, mid, development or late-stage) and the used planting method (direct sewing or transplanted). Moreover, the user has to insert information about the used irrigation system used such as the number of the nozzles, their discharge rate, and the overall irrigation system efficiency. The monitoring/controlling page is where the user decides whether to manage the greenhouse manually or automatically. If the user selected automatic control mode, then it will display the monitoring interface. This interface shows the newest sensors readings and the current actuators states. However, if manual control mode is selected then it will display the controlling interface. In this interface, the user can remotely control the actuators by turning them On/Off and control their PWM. The analysis page is where the user can view important data in a graphic form so that it is easier to understand and analyze.

3. Results

Many real-life testing scenarios have been achieved using the proposed control system using fuzzy logic strategy. The system has been tested with different initial and desired values. One experiment starts with high initial value and asked to reach a lower desired value, while the other starts with low initial value and asked to reach a higher desired value

a) Temperature Control System Results

To check the behavior of the temperature fuzzy logic control system as a heater, it was tested at starting inside temperature of (28.9 °C) while the outside temperature was changing in the range [27.9, 28.4] and the desired level was set to (34 °C). Fig9 illustrates the response of the system. It shows that it took the system about 16 minutes to reach the desired level and stabilize.

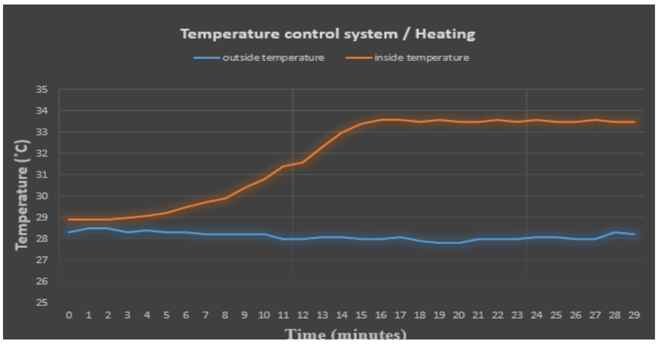


Figure 9: Temperature control system heating response

To check the behavior of the temperature fuzzy logic control system as a cooler, it was tested at starting inside temperature of (27.3 °C) while the outside temperature degreewas changing in the range [26, 27.7] and the desired level was set to (24). Fig 10 illustrates the response of the system. shows that it took the system about 22 minutes to reach the desired level.

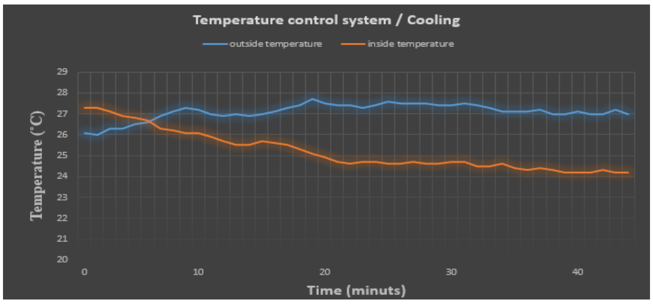


Figure 10: Temperature control system cooling response

To check the behavior of the ventilation system as a backup heater, the TEC (Thermo Electric Cooler) not working scenario was imitated by turning off its power supply. To make sure ventilation is suitable to be used as a backup heater the desired limit was set to (30 °C) which is within the range of the temperature outside the greenhouse. The test started with (27.9 °C). The response is illustrated in fig 11. shows that it took the system about 15 minutes to reach the desired level and stabilize.

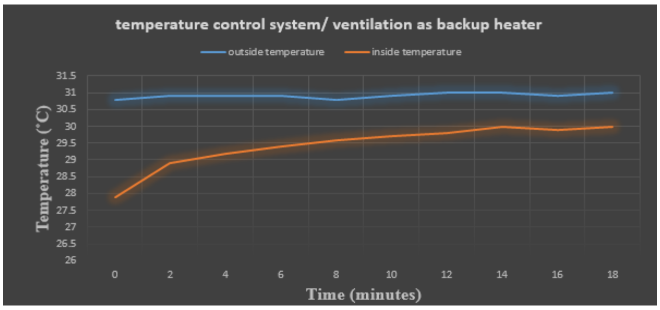


Figure 11: The response of the ventilation system as a backup heater

To check the behavior of the ventilation system as a backup cooler, the TEC not working scenario was imitated by turning off its power supply. To make sure ventilation is suitable to be used as a backup cooler the desired limit was set to (27 °C) which is within the range of the temperature outside the greenhouse. The test started at (33.7 °C). The response of the system illustrated in fig 12.shows that it took the system about 10 minutes to reach the desired level and stabilize.

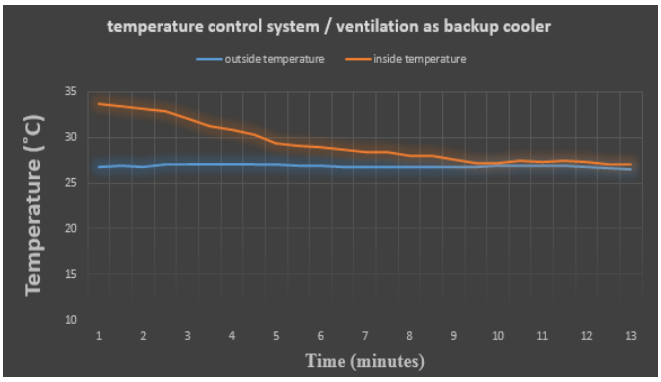


Figure 12: The response of the ventilation system as a backup cooler

b) Humidity Control System Results

To check the behavior of the humidity fuzzy logic control system as a humidifier, it was tested at starting inside humidity of (45.9 %) and the desired level was set to (65%). Fig 13 illustrates the response of the system. shows that it took the system about 10 minutes to reach the desired level and stabilize.

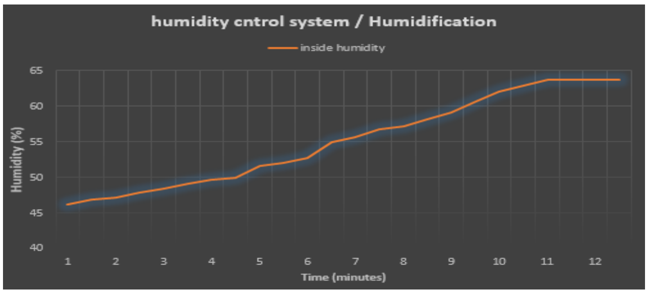


Figure 13: Humidity control system humidification response

To check the behavior of the humidity fuzzy logic control system as a dehumidifier, it was tested at starting inside humidity of (41%) and the desired level was set to (36 %). Fig14illustrates the response of the system. shows that it took the system about 20 minutes to reach the desired level and stabilize.

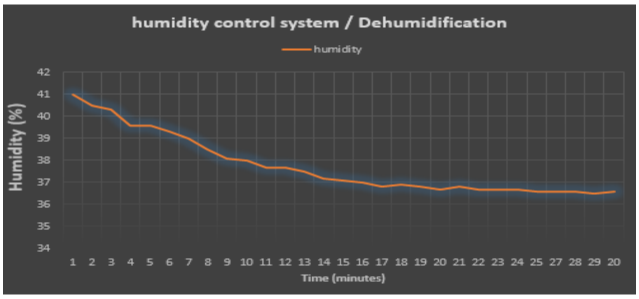


Figure 14: Humidity control system dehumidification response

To check the behavior of the ventilation system as a backup humidifier, the humidifier not working scenario was imitated by turning off its power supply. To make sure ventilation is suitable to be used as a backup humidifier the desired limit was set to (37%) which is within the range of the humidity outside the greenhouse. The test started with (24.1 %). the response of the system illustrated in fig 15. shows that it took the system about 12 minutes to reach the desired level and stabilize.

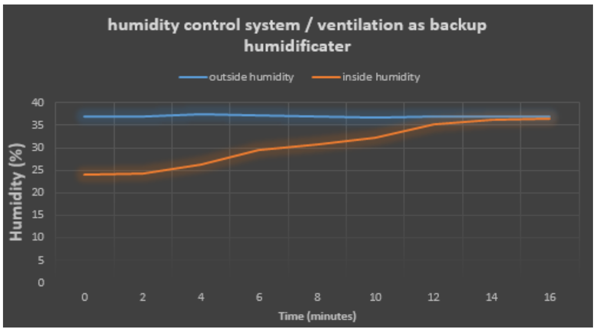


Figure 15: The response of the ventilation system as a backup humidifier

The dehumidifier not working scenario was imitated by turning off its power supply. To make sure ventilation is suitable to be used as a backup dehumidifier the desired limit was set to (37 %) which is within the range of the humidity outside the greenhouse. The test started at (60 %). the response of the system illustrated in fig 16.shows that it took the system about 14 minutes to reach the desired level and stabilize.

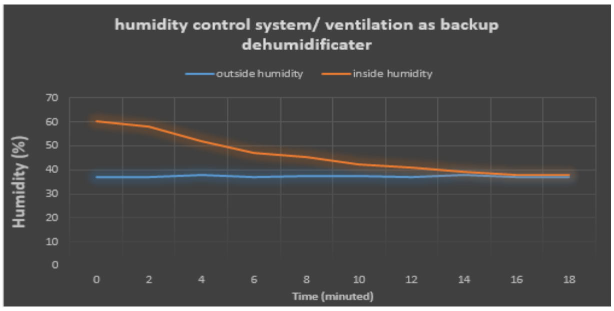


Figure 16: The response of the ventilation system as a backup dehumidifier

c) Light Control System Results

To check the behavior of the light fuzzy logic control system, it was tested at starting inside light of (15.35 lux) and the desired light level was set to (4 Klux). Fig 17illustrates the response of the system. shows that it took the system less than 0.2 sec to reach the desired level and stabilize.

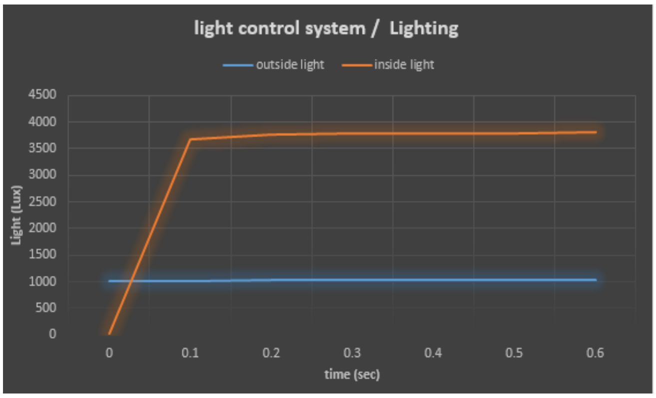


Figure 17: Light control system lighting response

To check the shade behavior of the light fuzzy logic control system, it was tested at starting inside light of (497.5 lux). Fig18illustrates the response of the system. shows that it took the system about 5 sec to open the shades and the inside light stabilized at 165 lux.

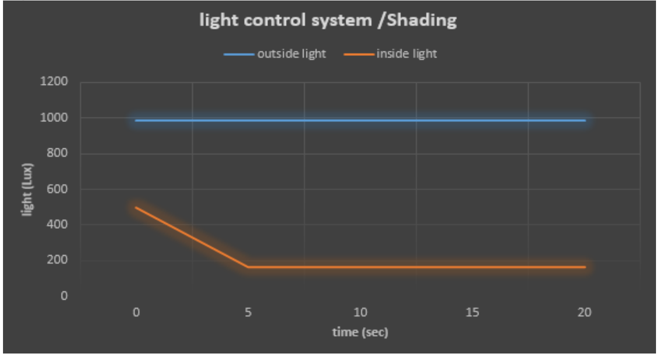


Figure 18: Light control system shading response

d) Co_2 Control System Results

To check the behavior of the Co_2 fuzzy logic control system, Co_2 level inside the greenhouse was increased using vinegar and soda mixture by placing the mixture inside the greenhouse for few minutes, then taking it out of the greenhouse. The Co_2 control system was tested at starting inside Co_2 of (753 ppm) while the outside level (410 ppm) and the desired degree was set to (410 ppm). Fig 19illustrates the response of the system. shows that it took the system about 12 minutes to reach the desired level and stabilize.

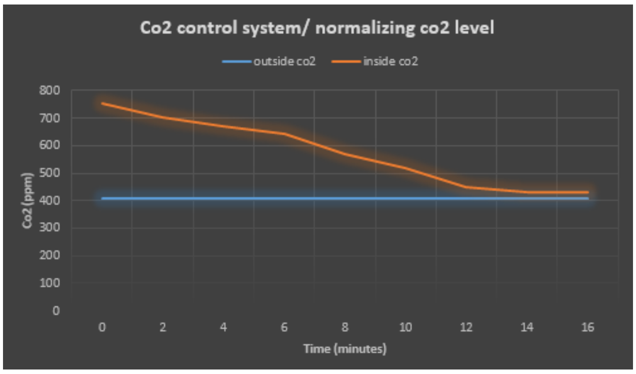
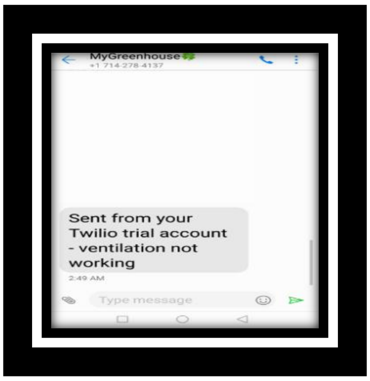


Figure 19: Co_2 control system response

The ventilation system not working scenario was imitated by turning off the power supply of the fan and the shades motors. An SMS notification was received as shown in Fig 20.



Sent from your Twilio trial account - ventilation not working

2:49 AM

Figure 20: Vents not working SMS notification received

e) Irrigation Control System Results

Daily ET_0 has been estimated based on Penman-Monteith (PM) method using FAO (Food and Agricultural Organization) developed software *EtoCal*. The PM estimated ET_0 values were considered as targets and used to train and test the ET_0 fuzzy logic model. The system has been trained using 2,366 datasets. To test the performance of the proposed ET_0 fuzzy logic model, 35 random datasets were used. The same datasets were used in *EtoCal* software and in the proposed ET_0 fuzzy logic model. To show the results, Root Mean Square Error (RMSE) and Correlation Coefficient (CC) values were obtained. Fig 21 shows the results of RMSE which was 0.25 and Fig 22 shows the results of CC which was 0.97.

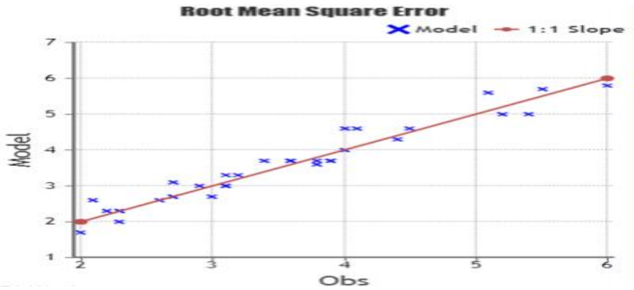


Figure 21: RMSE for the results of Et0Calc and fuzzy

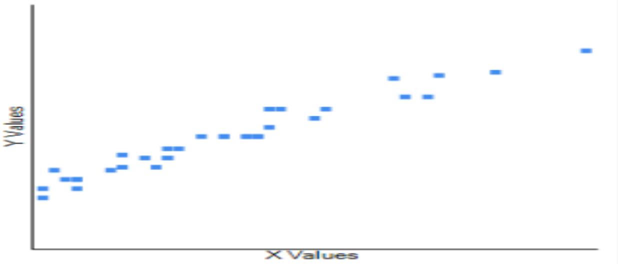


Figure 22: CC for the results of Et0Calc and fuzzy

After testing the proposed ET0 fuzzy model now it's time to test the overall irrigation system performance. The next values were used as input to the system, average inside temperature = 24 °C, Average inside humidity = 80%. Average light intensity = 28 Klux. Since sprinkle irrigation method is used and according to table (2.1) the system efficiency (E) is 75%, F_c = 32 m3/m3, Wp = 20 m3/m3, Zr =0.5 m, P = 0.5, K_c = 0.45, q = 0.13, and S_m = 31%. The results were as follow: ET_0 estimated as 2.3, ET_c = 1.03, TAW= 6000 mm, RAW = 3000 mm, IR_{net} = 0.6 L, IR_{gross} = 0.5 L, Ti = 51.2 sec., II = 2 hours. To actually show the results of the water pump and the drip irrigation system and a measuring container was used to show the amount of water supplied based on these calculated results as shown in Fig23. Shows that the water pump pumped the exact amount of water as specified by the IR_{net}which is 0.6L (600 ml).

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Figure 23: Irrigation system results

4. Conclusion

This system investigated five important greenhouse micro-climate parameters which are temperature, humidity, light, Co_2 and soil moisture. The system used type-2 (Mamdani) fuzzy logic to make all the required decisions to provide the desired growing environment. The system used web application for remote monitoring and controlling and used SMS notification to notify the user and the support team in case anything went wrong in the system. The results showed that fuzzy logic is a quick and accurate tool for making decisions to control the greenhouse environment. Moreover, it shows that the operation of the proposed system verifies the suggested desired states for the proposed smart greenhouse.

References

[1] Teemu Ahonen, D. Sc.Mohammed Salem Elmusrati, And M. Sc. Reino Virrankoski "greenhouse monitoring with wireless sensor network", University of Vaasa, 2008.

[2] D.T. Santosh, K.N. Tiwari, Vikas Kumar Singh and A. Raja Gopala Reddy "microclimate control in greenhouses", international journal of current microbiology and applied sciences, volume 6 number 3 pp. 1730-1742, 2017.

[3] "Smart greenhouse remote monitoring system", Accessed on 16 June 2019 at 12:31 PM, Available on https://www.postscapes.com/smart-greenhouses/.