VOL. 12, NO. 3, FEBRUARY 2017 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

DESIGN AND SIMULATION OF INTELLIGENT GREENHOUSE CLIMATE CONTROLLER

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ABSTRACT

In this research, an extensive insights design steps of Fuzzy Inference System are presented for greenhouse climate control. The temperature and relative humidity for a greenhouse are considered of a highly importance for successful and healthy yield production, also precise controlling schemes results in lowering the crop's diseases and hence provide better quality and enhance the productivity. Consequently, temperature and humidity inside greenhouses are mutual effect parameters; therefore, choosing of a fuzzy inference system to solve the nonlinear control problem of temperature and humidity in a accurate and reliable manner as well as provide less energy consumption for assistance devices is presented. The refining devices are represented by heating, cooling and misting devices. The detailed steps of greenhouse FLC designs are calculated and implemented using MATLAB programming language. The new library of RSS defuzzification method is added successfully and tested with the design and prove acceptable results based on the design constraints; this implementation of RSS method can be used and embedded within MATLAB package as RSS defuzzification method. Based on the design steps, the calculated outputs fully satisfy the system conditions and pave the way to implement this design within the SIMULINK simulator for climate control of greenhouse based Fuzzy inference engine.

Keywords: intelligent climate controller, greenhouse climate control, fuzzy logic, inference system, intelligent computation.

1. INTRODUCTION

Since greenhouse has blocked environment in which climatic and fertilization parameters can be vision and controlled precisely, providing an optimal growth of crops [1, 2]. Much engineering and agriculture efforts has been cooperated to decrease the complexity and produce high efficient methods to keep the desired sets of temperature and humidity. To trim down the complexity of controlling problem of a greenhouse (GH) due to coexist of many parameters that affect the climate and crops, Two parameters, temperature and relative humidity (RH), were studied as they are the most sensitive to each other and to crop production. The using of FIS within WSAN shows robust cooperation to build autonomous SWSAN [3, 8]. Temperature and humidity of GH climate can be controlled by ways of adopting heating, humidifying and fan systems. Those parameters are very important and related directly to the growth of plants, which is highly affected by temperature and humidity variation. The sunny weather cause to increase the indoor temperature and crop damage [4, 5, and 7], contrary at night time a lot of heat emission lost, thus temperature values may fall below their preferred values. Accordingly, the temperature and consequently, the humidity change frequently during day/night time which affects the crops health and thus a suitable controlling process to achieve optimal crop growth is needed [4,5]. For perfect variation of those parameters, two threshold values have to be declared so that optimal climate parameters inside the greenhouse must simulate the natural variation of those parameters in nature. The two threshold values proposed were produced a tolerance space that temperature and humidity can swipe up and down relative to the average value of max-minimum threshold values. The design of FIS for temperature and humidity must adopt the optimal variation of those two parameters during the day and night time within the predefined setting values. Several factors impinge on temperature and humidity and cause the deviation of their values from the setting range values. For example, diurnal temperatures of crops like tomato and cucumber have the range of 24- 30^{o}C while night temperature is 8-15^{o}C [1, 5-8].

2. TEMPERATURE AND HUMIDITY FLC DESIGN

Fuzzy logic concepts work on mimicking the human thinking and the natural language in a way much consistence than other traditional logical systems. Fuzzy logic allows for approximate values and inferences as well as incomplete or ambiguous data. Fuzzy system is defined as a system of variables that are associated using fuzzy logic while the fuzzy controller uses defined rules to control a fuzzy system based on the current values of input variables.

The FLC of microclimate of agricultural greenhouse, specifically for temperature and humidity, is shown in Figure-1. The structure of the controller is composed of input variables, decision making unit, and actuators that modify the environment for the plants under vision. The two most important input parameters, Temperature and Humidity, are manipulated as state variables represent by the Error and Error_rate variables. The output variable will be limited to three actuators devices based on system status, Heater, Fan, and Humidifier. Sensors will measure the temperature and humidity inside the plant and feed these measuring to the controller.

 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

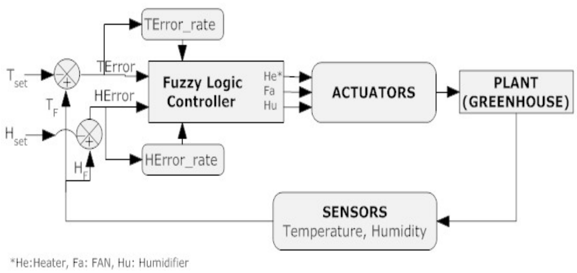

Figure-1. Fuzzy control system of temperature and humidity for a greenhouse.

2.1 Linguistic input and output variables

The input and output variables within a system under control are represented by Linguistic variables. There are two input linguistic variables, Error and Error_rate and two output linguistic variables, Heater FAN and Humid FAN. Each linguistic variable has a range of expected values that are indeed defined by Linguistic terms, which represent categories for the values of a linguistic variable. The linguistic variables Error and Error_rateeach include the linguistic terms NL, NS, ZE, PS, PL. The output linguistic variables included the linguistic terms ONL, ONS, ONC, OPS, OPL.

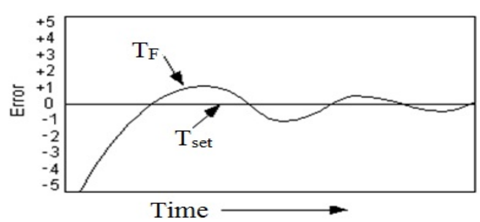

Figure-2. Error behaves of a simple control system.

Figure-2 above shows a general required response of a temperature or humidity control system, 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 measured/feedback temperature of the plants, hence, the system calls for heating action. The T_{set} is the desired temperature value while the T_F is the measured value of 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.

2.2 Fuzzy controller rules

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 rule base is equal to the product of the numbers of sets of each input variable. For input variables 1, 2 and 3, 4 there are 50 rules.

Linguistic terms are represented graphically by *Membership functions.* A membership function represents the degree of membership of linguistic variables 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-2 shows the rule matrix of linguistic variables where the rules are mapped into the matrix inputs. One benefit of using rule matrix, is that it is easy to infer the behavior of the system output based on a noticeable symmetry of the matrix, which yields a reasonable linear behave system.

Table-1. Rule matrix of the linguistic variables.

		TError_Dot				
		NL	***NS***	***NE***	***PS***	***PL***
TError	PL	ZE	NS	NL	NL	NL
	PS	PS	ZE	NS	NL	NL
	ZE	PL	PS	ZE	NS	NL
	NS	PL	PL	PS	ZE	NS
	NL	PL	PL	PL	PS	ZE

		HError_Dot				
		NL	***NS***	***NE***	***PS***	***PL***
HError	NL	PL	PL	PL	PS	ZE
	NS	PL	PL	PS	ZE	NS
	ZE	PL	PS	ZE	NS	NL
	PS	PS	ZE	NS	NL	NL
	PL	ZE	NS	NL	NL	NL

3. FUZZY CONTROLLER MEMBERSHIP FUNCTIONS

The graphical representation of the Linguistic input variables Error, Error_rate, HError, HError_rate is shown in Figures 3 and 4. There are five membership functions associate with each system input; positive, negative, and NE membership functions. These membership functions are of type rectangular, while the ZE and HZE membership functions are of trapezoidal shape with -1, +1 and -4, +4 settling regions respectively. These settling regions provide a tolerance of ±1 for Error and ±4 for HError so the system will be awaiting for a contribution from the second linguistic variable to realize the positive or negative fuzzy output set. Tuning the limits range of each membership function will assist of finding optimal solution for the specified crop based on plant requirements and working experience knowledge. Adjusting these values was controllable and verily, resulting in making the outputs to be more adequate to the requirements of the crop. The output fuzzy sets represent the percentage duty cycle that define the period of ON “actuating’ time for the output devices.

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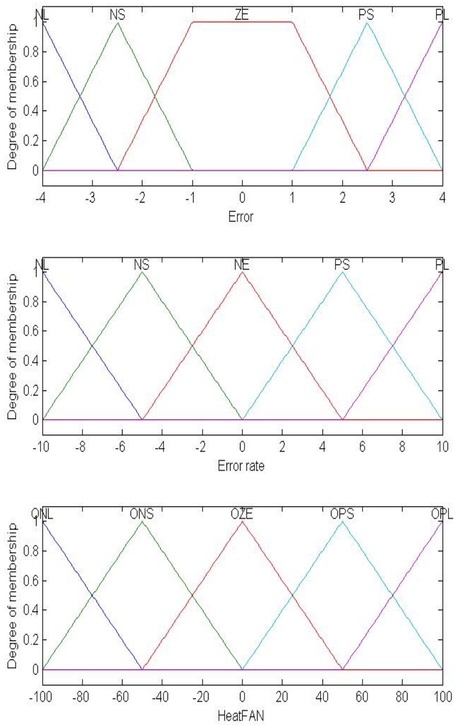

Figure-3. Membership functions of Error, Error_rate and HeatFAN.

3.1 Fuzzification

Fuzzification is the process of associating crisp input values with the linguistic terms of the corresponding input linguistic variables, after that, the fuzzy controller uses the corresponding input linguistic terms and the rule base to determine the resulting linguistic terms of the output linguistic variables.

The rules use the input membership values of Error and Error_rate, degree of membership, as weighting factors to determine their influence upon the output fuzzy.

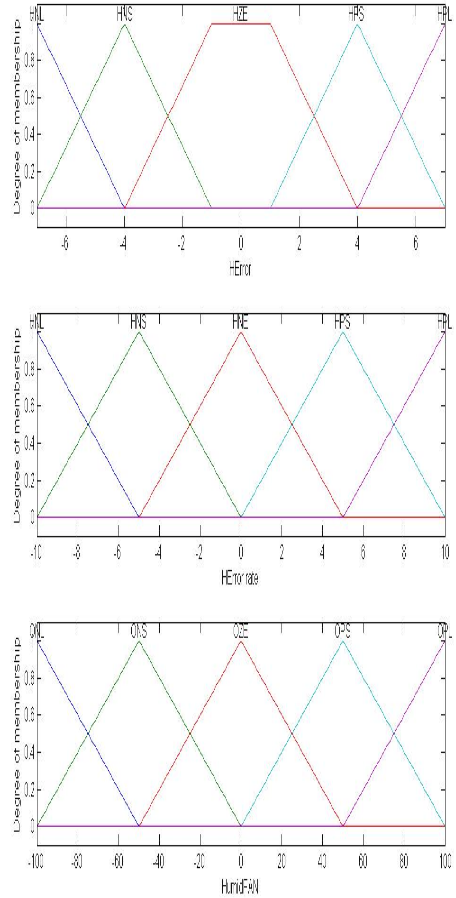

Figure-4. Membership functions of HError, HError_rate and HumidFAN.

Membership functions to produce the final output conclusion. Once the processes of inferring, scaling and combining for functions are done, Once the functions are inferred, scaled, and combined, they are defuzzified into a crisp output which drives the actuators.

The logical products for each rule must be combined or inferred before being passed on to the defuzzification process for crisp output generation. The Root Sum Squared (RSS) method is used to find the firing strength of each output membership. RSS combines the effects of all appropriate rules, weighting the functions at their relevant magnitudes, and computes the fuzzy centroid of the composite area.

3.2 Defuzzification

It is a process of converting the degrees of membership of output linguistic variables within their linguistic terms into crisp numerical values. It is accomplished by combining the results from the inference process (NL, NS, ZE, PS, PL) and thus finding the fuzzy centroid of the area. The scaled strengths of every output membership function are multiplied by their own output membership function center points and then summed together. In conclusion, this area is divided by the sum of the weighted member function strengths, and the result is taken as the crisp output.

$$C\_out = \frac{\sum_{i=1}^{n} P_i \mu(x_i)}{\sum_{i=1}^{n} \mu(x_i)} \qquad (1)$$

The crisp output duty cycle P_i is evaluated based on equation 1, i^{th} is the peak value of i^{th} crsip output fuzzy set, and $\mu(x_i)$ is the weighted strengths of each output member function.

4. FUZZY LOGIC CONTROL BASED ON RSS METHOD

To finalize the designing steps of the FLC described above, we produce a new library based on RSS method. The program is written as m_file within Matlab package. The new RSS fuzzy inference process file can be embedded into the FUZZY LOGIC TOOL of Matlab Simulink* and also it can be called as a m_file where the code can be edited and modified to meet user's requirements. The FUZZY_RSS.m file is integrated with Matlab package. Also, a graphical representation of the fuzzy inference process is shown in Figure-5. This type of representation is highly helped in understanding and evaluating the rule base and the inference process and finally, the defuzzification process.

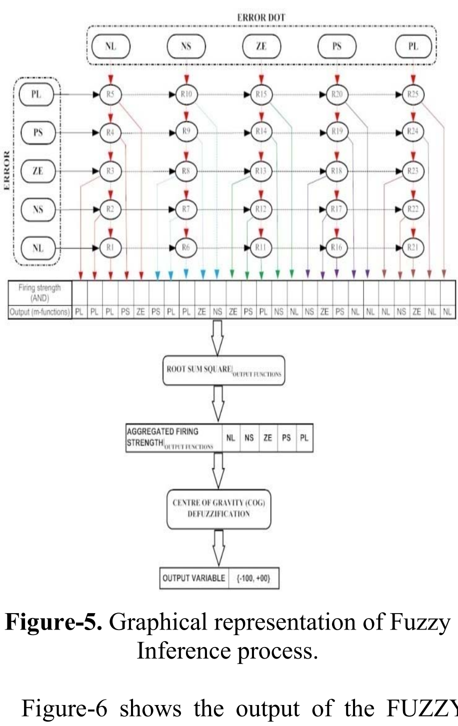

Figure-5. Graphical representation of Fuzzy Inference process.

Figure-6 shows the output of the FUZZY_RSS program for selected values of Error and Error_rate. When the Error value, for example, is 1.25, and the Error_rate is 2.5, then the program shows the input and output membership functions and gives the defuzzified output functions with a notification of the crisp output value (-36). The degree of membership value for Error yields of the overlapping parts of ZE and PS memebership functions with weighting of 0.5 and 0.5 respectively, while the value of Error_rate stimulates the NE and PS memberships parts with weighting of 0.833 and 0.166 respectively. Therefore, only rules associate with ZE, PS and NE, PS will contribute to the output fuzzy variables. Figure-7 illustrates the steps of the fuzzy inference process with Error and Error_rate (1.25, and 2.5) which feed the rule matrix. The designed rule matrix is based on AND logical operator and the outputs of the matrix which represent the firing strength for individual membership output functions. The RSS method is implemented for each output membership then it will be aggregated based on membership function type and pass the resulting values to the defuzzification process where the centre of area of the resulting weighted output function is computed.

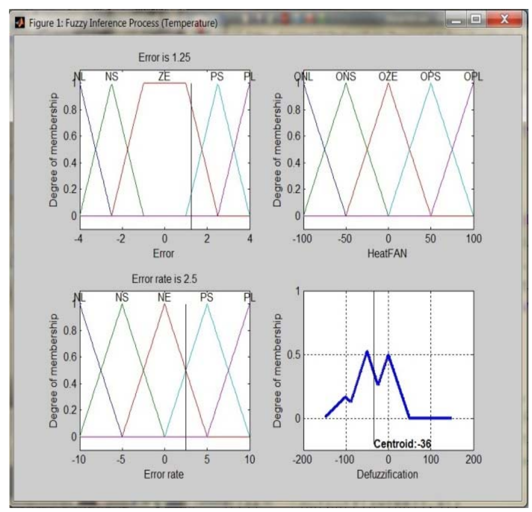

Figure-6. The output of FUZZY_RSS for temperature.

The output value will be either positive or negative value where positive value associate with the heating system while the negative value for cooling system representing by FAN. Figure-8 shows the response of the Inference process to HError of 4.5 and HError_rate of 3, the crisp output is -81 which refer to the cooling system represented by FAN Actuating. The system does OR fuzzy operator of the HeatFan and HumidFan crisp output (-36,-81) of cooling process, the OR operator yields of -81% of cooling process need to be applied at the plant. Figure-9 shows the surface plot of both temperature and humidity fuzzy inference process where linguistic variables are mapped to the output variables.

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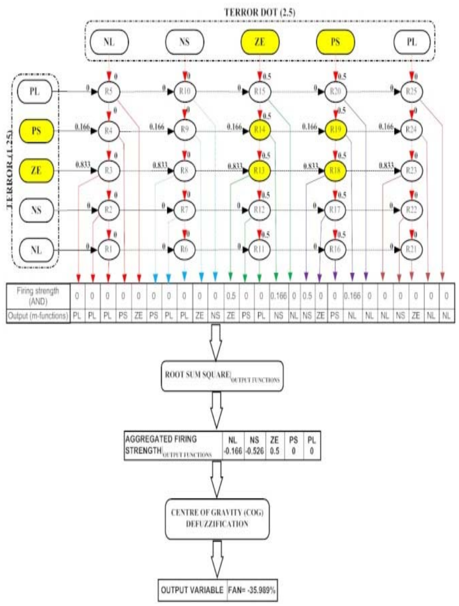
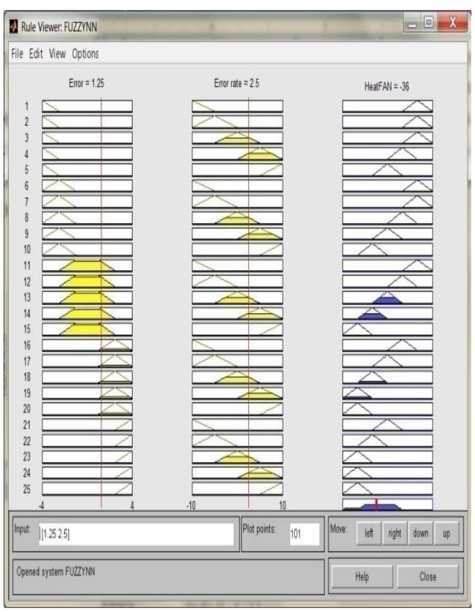


(a)



(b)

Figure-7 (a, b). Illustrative of the fuzzy inference process for 1.25 TError and 2.5 TError_rate example.

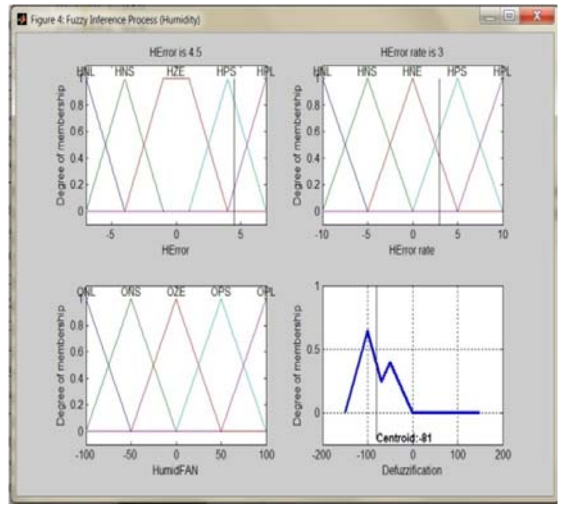


Figure-8. The output of FUZZY_RSS for humidity.

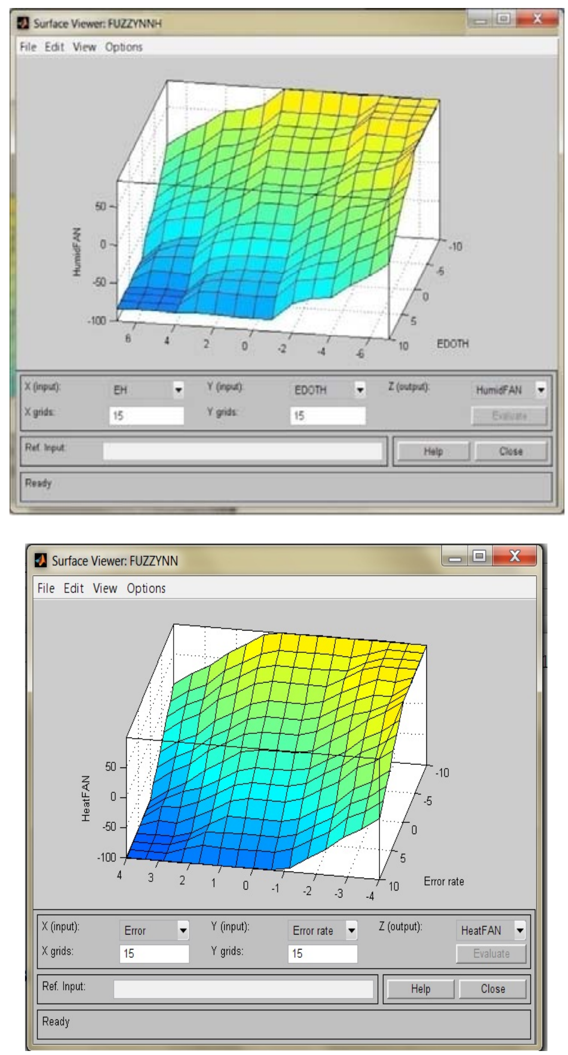


Figure-9. The fuzzy surface for temperature (above) and humidity (down) of the designed fuzzy inference system.

5. CONCLUSIONS

The FLC inference process followed in this research can be summarized into five steps; **Step 1: Inputs and Fuzzy DOM;** This step involves with system inputs, then evaluating the membership's weights to which they belong to each of the appropriate fuzzy sets. **Step 2: Fuzzy Operators;** After the fuzzified process, the fuzzy logical operators are applied to evaluate the composite firing strength of each rule in the rule base. **Step 3: Implication Method;** The implication method is defined as the shaping of the output membership functions on the basis of the firing strength of the rule. Two commonly used methods of implication are the minimum and the product. **Step 4: Aggregate all Outputs;** Aggregation is a process whereby the outputs of each rule are unified. Aggregation occurs only once for each output variable. The aggregation procedure's input is the truncated output fuzzy sets returned by the implication process for each rule. The result of the aggregation procedure is the combined output fuzzy set. **Step 5: Defuzzify;** The input for the defuzzification process is a fuzzy set (the aggregated output fuzzy set), and the resultant of the defuzzification process is a crisp value obtained by using a defuzzificationmethod.

The process of simulation is to adjust the parameters of FIS so adequate output values can be achieved for the actuators devices. The simulation start with defining the input and output crisp which are four crisp input and three for crisp output, then define a set of 50 rules to define the output crisp. The RSS is adopted; it depends upon the contribution of all rules for each output set. The output rules are simulated and the result has been studied and analyzed. The membership functions will be fine-tuned to adjust the result; simulation has been repeated for different tuning setting of temperature and humidity threshold's values until a satisfied result is obtained for diurnal and nocturnal settings. The detailed steps of greenhouse FLC design are calculated and implemented using MATLAB programming language. The new library of RSS defuzzification method is added successfully and tested with the design and prove acceptable result based on the design constraint. This implementation of RSS method can be used and embedded within MATLAB package and called as RSS defuzzification method. Based on the detail's design steps, the calculated outputs fully satisfy the system conditions and pave the way to implement this design within the SIMULINK block simulator for climate control of greenhouse based fuzzy inference engine. The SIMULINK simulator combines FLC design, actuators, greenhouse energy balance model and external disturbance blocks and it's fully described in part2 of this research.

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