Modelling of Ventilation Rate and Heating Rate using Multi-Module Fuzzy Control System for A Greenhouse

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Abstract—The implementation of Ventilation rate and Heating rate can save energy and reduce cost of production. In previous studies, ventilation rates and heating rates were calculated based on mass and energy balance but they are mainly influenced by several factors. In order to check for the effectiveness and applicability of greenhouse ventilation rate and heating rate, we study a multi-module fuzzy control method and use fuzzy logic controllers to control the coordination of a greenhouse heating and ventilation systems. The complexity is reduced by using fuzzy tool in Matlab-Simulink environment which enables a quick design. The experimental data showed that the new multi-module fuzzy control reduced temperature and humidity fluctuations and maintained temperature and humidity closer to the desired temperature and humidity; this method can be easily used to control other equipment in the greenhouse.

Index Terms—Ventilation, Multi-Module, Heating Rate, Temperature and Humidity.

I. INTRODUCTION

A greenhouse is an enclosed construction that enables plants to be in optimally controlled environment with regulated plants growth conditions, thereby decreasing cost of production and increasing crop revenues [1]. The greenhouse environment can be improved by incorporating components such as heating, ventilation and CO₂ supply systems, in order to provide the best environmental conditions. Previously designed greenhouses use a conventional control, but this control strategy may not be suitable to guarantee the desired performance [2]. A greenhouse environmental control system considers the greenhouse environment and crop growth model to manipulate greenhouse temperature, humidity, and other environmental factors in order to achieve the optimal conditions for crop growth. Currently, there is a good deal of research into providing computer-based management systems using optimal or sub-optimal methods [3]. Ventilation is one of the most important methods of greenhouse environment regulation, the basic principles of natural ventilation are discussed in [4, 5] and the calculating model and simulation using CFD are presented based on the indoor thermal pressure and outdoor wind pressure [6]. Fuzzy control is based on fuzzy set theory, fuzzy linguistic variables and fuzzy logic inference; it works based on expert experience and formulates rules which can be used in making decisions.

Fuzzy control is mainly applied to non-linear and complex systems. Previous works has been done by considering the characteristics of a greenhouse’s microclimate and the advantages of fuzzy control technology, few researches done include [7-12].

In this study, the multi-module controller has been implemented using fuzzy logic control in the Nigerian greenhouse, the system uses the appropriate temperature and humidity for crop growth in the greenhouse, the current greenhouse internal temperature, humidity and change rate as well as ambient temperature and wind speed to control ventilation rate and heating rate.

II. DESCRIPTION OF NIGERIAN GREENHOUSE

The experimental greenhouse is located in the Lagos, South-western part of Nigeria; detailed information about the greenhouse is shown in Table 1 below. The greenhouse is the plastic type using polyethylene material and steel frame, it consist of water tank stand constructed which is about 2m high, the water supply is properly connected through pipes to supply adequate water to the crops in the greenhouse. The seasons in the area is broadly divided into dry and wet under the influence of Inter-tropical Convergence Zone (ITCZ). The dry season is around November-March while the rainfall is high in the presence of ITCZ between April-October. The warmest month (with the highest average high temperature) is February (33.1°C). Months with the lowest average high temperature are July and August (28.1°C). The month with the highest average low temperature is March (23.8°C).

III. MATERIALS AND METHOD

The main objective of the climate control system is to maintain the temperature inside the greenhouse within a suitable range. In the Nigerian greenhouse, the ventilation system and heating systems were used to archive the desired temperatures and humidity values.
A. Fuzzy Controller design for the Nigerian greenhouse

The basic structure of a fuzzy controller includes a fuzzification interface, rule base, inference engine and defuzzification interface.

TABLE I: NIGERIAN GREENHOUSE DESCRIPTION AND SENSORS SPECIFICATIONS

| Item                        | Characteristics                  |
|-----------------------------|----------------------------------|
| Ventilation                 | Roof vent insect screens         |
| Temperature sensor          | 43347-LRTD Temperature Probe, Air temperature, ±50±80°C±0.1°C |
| Wind Speed sensor           | ANDWML, 0-70m/s, ±0.2m/s         |
| Data Logger                 | PM-11 Phytomonitor               |
| Communication               | GPRS modem                       |
| Software                    | MATLAB                           |
| Crop                        | Tomatoes                         |
| Plants per m²               | Ten                              |
| Length                      | 25m                              |
| Height                      | 10m                              |
| Structure                   | Steel Truss                      |
| Sliding insulation cover    | Polyethylene                     |
| Coordinates                 | Latitude: N 6° 26′ 28.1688″, Longitude: E 3° 25′ 4.7122″ |

In order to study the Nigerian greenhouse, Single Input Multiple Outputs (SIMO) and Multiple Inputs Single Output (MISO) were adopted. Based on the research on natural ventilation (ventilation rate) and heating rate, the control factors used in this study area as follows: the internal temperature error $Err(T_{in})$, internal humidity error $Err(H_{in})$ and internal temperature error change $Errch(T_{in})$. The effect of solar radiation is neglected by the internal temperature, the control outputs are Ventilation Rate (VR) and Heating Rate (HR). The equations for the above variables are as follows:

\[
Err(T_{in}) = T_{in} - T_{setpoint_{in}} 
\]

\[
Errch(T_{in}) = T_{in} - T_{in-last} 
\]

\[
Err(H_{in}) = H_{in} - H_{setpoint_{in}} 
\]

Where;

- $T_{in}$ = internal temperature
- $H_{in}$ = internal humidity
- $T_{in-last}$ = last internal air temperature measured by the sensor
- $T_{setpoint_{in}}$ = set point of the internal temperature (23°C)
- $H_{setpoint_{in}}$ = set point of the internal humidity (70%)

The SIMO includes the internal temperature error $Err(T_{in})$ as the input and HR and VR as the outputs. The MISO includes internal temperature error $Err(T_{in})$ and internal temperature error change $Errch(T_{in})$ as inputs and VR as output. The logical structures of the system controller are shown in Figs. 1, 2 and 3.

B. Universe

The range of input and output parameters, quantization universe and quantization factor involved in the control system are shown in Table 2. The value of $Errch(T_{in})$ is related to the data sampling frequency of the sensor and temperature variation in the greenhouse.

TABLE II: QUANTIZATION UNIVERSE FOR THE NIGERIAN GREENHOUSE

| Item       | Name          | Range            | Quantization Factor |
|------------|---------------|------------------|--------------------|
| $Err(T_{in})$ | Internal temperature error | [-3±3] | $K_{err}=1$ |
| $Errch(T_{in})$ | Internal temperature error change | [-3±3] | $K_{errc}=1$ |
| $Err(H_{in})$ | Internal humidity error | [-50±50] | $K_{errh}=1$ |
| VR         | Ventilation Rate | [0 4] | $K_{VR}=1$ |
| HR         | Heating Rate | [0 500] | $K_{HR}=1$ |

C. Linguistic value

The number of linguistic values affects the complexity and efficacy of the system. In studying the Nigerian greenhouse, number of linguistic variables was set to three, five and seven with corresponding symbols. The three linguistic values includes High (H), Zero (Z), Low (L) and High (H), Medium (M), Zero (Z) for two different scenarios, the five linguistic values includes Negative-Big (NB), Negative-Small (NS), Zero (Z), Positive-Small (PS) and Positive-Big (PB), the seven values includes Negative-Big (NB), Negative-Medium (NM), Negative-Small (NS), Zero (Z), Positive-Small (PS), Positive-Medium (PM) and Positive-Big (PB).

D. Membership functions

The fuzzy controller in this design used the Gaussian-type, triangular and trapezoidal membership functions.

E. Fuzzy Rule Base

The fuzzy rules were based on expert knowledge and practical evidence to form the fuzzy condition inference. In the fuzzy control, the fuzzy rule is the core of the fuzzy controller, directly affecting the performance of the control system, the specific rules are Tables 3, 4 and 5. For SIMO (Tables 4 and 5), the input variable has five values while the output variables have three values, so the total number of rules was 5, for MISO (Table 3), each fuzzy controller has
two inputs and an output variable, and each variable had seven values, so the total number of rules was 49. The fuzzy decision mechanism used the min (minimum) method to achieve the fuzzy AND operator and the max (maximum) method to achieve the fuzzy OR operator. The implication method was min and the aggregation method was max. Defuzzification used the centroid method, which requires relatively large numbers of calculations but is more accurate.

**TABLE III: FUZZY RULES FOR THE NIGERIAN GREENHOUSE CONSIDERING TEMPERATURE ERROR, INTERNAL TEMPERATURE ERROR CHANGE AND VENTILATION RATE**

| VR         | Err\(T_{n}\) | NB  | NM  | NS  | Z   | PS  | PM  | PB  |
|------------|---------------|-----|-----|-----|-----|-----|-----|-----|
| Errch\(T_{n}\) | NB  | NB  | NB  | NB  | NM  | NS  | Z   | Z   |
| NM         | NB  | NB  | NB  | NM  | NS  | Z   | PS  | PS  |
| NS         | NB  | NB  | NM  | NS  | Z   | PS  | PM  | PM  |
| Z          | NB  | NM  | NS  | Z   | PS  | PM  | PB  | PB  |
| PS         | NM  | NS  | Z   | PS  | PM  | PB  | PB  | PB  |
| PM         | NS  | Z   | PS  | PM  | PB  | PB  | PB  | PB  |
| PB         | Z   | PS  | PM  | PB  | PB  | PB  | PB  | PB  |

**TABLE IV: FUZZY RULES FOR THE NIGERIAN GREENHOUSE CONSIDERING INTERNAL HUMIDITY ERROR, VENTILATION RATE AND HEATING RATE**

| Humidity Error Err\(H_{n}\) | Ventilation Rate | Heating Rate |
|-----------------------------|------------------|--------------|
| Negative-Big (NB)           | High(H)          | Low(L)       |
| Negative-Small (NS)         | High(H)          | Low(L)       |
| Zero                        | Zero(Z)          | Zero(Z)      |
| Positive-Small (PS)         | Low(L)           | High(H)      |
| Positive-Big (PB)           | Low(L)           | High(H)      |

**TABLE V: FUZZY RULES FOR THE NIGERIAN GREENHOUSE CONSIDERING INTERNAL TEMPERATURE ERROR, VENTILATION RATE AND HEATING RATE**

| Temperature Error Err\(T_{n}\) | Ventilation Rate | Heating Rate |
|-------------------------------|------------------|--------------|
| Negative-Big (NB)             | Zero(Z)          | High(H)      |
| Negative-Small (NS)           | Zero(Z)          | Medium(M)    |
| Zero                          | Zero(Z)          | Zero(Z)      |
| Positive-Small (PS)           | Medium(M)        | Zero(Z)      |
| Positive-Big (PB)             | High(H)          | Zero(Z)      |

**F. Establishment of Fuzzy Model**

In order to debug and set up the fuzzy controller quickly, fuzzy tool in MATLAB (Fuzzy Inference System Editor, Membership function Editor, Rule Viewer, Surface Viewer, The MathWork Inc. Natick, Mass.) was used as shown in Fig. 4. This tool was used to establish fuzzy inference system, complete the fuzzy controller design, and establish the rules. The fuzzy rule browser and surface view was used to observe and debug the constructed fuzzy system, correct the relevant parameters for the membership function and verify whether its function was consistent with expectations (Figs. 5 and 6).

**IV. RESULTS AND DISCUSSION**

The simulation was performed using a weather database that was carried out in Lagos, Southwestern, Nigeria during the period of May, 2020 with a sampling time equal to 1
hour, this was divided into 8 days and 9 days’ intervals to enable faster simulation. This database includes the measurements of solar radiation, outside temperature, relative humidity, precipitation, sunshine duration, shortwave radiation, evapotranspiration, wind speed, wind direction, soil temperature and soil moisture. The Fuzzy Logic Controller was applied using the dynamic model, the modified sim- ulink models that includes the Fuzzy Logic Controller block are shown in Fig. 7.

The inputs (the internal temperature error $Err(T_{in})$, the internal humidity error $Err(H_{in})$, internal temperature error change $Errch(T_{in})$) and outputs (Ventilation Rate $VR$ and Heating Rate $HR$) with mamdani model are shown in Figs. 8, 9, 10, 11 and 12.

The inputs membership functions are shown in Figs. 13 - 17, while the outputs membership functions are shown in Figs. 18 - 21.
FLC surface viewer with various inputs and outputs are shown in Figs. 22 – 26. Fig. 22 shows the variation \( \text{Errch}(T_{in}) \) and \( \text{Err}(T_{in}) \) with Ventilation Rate (VR), Fig. 23 shows variation of \( \text{Err}(T_{in}) \) with Heating Rate (HR), Fig. 24 shows the variation of \( \text{Err}(T_{in}) \) with Ventilation Rate (VR), Fig. 25 shows variation of \( \text{Err}(H_{in}) \) with Heating Rate (HR) and Fig. 26 shows variation of \( \text{Err}(H_{in}) \) with Heating Rate (HR).
The rules and the rule viewer are shown in Figs 27 - 32. Figs 27 and 28 shows the rules and the rule viewer for MISO (Multiple Input Single Output) with input variables $Err(T_{in})$ and $Errch(T_{in})$. Figs. 29 and 30 shows the rules and rule viewer for SIMO (Single Input Multiple Output) with $Err(T_{in})$ as input. Figs. 31 and 32 shows the rules and rule viewer for SIMO (Single Input Multiple Output) with $Err(H_{in})$ as input.

Fig. 22. Relationship between inputs “Err(T_{in}) and Errch(T_{in})” and Output “Ventilation Rate (VR)”

Fig. 23. Relationship between Err(T_{in}) and Heating Rate (HR)

Fig. 24. Relationship between Err(T_{in}) and Ventilation Rate (VR) for SIMO

Fig. 25. Relationship between Err(H_{in}) and Heating Rate (HR) for SIMO

Fig. 26. Relationship between Err(H_{in}) and Ventilation Rate (VR) for SIMO

Fig. 27. Rules display for MISO with Inputs “Err(T_{in}) and Errch(T_{in})” and Output “Ventilation Rate(VR)”

Fig. 28. Rule Viewer Showing Selected values for design algorithm using MISO with Inputs “Err(Tin) and Errch(Tin)”

Fig. 29 Rules display for SIMO with Inputs “Err(T_{in})” and Outputs “Heating Rate” and “Ventilation Rate(VR)”

Fig. 30. Rule Viewer Showing Selected values for design algorithm using SIMO with Input Variable “Err(T_{in})”
V. CONCLUSION

In Nigeria, controlling the temperature and humidity in the greenhouse is very important and ventilation control and heating system are some of the important ways to achieve that goal. The Nigerian greenhouse assembled with polyethylene has ventilation windows and heating systems for the control of greenhouse operations. The microclimate of the Nigerian greenhouse is very complex and is difficult to control. The multi-module fuzzy method is applied to the Nigerian greenhouse and achieved good control effect. Using ventilation rates and heating rate under multi-module fuzzy control for the Nigerian greenhouse, the internal temperature and humidity during the day was maintained at about 25°C and 70% respectively.

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