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Fuzzy logic controller devoted to a geothermal greenhouse

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***Abstract*—This paper presents a new digital control for a greenhouse system, an intelligent system of greenhouse temperature controller that based on fuzzy logic controller has been presented. This work propose an intelligent control of the parameter of a agricultural greenhouse. A fuzzy logic controller is designed in order to improve the system efficiency. An extensive simulation work was performed to verify significant tests. The fuzzy logic controller presented in this work provide fast response and good performance against the disturbances that affect the environment around the greenhouse (climatic change).The simulation result prove and show the validity of the fuzzy control strategy.**

***Index Terms*—Agriculture,Greenhouse,simulation,fuzzy logic controller(FLC),humidity,temperature,heat**

I. INTRODUCTION

A little more than fifty years ago, the system of sheltered culture ”greenhouse” is now a system of inescapable mass production, which assures the needs of the populations in fruits and fresh vegetables everywhere.The hight evolution in agriculture area reflects the economic development.

The greenhouse climate control concerns the creation of a adequate environment for the crop in order to reach predetermined results for high yield quality. A greenhouse is a closed space that creates a difference between the outside and the inside air due to the confinement of the air and to the absorption of short-wave solar radiation by cover. In addition, the long-wave radiation is interchanged between the different components of the greenhouse (ground, heating system, plants, cover). Greenhouse is highly nonlinear and strongly coupled Multi-Input Multi-Output(MIMO) systems that are largely influenced by the outside weather (wind velocity, outside temperature and humidity) and by many other practical constraints. In recent years, various advanced control techniques and related strategies are developed. However it is difficult to establish the environment model of the whole greenhouse.It can't reach the ideal control effect using traditional on-off control or proportional control based method[1]. In addition, adopting on-off or proportional based control methods in order to run the heating equipment may result a loss of energy. In the other hand the energy prices has known an increasingly prices in recent years.

Heating the greenhouse in winter is a key success for system efficiency. However using traditional energy sources in heating greenhouses are costly specially with the increasing price of the fuel. Consequently heating using geothermal water present a better solution from economic point view.

Greenhouse controller uses conventional proportional,integral, and derivative (PID) controllers . This method guarantee a simple architecture, simple implementation and good performance.In the literature this type of the controller (proportional,integral, and derivative) is the most controller that have been used for climate control in greenhouses. But,this controller have several disadvantages: constraints are not considered,and only Single Input Single Output(SISO)loops are implemented, resulting in poor performance[2].

Fuzzy logic provides a formal methodology to represent, manipulate and implement expert knowledge for controlling a system [2]-[3]. A fuzzy logic controller performs well in robustness and cost saving[4].In this sense, fuzzy logic proposes an attractive and well-established alternate been soaring. The dynamic behaviour within the greenhouse is governed by the energy and mass balances. The energy balance is affected by the energy contribution of the heating system, the energy losses caused by the air exchange through transmission between the cover and the outside environment, as well as through the natural ventilation provided by the windows, and finally the energy contribution of the solar radiation .The humidity balance is determined by the plants transpiration and the air exchange due to window ventilation. So in this paper we will discuss an implementation of a fuzzy inference of a fuzzy control system heating system to avoid the excess required limits for heating system.There are many fuzzy inferences but in this article a Mamdani inference mechanism was preferred as it is both easy and suitable for the system design.

II. METHODS

A. Greenhouse Dynamic Model

The non-linear behavior of the greenhouse-climate is a combination of complex physical interactions between energy transfer such as temperature and radiation and mass transfer like wind and humidity. This mass balance theory can be

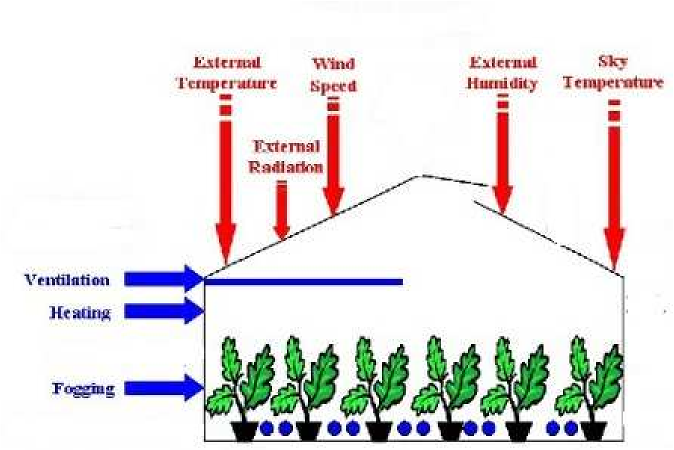

Fig. 1. energy transfer between greenhouse and outside.

written as demonstrate in[1]-[5][6]:

$$V \cdot \rho \cdot C_p \cdot \frac{dT_{in}}{dt} = \begin{aligned} & Q_{Solar} + Q_{Heat} + Q_{Conde,sensible} \\ & - Q_{Wave} - Q_{condu} \\ & - Q_{fog,sensible} - Q_{Adv} \end{aligned} \quad (1)$$

And the mass balance theory for humidity can be written according to the mass balance as in [7]:

$$V \cdot \rho \cdot \frac{dH_{in}}{dt} = \begin{aligned} & q_{fog,latent} - q_{conde,latent} \\ & - q_{latent,inf} - q_{latent,vent} \end{aligned} \quad (2)$$

Where,Q_{Solar} is the energy absorbing from the solar radiation,Q_{Heat} is the energy change in heat caused by heating pipe,$Q_{Conde,sensible}$ is the gain through condensation phenomena,Q_{Wave} is the long wave radiation energy,Q_{condu} is the heat loss through the infiltration process,$Q_{fog,sensible}$ is the heat loss through the foggers system,V is the greenhouse volume,m^3;ρ,air density,$1.2\ kg.m^{-3}$;C_p ,the specific heat of air,$1006 J.kg^{-1}.g\ °C^{-1}$,T_{in} is the inside greenhouse temperature,S_a the surface area of greenhouse cover material m^2,I is the total radiation flux density$W.m^{-2}$,$q_{conde,latent}$ is The flux density of water condensing at the cover surface andτ_{trans} is the light transmittance.

We can clarify each term of two equations(1,2) written recently as following:

(a) Energy from solar radiation:

$$Q_{Solar} = S_a \cdot I \cdot \tau_{trans} \quad (3)$$

Where,S_a the surface area of greenhouse cover material(m^2) ,I is the total radiation flux density $(W.m^{-2})$ and τ_{trans} is the total light transmittance.

(b)Heat exchange between the heat supply and the air inside greenhouse can be written as in [8]:

$$Q_{Heat} = A_P \cdot P \cdot (T_P - T_{in}) \quad (4)$$

Where

$$P = 1.95 \mid T_P - T_{in} \mid^{0.33}$$

(c)wave radiation:Thermal radiation is emitted by the surfaces reaching the cover that can either be transmitted to the sky or absorbed and re-radiated. Emissivity differ among over materials;ranging from as low as 0.2 for polyethylene film to as high as $0.99 - 0.95$ for high-iron glass and are a major determining factor in the effective conductance of the greenhouse envelope. If we assume that the internal surfaces of the greenhouse are at the same temperature as the air. In this case energy in long wave radiation can be calculated as in[9]:

$$Q_{Wave} = \xi \cdot A_s \cdot \sigma \cdot (T_{Sky}^4 - T_{in}^4) \quad (5)$$

Where,T_{Sky} is the temperature at clear sky,($°$ C), ϵ_{sky} is a clearness index like used in [10], A_P is the surface area of heating pipe(m^2), T_P is the temperature of pipe($°C$)and P is pipe air heat transfer coefficient($W.m^{-2}.°C^{-1}$), σ is Stefan-Boltzmann constant($5.67.10^{-8}$) $(kg.s^{-3}.K^{-4})$, ξ is surface emissivity. It is determined by the radiation coefficient of the sky ξ_1 and greenhouse emission rate of the surface of the cover material ξ_2 with.

$$\xi = \frac{1}{\xi_1^{-1} + \xi_2^{-1} + 1}$$

(d) Conduction is the primary means of heat exchange between the greenhouse and the outside. It occurs between the soil and the floor and between the greenhouse air space and the outside. It was calculated as in [11] with the following equation:

$$\begin{aligned} Q_{Condu} = & (U_{cover}.A_{cover} + U_{glazing}.A_{glazing} \\ & + U_{perimeter}.A_{perimeter}).(T_{in} - T_o) \end{aligned} \quad (6)$$

where U_{cover} is the overall heat transfer coefficient $(W.m^2.°C^1)$, A_{cover} is a ratio of the cover, $U_{glazing}$ is the overall heat transfer coefficient $(W.m^2.°C^1)$, $A_{glazing}$ is a ratio of the glazing, $U_{perimeter}$ is the overall heat transfer coefficient $(W.m^2.°C^1)$ and $A_{perimeter}$ is a ratio of the perimeter.All value of the U can be found in many handbooks[12].

(e)The advection of heat across the greenhouse envelope can be viewed as the sum of two processes: ventilation and infiltration;which differ in their controllability, energy requirement,and response to a change in pressure. It was computed with the following equation[13]-[14]-[15][16]:

$$Q_{adv} = \dot{V_{inf}}.C_p.\rho.(T_{in} - T_{out}) + \dot{V_{vent}}.C_p.\rho.(T_{in} - T_{pad}) \quad (7)$$

Noting that in a greenhouse,evaporative cooling devices are used in order to reduce temperature when ventilation cannot achieve the levels suitable for optimal plant growth. In greenhouses those equipped constitutes the second portion of latent gain. Most evaporative cooling methods can be modeled as adiabatic cooling processes ; the minimum temperature and maximum vapor pressure achievable are equal to that wet bulb. In our simulation, there are two possible evaporative cooling methods(cooling-pads and foggers).The cooling-Pads was installed at one end of the greenhouse, the section fan installed in the other end. When the air in greenhouse is required to be cooled, the fan control system will start. Fans and cooling pad system is the most economical and efficient way to cool the greenhouse temperature in summer,with temperature of cooling T_{pad} ,it can be calculated:

$$T_{pad} = T_{out} - \eta.(T_{out} - T_{wet})$$

And the Wet-Bulb temperature outside the greenhouse from relative humidity and air temperature can be expressed as in [17]:

$$\begin{aligned} T_{wet} =& T_{out}. \arctan[0.151977(H + 18.313659)^{1/2}] \\ &+ \arctan(T_{out} + H) - \arctan(H - 1.676331) \\ &+ 0.00391838(H)^{3/2}. \arctan(0.023101.H) \\ &- 4.686035. \end{aligned}$$

where, $\dot{V_{vent}}$ is the ventilation rate $(m^3.s^1)$,$\dot{V_{inf}}$ is the infiltration rate $(m^3.s^1)$, C_p is the specic heat of moist air $(J.kg^1.°C^1)$ and $(T_{in} - T_{out})$ defines the air temperature difference,between inside and outdoor the greenhouse, respectively, $T_{dewpoint}$ is the temperature at witch air becomes completely saturated,$(°C)$, H is the outside humidity $(\%)$, T_{wet}, $(°C)$.

(f)The fogging process is modeled as a mass transfer between the fog droplet and the air.The maximum humidity occurs at wet bulb, so the driving force is the difference between current vapor pressure and that at wet bulb. The rate of heat sensible effect and the latent are defined as follow [18]-[19]:

$$\begin{aligned} Q_{fog,sensible} &+ q_{fog,latent} \\ &= (\lambda.(\frac{R_{conve,o} + R_{cond,c}}{R_{conv,i} + R_{cond,c} + R_{conv,o}}) \\ &+ 1)1.64.10^{-3}.\Delta T^3.A_{net}.(Va - Vsat) \quad (8) \end{aligned}$$

(g)The flux density of water condensing at the cover surface can controlled by the difference between current vapor pressure and saturation vapor pressure inside the cover wall [20]. The flux density of water condensing at the cover can be described:

$$q_{cond,latent} = g_{cond}.(Va - Vsat) \quad (9)$$

The mass transfer conductance g_{cond} can be calculated by[21]:

$$g_{cond} = \frac{M_v}{A_c}.sh \simeq 2.49.10^{-5}.\frac{sh}{A_c}$$

whereM_v is the molecular diffusion coefficient of water vapor and A_c is the cover surface.The Nusselt number of a greenhouse cover of small slope was found by [22]to be similar to that of a horizontal surface. Accordingly,the Sherwood number can be written

$$sh = 0.96.0.13Gr^{1/3}$$

TABLE I
PARAMETERS OF THE GREENHOUSE

Volume of the greenhouse	3710.8 m^3
Area Floor	790.13m^2
Perimeter	102.24 m^2
wall area	23.2289 m^2
Pads efficiency	0.85
window opening heights	3 m
coefficient of discharge	0.6

with

$$Gr = 1.47.10^8.A_c^3(\tilde{T_a} - \tilde{T_r})$$

Where $Vsat$ is the vapor pressure at saturation phase and $\tilde{T}$ is the virtual temperature.

Due to the exponential non-linearities of the saturation vapor pressure equation, they are not solved directly during the simulation can be defined as the same approximation as in [23]

$$\begin{aligned} Vsat =& (1/1000).(-5800/T_{in} + 1.391 - 48.64.T_{in} \\ &+ 4.176.10^{-5}.T_{in}^2 - 1.445.10^{-8}.T_{in}^3 + 6.546. \ln(T_{in}) \end{aligned}$$

considering $Q_{cond,sensible}$ value is proprotionnelle to $q_{cond,latent}$. After modeling the whole system the parameters used in simulation work are showing in table.1. The used greenhouse is a span greenhouse have a single cover glass construction ,it parameterized for a 34 m by 17 m.

B. Design of fuzzy logic controller

Fuzzy logic is a branch of mathematics and, as such, a number of basic concepts are developed. These concepts are used to justify and demonstrate some basic principles. In order to control our system a fuzzy logic controller has been chosen. It was implemented with five operations[24]:

1) Fuzzify numerical inputs based on measurement(temperature difference and/or rate of temperature)using input membership functions.
2) Apply fuzzy operators to the antecedents of the rule base.
3) Perform implication.
4) Aggregate each rules output into a common fuzzy set.
5) De-fuzzify the aggregate fuzzy set to obtain control output using a center of gravity output rounded to the nearest integer.

To make obvious the design of the fuzzy logic controller, is considered a system which consists of two-inputs and one-output FLC. The membership functions for the temperature difference,the change rate of temperature and of the output (heating) use seven linguistic variables to apportion over the range of error -6 to $+6$ $°C$(NB, NM, NS, ZO, PS, PM, PB). Where, NB, NM, NS,ZO,PS, PM and PB, stand for negative big,negative middle, negative small,zero,small positive, middle positive, big positive, respectively. The greenhouse control system can be allowed to act in response to the combined situation of greenhouse temperature difference and the rate at which the greenhouse temperature difference changes to eliminate the temperature deviation. Corresponding control rules can be described using fuzzy statement as showing in table.2: Fuzzy decision uses maximum value method.

TABLE II
FUZZY LOGIC RULES

e	ec						
	NB	NM	NS	ZO	PS	PM	PB
NB	PB	PB	PB	PM	PS	ZO	ZO
NM	PB	PB	PM	PM	PS	ZO	ZO
NS	PB	PB	PM	PS	ZO	NS	NM
ZO	PM	PM	PS	ZO	NS	NM	NM
PS	PM	PS	ZO	NS	NM	NM	NM
PM	ZO	ZO	NM	NM	NM	NM	NB
PB	ZO	ZO	NM	NB	NB	NB	NB

III. SIMULATIONS

The modulation step of the whole system greenhouse as showing in figure.2 (the controller and the greenhouse) in order to attain desirable heat water output of the pipelines is complited.The next step is the simulation. All data needs in this last are presented such as solar radiation in figure 3,outdoor temperature in figure 4,wind speed in figure.5 and humidity in figure.6,all data are needed for the fuzzy logic control system.Greenhouse simulations were performed using two set point temperature step changes at $25,200$ s and $72,000$ s,and diurnal variation in solar radiation. The error universe is $[-1.2, 1.2]$,quantification universe$[-6, 6]$,therefore the quantification factor Ke should be 5; and the basic universe of the temperature difference change rate is $[-0.15, 0.15]$,the quantification universe$[-6, 6]$,therefore quantification factor Kec should be 40.By the token,the quantification factor Ku equals 1.

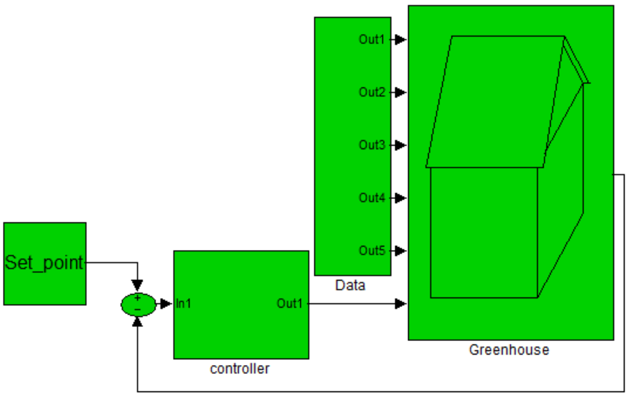

Fig. 2. The fuzzy control system simulation.

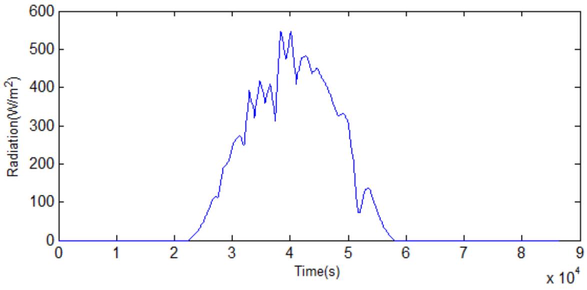

Fig. 3. The diurnal solar radiation.

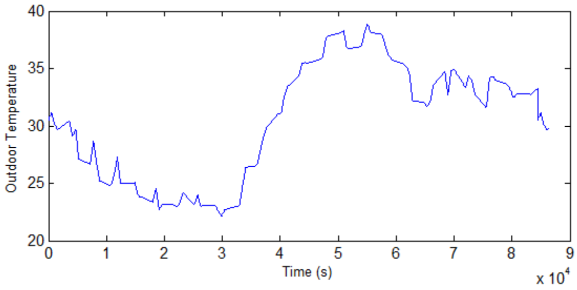

Fig. 4. The outside temperature.

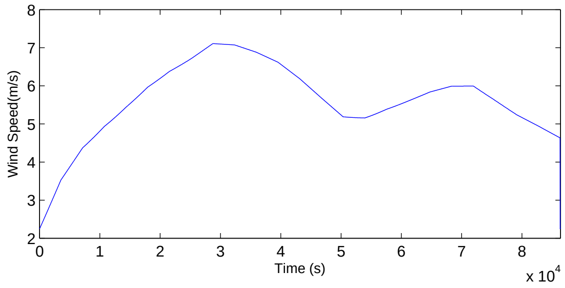

Fig. 5. Wind Speed .

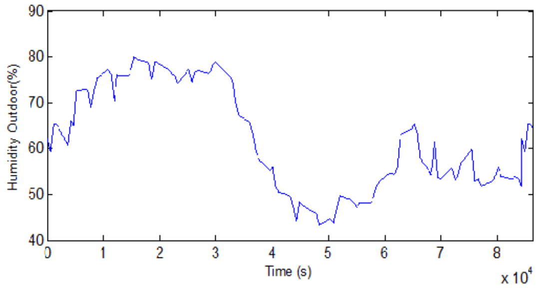

Fig. 6. The outdoor humidity.

IV. RESULT AND DISCUSSION

The simulation results show that the interior temperature can attain the desirable set point temperature. But, there is an oscillation occurrence in the results.We can relate those reasons for the construction of the controller. The humidity variation fllow the temperature variation one the same way as

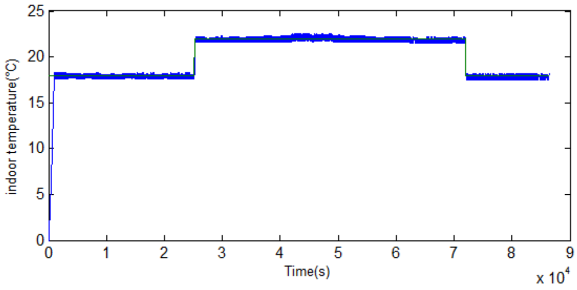

Fig. 7. Simulation result of greenhouse temperature.

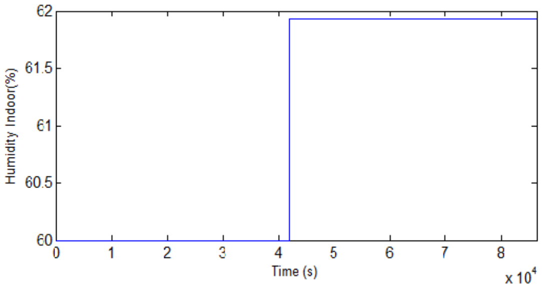

Fig. 8. Simulation result of greenhouse humidity.

well as the temperature , it respects the area that we set during the simulation with saturation block so we assures that there is no divergence. Our controller has proportional and derivative control function. It can speed up the response speed of system and reduce the overshoot. But the controller present a lack of integral action. So its function of eliminating the system error present a weak performance. It is difficult to achieve high control precision. So our controller regularly adjusts the output to meet the demand temperature of greenhouse. The obtained results confirm that the fuzzy control is appropriate for the control of the greenhouse.

V. CONCLUSION

The fuzzy greenhouse temperature controller had been designed in order to control the temperature according to the greenhouse environment. Every input and output consists of several membership functions to increase the performance of the system. Fuzzy Logic Toolbox is used for system design. The effectiveness and rationality of the controller was proved through simulation. The results show that fuzzy control system can heat greenhouse effectively with outside interference factors making the greenhouse environment (such as outdoor temperature,outdoor humidity,solar radiation,wind speed). This techniques can be used as references to implement in real time system. Future planning is the implementation of this controller into real time and it can also be commercialize to market if the performances is the same as simulation.

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