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Research Paper

Development of a Fuzzy Logic Controller applied to an agricultural greenhouse experimentally validated

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HIGHLIGHTS

- Modeling, optimization and control strategy of the agricultural greenhouse.
- New dynamic modeling of the greenhouse with a good statistical performance.
- A better performance of the developed FLC controller.

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ABSTRACT

The agricultural greenhouse presents a complicated procedure since the strong perturbations and the important number of its input parameters, which have a great potential and capacity to influence the climate inside it. For this reason, a Fuzzy Logic Controller (FLC) is developed in order to promote a suitable microclimate by activating the appropriate actuators installed inside the greenhouse with the appropriate rate. The dynamic modeling of the studied greenhouse is presented and simulated under MATLAB/Simulink environment to be experimentally validated within the Research and Technology Center of Energy (CRTEn) in Tunisia. The simulation results illustrate the effectiveness of the proposed dynamic model to investigate the internal air temperature and relative humidity with a low percentage of error. In addition, the developed controller FLC presents an effective solution to get an optimized microclimate indoor the agricultural greenhouse.

1. Introduction

By 2050, global demand for energy will nearly double, while water and food demand is set to increase by over 50%, where the International Renewable Energy Agency (IRENA) has estimated that food production will need to increase by 60%, water availability by 55% and energy generation by 80% [1]. Food security is a global issue, which has to be treated effectively in order to meet the future global demand.

The open field cultivation presents a thorny problem mostly in the countries characterized by some unfavorable climatic conditions. Nevertheless, the greenhouses are already a recognized solution to protect the canopy against diseases and unfavorable meteorological conditions. It is a complex system, which has many factors affecting the climate inside it like, the wind speed, the solar irradiation, the outside temperature and relative humidity, etc. However, the control of the climate inside the greenhouse is an important aspect to reach a comfortable microclimate for the plant growth. In fact, Atia et al. [2] have developed four controller techniques to adjust the air temperature inside the greenhouse at the required value, which are the Fuzzy Logic Control (FLC), Adaptive Neuro-Fuzzy control (ANFIS), Artificial Neural Network control (ANN) and PI control. Many other researchers have been interested in this field and several control strategies have been developed to optimize the indoor microclimate such as: the Neural Network [3,4], the Adaptive Predictive control, the Proportional–Integral–Derivative controller (PID controller)[5], the PI controller (SSOD-PI and PI-SSOD event-based controllers) [6], the Nonlinear Adaptive PID control [7], the Optimal Control [8], the Genetic Algorithm [9], the Adaptive Neuro-Fuzzy Controller [10,11] and the Fuzzy Logic Controller (FLC) [12], which presents one of the most known and used regulator for the nonlinear and complex process like the greenhouse. The FLC aims to control the inside microclimate by using a membership function based on the learning of the actuators involved in the optimization of the microclimate. This controller has been used to control many parameters inside the greenhouse such as the air temperature and the relative humidity. Besides, many studies proved that the FLC

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Nomenclature

C_a	specific heat of air ($J\,kg^{-1}\,K^{-1}$)
Ce	transfer coefficient of water vapor in the air ($kg\,m^{-3}\,Pa^{-1}$)
d_a	air density ($kg\,m^{-3}$)
E	Evapotranspiration ($kg\,m^{-2}\,s^{-1}$)
H	relative humidity (%)
H	heat transfer coefficient ($W\,m^{-2}\,K^{-1}$)
I	solar radiation ($W\,m^{-2}$)
LAI	leaf area index
L	characteristic length of greenhouse (m)
L	characteristic length of the leaf canopy (m)
l_{ca}	average length of the canopy (m)
m_j	measured parameters
n	number of variables
N_h	number of heaters
T	temperature (K)
t	time (hours)
r_a	aerodynamic resistance ($s\,m^{-1}$)
r_s	stomatal resistance ($s\,m^{-1}$)
RE	rate of air infiltration ($m^3\,s^{-1}$)
R_h	capacity of the heating system (W)
S	surface area (m^2)
S_v	vertical section of the greenhouse (m^2)
p	saturated vapor pressure (Pa)
P_j	predicted parameter
$P(T)$	water vapor pressure at temperature T (kPa)
Q	heat rate (W)
V	volume (m^3)
V_r	ventilation rate provided from the ventilation ($m\,s^{-1}$)
W	wind velocity ($m\,s^{-1}$)
Z	depth sub_soil (0.5 m)
EF	model efficiency
$RMSE$	root mean squared error
R	humidity rate ($g\,s^{-1}$ of water)
R^2	coefficient of determination
$MAPE$	mean absolute percentage error
$TSSE$	total sum of squared error

Greek symbols

α	absorbtivity for solar radiations
α_t	absorbtivity for thermal radiations
ε	emissivity
γ	psychometric constant ($kPa\,K^{-1}$)
λ	thermal conductivity ($W\,m^{-1}\,K^{-1}$)
ρ	reflectivity
σ	Stefan-Boltzmann constant $5.670\cdot 10^{-8}\,W\,m^{-2}\,K^{-4}$
τ	Transmissivity

Subscripts

Av	average
C	cover
ca	canopy
I	inside greenhouse
O	outside greenhouse
S	soil
sky	sky
inf	infiltration
Z	depth
ventilation	ventilation system
heating	heating system
dehum	dehumidifying system
hum	humidifying system

Exposants

A	absorbed heat
C	convective heat
Cd	conductive
L	latent heat
R	radiation heat
*	at saturation

represents a useful tool to solve the non-linearity problem of the greenhouse. Marco et al. [13] have used a MISO greenhouse and in order to control its internal air temperature, they have developed a fuzzy modelling application, which is used also by Salgado et al. [14] with a new methodology that automatically organizes a flat fuzzy system into a hierarchical collaborative structure. This structure aims to transfer the information contained in the sets of fuzzy rules to another fuzzy sub-systems. In addition, Lafont et al. [15] have presented a comparative study of two types of multi-variable fuzzy controllers (the basic and the optimized fuzzy controllers) to show their advantages and disadvantages. Generally, the Scientific researchers who were concentrated on the control strategy of the climate inside the greenhouse, had utilised a very simplified models, whereas the results might be more precise if the modeling was more efficient.

The algorithm of the FLC requires a dynamic model that governs the different physical phenomena describing the evolution of the microclimate inside the greenhouse by taking into account the dynamics of its input/output variables. However, several dynamic modeling of the greenhouse referred in the literature to quantify the heat and water transfer between its different components. Fitz-Rodríguez et al. [16] have developed a web-based application that presents several scenarios of modeling and simulation of the microclimate inside the greenhouse under several climatic conditions and in four geographical locations in the United States: Arizona (Tucson); Floride (Fort Pierce); Ohio (Columbus) and Vermont (Burlington) during the four seasons. Indeed, a three year experimental comparative analysis based on desiccant and a traditional air conditioning system for two identical flower greenhouses in the winter season is demonstrated by Longo et al. [17]. In Tokyo, Abdul-Ghany et al. [18] have presented an experimental study of a dynamic model for heat and water vapor transfers in natural ventilation and fog-cooled greenhouse to predict the inside temperature and relative humidity during one summer day. In North Africa, many studies present an experimental analysis of the greenhouse like Algeria, in which an experimental measurement of the dynamic model based on the transfer coefficients of the convection heat inside and outside the greenhouse has been estimated and analyzed under three scenarios of climatic conditions at night: cloudy, windy and cloudless [19]. In Baghdad, a model of knowledge applied to an innovative greenhouse without crops has been developed by Joudi et al. [20]. They have combined a traditional greenhouse to a bank of solar air heaters as one structure in order to eliminate a lot of space that would otherwise be needed. In south Morocco, a dynamic model based on latent heat balance of a global greenhouse equipped with insect-proof nets has been simulated and validated by Fatnassi et al. [21] and also in Tunisia many research studies and experimental analysis of greenhouses have been developed especially in the CRTEn research center. Like Bouadila et al. [22,23], which have developed a heat balance of the agricultural greenhouse with an experimental comparison between two identical greenhouses, one of them is equipped with a latent heat system. Kooli et al. [24] and Lazaar et al. [25] have also presented a comparison