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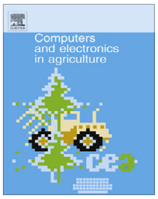

Original papers

Smart frost control in greenhouses by neural networks models

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ABSTRACT

Thermal comfort in greenhouses is a key fact to enhance productivity, due to the excess demand of energy for heating, ventilation and agroclimatic conditioning. Frost, in particular, represents a serious technological challenge if the crop sustainability is to be ensured. A Multi-Layer Perceptron artificial neural network, trained by a Levenberg-Marquardt backpropagation algorithm was designed and implemented for the smart frost control in greenhouses in the central region of Mexico, with the outside air temperature, outside air relative humidity, wind speed, global solar radiation flux, and inside air relative humidity as the input variables. The results showed a 95% confidence temperature prediction, with a coefficient of determination of 0.9549 and 0.9590, for summer and winter, respectively.

1. Introduction

The greenhouse cultivation is one of the main economic activities in the agricultural sector, in the agro-climate control greenhouses context; there are strategies that deal cold technology for better agriculture performance (e.g. Kumar et al., 2009; Zabeltitiz, 2011). Currently, precision agriculture for their monitoring and control is used by technology (e.g. Mesas et al., 2015; Ojha et al., 2015; Rehman et al., 2014; Simbeye et al., 2014; Srbinovska et al., 2015). But nature imposes limits as climate frost, that is, in agriculture plants as resistant or not to light frosts, let alone medium and heavy frosts (e.g. Cao et al., 2009; Kathke and Bruelheide, 2011; Savi et al., 2015). But several greenhouse crops are affected by the frost, because the low temperatures cause irreparable damage to crops (e.g. Kandula, 2011; Chávez et al., 2014). In recent years there has been a significant development and research projects aimed at increasing the heating and ventilation of greenhouses (e.g. Abdel and Al, 2011; Bennis et al., 2008; Körner and Van Stratenb, 2008; Mashonjowa et al., 2013; Molina et al., 2010; Pierre and Thierry, 2010; Sethi and Sharma, 2008; Sethi, 2009). But usually these systems already applied in the greenhouse uses heating means as turbines or pumps for heating water, among other methodologies heating involved directly with crop natural ventilation, the criticality of these methodologies is that the plant to these conditions CO_2 begins to perspire allowing low temperatures of frozen condensed water into plant, damaging the crop, which normally generates total loss of the crop, this process plant transpiration by heating the greenhouse which is affected by frost shown in Fig. 1, where the plant transpiration, which is water loss as vapor through stomata, cuticle and the periderm, this process heat from the air is used for passing liquid water on vegetation in water vapor, so that the low temperature in the vicinity of the leaves (e.g. Boulard et al., 2010; Chai et al., 2012). Of the total amount of water that is absorbed soil, carried on the stem and transpired to the atmosphere, only a very small fraction of 1% is incorporated into biomass, almost all the water lost by the blade makes through stomatal pores, which are more abundant on the underside of the leaf (e.g. Boulard et al., 2010; Chai et al., 2012; Teitel et al., 2010; Tong et al., 2010). The transpiration rate in the plant by heating that is affected by frost is influenced by such factors as the plant species and size, soil moisture, the amount of sunlight considering its duration and intensity, air temperature or wind speed, where climatic factors are temperature, solar radiation, rainfall, humidity, wind speed, through use of weather stations to monitor possible environmental conditions remotely on a greenhouse, where incorporating the use of embedded systems to embedded computing part for predicting natural events implementing statistical and artificial intelligence and knowledge engineering (e.g. Chevalier et al., 2012; Dombaycı and Gölcü, 2009; Hea and Ma, 2010; Higginsa et al., 2010; Huang et al., 2010; Li

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Nomenclature

$A(z)$	matrices
a_{ij}	model parameter (with i and j any natural number)
a_{na}, b_{nb}	model parameters
$B(z)$	matrices
b_{ij}	model parameter (with i and j any natural number)
C	classroom
C_c	control room
$D_{\bar{y}i}$	standard deviation
e	perturbation
$e(t)$	perturbation or any not-measurable input in the system (noise)
f	activation function of the ANN
H	humidity, %
H_0, H_1	hypothesis test
I_c	clothing insulation (clo), where 1 clo = 1.155 m^2 °CW^{-1}
M	metabolic rate (met), defined *met* as 58.2 Wm^{-2}
M_1	meeting room
N	number of data sets used for estimation
n	number of samples
n_a	number of pole
n_a, n_b	order of the respective polynomials (output, input)
$n_b - 1$	number the zeros
n_k	time delay
R_{hi}	inside air relative humidity, %
R_{ho}	outside air relative humidity, %
S_a	air speed, ms^{-1}
S_r	solar radiation, Wm^{-2}
T	transpose
t	domain (discrete) time interval
T_a	air temperature, °C
T_i	inside air temperature, °C
T_o	outside air temperature, °C
T_r	radiant temperature, °C
$u(t)$	input signal at (discrete) time t
$u(t - n_k)$	input signal at (discrete) time $t - n_k$
W	vector of synaptic weights of the ANN
W_s	wind speed, ms^{-1}
X	input vector of the ANN
X_{norm}	normalized value of X
$X_{\min}$	minimum values of X
$X_{\max}$	maximum value of X
X_r	real value in a parameter
y_i	actual value of the data set (observed output)
$\bar{y}_i$	mean value of the observed outputs of the prediction set
$\hat{y}_i$	predicted value of the data set (estimate output)
$y(t)$	output signal at (discrete) time t
$y(x)$	output of the ANN
z^{-1}	backward shift operator
α	number of the replicates or observation
δ_{ij}	kronecker symbol
θ	bias value

et al., 2015; Liu et al., 2015; Martí et al., 2013; Mohammadi et al., 2015; Prabha and Hoogenboom, 2008; Smith et al., 2009; Zhang et al., 2015). The light frosts are temperatures drop slightly below 0 °C exceptionally and temperatures rise again past few hours, this type of frost occurring in México central region, mainly it occurs with concurrency in the states of Mexico, Hidalgo, Tlaxcala. A particular type of soft ice is frozen by evaporation that occurs in plants due to the evaporation of water or mist that remains in the plant surfaces after rain or lowering the humidity. The phenomenon of evaporation of water causes the adsorption heat, which in turn produces heat loss to the plant and decrease in temperature may fall below the 0 °C level, this phenomenon can also occur in animals and can produce hypothermia or death. The stockings frost is temperatures drop below 0 °C during the nights and days of winter, temperatures remain very exceptional register below −10 °C. It is produced by the entrance of a mass of dry air and cold temperatures below 0 °C, accompanied by winds with speeds of 15 km/h. The action of the cold air, dehydrated plants and ending with the cellular fluids that serve as defense against frost (e.g. Cao et al., 2009; Ghielmi and Eccel, 2006). On the other hand, the high consumption of energy generated by the heating, ventilation and Agroclimatic Conditioning Systems (ACCS) is due to the use of inefficient methods; likewise, inadequate operation sequences and failure systems, rising production costs and lower profits generated by the crop, this becomes unprofitable to the farmer. Research shows that energy saving can be reached with the correct use of control systems regarding the models to predict the internal temperature at the greenhouses (e.g. Bennis et al., 2008; Körner and Van Stratenb, 2008). According to the models relied on both statistical and non-statistical methods, they are able to provide an important technique to raise the comfort heat level required by the greenhouses (e.g. Sethi and Sharma, 2008; Smith et al., 2009; Pierre and Thierry, 2010).

Due to the inside temperature of the greenhouses seems to be affected by several inputs and output variables; along with the relevant control of the temperature predictions in standard rules and models concerned about the quantity of input variables for the purpose of getting the wanted precision, during the prediction of the concerned variables. On the other hand, there are some variables that affect directly the interior climate and those are proportionally related to specific variables such as the external climate conditions, outside and inside air temperature, outside and inside air relative humidity, wind speed, global solar radiation flux, and wind direction. In recent research several authors have dedicated time to find out mathematical models as a proficient tool to transform data into main information, in order to calculate and predict temperature (e.g. Frausto et al., 2003; González and Zamarreño, 2005) associated with the linear autoregressive models, physical models, as well as the artificial neural network models, allowing to give a better prediction and control in ACCS systems, generating more crop savings. Estimating the inside temperature in greenhouses is difficult and important to accomplish the main goal of this study. In this case, this data can be determined by two sorts of models either statistical or non-statistical, applied using mathematical models that is implemented in weather stations using embedded systems that capture data to be processed in real time (e.g. Chevalier et al., 2012).

A discrete model of the continuous climatic system in a greenhouse can be obtained in several ways, one of which is autoregressive relationships between the discrete output $y(t)$ and input $u(t)$. One of the most commonly used structures for the estimation of systems are the autoregressive models with external input (ARX) (e.g. Frausto et al., 2003; González and Zamarreño, 2005). On the other hand, the development of artificial neural network models (ANN) has proved those methods are capable of recognizing and learning the prediction of temperature with the advantage of being absolutely competent to solve complex problems during the time of requiring the greater precision of the new information (e.g. Smith et al., 2009). In this sense, ANN models can be handling as one of the non-linear or statistical methods with a multivariable