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Trends in Automated Systems Development for Greenhouse Horticulture

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ABSTRACT

This study aims to present recently developed applied approaches for climate control in greenhouses as well as modern trends in algorithm usage. This knowledge has been applied to the optimization of greenhouse operation. Consequently, the quality and quantity of crops have improved and a timed harvest has been made possible. The use of neural networks, genetic algorithms and fuzzy logic control is also discussed. Finally, a proposal for a greenhouse climate control system based on fuzzy logic is presented; the system uses only temperature and relative humidity as inputs.

Key words: Greenhouse, automation, microclimate, control algorithms

OVERVIEW OF HORTICULTURAL GREENHOUSE PRODUCTION

Traditional agriculture in open fields is being replaced by protected cultivation in greenhouses using new automation technologies, due to the high efficiency of this approach. Greenhouse cultivation has great potential for increased food production to meet market demands (Rico-Garcia *et al*., 2009) and provides a source of income in less-developed countries, particularly in rural zones. Greenhouses are facilities specially built to provide favorable microclimates for optimal crop development (Salazar *et al*., 2010). The use of pesticides is also lower than in open fields, improving product safety and quality in addition to increasing the productivity and profitability of horticultural activities.

Traditionally, greenhouse cultivation was carried out manually and included the following responsibilities:

- Preparation of nutrient solutions, taking into account the optimal pH and electric conductivity as well as the correct balance of micro- and macro-nutrients for the crop produced. Concentration measurements were most commonly made with spot meters, increasing the possibility of human error
- Irrigation control was performed through manual manipulation (i.e., turning the pumps ON and OFF). Normally, the length and volume of the irrigation were determined by soil tension
- Ventilation to create the optimum microclimate. Temperature and relative humidity were modified by opening and closing side and roof greenhouse windows (Rico-Garcia *et al*., 2008)

Currently, in high-technology greenhouses, these activities are controlled using timing, ON/OFF and classic control as Proportional Integral Derivative (PID) controllers in separated loops. Normally, the system programming and calibration is based on trial and error without the use of mathematical models and precise control according to crop demands is not possible.

OVERVIEW OF AUTOMATION SYSTEMS FOR GREENHOUSE HORTICULTURAL PRODUCTION

All growing phases of crops can be modified by the control of temperature, relative humidity, light and CO_2 in order to provide optimal conditions for growth, floration, fruit ripeness and crop health until harvest (Van Straten *et al.*, 2010). These factors may be altered by climatic control systems that manage greenhouse actuators such as heaters, coolers, motors for opening and closing windows, pumps and electrovalves.

In most cases, the greenhouse control systems are central computers (Morais *et al.*, 2008) that are connected to sensor sets by data acquisition systems with communications protocols such as RS-232 (Soto-Zarazua *et al.*, 2008), USB, radiofrequency (Duarte-Correa *et al.*, 2008) or ZigBee (Martinez-Ibarra *et al.*, 2009). The data collected are recorded in text files and daily log files of variable measurements and actions taken are generated. Computers use graphical user interfaces to display these measurements (Ramirez-Rodriguez *et al.*, 2008).

A new trend in automation systems relates to the application of algorithms that control decisions based on environmental data collected by the sensors inside the greenhouse. These algorithms have the capacity to make optimal decisions and thus generate better environmental conditions according to the crop requirements, increasing quality and production. Currently, the major control algorithms used for greenhouse operation are timing, ON-OFF and PID. In the last several years, various strategies and intelligent control techniques have been proposed for greenhouse automation, some of which are related to models of neuronal networks (Salazar *et al.*, 2010; Ferreira *et al.*, 2002), fuzzy logic control (Lafont and Balmat, 2002, 2004; Castaneda-Miranda *et al.*, 2006), genetic algorithms (Guzman-Cruz *et al.*, 2009) predictive control (Pinon *et al.*, 2000; Coelho *et al.*, 2005), optimal control (Pohlheim and Heissner, 1997), adaptive control (Arvantis *et al.*, 2000) and robust control (Bennis *et al.*, 2005).

Timing control: Timing control was the first system applied in greenhouses to manage actuators including irrigation pumps, motors for opening and closing windows, heaters, coolers and foggers. This system uses timers that are programmed by the greenhouse grower.

- **Advantages:** Does not require sensors to carry out programming
- **Disadvantages:** Requires extensive knowledge of crops and weather conditions (which are not totally predictable) to operate efficiently. Lacks feedback from the crop and could damage the crop if programmed incorrectly. Require continuous supervision by the grower in order to maintain acceptable conditions for crop growth and health

ON/OFF control: The ON/OFF control is the simplest form to control with feedback. The purpose is to keep a given variable within certain limits or to change it according to a predetermined program. The mathematical description of an ideal ON/OFF controller is presented in Eq. 1:

$$U(s)\begin{vmatrix} U\max \text{ if } e > 0 \\ U\min \text{ if } e < 0 \end{vmatrix} \quad (1)$$

where, U(s) is the control variable, U max and U min are the maximum and minimum limits of the control operation, respectively and e represents the error.

The ON/OFF controller is currently the most frequently used controller in greenhouse automation; it is based on cause and effect in independent loops. For example, a humidity sensor reading below the allowed value (cause) might turn ON the nebulizer system (effect) to increase the relative humidity to an acceptable level (or vice versa).

- **Advantages:** It maintains climatic conditions within the acceptable ranges for a particular crop, is easy to install and adjust, is reliable and inexpensive
- **Disadvantage:** It creates many conflicts with control variables due to the interrelation between variables such as temperature, relative humidity and CO_2 and generates continuous oscillation in these variables

Classic control PID: The classic control can be applied to improve the management of the ON-OFF control technique. This type of control not only responds to high or low levels of the control variables but also takes into account a set point. However, the application of PID control to climate control inside the greenhouse presents various inconveniences due to the requirements for its implementation. The system is controlled by a transfer function that describes the system behavior, but also considers the interactions among all variables. Thus, the possibility of integrating classic controls for climate control is reduced. The main applications of classic controllers are related to the preparation of nutritive solutions in order to provide a precise dose during irrigation. Figure 1 is the schematic diagram of a PID controller. The components of the controller include the reference input R(s) which represents the set point value of the control variable given by the user, the feedback H(*s*) and the error obtained with Eq. 2.

$$E(s) = R(s) - H(s) \quad (2)$$

U(s) represents the controller output obtained using the mathematical representation of a general PID controller as shown in Eq. 3, the control plant G(s) and the output Y(s).

$$U(s) = K_p + \frac{K_i}{s} + K_d s \quad (3)$$

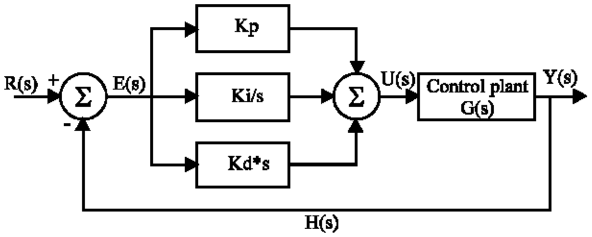

Fig. 1: Block diagram of general PID controller

Artificial Neural Networks (ANN): ANN use mathematical algorithms to mimic the human brain. These algorithms are trained with data sets to yield models that describe the behavior of the variables and finally generate outputs that represent control actions or predictions about certain phenomena (McCulloch and Pitts, 1943). This type of learning algorithm has recently been used to optimize greenhouse operation through the integration of so-called artificial intelligence in controllers development.

Neural networks provide a viable alternative for predictable control that can be widely used for intelligent greenhouse automation. However, their use is limited by computational costs and the large multi-dimensional sets of data that are required for algorithm training (Seginer, 1997). In practice, ANN are only applied to obtain estimation models. Abedi-Koupai *et al.* (2009) estimated plant evapotranspiration in greenhouse crops using a neural network; the inputs consisted of greenhouse sensor measurements of temperature, relative humidity, solar radiation and wind speed. Trejo-Perea *et al.* (2009) presented an analysis of a greenhouse energy consumption predictor with cascade architecture using a multi-layer perceptron artificial neural network trained with a Levenbergh-Marquardt back propagation algorithm. Salazar *et al.* (2010) show the development of a predictive temperature, CO_2 and photosynthesis model with the goal of replacing sensors and generating predictive information for higher quality control of an open loop control system.

Figure 2 shows a typical neural network known as multi-layer perceptron. The network consists of processing neurons (circles); channels of information called interconnections flow between the neurons. The rectangles are neurons that simply store entrances to the network. Each processing neuron has a limited amount of memory and performs a local calculation that transforms the entries in the output. This calculation is known as the activation or transference function of the neuron. Transference functions can be linear or non-linear and consist of algebraic or differential equations. Theoretical details of ANN can be found by Jamshidi (2003).

Genetic algorithms (GA): GA are optimization techniques for complex problem solving when more traditional methods cannot be efficiently applied or produce unsatisfactory solutions. GA are involved in the artificial intelligence called evolutive computation (Dozier *et al.*, 2001). GA are based on Darwin's theory of evolution and mathematical processing functions through software that considers a number of individual algorithms as inputs and determines which of them best

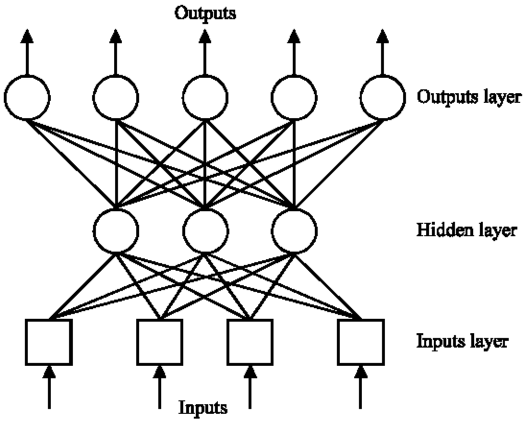

Fig. 2: Perception with three layers: inputs, hidden and outputs

describe the behavior of the given system. These are then modified slightly to generate descendants for the next generation. The process is repeated until a satisfactory result is achieved.

The main advantages of this type of algorithm are that little knowledge is required to solve a specific problem and that they can flexibly adapt to any optimization problem.

The disadvantage is the time required to find the solution, which depends on the population size and the number of generations. However, specialized techniques can improve GA efficiency.

In greenhouses, GA are used to develop optimized models applied to enhance control actions, to contribute to the adaptation of greenhouse controllers in regions with different climates and to calibrate and adapt previously proposed climate models (Hasni *et al.*, 2009; Guzman-Cruz *et al.*, 2009).

Fuzzy Logic Control (FLC): FLC is a powerful mathematical tool used to model non-linear systems and to develop complex controllers (Zhu and Liu, 2004; Kovacic and Bogdan, 2006). FLC is considered when the complexity of a system precludes the application of other modeling techniques. Due to their use of imprecise information, FLC applications tend to generate so-called expert and intelligent systems (Pueyo, 2005; Soto-Zarazua *et al.*, 2005).

FLC has been applied in multiple engineering areas and industrial sectors (Velo *et al.*, 2003; Phillis and Davis, 2008; Mitra *et al.*, 2008; Nair *et al.*, 2009) including bioprocess, greenhouse climate control and automatic feeders for aquaculture (Bonissone, 1997; Horiuchi, 2002; Lafont and Balmat, 2002; Soto-Zarazua *et al.*, 2010). The most recent implementations of these systems have been developed for modern low-cost platforms for embedded systems based on Digital Signal Processing (DSP) standards (Baturone *et al.*, 2005) and Field Programmable Gate Arrays (FPGA) (Castaneda-Miranda *et al.*, 2006). Theoretical details of FLC design and implementation are presented by Soto-Zarazua *et al.* (2010).

Due to its powerful mathematical foundation, FLC is a viable alternative for climate controller development that can be implemented through low cost technologies (e.g., microcontrollers and FPGA).

Finally, a general proposal for a FLC system for temperature and relative humidity (inputs) control for greenhouse is presented. The outputs are the opening and closing of windows and the operation of foggers (0-100%).

Table 1: Real inputs and outputs converted in linguistic values

	Relative Humidity	Foggers	Windows position
Temperature (°C)	(%)		
16 (TL, low temperature)	60 (low relative humidity)	0 (FC, fogger close)	0 (WC, window close)
28 (TO, optimal temperature)	70 (optimal relative humidity)	50 (FM, fogger mean)	50 (WM, window mean)
30 (TH, high temperature)	80 (high relative humidity)	100 (FO, fogger open)	100 (WO, window open)

Table 2: Rules base proposed for the FLC controller

	RHL		RHO		RHH	
TL	WC	FC	WC	FC	WO	FC
TO	WC	FC	WC	FC	WM	FC
TH	WO	FO	WO	FC	WC	FC

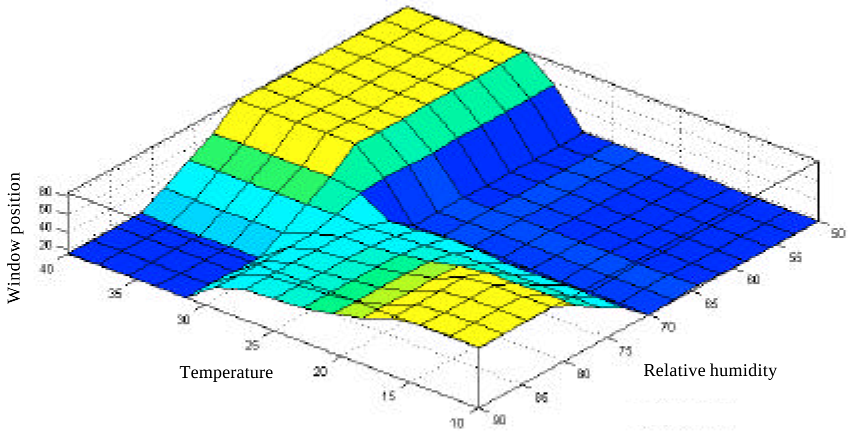

Fig. 3: Behavior of windows position by the effect of the FLC application

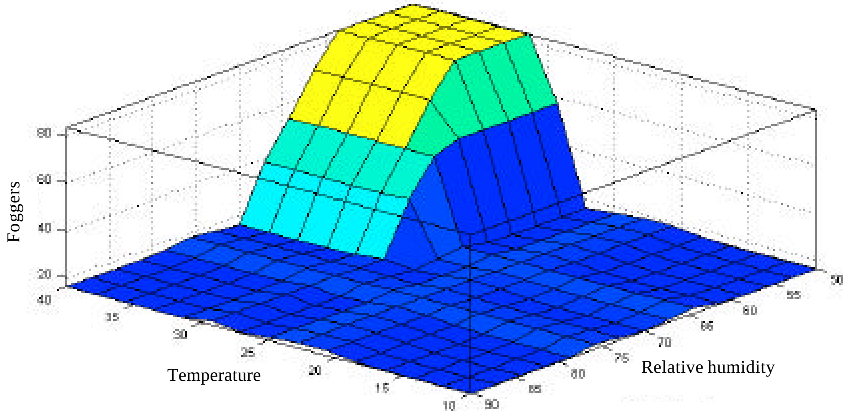

Fig. 4: Behavior of foggers activity by the effect of the FLC application

The actual values of inputs and outputs converted in linguistic values to construct the fuzzy sets are presented in Table 1. The rule base Table 2 was integrated using the knowledge of an expert in greenhouse production. The system was simulated using the software Matlab 6.0. Figure 3 and 4 show the controller behavior used to maintain the desired condition inside the greenhouse.

CONCLUSIONS

Greenhouse automation demands new approaches to implement in new systems for greenhouse operation. All techniques must be feasible for implementing in products for the end users, i.e., the greenhouse growers.

Independent of the involved technique (timing, ON/OFF, classic control or artificial intelligence algorithms), the system must be functional, user-friendly (easy to use) and inexpensive.

Greenhouse automation development also requires the development of models and control strategies that can be implemented with low cost technologies such as microcontrollers and FPGA, that allows the grower to configure the system themselves. Because of this, we suggest that Fuzzy Logic Controls be applied.

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