International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 1 (2017) pp. 62-67

Advances, Processes Today, Methods of Control and Automation of Greenhouses for Crops

Diego Fernando Baquero Hernández, Juan Pablo Espitia Alba and Lilia Edith Aparicio Pico

Faculty of Engineering, University district Francisco José de Caldas, Bogotá, Colombia.

Abstract

This article makes reference to the processes, control methods and automation implemented on greenhouses, designed to generate specific microclimates and improved crop production in general.

A review was made about variables associated with the control of greenhouses, optimal control methods and free control. Studies were made about the wiring communications and wireless that makes possible the interaction of devices, alongside different protocols and communication standards typical of each device. Finally, an analysis was made about the technologies used and tools used more often divided into software tools (programs and applications) and hardware (sensors, processors actuators, computer equipment, robots, etc).

Keyword: Automation, control, greenhouses, software and hardware tools, communication protocols.

INTRODUCTIÓN

Automation is understood as the faculty of autonomy or action to operate alone that possess industrial processes and where production activities are conducted through autonomous actions, and the involvement of human physical strength is minimal and artificial intelligence, maximum [1], using a set of technological features and methods associated with them, such as the classic control (ON-OFF, Proportional P, Proportional-Integral-Derivative PID), fuzzy control, the method of acquisition, monitoring, control of data SCADA and methods of wired and wireless communication, makes its feasible use in greenhouse automation , understood as an agricultural building with a translucent cover, which aims to reproduce or simulate climatic conditions suitable for the growth and development of crop plants established in its interior, with some independence from the external environment [2], to achieve specific conditions of microclimates that protect crops from external inclement as heavy rains, frost, wind, extended summer seasons, among others; using communication technologies with different protocols, software tools and hardware.

The main concerns of growers are in control of the amount of water supplied to crops, the desired relative humidity and the correct amounts of Carbon Dioxide CO2 inside the greenhouse. However, research progress over control of other variables that become important today, as levels of hydrogen potential PH, solar radiation to which must be subjected crops, pests and plant diseases, and even, pruning and harvesting of plants at the end of their growth.

The implementation of an efficient greenhouse, must be designed by the maximum optimization of water resources, energy, space, and time in data collection; therefore, this work is interdisciplinary in finding new and better irrigation techniques, use of alternative energy, new architectural concepts and construction of physical structures of greenhouses [3], using wireless networking platforms that make it possible to know the information in a very short time to make good decisions and achieve low-cost implementations with affordable technological elements and easy to handle.

CONTROL METHODS USED IN GREENHOUSES

Among the known control methods and widely used in greenhouses are the On-Off, Proportional (P), proportional-integral-derivative (PID) and in recent times, are found fuzzy logic systems (FLS) or fuzzy control [4] [5], the intelligent control, artificial intelligence (AI), artificial neural networks (ANNs) [6], control predictive model (MPC) [7] and each of them is chosen according to the needs, budgets and control parameters.

The On / Off control is ideal for variables such as temperature, which is between two specific ranges close to each other, allowing the heaters on and off, sliding skylights and fans that regulate this variable; and irrigation systems, allowing the on-off solenoid valves and pumps [8], for the use of drip irrigation and sprinkler.

This nonlinear control is characterized by having a signal in the output of the controller u(t) and an error signal e(t). The signal u(t) remains at a maximum or minimum value depending on whether the error signal e(t) is positive or negative. This is expressed in equation (1) as:

$$u(t) = \begin{cases} u_1, & para\ e(t) > 0 \\ u_2, & para\ e(t) < 0 \end{cases} \tag{1}$$

Where u_1 y u_2 They are constant and, usually, the minimum value of u_2 is zero o $-u_1$ [9].

The P and PID controls are primarily used individually, even to perform the same tasks of the given above On-Off control, but with better results.

In the proportional control P, the output signal of the controller u(t), is proportional to the error signal e(t). This result is expressed in equation (2) as:

$$u(t) = K_p e(t) \tag{2}$$

Where K_p is considered proportional gain.

And in the PID control, use of proportional, integral and derivative controls together in a single controller is done. In the time domain, this can be seen as:

$$u(t) = K_p e(t) + \frac{K_p}{T_i}\int_0^t e(t)dt + K_p T_d \frac{d}{dt} e(t) \quad (3)$$

Where K_p is the proportional gain, T_i is the integral time and T_d is the derivative time. [9]

Also, these controls are usually part of a fuzzy control system, when there is a considerable number of variables as is the case of thermal balance on the presence of carbon dioxide CO2 in the greenhouse, the balance of latent heat and profits due to heat radiation. This fuzzy control by its nature turns out to be adaptive to any crop, regardless of the environmental variables that controlled, giving the main advantage the design of suitable drivers for each type of crop [10]. As a particular case of this control, that may be mentioned the good results in the decrease in the cracking of tomatoes, 52% to 17%, by controlling the variables of solar radiation and temperature [5].
Currently, are studied and tested other more advanced controls in greenhouses as adaptive control, predictive control, stochastic control, nonlinear control, neural networks etc. [11].

VARIABLES FOR THE CONTROL OF GREENHOUSES

The main concerns of growers are the temperature control, humidity, radiation and recently was included CO2, pH, electrical conductivity, and nutrients.

A. Temperature

In [5], [10], it is evident that this variable is one of the most critical, as is typical in each type of crop to obtain good results. Despite correctly choose the right thermal floor for each particular crop, can't guarantee the ideal temperature and in fact, was one of the main reasons that led to the existence of greenhouses [12], [13], [14].
Having an enclosed space, improved temperature stable conditions but does not guarantee exact ranges. Therefore, for the control of this variable, actuators are used mainly for generating cold and heat, maintaining a unique tolerable range of each crop.

1) Cold generation: Regarding the generation of cold within greenhouses, they are considered three methods: Convection cooling using fans and evaporative cooling. In convection cooling actuators are Sliders ceiling (zenithal windows) and on the side of the greenhouse [3], [5], [10], [15], controlled by servomotors, which allow air circulation fresh into the crop, the hot air escape through the top, being replaced by fresh air from the side windows [16]. In a high-temperature environment, typically desert areas, this condition is used to implement evaporative cooling systems, thus controlling not only the temperature but also the relative humidity of the greenhouse. One of the evaporative cooling systems that offer better results is using cellulose pad as a filter [3], whose main function is to evaporate water and cool the air passing through it. The system fans, allows these actuators be a way of hot air extraction, the most important parameters to take into account are the size, the right amount and location to cover the entire volume inside the greenhouse. In addition, it is also important the strategic location of temperature sensors, to have temperature information closer to the truth and make the best possible control.
2) Heat Generation: Primarily it is necessary in places where the ambient temperature is very low at night or in times of winter. Heat can be generated through hot water, producing water steam from boilers using and distributing along pipes arranged along the greenhouse. The other method is based on hot air generators, where the main actuator is the heater, either gas or diesel [16] and as well in the generation of cold, success lies in the location and amount of heating in the greenhouse and the correct arrangement of temperature sensors for a correct reading of the parameter.
The unit to identify the required heating capacity for greenhouses is given in BTU (British Thermal Unit) and can be determined by equation (4) [17]:

$$BTU = V(〚ft〛 \text{^}2) * 0.133 * T(℃) \quad (4)$$

3) Temperature sensors: Whether the case of temperature sensors thermistor, RTD (temperature resistance detector) [13], or Thermocouple [5], the latter one of the most used, there are many sensors on the market used for temperature measurement. The use of one or another type of sensor is mainly chosen taking into account the signal acquisition module or the thermometer to be used. A specific case is the use of a thermocouple to the thermocouple module NI 9219 to be used in the chassis built by National Instruments 97178 CDAC for data acquisition [19].

B. Humidity

In [2], [12], [13], presents work about control and automation focused on moisture, including terrestrial outside space [18]. When referencing this variable, it is necessary to make clear about two types of moisture present inside the greenhouse. One is the soil moisture and other relative humidity in the air [15], [19].

1) Relative humidity: As the relative humidity RH, can be defined as the relationship between the partial pressure of water steam (P_w) and the saturation pressure of water steam at a particular temperature P_ws [20].

$$\%RH = 100\% * P_w/P_{ws} \quad (5)$$

This is linked in an inverse relationship to ambient temperature so that, if the ambient temperature rises, the relative humidity decreases and if the ambient temperature decreases, the relative humidity increases.
While temperature control inside the greenhouse is made, relative humidity control is also made. This as mentioned in paragraph 3.1.1 of cold generation is achieved through ventilation systems taking advantage of the inverse relationship between temperature and relative humidity
2) Soil moisture: As for the humidity of the soil is concerned, it means the amount of water per volume of

the earth which is present in a terrain. The methods used in greenhouses are sprinkler and drip surface and underground; It is the drip method which requires less water pressure for operation [21]. The main irrigation actuators are the pumps and valves. The pumps are used to supply water to crops, for selection, it is necessary to know the pressure, water flow and NPSH (Net Positive Suction Head) available, being these electric pumps or pumps [22]. The solenoid valves have the function of allowing the passage of water from the mains to the sprinklers or to gifted tubes of drip, functioning in NO (normally open) and NC mode (normally closed). There, on the solenoid valves, which is exerted control, typically ON / OFF, according to the information obtained from soil moisture or times typical watering programmed for each culture.

3) Radiation: This variable is closely linked with the temperature, in particular because solar radiation is essential for the process of photosynthesis in plants and therefore are of particular care exposure times of plants in the sun. As such, its control is linked to the use of sliding curtains, shades poly and plastic materials with the different opacity that greenhouses are built. It is to exalt artificial ways of generating radiation using LED technology (Light Emitting Diode), implemented since 1990. A particular case is evident in the experimental work on the physiology of plants using the LED light within the required parameters of wavelength range (430 nm) and (610 nm) in [23].

C. Other Variables

1) PH, electrical conductivity, and nutrients: With the measurement of pH and electrical conductivity present in the substrate can be corrected nutritional problems in crops, because the values of PH affect the presence of nutrients, especially micronutrients, and the electrical conductivity is a measure of the concentration of dissolved salts in the growth substrate. As methods of measuring pH, are found the method of saturation extract the substrate, the PourThru method and the method of dilution 1: 2 [24]. the Complicated about control of PH, is that this variable is not linear, so stand investigations into the use of neural and fuzzy control to carry out this process [25], [26]. As for nutrient control, soluble fertilizers are combined with water applied to crops, this technique called "fertigation" getting through drip irrigation, uniform distribution of nutrients to the roots of plants [27], which takes part important knowledge of the electrical conductivity of water for optimal distribution of nutrients.
2) CO2: Because of the importance that take the presence of this compound in the process of photosynthesis in plants, will have controls to increase its quantity inside greenhouses, especially when it is not well ventilated [28], using pressurized tanks with this gas, or the product of the internal combustion diesel engine, making distribution through perforated pipes. The release of an excess of this element inside the greenhouse is made by opening sliding windows in the roof, so it is strongly linked to the temperature control [29].
3) The growth of plants and pests: Thinking about the exact times of crop harvesting, pruning and increased plant pest within greenhouses, have been taken into account two new variables of growth of both plants and pests. This it was thought for the implementation of algorithms capable of performing a measurement of plant growth and pest present [30]. It as a particular case to assess the growth of the plant, the implementation of the detection algorithm based on the Radial transformed Hough for identifying outbreaks in chrysanthemum in order to guide a robot arm in selective pruning of the plant [31] and as particular cases control pest growth, implementation of segmentation algorithms using digital image processing following conversion steps RGB color format chrominance components and luminance, Calculation of entropy, noise Reduction and counting of pest, in particular, amount of flies present in the leaf [32], [33] [34]

COMMUNICATION TECHNOLOGIES AND PROTOCOLS USED IN GREENHOUSE CONTROL AND AUTOMATION

Currently, the trend is given to reduce communication processes still performed by using physical connections (reducing their use to very small greenhouses and local systems ETHERNET) and increasingly implemented the wireless communication systems that enable management automation remotely crop and greater coverage of surface area without the problems of data loss occur in long distances own wired networks and physical wear of the cables inside the greenhouse.

A. WSN: sensor networks

They proved to be efficient when it comes to cover large physical areas, despite not having a big range. This is due to the same networking topology that enables great coverage; are becoming ever cheaper, low consumption and multifunctional; so enabling particularly high accuracy measurements on their own variables to be measured within greenhouses [35]. Sensor networks need the Wi-Fi technology so that it can be interconnected, therefore, should have different points of Wi-Fi access, and for other purposes such as access to internet and web services (World Wide Web) [3], [36], [37] and therefore the location of the information in the cloud for later reference remotely and implementation in this field of Internet of things [38]

B. Ethernet

Despite advanced developments with other local connections like USB, ETHERNET is still present as standard for connecting devices to local area, especially when it has existence of one or more computer equipment connected to programmable logic controllers PLC [36] or a different data acquisition modules DAQ that still perform their connections in this way, for displaying measurement parameters and the programming of the controller; as well as serving as a platform for connecting devices that serve as ETHERNET links (Ethernet Gateway) [39].

C. GSM/GPRS

The mobile communication technologies GSM / GPRS (Global System for Mobile Communications or GSM and General Packet Radio Service) and RF radio frequency, have also been implemented to achieve sending information of variables measured in greenhouses in order to create monitoring systems remote thereof, including from smartphones with the appropriate application for it. The operation of these technologies involves the creation of a central station and a base station. the central station is available a server with an appropriate software, the GSM module, and a database. In the base station, it has a microcontroller, sensors, and GSM [40] module. There have also been combined with designs of radiofrequency RF communication, to monitor sensor nodes. About the GSM modules used for this purpose, we can cite as particular cases the use of TC35 module SIEMENS with RS-232 [40] connection module Huawei GSM / GPRS GTM900 [14] and the module produced by SIMCOM SIM900B [41].Zigbee

This wireless communication standard is of special attention because of their approach to the Internet of things in areas of consumer, commercial and industrial [42]. its use is favorable inside greenhouses by their orientation towards domotic [43], with the variety of having instead of a house, a greenhouse, while retaining use towards automation, accessibility, security, energy management and communication between the user and the controlled system, through devices such as smartphones, tablets, and computers in general [44]. Defined under the IEEE802.15.4 standard, there are several work modules used in different jobs using this standard [45], either as a form of communication to control all parameters in general, where the XBee-PRO module was used [39] for control of an exclusive parameter as measuring CO_2 levels with the development kit ZigBee CC2530 Texas Instruments [46] or for combined use with sensors networks WSN with a Zigbee module of DIGI Company [43]. As positive aspects are highlighted for easy implementation, for be wireless and has a stable performance [46] and as a drawback, some communication delays that are part of future improvements of the research presented [43]

TOOLS

Either from the field of research, simulation or implementation of physical automation systems, there is needed a few software tools that facilitate this work. One of the most used systems is the SCADA (Supervisory Control And Data Acquisition), is one of the most completed and provide user-machine interaction by encouraging decision making and feedback control. One of the SCADA type software, most used is LabVIEW (Laboratory Virtual Instrument Engineering Workbench), produced by National Instrument as a graphical programming language for system design of data acquisition, instrumentation and control, allowing design user interfaces by interactive console based on software [47]. its use is evident in the analysis of the size of seedlings, in tomato crops for grafting by a robot, using LabVIEW version 7.0 [48], in acquisition and control temperature and humidity in a model-free control in the implementation of a fully automated greenhouse, in order to achieve an autonomous system for any user, regardless of whether this is a beginner and do not have technical knowledge.

Another important software used in automation and control of greenhouses is MatLab (Matrix Laboratory), which offers possibilities in the design of different control systems. As particular cases, they have image processing from pictures taken at plants with version 7.1 of this software [32], the modeling and simulation of a solar heating system [15] programming neural networks [12] image processing for the development of positioning a robot inside the greenhouse [30] and simulation of a solar hybrid system for greenhouses [15]. In some particular uses is also used Visual Basic 6.0 as programming of mobile communications [40] and capture and image analysis [50]. And when it comes to acquiring spectra of light using LED technology, SpectraSuite is a good choice [23].

Concerning hardware, actuators and sensors used, it is interesting to mention some elements that are also part of the automation process as the PLC with communication protocol Profinet [8], [36], microprocessors [14], [41], computer equipment with processing speeds between 2.4GHz up to 3.06GHz [19], [30], LCD (liquid crystal display) monitors, as a special case teleoperation systems in watermelon crops [51], the use of LED (Light Emitting Diode), [23] [48], cameras and video as guide of a robot inside the greenhouse for pruning and harvesting [52].

CONCLUSIONS

Currently in the control methods used in greenhouse automation, we found that the ON-OFF, PI, PID, classical control systems work efficiently in small crops, given few control variables for characterization. But when the greenhouses grow and include many variables, the best control methods are in adaptive control, predictive control, stochastic control, nonlinear control and the use of neural networks.

The main variables to be controlled within a greenhouse are temperature, humidity, and radiation. For best results in the growth of crops, technically sophisticated greenhouses have control over variables such as pH, electrical conductivity, nutrients, CO_2, plant size and pest detection.

In the process of automation of greenhouses, it has needed to cover large areas and has access to measurement data obtained via sensors networks WSN located along the crop. To do this, the implementation of wireless communication systems has accommodated the use of technologies such as GSM / GPRS, Zigbee and the use of internet and hosting of information in the cloud for consultation and decision making remotely.

Finally, in the effort to obtain crops of good quality in automated greenhouses, emulating specific microclimates, also achieved significant benefits for the environment, which are evident in lower water consumption, control and proper use of greenhouse gases, better utilization of the compound and nutrients, the necessary supply of fungicides in controlling pests which relent the damage of the earth.

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