# AUTOMATIC CONTROL AND ROBOTICS FOR GREENHOUSES: A REVIEW ON HEATING TECHNOLOGIES

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**Abstract:** The use of technologies in greenhouses, with plants growing in soil or hydroponic way, continuously evolves by the use of different computational resources. This paper presents a review about the use of technologies for automated activities in greenhouses. The analysis of the works cited demonstrated the increasing use of wireless communication technologies coupled to sensors, particularly for the control of climatic variables. Related to the use of robotic features for greenhouses, it was detected a strong demand for applying them, mainly in fruit pick and plants feature extraction using images.

**Keywords:** Automation; Robotics; greenhouses.

## 1. INTRODUCTION

With the advancement of technology and looking for better quality and food production, the use of automatic features for controlling and monitoring cultures has become increasingly important, even in greenhouses.

According to Teruel (2010), greenhouses can be defined not only as a covering and housed artificially structure for different types of plants and crops by protecting them against external weather agents, but also as a controlled environment in which plant growth depends on factors such as water, lighting, fertilizers, oxygen and carbon dioxide.

Crops in greenhouses are widely adopted to markets, linking the use of high-tech products with high additive values, keeping the growth of planting for quality control and not being affected by the weather, insects or diseases (Yang et al. 2013).

In recent years the use of robotics in greenhouses has significantly increased, mainly for harvest and visual analysis of fruit features. The aim of this study was to conduct a literature review about the use of automation, control and robotics technology in greenhouses, focusing on their use for automated activities, bringing work of recent years providing advancement and contribution to the scientific society.

Automation can occur since the control of simple tasks such as brightness, to automation of complex systems, evolving to robotic application. Thus, the review presented in this paper focuses the automated control in section 2, automated systems in section 3, the application of robotics mainly in greenhouses in section 4 and, finally, section 5 shows the final considerations.

## 2. AUTOMATED CONTROL

Automated control can be used for production controls in several areas of knowledge. According to Silva et al. (2007), since human beings are prone to errors due to fatigue or distraction while developing a particular activity, the use of automated control aims to monitoring and controlling the operation of a physical system in a safe, fast and automatic way,. There are several examples of automated systems with different complexity degrees. However, all of them have several things in common, that characterize them.

Automation in agricultural environments is becoming more popular and has generated great advances in control indoors as it allows fast and reliable data acquisition, contributing to streamline decision making (Jansen et al., 2010).

One of the application of automation and control in agriculture is the automatic irrigation. Romero et al. (2012) state that measures of soil, plant and atmosphere variables, related to water plant condition, can provide information of consequences of previous actions helping to calculate the frequency and duration of irrigation. Thus, it can be noted that automation systems require a predetermined parameter to evaluate the current state of the environment. According to Teruel (2010), those parameters can be obtained from sensors that measure characteristics of the site such as temperature, relative humidity, sun radiation, CO2 concentration, ventilation, etc.

A greenhouse can have different kinds of automation. So, the need for parameters control such as light intensity, environment temperature, nutrient solution temperature in reservoir and in planting rows, electrical conductivity number of water replacements in reservoir, nutrient solution pH in reservoir and in planting rows. The monitoring data can be stored on disks using manager software on a computer (TERUEL, 2010).

The application of automated controls in greenhouses can provide advantages for the development of production in various aspects: better control, being more accurate and reliable; reduction of manpower, fewer people working, reducing the flow of diseases; optimizing the consumption of electricity and improving the quality of the product (Domingues et al., 2012).

In order to control the environment of a greenhouse, can be found in various literatures, as set out by Silva et al. (2007), Teruel (2010) and Attar et al. (2013), the use of technologies and methodologies for monitoring climatic variables, since they are directly related to the quality and yield of plants. According to Yang et al. (2013), the three most important physical quantities to control in the internal environment of a greenhouse are temperature, relative humidity and light.

In the study of Yang et. al. (2013), it was developed a system consisting of an intelligent air conditioning with temperature and humidity wireless sensors, comprising a module using fuzzy methodology, responsible for controlling and calculating the values of these variables. Results were obtained with good performance related to air conditioning features as heating, cooling and dehumidification.

Beyond the control of climate variables in a greenhouse, there is also concern about the use of renewable energy sources. Attar et al. (2013) developed and evaluated a system for control temperature in greenhouse using sun energy. Three different studies, theoretical, economic and practical were performed. The theoretical study aimed to determine the best way to capture sun energy and also define a formula to calculate the heating level required to maintain the temperature. In the economic study it was verified the cost of each component of the system and sun gain. Finally, the practical study evaluated the effectiveness of the system proposed according to the calculated losses and alternative systems that use electricity or fuel. The results of these studies were promising, but proved to be necessary to evaluate possible additions using secondary energy sources.

## 3. AUTOMATIC SYSTEMS

The application of automatic systems can contribute to agriculture for improving quality, reducing losses, increasing productivity, reducing costs and reducing time for return on investment, planning and making decision, as well as, in reducing the impact to the environment, making easier the work and increasing the quality of life of producer, in order to become more competitive (TERUEL, 2010).

Automated systems have the principle of control, using software and hardware, programming and logic controllers, as well as various types of sensor devices and actuators that must work together in a robust way to process data in real time. However it is essential detailed planning and monitoring of subject experts to apply a skilled labor for installation and testing.

One of the factors that usually influence in decision making when agricultural automated systems are considered is related to the availability of sensors and actuators that meet the needs of the project and maintain the cost benefit ratio in acceptable limits.

Currently, issues related to reducing the environmental impact , the quality and efficient production are leading the greenhouses to the path of precision agriculture (EMMI et al., 2013). According to these authors, precision agriculture is the management of agricultural automated systems, using resources such as production mapping, decision support tools and localized application of agricultural inputs. The use of this technology allows investment in areas where the production potential is more effective, ensuring greater economic and ecological return.

## 4. APPLICATION ROBOTICS

In recent years, technologies for greenhouses obtained many improvements, such as improvement in the structure, irrigation, fertilization and climate control systems. However, many tasks in greenhouses crops are still carried out manually, such as harvesting, pruning and application of plant protection products (HERMOSILLA et al., 2013). In this context, multidisciplinary and technological advances which now involve new agricultural practices open the opportunity for inclusion of autonomous systems in the field. This in turn should be construed as an aid tool that will compose and improve the management system and not as an isolated and immediate solution.

Suprem et al. (2012) explain that farmers have sought to take intelligent machines in their fields to facilitate manual work, reducing costs with labor, giving speed to the process of agricultural activities. The application of robotics can not only increase productivity but also provide quality content, enabling better control over the environmental implications. Despite these aspects, various agricultural tasks are still being done manually, which becomes tedious, according to Arefi and Motlagh (2013), challenging the strength of the agricultural work and lengthy operations that are still too sophisticated for current robotic systems.

The research developments for robotic applications can be realized in small and large machines, with projects based on robotic manipulators. Most large machines have the purpose of being used in open fields, and they are not suitable for applications in the greenhouse. The applications of robotic systems in controlled environments are growing, because they improve productivity, supply the manpower shortage, have feasible projects and are easy to handle (SUPREM et al., 2012).

The development of robotic projects usually involves activities such as mechanical design, implementation of robust control architecture and embedded technology and its integration with communication systems and computing platform. In addition to its mechanical structure needed for the specific application, the integration of sensors and control automation system is a challenge because of the complex combination of hardware and software (SUPREM et al., 2012).

According to Martinovic and Simon (2014), the use of mobile robots is an important area of current research, having research applications and scientific practices. In this context a literature review regarding the recent development work and application of robotics in greenhouses with different methodologies and applications is presented below (Figure 1).

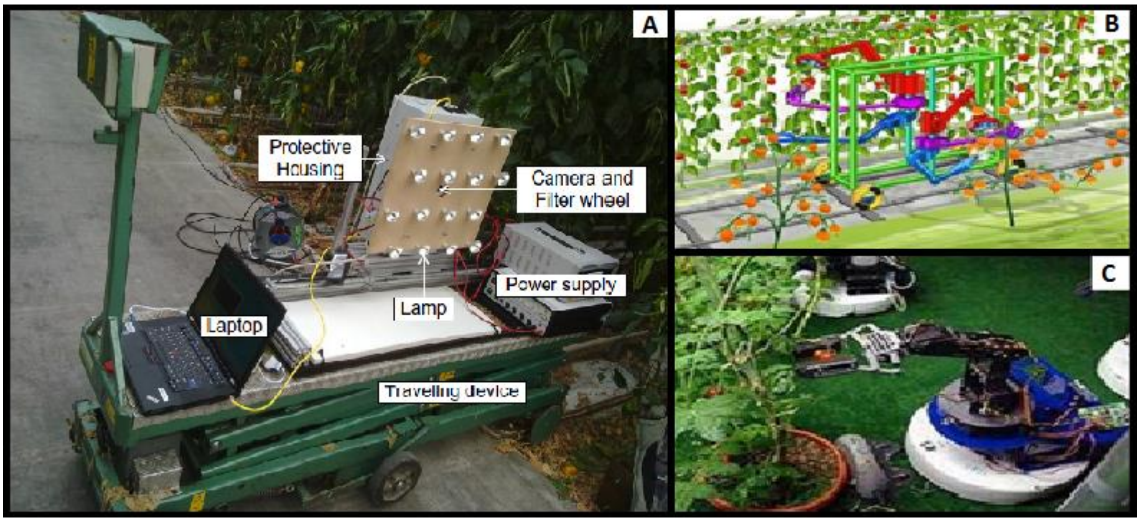


**Figure1. Robotic applications in greenhouses. a) extraction of vegetation characteristics (BAC et al., 2013), b) intelligent robot to select and pick fruit (CROPSROBOTS, 2014), c) robot for tomato crop (Nezhad et al., 2011)**

Qingchun et al. (2012) developed an autonomous robot to pick strawberries in greenhouses. It has been described a modular concept of a mechanical arm with a gripper configured to make the cut appropriate to practice strawberry gardening. The accuracy of the robot shown to be sufficient to strawberry harvest. Obtained a 86% utilization from a test in a greenhouse with 100 strawberries at different levels of maturity, where the robot was able to successfully collect 86 strawberries. The robotic platform has a 3D vision camera with 1024 x 768 pixels and focal lengths from 6mm to locate the strawberries. Furthermore, the platform is incorporated into a digital image processing algorithm for strawberry cut planning. During processing, the image is captured in RGB (Red Green Blue) and converted to the format HSI (Hue Saturation Intensity). Using values of the bands H and S is determining a threshold for image segmentation, describing the fruit of the plant leaves. It ignored the value of the band I in the light level in the greenhouse does not influence the result. With the defined threshold is generated a binary image and the size difference and the target circularity are eliminated noise image and the fruit is identified effectively. Finally, with the binary image containing only the fruits are performed calculations to determine the center of the fruit, and through this value the harvest is performed.

Nezhad et al. (2011), created a robot prototype able to harvest tomatoes in a greenhouse (Figure 1 - C). The prototype consists of a detection unit and an integrated hand with a robotic manipulator. The sensing unit, or robotic eye, scans the tomato plant and determines the number and position of red fruits. This information is needed to move the robot hand based on the direction of the fruit. Then, fingers are positioned around the tomato and a twisting motion is applied to remove it. An ultrasonic sensor emits and receives sound waves and based on the length of time that propagation of the robot calculates the distance to the target object. At hand of the robotic arm is used, a servo motor, which consists of an electronic control circuit and a motor capable of positioning its axis at a specific angle. For detection of the fruit, it has developed a unit comprising a digital image processing algorithm using the OpenCV library (Opencv, 2014), can be used for the detection of other fruits. According to the survey, the advantages of the robot consist of not getting lost in the sample taken, able to reap in a larger area with less time and without any fatigue and impairment of work compared to humans.

A survey conducted by Bac et. al (2014), aimed at developing a sweet pepper robotic harvester. The robot base is composed of a carrier platform and a robotic arm, which captures and cuts the fruit, similar to Figure 1 (A). The harvester also has an electrical control consists of computers and sensors for fruits and obstacle detection. They were discussed different concepts for obstacle detection, determination of maturity and location, as well as specific concepts for the extraction of fruits. The location of the ripe fruit occurs in two distinct stages. At first, the image is obtained from the side of the canopy and is taken by a color camera. Images from two cameras were obtained to have complete information about the color combined with 3D data to avoid collisions with fruit stem. After the arm is positioned in front of the target fruit is used a common camera and 3D camera in an integrated robotic hand to calculate the position result with high accuracy. The obstacle detection algorithm attended to within 1 cm in laboratory conditions, but in greenhouse accuracy was 4.5 cm. Thus, the authors propose the search for other solutions as future work.

The multispectral images when related to the physiological status of plants, provide essential information for the development of remote sensing algorithms oriented plants. It can be managed needs of the specific location of the cultivation of these plants, like watering and nutrient management (Yang et al., 2014). A multifunctional remote sensing system based on spectral imaging and environmental sensors to produce seedlings in the greenhouse is presented by Yang et al. (2014). As a result, the irrigation of plants criteria was determined from images obtained through indices and other environmental factors such as temperature, humidity and light intensity. It was concluded that the multispectral image analysis system in greenhouses improved management and cultivation. The study also explored the applications of radio frequency identification system (RFID) to build a traceability system for the production of seedlings in the greenhouse.

The cost for the development of an application or platform using robotics may be high, being directly related to the technologies and / or methodologies used. There are some tools that can be used for robot simulation, and with these simulators (Table 1) can be developed prototypes of robotic projects applied in greenhouses.

**Table 1.Tools currently used for robot simulation.
Adapted from Emmi et al. (2013)**

| Simulator | Description |
|---|---|
| Gazebo | 3D multi-robot simulator with dynamics, capable of simulating articulated robots in complex and realistic environments (VAUGHAN et al., 2003). |
| Simbad | 3D java robot simulator for studies in AI located and machine learning (AI algorithms) in the context of robotics and autonomous agents (HUGUES And BREDECHE, 2006). |
| Microsoft Robotics Developer Studio | Virtual simulation environment that allows users to develop robots in a rich virtual environment with realistic physics and rendering state of the art (JOHNS AND TAYLOR, 2008). |
| Robot studio, ROS | Open Source, meta-operating system for robots. It provides features such as hardware abstraction, low-level device control, implementation of commonly used functionality, message between processes and management packages (ROS, 2012). |
| Webots | Development environment used to model, program and simulate mobile robots. The user can design complex features for one or more robots similar or different, in a shared environment (CYBERBOTICS, 2012). |

## 5. FINAL CONSIDERATIONS

For the control and monitoring of climate variables in greenhouses, the increasing use of wireless sensors coupled with communication technologies can be highlighted. This occurs because of the ease of disposal of these components, plus the ability to increase the amount of sensors without having to make changes in the infrastructure. The disadvantage of this method is the need to provide separate power sources for each sensor module. Thus, it is necessary to carry out other specific studies relating to energy consumption which is proportional to the types of sensors used and especially communication technology.

The use of robotic features in greenhouses has wide application, mainly in fruit picking and extraction of plant characteristics through images. There are works where robotics is used for irrigation and application of inputs, but this kind of activity is commonly performed by physical structures, due to cost and ease of use.

The cultivation in greenhouses is extremely important, especially for plants more sensitive to disease and climatic variables or high additive value. With the technology advancement and the need for increased food production, it becomes increasingly important the use of automatic controls methods aiming to obtain higher yields and quality in plant cultivation.

This paper presented several studies using different technologies and methodologies aimed at controlling and performing independent tasks in greenhouses and can be used as a reference for knowledge of the current state of this area.

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