Development of an intelligent indoor environment and energy management system for greenhouses using a fuzzy logic controller and LonWorks® protocol

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ABSTRACT

This paper presents an indoor environment and energy management system for microclimate control of greenhouses. Two fuzzy logic controllers, where expert knowledge of the agriculturists and growersis emdedded, are developed. These controllers consist of a fuzzy P (Proportional) and a PD (Proportional-Derivative). The monitored variables are the greenhouse's indoor illuminance, indoor temperature, relative humidity, CO_2 concentration and the outside temperature. Moreover, necessary meteorological data are collected from a meteorological mast. The actuators of the system are the heating units, motor-controlled windows, motor controlled shading curtains, artificial lighting, CO_2 enrichment bottles and water fogging valves. The fuzzy controllers' aim is to obtain the best possible indoor conditions for any cultivation (set-points). The platform used is the LonWorks™ platform. The controllers were prototyped in Matlab™ and were interconnected into the system as a separate node by taking the advantages of the LonWorks protocol. The system is installed in a greenhouse located in the Mediterranean Agronomic Institute of Chania, Greece (MAICh).

1. INTRODUCTION

The energy efficiency nowadays is a critical matter that has lead to recent design trends of automation platforms and protocols. Energy efficiency in greenhouses is also critical as the energy consumption in such structures is significant, especially in cold climates. The most important thing is to balance the use of the appropriate actuators with the desired microclimate result. Furthermore it is very important to design a simple but quite efficient system that with low cost can be used in any cultivation. This system uses the most common actuators in order to control the environmental variables (above ground) that influence the plant's growth, i.e. relative humidity, luminance, temperature and CO_2 concentration.

2. THE FUZZY CONTROLLER

The fuzzy controller is separated in two controllers for design and presentation simplicity (Saridakis et al., 2005; Lafont et al., 2002). The first fuzzy controller (FLC-1) (Fig. 1) is P (Proportional) and PD (Proportional - Derivative) depending on the input. The FLC-1 aims to control the CO_2 concentration and the radiation inside any greenhouse using actuators such us: CO_2 enrichment bottles, shading curtains and artificial lighting. The inputs of the fuzzy controller are the CO_2 Δerror, CO_2 error and luminance error. In the set points are placed the de-

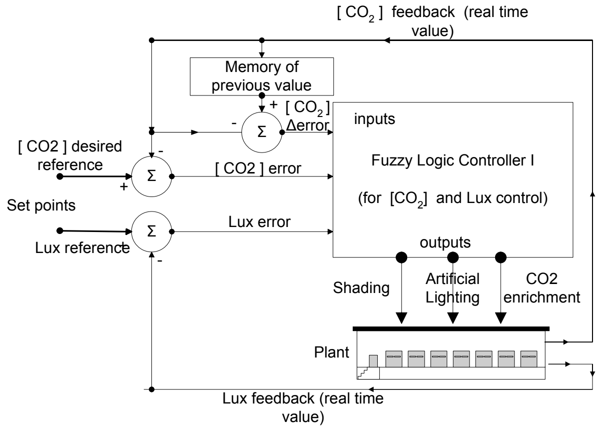

Figure 1: The FLC-1.

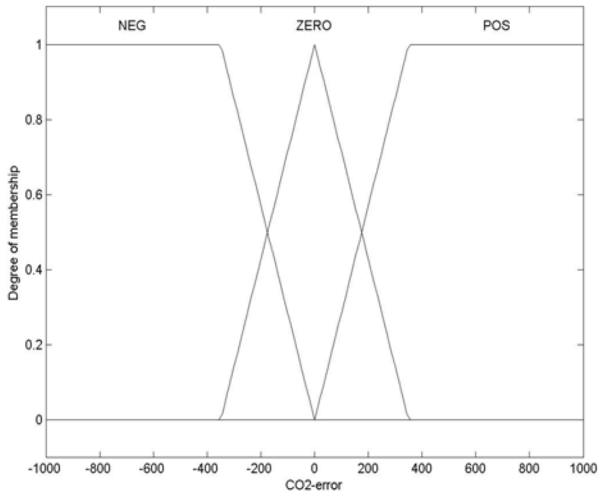

Figure 2: The membership functions for CO_2 error.

sired values of the CO_2 concentration and the luminance, in order to achieve these values into the greenhouse.

Indicatively, for the CO_2 error and the CO_2 change of error are used three triangular membership functions with the N (Negative), ZE (Zero), P (Positive) names. When an input value enters the Negative region for the error axis (Fig. 2), it means that this value is above the set point.

In correspondence in Δerror axis, a value in a Negative region (NEG) means that there is an increase (Fig. 3).

The output for controlling the CO_2 concentration consists of four membership functions and controls the enrichment bottles flow (Fig. 4).

The second fuzzy controller (FLC-2) (Fig. 5) has the same structure with the first one (Saridakis et al., 2005). It consists of one P and one PD part. The FLC-2 tries to obtain the desired temperature and the humidity in the interior of the greenhouse using automations as heaters, windows and water-fogging units. In the set points can be inserted the desired references that a grower wants for certain cultivations. The internal temperature, the relative humidity can be set through these set-points.

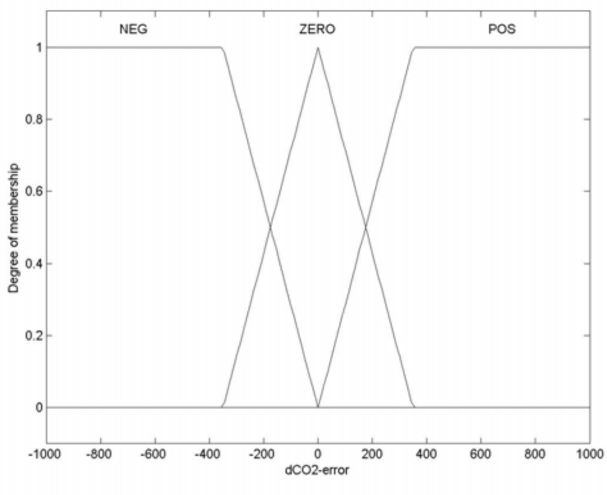

Figure 3: The membership functions for CO_2 Δerror.

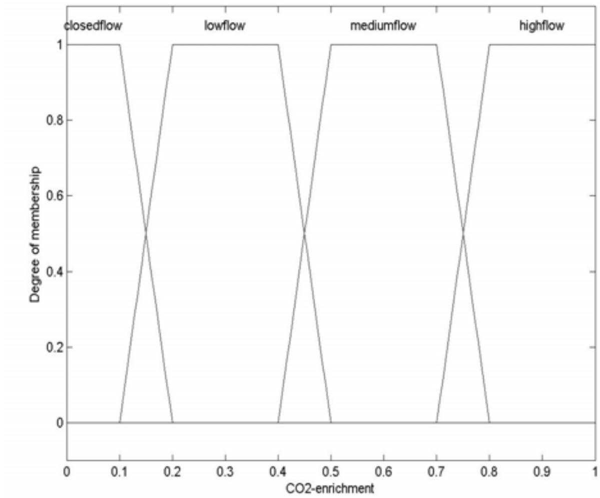

Figure 4: The membership functions for the CO_2 enrichment output.

The inputs of the controller are the internal temperature error (Tin error), the temperature change of the error (Tin Δerror), the outside temperature (Tout) and the RH error. In order to create the rule base for both of the controllers (Saridakis et al 2005) a wide literature was studied (Arbel et al., 1999; Arbel et al., 2003; Al faraj et al., 2001; Baille et al., 2001; Chou et al., 2004; Gates et al., 2001; Goggos et al., 2000; Katsoulas et al., 2000; Korner et al., 2004; La-

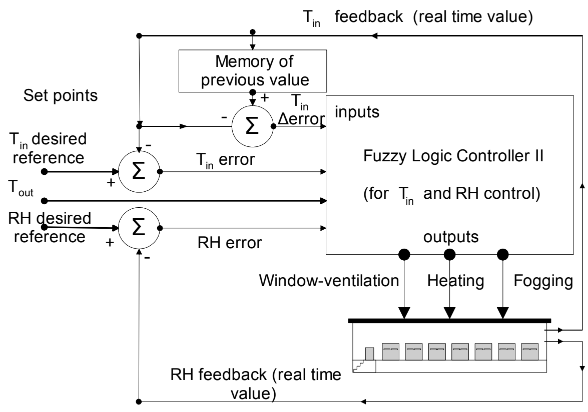

Figure 5: The FLC-2.

font et al., 2002; Mavrogiannopoulos, 2000; Morimoto et al., 2003; Parra et al., 2004; Santamouris 1999).

3. THE INSTALLATION OF THE SYSTEM

3.1 Description of the installation

A greenhouse located in the Mediterranean Agronomic Institute of Chania (MAICh) has been chosen to install and test the fuzzy logic controller using the LonWorks automation protocol. The controller is embedded into a separate LON node. In the node controller, the neuron chip and the flash memory holds the application (fuzzy logic controller) that was developed. (Neuron chip data book 1995). The application is programmed in neuron C, a special C language that is released from Echelon in order to program the neuron chips and it is based on ANSI C. (Neuron C programmer's guide 1997) Two software platforms are used; the LonMaker Integration Tool™ and the NodeBuilder™ development tool. The LonMaker tool is essential for configuring the devices (nodes) by setting the necessary Network Variables (NVs) and the Configuration Properties (CPs) (LonMaker™ user's guide Release 3.1 1997). The NodeBuilder tool is used to develop applications in Neuron C language, in order to export them to the LonMaker. (Nodebuilder™ user's guide. Release 3.1 1997). The hardware that used for the fuzzy controller node is a control module, which includes the neuron chip, the transceiver, and the extra flash memory. The finalized Lonworks network consists of the fuzzy controller node, the analog inputs devices, the sensors, the digital outputs and the actuators. The whole network is decentralized because there is no necessity for a central processing unit (e.g. PC) as each device has the necessary application parameters embedded in the neuron chip. In addition an i-Lon server is installed in the LonWorks network. This Internet server offers streamlined monitoring and control of all control networks and devices. It can access devices from a local network, a virtual private network, or the Internet in order to manage, monitor and collect the necessary data. The transmission media of the installation is twisted pair.The packets can be addressed to a single device, to a group of devices, or to all devices.

In the greenhouse installation (Fig. 6), the fuzzy logic controller is connected directly to the LON (twisted pair) channel. Additionally, the outside temperature sensor and the 3-in-1 combo sensor (of CO_2 concentration, relative humidity and temperature) are connected to the LON channel. The illuminance sensor, which is a 0-10Volt sensor is connected to a LonWorks AI-10 device. The LonWorks AI-10 device is used to interpret the analogue signals (Voltage or current) from sensors that are not LonWorks protocol standardized. Furthermore three digital outputs (DO-10) are also connected directly to the channel in order to activate the appropriate actuators.

3.2 The fuzzy node of the installation

The Fuzzy controller hardware that is used consists of two control modules. Each control module has a Neuron chip which is its most important part. The interconnections were committed through Network Variables (NVs). The reason that two control modules are used is that the size of the program that created in Neuron C was too big and the memory was insufficient. So the code it is separated to two parts. Actually the

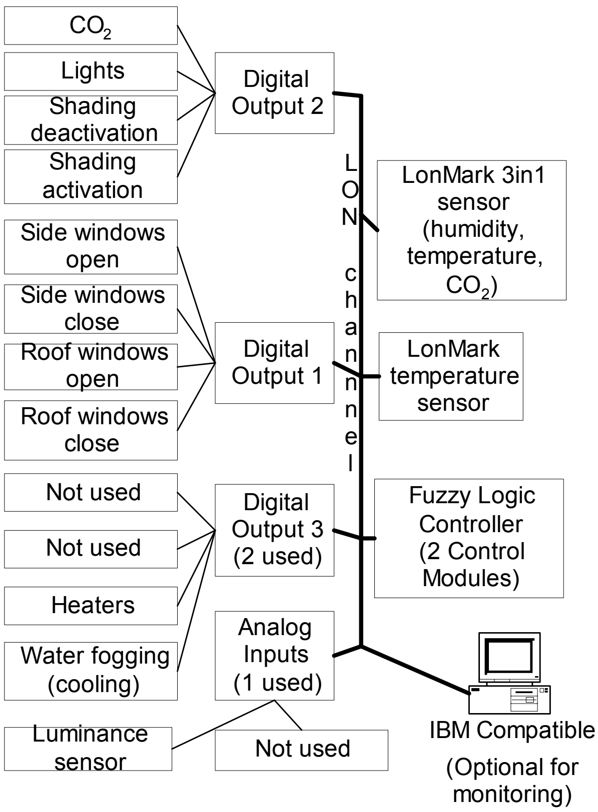

Figure 6: The LonWorks real installation in the greenhouse.

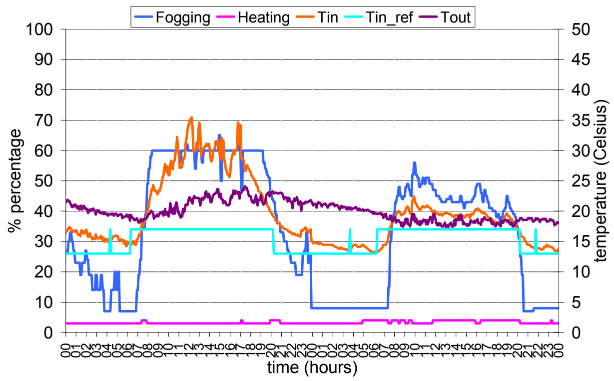

Figure 7: Some measurements from the greenhouse at 3/5/2006.

FLC-1 fuzzy controller is in the first control module and the FLC-2 fuzzy controller in the second control module. The logical union of the two control modules is actually the fuzzy logic controller that regulates the microclimate of the greenhouse. The two control modules are the most important devices in the whole LonWorks Network in the greenhouse. All the decisions about the proper use of the necessary actuators are taken through the controller.

4. RESULTS AND CONCLUSIONS

This greenhouse control seems to be quite efficient by achieving the desired factors that any cultivation demands. A wide set of measurements showed that the set-points can be reached into the maximum possible values into the greenhouse. In Figure 7 indicative measurements taken on 3/5/2006 are presented. The chosen cultivation is lettuce with the following set points: 13°C night temperature, 17°C day temperature. The system understands the day and night operation through the measured outdoor illuminance value. The outside temperature is oscillating between 18°C to 24°C. The first day the internal temperature (Tin) is 14°C (time 6:00 am of 3 May) and starts to rise fast. For that reason the heating output it is set always 0. At 9:00 am the temperature is above the desired value and its raising significantly (the rate error is high) so the fogging output is set immediately to 60%, and its output remains to a high value until night. In these measurements the fogging units were out of order so that is the reason that the temperature remains in high levels. The controller's output concerning the heating and cooling is satisfactory as it triggers the necessary actuators the right time.

The system is still redesigned and improved through the consideration of the continuous measurements. The most underlying characteristic is that this control is universal and can be used in any cultivation by setting the grower's desired factors.

ACKNOWLEDGEMENTS

This work is developed in the framework of the Archimedes project EY_THERMO: "Development of an intelligent system for the e-management of greenhouses" co-funded by the European Social Fund and National Resources.

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