An advanced control system for microalgae growth in a laminar photobioreactor

Jorge Miñón[1], Victor Martínez[2], Gonzalo Ruiz[1], Luis M Navas[1]*, José M Duran[3]

[1]Department of Agricultural and Forestry Engineering, University of Valladolid. Avda. Madrid, 44, 34004-Palencia (Spain)
[2]Department of Signal Theory, Communications and Telematic Engineering. University of Valladolid. Camino del Cementerio, s/n, 47011-Valladolid (Spain)
[3]Department of Crop Production. Technical University of Madrid. Ciudad Universitaria, s/n, 28040-Madrid (Spain)
** E-mail: lmnavas@iaf.uva.es*

Abstract

Microalgae cultures are currently one of the most promising third generation biofuel feedstocks. Microalgae have a high photosynthetic rate, so this crop produces a high amount of biomass (Chinnasamy *et al*., 2010). On the other hand, automatic crop monitoring and control is nowadays one of the main research trends in agriculture (Xiang & Tian, 2011). Therefore, the use of automatic control systems for microalgae growth may be regarded as a particularly important application of this technology. The goal of this work is to present a novel advanced control system aimed at optimizing the microalgae cultivation process.

Keywords: SCADA, advanced control system, microalgae, photobioreactors.

1. Introduction

Recently, there has been increasing interest in biofixation of greenhouse gases (GHG) by microalgae (Michiki, 1995). This is a promising approach so as to improve air quality and obtain microalgae biomass. This biomass can subsequently be used in biofuels, fertilizers and others synthesis compounds (e.g. pigments).

Microalgae can capture solar energy 10-50 times more efficiently than terrestrial plants (Wang *et al*., 2008). Microalgae also capture carbon dioxide (CO_2) and others greenhouse gases for photosynthesis.

Optimal conditions for microalgae growth can be achieved in photobioreactors, which simultaneously allow optimum temperature, dioxide carbon concentration, pH, and nutrients concentration, for example. However, in order to maximize biomass production and gas capture, skilled workers and permanent supervision of the installation (so as to regulate the different factors) are required. This involves variable costs which have a significant effect on the economic viability of the project (Lee, 1995).

For aforementioned reasons, the possibility of incorporating a Supervisory Control and Data Acquisition system (SCADA) to photobioreactors holds great promise for the optimization of microalgae biomass production and the maximization of greenhouse gases capture.

2. Material and Methods

The advanced control system was developed according to a modular architecture, whose components are a controller, a database server and one or more user interfaces (clients).

The chosen controller was a National Instruments CompactRIO (cRIO), a reconfigurable embedded control and acquisition system. The graphical development environment NI LabVIEW was used to program the cRIO system, as well as the other SCADA components.

The novel system field-tests have been conducted at the experimental facilities of the Agroenergy Group at the Technical University of Madrid. The setup consists of a greenhouse which contains three laminar photobioreactors modules. In these photobioreactors, microalgae are grown as a sort of biofilm on vertical fabric sheets that cover a hollow panel. The inner side of the sheet receives enriched CO_2 flue gas, while the other side faces the air. The sheets are continuously moistened by the algae growth medium, which gently flows from above. This provides a hydraulic closing which prevents the leakage of the chamber CO_2-enriched gas. Algae biomass is periodically harvested from the sheets in the form of a concentrated algae mass (10-20% dry matter content), always leaving a residual biofilm that allows the growth of new layers of algae.

Several sensors have been used in this experimental setup in order to monitor the different factors that affect microalgae culture, as shown in Table 1. In addition, so as to monitor the correct operation of the SCADA system, it is also necessary to record when the various devices are functioning. For this purpose, several contactors have been connected to the acquisition system.

Moreover, there are different devices aimed at the control of the process variables. These devices are: a gas compressor, which injects greenhouse gases into the photobioreactors; a water pump, which moves the culture medium in the photobioreactors; and an electric heater, which regulates the culture medium temperature in the algae culture medium tank.

Finally, there are also other devices or complementary installations, such as a combustion engine, a gas tank for the combustion gas storage and a greenhouse heater fan. These latter devices are not controlled or monitored by the SCADA system.

TABLE 1. Variables and sensors used in the SCADA system

Variable	**Sensor**	**Output**	**Location**
Volume of injected gas	Gas meter	Digital	Gas tank output port
Ambient temperature	Ambient temperature sensor	Analogical	In the greenhouse
Ambient relative humidity	Relative humidity sensor	Analogical	In the greenhouse
Volume of water injected	Water meter	Digital	Growth medium tank input port
Culture medium temperature	Water temperature sensor	Analogical	Growth medium tank
Culture medium pH	pH sensor	Analogical	Growth medium tank
Culture medium electrical conductivity	Water electrical conductivity sensor	Analogical	Growth medium tank
CO_2 concentration in the photobioreactors	Carbon dioxide concentration sensor	Analogical	In the photobioreactors
CO concentration in the photobioreactors	Carbon monoxide concentration sensor	Analogical	In the greenhouse
Solar radiation in the photobioreactors	Radiation sensor	Analogical	In the greenhouse

3. Results and conclusions

3.1. Server

The server is an important element in the SCADA system. It manages the database, providing functionality to the client devices that are enabled for a particular application.

The soft real-time data are stored in shared variables, allowing different users to display the updated system information in the client devices. Furthermore, when the internet or local connection is lost, messages are generated in order to inform the user about the error: server connection loss, electrical source failure, etc.

The chosen server is a computer in which Microsoft Server SQL (structured query language) has been installed, thus all consults to the database are conducted using SQL language.

3.2. Programmable automation controller

A National Instruments CompactRIO has been selected as the programmable automation controller. This is a reconfigurable embedded control and acquisition system. The CompactRIO system rugged hardware architecture includes I/O modules, a reconfigurable field-programmable gate array (FPGA) chassis, and an embedded controller. Additionally, CompactRIO can be programmed with NI LabVIEW graphical programming tools and may be used in a variety of embedded control and monitoring applications.

The CompactRIO programmable automation controller is connected to the different sensors and contactors discussed above. These devices monitor and control the microalgae cultivation process. The control algorithm configured for an authorized user is run in CompactRIO. If this subsystem loses the connection with other subsystems, it will still keep running. When this occurs, data acquired during this timeframe is saved in the CompactRIO, and once the connection with server is restored, it is transferred to the server.

3.3. Client device

The proposed SCADA system architecture allows several client devices. These client devices may be installed in different machines, such as personal computers, personal digital assistants (PDA) or laptop computers.

The client device shows several features which are described below. This application has also been developed using NI LabVIEW. It has been structured in several tabs to configure the culture process supervision.

CONFIGURATION CONTROL

This tab (shown in Fig. 1) provides access to all configuration parameters of the different devices, namely water pump, gas compressor and electric heater. The parameters and variables which intervene in the control of these devices are described below.

Carbon dioxide concentration is controlled by means of the gas compressor. The configuration of the control algorithm is as a function of solar radiation and dioxide carbon concentration. The user must indicate relation set-points, which relate solar radiation measurements with fixed carbon dioxide concentrations. The user can define many pairs of set-points. Furthermore, the user can specify the type of interpolation between the points that have been entered: either lineal or by integer-valued polynomials.

In brief, once the desired carbon dioxide concentration for a certain solar radiation value is configured, after the latter is measured, the CO_2 concentration will be automatically adjusted by starting the gas-compressor (if the concentration is lower than that fixed at the set-point) or by stopping it (if the instant value of CO_2 concentration is higher than the set-point).

The culture medium temperature control has a similar control algorithm than that discussed for CO_2 concentration. In this case, the variables which intervene are culture medium temperature and solar radiation. Solar radiation values are related to set-point temperatures, and the control algorithm switches the electric heater on or off accordingly, in a similar way to what it does with the gas compressor.

The recirculation pump control has been defined with a relative time control: the user can define several standard day sequences. Within each sequence there are four parameters to define, namely start time, stop time, on period and off period. Therefore the user can specify how for long the water pump is on or off. Thus define different recirculation intervals may be achieved as a function of evapotranspiration in the photobioreactors.

PROCESS DIAGRAM

This tab shows the instantaneous values for all the monitored variables (Fig. 2).

PROCESS MONITOR

There are two tabs to perform this consult. The first option is to monitor the process in real time; in which the user selects the variables and then the start time. The second option is to monitor process in a range; in which start time, stop time and variables must be selected. The interface is shown in Fig. 3.

EXPORT DATA

In this tab the user can export data acquired during a defined time interval. A csv (comma-separated values) file is generated, which stores tabular data in plain-text form. This file format is widely supported by consumer, business, and scientific applications, and can be regarded as a *de facto* standard for moving tabular data between programs that natively operate on incompatible (often proprietary and/or undocumented) formats.

STATISTICAL PROCESS

In this tab the user can consult indirect parameters of all monitored variables, such as average, mode, median, thermal units, accumulated, etc. For digital variables the accumulated on/off time is also calculated.

FERTIGATION MODULE

This tab allows the user to evaluate the concentration in macronutrients: nitrogen, phosphorous and potassium. Moreover, the amount of fertilizers required for the culture medium can be calculated, and a database with different nutrients that can be used in fertigation is also available.

USER MANAGEMENT

As indicated above, the SCADA system defines different permissions for the different user categories. These permissions are summarized in Table 2.

TABLE 2. User permissions enabled in the SCADA system

Category	**Description**
Administrator	All functionalities are enabled
Supervisors	The user has access to all functions except for the application ones
Worker	The user can only access monitoring functions and cannot access any control functions

The administrator is allowed to manage both system users (including personal information) and their permissions from this user management tab.

Finally, the SCADA system can enable a communication system *via* Short Message Service (SMS). The user on duty in the installation is notified by means of a SMS if an alarm in the process is triggered. The user subsequently replies with another SMS to the SCADA system once the problem is corrected. Nonetheless, this subsystem has not been integrated yet in the field-test setup at the Agroenergy Group facilities.

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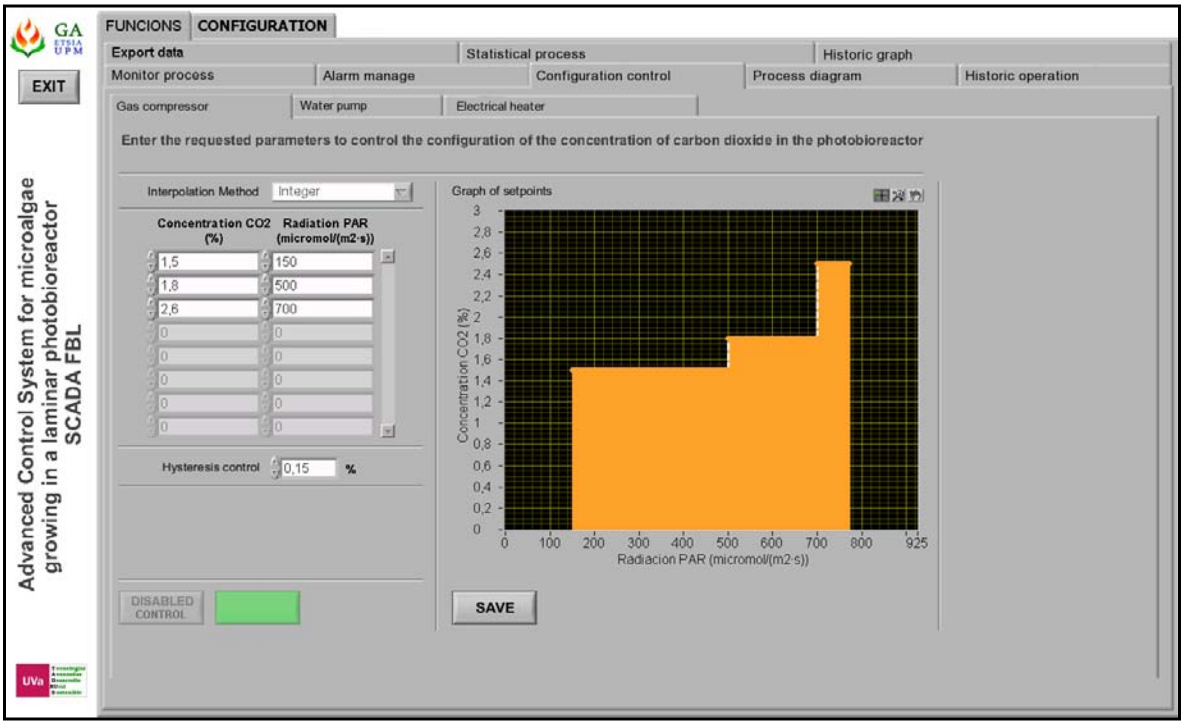

FIGURE 1. Configuration interface for carbon dioxide concentration control

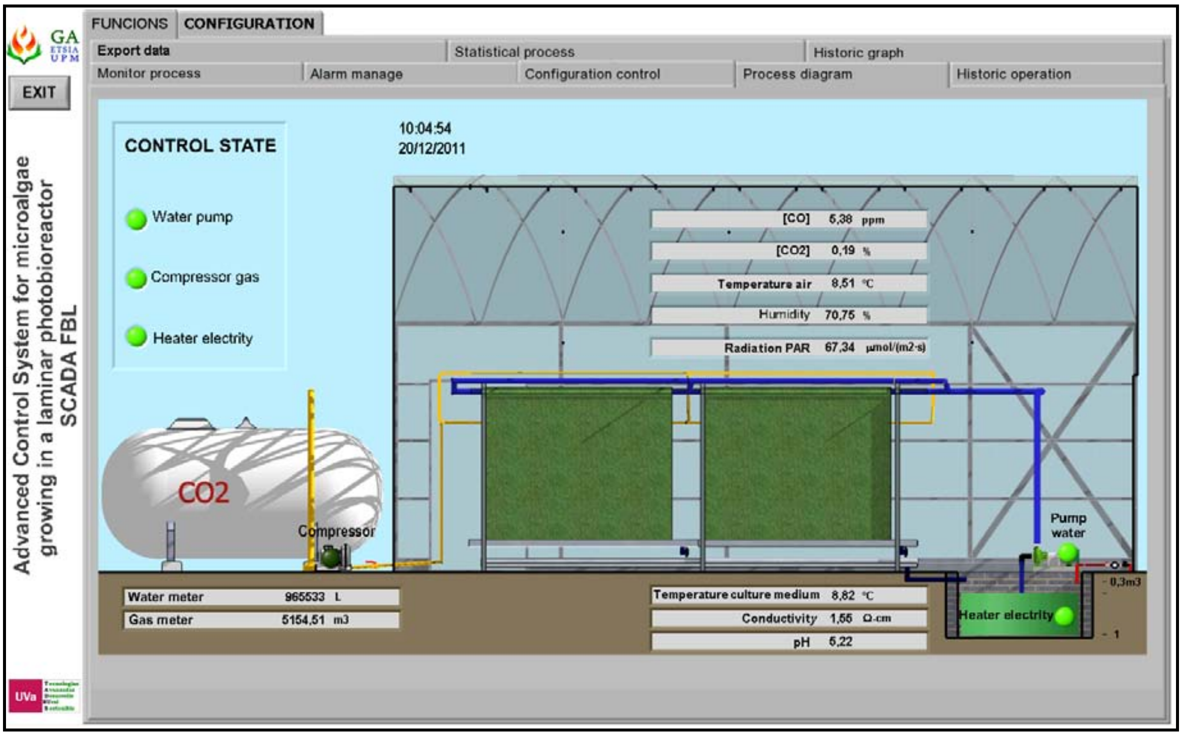

FIGURE 2. Process diagram interface

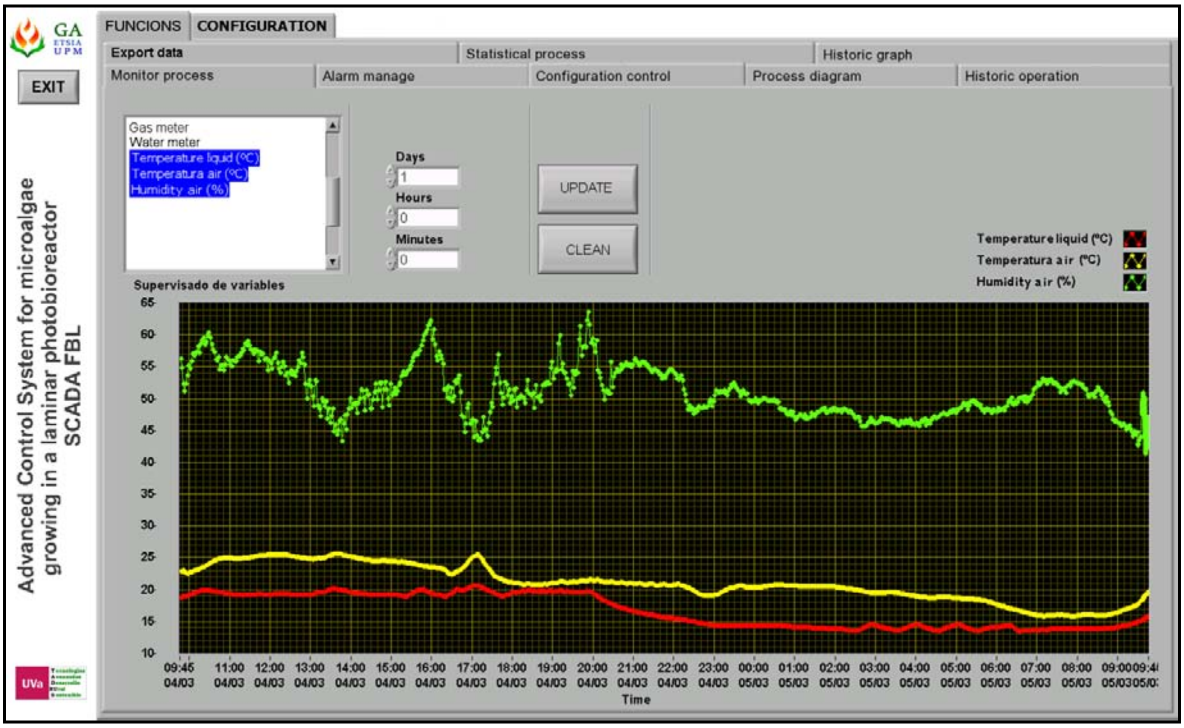

FIGURE 2. Process monitor interface