Computerized Greenhouse Environmental Monitoring and Control System Based on LabWindows/CVI

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***Abstract*—Crop management depends on having the right information to make necessary decisions. Real-time monitoring of the greenhouse environment with sensors and advanced software can greatly improve yields and economic performance by optimizing plant growth. In this paper, we propose a system that can collect the information related to greenhouse environment and crop status and control the greenhouse automatically based on the collected information to predict and act on situations for perfectly controlled climatic conditions. By densely monitoring climatic conditions, this research has the purpose of establishing correlation between sensors signals and reference measurements, analyzing the growth, development of crops and the environmental variables to which they are exposed, to develop an automated computerized monitoring system for an intensive greenhouse facility that provides adequate control regardless of plant type or specie, and using this information to help farmers to increase yield, improve quality and timeliness of crops. Computer control software of LabWindows/CVI will provide data acquisition and control, real-time graphical display, dates and time tags the information and stores it for current or later use. Through long time running and practical using, the system has been proved that it has many advantages such as high testing precision, accuracy, and clear data management.**

***Index Terms*—computerized monitoring, data acquisition, greenhouse environment, LabWindows/CVI, real-time monitoring, sensors.**

I. Introduction

A greenhouse is a specially designed farm structure building to provide a more controllable environment for better crop production, crop protection, crop seeding and transplanting. Moreover, the available space of land for cultivating crops has been significantly decreasing, since more space of land is heavily used for housing and industries in this modern era. In most tropical countries, the use of greenhouse has been growing for commercially horticulture (i.e. fruits, fresh flowers and vegetables) production [1]. A greenhouse environment is an incredibly complex and dynamic environment and strongly influences crop cultivation. The efficiency of plant production in greenhouses depends significantly on the adjustment of optimum climate growth conditions to achieve high yield at low expense, good quality and low environmental load. To achieve these goals several parameters such as air temperature, humidity, light intensity, and carbon dioxide concentration must be controlled optimally given certain criteria through heating, lighting, ventilation and carbon dioxide injection [2]. Continuous monitoring and controlling of these environmental factors gives relevant information pertaining to the individual effects of the various factors towards obtaining maximum crop production [3].

Greenhouse environments present unique challenges to good control. Temperature changes occur rapidly and vary widely depending on solar radiation levels, outside temperatures and humidity levels, wind speed and direction and the amount of plant material in the greenhouse. Poor light intensity and high humidity often result in poor fruit set and quality. Proper control of plant disease is critical in greenhouse environments, where high temperatures and high humidity are ideal for diseases to develop. Insect and nematode infections, too, can become rampant under the confined greenhouse conditions. More accurate control can reduce heating fuel and electrical costs, increase the productivity of workers by enabling them to attend to more valuable tasks, enabling managers and growers to make better management decisions and spend more time managing the process. More precise control of temperatures and humidity helps reduce plant stress and diseases and consequently the need for fungicides and other chemicals, helps produce healthier plants less susceptible to disease and insect infestation, improved grower information and management all combine to increase the health and uniformity of plants [4].

Today, computerized control systems are the standard for modern greenhouses, with continued improvements as the technology advances. Environment conditions can be maintained by these computerized control systems, where the system can be operated manually and/or automatically. The main components of any control system are measurement controller, data processing, data acquisition,

Manuscript received July 18, 2012; revised August 16, 2012; accepted August 25, 2012
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doi:10.4304/jcp.8.2.399-408

data presentation and recording. In the environment control system, each parameter must be maintained continuously within a certain range [5]. However, no such models yet exist for commercial greenhouse horticulture. In the agricultural sector, especially developing countries, the application of the environment control technology is still limited, mainly because of its high cost. Therefore, a sustainable development of environmental monitoring and control system for intensive greenhouse production is inevitable.

In this paper, we propose a system that can collect the information related to greenhouse environment and crop status and control the greenhouse automatically based on the collected information to predict and act on situations for perfectly controlled climatic conditions. By densely monitoring climatic conditions, this research has the purpose of establishing correlation between sensors signals and reference measurements, analyzing the growth, development of crops and the environmental variables to which they are exposed, to develop an automated computerized monitoring system for an intensive greenhouse facility that provides adequate control regardless of plant type or specie, and using this information to help farmers to increase yield, improve quality and timeliness of crops. Computer control software will provide data acquisition and control, real-time graphical display, dates and time tags the information and stores it for current or later use. Moreover, by continuously monitoring numerous environmental variables at once, a farmer is able to understand how growth conditions are fluctuating, and react to those changes in order to maximize efficiency [6]. Using a data printout option, farmers can produce reports and summaries of environmental conditions such as temperature, humidity, light intensity and carbon dioxide status for a given day, or over a long period of time [7]-[10].

II. Related Works

An automatic control of greenhouse climate using a fuzzy interface system has been constructed [11]-[12]. However, the operation of fuzzy interface system is inflexible which shall be manipulated within the greenhouse. A greenhouse climate control system has been constructed with the objective of decreasing energy consumption while maintaining, or even increasing plant production [13]. The system is based on the use of mathematical models for estimating the absorption of irradiance, leaf photosynthesis and respiration and can be used for different greenhouse crops. Nevertheless, this system is expensive and cannot be applied in small scale greenhouse production. A real-time control algorithm for generating optimal heating setpoints has been implemented and tested on commercial greenhouse nursery with a tomato crop [14]. The algorithm is based on model of the greenhouse energy requirements on a numerical method for optimization, and uses weather forecasts supplied by Meteorological office and resides on a personal computer (PC) which communicates with a commercial greenhouse computer system which receives weather forecasts remotely via a modem. Still, if a grower changes species and varieties with each season, or mixing cultivars and species in the same environment, this model may be of limited use.

Economically optimal computerized control of greenhouse using information about crop growth is well underway in research community [15]. But the acceptance in practice is still limited due to doubts about the quality of the crop models and lack of experimentally proven advantages. The simpler approaches to minimize operation costs while maintaining pre-defined environmental parameters are likely to penetrate into the market because they do not rely on crop models. Improved computer systems combined with more sophisticated software are the most obvious candidates to help met these new demands. They also share an efficient tool to distribute the results generated by science directly to the industry by integrating mathematical models describing crop growth and production systems [16]. To integrate dynamic model based climate controlling in real-time with an environmental control computer, a system integration interface was developed [17]-[18]. The main objectives were: to supply standard routines for communication with the environmental control computer; to establish a set of databases to represent the current informational environment for the greenhouse; and to formulate a language capable of defining the working concepts of greenhouse process control.

There are a number of requirements to be met if a crop monitoring system is to be used in a commercial greenhouse setting. The equipment should be capable of recording data continuously and automatically. It must be non-invasive, robust, and integrate with greenhouse crop management practices. It should be capable of monitoring groups of plants rather than a single plant or plant part to provide more representative crop data. Lastly, it should provide useful measurements that the grower cannot easily obtain using other techniques [19].

III. Materials and Methods

A. Automatic Greenhouse Environmental Monitoring System

The scheduling model of the computerized greenhouse environmental monitoring system by the computer based on LabWindows/CVI program is shown in Fig. 1. The air temperature, relative humidity, light intensity and carbon dioxide concentration of greenhouse were measured every 5 seconds by their respective sensors. The low level input signals directly from sensors are signal conditioned, amplified and then transmitted to computer system through the Data Acquisition (DAQ) unit. Then the computer through a comparison with standard parameters issues control signals to drive relays for each driver motor for heating system, ventilation system, lighting system and carbon dioxide injection unit.

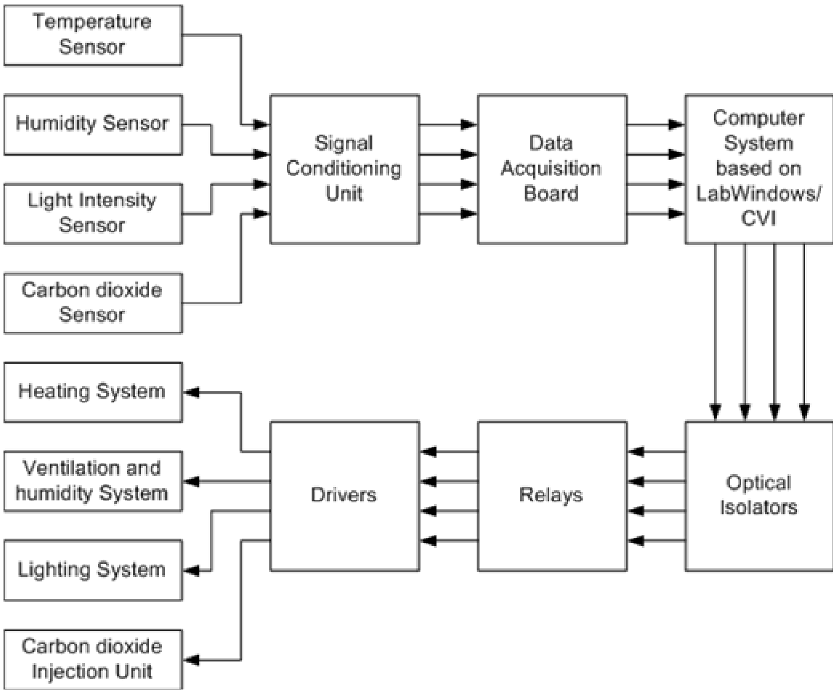

Figure 1. Scheduling model of the computerized greenhouse environmental monitoring system.

The host computer has priority, records these data for user to query at any time according the actual needs, provides real time graphical display and stores it in a disk for later use.

B. Data Acquisition Board

The DAQ board PCI 6023E were chosen for this project. This device has 16 channels (eight differential) of analog input, a 68-pin connector and eight lines of digital Input/output (I/O). It uses the National Instruments DAQ-STC system timing controller for time related functions. The device can interface to an SCXI system, the instrumentation front end for plug-in DAQ devices so that analog signals can be acquired from thermocouples, strain gauges, voltage sources, current sources, etc. It can acquire or generate digital signals for communication and control. This device can scan multiple channels at the same maximum rate as its single-channel rate. However, careful attention should be paid to the settling time. The analog input signals from sensors are interfaced to the analog channels ACH, ASENSE and AIGND. The device has inbuilt digital to analog (D/A) converter and analog to digital (A/D) converter. The device user interface (UI) counter normally generates the update signal unless some external sources are selected. The UI counter is started by the WFTRIG signal and can be stopped by software or the internal buffer counter [20]. This DAQ board can measure and correct for almost all of its calibration-related errors without any external signal connections. This self-calibration process is the preferred method of assuring accuracy in the application. Initiating self-calibration minimizes the effects of an offset, gain, and linearity drifts, particularly those due to warm-up.

LabWindows/CVI is a software development environment chosen for this project. LabWindows/CVI provides powerful function libraries and a comprehensive set of software tools for data acquisition, analysis, and presentation that are used to interactively develop data acquisition and instrument control applications. LabWindows/CVI combines the power and flexibility of ANSI C with easy-to-use tools for building virtual instrumentation systems. A virtual instrument consists of an industry-standard computer or workstation equipped with powerful application software, cost-effective hardware such as a plug-in board, and driver software, which together perform the functions of traditional instruments. However, virtual instruments can provide more customization, scalability, and modularity than traditional instruments. One can edit, compile, link, and debug ANSI C programs in the LabWindows/CVI development environment. Additionally, one can use compiled C object modules, dynamic library link (DLLs), C libraries, and instrument drivers in conjunction with ANSI C source files when developing programs.

When we create a virtual instrument using LabWindows/CVI and NI hardware, we keep in mind the three-step process for creating virtual instruments: acquiring, analyzing, and presentation. We acquire the data through a hardware interface. Then we use the user interface created to control data acquisition from an instrument or from a plug-in DAQ device. The user interface created can also display the acquired data. After acquiring data, we must analyze it by performing formatting, scaling, signal processing, statistical analysis, and curve fitting. We present data in a user interface created that may contain graphs, strip charts, and other controls. We also can display graphics, create pull-down menus, and prompt users for input with pop-up dialog boxes. The User Interface Editor can be used to create these items interactively, or the User Interface Library can be used to create and configure them programmatically. The program control portion of the program coordinates the data acquisition, data analysis, and user interface. Program control contains the control logic for managing the flow of program execution and user-defined support functions [21].

C. Selecting the Sensors

Environmental temperature and relative humidity are monitored using an integrated sensor (type: JWSB, accuracy of 0.5°C, ColliHigh Sensor technology center) with temperature measurement range of -20-80°C and humidity range of 0-100%; carbon dioxide concentration is detected by a carbon dioxide sensor (GMW22, Vaisala Corporation) with a measurement range of 0-2000 ppm and resolution of 1 ppm. The light intensity is measured by a light sensor (range from 0-100 Klux, KRIWAN Industrie-Electronik GmbH). The sensors applied in the greenhouse are selected on the basis of the significant fluctuation in temperature between day and night so the temperature characteristics of the electrode must be stable, the electrodes used in the greenhouse should not be polarized and eroded and the input impedance of the preamplifier must be high ($>10^{10}\Omega$), and the temperature drift must be low [22].

D. Heating Subsystem

Temperature control is necessary for attaining high crop growth, yield and quality. Extreme temperatures may induce stress and associated damage to the plasmatic structures or the photosynthetic apparatus of the plant. Less extreme suboptimal temperatures may delay plant development and affect other plant characteristics such as dry matter distribution [23]. There are two main factors affecting greenhouse temperature: the impact of greenhouse structure and regions which includes greenhouse volume, wall thickness, transparent area, the heat capacity, temperature and infiltration of outdoor environment, etc; the effect of the adjustment of other environmental parameters on the temperature, these parameters include humidity, light illumination, carbon dioxide etc. The aim of every producer is to reduce the energy input per unit of production, and maintain and increase the quality of final product [24]. Uniform crop growth is very important for most production systems and the heating and ventilation systems have a major impact on producing uniform crops [25].

E. Ventilation and Humidity Subsystem

It is important to maintain the proper humidity since the humidity inside the greenhouse has a close relation to crops growth, volume and insect damages. In particular, ventilation plays an important role in controlling relative humidity inside facilities, and ventilation equipment should be installed with a consideration of the physiological need of a crop. Too much ventilation in the afternoon changes the size of flower buds near the growing point of flowers and it lowers quality of flowers, and this in turn, is the cause of fallen fruit and blossom [26]. Whenever the natural ventilation is insufficient it is necessary to use ventilators. The cooling efficiency can be increased by combining the natural and mechanical ventilation systems with air humidifiers. A general type of cooling system uses a porous pad installed in one top side of the greenhouse, which is maintained wet. On the opposite side, an exhaust fan is installed. The air admitted through the pad becomes cooler by evaporation effect. The fog system is formed by suspended pipes on the greenhouse structure, spraying tiny drops of water into the greenhouse, contributing to increase air humidity and decrease the air temperature. Dehumidifier system is used for decreasing the air humidity [27].

F. Lighting Subsystem

During winter time, the light level in China is not adequate for optimal plant production, and because light is the energy source promoting photosynthesis and growth, under low light conditions other environmental factors cannot be utilized efficiently. The irradiance level is therefore the growth limiting-factor during winter. Under low irradiance conditions, energy use can be reduced because increased temperature cannot be used efficiently for growth. In contrast, when irradiance is higher, the plants are able to utilize both a higher temperature and carbon dioxide concentration [13]. Greenhouse lighting systems allows us to extend the growing season by providing plants with an indoor equivalent to sunlight. Using the supplemental lighting system is a common way for greenhouse lighting. However, it can be done either with photoperiod lighting system or through walkway and security lighting.

G. Carbon dioxide Injection Unit

Carbon dioxide concentration plays a very important role in the photosynthesis process. The average carbon dioxide concentration in the atmosphere is approximately 313 ppm, which is enough for effective photosynthesis. A problem arises when a greenhouse is kept closed in autumn or/and winter in order to retain the heat, when not enough air is circulated to have the appropriate carbon dioxide concentration [28]. Air movement in greenhouse is needed for acceptable carbon dioxide distribution and to maintain uniform temperature within the crop zone. In order to improve the growing of herbs inside the greenhouse, it is necessary to increase carbon dioxide concentration in company with favorable conditions of temperature and light.

H. Physical Description of the Greenhouse

The experiments have been carried out at Tianjin Jinnan agricultural science and technology greenhouse park, located in Jinnan District, the Balitai Town, 15 km of the central area of Tianjin, north latitude 39.04, longitude 117.33. The prototype of environmental monitoring system has been installed since 2009 to verify the performance of the system, as shown in Fig. 2(a). The greenhouse under consideration is $4026\,m^2$ as shown in Fig. 2(b). The greenhouse is divided into sections where different types of crops like tomatoes, cucumbers, apples and grapes are produced.

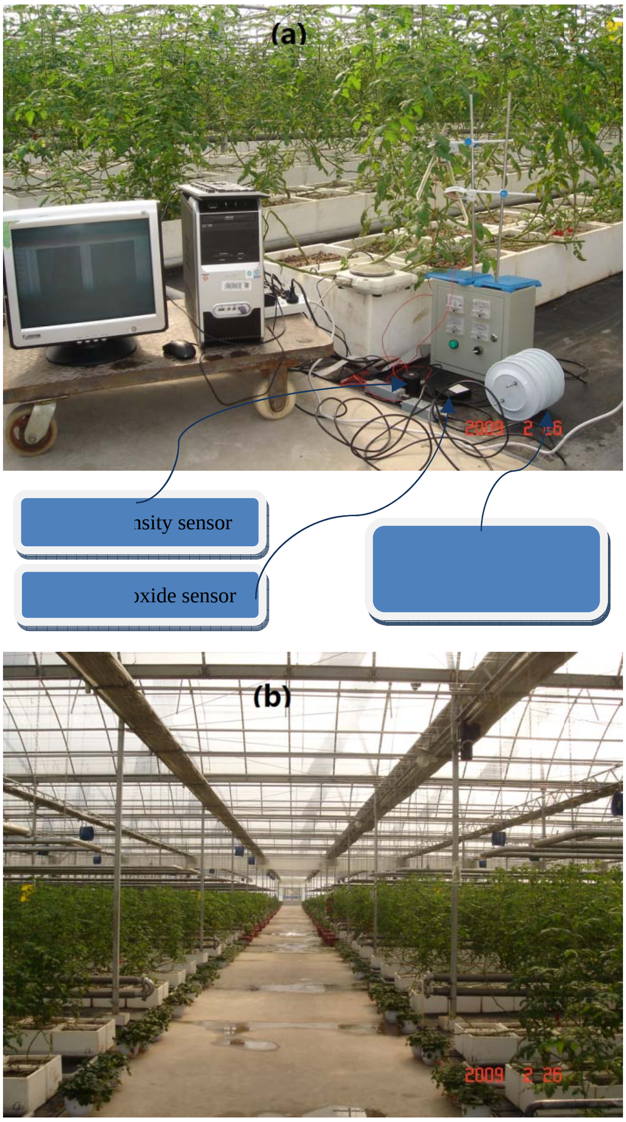

Figure 2. (a) Experimental setup of the computerized environmental monitoring system, and (b) Practical greenhouse farm where the experiments were conducted.

IV. Results and Discussion

The entire system have been tested and verified for about 3 years from February 2009 to May 2012. Statistics of the data of all input sensors show that the system is rather reliable. The monitoring system is also easy expandable with many sensor channels available. Fig. 3 shows the real-time monitoring interface of temperature and humidity, and Fig. 4 shows the real-time monitoring of light intensity and carbon dioxide. These interfaces are responsible for collecting the relevant real-time temperature, humidity, light intensity and carbon dioxide data to achieve automatic acquisition by sensor nodes. The screen layout consists of main menu where users can click to fulfill the expectant function. The frequency of measurements every 5 seconds were recorded by the system and saved to the computer hard drive for future use.

As we see in Fig. 5, the temperature monitored in the greenhouse fluctuates between 20 ° C and 36 ° C throughout the year, which is optimum for plant growth. There were a rapid descending of carbon dioxide during the day between 08:00 and 17:00 as seen in Fig. 6. This is because plants use carbon dioxide in the process of photosynthesis to produce oxygen. The trend was different in cloudy days in winter season where most of the day is dark. However, during night time carbon dioxide increased due to respiration process of plants. The detailed changes of light intensity are shown in Fig. 7. Light intensity changes depending on the local weather. On cloudy and wither season, light intensity recorded during the day were low, resulting in use of artificial lighting to increase irradiance to facilitate photosynthesis process optimum for plant growth. However, under normal weather, light intensity increased during the day and descended to low values during the night. The humidity level recorded is shown in Fig. 8. Nominally the growth environment should be maintained between a humidity level of approximately 20% and 80%, but optimally level can vary with the crop being grown [29]. Fig. 8 demonstrates that the humidity in the greenhouse is maintained within these course bounds.

Regression analysis of the carbon dioxide monitored data experiment with a linear fit gave a determination coefficient, $R^2 > 0.977$ (Fig. 9). It can be seen from the graph that a close relation between the values exists. Similar observations were noticed for the monitored temperature, humidity and light intensity data where the determination coefficient, $R^2 > 0.97$. Fig. 10 shows output interface control for turning on or off of relays for heating and ventilation subsystems. Analysis of these results reveals that the accuracy of the system and the reliability of the values are good. These results are in agreement with those of field programmable gate array (FPGA)-based real-time remote monitoring system study results presented by [30] and environmental control and monitoring of the Arthur Clarke Mars greenhouse in the Canadian high Arctic revealed by [31].

The data acquisition feature of this system is often an attractive aspect for the grower as such records are helpful in determining what the growing conditions were for crops. The system test and experiment evaluation proved itself an effective greenhouse quality management tool that leads to maximize monitoring and recording of greenhouse workflow. It effectively reduces the probability of the high risk of diseases during culture process through enabling constant monitoring the critical parameters in the greenhouse environment. After the system has been deployed, most environmental parameters were constant. The system continuously record environmental parameters of the greenhouse daily, month after month and year after year. At the same time simultaneously produce the daily, weekly, monthly and yearly report and trend curve charts of environmental parameters. These parameters are around the optimal range of plant health with little fluctuations. Plant health has improved and cultivation is done throughout the year, replacing different types of plants immediately after harvest of one produce resulting in greater plant consistency and on-schedule production.

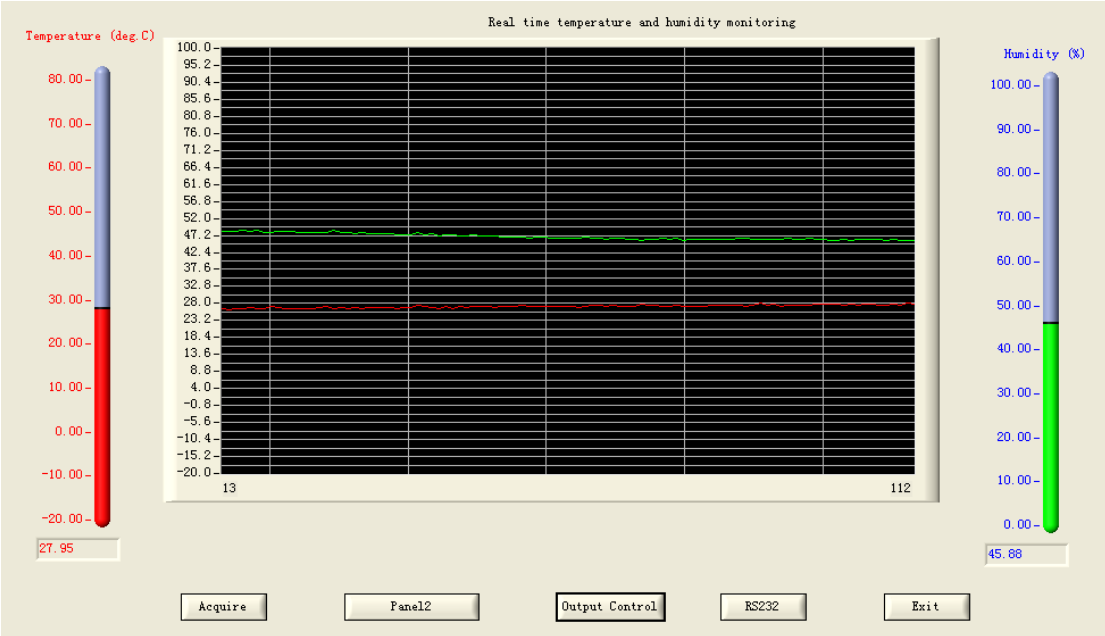

Figure 3. The real-time monitoring interface of temperature and humidity.

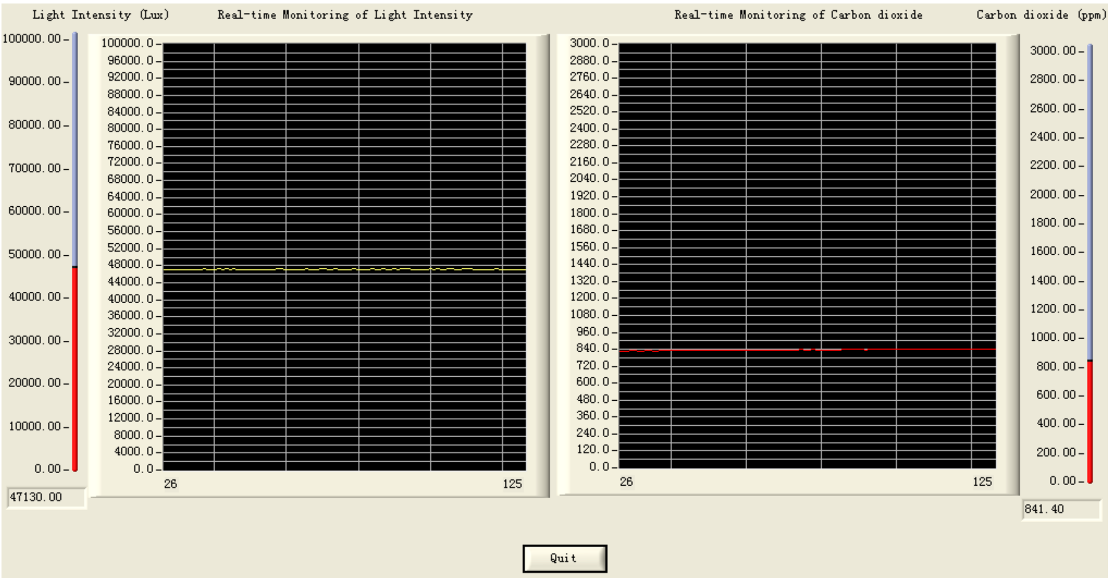

Figure 4. The real-time monitoring of light intensity and carbon dioxide.

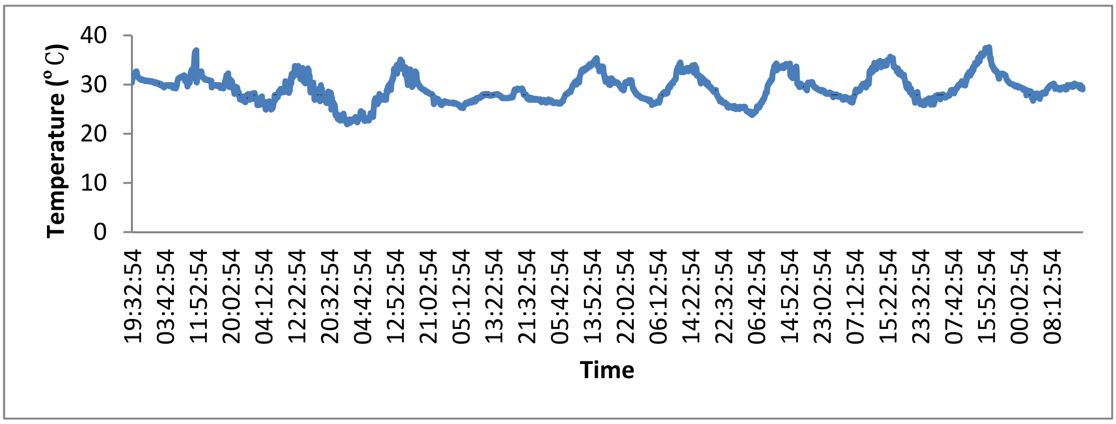

Figure 5. The temperature data monitored in the greenhouse.

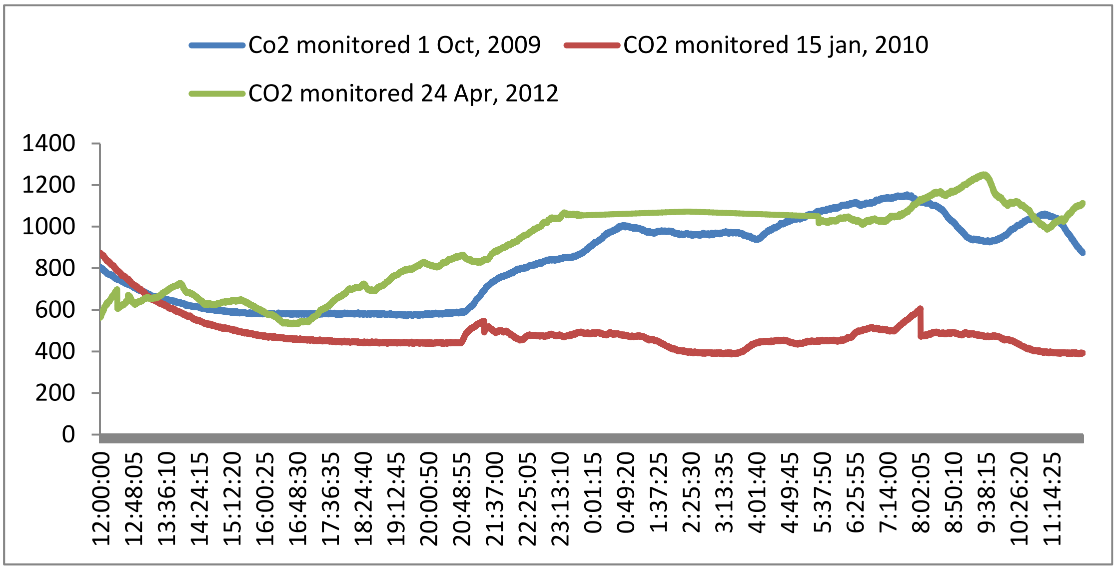

Figure 6. The carbon dioxide data monitored in the greenhouse.

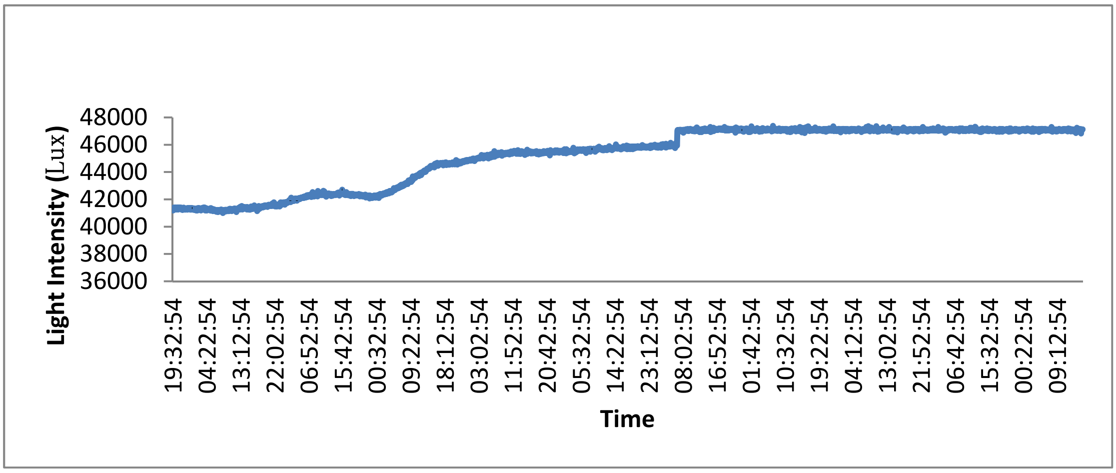

Figure 7. The light intensity data monitored in the greenhouse.

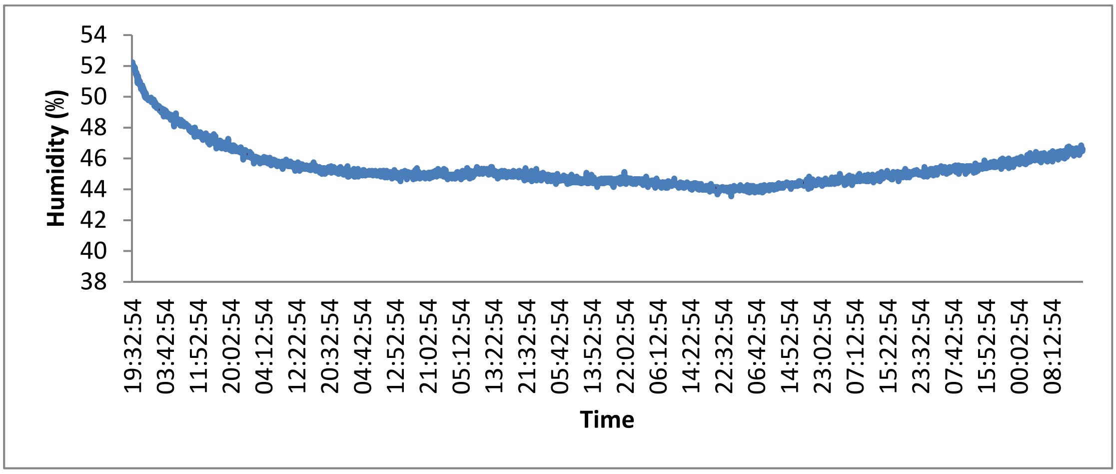

Figure 8. The humidity data monitored in the greenhouse.

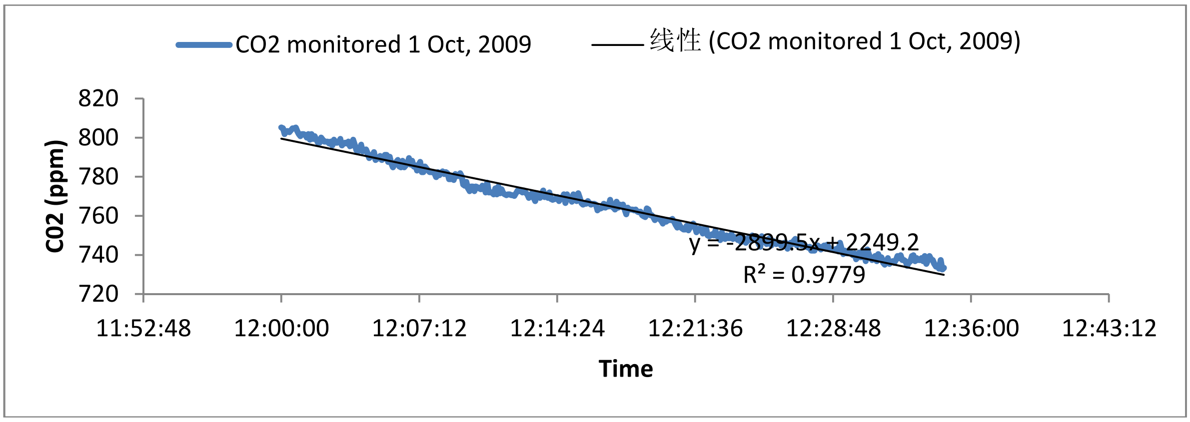

Figure 9. The regression analysis of carbon dioxide data monitored in the greenhouse.

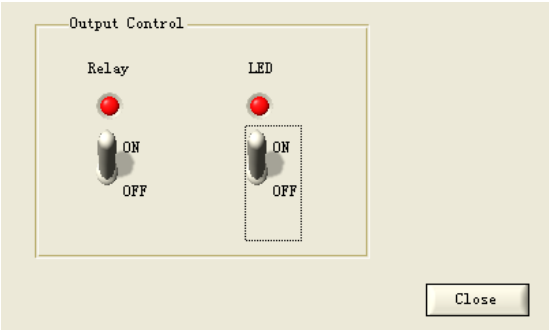

Figure 10. The output control interface.

V. Conclusion

In this study, a design of automatic greenhouse environmental monitoring and control system based on LabWindows/CVI is presented. The system has been deployed in the Tianjin Jinnan agricultural science and technology greenhouse park and has been tested for three years period. Through this time running and practical using, the system has been proved that it has many advantages such as high testing precision, accuracy, and clear data management.

On the basis of present study, the following conclusions can be made:

- The system can monitor automatically the data of temperature, humidity, illumination and carbon dioxide in real-time and continuously every 5 seconds. The results indicate the periodic variation of these parameters depending on the daily weather condition.
- The system can provide early warning in case of malfunction, especially suitable for intensive greenhouse farms. The results can be used as forecasting model for predicting the trend of environmental parameters and the plant responses for optimum plant growth in the long-term in greenhouse applications.
- The control system is capable of automatically transferring data to the local PC hard drive for long-term data storage. It also performs automatic backup of settings and data once per day for all changed parameters for restoration of settings in case of data acquisition board replacement.
- The application of the proposed system is wide by its simplified operational requirements and user friendly interface and hence low maintenance cost. However, the sensors need to frequent cleaning to prolong the useful span.
- The actuators can be set to automatic starting to the parameter values in order to reduce labor cost and efficient energy consumption.

Acknowledgment

This work was supported in part by the National Natural Science Foundation of China under Grant 60771014 and Tianjin Agricultural Scientific Committee Foundation under Grant 201101190. The authors would like to thank members of Tianjin Jinnan agricultural science and technology greenhouse park of China for the assistance on the setting up of the experiment and collection of environmental parameters data.

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