A Supervisory Control System for Greenhouse

Kudang B. Seminar, Herry Suhardiyanto, Soedodo Hardjoamidjojo
Department of Agricultural Engineering
Bogor Agricultural University (IPB)
P.O. Box 220 Bogor, Indonesia
kseminar@bima.ipb.ac.id

Tamrin
Department of Agricultural Engineering
Sriwijaya University
P.O. Box 303, Palembang
Indonesia
tamrin@sriwijaya.ac.id

ABSTRACT

Computer-based control systems for greenhouse (i.e., crop production house) has been developed for many years. However, these control systems provides a limited or no choices of control preferences such as control methods and controlled parameters. For some reasons, a user may need only to control indoor temperature and humidity using PID control method; but in another situation the user may need only to control indoor temperature and light intensity using fuzzy control method or genetic-algorithm method. This paper describes the proposed supervisory control system for greenhouse that provides a much greater flexibility for selecting control preferences. Given α (a set of alternative control methods) and β (a set of alternative parameters relevant to greenhouse environment), the proposed supervisory system allows a user to select a certain control method from α to manipulate a subset of controlled parameters from β. Thus the system receives input as a tuple pair (A, B) where $A \in \alpha$ and $B \subseteq \beta$ from the user to perform its control task for a greenhouse operation. The implementation issues of the system prototype are discussed and future recommendation is addressed.

KEYWORDS

Supervisory system, intelligent system, computer-based control system, greenhouse technology, fuzzy control, genetic algorithm.

1. Background and Motivation

A greenhouse is a farm structure specially designed for crop production with a better environmental protection system [4]. Historically, a greenhouse was developed for cold regions, protecting crops from undesirable, cold weather. Nowadays, the use of a greenhouse has been developing into several purposes: crop production, crop protection, crop seeding and transplanting. Crop production using a greenhouse technology is becoming a trend not only in cold regions due to the increasing needs of high quality crops particularly on horticulture (i.e. fruits and vegetables). A greenhouse provides a way and space of growing crops with more controllable parameters, enabling the provision of optimum environment for growth of a certain type of crops within a greenhouse. 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 tropical countries like Indonesia, the use of greenhouse has been growing for commercially horticulture (i.e. fruits, fresh flowers, and vegetables) production.

The development of computer-based control systems for greenhouse has been geared for many years [1,2,3,4,5]. However, these control systems provides the user with a limited or no choices of control preferences such as control methods and controlled parameters. For some reasons, a user may need only to control indoor temperature and humidity using PID control method; but in another situation the user may need only to control indoor temperature and light intensity using fuzzy control method or another control method. The selection of control scenario for a greenhouse varies according to some factors: (1) variety and volume of crops, (2) the purpose of crop production, (3) the available resources, and (4) the climatic condition surrounding the greenhouse. Therefore, the user must be given a way of selecting control scenario that best fits his needs.

This paper attempts to propose a supervisory control system for a greenhouse that provides a much greater flexibility for selecting control preferences. Given α (a set of alternative control methods) and β (a set of alternative parameters relevant to greenhouse environment), the proposed supervisory system allows a user to select a certain control method from α to manipulate a subset of controlled parameters from β. Thus the system receives input as a tuple pair *(A, B)* where $A \in \alpha$ and $B \subseteq \beta$ from the user to perform its control task for a greenhouse. A system also provides a default control scenario if the user selects no preference. This will ease novice user to use the control system.

2. Literature Study

A greenhouse is a specially designed farm structure building to provide a more controllable environment for better crop cultivation. A greenhouse environment is an incredibly complex and dynamic environment. The pressures of labor availability and costs, energy costs, and market demands increasingly make efficiency and automation become key components for success and profitability. Environmental control technology affects all of these critical areas, and many others, so understanding controls and implementing their use become important than ever. Precise control of the greenhouse environment is critical in achieving the best and most efficient growing environment and efficiency. The control system uses technologies enabling the controller to predict and act on situations for perfectly controlled climatic conditions. It also performs repetitive and time driven tasks when programmed, thus saving manpower.

Early greenhouse control was as simple as pulling a chain to open or close a vent, turning a valve to control heat or irrigation water, or tuning a switch to activate a pump or fan. Over the years, this evolved as greenhouse systems themselves, became more complex and more reliable. However, many of these control devices and methods cannot deliver the level of automation and efficiency needed in today's dynamic, competitive environment.

As operating costs increased, and greenhouse systems became increasingly complex, the demand grew for increased control capability. The computer revolution of the late 70's/early 80's created the opportunity to meet the needs for improved control. Consequently, there have been dramatic improvements in control technology. Today, computerized control systems are the standard for modern greenhouses, with continued improvements as the technology advances.

One of work efforts in greenhouse supervisory control is demonstrated by free-standing greenhouse using Supervisory Control & Data Acquisition (SCADA) system [2]. In SCADA, an entire greenhouse operation is governed and monitored through this the supervisory control kiosk. This approach is fairly novel considering the unified system design and the SCADA platform. The design uses efficient sensing technologies enabling the controller to predict and act on situations for perfectly controlled climatic conditions.

3. The Design of Supervisory Control for Greenhouse

Due to this complexity a supervisory control system is designed to provide option control modes and parameters. The system is also equipped with an optimal crop growth selection to determine control values of all controlled variables for various types of crops. The system should take care of defining adequate regulatory and supervisory frameworks to control a greenhouse, equipped with a heating system, an automatic watering system and external and internal independent variables such as temperature, humidity, wind direction and magnitude, and rain drop level are monitored to support the greenhouse operation. Sensors and actuators IN/OUT signals must be of analog and digital standard systems.

The architecture of the proposed supervisory greenhouse control is shown in Figure 1. A user interacts with the supervisory system to perform selection or determination of control modes, controlled parameters, and optimality criteria for a certain crop cultivated in a set of greenhouses. Afterwards, the user preference specifications are passed to the *Supervisory Control Engine (SCE)* that performs the main supervisory computation scenario by utilizing the knowledge-base (i.e., control, climatic, crops, and I/O knowledge). The SCE then produces set of control instructions to array of controllers that directly control and monitor a set of greenhouses.

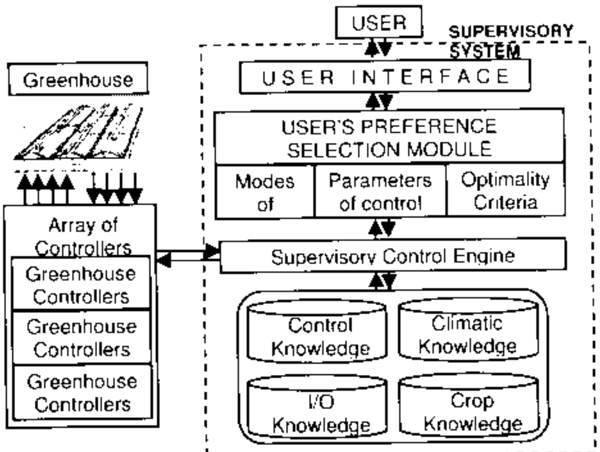

Figure 1: The architecture of greenhouse supervisory control system

The *Control Knowledge-Base* is a knowledge repository of various control methodologies, constraints, tools, and requirements. The *Climatic Knowledge-Base* stores all information about climatic parameters and characteristics. The *Crop Knowledge-Base* is a knowledge repository of crop agronomics requirements, crop types and characteristics. The *I/O Knowledge-Base* stores all relevant characteristics and usage requirements of I/O devices (sensors, transducers and actuators) that may be involved in a certain control scenario.

4. Implementation Issues

The implementation of the proposed supervisory system (Figure 1) has been done on the interface module, user's preference selection module, and partly on supervisory control engine, control knowledge-base, climatic knowledge-base, and crop knowledge-base. The implemented prototype interface has been built on Window-Based Operating System in order to ease user interaction and to enhance the visualization of control display[6]. The main functionality menus (*Identification, Optimization, Simulation, Timer, Interface, Controller*) are displayed on the top bar menu, as shown in Figure 2.

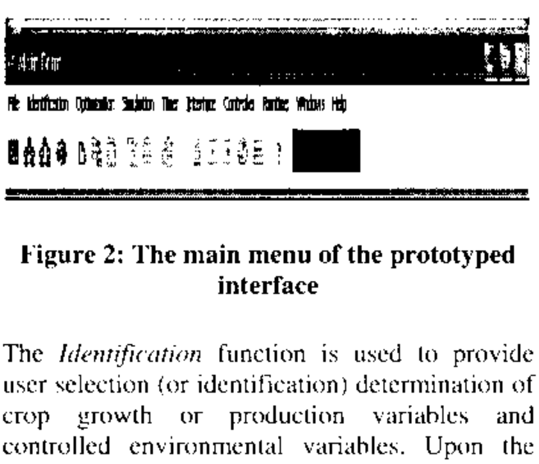

Figure 2: The main menu of the prototyped interface

The *Identification* function is used to provide user selection (or identification) determination of crop growth or production variables and controlled environmental variables. Upon the completion this selection, the system will compute the relation between crop growth or production variables with controlled environmental variables using *Artificial Neural Network (ANN)*. As illustration, for the case of mini cucumber crops a user may use ratio between crop canopy area and the stem diameter as a dependent variable for monitoring crop growth or production; and temperature, humidity, irradiation, added nutrient volume as independent variables of controlled environmental variables. Therefore, the supervisory system must able to measure the canopy area of the crop using, for example, camera capture as shown in Figure 3.

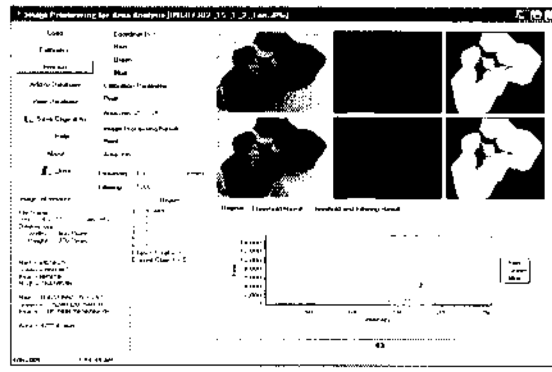

Figure 3: Measurement of canopy area using camera capture

Furthermore, the determination of relation between crop growth or production variables with controlled environmental variables can be done by using ANN as shown in Figure 4.

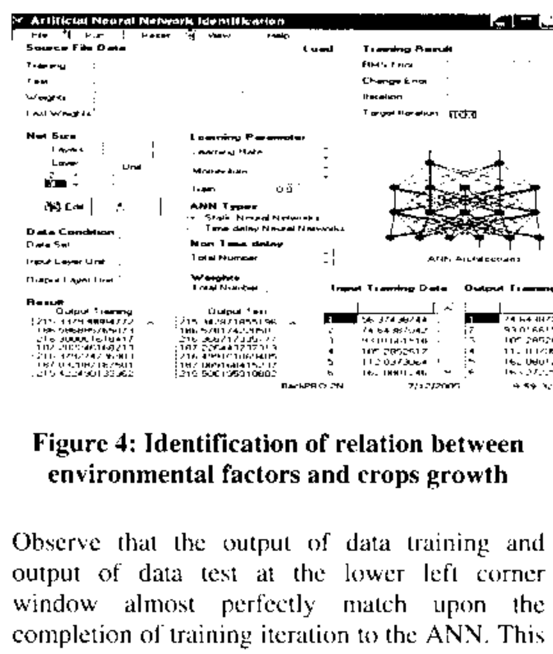

Figure 4: Identification of relation between environmental factors and crops growth

Observe that the output of data training and output of data test at the lower left corner window almost perfectly match upon the completion of training iteration to the ANN. This observation is also proven by the result of comparative plot in Figure 5. In this stage the relation between crop growth or production variables with controlled environmental variables can be computed.

The *Optimization* function enables a user to establish optimal reference setting for controlled variables that have been selected via *Identification* function or menu. To obtain optimal reference setting, the selection control mode must be performed, as shown in Figure 6.

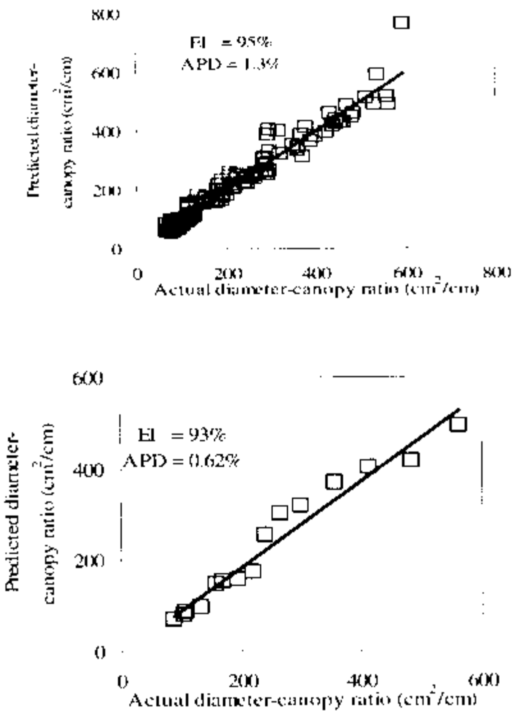

Figure 5: Comparative graph between predicted and actual canopy-diameter ratio

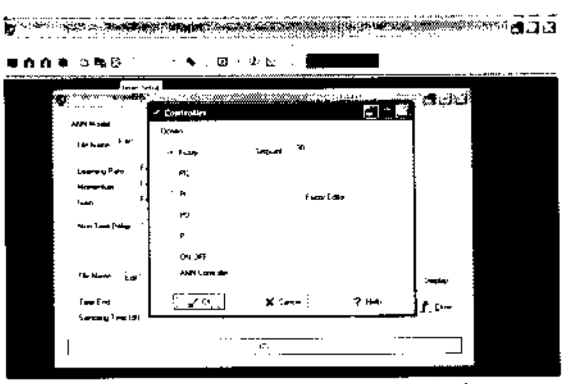

Figure 6: Selection control mode before optimal reference setting

After the optimal reference setting is performed, simulation can be run to observe and validate controlled variables, such us temperature, humidity as shown in Figure 7.

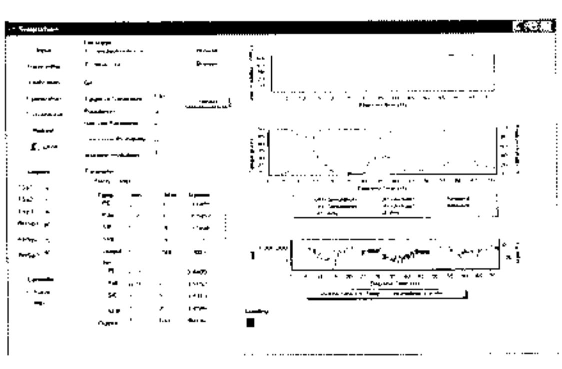

Figure 7: Optimization of controlled variables

The functions *Timer, Interface*, and *Controller* are used to setup the hardware (sensors and actuators/input-output devices) configuration, timing behavior of real-time control for a greenhouse, and interface testing. The last remaining function is *RunTime* that provides the real execution of the whole supervisory control system for greenhouses.

The experimental observation is categorized into nine different treatments with respect to the added nutrient volumes within 15 days of observation. The purpose of these treatments is to observe the control response behavior towards different nutrient conditions, humidity, temperature, irradiation and ratio canopy-stem diameter are shown in Figures 8-10.

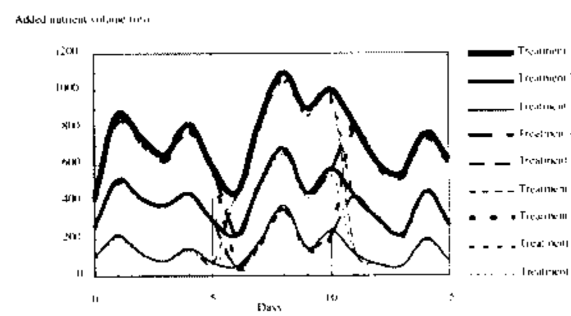

Figure 8: Added nutrient volumes with 9 treatments during 15 days

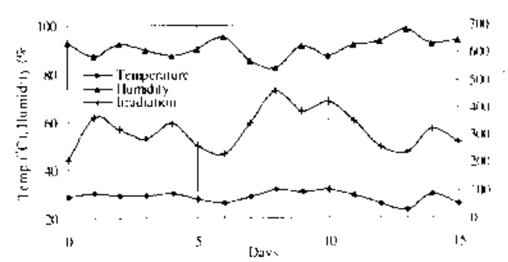

Figure 9: Temperature, humidity and irradiation within greenhouse for 15 days

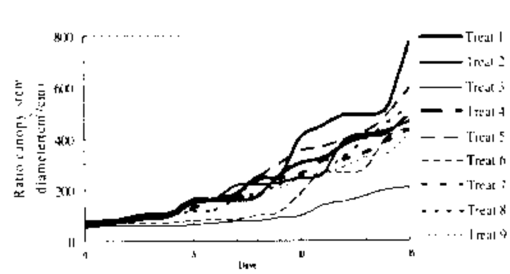

Figure 10: The observed ratio canopy-stem diameter with 9 treatments for 15 days

5. Conclusions & Future Directions

The supervisory system for greenhouse control has been developed and tested with cucumber crops. The novel results of this development and testing is the working functionalities that meet the control criteria and objective based on user preferences. This provides much greater flexibility to the user to cope with varieties of environmental constraints or conditions, types of crops to be controlled in a greenhouse, hardware constraints, and types of control modes.

The future direction to improve the system is to add a module for enabling on-line measurement of climatic parameters from satellite and a module that stores complete behavior and characteristics of crop varieties.

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