Integrating Fuzzy & PID Control Techniques for Plant Cropping Management in a Greenhouse

Kudang B. Seminar
Agricultural Engineering Dept., Faculty of Agricultural Technology,
Bogor Agricultural University, P.O. Box 220 Bogor 16002
e-mail: kseminar@indo.net.id

Abstract

The use of greenhouse technology for plant cropping in a specially designed building structure (called greenhouse), whose environmental parameters can be artificially controlled, has been growing in many countries including Indonesia. The environmental parameters, such as humidity, temperature, light intensity, soil humidity, water and nutrient content in growth media (soil, tissue culture), within a greenhouse must be controlled to produce an optimum condition for plant growth. Managing these parameters to satisfy the best growth condition for the plants is a very difficul task, and thus it is unlikely possible to be done by human operators . Therefore, an automatic control system is required to perform such a job. This paper discusses the design and implementation of a computer-based control system that integrates fuzzy & PID control techniques to regulate three environmental parameters: humidity, temperature, and light intensity inside a greenhouse.

1. Introduction

The use of greenhouse technology for plant cropping in a specially designed building structure (called greenhouse), whose environmental parameters can be artificially controlled, has been growing in many countries including Indonesia. The environmental parameters within a greenhouse must be controlled to produce an optimum condition for plant growth. These parameters include humidity, temperature, light intensity, soil humidity, water and nutrient content in growth media (soil, tissue culture). Managing these parameters to satisfy the best growth condition for the plants is very difficult, and thus it is unlikely possible to be done by human operators. Therefore, an automatic control system is required to perform such a task.

The work on the application of fuzzy techniques for crop production has been done successfully by Morimoto and Hashimoto[4] and Seminar *et al* [8]. However, the combination of fuzzy logic and PID controllers has not been explored thoroughly to support the process control in greenhouses. This paper discusses the design and implementation of a computer-based control system that integrates fuzzy and PID control techniques. The system was designed to accurately regulate three environmental parameters (i.e. humidity, temperature & light intensity) inside a greenhouse in an integrated fashion [7].

2. Control System Design

Since the control system has to perform an intensive computation for controlling the fluctuation and distribution of temperature, humidity, and light intensity inside a greenhouse, a computer becomes the vital part of the control system that performs data acquisition, computation, and conclusion to produce a set of accurate actions for actuators (see Fig. 1). The sensing elements include temperature and humidity sensors (using NTCs/Negative Temperature Coefficients), and light intensity sensors (using LDRs/Light Dependent Resistors).

The software part of the system consists of two main modules: front end interface module and control module, which are implemented using *Visual Basic* and C languages respectively. The front end interface module allows human operators to easily set up desired values of controlled variables and to display and record all observed variables during the process. The C language was chosen to implement the control module for the sake of speed.

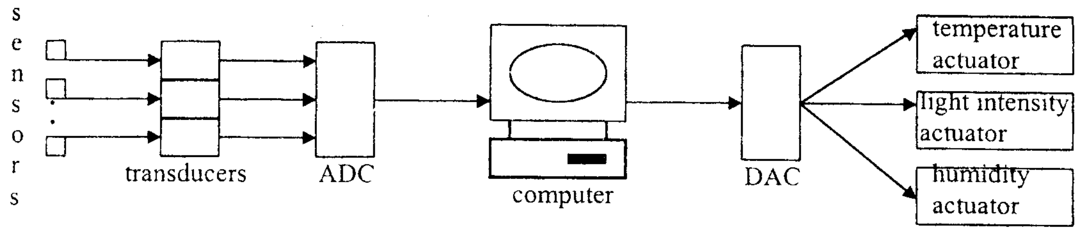

Fig.1 The functional components of the control system.

2.1. Humidity Measurement

The measurement of relative humidity is done by taking the values of wet and dry bulb temperatures using the formula developed by Brooker *et al.*, 1992 [3] as follows:

$$\rho_a C_a \left(\frac{Sc}{\Pr}\right)^{2/3} (T_\infty - T_{wb}) = \frac{M_w . h_{fg}}{R_0 T_{abs}} (P_{vswb} - P_{v\infty}) \qquad (1)$$

where ρ_a : dry air density (kg/m^3)
C_a : dry air specific heat ($J/kg.^0C$)
Sc : Schmidt number (dimensionless)
Pr : Prandtl number (dimensionless)
T_∞ : temperature of free moisture flow (^0C)
T_{wb} : wet bulb temperature (^0C)
M_w : moisture molecule weight (=18.01)
R_0 : universal gas constant
T_{abs} : absolute temperature of dry air (^0K)
P_{vswb} : pressure of partial saturated moisture at wet bulb temperature (Pa)
P_{vs} : pressure of partial saturated moisture (Pa)
h_{fg} : saturated evaporation heat (J/kg)

Furthermore, P_{vs} and P_{vswb} can be computed using the following equations:

$$\ln\left(\frac{P_{vs}}{R}\right) = \frac{A + B\times T + C\times T^2 + D\times T^3 + E\times T^4}{F\times T - G\times T^2} \qquad (2)$$

$$\ln\left(\frac{P_{vswb}}{R}\right) = \frac{A + B\times T + C\times T^2 + D\times T^3 + E\times T^4}{F\times T - G\times T^2} \qquad (3)$$

where R, A, B, C, D, E, F, G are constants, and $273.16\ ^0K \le T \le 533.16\ ^0K$.

Therefore, using Equations (1), (2) and (3), $P_{v\infty}$ can be computed using the following equation:

$$P_{v\infty} = P_{vswb} - ((\rho_a C_a) \times \left({S_c}/{P_r}\right)^{2/3} \times (T - T_{wb})) \times \left({(R_0 \times T)}/{(M_W \times h_{fg})}\right) \qquad (4)$$

Finally, relative humidity (RH) can computed using the equation

$$RH = \frac{P_{v\infty}}{P_{vs}} \times 100\% \qquad (5)$$

2.2. PID Controller

The equation describing the behavior of the PID controller is as follows [2]:

$$I_{out} = K_P(\varepsilon(t) + K_I \int \varepsilon(t)dt + K_D \frac{d\varepsilon(t)}{dt}) + I_0 \tag{6}$$

where I_{out} is the output from the controller when there is an error ε; K_P, K_I, and K_D are proportional, integrative, and derivative constants respectively; I_o is the set point output when there is no error. The determination of constants K_P, K_I, K_D is done using Ziegler and Nichols method [1].

2.3. Fuzzy Controller

Fuzzy control is characterized by linguistic statements which can be expressed qualitatively using *"IF-THEN"* rules, such as

IF the light intensity is *very high*
THEN move the fins to position *almost-fully-closed.*

In this work, we utilize fuzzy logic to achieve flexibility, smoothness, and robustness. The membership function is determined using triangular model such as shown in Figure 2. This model is simple and has shown good performance in our experiment. Other models [10] for determining membership functions can be used for this purpose, but it might introduce higher computational cost and slower response time.

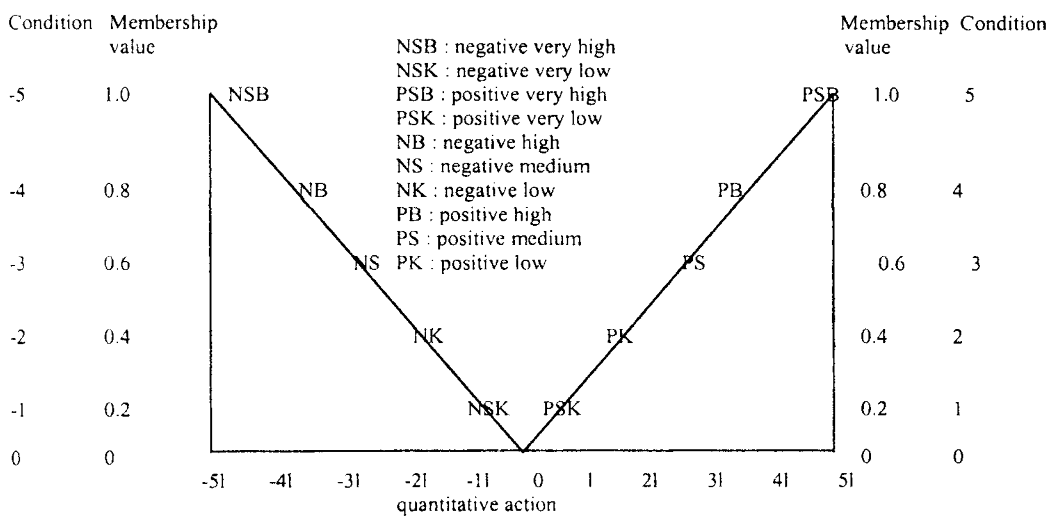

Fig. 2 Membership function of the fuzzy controller.

2.4. System Control Architecture

The system control consists of PID and fuzzy controllers, as shown in Figure 3, which work alternately in an integrated fashion. The output of the PID controller is applied to the process if the error $\varepsilon(t)$, as expressed in Equation (1), is small and is linear with respect to time t. Otherwise, the output of fuzzy controller is applied to the process. The selection of the applied output from the PID and fuzzy controllers is mechanized by the multiplexer (MUX) controlled by the fuzzy controller.

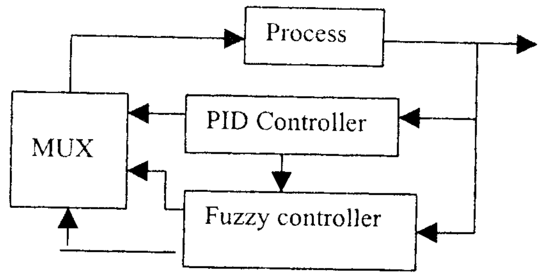

Fig. 3 The control system architecture.

3. Implementation and Practical Results

The whole structure of the implemented control system and greenhouse is shown in Figure 4. Multiple sensors are used for each environmental parameter measurement to ensure representative distribution of measured values of each parameter. The roof of the greenhouse consists of four sets of fins to control the entrance levels of solar radiation. Each set of fins is controlled by one motor so that four sets of fins can be moved independently based on the position of the sun. Figure 5 shows the variation of fin opening angles.

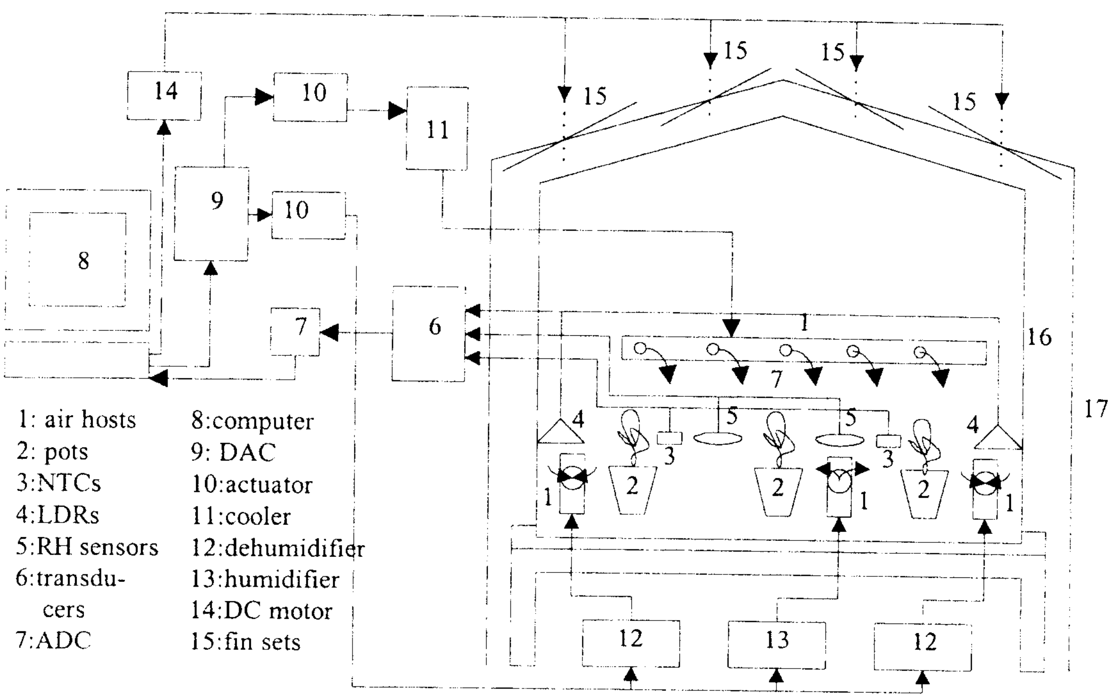

Fig. 4 The whole implemented control system and greenhouse.

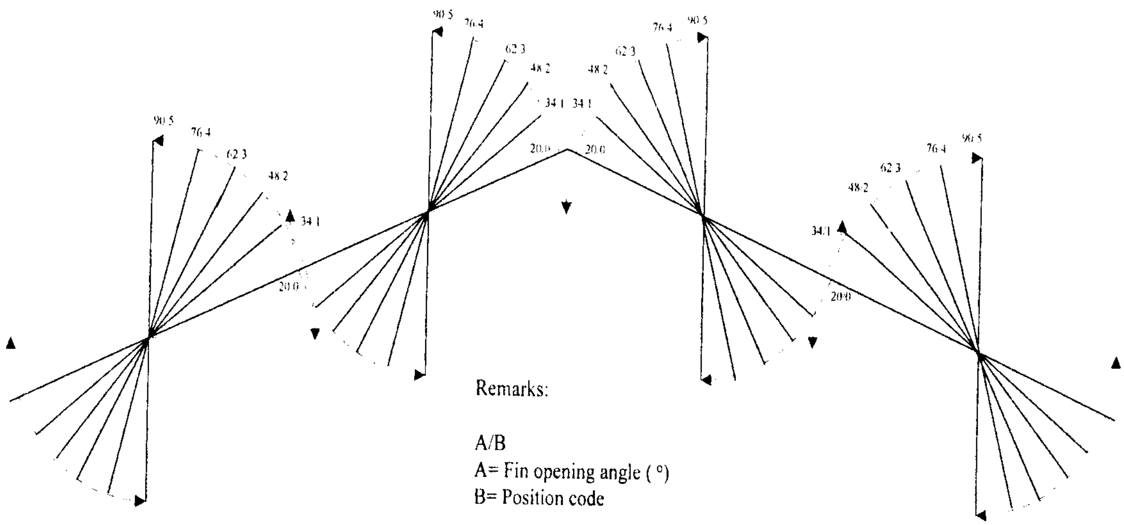

Fig. 5 The variation of fin opening angles.

It is shown in Figure 6 that within 150 seconds, the light intensity level inside the greenhouse reaches the light intensity set point (i.e., 6000 lux). However, between time 0 to 600 (in seconds), the error $\varepsilon(t)$ is large and is not linier, and thus the fuzzy controller takes care the control. After 600 seconds, $\varepsilon(t)$ becomes small and is linear with respect to time t. At this point, the PID controller takes over the controll process and maintains the light intensity level to coincide with set point level. It is worth noting that the fluctuation of light intensity corresponds with the fluctuation of fin opening angles (Δ).

The performance of humidity controller with set point 80% is shown in Figure 7, where, the initial relative humidity (RH) inside the greenhouse was 75%. The controller reaches the set point level after 40 seconds. Figure 8 shows the performance of the temperature controller with set point 22^0 Celsius. The zone cooling method [9] is used to implement the cooling system.

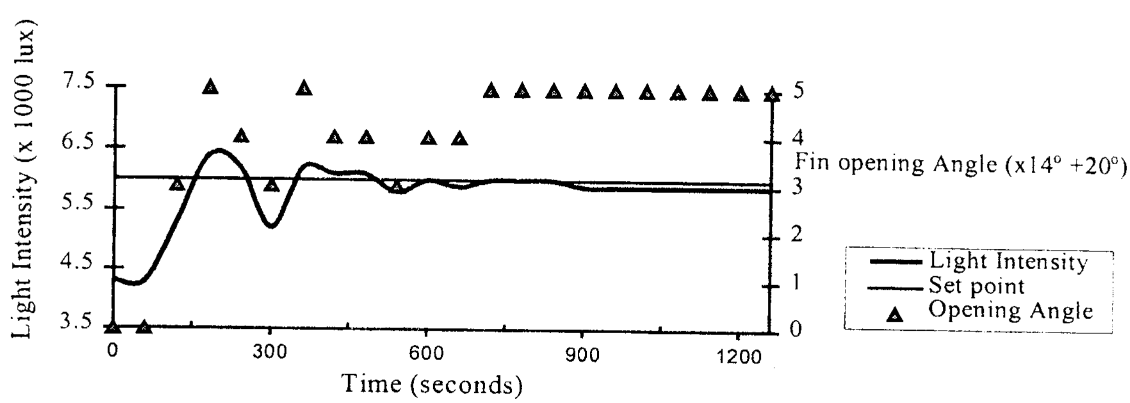

Fig.6 The performance of light intensity controller with set point 6000 lux.

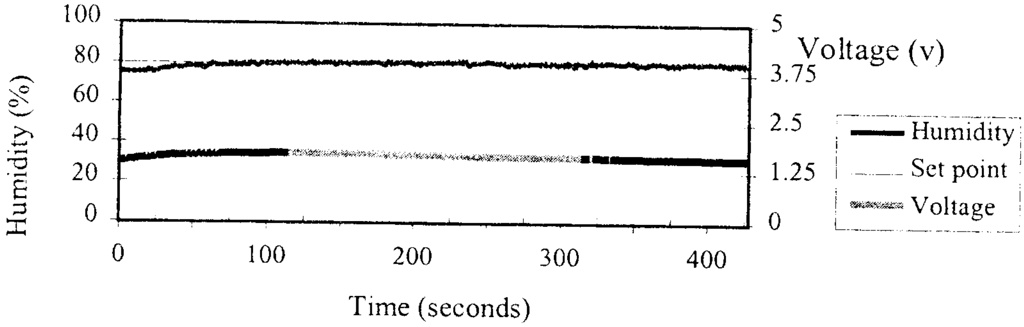

Fig. 7 The performance of humidity controller with set point (SP) 80%.

To evaluate the overall performance of our system, we tested the system to control the growth of Japanese Spinach (*Amaranthus sp.*), called Horenzo. This spinach is produced by Takii & Co.Ltd, Kyoto, Japan. The sample of this test was split into two groups: (1) a group of spinach with controlled treatment inside the greenhouse, and (2) the group of spinach without control treatment outside the greenhouse. The two sample groups were compared with respect to their height, dried weight, and fresh weight. Based on the daily observation (Figure 8), the h~~w~~eight and weight of the controlled spinach is higher than that of uncontrolled spinach.

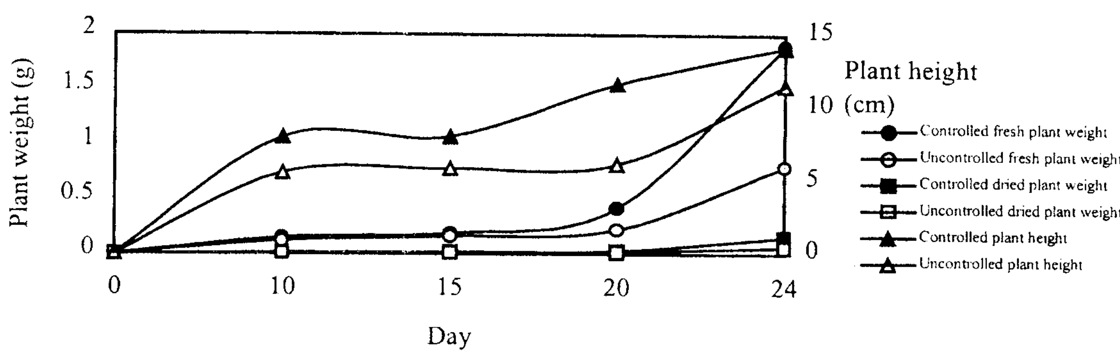

Fig. 8 The daily observed height and weight of controlled and uncontrolled spinach.

4. Conclusion and Future Recommendations

The design of a computer-based control system for regulating temperature, relative humidity, and light intensity inside a greenhouse for crop production has been implemented and tested. The current implemented software part is run on personal computers, and the interface PCL-812 PG was used to implement ADC and DAC. The system shows good control performance in terms of response time, stability, and accuracy. The control system utilizes both fuzzy and PID control techniques which are suitable for dealing with highly fluctuating and intrinsically fuzzy environmental parameters.

Future improvement needs to be done to the current system is the development of an adaptive control system which can automatically recalculate the PID constants (i.e., K_P, K_I, K_D) and membership functions of the fuzzy controller for different types of crops or plants based on their environmental parameter requirements. Moreover, the ability to extract vital features of plants being controlled using image processing techniques can be added to the current system to enable more comprehensive control handling, such as discussed by Murase, Nishiura and Mitani [5].

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Bibliography

[1] Astrom, K.J. and T. Hagglund, "*Automatic Tuning of PID Controller*", Instrument Society of America, USA, (1988).

[2] Bolton, W, "*Mechatronics: Eelectronic Control Systems in Mechanical Engineering*", Addison Wesley Longman Ltd., Edinburg Gate, England, .(1995).

[3] Brooker, D.B., W.B.A. Fred and W.H. Carl, "*Drying and Storage of Grains and Oilseeds*". Van Nostrand Reinhold, USA, (1992).

[4] Morimoto, T. and Y. Hashimoto, "Application of Fuzzy Logic and Neural Network to the Process Control of Solution pH in Deep Hydroponics Culture", *Mathematical and Control Applications in Agriculture and Horticulture*, editor: Y. Hashimoto and W. Day, p.147-152. IFAC Workshop Series, 1, (1991).

[5] Murase, H, Nishiura, and Mitani, K, "Environmental Control Strategies Based on Plant Responses Using Intelligent Machine Vision Technique", *Computers and Electronics in Agriculture*, 18, p.137-148, Elsevier Science B.V., (1997).

[6] Phillips, C.L. and R.D. Harbor, "*Feedback Control Systems*", Prentice-Hall International, Inc. NJ. USA, (1988).

[7] Seminar, K.B, "Capturing and Integrating Knowledge, Goal, and Actions of Intelligent, Cooperative Agents", *Agricultural Engineering Bulletin*, 1, IX, p. 30-40, (1994).

[8] K.B. Seminar *et al.* "The design and implementation of a computer-based system for greenhouse in tropical regions". *3rd IFAC/CIGR Workshop on Artificial Intelligence in Agriculture*, editor: T. Kozai, H. Murase, & T. Hoshi, p. 42-47, Chiba, Japan, (1998).

[9] Suhardiyanto, H., "*Studies on Zone Cooling Method for Greenhouse Culture*", Dissertation, The United Graduate School of Agricultural Sciences, Ehime University, Japan, (1994).

[10] Wang, LA, "*Course in Fuzzy Systems and Control*". Prentice-Hall International, Inc. NJ., USA, (1997).