

- Invited paper -

Fuzzy Control of a Germination Chamber

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Abstract

The design of a fuzzy control system for a germination chamber for hydroponic crops is presented. The system measures humidity and temperature inside the chamber and, by means of a Sugeno type fuzzy controller embedded in an Arduino board, it generates control signals that are sent to a forced ventilation system and to the artificial lighting control system. Experiences were carried out with a germination chamber using this fuzzy control system. Lettuce seeds were sowed in the fuzzy control chamber and on a conventional culture tray, with the former yielding better growth results.

Keywords: Fuzzy Logic, Embedded Systems, Sugeno, Germination Chamber.

1. Introduction

The fuzzy sets theory proposed by Zadeh [1], unlike mathematical logics, allows using easily understandable linguistic terms. There is a branch of fuzzy logics that deals with the study of control systems [2]. Fuzzy controllers offer the advantage of greater interpretation ability to be designed based on knowledge provided by an expert on a given topic. To that effect, linguistic labels can be used for the variables used, such as: “very low”, “low”, “high”, “very high”. On the other hand, the fuzzy sets that define variables have flexible membership values. As a result of these characteristics, fuzzy control systems can respond better than conventional reactive systems. Additionally, it allows using the experience of experts for building the control system, rather than using a mathematical model to do so.

In hydroponic germination chambers, ventilation is a significant variable for seed germination and crop development, not only due to CO₂ contribution, but also due to temperature control [3], [4]. With the system proposed here, the Sugeno type fuzzy controller measures both temperature and humidity inside the germination chamber, and then generates

the corresponding control signals for the forced ventilation system and temperature control provided by an incandescent lamp.

2. Data Acquisition System

Humidity and temperature variables were acquired using DHT22 sensors, which allow taking measurements through a serial connection.

For the data acquisition procedure, an embedded Sugeno type fuzzy controller software was developed, and for output signal control, an Arduino Mega 2560 board with Atmel Atmega2560 processor was used. It has 54 input/output digital pins (15 of which can be used as PWM outputs), 16 analog inputs, 4 serial ports, one USB connection, one power connector, and one reset button.

The Atmega2560 has 256 KB flash memory to store the code. The bootloader uses 8 Kb, and it also has 8 KB of SRAM and 4 KB of EEPROM, which allows reading and writing using the EEPROM library.

To avoid galvanic contact between the digital system of the Arduino board and the power stages, optocouplers controlling the artificial lighting and forced ventilation systems were used. Fig. 1 shows a block diagram of the fuzzy controller.

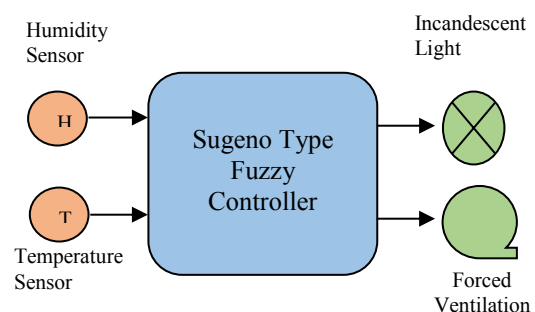


Fig. 1. Block diagram of the fuzzy control system

2.1. Fuzzy Controller Design

Given that the fuzzy controller is embedded into the memory of the Arduino board, a Sugeno type control system was selected, since fuzzy inference calculation can be designed in less code lines than in Mamdani type controllers because there is no defuzzification stage.

For fuzzy partition design, data provided by experts in Plant Biology from the Biotechnology Institute of Misiones "María Ebe Reca" (InBioMis), which belongs to the National University of Misiones, were used.

Input and output fuzzy sets (Figures 2 and 3) were defined, as well as the discourse universe for each variable (U_T°, U_H, U_V, U_LC) and the corresponding linguistic labels (Tables 1 and 2).

Tables 3 and 4 show the fuzzy sets for output variables Ventilation and Lighting, respectively.

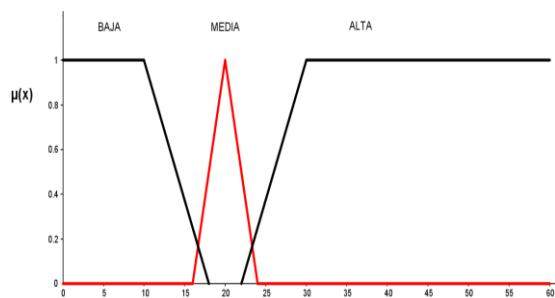


Fig. 2. Fuzzy sets for the input variable Temperature

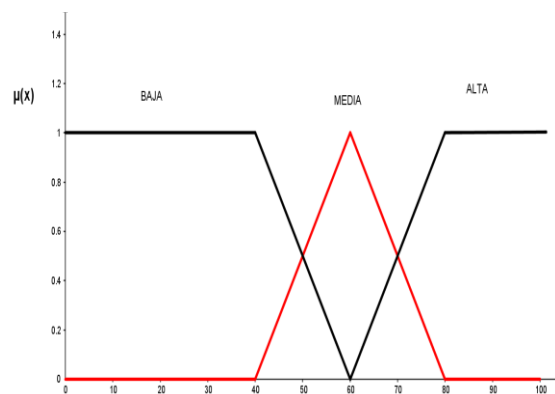


Fig. 3. Fuzzy sets for the input variable Humidity

Table 1. Coordinates of the fuzzy sets for the input variable Temperature

Label	Temperature (°C)
U_T°	[0, 60]
LOW	[0, 0, 12, 18]
MEDIUM	[16, 20, 24]
HIGH	[22, 30, 60, 60]

Table 2. Fuzzy sets for the input variable Humidity

Label	Relative Humidity (%)
U_H	[0, 100]
LOW	[0, 0, 40, 60]
MEDIUM	[40, 60, 80]
HIGH	[60, 80, 100, 100]

Table 3. Fuzzy sets for the output variable Ventilation

Label	Power %
U_V	[0, 100]
OFF	[0]
MEDIUM	[50]
HIGH	[100]

Table 4. Fuzzy sets for the output variable Lighting

Label	State
U_V	[0, 1]
OFF	[0]
ON	[1]

2.2. Fuzzy Rules

The base of fuzzy rules was designed with the input of an expert in Plant Biology, who indicated which are the optimal values for the variables involved in the germination and growth process of hydroponic crops. These fuzzy rules are described in Fig. 4.

3. Sugeno Type Fuzzy Controller Software Design

To define the subroutines used, an example of the function that allows calculating membership for a triangular fuzzy set defined by points a, b and c is presented (see Fig. 5), and a value of the input variable given by x is defined as the type of data to return. In this case, PE_T; all variables are defined as float variables.

The flow chart shown in Fig. 6 presents the setup routine for the fuzzy control program of the germination chamber.

1. If (temperature is low) and (humidity is low) then (ventilator is off) (hot_light is on)
2. If (temperature is low) and (humidity is medium) then (ventilator is off) (hot_light is on)
3. If (temperature is low) and (humidity is high) then (ventilator is 50%) (hot_light is on)
4. If (temperature is high) and (humidity is high) then (ventilator is 100%) (hot_light is on)
5. If (temperature is medium) and (humidity is low) then (ventilator is off) (hot_light is off)
6. If (temperature is medium) and (humidity is medium) then (ventilator is 50%) (hot_light is off)
7. If (temperature is medium) and (humidity is high) then (ventilator is 100%) (hot_light is off)
8. If (temperature is high) and (humidity is low) then (ventilator is 100%) (hot_light is off)
9. If (temperature is high) and (humidity is medium) then (ventilator is 100%) (hot_light is off)
10. If (temperature is high) and (humidity is high) then (ventilator is 100%) (hot_light is off)

Fig. 4. Fuzzy rules involved in the germination and growth process of hydroponic crops

```
float PE_T(float x, float a, float b, float c)
{
    float membership;
    if (x<a or x>=c)
    {
        membership=0;
    }
    if (x>=a and x<b)
    {
        membership=(x-a)/(b-a);
    }
    if (x>=b and x<c)
    {
        membership=(c-x)/(c-b);
    }
    return membership;
}
```

Fig. 5. Flow chart of the setup routine

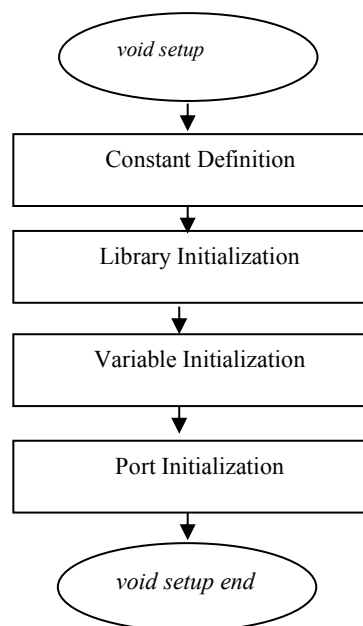


Fig. 6. Flow chart of the setup routine

The main body of the fuzzy control program for the germination chamber starts by reading ports and sensors to get system variable values. Then, with the values of input variables H and T, membership functions are used for calculations to determine the active rules. Since rules have the format R_n : if x_1 is A_1 and y_2 is B_2 , the defuzzified output z is:

$$z = \frac{x_1 \omega_1 + y_1 \omega_2}{\omega_1 + \omega_2} \quad (\text{Eq. 1})$$

Where ω_1 and ω_2 are the weights of the fuzzy outputs of the active rules. Once control variables are obtained, the corresponding signals are sent to the power board. Then, variable values are sent through both communication channels - USB port and BT module. Before going back to the start of the cycle, a one-second delay is activated, as shown in the flow chart in Fig. 7.

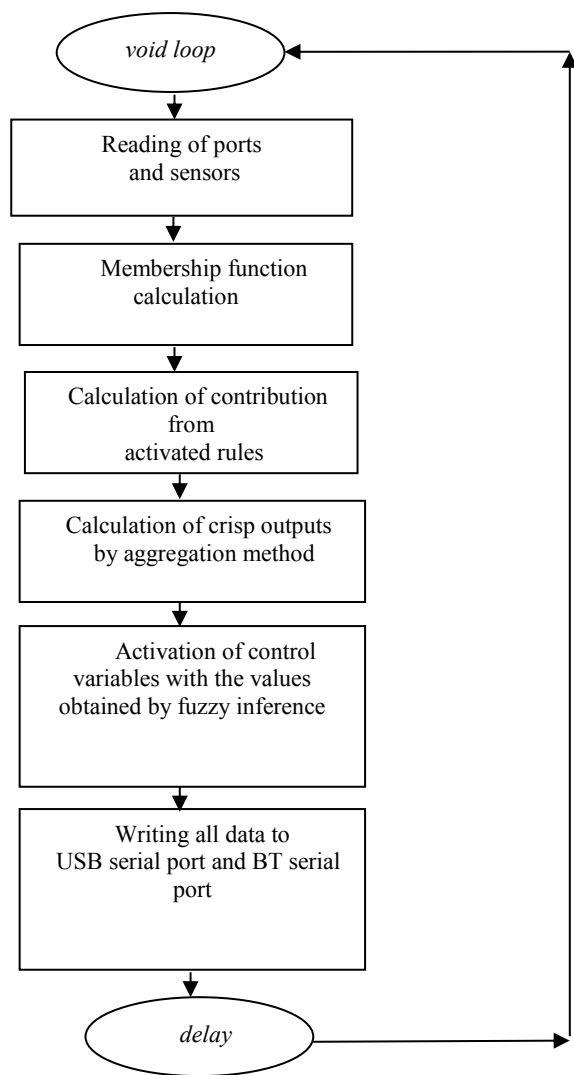


Fig. 7. Flow chart of the loop routine

4. Results

To assess the efficacy of the germination chamber, the system was compared with a conventional floating root system mounted on a tank in an adiabatic enclosure with temperature controlled by means of an air conditioning system and a fluorescent tube panel to provide constant artificial lighting. Hydroponic nutrients were supplied in the same proportion in both systems. To check the amount of nutrients present, EC was measured using a TDS digital conductivity meter, obtaining a value of 2000 ppm.

Light intensity measurements were done using a Hepta- Instruments light meter (CEM), which is calibration-certified by the INTI. In the tank, 1150 lux were recorded, and in the interior of the chamber, 2100 lux were recorded.

Fig. 8 shows the difference in quality of the seedlings in both germination systems.

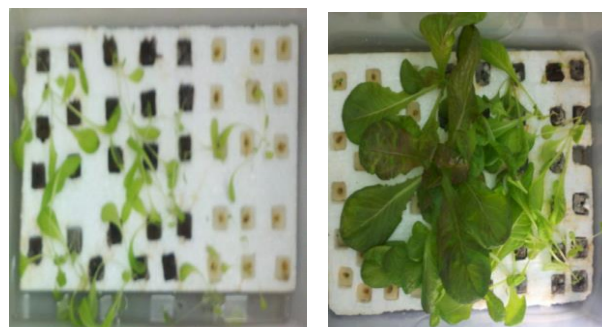


Fig. 8. Seedling evolution in a tank (left) and in the germination chamber (right).

The temperature and relative humidity data for each germination system, as well as their stability inside the chamber, are represented in Figures 9 and 10.

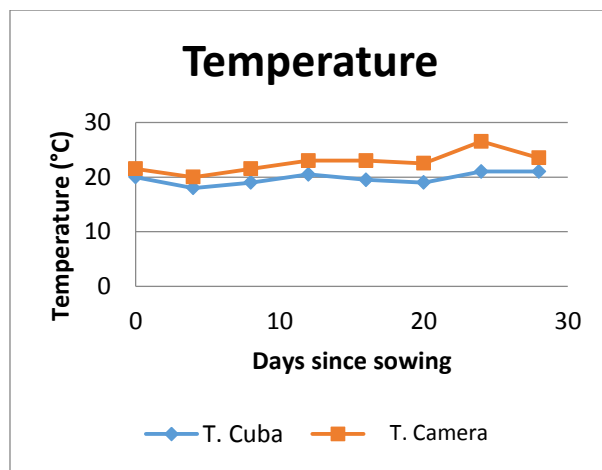


Fig. 9. Chamber temperature as a function of days since sow

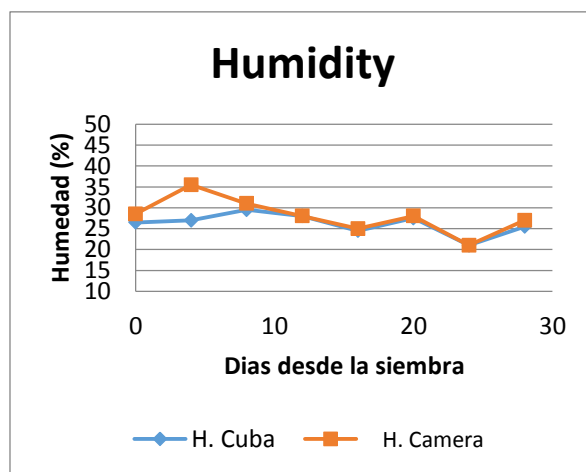


Fig. 10. Chamber humidity as a function of days since sow

Fig. 11 shows a seedling from the chamber, with a total length of 30 cm, 13-cm radicle, and between 5-7 leaves, which far exceeds the results obtained

in the open air tank. These values are better than those reported in the literature by other authors, both with commercial solutions as well as those manufactured with distillation residue from alcohol manufacture [5]. On the other hand, experiences with various bioactive products were carried out on compacted red ferralitic soil, and, on average, plants grew between 3.97 and 5.71 leaves each on soil after 30 days [6], which is lower than the values obtained in this experience.



Fig. 11. Crop obtained after 30 days.

The control costs for this work are smaller than with other hydroponic systems such as the Dynamic Root Floating (DRF) Hydroponic System [7] that use digital control systems, which are also harder to implement for small producers. Other control systems that use fuzzy logic in embedded systems [8] do not show field results, while other researchers focus on keeping the amounts of nutrients and CO₂ stable [9], using expensive sensors.

5. Conclusions and Future Work

A Sugeno type fuzzy controller was designed to control a hydroponic germination chamber with the input from experts in Plant Biology from the InBioMis. An Arduino Mega 2560 board was used for data acquisition and processing. Input variables are analog values measured with humidity and temperature sensors and processed using fuzzy control software, generating forced ventilation and incandescent lighting control signals.

The results obtained show that the fuzzy controller is able to control the environment inside the

chamber to improve crop production.

As future work, we are planning to use controllers based on fuzzy logic designed for other types of hydroponic crop devices, such as nutrient film circulation devices and floating root with nutrient agitation devices.

References

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