



## Realization of a Greenhouse Monitoring and Control System Using Fuzzy Logic Controller

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### ABSTRACT

The design, development and construction of a Greenhouse monitoring and control system using a fuzzy logic controller were presented in this paper. The study was aimed at controlling various system parameters such as temperature, humidity, soil moisture, and lighting. The greenhouse controller system was designed using two microcontrollers, of which one microcontroller was interfaced with a DHT11 temperature sensor, an FC-28 soil moisture sensor, and a light-dependent resistor sensor used to measure the various climatic conditions. The microcontroller also sent these measured parameters as data to the control and monitoring application, while the other microcontroller was interfaced with an L298N motor driver module and a TIP122 power metallic field-effect transistor. Which was used to control the fans, heater, irrigation pump and light-emitting diode (LED) using Pulse Width Modulation (PWM). The system output parameters varied with a sudden change in the input value and error value to ensure the environment was optimal with little to no overshoot in the actuators. This controller can be useful in the automation of agricultural processes, most especially in commercial food crops production. And can be helpful in the monitoring of crops during the nursery stage when the plants are still tender and require a controlled environment to survive.

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### INTRODUCTION

The environmental requirements of living plants are quite complex and non-linear as the biological environment likely has a significant effect on the physical surroundings. In (Pascianos et al, 2003), a fuzzy logic control method (FLC) was used in the design of a highly reliable and efficient control system for the control of greenhouse. Parameters such as temperature, soil moisture and light intensity were considered since these parameters were stochastic process variables. However, this is in contrast with the use of conventional control methods such as ON and OFF actuation and Proportional Integral Derivative (PID), which involves the mathematical modelling of the control system.

In general, the elements affecting the growth of plants include both outside conditions and greenhouse conditions. The outside

conditions include; radiation, cloudiness, temperature, humidity, rain and wind speed. The greenhouse conditions include; heating, ventilation, lighting and plant conditions. The outside conditions are unchangeable. However, greenhouse climatic conditions can be managed and controlled more easily as presented in (Jung et. al., 2008; Ali et. al., 2016; Carrasquilla-Batista and Chacon-Rodriguez, 2017).

In recent times, there is a serious need for automation and intelligent control of various environmental parameters that are necessary for the efficient growth and development of crops and plants (Nyong-Basse and Epemu, 2022). The use of a smart greenhouse in the cultivation of plants is one way to provide an environment that is close to better conditions for plant growth. To ensure that life thrives and flourishes in this environment, there is a serious need to control the



various system parameters. Many efforts have been made to develop advanced computerized greenhouse climatic control systems of which interesting optimal control approaches such as artificial neural networks and genetic algorithms have been proposed (Ioslovich et al., 2009; Van Straten and Van Henten, 2010).

The flexibility of the fuzzy logic control method is useful in coping with the imprecision of real-world situations. Fuzzy logic thus refers to fuzzy sets which are sets with non-sharp boundaries. It is hence widely used in machine control. Therefore, it allows for a generalization of conventional logic and provides for terms between true and false as presented in (Isizoh, et al 2012).

The simplicity in the design of a Fuzzy controller is based on the fact that for the control of climatic conditions, only reliable information about the system's behaviour provided by a grower's experience is necessary to create the control algorithm. Hence, eliminating the need for a mathematical model that describes the behaviour of the system (Revathi and Sivakumaran, 2016).

Devi et al., (2015) stated that the fuzzy logic approach was feasible and can be an interesting alternative to other conventional control, even when the system model was known and the system is linear. The authors implemented a fuzzy logic controller which presented a slightly superior dynamic performance. They proposed the use of MATLAB/Simulink and LabVIEW which are powerful tools, respectively for simulation and controller design.

Urrea et al., (2020) proposed a new scheme for a fuzzy logic controller, which includes acceleration as one of its linguistic variables, as opposed to other techniques and approaches that have been developed and reported in previous years. This method is used for controlling the

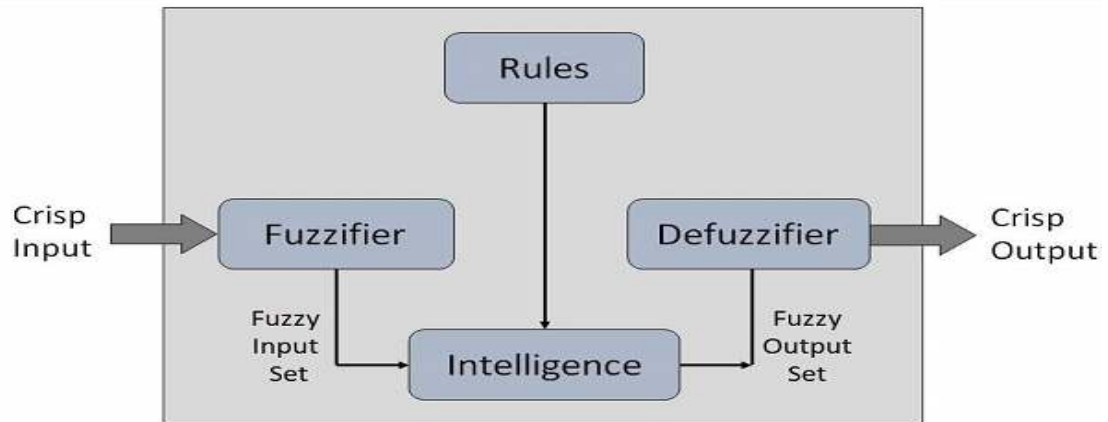
tracking of the trajectory followed by the joints of a 2-Degree of Freedom (DoF) manipulator robot. To this end, a complete simulation environment was developed through the MATLAB/Simulink software. Finally, the performance of the developed system was assessed and then compared to the performance of a classic Proportional Integral (PI) controller. It was found that the incorporation of the fuzzy variable acceleration significantly improved the system's response.

The purpose of the work is to implement a greenhouse monitoring and control system using fuzzy logic. This can be useful in the automation of agricultural processes, most especially in commercial food crops production. And can be helpful in the monitoring of crops during the nursery stage when the plants are still tender and require a controlled environment to survive.

## METHODOLOGY

In this study, the ATmega328P microcontroller onboard the Arduino development board and LabVIEW Control Software were used to implement the design of the Greenhouse monitoring and control system.

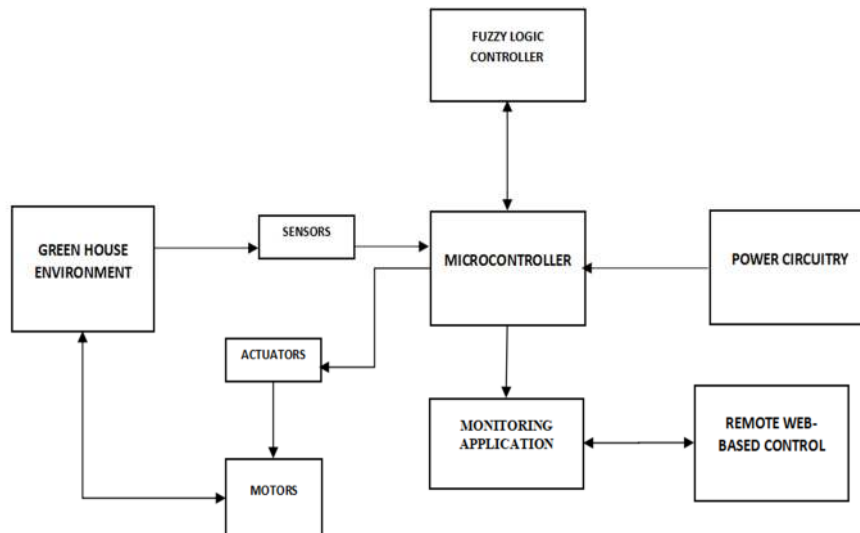
The microcontroller was used to receive data from the sensors, which was sent to the monitoring and control application. The control application implemented the fuzzy algorithm thus generating the output parameter based on the variation in system parameters. This output was also sent as a control signal to the microcontroller. The fuzzy logic controller designed consists of four main sections which include; (a) Fuzzifier; (b) Rules; (c) Inference system; (d) Defuzzifier. Figure 1 shows the block diagram of a fuzzy logic controller.



**Figure 1.** Block diagram of a fuzzy logic controller

The Fuzzifier is the section of the controller where crisp input values were converted into fuzzy values based on user-defined values known as membership functions or linguistic variables. The rules consist of defined algorithm patterns, described using **IF THEN** statements based on the grower's experience that determines the output parameters. The inference system determines the output derived from the combination of input membership functions and rules. Defuzzifier is the section of the controller in which output values are converted into crisp or analog values.

The greenhouse system design consists of both hardware and software. The hardware was implemented using two ATmega328P microcontrollers onboard the Arduino development board, DHT11 temperature sensor, FC-28 soil moisture sensor and light-dependent resistor sensor, L298N motor driver module, TIP122 power transistor, 12V fan, heater and pump. These components were connected and mounted on a greenhouse structure, which was used to test the performance of the fuzzy controller. The general system Block diagram is shown in Figure 2.



**Figure 2.** System block diagram



The software consists of a fuzzy controller and monitoring application. This was implemented using LabVIEW software and Arduino integrated development environment. The fuzzy controller was divided into three major sub-controllers which include a lighting controller, a temperature controller and an irrigation controller. The design process of the various controllers was discussed as follows;

### Lighting Controller Design

The controller membership functions consist of input membership functions and output membership functions. The input membership functions consist of the current light intensity value and error value. This membership function was obtained by mapping the measured values of the light-dependent resistor to the input membership function. The range of values of the input membership functions was 0% to 100% mapped

from 0.5V to 4.85V measured by the sensor. The desired lighting value required by the Plants was around 70% to 80% which gave an error membership function range of -30% to 70%. The output membership function representing the lighting rate was around 0% to 100% which represented the light-emitting diode duty cycle in percentage. The rule was designed using simple **IF THEN** rules that determine the output values. The maximum number of rules that can be used is given by the formula.

$$\text{Rules} = N^M$$

Where N = Total number of membership functions  
M = Total number of input variables

Hence, the maximum number of rules that can be created was 16. However, since the input parameters were related the number of rules created for this controller was four. Table 1 shows the membership functions of the lighting system.

**Table 1.** Membership functions of lighting system

Membership function	Current light intensity (%)	Membership function	Error in light intensity (%)	Membership function	Lighting rate duty cycle (%)
Very dark	0 to 25	Small Negative	-30 to -3	Stop	0 to 5
Dark	23 to 50	Zero	-5 to 23	Low	4 to 45
Medium	47 to 75	Small Positive	20 to 47	Average	40 to 65
Bright	73 to 100	Large Positive	45 to 70	High	55 to 100

### Temperature Controller Design

The temperature controller membership functions consist of both input membership functions and output membership functions. The input membership functions were the input temperature value and error in temperature value. This was designed by mapping the measured values of the DHT11 temperature sensor to input membership functions. The range of values of the input membership functions was 100°C to 0°C. The desired temperature range required by the plants was set to 24°C to 29°C. This desired value gave an error in the temperature membership

function range of -75°C to 29°C. The rules governing the controller were implemented using simple **IF THEN** rules which determine the output values.

The output membership function range consists of the ventilation rate and heating rate. The ventilation rate was around 0% to 100%. This percentage value was mapped into a duty cycle value used to control the fan speed. The heating rate was also around 0% to 100% and was mapped into a value to control the voltage applied to the heating element used. The membership functions of the temperature system are presented in Table 2.



**Table 2.** Membership functions of temperature system

Membership functions	Current temperature (°C)	Membership function	Error (°C)	Membership function	Ventilation rate (%)	Heating rate (%)
Very cold	0 to 16	Large negative	-75 to -6	Stop	0 to 5	0 to 20
Cold	15 to 24	Small negative	-8 to 5	Slow	4 to 45	15 to 60
Medium	25 to 35	Zero	3 to 12	Medium	40 to 60	55 to 80
Hot	33 to 100	Large positive	10 to 29	Fast	55 to 100	75 to 100

### Irrigation Controller Design

The irrigation controller membership functions consist of both input membership functions and output membership functions. The input membership functions consist of the current soil moisture value and error in soil moisture value. This was implemented by mapping the measured values of the FC-28 soil moisture sensor to input membership functions. The range of values of the input membership functions was 0% to 100% mapped from 1.72V to 4.85V

measured by the sensor. This desired value gave an error in the temperature membership function range of -75°C to 30°C. The rules governing the controller were implemented using simple **IF THEN** rules which determined the output values. The output membership function range for the irrigation rate was around 0% to 100%. This output value was mapped into the duty cycle used to control pump speed. Table 3 shows the membership functions of the irrigation system.

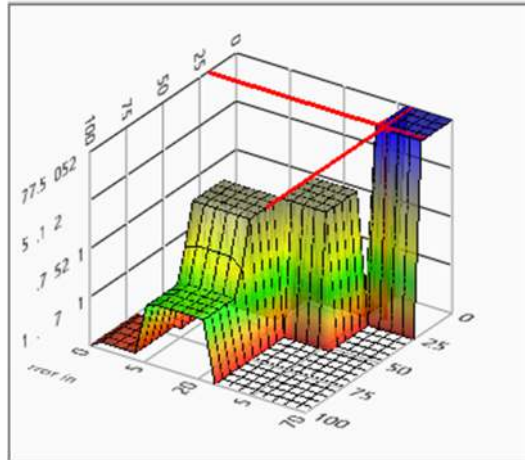
**Table 3.** Membership functions of irrigation system

Membership functions	Current soil moisture range (%)	Membership functions	Error in soil moisture range (%)	Membership function	Irrigation rate duty cycle (%)
Very wet	0 to 20	Negative large (LN)	-70 to -48	Stop	0 to 5
Wet	18 to 40	Negative small (SN)	-50 to -28	Slow	4 to 25
Average	38 to 60	Zero	-30 to -8	Medium	20 to 45
Dry	58 to 80	Positive small (PS)	-10 to 12	Fast	40 to 65
Very dry	78 to 100	Positive large (PL)	10 to 30	Very fast	60 to 100

### RESULTS AND DISCUSSION

After simulating the fuzzy controllers using LabVIEW's built-in control and simulation tool, it was observed that the lighting controller for the lighting system, fluctuated with the lighting conditions in the greenhouse. This was based on the value of luminance intensity measured using

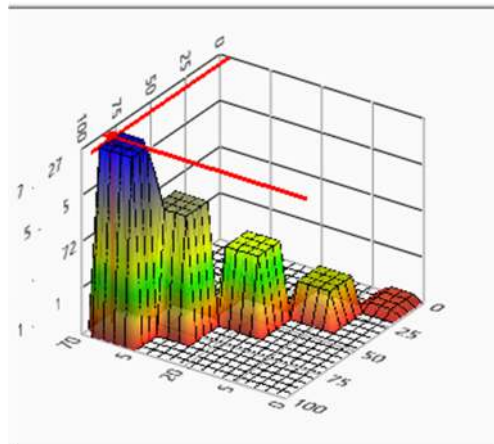
the light-dependent resistor sensor. However, the system experienced a response delay of 4 seconds when switching from one state of operation to another. The simulation 3D Plot of the output to input relationships from the LabVIEW test system for lighting control is presented in Figure 3.



**Figure 3.** 3D Simulation Plot of the lighting controller input and output relationship

It was also observed that the soil moisture controller, was able to control the rate of water supply to the greenhouse. This control was dependent on the soil moisture. As the pump was switched on when in very dry soil, and turned off in very wet soil. However, when the range of input membership function was exceeded, that was

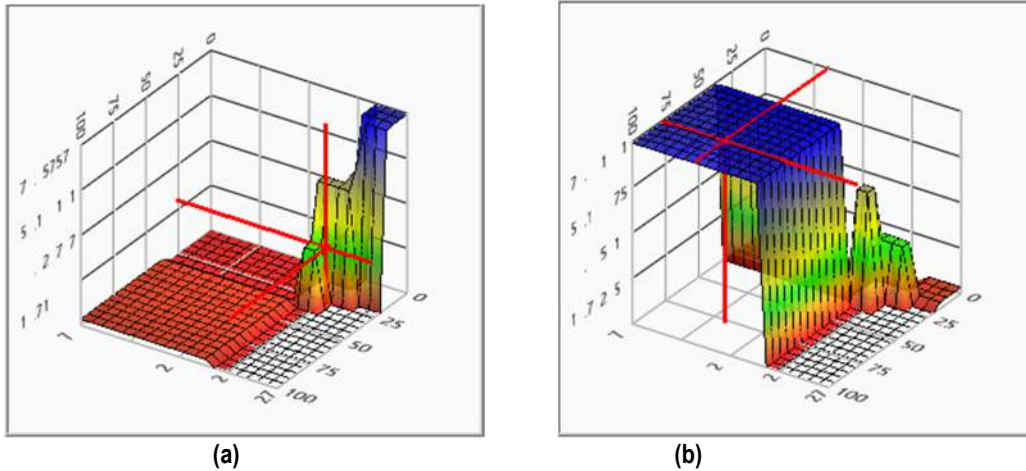
caused by using a different sensor that required a different mapping value. The system responses differed from the desired output. Figure 4 shows the simulation 3D Plot of the output to input relationships from the LabVIEW test system for irrigation control



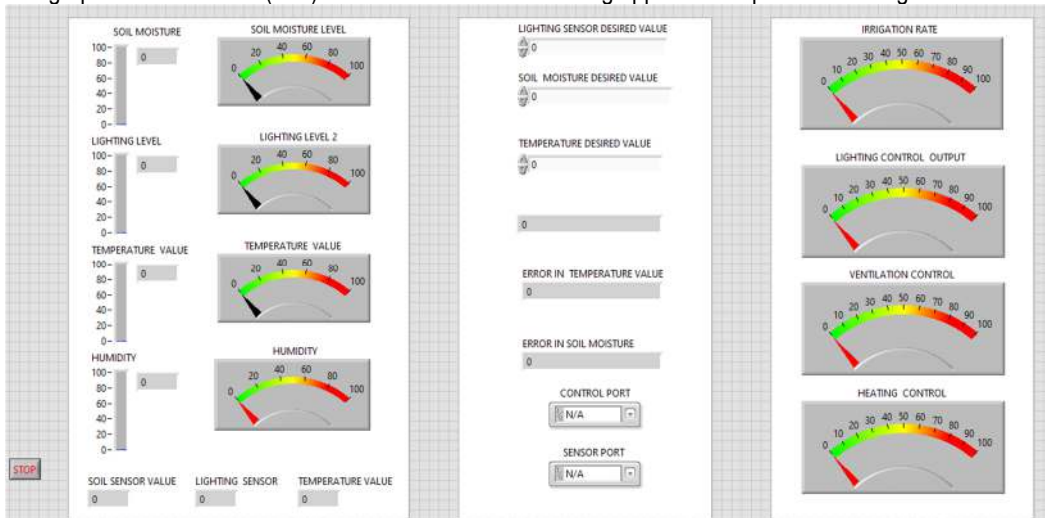
**Figure 4.** 3D Simulation Plot of the Irrigation controller input and output relationship

The temperature controller was able to control the speed of the fan and heat generated by the heater based on the temperature value measured from the greenhouse. This control was done by, varying the speed of the fan and the heat generated by the heater using a duty cycle set by

the control signal sent as data to the microcontroller. The simulation 3D Plot of the output to input relationships from the LabVIEW test system for temperature control is presented in Figure 5.



**Figure 5.** 3D Simulation of the controller input and output relationship (a) Temperature and heating rate relationship plot, (b) Temperature and fan speed relationship plot  
 The graphic user interface (GUI) of the Greenhouse monitoring application is presented in Figure 6.



**Figure 6.** GUI of Greenhouse monitoring application

The Greenhouse controller was able to control the responses of the various system actuators within the range set for the input variable membership functions. However, the controller showed a response time delay of 3 seconds when switching from one state to another. For example, when moved from dry soil to wet soil the pump took about 5 seconds to change state. This delay was caused by communication latency between the microcontroller, sensor and monitoring application. This can be reduced by using a highly sensitive sensor.

During implementation, the system's overall performance and responses were smooth, especially in areas where the membership function ranges were not exceeded. Thus, to improve the overall performance of the future greenhouse controller systems, it is recommended that the controller be improved, by refining the fuzzy sets and increasing the number of membership functions or rules in the rule base.



## CONCLUSION

The Greenhouse monitoring and control system fuzzy controller was designed, tested and implemented using LabVIEW software. The fuzzy algorithm made the system efficient and under control. The results showed the advantages of fuzzy logic in handling problems that are difficult to overcome analytically, yet are easily solved intuitively in terms of linguistic variables.

The fuzzy logic controller helped to provide a solution to a complex problem, without utilizing a detailed relationship with the system mathematical model. Thorough knowledge and understanding of the input and output parameters were enough to design the desired system.

The greenhouse system was built to monitor and control the lighting of Light Emitting Diodes (LEDs), the rate of water pumped, the speed of the DC fan and heat supplied by the DC heater to the greenhouse. Each input and output comprise different membership functions, which increases the overall performance of the system.

Although the fuzzy logic algorithm was efficient in the design of controllers that are difficult to model mathematically. It also has its limitations, which can be greatly reduced when combined with other optimal control methods such as genetic algorithms and artificial intelligence.

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