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MODELING OF EMBEDDED FUZZY SYSTEM TO CONTROL HYDROPONIC CROPS

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Abstract. The hydroponics consists of a technique for cultivation that dispenses the use of soil, cultivating the plants in water medium, from a solution enriched with nutritious substances necessary for the development of the plant. Although still incipient, there is a significant increase in the use of this technique in several locations where the unstable climate harms agricultural production. In this sense, automation is extremely necessary to minimize the losses, through the control of several variables in crop shelters. In addition to minimizing the risk of crop failure, automation enables a higher quality of products by providing optimal conditions for production, allowing autonomy in cultivation and, consequently, that the human workforce is directed to activities that require greater dedication. This paper presents a system of multiple inputs and multiple outputs (MIMO) that allowing to control the production and the monitoring of vegetables in greenhouses for cultivation, collecting and controlling essential variables such as temperature, humidity, luminosity, among others, using fuzzy logic. This system optimizes production by automating data collection and hydroponic crop management in order to minimize errors resulting from these activities. First, the study of the variables and the survey of the components necessary for the assembly of the system were realized, defining the following input variables: temperature, humidity, time and luminosity as input variables, and LEDs irradiation and ventilation, as output variables. Then, a study of how these variables are related in the fuzzy system decision-making process was carried out. The Mamdani model was chosen as an inference method, since it is better suited to use in systems to support decision making. Thus, the fuzzy sets and rules of the Mamdani model were defined. The fuzzy controller was implemented in C language using an Arduino Mega 2560 board. In order to verify the operation of the system, tests were performed in the data collection stage, inference procedure and output activation. The test results converged, and the system outputs responded appropriately.

Keywords: Hydroponics, Intelligent System, Fuzzy Control, Embedded Systems.

1 Introduction

The hydroponics technique is relatively old, although it became famous from 1930, with the creation of the nomenclature by Dr. W. F. Gericke of the University of California. It consists of a technique for the cultivation of plants, without soil, in water, where the roots are replaced by a nutrient solution that contains water and all the essential nutrients for the plant development, and can be added in up to 70% of water used [1], ensuring economy, precocity and hygiene of the product.

It is currently more widespread in countries such as the Netherlands, Germany, Italy, Japan, the United States, Mexico, and neighboring areas of Central America. Although still incipient, the trend is that there is a significant increase in the use of this technique in several locations where the unstable climate harms agricultural production.

Techniques like this have gained a lot of importance over the years, and they are gradually being employed for commercial agriculture [2]. One of the most used systems is the NFT - Laminar Nutrient Flow System - where plants grow having their root system within a channel where a nutrient solution circulates. This system is basically composed of a nutrient solution tank, a culture channel pumping system and a return tank system. The nutrient solution is pumped into the channels and drains by gravity forming a thin blade of solution that irrigates the roots [3].

The embedded fuzzy system applied to hydroponic cultivation presented in this paper aims to reduce costs and errors in production control, since the correct control of processes in a hydroponic cultivation system directly influences the productivity, quality and precocity of the product.

2 Motivation

The conventional cultivation method has several disadvantages when it comes to climate, as changes in temperature, humidity, decreased solar incidence and other factors can seriously compromise the crop causing damage [3]. In this sense, automation is extremely necessary to minimize damage through the control of variables such as temperature, luminosity, air humidity, water alkalinity, among others, in grenhouses. In addition to minimizing the risk of crop loss, automation enables higher product quality by providing optimal production conditions, and allows for autonomy in cultivation, enabling human labor to be directed to activities that require greater dedication.

There are currently some hydroponic automation works aimed at improving control in greenhouses, as in [4], [5], [6], [7]. However, it is observed that these works are based on conventional logic (Boolean logic). Although efficient in some cases, these systems do not allow you to control the intensity of some outputs because of their crisp nature. Thus, for lighting and ventilation in cultivation greenhouses, for example, the possible states would be: on or off. In this context, fuzzy logic can represent an efficient decision-making tool, since it uses reasoning and natural language in order to represent values, which are expressed linguistically [8], which allow us to represent half-terms in variables, allowing the treatment of uncertainties, giving robustness to the proposed system, and providing energy savings by allowing intensity control in lighting and ventilation.

By using this system, we seek to reduce human intervention in data collection and management of hydroponic cultivation, reducing the repetitive work and errors that normally accompany these activities.

3 Methodology

The intelligent system proposed in this paper is based on a fuzzy model developed using the Mamdani inference method. In this method, the ith model rule is given by:

$$R^{(i)} : SE x_1 \text{ É } A_1^{j*} \text{ E ... E } x_n \text{ É } A_n^{j*} \text{ ENTÃO } y_1 \text{ É } B_1^{m*} \text{ E ... E } y_n \text{ É } B_n^{m*} \tag{1}$$

where $x_{1,...,n}$ corresponds to the fuzzy variables; $A_{1,...,n}^{j*}$ correspond to the fuzzy partitions of the linguistic variables.; $y_{1,...,n}$ are the outputs of the fuzzy model, represented by fuzzy partitions $B_{1,...,n}^{m*}$.

The inputs $x_{1,...,n}$ of the system were defined according to the influence on the microclimate within the cultivation greenhouses. In [9], the control and monitoring of meteorological variables, such as temperature and humidity, in hydroponic greenhouses is of paramount importance, as variations of these variables directly influence crop development through effects on transpiration and photosynthesis and may interfere beneficially or maliciously in the development of the plant. Besides that, it is important to consider the effect of time and solar incidence. Still in [9], the largest temperature variations occur between 12h and 16h, during which time the air temperature is highest. These variations in temperature, in turn, influence the relative humidity within the greenhouses, which during the daytime decreases with great intensity and during the night increases rapidly. Thus, due to the importance of the weather and time variables, as well as the solar incidence, the variables defined as the inputs x_i of the proposed fuzzy system were: temperature, humidity, time of day and luminosity.

The outputs y_i chosen were the LEDs irradiation and internal ventilation variables. LEDs irradiation is a very important factor in greenhouses, as direct exposure to sunlight is not always possible; Internal ventilation, in turn, can provide a reduction in temperature and humidity inside the greenhouse. The output value of the LEDs irradiation variable is intended for an LED module for light intensity control. The purpose is to provide sunlight compensation through specific RGB LEDs in order to create lighting that can meet the need for sunlight to ensure greater photosynthetic activity and therefore, the full development of cultivated vegetables. Some studies, such as in [10], show techniques that consist of increasing photoperiod, aiming at an increase in the early production of crops. Based on these studies, the activation of artificial lighting was applied from 18h to 21h. The second output variable, ventilation, is for the two-fan speed control pin for adjusting ventilation through the exhaust and air inlet in the hydroponic greenhouse.

In the next step, the data is inserted into the fuzzy controller. For this, the step of fuzzification of the variables x_i is performed. The values obtained during data collection are mapped to values in the range 0 to 1, given by: $\mu_A(x) \rightarrow [0, 1]$ where $\mu_A(x)$ is the membership of x to A set. The fuzzyfication evaluates the degree of pertinence of the numeric input, x_i, with activation of the rules for composition of the output fuzzy sets, which will be defuzzyficated generating a numerical result for the output y_i [11].

Fuzzy partitions $A^{j*}_{1,...,n}$ were defined for each x_i, and the sets were modeled using triangular membership functions considering the range from 0°C to 50°C for temperature and 0 to 100% for relative humidity for humidity. For the period, the interval corresponds to each hour of the day. For brightness, the range 0 to 1023 is the result of mapping, and later analog-digital conversion, of the voltage values detected in the LDR sensor read by the Arduino. Because it is a light-dependent resistor, the relationship between the value read by the Arduino and the incidence of light is inversely proportional. The higher the ambient brightness, the lower the value read.

Fuzzy partitions $B^{m*}_{1,...,n}$ were defined for each output variable y_i, using triangular membership functions considering the range from 0 to 100% of the power for LEDs and ventilation. Figure 1 shows the membership functions of the input variables considered in the system. Figure 2 shows the membership functions of the output variables.

After fuzzifying the values of each variable - responsible for converting the scalar values to corresponding fuzzy values - the rule base processing step begins: the fuzzy inference machine performs the operations between sets $A^{j*}_{1,...,n}$, to get fuzzy sets $B^{m*}_{1,...,n}$. The rules have structure according to Eq. (1).

Finally, fuzzy sets obtained by inference need to be converted to a numeric output, enabling outputs to be triggered by the Arduino. At this point it is necessary to perform the defuzzification of the output obtained in the inference step. For this, we used the method of centroid which consists in calculating, for a given fuzzy set from the inference process, the abscissa of the center point of mass,given as follows:

$$y* = \frac{\sum_{m=1}^{N_y} y_m \mu_0(y_m)}{\sum_{m=1}^{N_y} \mu_0(y_m)} \tag{2}$$

where y_m is the central value of the m rule and N_y is the number of fuzzy system rules. From this point, having the numerical values obtained, the decision-making is performed and the outputs are triggered according to the active rules at the moment considered.

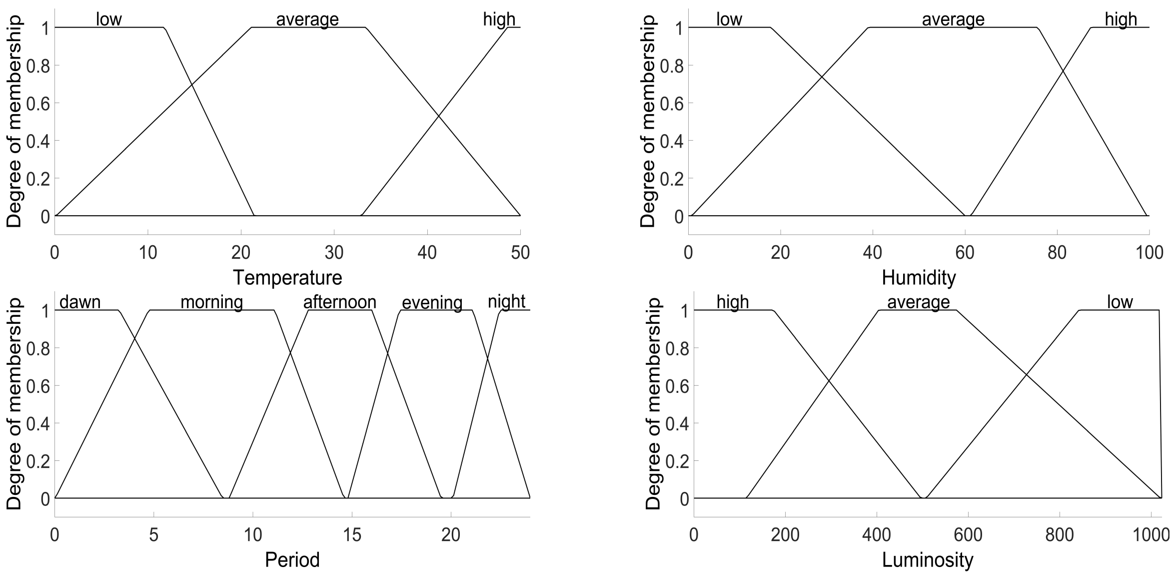

Figure 1. Membership functions of the variables: Temperature, Humidity, Period and Luminosity.

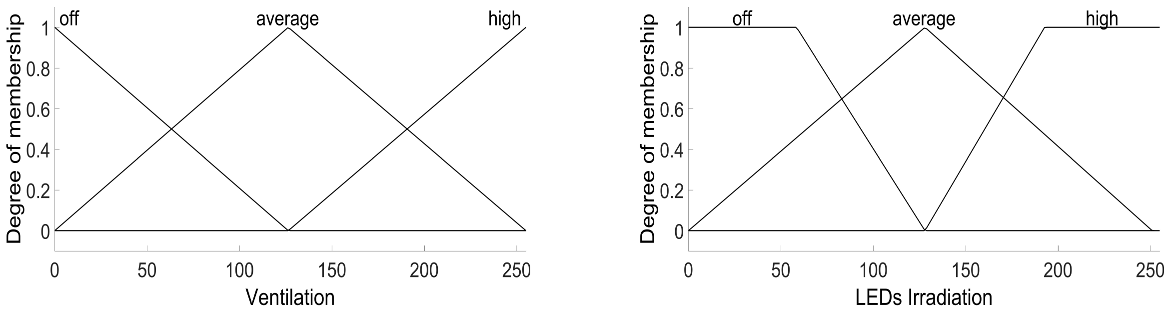

Figure 2. Membership functions of the variables: Ventilation and LEDs Irradiation.

4 Results

The embedded fuzzy controller was then subjected to tests to verify the robustness of the sensors, as well as to evaluate the inference process and the output activation. Figure 3 shows the implementation of the proposed system in a prototype, with a fan, for the representation of the output variable called Ventilation, and some LEDs for the output variable called LEDs Irradiation.

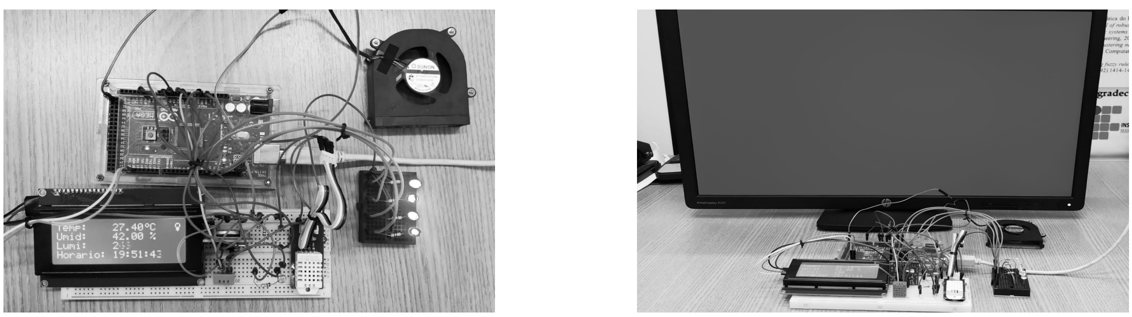

Figure 3. (a) Platform details and (b) Prototype implemented.

The experimental results showed the efficiency of the proposed methodology, since the system presented satisfactory results for temperature and illumination control. The surfaces obtained with the application of the proposed method are shown, using a fuzzy model Mamdani and the centroid method for Ventilation and LEDs Irradiation, in Fig. 4.

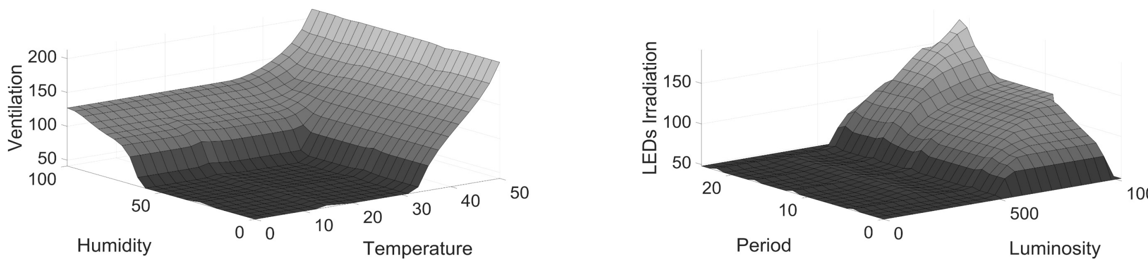

Figure 4. Surfaces representing Ventilation and LEDs Irradiation as a function of the inputs.

5 Conclusions

The application of fuzzy logic proved to be quite adequate for the proposed problem. The smooth variation of the outputs - unlike systems with outputs *ON/OFF* - allowed for better energy management as the power supplied to the lighting and ventilation was controlled according to the time and brightness already present in the environment. The ease of implementation of knowledge proves to be a well-desired feature, as it enables the addition of instructions for microclimate control according to the crop defined for cultivation. Thus, it becomes possible to grow various types of vegetables adapted to different microclimates just by changing the rules. More variables may be added, however, the number of components and rules required will be greater. Therefore, the system as a whole will become more complex. However, as a future proposal, a model with more variables will be formulated. Still as a future proposal, there is the creation of the system-user interface for data display and system management as a whole.

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