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A FUZZY LOGIC BASED CONTROLLER FOR INTEGRATED CONTROL OF PROTECTED CULTIVATION

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Abstract. *In terms of systems theory, the greenhouse represents a complex nonlinear system with emphasized subsystem interactions. System decoupling is used in order to obtain simplified control structures for independent control loops. This gives limited results because of the strong interaction between system variables. Such system does not allow system behaviour optimization primarily in terms of energy efficiency and/or water consumption. This paper presents a design of fuzzy logic based controller, which optimizes the Greenhouse heating, energy and water consumption. The design includes the main linguistic variables for sensors and actuators. Membership functions of Fuzzy Inference System (FIS) are generated and simulation and analysis of the behaviour of the designed control system is performed.*

Key words: *fuzzy control, protected cultivation, complex systems, energy efficiency, water management, inference engines*

1. INTRODUCTION

Protected Cultivation, as an alternative way for food production, has become more important in recent years due to several factors that change the global picture in the world of agribusiness.

The most relevant factors are:

- Global increase on food prices by 33% in 2010
- Reduced amount of quality water for irrigation
- Increased use of arable land for production of raw materials used for biodiesel

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- Increased toxicity of arable land with heavy metals, excessive and/or misuse of fertilizers as well as long-term contamination due to the use of pesticides
- Global climate changes

Global trends show that these conditions will continue to rise in the future. Protected (Greenhouse production) allows for drastic reduction of amount of water for irrigation. So-called Hydroponics or soilless systems address the growing problem of soil pollution, allow increased density of plants per unit area, reduces impact of climate changes, as well as application of bio control as an effective alternative to traditional methods of plant protection.

The main advantage of these systems is the efficient use of water for irrigation. Using rock-wool as a growing substrate, offers the possibility to use water and fertilizers very sparingly. This is especially emphasized in the so called "closed irrigation systems", where water with fertilizers recirculation through the system and water is lost only through leaf transpiration. The water in rockwool substrate is fully and easily available to the plant, as opposed to many other substrates used. There is also significant economic impact regarding the possibilities for off season and early season production.

The role of the greenhouse in protected cultivation is to provide optimal microclimate conditions for plant growth. From the systems theory aspect, protected food cultivation in greenhouses represents a complex nonlinear system, including number of subsystems with emphasized variables interdependency. Basically, the main controlled variables are:

Temperature control: The optimal growth condition assumes constant temperature inside the Greenhouse. Disturbance variables which affect the inside greenhouse temperature are; Outside temperature, Relative Humidity (RH), Light Irradiation, Plants growth stage, speed and direction of wind. It should be emphasized that the temperature can be controlled under various operating modes such as daily/night mode and different modes for each stage of plant development. Also, in more advanced systems, besides the inside temperature, the temperature of the plant and the temperature of the substrates are also measured.

Relative Humidity (RH): Air RH should be kept in the appropriate limits depending primarily on the type and stage of the plant growth. High RH levels cause development of bacterial diseases, while low RH causes difficulties in the pollination process and exceeded water loss. Disturbance variables are: Air temperature, Light Irradiation, Plants growth stage which increases RH by transpiration process, intake of fresh air and foliar irrigation. Beside the RH level of the inside air, in more advanced systems, the moisture content of the substrate is also measured.

Lighting: The amount of lighting is of decisive importance for the physiological processes affecting plant growth. Insufficient amount of natural (solar) lighting can be supplemented by so-called HID lamps (High Discharge Lights). Recent studies show substantial progress in usage of LED (Light Emitting Diodes) lighting, which is signify-cant to HID both in terms of energy efficiency and in presetting the specific lighting spectral density corresponding to the two peaks of chlorophyll a and b (420 to 450 nm in blue and 630 to 660nm in red spectrum wavelength).

Irrigation and nutrient solution control: When it comes to irrigation of soilless systems, it is necessary to establish the correct ratio of macro and micro - nutrients, appropriate level of Ph and EC (Electrical Conductivity) or TDS (Total Dissolved Solids). This is opposite to the plant growth in soil, where all nutrient unbalances can be fixed by the soil itself. The control of an open irrigation systems has a relatively simple structure.

The only problem refers mainly to the balance of all macro and micro nutrient ions, together with balanced Ph and EC. In the case of closed irrigation systems, all unused water is collected and reused, as opposed to the open irrigation systems, where usage of water for irrigation is 15 to 20% increased. In the closed irrigation systems water is reused, but in every irrigation cycle, nutrient solution should be rebalanced due to different absorption rate of nutrients. In both cases disturbance variables are: Air temperature, RH, lighting and Plant growth stage. According to [6], only in recent years concrete efforts have been made to place problems particular to water loss in greenhouses. The vital relation between water supply and demand has not been adequately studied for greenhouse practice. Principal investigators have commented the limits of empirically obtained data [15] [18], using statistically derived relationships that have little relationship with physical principles.

Carbon Dioxide (CO2): The amount of carbon dioxide in the atmosphere is essential for plant growth. The natural concentration of CO2 is about 350 ppm, and given the limited space, this amount of CO2 can be absorbed within a few hours. Also, it has been proved that additional concentration of CO2 can significantly increase yields, and positively affect the shelf life of fruits. Here, the disturbance variables are Air temperature, RH, Light, and Plans growth stage.

2. Greenhouse Control

The problem of optimal control of greenhouse can be defined as achieving the control trajectory

$$\vec{u}(t), t_0 \leq t \leq t_f \tag{1}$$

which minimize the predefined goal function

$$J(\vec{u}(t), t_0, t_f) = \Phi(\vec{x}(t_f), t_f) + \int_{\tau=t_0}^{\tau=t_f} L(\vec{z}(\tau)d\tau \tag{2}$$

for the dynamic system model with the initial state

$$\vec{x}(t) = \vec{f}(\vec{x}(t), \vec{u}(t), \vec{d}(t)), \vec{x}(t_0) = \vec{x}_0 \tag{3}$$

with output accessible for observation

$$\vec{y}(t) = \vec{g}(\vec{x}(t), \vec{u}(t), \vec{d}(t)) \tag{4}$$

And additional output representing auxiliary variables of interest

$$\vec{z}(t) = \vec{h}(\vec{x}(t), \vec{u}(t), \vec{d}(t)) \tag{5}$$

Where *d*(*t*) represents external input variables which are measurable but not accessible for control.

System complexity and its nonlinear nature caused numerous researches to try and find a way to simplify the control structure in greenhouse production, or at least to automate part of it. The reasons for this approach, is the high cost of integrated control systems and the lack of a general system model that will cover important controlled and disturbance variables. Decoupling of the control system typically includes three different aspects:

Greenhouse atmosphere control includes:

- Inside Air Temperature; Plant Temperature; Substrate Temperature; Relative Atmospheric Humidity (RH); Substrate Moisture content; Carbon Dioxide (CO2)
- Irrigation and Fertilization Control includes: Amount of water per plant per hour; Balancing of macro and micro nutrients; Ph levels; Electric Conductivity (EC); UV Water disinfection (for closed irrigation systems)
- Lightning Control includes: Daylight Intensity; Additional HID Light; Add. LED Light for photosynthesis spectral balancing

It should be noted that this approach gives only partial results because of emphasized subsystems variables interaction. Lighting proportionally affects the plants transpiration, and thus the amount of irrigation water; Leaf water transpiration increase RH in the atmosphere; The RH is inversely dependent on the temperature; it is meaningless to activate CO2 dosing system when windows are open for ventilation, and etc.

It is important to note that these systems are quite energy demanding, and a particular aspect of control design should be their energy efficiency. Besides the optimal value of the controlled variables, two additional threshold values must be declared, and all controlled variables must stay in these boundaries.

3. Current Systems for Automatic Control of Greenhouses

All growing phases can be controlled through Control of Air Temperature, Relative Humidity, CO2, Irradiation and Irrigation [20]. Good overview can be found in [18]. Common control systems for automatic control consist of sensor network for data acquisition connected to the central computer system through adequate communication protocols. Based on obtained data, and adequate algorithms, different actuators (motors, heat pumps, coolers, HID lights, etc.) can be activated in order to keep the measured variables in optimal range. Also, data from sensors and actuators is recorded in log files. Usually, GUI is used to display this data and to provide more optimal control of measured variables.

There are different approaches in designing control systems according to their complexity, control algorithms used, and number of controlled parameters.

Timing Control: The simplest system used today is “Timing Control” system, where simple timers are used to manage actuators. This is open loop control system and requires high level of expert knowledge from the growers. Also, possibility for mistake is very high and requires continuous supervision by the grower.

ON/OFF Control: This control design is based on simple feedback loops where the main goal is to keep desired variable in certain limits. The main advantage of this design is simplicity, they are inexpensive and reliable. But, this control strategy does not encompass strong interaction between variables (for example, influence of fogging over temperature drop, or air heating over the drop of RH).

PID Control: PID Control systems overcome some of the disadvantages that the ON/OFF control has, but adjusting the parameters (P-proportional, I-Integrative and D-derivative) is based on system transfer function, which represents a problem with this type of control systems. Currently, PID control is usually applied in systems for nutrient solutions.

4. Fuzzy Logic based Control Design

Fuzzy logic [11], [12] [22], [23] is mathematical theory dealing with uncertainty. This approach is widely used in modeling nonlinear systems with high complexity, plant dynamics is unknown or it can change rapidly. This approach is intuitive, input and output variables are linguistically described, and design of control algorithm is primarily based on if-then-else rules.

Fuzzy Logic Controllers are widely used in different engineering areas [7-10], [21] including AI, Expert systems, Robotics and Biotechnology. There are few researches in applying this promising method into control of greenhouses [2], [5], [14].

The main unit of the Fuzzy Logic Controller is Fuzzy Inference system (FIS). The FIS consist of five processing parts:

- Fuzzification interface which generates linguistic variables based on crisp data inputs from sensor subsystem
- Defuzzification interface which generates crisp control output to the actuators
- Decision making unit, based on predefined control logic, generates inference operations
- Database process provides the fuzzy sets and membership functions used in fuzzy rules
- Rule base unit consisting of an adequate number of fuzzy rules

In the presented system input (sensor) variables are: Indoor Air temperature (IAT) in °C. (Fig. 1), Relative Humidity (RH) presented in % (Fig. 2), level of Carbon Dioxide (CO2) inside the greenhouse presented in ppm (Fig. 3), stage of plant growth in days (Fig. 4), and Light Intensity (Lux) (Fig. 5).

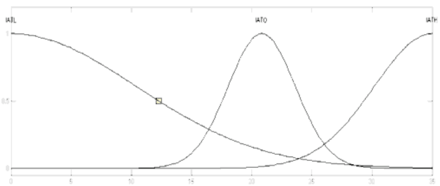

Fig. 1. Temp. Membership function (°C)

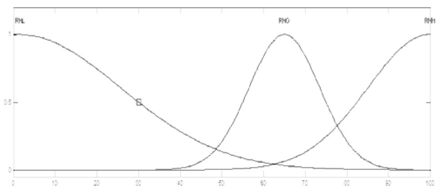

Fig. 2. RH Membership function (%)

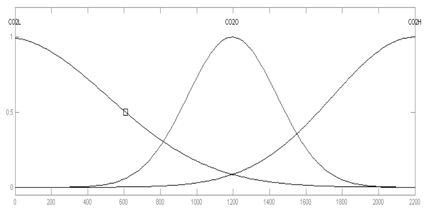

Fig. 3. CO2 Membership function (ppm)

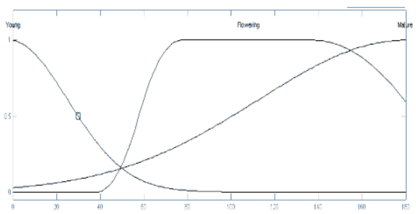

Fig. 4. Plant Growth Stage (days)

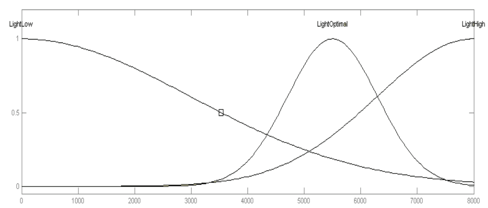

Fig. 5. Light Intensity (Lux)

Output (Actuator) variables are: Heating system which can be activated in linear working regime from 0 to 100 %,, Windows position on the top of the greenhouse (closed - 0% full open -100%), CO2 dosing system (0-100%) (Fig. 6) and Irrigation system with irrigation time of 0 to 200 sec (Fig. 7). (This assumption is made for 4L/hour drip irrigation system which is equal to 1.1 mL/sec)

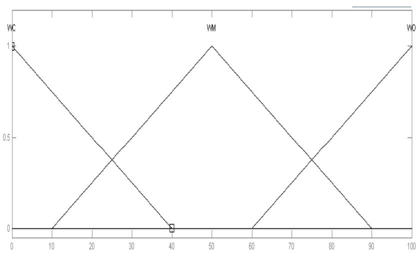

Fig. 6. Heating, Window and CO2 membership function (%)

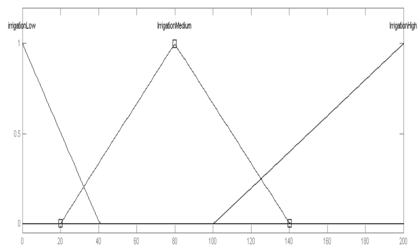

Fig. 7. Irrigation membership function (sec.)

Presented FIS for Greenhouse control executes three actions, First process of fuzzification (conversion of crisp values from sensors) into linguistic variables within predefined fuzzy sets. Then, rule base unit based from the knowledge database generates control strategy, and third action is defuzzification where crisp outputs are generated for actuators.

On Fig. 8 is presented the membership function of the Ventilation subsystem activity depending on measured Air Temperature and RH. This is 2-dimensional functions which define the status of windows on the greenhouse roof (0%- closed 100% full open) as a membership function depending of air temperature inside the greenhouse and Relative Humidity. On Fig. 9 is presented membership function of CO2 Dosing subsystem depending of the measured level of CO2 and temperature in the greenhouse.

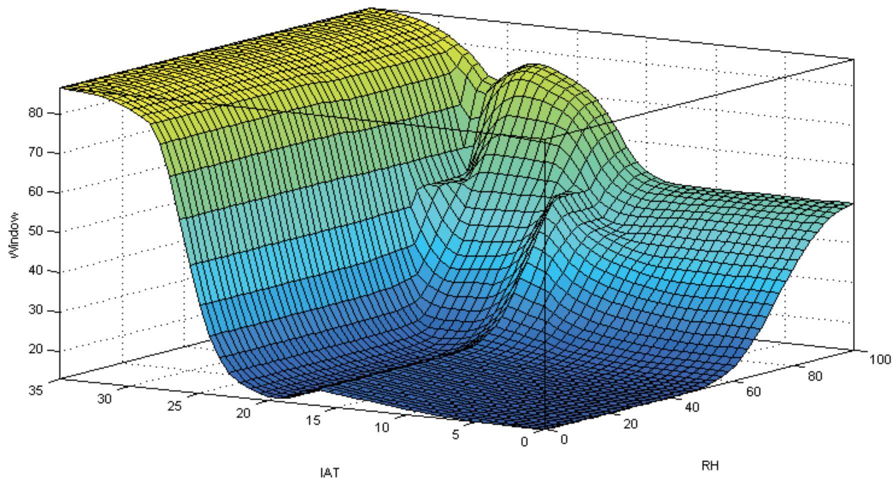

Fig. 8. Ventilation subsystem activity depending on measured Air Temperature and RH

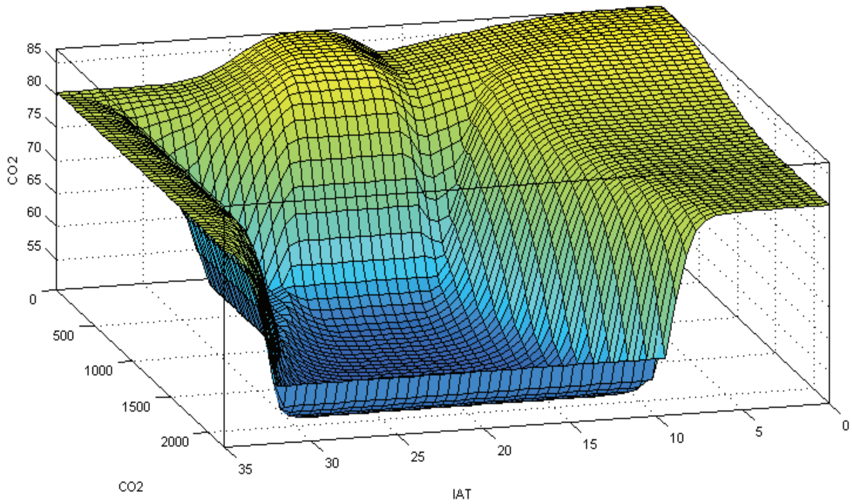

Fig. 9. CO2 subsystem activity depending on measured Air Temperature and current level of CO2

On Fig. 10 is presented membership function of Irrigation subsystem activity depending on measured Light Level (PAR) and Growth stage of the plant.

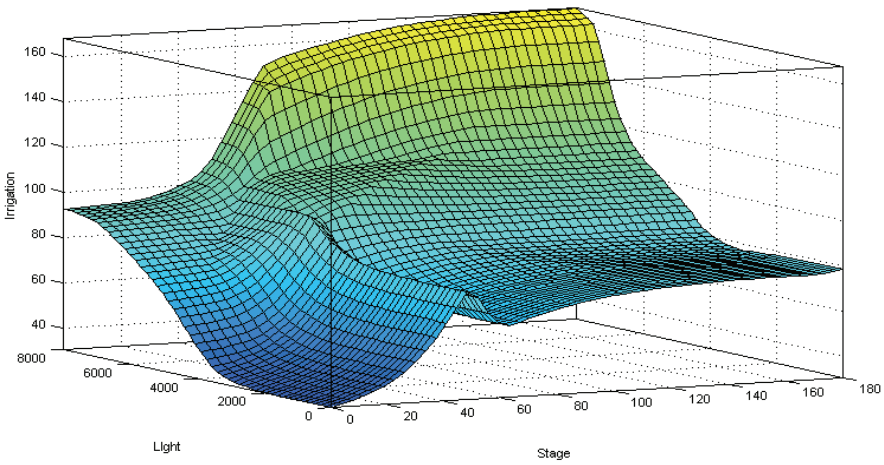

Fig. 10. Irrigation subsystem activity depending on measured Light Level (PAR) and Growth stage of the plant

Next step in the designing process is simulation of the obtained FIS. Obtained crisp outputs for actuator devices from the simulation has been studied, analyzed and compared with the previously collected data from the real system.

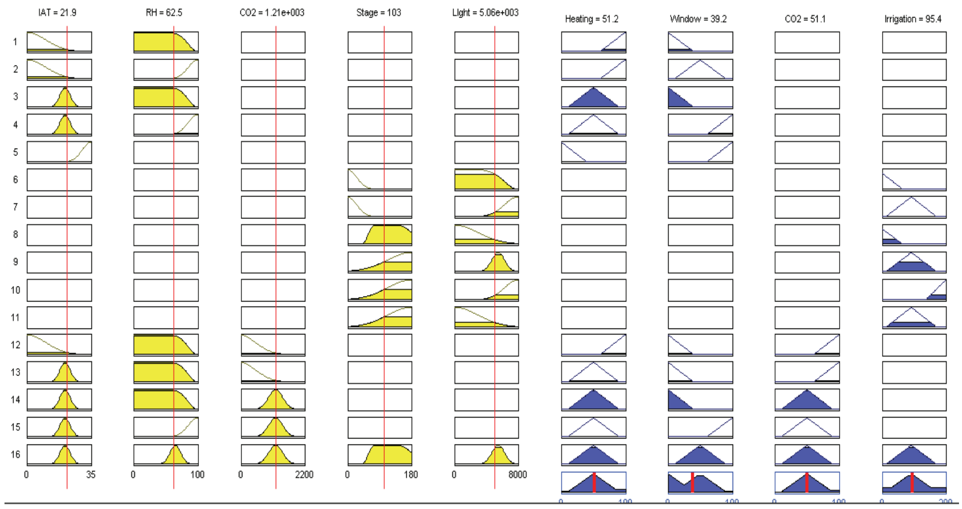

Fig. 11. Defuzzified (crisp) actuators output for heating, ventilation, CO2 Dosing system and Irrigation system, depending of the measured values of Air Temperature, RH, CO2 and Growth stage of the Plant crisp inputs

On Fig. 11 is presented Fuzzy Logic control strategy based on measured input variables. In this case for input temperature of 21.9 C, RH of 82.5% level of CO2 of 1200 ppm, Plants old 103 days, and Light level of 5.000 Lux, values of actuators should be positioned at 51.2% of Heating system, ventilation windows should be positioned on 39.2% of maximal capacity, CO2 system should work on 51,5% and Irrigation system should work 95, second in every irrigation cycle. This is real assumption regarding that the temperature is near to the optimum, but high level of RH should be decreased by opening of ventilation windows. Also relatively old plants (113 days) will produce additional increase of RH, and light level of 5000 lux assume clear sun and in this case 91.6 sec × 1.1 ml × 10 cycles = 1007 ml of water per plant per day is quite real assumption for this growing stage of plants.

5. CONCLUSION

Presented design of Fuzzy logic based controller for integrated control of Greenhouse generates control strategies based on linguistic variables. This approach allows for human expert knowledge to be incorporated into computer based control. Furthermore, number of different expert based strategies can be simulated and analyzed and compared. The further research will be in area of optimizing energy and water consumption, in order to obtain optimal control of greenhouse systems.

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FAZI LOGIČKI BAZIRAN KONTROLER ZA INTEGRISANO UPRAVLJANJE ZAŠTIĆENE PROIZVODNJE

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U smislu sistemske teorije, staklenici pretstavljaju kompleksan nelinearan sistem sa naglašenom podsistemskom interakcijom. Razdvajanje sistema na nezavisne podsisteme se koriste da bi se dobile pojednostavljenje upravljačke strukture za nezavisne upravljačke petlje. Ovakav pristup daje ograničene rezultate zbog jakih interkcija koje postoje između sistemskih varijabli. Ovaj pristup ne omogućava optimizaciju sistemskog ponašanja u smislu energetske efikasnosti i potrošnje vode u sistemu. U ovom radu je prezentiran dizajn fazi logički baziranog kontrolera koji optimizira grejanje staklenika, energetsku potrošnju i potrošnju vode. Dizajn uključuje glavne lingvističke varijable za senzorski i aktuatorski podsistem. Funkcije pripadnosti fazi inferencijskog sistema (FIS) su generisane, izvedene su simulacije i analiza ponašanja dizajniranog sistema.

Ključne reči: *fazi kontrola, zaštićena proizvodnja, složeni sistemi, energetska efikasnost, upravljanje voda, inferncijske mašine*