The 9th Conference for Informatics and Information Technology (CIIT 2012)

FUZZY LOGIC BASED CONTROLLER FOR INTEGRATED CONTROL OF GREENHOUSES

Oliver L. Iliev
FON University, Faculty of Information and Communication Technologies
Skopje, Republic of Macedonia

Pavle Sazdov
FON University, Faculty of Information and Communication Technologies
Skopje, Republic of Macedonia

Ahmad Zakeri
University of Wolverhampton, School of Engineering and the Built Environment
Wolverhampton, United Kindom

ABSTRACT

In terms of systems theory, the greenhouse is regarded a complex nonlinear system with emphasized subsystem interactions. System decoupling in order to obtain simplified control structures for independent control loops gives limited results because of the presence of critical system variables interactions. Such a traditional approach to control design does not allow effective optimizations of systems behaviour in terms of the energy efficiency and/or water consumption.

I. INTRODUCTION

Protected Cultivation, as an alternative way for food production, in years is becoming more important due to several factors that change the global picture in the world of agribusiness. The most relevant are:

- Increased food prices by 33% in 2010 on global level
- Reduced amount of quality water for irrigation
- Increased use of arable land for production of raw materials for biodiesel
- Increased toxicity of arable land with heavy metals, excessive and/or misuse of fertilizers as well as long-term contamination due the use of pesticides
- Global climate changes

Global trends show that these conditions will continue to rise in the near future. Protected (Greenhouse production) allows drastic reduction of amount of water for irrigation. So-called Protected Hydroponic 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 very efficient usage of water for irrigation. Using a rock-wool as a growing substrate offers the possibility to use water and fertilizers very sparingly. Especially in so called closed irrigation systems where water with fertilizers recirculation and water loss is only through leaf transpiration. As opposed to many other substrates, the water in rock-wool substrate is fully and easily available to the plant. 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 aspect of systems theory protected food cultivation in greenhouses is a very complex 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. Disturbing variables are; Outside temperature, Relative humidity, Irradiation, 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 advanced systems beside 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 development. High RH causes development of bacterial diseases, while low RH causes difficulties in the pollination process and exceeded water losses. Distorting variables are air temperature, irradiation, plant development stage which increases RH by transpiration process, intake of fresh air and foliar irrigation. Beside the RH of the inside air, in 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 significant to HID both in terms of energy efficiency and in setting 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
In irrigation of soilless systems it is necessary to establish the correct ratio of macro and micro - nutrients, and appropriate level of Ph and electrical conductivity or TDS (Total dissolved solids), as an opposite to the growing in soil where all nutrient unbalances can be fixed by the soil itself. Control of an open irrigation systems is relatively simple control problem consisting mainly of lead to the balance all macro and micro nutrient ions, together with balanced Ph and EC (Electrical conductivity). IN this case, all unused water will be collected and used for open crop irrigation, but in this case, usage of irrigation is 15 to 20 % bigger compared with closed irrigation systems. In the closed irrigation systems water is

©2012 Faculty of Computer Science and Engineering

reused, but in every irrigation cycle, nutrient solution should be rebalanced due to different absorption rate of nutrients. In both cases disturbing variables are: Air temperature, RH, lighting, and stage of plant development. According to [6] only in recent years have concrete efforts been made to place problems peculiar to greenhouses on a firm basis concerning water lost. 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 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.

II. GREENHOUSE CONTROL

System complexity and his nonlinear nature caused numerous researches in order to simplify the control structure or to automate part of it. The reasons for this approach are high cost of integrated control systems and the lack of a general system model which will covers important controlled and disturbing variables. Decoupling of the control system typically includes three different aspects:

Greenhouse atmosphere control include: Inside Air Temperature; Plant Temperature; Substrate Temperature; Relative Atmospheric Humidity (RH); Substrate Moisture content; Carbon Dioxide (CO2)

Irrigation and Fertilization Control include: Amount of water per plant per hour; Balancing of macro and micro nutrients; Ph; Electric Conductivity (EC); UV Water disinfection (for closed irrigation systems)

Lightning Control include: Daylight Intensity; Additional HID Light; Additional 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 depending on the temperature; It is meaningless to activate CO2 dosing system when windows are open for ventilation, and so on.

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

III. CURRENT SYSTEMS FOR AUTOMATIC CONTROL OF GREENHOUSES

All growing phases can be controlled through Control of Air Temperature, Relative Humidity, CO2, Irradiation and Irrigation (Van Straten et al, 2010). Good overview can be found in (G.M. Soto-Zarazua et al. 2011). 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, collected data from sensors and actuators are 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 is Timing Control where simple timers are used to manage actuators. This is open loop control 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 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, and this in general is a problem. Currently, PID control is usually applied in systems for nutrient solutions.

IV. FUZZY LOGIC BASED CONTROL DESIGN

Fuzzy logic (Zadeh, 1993), (Zimmermann,1991), (Jamshidi,2003), (Kovacic&Bogdan, 2006) is mathematical theory dealing with uncertainty. This approach is widely used in modelling of non-linear 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 based on if-then rules.
Fuzzy Logic Controllers are widely used in different engineering areas (Yager&Zadeh, 1992), (Iliev et al.1996, 1999a, 1999b) (Horiuchi,2002) including AI, Expert systems, Robotics and Biotechnology.

There are few researches in applying this promising method into control of greenhouses (Baturone et al., 2005), (Mitra et al., 2008), (Dozier et al., 2001).

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. , Relative Humidity (RH) presented in %, level of Carbon Dioxide (CO2) inside the greenhouse presented in ppm stage of plant growth in days and Light Intensity (Lux).

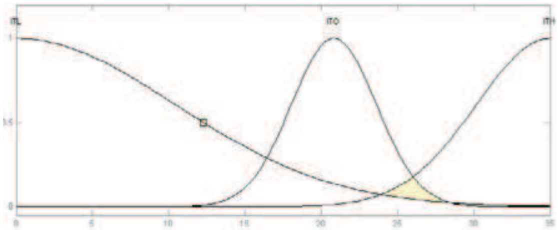

Figure 1: In Temp. Membership function (ºC)

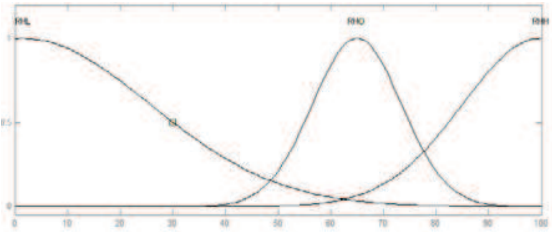

Figure 2: RH Membership function (%)

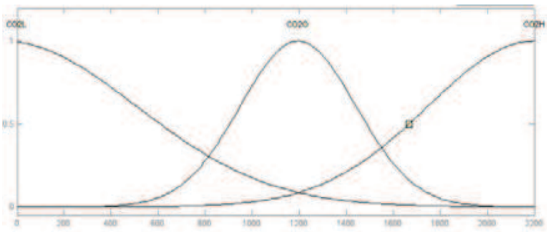

Figure 3: CO2 Membership function (ppm)

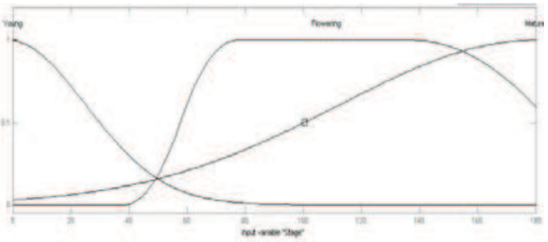

Figure 4: Stage of Plant Growth (days)

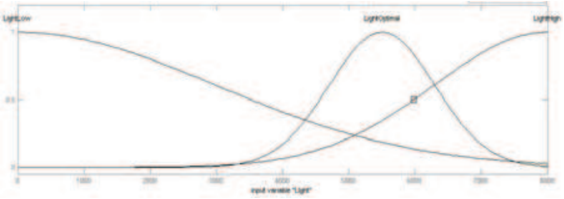

Figure 5: Light Intensity (Lux)

Output (Actuator) variables are defined as: 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%) and Irrigation system with irrigation time of 0 to 200 sec. (This assumption is made for 4L/hour drip irrigation system equal to 1.1 mL/sec).

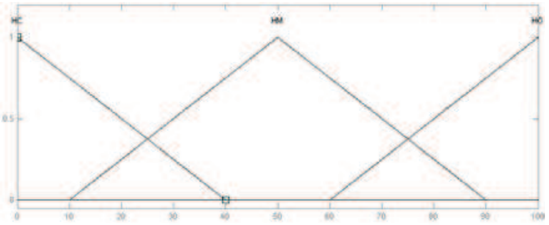

Figure 6: Heating, Window and CO2 membership function (%)

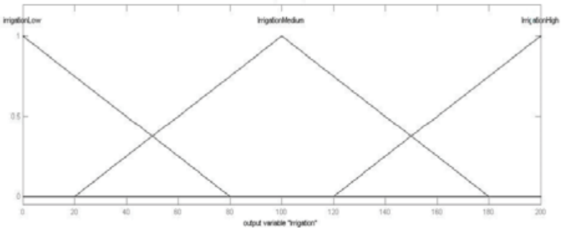

Figure 7: Irrigation membership function (sec.)

Presented FIS for Greenhouse control executes three actions: Process of Fuzzification (conversion of crisp values from sensors into linguistic variables) within predefined fuzzy sets; Generating control strategy rules based on the rule knowledge database; Defuzzification (conversion of linguistic variables into crisp outputs for actuators).

Figure 8 defines the membership function of the fogging subsystem depending of the relative humidity and temperature in the greenhouse, while Figure 9 defines membership function of CO2 dosing subsystem depending of the measured level of CO2 and temperature in the greenhouse.

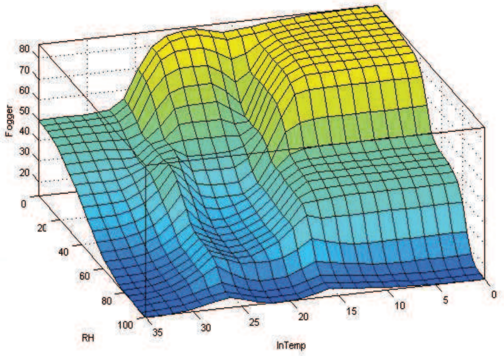

Figure 8: Fogging subsystem activity depending on measured Ait Temperature and Air RH

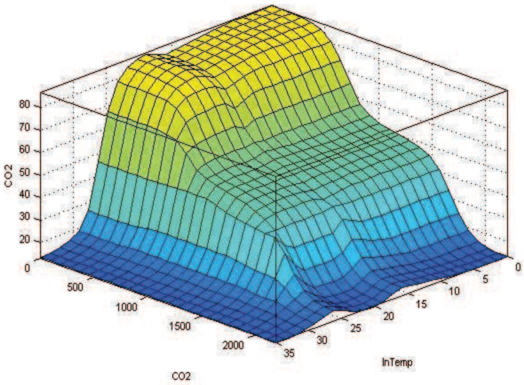

Figure 9: CO2 dosing system activities depending on Temperature and measured CO2 variables

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

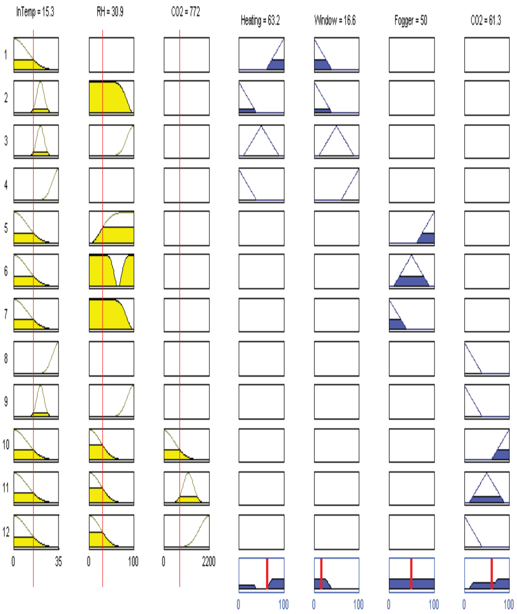

Figure 10: Defuzzified (crisp) actuators output for heating, ventilation, fogging and CO2 Dosing system, depending of the values of Temperature, RH and CO2 crisp inputs.

On Figure 10 is presented on of control strategies based on predefined input variables. In this case for input temperature of 15.3 C, RH of 30.9 % and level of CO2 of 772 ppm, values of actuators should be positioned at 63,2 % of Heating system, ventilation windows should be positioned on 16.6 %, Fogging system should work on 50 % and CO2 unit should work on 50 % of his capacity.

V. 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 analysed and compared. The further research will be in area of optimizing energy and water consumption, in order to obtain optimal control of greenhouse systems.

REFERENCES

[1] Arvantis, K.G., P.N. Paraskevopoulos and A.A. Vernados, 2000. Multirate adaptative tempe-rature control of greenhouses.Comp.Electronics Agric., 26:303-320.

[2] Baturone, I., F.J.Moreno-Velo, S.Sanchez-Solano, V. Blanco and J.Ferruz, 2005. Embedded fuzzy controllers on standard DSPs. Proceedings of the IEEE International Symposium on Industrial Electronics, June 20-23, Dubrovnik, Croatia, pp: 1-7.

[3] Bennis, N., J. Duplaix, G. Enea, M. Haloua and H. Youlal, 2005. An advanced control of greenhouse climate. Proceedings of the 33rd International Symposium Actual Tasks on Agricultural Engineering, Feb. 21-25, Croatia, pp: 265-277.

[4] Castaneda-Miranda,R., E.Ventura-Ramos, R.R. Peniche-Vera and G.Herrera-Ruiz,2006. Fuzzy greenhouse climate control system based on a field programmable gate array. Biosyst. Eng., 94: 165-177.

[5] Dozier, G., A. Homaifar, E. Tunstel and D. Battle, 2001. An Introduction to Evolutionary Computation. In: Intelligent Control Systems using Soft Computing Methodologies, Zilouchian, A. and M. Jamshidi (Eds.). CRC Press, Boca Raton, FL.

[6] Hanan J.J.(2001), Greenhouses Advanced Technology for protected Horticulture CRC Press

[7] Horiuchi, J.I., 2002. Fuzzy modelling and control of biological processes. J. Biosci. Bioeng., 94: 574-578.

[8] Iliev,O.L., N.E.Gough, G.K.Stojanov, G.M.Dimirovski and A.Zakeri (1996), “Obstacle avoidance for intelligent AGVs based on fuzzy control and expectation”. 13th IFAC World Congress (J.B.Cruz, Jr., IPC Chairman), San Francisco CA (USA), Volume Q, pp.441-447

[9] Iliev O.L.,G.Dimirovski, Z.M.Gacovski, N.E.Gough and I.Griffith (1996),“Discrete event object oriented modelling of intelligent communication protocols”. World Automation Congress (WAC’96), Intelligent Automation and Control M.Jamshidi (Ed.) Vol.4 pp 325-330, TSI Press (*Selected Papers*), Albuquerque NM (USA)

[10] Iliev O.L., B.Percinkova, N.E.Gough, and A. Zakeri (1999), “Two Level Control System for FMS – An Object Oriented Approach”, 14th World Congress of I nternational Federation of Automatic Control, Beijing . P.R. China (5-9) July

[11] Jamshidi,M.2003. Tools for intelligent control: Fuzzy controllers, neural networks and genetic algorithms. R. Soc. London Trans. Series A, 361: 1781-1808

[12] Kovacic, Z. and S. Bogdan, 2006. Fuzzy Controllers Design Theory and Appliations. CRC Taylor and Francis Group, Boca Raton, FL., ISBN: 0-8493-3747-X, pp: 397

[13] Lafont, F. and J.F. Balmat, 2002. Optimized fuzzy control of a greenhouse. Fuzzy Sets Syst., 128: 47-59.

[14] Mitra, A.K., S. Nath and A.K. Sharma, 2008. Fog forecasting using rule-based fuzzy inference system. J. Indian Soc. Remote Sens., 36: 243-253

[15] Monteith J.L. 1981 Evaporation and surface temperature. Quart. J.Royal Metor. Sci. 107:1-27

[16] Pinon,S.M,E.F.Camacho and F.K.Uchen,2000.Constrained Predictive Control of Greenhouse. Elsevier Science Ltd., Spain, ISBN: 0-0-8044184-X.

[17] Rodriguez, F., J.L. Guzman, M. Berenguel and M.R. Arahal, 2008. Adaptive hierarchical control of greenhouse crop production. Int. J. Adap. Cont. Signal Process, 22: 180-197.

[18] Soto-Zarazua G.M,B.A.Romero-Archuleta, A.Merca-do-Luna, M. Toledano-Ayala, E. Rico-Garcia, R.R. Peniche-Vera and G. Herrera-Ruiz, 2011. Trends in Automated Systems Development for Greenhouse Horticulture. *International Journal of Agricultural Research, 6: 1-9*

[19] Tanner. C.B. 1966. Comparison of energy balance and mass transport methods for measuring evaporation. Proc. Evarotranspiration and its role in water resources management ASAE, St. JOspeh MI.45-48.

[20] Van Straten, G., E.J. van Henten, L.G. van Willigen-burg and R.C.van Ooteghem, 2010. Optimal Control of Greenhouse Cultivation. CRC Press, New York, ISBN: 978-1-4200596-1-8.

[21] Yager, R.R. and L.A. Zadeh, 1992. An introduction to fuzzy logic applications in intelligent systems. 1st Edn., Springer, New York

[22] Zadeh, L.A., 1993. The role of fuzzy logic and soft computing in the conception and design of intelligent systems. Proceeding of the 8th Austrian Artificial Intelligence Conference on Fuzzy Logic in Artificial Intelligence, (FLAI'93), Springer-Verlag, London, UK, pp.: 1-1.

[23] Zimmermann, H.J., 1991. Fuzzy Set Theory and its Applications. 2nd Ed., Kluwer Academic Publishers, Boston, MA.