A NEW GENERIC MODEL FOR GREENHOUSES USING FUZZY COGNITIVE MAPS

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ABSTRACT

Greenhouses are protected cultivation areas which are designed to control their micro-climate in order to obtain higher crop quality and increase the economic benefit of the producer. During the last two decades, a large effort was devoted to develop adequate greenhouse climate and crop models in order to simulate, control and manage the whole procedure. As the complexity and uncertainty of such systems increases, system theoretical methods become more crucial. One new theoretical approach in modeling dynamic complex systems is Fuzzy Cognitive Maps. FCMs are a symbolic representation for the description and modeling of a system. This paper is using for first time Fuzzy Cognitive Maps to model greenhouse environment so as to control all these parameters that affect the whole production in quality and quantity too. A generic model is developed and it can be modified depending on the application. Simulation studies, expected results and future research directions are presented.

Keywords: greenhouses, photosynthesis, intelligent systems, fuzzy cognitive maps

1. INTRODUCTION

Greenhouses provide a suitable environment for the intensive production of various crops. They are designed to control the micro-climate of the greenhouse in order to obtain higher crop quality and increase the economic benefit of the producer even when the environmental conditions do not favor the growth of some plants. Many different parameters of the climate inside a greenhouse have to be controlled, the most important of which are, generally, the temperature and the composition of the air.

During the last two decades, a significant effort was devoted to develop adequate greenhouse climate and crop models in order to simulate, control and manage the whole procedure. The scientists have focused on the optimal designing of greenhouses and on the better possible control of their environment, too. They have tried to model the conditions of the greenhouse environment so as they are very close to the real world and in this way they have the opportunity to best simulate it and make better future decisions.

Today's complex systems of any interdisciplinary nature can hardly be analyzed and/or modeled without comprehensive usage of system theoretic approach. The complexity and uncertainty of the nature of modern systems, make systems analysis harder and it is needed to use existing information and expert knowledge so as to control modeling simulation. As the complexity of systems increases, system theoretical methods become more crucial. One new theoretical approach in modeling dynamic complex systems is Fuzzy Cognitive Maps.

FCMs are a symbolic representation for the description and modeling of a complex system. They consist of concepts, that illustrate different aspects in the behavior of the system and these concepts interact with each other showing the dynamics of the system. Experts are used to show how the concepts affect each other and the output, too. This paper is using for first time Fuzzy Cognitive Maps to model greenhouse environment so as to control all the parameters that affect the whole production in quality and quantity too. The parameters which have been taken into consideration are the light intensity, the air temperature, the relative humidity, the air concentration in CO_2 as well as the air flow and the artificial heat. The expert who has been used so as we are able to construct the FCM model, has indicated photosynthesis of the plants as the output of the system.

A generic model is developed and it can use some of the climate variables inside the greenhouse, or all of them, depending on the application. So, the number of concepts and the number of experts which can be used in the proposed new model, can be varied in order to analyze and study different greenhouse systems. Simulation studies and expected results will be presented at the conference. Future research directions will also be outlined.

In section 2 a review of the ways that scientists have used to model a greenhouse microclimate and the most important control methods to control it are presented. In section 3 an introduction to the basic theories of Fuzzy Cognitive Maps is given while in section 4 the proposed decision making support system in greenhouses is shown. Finally, in sections 5 and 6 simulations, results and some conclusions about future work are given, too.

2. MODELING GREENHOUSE MICROCLIMATE

During the last decades many scientists have given importance to the modeling of greenhouse microclimate. However, most of them have focused on optimizing the design for a specific location, or considered only a single design parameter (Baptista 2007; Bot 1983; De Halleux, Nijskens and Deltour 1991; De Zwart 1996). An effort to model greenhouse environment in order to be implemented in different greenhouse constructions and in different climate conditions was made by Fitz-Rodrı´guez (Fitz-Rodrı´guez, Kubota, Giacomelli, Tignor, Wilson and McMahon 2010) but only for educational purposes. B.H.E Vontour et al (Vanthoor, Stanghellini, Van Henten and De Visser 2011) have directed to the generalization of greenhouse modeling. By building on the work of Bot (Bot 1983), and De Zwart (De Zwart 1996), in their study a more generic greenhouse model was developed and validated for a wide range of greenhouse designs and climates. The following climates were selected to validate the model: a temperate marine climate (northwest part of The Netherlands); a Mediterranean climate, (Sicily, Italy); and a semi-arid climate (Arizona and Texas, USA). The authors managed to predict with a relatively good precision the greenhouse climate in most cases. Because of the non linearity of the environment of a greenhouse, Neural Networks have also been used in modeling its microclimate (Ferreira, Faria and Ruano 2002). Furthermore, some scientists used logic control (On-Off) while others used optimal control (Pohlheim and Heißner 1997).Some other kinds of control which have been applied in order to simulate and control the climate conditions inside a greenhouse are the adaptive control (Arvantis, Paraskevopoulos and Vernados 2000), the intelligent control (Lafont and Balmat 2002; Lafont and Balmat 2004), the non-linear control (Pasgianos, Arvanitis, Polycarpou and Sigrimis 2003), and also the robust control (Bennis, Duplaix, Enea, Haloua and Youlal 2005). The controls mentioned above had their advantages and disadvantages with respect to the kinds of the greenhouses that they could be used, their flexibility and the outgoing results. Finally, it is worth noting that many scientists have used fuzzy control so as to model and control the climate inside a greenhouse (Castaneda-Miranda, Ventura-Ramos, Peniche-Vera and Herrera-Ruiz 2006).

3. INTRODUCTION TO FUZZY COGNITIVE MAPS

Fuzzy Cognitive Maps (FCMs) have come from the combination of the ideas and methods of both fuzzy logic and Neural Networks (Kosko 1986). They have been used in modeling complex systems (Groumpos and Stylios 2000; Stylios and Groumpos 2004). FCMs consist of concept nodes and weighted arcs, which are graphically illustrated as a signed weighted graph with feedback. Signed weighed arcs, connecting the concept nodes, represent the causal relationship that exists among concepts. In general, concepts of a FCM, represent key-factors and characteristics of the modeled complex system and stand for: events, goals, inputs, outputs, states, variables and trends of the complex system been modeled. This graphic display shows clearly which concepts influences with other concepts and what this degree of influence is.

A Fuzzy Cognitive Map is a graph shows the degree of causal relationship among concepts of the map while the knowledge expressions and the causal relationships are expressed by fuzzy weights. Existing knowledge on the behavior of the system is stored in the structure of nodes and interconnections of the map. Relationships between concepts have three possible types; a) either express positive causality between two concepts (Wij > 0) b) negative causality (Wij < 0) and c) no relationship (Wij = 0). The value of Wij indicates how strongly concept Ci influences concept Cj. The sign of Wij indicates whether the relationship between concepts Ci and Cj is direct or inverse. The direction of causality indicates whether concept Ci causes concept Cj, or vice versa. These parameters have to be considered when a value is assigned to weight Wij . Concepts stand in the interval [0,1]. Causality between concepts allows degrees of causality and not the usual binary logic, so the weights of the interconnections can range in the interval [-1,1].

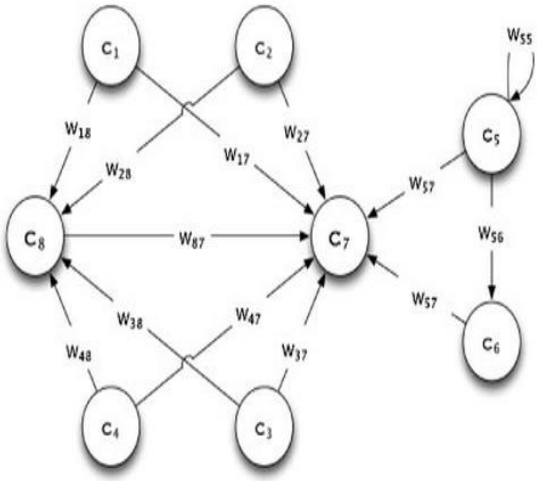

Figure 1. A Fuzzy Cognitive Map

The inclusion of the previous value of each concept in the calculation rule, results in smoother variation on the values of concepts after each recalculation of their value. The value Ai for each concept Ci is calculated by the following rule:

$$A_i^t = f\left(\sum_{\substack{j=1 \\ j \neq i}}^{N} A_j^{t-1} \cdot W_{ji} + A_i^{t-1}\right) \tag{1}$$

The value A_i^t is the value of concept Ci at time t , A_i^{t-1} is the value of concept Ci at time t −1, A_j^{t-1} is the value of concept C_j at time t −1, and the weight W_{ji} of the interconnection from concept C_j to concept Ci. The function f is a threshold function and to squash the result in the interval [0,1], two kinds of threshold functions are used in the Fuzzy Cognitive Map framework, the unipolar sigmoid function, where $\lambda > 0$ determines the steepness of the continuous function f :

$$f(x) = \frac{1}{1+e^{-\lambda x}} \quad (2)$$

4. A DECISION MAKING SUPPORT SYSTEM IN GREENHOUSES

The method described above will be used in order to model greenhouse microclimate. The current Fuzzy Cognitive Map consists of seven concepts. Concept 7 is the decision concept (output), which will show the photosynthesis rate. Specifically these concepts are the following:

C1: Light Intensity
C2: Artificial Heat
C3: Air flow
C4: Air temperature
C5: Air humidity
C6: CO_2
C7: Photosynthesis

As it has been mentioned above, Photosynthesis rate is a very important indicator of the plant development. When the value of the output concept is getting closer to 1, the photosynthesis rate is higher. The higher the photosynthesis, the better the operation of the greenhouse.

The expert of the system has indicated the relationships between concepts and the following table was constructed:

RELATIONSHIPS BETWEEN CONCEPTS							
	C1	C2	C3	C4	C5	C6	C7
C1	0	-0.4	0	+0.5	-0.25	0	+0.7
C2	0	0	0	+0.6	0	0	0
C3	0	0	0	-0.25	-0.4	+0.3	0
C4	0	-0.55	0	0	+0.7	0	-0.3 (or +0.5)
C5	0	0	0	+0.45	+0.4	0	+0.3
C6	0	0	-0.35	0	+0.25	0	+0.65
C7	0	0	0	0	0	-0.45	0

Table 1. Values of the relationships between concepts

The following table shows the matrix of the weights between nodes:

$$W = \begin{bmatrix} 0 & -0.4 & 0 & +0.5 & -0.25 & 0 & +0.7 \\ 0 & 0 & 0 & +0.6 & 0 & 0 & 0 \\ 0 & 0 & 0 & -0.25 & -0.4 & +0.3 & 0 \\ 0 & -0.55 & 0 & 0 & +0.7 & 0 & -0.3(or+0.5) \\ 0 & 0 & 0 & +0.45 & +0.4 & 0 & +0.3 \\ 0 & 0 & -0.35 & 0 & +0.25 & 0 & +0.65 \\ 0 & 0 & 0 & 0 & 0 & -0.45 & 0 \end{bmatrix}$$

Table 2. Matrix of weights between concepts

The initial Fuzzy Cognitive Map with the first values of concepts and if we take into account the expert's knowledge of the interaction of the concepts will be as follows:

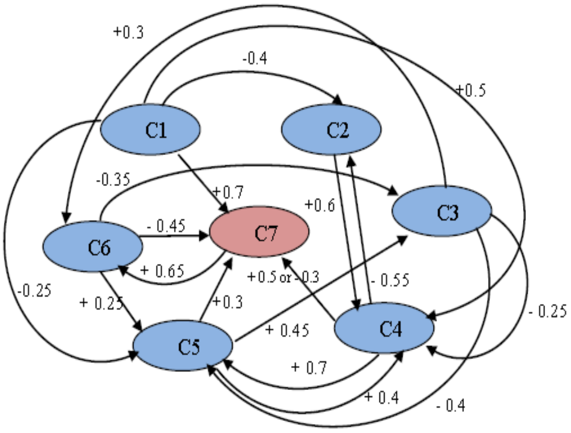

Figure 2. The initial Fuzzy Cognitive Map

5. SIMULATIONS AND RESULTS

Three different cases of the conditions that exist inside the greenhouse were simulated in order to note the rate of plant photosynthesis.

1st case:

We suppose that the climate conditions inside the greenhouse are the above:

VALUES OF NODES (1^{ST} CASE)	
C1	0.2/1 → Very Low
C2	0.3/1 → Low
C3	0.2/1 → Very Low
C4	0.4/1 → Medium
C5	0.2/1 → Very Low
C6	0.25/1 → Very Low

Table 3. Values of initial nodes for the first case

Simulating the Fuzzy Cognitive Map which has been constructed by our expert, we extracted the results below with the value of output concept to be C7=0.4.

This value, according to our expert, is satisfactory enough if we take into account that the initial values of concepts correspond to bad conditions and the low rate of photosynthesis was totally expected. For example, the expert told us that because of the low light intensity and the lack of CO_2, the photosynthesis rate would be very low and so it was.

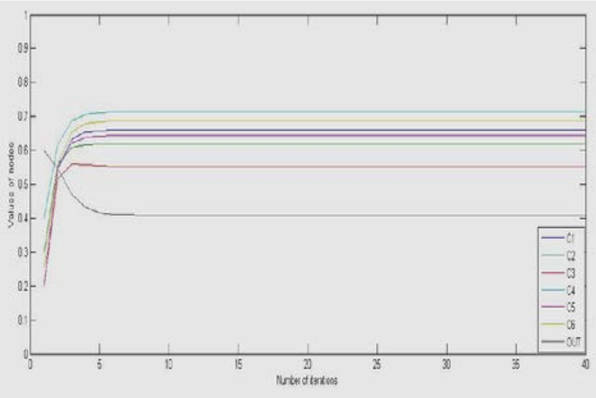

Figure 3. Subsequent values of concepts till convergence for the first case.

2nd case:

We suppose that the climate conditions inside the greenhouse are the above:

VALUES OF NODES (2nd CASE)	
C1	0.6/1 → High
C2	0.3/1 → Low
C3	0.5/1 → Medium
C4	0.6/1 → High
C5	0.45/1 → Medium
C6	0.55/1 → Medium

Table 4. Values of initial nodes for the second case

Simulating the Fuzzy Cognitive Map which has been constructed by our expert, we extracted the results below with the value of output concept to be C7=0.78.

This value, according to our expert ,is very good as it corresponds to a high rate of photosynthesis and this was expected because of the good conditions inside the greenhouse. So, all the agents that affect photosynthesis inside the greenhouse had the appropriate values to get a high rate of it.

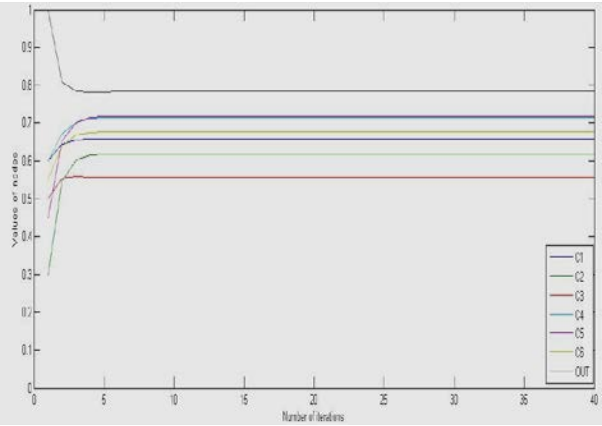

Figure 4. Subsequent values of concepts till convergence for the second case

3rd case:

We suppose that the climate conditions inside the greenhouse are the above:

VALUES OF NODES (3rd CASE)	
C1	0.45/1 → Medium
C2	0.2/1 → Low
C3	0.2/1 → Low
C4	0.55/1 → Medium
C5	0.35/1 → Low
C6	0.4/1 → Medium

Table 5. Values of initial nodes for the third case

After having simulated the conditions above, we took the results below and the value of output concept is C7=0.59.

The value of the output concept, according to our expert is reasonable because in this case the conditions inside the greenhouse are neither good nor bad and the rate of photosynthesis was expected to be medium:

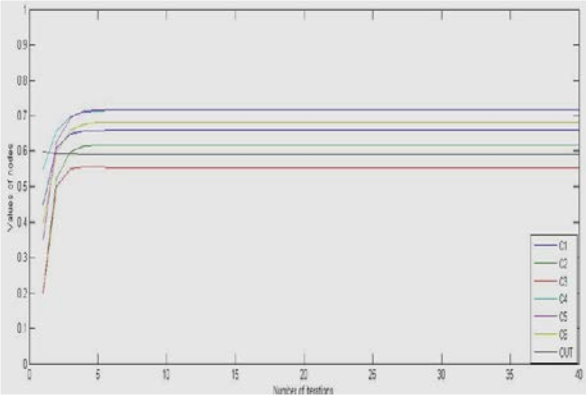

Figure 5. Subsequent values of concepts till convergence for the third case

As it was mentioned in the paragraph 3 the values of all the concepts, including the output concept, are changing and their values are calculated by the rule (equation (1)). After some calculations the values of the concepts do not change anymore and we have the equilibrium point.

6. CONCLUSIONS

In this paper, advanced techniques have been used in greenhouse modeling and the results show that these techniques had satisfactory results. For first time, Fuzzy Cognitive maps which were used to predict the photosynthesis rate of the plants inside a greenhouse gave us simple models while the simulations were understandable, flexible and easy to use. A new way for studying and analyzing the good operation of a greenhouse was presented, too.

In order to be more accurate in the future, we need to use more experts who will give us a better approach of the greenhouse microclimate model and who will probably propose new concepts which have to be inserted in the Fuzzy Cognitive Map. Moreover it is needed to use learning algorithms in order to study the process of the greenhouse microclimate and to extract more accurate results. In this way the possibility to control better the different technical control parts will be given and we will have the chance to achieve the better possible climate conditions inside a greenhouse.

All these challenging problems will be the subject of our future research work.

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