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Energy Procedia 18 (2012) 416 – 425

Energy Procedia

GA Optimization of the Coupled Climate model of an order two of a Greenhouse

Khelifa Lammari [a], Fateh Bounaama [a], Belkacem Draoui [a], Benyoucef Mrah [a], Mohamed Haidas [a]

[a] *University of Béchar B.P 417, 08000 Béchar -,Algeria*

Abstract

Greenhouses are used for the main purpose of improving the environmental conditions in which plants are grown.The efficiency of plant production in greenhouses depends significantly on the adjustment of several components particularly, the greenhouse interior temperature, vapour pressure and Co2 concentration. Here are developed a nonlinear coupled multiple-input, multiple-output (MIMO) model of an environmental greenhouse under matlab/simulink. This paper presents the optimization of temperature and vapour pressure employing a complex greenhouse climate model .The investigation of the newly developed approach for determining the optimal values for the greenhouse model parameters using the genetic algorithm technique (GA) was used.The mathematical model and the data used to test the proposed method were acquired in a commercial greenhouse using a sampling time interval of 1 hour. The greenhouse is automated with several actuators and sensors that are connected to an acquisition and control system based on a personal computer. The simulation results demonstrate the effectiveness of the proposed method.

Keywords: The mathematical model, Temperature, Vapour Pressure, optimized parameters, MIMO, GA.

1. Introduction

The greenhouses were developed in order to cultivate plants under controlled conditions. They offer high productivity and efficiency, and remove much of the risks caused by the inappropriate weather and climate. Simulation models to describe the dynamic behavior of the air temperature and humidity and dioxide concentration inside the greenhouses have primarily focused on the determination of heating requirement, other systems of climate control have been largely ignored although they play an important role, particularly under Mediterranean conditions where the surface area of greenhouse production has increased tremendously over the last ten years. These other systems include natural

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* Corresponding author. *Tel / Fax: 049 81 52 44.*
E-mail address: lammarikhelifa@yahoo.fr.

doi:10.1016/j.egypro.2012.05.053

ventilation, evaporative cooling, and shading and irrigation control. Analysis of these problems requires consideration of coupled mechanisms involving heat and mass (air, water vapour). Nonlinear models describing the above processes have archived some success and offer a closer interpretation of phenomena, focusing on issues such as physical models, black-box models, and neural networks models[1-2-3]. However, they are complex and not easy to use in practice because they require a considerable time of calculates of which is inversely proportional to the fineness of space and time discretization. They also demand knowledge of large number of model parameters, as well as, meteorological inputs. Finally, numerical iterative solution techniques can diverge if the choice of initial conditions is wrong [4]._This paper presents the theory and methods involved in the development of a nonlinear coupled multiple-input, multiple-output (MIMO) model of greenhouse which is based on an order two thermal model [5], and first order hydric model of the greenhouse [2]. A new method for selecting the parameters based on the genetic algorithm is presented, which optimizes the choice of parameters by minimizing a cost function. A coupled model of a horticultural greenhouse defines the cost function. This approach is validated by experimental results [2]. Measurements of air exchange rate and simultaneous recording of the climatic parameters and opening surfaces were performed with an experimental greenhouse, covered with a single layer of polyethylene, and equipped with roof and side openings. This greenhouse is located at the INRA Bioclimatology station, Avignon, France (Lat *43° 55'*).A schematic plan of the greenhouse and its environment is shown in Fig.1. The proposed algorithm gives a fast convergence towards the optimal solution. Genetic Algorithm optimizers are robust global stochastic search methods based on the Darwinian concepts of natural selection and evolution. The parameters of each individual of the population are usually encoded as a string of bits (chromosomes). The first group of individuals (generation) is created randomly. The fitness of each individual is determined by the cost function, and a new generation is formed by mating these individuals. The more fit individuals are selected and given greater chance of reproducing. Crossover and mutation are used to allow global exploration of the cost function. The best individual may be passed unchanged to the next generation (elitism). By these iterative processes, successive generations are created until a stop criterion is reached. It is expected that the individuals of the successive generations converge to the global maximum [6].

2. The coupled model of greenhouse

Studies with complex dynamic models and simplified models [2-5-7] allow us to write the transfer phenomena according to the formalism of the systems approach. To reduce the system order, the non linearity and the coupling of physical processes involved, we consider here an empirical approach. After consideration of the characteristic time scale of each process, we shall consider two main components:

- Soil which acts as a thermal mass [8-9], and heavy structural elements with characteristic time scale much longer than our observation time scale (1 hour). They were covered (in our case) by a plastic white mulch (no latent heat exchange) and they will be collectively gathered under a virtual thermal mass characterised by temperature *Tm* and thermal capacity *Cm*;

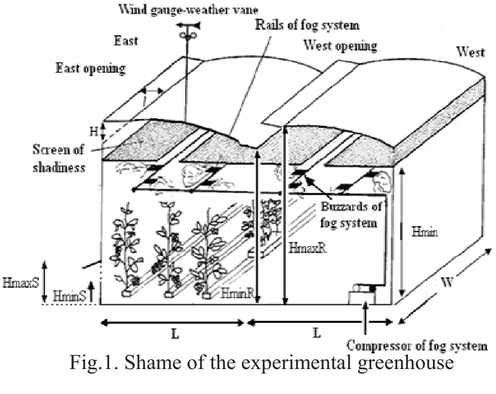

Fig.1. Shame of the experimental greenhouse

- The crop, greenhouse superstructure and the enclosed air space, whose characteristic time scale is small (200s< τ_c <500s) compared to our observation time scale (3600s) and for our purpose will be characterized by temperature *Ti* and water vapour pressure *Pi.*

The state space representation of the above greenhouse system is expressed by the following energy balance and water vapour equations:

Virtual thermal mass:

$$C_m \frac{dT_m}{dt} = h(T_i - T_m) + \beta R_g + Q_{sol} \qquad (1)$$

where the first term of the right side is thermal exchange with the greenhouse air, the second one is the profit solar directly absorbs by the thermal mass and the last one is the heating on the ground level.

Vegetation:

$$C_v \frac{dT_v}{dt} = h'(T_i - T_v) \qquad (2)$$

where the first term of the right side is the thermal exchange with the vegetable air.

Air thermal balance:

$$Q_{air} + \alpha R_g + h(T_m - T_i) + h'(T_v - T_i) + K(T_e - T_i) + K_s(T_e - T_i) + K_l(P_e - P_i) = 0 \qquad (3)$$

where the first is the heating air level, the second term at the right hand is the solar profit, the 3rd is the heat exchange with the thermal mass, the 4th is the thermal exchange with the vegetation, the 5th is the global exchange between the inside and the outside, the two last are respectively the tender and latent heating transfers by ventilation.

Water vapor balance:

$$C_l \frac{dP_i}{dt} = A\tau' R_g + B(P^*(T_i) - P_i) - K_L(P_i - P_e) + \varphi_l \qquad (4)$$

where the first term of the right hand side represents the crop transpiration (simply described as a linear function of global radiation and saturation deficit) the second one the exchanges by the ventilation and the last one the contribution of the fog system [10].

And the water vapor saturation pressure is given by [2]:

$$P^*(T_i) = 6.1070((1 + \sqrt{2}.\sin(\frac{\pi T_i}{540}))^{8.827}) \qquad (5)$$

A multiple-input, multiple-output diagram model is shown in Fig.2, where variables to be optimized are internal temperature (*Ti*) and the internal water vapour pressure (*Pi*), manipulated variables are opening-wind (*s*), air heating loads (*Qair*),sol heating loads (*Qsol*) , power of the evaporative cooling fog system (φ_l) and measurable disturbances are solar radiation (*Rg*), wind speed (*V*), outside temperature (*Te*) and outside water pressure vapour (*Pe*). Other variables and the whole parameters {greenhouse + culture}: h, K, Cm, Cp, Cv, h`, s0, d0, B, and $Al\sqrt{C}$, where some are known then we propose to identify for others.

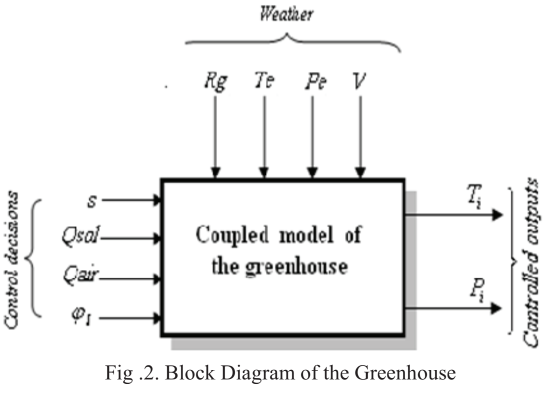

Fig .2. Block Diagram of the Greenhouse

The energy assessment integration of the equations (eqs.1, 2, 3 and 4) and the calculated water vapour saturation pressure (eq.5) leads to obtain a coupled MIMO model of order two of greenhouse with four unknown factors (*Tm, Tv, Ti, Pi*) . The great number of the parameters to be optimized has led us to fix some of them. These parameters take some values that are known before hand with a good accuracy. These include:

K: Overall heat loss coefficient through greenhouse cover ($Wm^{-2}K^{-1}$) to: $K = 7{,}6 + 0{,}42.V$

$Al\sqrt{C}$: Parameter of the model of natural ventilation, is fixed at 0,2.

The 12 parameters of the equations (eqs.1, 2, 3 and 4), which make the objective of our optimization, are presented below:

s_0 : Leakage surface (m^2)

d_0 : leakage (m^3s^{-1})

β :The rate of absorption of the global radiation by the thermal mass compartment of the greenhouse.

α :The rate absorption of the global radiation by the aerial compartment of the greenhouse.

h : The air/ sol convective Exchange coefficient ($Wm^{-2}K^{-1}$)

h' : Air/vegetal convective exchange coefficient ($Wm^{-2}K^{-1}$)

Cm : The thermal capacity ($Jm^{-2}K^{-1}$).

Cv : Heat-storage capacity of the vegetation ($Jm^{-2}K^{-1}$).

B : Parameter of the model of transpiration ($Wm^{-2}hPa^{-1}$)

T_{m0} : The initial thermal mass temperature (°C)

Tv_0 : The initial vegetal temperature (°C)

Pi_0 : The initial Outdoor relative humidity (hPa)

3. Overview of genetic algorithm (GA)

The basic principles of Genetic Algorithm (GA) were first proposed by [11]. Genetic algorithm (GA) is stochastic method for solving optimization problems, which are complex and difficult to solve by conventional optimization methods, with and without restriction based on natural selection determining the biological evolution process.GA maintains a set of candidate solutions called population and repeatedly modifies them. At each step, the GA selects individuals from the current population to be parents and uses them to produce the children for the next generation. Candidate solutions are usually represented as strings of fixed length, called chromosomes. A fitness or objective function is used to reflect the goodness of each member of the population. Given a random initial population, GA operates in cycles called generations, as follows:

- Each member of the population is evaluated using a fitness function.
- The population undergoes reproduction in a number of iterations. One or more parents are chosen stochastically, but strings with higher fitness values have higher probability of contributing an offspring.
- Genetic operators, such as crossover and mutation, are applied to parents to produce offspring.
- The offspring are inserted into the population and the process is repeated.

Field of research

Once we have chosen the lower and upper band optimization values, we must define, that is limit, the corresponding field of research through physical, technological and numeric criteria. Based on these criteria, we have defined the following field of research: (Table 1)

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Table 1: The parameters bounds for optimization
(Period of May)

Parameters	LB	UB
s_0 (m^2)	0	0.7
d_0 (m^{3}s^{-1})	0	0.6
β (.)	0	0.09
α (.)	0	0.5
h (Wm^{2}K^{-1})	1	8
h' (Wm^{2}K^{-1})	1	4
Cm (Jm^{2}K^{-1})	10	300
Cv (Jm^{2}K^{-1})	1	4
B (Wm^{2}hPa^{-1})	1	4
T_{m0} (°C)	15	25
T_{v0} (°C)	9	20
Pi_0 (hPa)	10	18

Objective functions

As an objective function for the optimization, we take into consideration the equations of the internal air temperature ***Ti*** and the internal water vapour pressure ***Pi*** in order to minimize the error of ***Ti*** and the error of ***Pi***. The GA-optimization algorithm was run for 100 generations with each generation having a population size of 10 and crossover fraction equal to 0.5. Optimization problems adjusting parameters of greenhouse is designed in MATLAB / SIMULINK.

4. Simulation Results

The validation of the coupled model of the greenhouse was realized using the collected data of a greenhouse [2]. This latter are collected when the greenhouse was used to grow a tomato crop on a rock wool substrate. Input variables and control variables were sampled once a minute and averaged over 1 hour. One of the difficulties of use of genetic algorithm lies in the choice of the numerous parameters that control it, the number of individuals of the population, the number of generation and/or ending criteria, probabilities of crossing and mutation. A small size of populations will probably evolve towards a local optimum not really interesting. A high size of populations will be useless because the time of convergence will be excessive. The size of the population will be chosen according to a good compromise between the time of calculation and the quality of the result. As for the problem we were interested in with the available means of calculation, we have noticed that a population of 100 individuals and the population size equal to 10 constituted a good compromise. In Fig. 3, the daily course of the temperature is displayed for one week. In general, plant temperature, optimized by Genetic Algorithm, reproduces quite satisfactorily the measured temperatures. The variations in temperature higher than the degree, observed during simulations, are not harmful on the growth of plants. In Fig. 4, the simulation of the water vapour pressure is illustrated for one week. A good agreement was observed between the experimental results and the optimized results. The variations in water vapour pressure, observed during simulation, are related to the complexity and the nonlinearity of the model. In order to qualify the validity of our model and the choice of GA algorithm, the error between the experimental results and those obtained by the Genetic Algorithm are presented in (Fig.5 and Fig.6). The criteria performance used is the root means squared error $RMSE = \sqrt{\frac{1}{N}\sum_{k=1}^{N} e_k^2}$, and the mean absolute error $MAE = \frac{1}{N}\sum_{k=1}^{N}\left|e_k\right|$ with N being the size of the data samples and e_k the error between simulated and measured values (Table 2) and (Table 3). After running the simulation model, the final optimal process parameters settings were determined after the minimum unit tuning and are shown in (Table 4).

Table 2: The RMSE of the air temperature and water vapour pressure model for the data set

RMSE	Temperature (°C)	Water vapour pressure (hPa)
May	1.0540	1.5469

Table 3: The MAE of the air temperature and water vapour pressure model for the data set

MAE	Temperature (°C)	Water vapour pressure (hPa)
May	0.8407	1.1570

Table 4: Parameters values of the Genetic Algorithm Optimization

Parameters	Period of May
s_0 (m^2)	0.6215
d_0 (m^{3}s^{-1})	0.5347
β (.)	0.0834
α (.)	0.3395
h (Wm^{2}K^{-1})	7.0225
h' (Wm^{2}K^{-1})	3.9555
Cm (Jm^{2}K^{-1})	187.5983
Cv (Jm^{2}K^{-1})	3.4374
B (Wm^{2}hPa^{-1})	3.2626
T_{m0} (°C)	19.5271
T_{v0} (°C)	13.0403
Pi_0 (hPa)	12.4786

In Fig. 7, fitness value is plotted against number of generations when optimized by GA. It was observed that all the population converges to a single value and thus confirms the reliability of results obtained using GA. We remark that the optimizations by the Genetic Algorithm demonstrate a high amelioration to the coupled MIMO model of a greenhouse.

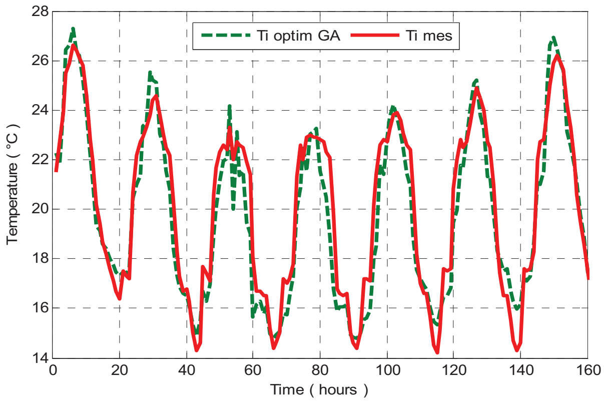

Fig.3. Comparison between the results given by the optimized (GA) inside air temperature and the measured air temperature for May

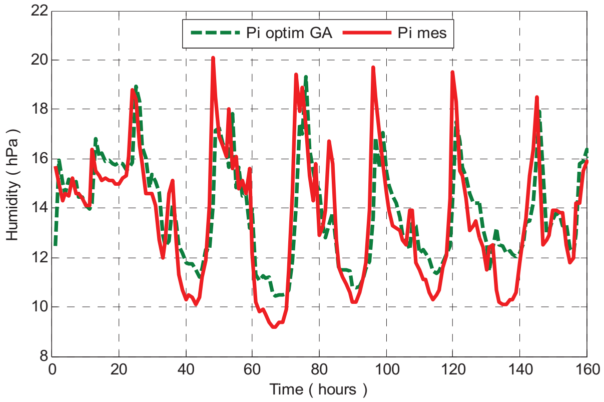

Fig.4. Comparison between the results given by the optimized (GA) inside water vapour pressure and the measured water vapour pressure for May

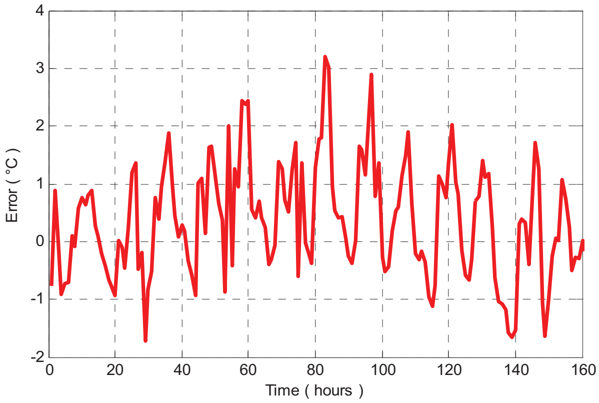

Fig.5. Error between the results given by the optimized (GA) inside air temperature and the measured air temperature for May

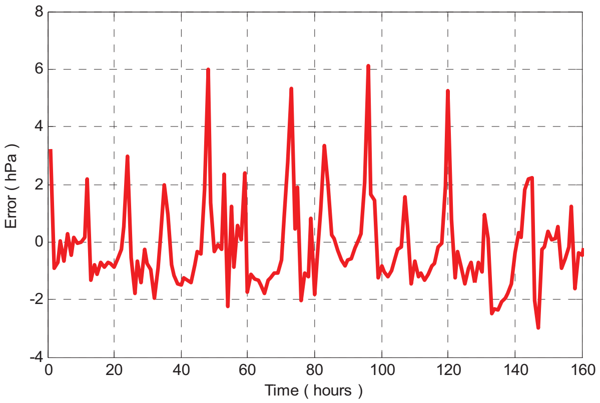

Fig.6. Error between the results given by the optimized (GA)
inside water vapour pressure and the measured water vapour pressure for May

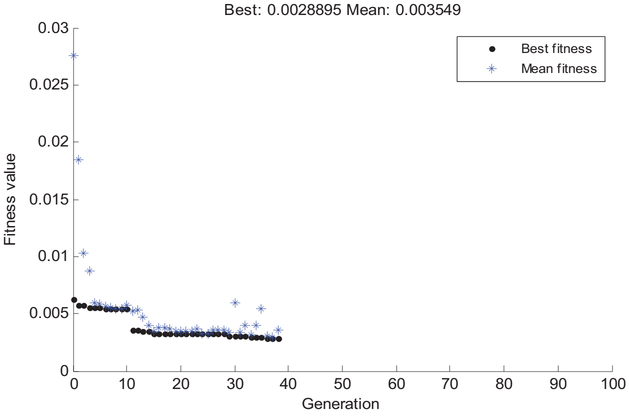

Fig. 7. fitness value versus number of generations (using GA) for May

6. Conclusion

This paper has presented a modelling approach for a MIMO model of greenhouse system. Determination of optimal parameters of a physical model of order two of greenhouse that considers the coupled balance of energy and water vapour is critical work that influences productivity, quality, and costs of product production. In this paper the comparison of measured and calculated temperatures and water vapour pressure in the plant model showed a good agreement. Simulation results demonstrate that the proposed method with the Genetic Algorithm approach achieve objectives and have satisfied the potential of robustness in the presence of weather disturbances and parameter variation since the efficiency of such method relies mainly on the accuracy of the physical model used, subject to constraints and real weather disturbances. The robustness of this model of greenhouse is evaluated through simulation using Matlab and Simulink.

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Variables and parameters of the greenhouse climate control

$Al\sqrt{C}$	Parameter of natural ventilation model (.).
B	Parameters of the model of transpiration ($Wm^{-2}hPa^{-1}$).
C_p	Thermal capacity of the greenhouse air component ($Kg^{-1}K^{-1}$) .
C_m	Water vapour thermal capacity ($Jm^{-2}K^{-1}$).
C_v	Heat-storage capacity of the vegetation ($Jm^{-2}K^{-1}$).
d_0	Leakage (m^3s^{-1}).
h	Air/sol convective exchange coefficient ($Wm^{-2}K^{-1}$).
h'	Air/vegetal convective exchange coefficient ($Wm^{-2}K^{-1}$).
K	Overall heat loss coefficient through greenhouse covers ($Wm^{-2}K^{-1}$) .
K_l	Latent heat transfer coefficient driven by ventilation ($Wm^{-2}hPa^{-1}$) .
K_s	Sensible heat transfer coefficient driven by ventilation ($Wm^{-2}K^{-1}$) .
$P*(Ti)$	Water vapour saturation pressure at Ti (hPa) .
P_e	Outdoor humidity (hPa) .
P_i	Indoor humidity (hPa) .
$Qair$	Air heating loads (Wm^{-2}) .

Qs	Soil heating loads (Wm^{-2}) .
R_g	Outside global radiation (Wm^{-2}) .
r	Ratio (s/m) .
S	Exchange surface between two constituents of the greenhouse (m^2) .
s	Vents opening surface (m^2) .
s_0	Leakage surface (m^2) .
T_e	Outdoor temperature (°C) .
T_m	Virtual mass temperature (°C) .
T_i	Indoor temperature (°C) .
V	Wind speed (m/s) .
v	Greenhouse volume (m^3) .
α	Rate absorption of the global radiation by the aerial compartment of the greenhouse (.).
β	Rate absorption of the global radiation by the thermal mass compartment of the greenhouse (.).
γ	Psychometric constant ($hPaK^{-1}$) .
φ_l	Injected evaporative cooling by fog system (Wm^{-2}) .
ρ	Air density (kgm^{-3}) .
τ'	Greenhouse covers transmitivity (.).

All fluxes are expressed per m^2 of soil. Dimensionless values are indicated by (.)

Appendix

$C_l = \rho C_p v / \gamma S$ is the equivalent thermal capacity of water vapour in air.

$r = A / B$ the Ratio (s/m) is composed of two parameters A and B

$$K_s = \frac{\rho\ C_P\ G_v}{S} \text{ and } K_l = \frac{\rho\ C_P\ G_v}{\gamma\ S}$$

$$G_v = \left\{ \frac{(s + s_0)}{2} \right\} Al\ \sqrt{C}\ V + d_0$$