Multivariable Greenhouse Control: Applications to Fertigation and Climate Management

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Keywords: fertigation, climate, multivariable control, real time, models, set points

Abstract

The objectives of this study were to analyse and develop an original methodology applied to the greenhouse controls, in particular for fertigation (control of humidity and electroconductivity inside slab, drainage ratio) and climatic management (control of the main climatic parameters like air humidity and temperature). Predictive commands are used for these controls; they offer good compromises between performances and costs for climatic control and more generally, they are well adapted to this type of process (multivariable device, important delays, robust method). Command rules need a model of the process. General transfer function are used with a periodically identification (each week). Last, results given in this paper are obtained in simulation for climatic control and in real conditions for fertigation.

INTRODUCTION

Fertigation in soilless culture consists in the simultaneous supply of water and minerals to the substrate units, its management requests the control of several supply parameters (input parameters) and particularly:
- the watering dose, which is a function of substrate physical properties;
- the watering frequency, a function of the crop water demand, which can be estimated by computing the PET (Potential Evapo-Transpiration, litres/m²) in the form a.RG + b.DH (RG: global radiation, J/cm²; DH: water deficit, g/kg),
- the daily watering period, during which water is supplied to the plant,
- the overall mineral concentration of the solution, estimated by the electroconductivity measurement (EC, mS/cm),
- the concentration of each mineral in the solution (meq/l).

In conventional systems, this whole set of parameters is manually adjusted, in order to optimise the output parameters which are:
- the substrate humidity,
- the substrate electroconductivity,
- the daily drainage rate.

In a Real-Time Controller, the challenge is to generate automatically commands for managing optimally these parameters.

For the climate control, the objectives are to maintain optimal conditions (air temperature and humidity) by searching best compromises between crop needs and energy costs.

MATERIALS AND METHODS

The methodology developed for this study is generic and the approaches for fertigation and climate are the same.

We can consider two fundamental steps:
- model simulation,
- command rules.
Model

To be able to command a process, we need a model which can predict its dynamic behaviour. This prediction is needed around a steady state in order to know how to act on control variables. Therefore, we do not need a complex non linear mathematical model, and use classical transfer functions applied to numerical signals. However, the choice of the “good” inputs and outputs is crucial.

We have chosen a classical representation in transfer function by means of the z transform (\(z^{-1}\) is a delay operator and is depending on sampling time \(T_s\)) for sampled signals.

If we suppose that we have a process with \(p\) inputs and \(m\) outputs, each output \(y_k\) is given as a function of every input \(u_i\) by the following generic expression:

\[
y_k = \frac{\sum_{i=1}^{p} (z^{-r_{ki}} \sum_{j=1}^{n_{ki}} b_{ki} z^{-j} u_i)}{\left(1 + \sum_{j=1}^{\sum_{j=1}^{m} a_{kj} z^{-j}}\right)} \quad \left\{ k = 1 \text{ to } m, \quad i = 1 \text{ to } p \right\}
\]

\(n_{dk}\) = degree of denominator of the output \(k\)
\(m_{nki}\) = degree of numerator of output \(k\) and input \(i\)
\(r_{ki}\) = delay between input \(i\) and output \(k\) (in sampling time \(T_s\) units)

The complete model will be defined by the determination of the coefficients \(a_{kj}\) and \(b_{ki}\). They are identified using the minimisation of the quadratic error criteria (non linear) between the predicted and measured outputs.

In addition, choosing \(n_{dk} = m_{nki} = 1\) is generally sufficient. Every delay is set equal to zero, except the delay between the input solution \(V_i\) and the drainage (see Annex I for definitions) which can be taken between 0 and 12 (always in \(T_s\) units).

The different adopted configurations are described in Table 1.

This model structure (inputs and outputs choice) has been determined from process analysis and from mathematical model structure (Draoui et al., 1995). Model parameters have been obtained from an identification procedure, based on the output error method implemented in MATLAB: experimental data from process operation during several weeks have been used to compute the model after a suited pre-treatment. The three graphs from figure 1 show simulated (results of identification) and measured data during one month for the three output parameters. It can be noticed that the very satisfactory identification results validate the chosen approach based on a MIMO ARX model.

Predictive Commands

To find command rules, predictive commands are used. This methodology has many advantages, especially:
- efficiency for process with delays,
- ability to take into account set point variations,
- robustness (available responses with noise on signals).

Predictive commands require a model, and is based on the following principles. At a given time \(t\), inputs and outputs (measures) of the process are known and, if a future command strategy \(U_1\) is applied, the future outputs \(Y_1\) can be predicted through the model and so on for \(U_2\).

The strategy which minimizes a given criterion \(\rho\) will be selected. This criterion can relate to:
- the output errors (differences between set points and measures),
- the cost of the generated commands,
- the relative variations of the commands (to minimize sudden variations of the actuators).

Each of the term in the criterion can be weighted by a coefficient whose value depends on the importance of the related term.
The quadratic form selected in this study is as follows:

\[ \rho = \sum_i \lambda_i \left[ \sum_j (y_j - SP_j)^2 \right] + \sum_i \nu_i \left[ \sum_j \Delta u_j^2 \right] + \sum_i \mu_i \left[ \sum_j u_j^2 \right] \]

For the climate control, only the terms \( \lambda_i \) and \( \mu_i \) are used, for fertigation only the terms \( \lambda_i \) are used.

**Constraints on the Actuators**

Some actuators do not allow low command levels, indeed it is the case for the supply solution volume in fertigation. It is then necessary to determine a minimum threshold value under which no command will be sent. Thus, the level determined by the regulator is not the same as the level sent to the actuator, and the relation between the command given by the regulator and the actual command is as mentioned in Figure 2.

Table 2 gives the complete list of the used parameters.

**Climat Control Experiment**

Data for climate identification operation were obtained using an experimental design in a plastic greenhouse (Richel®) with Rosa hybrida cv First red® (NIRP) soilless cultivated on perlite substrate. Air temperature and relative humidity set points were maintained in the greenhouse with a climate control computer (INRA-SYSPIL®). The prescribed daytime temperature ventilation was set at 22°C, the relative humidity set at 70% (Micro-mist® fog system) with a minimum night time temperature heating of 16°C.

**Fertigation Control Experiment**

This experiment took place in 2004 in one of the CTIFL research station in Carquefou, in two 4.20 meters high heated glasshouses (250 m²) with both roof side vents.

In 2003, we used the cultivar ‘Triple 4’ (Enza Zaden), sown on October 31th 2002, planted on December 17th 2002 with Grodan FL rock wool slabs, and harvested once a week from march 5th 2003.

In 2004, we also used the cultivar ‘Triple 4’ (Enza Zaden), sown on October 31th 2003, planted on December 17th 2003 with Grodan Master rock wool slabs, and harvested once a week from march 3rd 2004.

As a cultural system we used 2 stem-plants, with a plant density of 3.125 plant/m² and integrated pest management.

The average inside temperature set point was about 20°C and the average inside measured temperature about 21°C. Roof sprinkling was used in order to optimise greenhouse climate.

We managed 2 different irrigation/drainage valves by controlling both supply/drainage volumes and electroconductivity of the nutrient solution. Drainage was recycled without disinfection.

We also controlled substrate relative humidity and electroconductivity within the substrate with 3 different Grodan sensors.

**RESULTS AND DISCUSSION**

**Results on Climate (see Figures 3 to 5)**

These methods have been implemented for climate control. Three configurations were studied to determine the influence of the different weighting parameters. The studied period lasted for 6 days during February 2003, during which the set points varied between 18°C and 22°C for Ta, and between 70% and 80% for HR.
We can observe the influence of each parameter. The configuration for test 2 gives the best results but requires an important heating cost. The configuration for test 3 decreases the heating cost but maintains air temperature 3°C below the set points.

**Results on Fertigation (see Figures 6 and 7)**

This methodology has been applied in real conditions at the CTIFL Carquefou site to control water and nutrient supply to the plants. To avoid discontinuity on humidity in slab and wrong drainage values, we have programmed particular set points (SP) functions (figure 6). $t_1$, $t_2$, $t_3$, $HR$, $t'_1$, $t'_2$ and $t_{final}$ are programmed by the user.

Figure 7 summarize the main results obtained during the period between 07/06/2004 and 13/06/2004.

The selected parameters are given in table 3. The final result is always a compromise between all the parameters.

The most important values to determine are weighting parameters: $U_{threshold}$ (depends on the process) and $k_{threshold}$.

General rules could be:
- do not weight drainage ratio too much,
- HRs and drainage ratio set point functions have to be adjusted as precise as possible, in order to take into account system inertia for drainage and to avoid over or under-irrigation,
- if the wished value is under (over) the corresponding set point, $k_{threshold}$ parameter could be decreased (increased).

**CONCLUSIONS**

Multivariable greenhouse control is an interesting tool for fertigation management, in order to better control substrate relative humidity, electroconductivity within the substrate and drainage rate.

However, it is important to adjust precisely the most important parameters in order to avoid over or under-irrigation, and by the way to lose all the advantages of such a precise system.

Multivariable greenhouse control will be intensively tested in the coming year in order to evaluate its feasibility to be used by growers and to be incorporated in a commercial greenhouse fertigation management system.

This project is carried out with financial support from the European Commission under the RTD programme "Quality of life and management of living resources" (project QLRT-1999-31301). It does not necessarily reflect the Commission's views and in no way anticipates its future policy in this area.

**Literature Cited**


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<table>
<thead>
<tr>
<th>test 1</th>
<th>test 2</th>
<th>test 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\lambda_{Ta}=1$</td>
<td>$\lambda_{HR}=1$</td>
<td>$\lambda_{Ta}=10$</td>
</tr>
<tr>
<td>$\mu_{Heat}=0$</td>
<td>$\mu_{V*S}=0$</td>
<td>$\mu_{Heat}=0$</td>
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</table>
ANNEX I (Definition of parameters used in this paper)

In general, U is a vector for inputs (size = {p,1}), Y is a vector for outputs (size = {m,1}),
SP is a vector of set points for each output or input (size = {m,1})
An input can be a real command (manipulated input) or a disturbance (unmanipulated input).

Common Definitions
U or u: general vector for data inputs
Umin and Umax: minimal and maximal values for commands levels
Uthreshold: minimal output value, greater than Umin (see figure 2 for complete definition)
k%threshold: coefficient giving the command level between Umin and Uthreshold (see figure 2 for complete definition)
Y or y: general vector for data outputs
SP: set points vector
p: number of inputs
m: number of outputs
Ts: sampling time
z: delay operator used in discrete transfer function
λi: weighting parameter on output i (the other weighting parameters νi et µi are not used in this study).

Fertigation Parameters
Vi: Input overall supply volume of nutrient solution (recycled volume + fresh-made solution), instantaneous value
Vd: Drainage volume (instantaneous value)
Vi x ECi: Product of the input volume by the input electroconductivity of the nutrient solution
SR: Input solar radiation
HRs: Substrate relative humidity
ECs: Substrate electroconductivity
Hdeb: Start hour of irrigation
Hfin: End hour of irrigation
Drainage rate ratio(t,T) = \[ \frac{\sum_{t=1}^{T} (Vd)}{\sum_{t=1}^{T} (Vi)} \] Hdeb < t < Hfin

Climatic parameters
SR: Input solar radiation
Tex: Input outside air temperature
HRex: Input outside air relative humidity
S x V: Product of opening area command with wind speed (differential equations of physical model show that this product must be used)
Heating: Heating command
Brum: Brumisation time command
Dsat: Inside air water deficit
HR: Inside air relative humidity
Ta: Inside air temperature
## Tables

Table 1. Configuration descriptions (definitions of each parameter are given in annex I).

<table>
<thead>
<tr>
<th>Type of control</th>
<th>Climate management</th>
<th>Fertigation control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental site</td>
<td>INRA Sophia Antipolis, France</td>
<td>CTIFL Carquefou, France</td>
</tr>
<tr>
<td>Test Period</td>
<td>February 2003</td>
<td>Since 2003 in simulation</td>
</tr>
<tr>
<td>Model</td>
<td></td>
<td>Since May 2004 in real conditions</td>
</tr>
<tr>
<td>Inputs/Outputs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ts</td>
<td>15mn</td>
<td>10mn</td>
</tr>
<tr>
<td>Identification interval time</td>
<td>each week</td>
<td>each week</td>
</tr>
</tbody>
</table>

Table 2. Used parameters in both experiments.

<table>
<thead>
<tr>
<th>Symbols</th>
<th>size</th>
<th>regards</th>
<th>applied to</th>
<th>depends on</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\lambda_i$</td>
<td>{m,1}</td>
<td>performances weighting</td>
<td>ferti</td>
<td>user’s choice</td>
</tr>
<tr>
<td>$\mu_j$</td>
<td>{p,1}</td>
<td>costs weighting</td>
<td>climate</td>
<td>user’s choice</td>
</tr>
<tr>
<td>Umin, Umax</td>
<td>{p,1}</td>
<td>absolute command values</td>
<td>ferti</td>
<td>climate</td>
</tr>
<tr>
<td>Uthreshold</td>
<td>{p,1}</td>
<td>threshold values for commands</td>
<td>ferti</td>
<td>climate</td>
</tr>
<tr>
<td>kthreshold</td>
<td>{p,1}</td>
<td>min threshold coefficient</td>
<td>ferti</td>
<td>climate</td>
</tr>
<tr>
<td>$H_{deb}$, $H_{fin}$</td>
<td>2</td>
<td>daily watering starting hour and closing hour</td>
<td>ferti</td>
<td>user’s choice</td>
</tr>
</tbody>
</table>

Table 3. Selected parameters in fertigation control experiment.

<table>
<thead>
<tr>
<th>Experimental parameters</th>
<th>Set points</th>
</tr>
</thead>
<tbody>
<tr>
<td>$H_{deb}=8H45$</td>
<td>$H_{fin}=19H15$</td>
</tr>
<tr>
<td>weighting parameters</td>
<td>$t_1=7H35$</td>
</tr>
<tr>
<td>$\lambda_{HR}=3$, $\lambda_{EC}=3$, $\lambda_{ratio}=1$, no costs</td>
<td>$t_2=10H15$</td>
</tr>
<tr>
<td>threshold parameters and values</td>
<td>$HR=72.5%$ à $75%$</td>
</tr>
<tr>
<td>$k_{Vi}=35$ à $50%$</td>
<td>$k_{EC}=5%$</td>
</tr>
</tbody>
</table>
Figures

Fig. 1. Identification results (fertigation control).

Fig. 2. Relation between real command and regulator value.

Fig. 3. The two disturbances SR and Tex (climate control experiment).
Fig. 4. Air temperature and relative humidity in the different tests (climate control experiment).

Fig. 5. The heating command –the others are not shown (climate control experiment).

Fig. 6. Set points adjustment (fertigation control experiment).
Fig. 7. The 3 inputs (Vi, ECi, SRad) and the 3 outputs (HRs, ECs, ratio) in fertigation control experiment.