ADAPTIVE CONTROL STRATEGIES FOR GREENHOUSE TEMPERATURE CONTROL

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Abstract

This paper presents the development of mixed feedforward-adaptive controllers for greenhouse climate control. These controllers are based on both simplified physical laws and on-line measured data and are discussed in terms of their suitability for adaptive control purposes. The schemes are tested using a highly nonlinear model of a typical Mediterranean greenhouse previously developed by the authors and some results and conclusions are included in the paper to show the main characteristic of the control system.

1 Introduction

Automatic greenhouse climate control systems are being widely installed nowadays in Southeast Spain. As a basic requirement, climate control helps to avoid extreme conditions (high temperature or humidity levels, etc.) which can cause damage to the crop and to achieve adequate temperature integrals that can accelerate the crop development and its quality while reducing pollution and energy consumption. The crop production system is characterised by both fast and slow dynamics, the first associated with the greenhouse climate and the second with crop growth. As a first approximation, seasonal optimisation [12] can treat the physical climate as immediately realisable through the control. However, when disturbances due to environmental variables are subjected to large changes (solar radiation, wind speed and direction changes, etc.), greenhouse climate dynamics seriously affects the net profit [15], even leading to dangerous situations (e.g. condensation) as a consequence of the surpassing of temperature or humidity limits. The dynamic behaviour of the micro-climate is a combination of physical processes involving energy transfer (radiation and heat) and mass balance (water vapour fluxes and CO_2 concentration). These processes depend on the outlet environmental conditions, structure of the greenhouse, type and state of the crop and on the effect of the control actuators. The main ways of controlling the greenhouse climate are by using ventilation and heating to modify inside temperature and humidity conditions, shading and artificial light to change internal radiation, CO_2 injection to influence photosynthesis and fogging/misting for humidity enrichment, although only natural ventilation, heating and shading screens are currently in use in Mediterranean productive sites. Due to the inherent complexity, the development of climate control systems has been mainly based in heuristic rules based on the experience of the growers [6]. During the last years, different control techniques are being applied to this problem, such as feedforward control [9], adaptive control [14], optimal control [5,15], robust control [7], predictive control [8], etc.

A mixed feedforward adaptive control scheme for greenhouse climate control is shown in this paper. This type of control strategy is adequate to control greenhouse temperature and humidity as the dynamics are nonlinear (e.g., the relation between natural ventilation and temperature) and time-varying due to several factors such as crop growth, wearing down of constitutive elements, etc. Previous works in this field like that presented by Sigrimis and Rerras [14] use MIMO linear models for on-line parameter estimation purposes, requiring the estimation a large number of parameters (36). The identification in this case is possible if a sufficient number of variables is monitored and under conditions of persistent excitation. Important nonlinearities such as product modulation of parameters (i.e., windows aspect with wind speed) can be accounted for by input variable transformation before entering the linearized model. Such feedforward actions and submodels are recommended due to the complexity of the greenhouse operation.

In the approach presented in this paper, the combination of feedforward and adaptive feedback schemes and the accounting for humidity control by on-line setpoint modification simplifies the estimation stage of the control algorithm as only two parameters have to be identified. The system should continuously update the model parameters as the greenhouse properties drift due to physical changes, and also to account for nonlinearities and model structure inaccuracies. As it is also pointed out in [14], supervisory mechanisms seem to be necessary for practical purposes. The diurnal climate control will be studied in this work (using vents as control inputs), although results shown are easily applicable to nocturnal operation (using heating systems as control inputs).

The paper is organised as follows. In section 2, the role of environmental conditions in greenhouse climate control and crop production is detailed. Section 3 is devoted to present the combined feedforward-adaptive control structure and the identification and adaptation laws. In Section 4, some simulation results are shown using a phenomenological complex nonlinear dynamic model [10] gathered from first principles to closely resemble the response of a real Mediterranean greenhouse.

2 Greenhouse climate system

The main variables affecting plant growth in Mediterranean greenhouses studied in this work are:

- ☐ State variables: internal air temperature, internal air relative humidity, soil temperature, cover temperature, 1st layer soil temperature, PAR radiation at plant level and CO_2 concentration (only monitored).
- ☐ Control inputs: pipe heating systems, ventilation windows and thermal/shading screens (fogging/misting systems and CO_2 supply systems have not an extensive use due to the associate high costs).
- ☐ Disturbance variables: outside solar radiation, outside air temperature, outside air humidity, wind speed and direction, rain, CO_2 concentration, leaf area of the plants (evapotranspiration rate inside the greenhouse), 2nd layer soil temperature and Sky temperature.

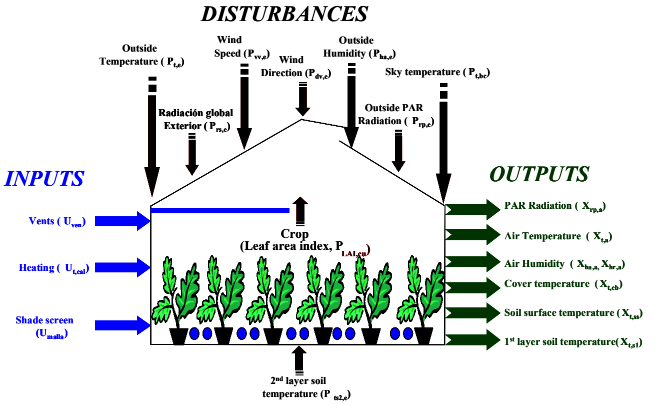
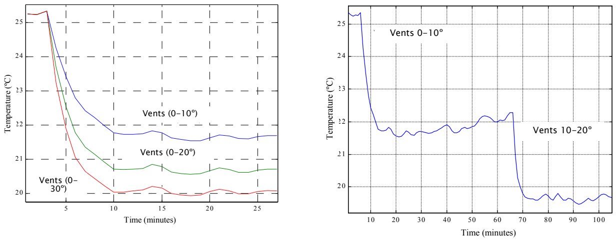


Figure 1. Greenhouse climate system

All these variables have been included in a highly nonlinear simulation model valid for many different types of automated greenhouses (after selecting characteristic parameters) that has been developed by the authors [10,11]. This model provides the values of state variables as a function of the state of the system, control inputs and disturbances, as it is shown in Fig. 1, and it has been validated for several representative greenhouses in the region (INAMED greenhouses, with two asymmetric curved slopes roof and six East-West oriented naves with 7,5 x 35 m of dimensions -1575 m^2- and ARABA greenhouses with two symmetric curved slopes roof and five North-South oriented naves with 7,5 x 40 m of dimensions -1500 m^2). This model has been used to perform the simulations shown in this paper.

A Web-based control system based on Labview® has been developed to control real greenhouses, as the proposed control system is going to be tested in a real greenhouse within a project "*Optimal hierarchical control of crop growth based on climate and fertirrigation*", that is being developed under the University of Almería-CAJAMAR agreement during 2003-2004.

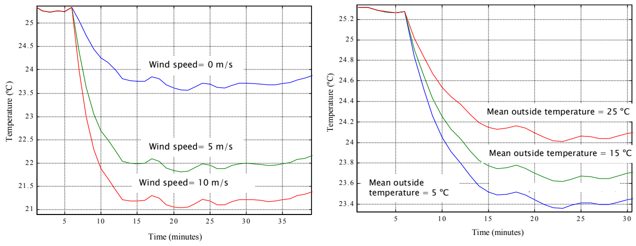
As it is commented in section 3, the use of adaptive and feedforward schemes for controlling greenhouse climate is justified by the nonlinear nature and changing dynamics of the system. Fig. 2 and 3 show several tests in which it can be seen how the inside greenhouse temperature changes when step changes in vents aperture are performed (nonlinear nature).



(a) Different steps in the same operating point

(b) Same aperture in different operating points

Figure 2. Inside temperature response to changes in vents aperture



(a) Same vents change (0-10°) under different wind speeds

(b) Same vents change (0-10°) with different outside temperatures

Figure 3. Inside temperature response to changes in vents aperture with different environmental conditions

As it has been pointed out in [14], disturbance variables have a dominant role and coherent action onto the formation of the greenhouse environment. Solar radiation has a strong immediate effect on the internal conditions and produces frequent oscillations (i.e., under passing clouds) in the controlled variables. In practice a time running average filter can be used when the measurements of this variable are used for control purposes. Outside temperature and humidity suffer slow variations and their measurements can be directly used for disturbance attenuation. Vapour produced inside the greenhouse is a very important factor for the condensation that occurs and its influence in greenhouse temperature is accounted for by using the leaf area index (notice that artificial humidifiers are not considered in this work). Two crop properties which can influence the inside environment are its albedo and canopy resistance [13]. In well-irrigated crops both properties are likely to be well correlated with the leaf area index, which can be included as a measurable disturbance, as in this case, where the growth and development of the plants are considered to be measured/estimated. Wind velocity includes a steady component, corresponding to the mean wind speed, and a transient component, corresponding to the gusting of the wind about the mean value. Mean wind velocity affects the air exchanges of the greenhouse or else the heat balance and can be also used for control purposes.

3 Mixed feedforward-adaptive control scheme

The main objective of the control system is to maintain the inside temperature around the desired temperature set point. As the solar radiation, which is the main energy source, cannot be manipulated, the control variables are natural ventilation and heating. During the diurnal operation, the changes in vents aperture produce large variations in the dynamics of the system (in fact, the relationship between vents aperture and inside temperature is not linear), justifying the inclusion of adaptive control schemes. It is even more interesting to compensate for changes in system dynamics due to crop growth and plastic cover deterioration, which require the modification of parameters in fixed parameters control schemes. In fact, many commercial solutions include heuristically tuned gain scheduling controllers to cope with both fast and slow changing dynamics. As an alternative, adaptive control allows self-tuning of control parameters in the face of changing dynamics. As has been previously mentioned, a feature of this type of system is that it is convenient to include a feedforward term [9] within the control scheme to compensate for disturbances acting on the system and, in this case, even to cancel nonlinearities, in such a way that if the feedforward controller is placed in series with the greenhouse, the variations in inside temperature would be mainly dependent on vents aperture changes. This is a feature of systems using solar radiation as the main energy source [3,4]. Fig. 4 shows the control scheme.

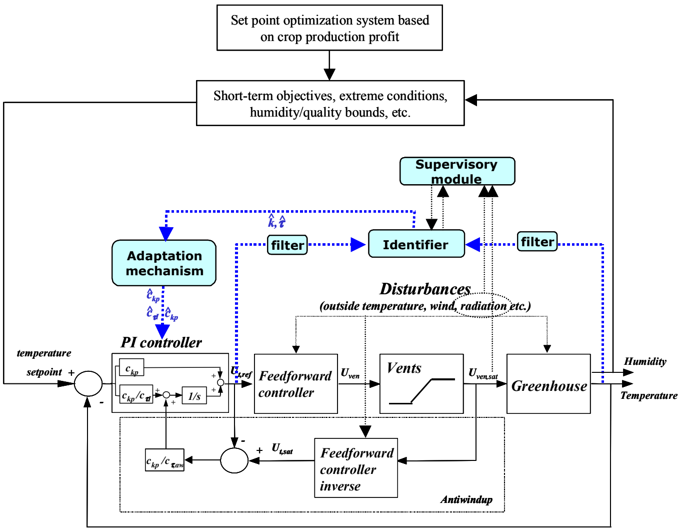


Figure 4. Control architecture

The developed simulation model [10,11] is not suitable for control purposes due to its complexity (although it can be used within an optimisation framework [12]). In what follows, an approximation introduced in [3,4] and successfully used in [9] for designing feedforward controllers is briefly explained. Taking into account the most relevant terms of the nonlinear differential equations representing inside temperature dynamics and by performing several simplifications and assumptions, a relationship can be obtained relating inside temperature with control variables and disturbances:

$$c_{ter,a}\frac{dX_{t,a}}{dt}=c_rP_{r,e}+c_h(X_{t,h}-X_{t,a})-(\phi_v+\phi_c)(X_{t,a}-P_{t,e})+ \\ +c_s(X_{t,s}-X_{t,a})+\lambda Evap \tag{1}$$

where $P_{r,e}$ is the solar radiation, $P_{t,e}$ is the outside temperature, $X_{t,h}$ is the temperature of the heating tubes, $X_{t,s}$ is the temperature of the soil, ϕ_v is the heat transfer coefficient due to ventilation, ϕ_c is the heat transfer coefficient from inside of the greenhouse out (assumed possitive), c_r is the solar heating efficiency, c_h is the a heat transfer coefficient of the heating system and , c_s is the a heat transfer coefficient from soil to inside air. A term accounting for latent energy fluxes has been included in the balance (λ *Evap*), where λ is the vaporisation energy of water and *Evap* the evapotranspiration. Another way to cope with the state of the crop is to include a gain reduction factor (extinction coefficient $c_{ext,oc}$) in the solar heating efficiency coefficient as a consequence of the growth of the crop, in such a way that $c_r=exp(-c_{ext,oc}P_{LAI})$, P_{LAI} being the leaf area index of the crop. This is due to the fact that the crop uses a fraction $[1-exp(-c_{ext,oc}\,P_{LAI})]$ of the incoming solar radiation to perform the transpiration process and so, the complementary part of this radiation is used to increase air temperature. In the approach treated in this paper, ϕ_c is considered to be constant (calculated in regime operating conditions) and ϕ_v is calculated by using the expression proposed by [2]:

$$\phi_v=\left\{\frac{c_{lv}c_dP_{t,e}}{3c_g(X_{t,a}-P_{t,e})}\left[\left[V_{h,efec}c_g\frac{X_{t,a}-P_{t,e}}{P_{t,e}}+c_wP_{v,e}^2\right]^{3/2}-(c_wP_{v,e}^2)^{3/2}\right]\right\}c_{den,a}c_{c-sp,a} \tag{2}$$

$P_{v,e}$ is the wind velocity, $V_{h,efec}$ is the volumetric flow rate and the new constants that appear in the formulation are: c_{lv} is the length of the vents, c_d is the discharge coefficient, c_g is the gravity constant and c_w is the wind effect coefficient. The discharge coefficient depends on environmental factors, but it has been considered to be constant in the obtaining of a simple feedforward controller. The volumetric flow rate is related to the vents opening (control signal U_α) by $V_{h,efec} = c_{w,v}\ [sin(\psi) - sin(\psi - U_\alpha)]$, where $c_{w,v}$ is the width of the vent and ψ is the slope of the roof.

The value of the coefficients in Eq. (1) and (2) have been obtained using input/output data obtained at the greenhouse and by iterative search in the range of values given by different authors using genetic algorithms. Data used for this calibration process have been obtained in different operating conditions in a real greenhouse.

By using the simplified representation of the heat balance given in Eq. (1) and considering a steady state balance ($dX_{t,a}/dt=0$), it is possible to derive a correlation for the input variables (ventilation and heating) as function of the environmental conditions and the inside temperature. In a series feedforward compensation scheme, the input to the series feedforward controller is a reference temperature ($U_{t,ref}$) provided by a feedback controller. As a first approximation, as there is one output variable (temperature $X_{t,a}$) and two control variables (ventilation U_α and heating $X_{t,h}$), these are considered to be exclusive control actions when controlling temperature in order to save energy. Then, using the mentioned static balance in Equation (1), the series feedforward controller is obtained by substituting the air temperature $X_{t,a}$ by the desired temperature $U_{t,ref}$. Thus, each sampling instant the following calculations have to be performed:

Day If $U_{t,ref} > P_{t,e}$

1. $$\phi_v = \frac{c_r P_{r,e} - \phi_c (U_{t,ref} - P_{t,e}) + c_s (X_{t,s} - U_{t,ref})}{(U_{t,ref} - P_{t,e})}$$

2. $$V_{h,efec} = \left\{ \left[\frac{\phi_v}{c_{den,a} c_{c-sp,a}} \frac{3 c_g (U_{t,ref} - P_{t,e})}{c_{lv} c_d P_{t,e}} + (c_w P_{v,e}^2)^{3/2} \right]^{2/3} - c_w P_{v,e}^2 \right\} \frac{P_{t,e}}{c_g (U_{t,ref} - P_{t,e})}$$

3. $$U_\alpha = \frac{180}{\pi} \frac{100}{31.7} \left(\psi - \sin^{-1} \left[\sin(\psi) - \frac{V_{h,efec}}{c_{w,v}} \right] \right) \quad \text{(\% aperture)} \tag{3}$$

Night

$$X_{t,h} = \frac{\phi_c (U_{t,ref} - P_{t,e}) - c_s (X_{t,s} - U_{t,ref})}{c_h} + U_{t,ref} \tag{4}$$

where a low-pass filter has been applied to solar radiation and wind speed disturbances to avoid sudden changes in the control signals. Notice that the effect of the crop has been included in c_r coefficient as it has been previously mentioned.

When humidity bounds are taken into account due to condensation, a reduced dynamic equation of humidity could be used in such a way that a system of two equations and two variables can be solved on line, providing the values of the desired heating and ventilation signals. These values should be implemented only when the humidity surpasses its limits. In other cases, the value given by the feedforward term obtained by using Equation (3) and (4) will be used. As will be commented, humidity control is really performed by set point manipulation.

The adaptive part of the control scheme used is shown in Fig. 4. It consists of a self-tuning regulator [1] in which the plant to be identified is composed by the feedforward controller in series with the system, in such a way that the feedback adaptive controller calculates the reference temperature for the feedforward term, that also generates the vents aperture to achieve the desired set point temperature. As the vents are physically constrained, an anti-windup scheme has to be included. In the classical approach, both the vents aperture demanded by the control system and that provided by the saturation block or actuator should fed the anti-windup block. The problem that arises in this application is that the control signal provided by the adaptive controller is the reference temperature for the feedforward controller, which provides the vents aperture depending on the measurements of environmental variables. So, the first input point to the anti-windup block has been displaced to the output of the feedback controller. Fortunately, when saturation occurs in the vents aperture, the corresponding reference temperature of the feedforward controller can be on-line calculated taking into account the actual value of disturbances (the feedforward term is invertible as inside temperature is higher than outside temperature when vents are used), in such a way that the scheme reproduces the classical one. In each sampling time, the adaptive controller:

1. Estimates the parameters of the linear model using filtered input (reference temperature for the feedforward controller) and output (inside temperature) signals. The identification algorithms used is described in [4] and is based on recursive least squares (RLS) identification with UDU factorisation and variable forgetting factor in order to reduce the identifier memory and to avoid the identifier gain reaching zero. A supervisory module has been included to check conditions under which identification has to be stopped (saturation of the control signal, poor dynamic excitation, etc.) and to avoid the use of wrong estimated parameters.
2. Adapts controller parameters. The design of the PI controller ($G_{PI}(z^{-1})=(q_0+q_1z^{-1})/(1-z^{-1})$) has been performed by pole cancellation. The system between the reference temperature to the feedforward ($U_{t,ref}$) and the inside temperature can be modelled as a first order system $G(z^{-1})=bz^{-2}/(1-az^{-1})$ with a delay of one sampling time, in such a way that only two parameters have to be identified (static gain and time constant). If the zero of the PI controller cancels the system pole ($q_1/q_0=a$, integral time equal the time constant), and, for instance, it is imposed that the closed loop system should have two real poles at the same location, the relationship $q_0=1/4b$ is obtained, in such a way that the adaptation mechanism is given by $q_0=1/4\hat{b}$ y $q_1=-\hat{a}\, q_0$, where $\hat{a}$ and $\hat{b}$ are on-line estimated by the RLS algorithm (related to static gain K and time constant τ).
3. Calculation of the control signal by the PI controller.
4. Supervision of the correct control behaviour.

Regarding humidity control, the adopted solution has been to modify temperature setpoints as a function of the relative humidity (Fig. 4).

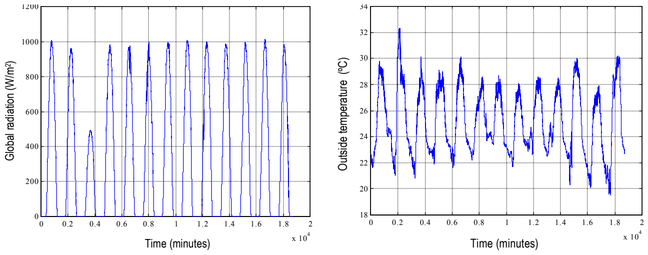
4 Representative results and discussion

The combined adaptive-feedforward scheme has been implemented and tested using the nonlinear model of the greenhouse [10,11] as the plant test bed. The sample time used for control purposes was 1 minute. The mixed feedforward-adaptive control scheme has been tested to analyse both short term and long term performance:

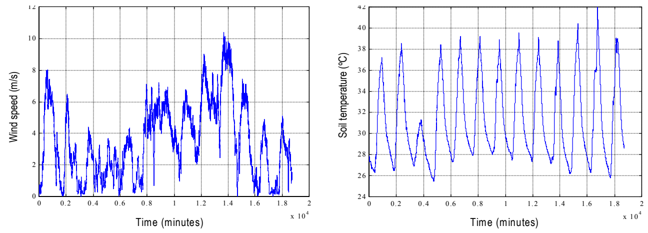
On one way, the behaviour of the control scheme has been analysed during daily operation (fast time scale) to compensate for changing dynamics induced by operating point changes and disturbance cycles. The inclusion of a series feedforward controller serves both to compensate for disturbances and to perform a pseudo-linearisation of the nonlinear structure of the system. Unmodeled dynamics can then be compensated by the action of the feedback controller. If the feedforward term perfectly accounted for changes in disturbances, the inside temperature changes observed would be caused solely by changes in the control input signal. Although obviously exact elimination cannot be achieved, a compensation element based on steady state considerations considerably reduces the major problems inherent in the single input model and permits the successful estimation of the system parameters. Thus, the feedforward term serves to preserve the validity of the assumed system models in the control scheme that uses a SISO description of the plant [4]. The improvement achieved is not quite high and there are some risks related to the coupling of system dynamics with adaptation dynamics. Nevertheless, the inclusion of filters in data entering the identifier and supervisory mechanisms helps to avoid or diminish these undesirable effects.

On the other side, as the greenhouse dynamics vary during the whole crop cycle (from 90 to 180 days) as a consequence of crop growth (characterised by changes in leaf area) and deterioration of plastic cover, the inclusion of adaptation in this slow time scale provides clear benefits, as in other case the parameters of fixed PI controllers should be manually changed accordingly to drifts in system dynamics.

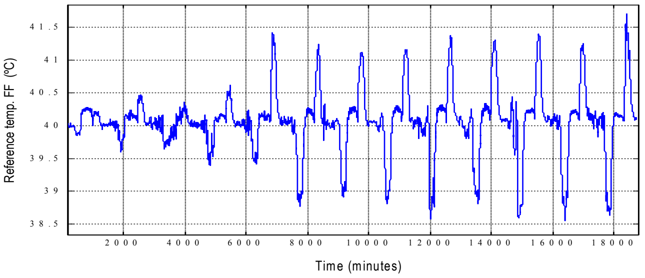
The behaviour of the control system in the fast time scale (10 days) in which the crop state (represented by the leaf area index) can be considered constant, can be observed in the following figures, representing summer and spring campaigns. Fig. 5 shows the evolution of the representative parameters of a tests with data of August 2000. The diurnal temperature set point has been 40ºC (quite high due to extreme outside conditions and closing of the shade screen the second day) to avoid actuator saturation. The controller has been working also during the night to see how the anti-windup block adequately works even under extreme conditions in which vents are completely closed during more than 8 hours.



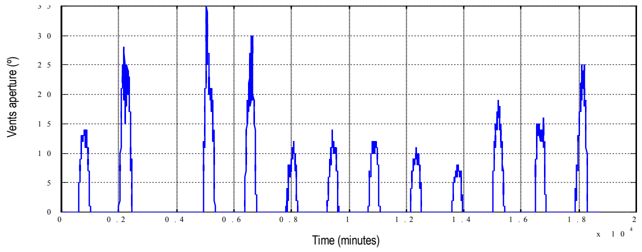
Global solar radiation (W/m^2) *Outside temperature (ºC)*



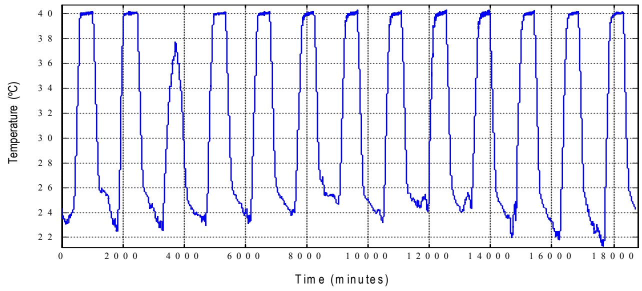
Wind speed (m/s) *Soil temperature (ºC)*



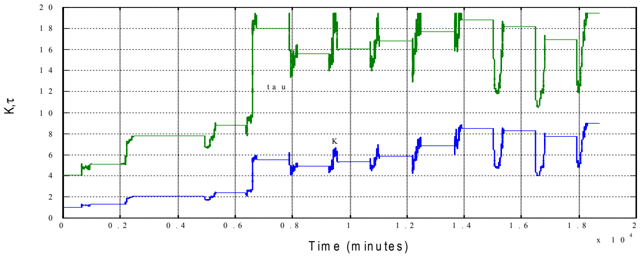
Reference temperature to the feedforward controller (ºC)



Vents aperture (º)



Inside temperature (ºC)



Estimated parameters of the linear model K (-) and τ (min)

Figure 5. Summer tests

Fig. 5 also shows environmental conditions during this test. All the filters and supervisory mechanisms have been implemented. The evolution of the estimated parameters is also shown in this figure. Fig. 6 shows the evolution of the inside temperature during a test performed with data of spring 1998. The diurnal setpoint temperature has been 30ºC. As can be seen, the effect of passing clouds and high wind speed values leads to saturation during several parts of the operation.

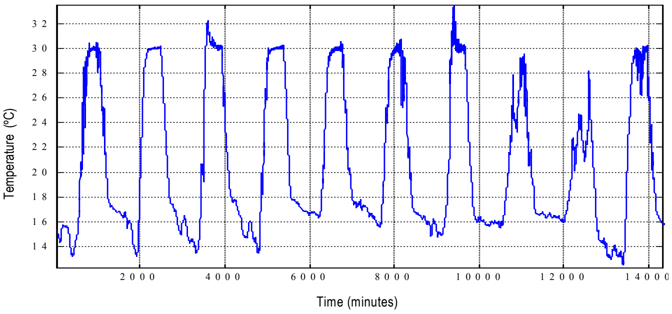


Figure 7. Spring test

The response of the adaptive PI control scheme is acceptable for all the considered seasons and for both slow and fast time scales (as the behaviour is pseudo-linearized by the action of the feedforward term). The control specifications will be smothered when implementing this control scheme at the real greenhouse to diminish changes in vents aperture, which is desirable from the exploitation point of view. From experiences in real greenhouses [11] it has been observed that a fixed parameter controller (without feedforward action) cannot cope with changing dynamics and its parameters have to be changed for different seasons. This is the main reason for including adaptation in this kind of systems. Nevertheless, as it has been pointed out, the improvement achieved in this case by the implementation of adaptation is not quite large in set point tracking performance. This is due to the action of the feedforward term in both cases, that not only compensates for disturbances acting on the system and nonlinearities but also positions the system around an operating point and linearizes the system behaviour thus indirectly improving the feedback controller performance. In any case, adaptation has the advantage that the change of control parameters is done in an automatic way (gain scheduling being another possibility). Notice that even in the long term scale, the leaf area of the plants is an input for the feedforward controller and thus the "adaptation" to crop growth can be performed in part by this term in such a way that the adaptation performed by the feedback controller will compensate for dynamics not accounted for by the feedforward term. It is also interesting to comment that the identification mechanism of the self-tuning controller tends to identify a system with time constants higher than those expected from step response tests. One possible justification is that one of the supervisory mechanism activates identification when the control signal (vents aperture) is greater than zero (to avoid identification windup). This usually occurs when solar radiation is rising. Although the effect of solar radiation should be compensated by the feedforward term, the unmodelled dynamics from solar radiation lead to the identification of a slower system (as the greenhouse integrates solar radiation). Another possible cause of the drift in the identified parameters may be the selection of the filters of signals entering the identifier. Nevertheless, the identification of a slower system increases the integral time of the PI controller leading to a more conservative behaviour, which is secure from the operational point of view.

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References

[1] K.J. Aström, B. Wittenmark. *Adaptive Control*, Addison-Wesley, (1995).

[2] T. Boulard, A. Baille, A. "Modelling of air exchange rate in a greenhouse equipped with continuous roof vents"; *J. Agr. Engng. Res*., **volume** 61, pp. 37-48, (1995).

[3] E.F. Camacho. F.R. Rubio, F.M. Hughes. "Self-Tuning Control of a Solar Power Plant with a Distributed Collector Field". *IEEE Control Systems Magazine*, pp. 72-78, (1992).

[4] E.F. Camacho, M. Berenguel, F.R. Rubio. Advanced control of solar plants. Springer, (1997).

[5] E.J. van Henten, *Greenhouse climate management: an optimal control approach*; Thesis, Agricultural University of Wageningen, The Netherlands; (1994).

[6] P.G.H. Kamp, G.J. Timmerman, *Computerized environmental control in greenhouses*; Ed. IPC Plant, The Netherlands; (1996).

[7] J.C. Moreno, M. Berenguel, F. Rodríguez, A. Baños. "Robust control of greenhouse climate exploiting measurable disturbances". 15th IFAC world congress, Barcelona, (2002).

[8] S.M. Piñón, E.F. Camacho, B. Kuchen, "*Constrained predictive control of a greenhouse"*; 15th IFAC World Congress; Barcelona; Spain, (2002).

[9] F. Rodríguez, M. Berenguel, M.R. Arahal. "Feedforward controllers for greenhouse climate control based on physical models". ECC01, Porto, Portugal, (2001).

[10] F. Rodríguez, L. Yebra, M. Berenguel, S. Dormido. "Modelling and simulation of greenhouse climate using Dymola". 15th IFAC world congress, Barcelona, Spain, (2002).

[11] F. Rodríguez. *Modelado y control jerárquico de crecimiento de cultivos en invernadero*. PhD Thesis. Universidad de Almería (Spain), (2002).

[12] F. Rodríguez, M. Berenguel, M.R. Arahal, M.R. "A hierarchical control system for maximizing profit in greenhouse crop production". ECC03, Cambridge, UK, (2003).

[13] I. Seginer, T. Boulard, B.J. Bailey. "Neural network models of the greenhouse climate*". J. Agr. Engng. Res*., **volume** 59, pp. 203-216, (1994).

[14] N. Sigrimis, N. Rerras, "A Linear Model for Greenhouse Control", *Trans. ASAE,* **volume** 39(1) pp. 253-261, (1996).

[15] F. Tap, F., L.G. van Willigenburg, L.G., G. van Straten. "Receding horizon optimal control of greenhouse climate based on the lazy man weather prediction"; 13th IFAC World Congress; San Francisco; USA; pp. 387-392, (1996).