ADAPTIVE CONTROL OF A GLASSHOUSE HEATING SYSTEM

A.J. Udink ten Cate
Dept. of Physics & Meteorology
Agricultural University
Wageningen - The Netherlands

J. van de Vooren
Glasshouse Crops Research and
Experimental Station
Naaldwijk - The Netherlands

Abstract

An adaptive (= self-tuning) control method for a computer controlled glashouse heating system is presented. The adaptation is based on a simple input-output model of the glasshouse heating dynamics, which is updated by an online estimation prodecure. Results of field trials indicate a significant improvement over conventional control.

1. Introduction

In the Netherlands, in most commercial glasshouses, the glasshouse climate is regulated by heating with heating-pipes and by ventilating with windows. This is usually performed by quite complex electronic control equipment. Because the control characteristics of the glasshouse can vary strongly because of their dependency on the outside weather conditions, these electronic controllers have to be tuned regularly. This is found too cumbersome in practice, so that different types of compensations are incorporated in these controllers. Usually, the control performs well, but under strongly varying weather conditions frequently poor control will result, which leads to heat losses due to overheating and simultaneously heating and ventilating. A computer-based controller in which other control methods than the conventional ones can be applied offers a potential solution to this problem.

This paper reports some of the results of a systems oriented approach to glasshouse climate control. A short description of the underlying ideas of this approach can be found in Bot and van Dixhoorn (1977). The research for this paper is carried out in close cooperation of the Agricultural University, Wageningen and the Glasshouse Crops Research and Experimental Station at Naaldwijk, The Netherlands, where an extensive digital computer control and data logging system is in operation (van de Vooren and Koppe, 1975).

An important motivation for this research is that in the Netherlands computer control is not restricted to experimental stations like Naaldwijk. At present over a hundred installations are in use or ordered by commercial growers. These installations are generally minicomputer or microprocessor based. Equipment cost is about $ 20.000,- and is at the break-even point with a sophisticated electronic controller for about six glasshouses.

The computer provides the grower with attractive data logging and averaging facilities. Algorithms used however, are generally a digital version of the conventional controller.

A first step, not reported here, has been the construction of a black box simulation model of a glasshouse, its heating system and associated control system. The model was validated with experimental data from the Naaldwijk installation. It was used to improve the conventional control algorithms. The results were used in the Naaldwijk computer control and showed a considerable improvement. It became clear, however, that no adjustments for the standard control algorithms could be found that gave satisfactorily control performance under the strongly varying environmental conditions.

So the next step, briefly reported in this paper and more extensively in Udink ten Cate and van de Vooren (1977) has been to develop an adaptive (=selftuning) control algorithm for glasshouse heating. This algorithm continously tunes the control algorithm depending on the actual situation. To track the actual situation a simple black box model with one adjustable parameter is incorporated in the control system. The adaptive algorithm is presently in operation in all computer control loops at Naaldwijk.

2. The control problem

To introduce the adaptive controller (Udink ten Cate and van de Vooren, 1977), the control problem has to be defined.
It is recalled that the glasshouse climate is influenced by the external factors showed in fig. 1, where also the heating system control loop is given.

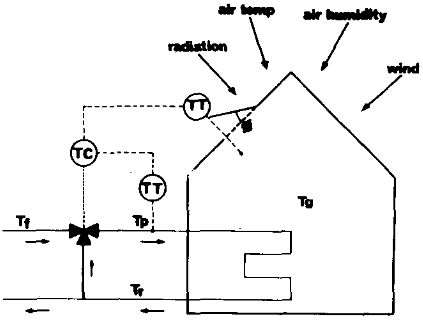

Fig. 1. Heating system control

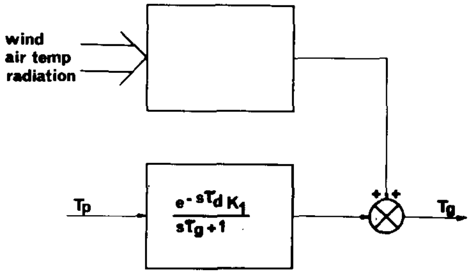

Fig. 2. A dynamic model

The objective of the heating system is to regulate the glasshouse temperature T_g. This temperature is influenced by the external factors and can be manipulated by ventilation which is caused by the position (with angle ϕ) of the control windows and by regulating the heating-pipe temperature T_p. The control problem can thus be regarded as a multi-input process. The inputs are the control variables ϕ and T_p, the output is the controlled variable T_g. The characteristics of this process are highly influenced by the external factors. In order to prevent heat losses it is desirable to manipulate T_p, since manipulation of ϕ causes opening of the windows and subsequent heat loss. Therefore, the control of the windows is separated from the heating system control. Manipulation of ϕ acts as a disturbance for the heating system control. Usually the setpoint for the window control is set higher than the heating setpoint so that interaction of both control loops is decreased to an acceptable level - from control theoretical point of view - and heat loss is prevented.

In the heating control loop, the heating-pipe temperature is controlled by a three-way valve that mixes the return water with temperature T_r

with the feedwater from the main boiler with temperature T_f (fig.1). The response of T_p on a change of the valve position is relatively fast if T_p has to increase, but slow if T_p has to decrease. The cooling response of the valve is rather slow. Since the temperature fall is dominated by T_r and T_r decreases slowly because of the large heat content of the pipe-water, the position of the mixing valve is in fact the proper control variable but is not selected because of the asymmetric relation between the valve position and T_p. This allows the selection of a simple control model, that produces specific control problems when large transients of T_p are required.

3. Adaptive control

3.1. A simple model

In order to design a control loop it is necessary to construct a dynamic model of the heating system. When the partial differential equations governing the heat (and vapour) flows from the pipes into the glasshouse are lumped into an approximate simple linear first order transfer function with a time delay, a dynamic model results as shown in fig. 2, with input T_p and output T_g. In this model the external influences are included following Roots[8](1969). Experiments were performed in the Naaldwijk glasshouse that consists of 24 identically, individually controlled compartments of 56 m^2 each. Under different conditions typical results for the parameters of the simple model of fig. 2 were: time delay $\tau_d \approx 6$ minutes, the time constant of the first order model $\tau_g \approx 30$ minutes and associated gain $K_1 \approx 0.25$-0.5; τ_d and τ_g being fairly constant. The external factors cause a disturbance signal, of which the significant part is relatively slowly time-varying. It is therefore assumed in this paper that the offset caused by the external influences and the dynamic gain K_1 can be lumped together producing a time variant gain K_g. This gain K_g is not easily determined because the dynamic model of fig. 2 assumes known offsets on T_p and T_g. Usually a model is defined by linearization around a nominal operation point. In the glasshouse this point is subject to large variations so that this approach

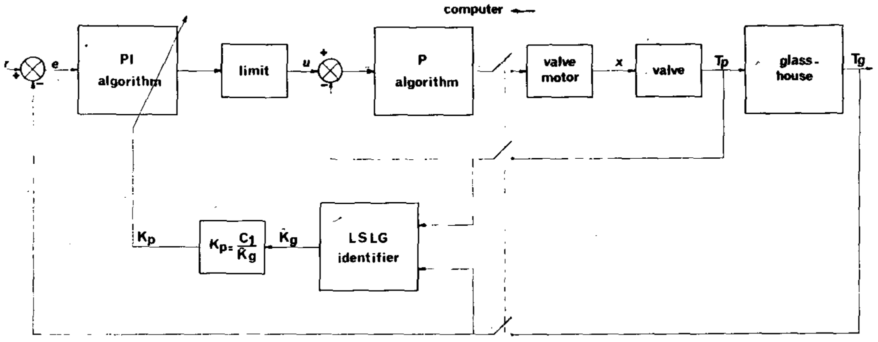

Fig. 3. Heating system control loop

cannot be used. Therefore, zero offsets were assumed producing a gain K_g related to a static plus dynamic model. In the Naaldwijk glasshouse typical values of $K_g \simeq 0.2-1.0$.

3.2. The adaptive control loop

In the adaptive controller of fig.3 the adaptation compensates for variations in K_g, which means that K_g has to be computed from input-output observations. This is performed by a recently reported "least-squares like gradient" identification technique (Udink ten Cate and Verbruggen, 1977), that is physically similar to the well-known recursive least-squares technique (Eykhoff, 1974).

In the identification procedure, the simple model of fig.2 is discretized and K_g is estimated. The estimate $\hat{K}_g$ of K_g is used to adjust a PI (proportional plus integral) algorithm that is a discrete version of the continuous PI controller with inputsignal e and output u:

$$u(t) = K_p(e(t) + \frac{1}{\tau_i} \int_o^t e(\tau)d\tau) \qquad (1)$$

The time constant τ_i = 25 min. The gain K_p of the PI controller is varied proportional to the inverse of the gain $\hat{K}_g$, thus keeping the product $K_p\hat{K}_g$ constant. The signal u acts as setpoint for the pipe temperature control (fig.3). In the controller, the signal u is limited between the minimum and maximum T_p. The values of T_p min./max. are time-varying and are based on horticultural requirements as well as on practical control considerations.

4. Field results

The adaptive control algorithm was programmed in the computer at Naaldwijk. Fig.4 gives some results on February 8 and 9, 1977.
The weather conditions on that day were: sunny, mean outside air temperature $\simeq 7^oC$, mean wind velocity 5 m/s.
Shown are the responses of the adaptive gain K_p, T_p, T_g and the setpoint of T_g; the setpoint is varied according to the amount of light. From the results it can be concluded that the controller follows the setpoint satisfactorily. An advantage of the adaptive control is that the value of the product $K_p\hat{K}_g$ was selected in January 1977 and since then (in May) there has been no reason to tune the controller for warmer weather conditions.

The responses stress the interesting features of the adaptive controller: after an initial tuning the controller is continuously and automatically adapted to varying weather conditions, leading to a control loop that is insensitive to external influences. It is remarkable that this succesful adaptive control is based on an almost too simple model of the glasshouse heating dynamics. On the other hand; the choice of this particular simple model and the detailed configuration are based on quite some engineering knowledge which makes the simple model rather the product of the design procedure than the starting point.

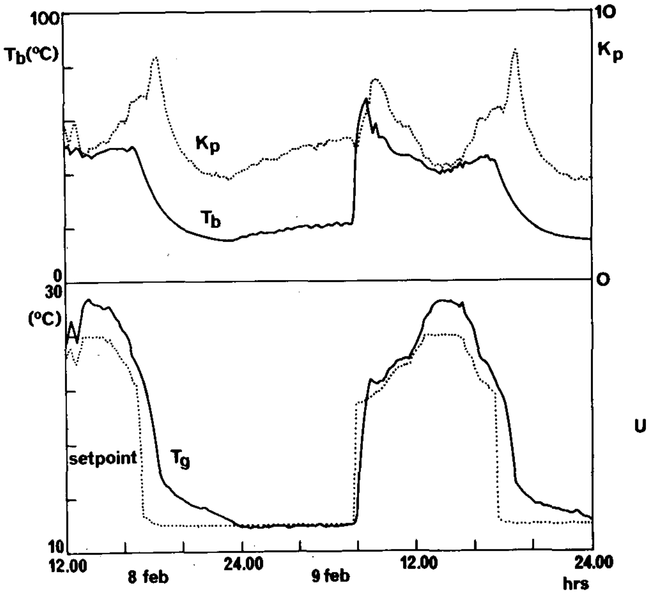

Fig. 4. Results of a field test at Feb. 8 and 9, 1977.

5. Conclusions

An adaptive glasshouse heating system control is presented. The adaptation is based on a simple input-output model of the glasshouse heating dynamics. This model is continuously updated and thus operates in a feedback situation. Therefore, it can be far more simple than a model that describes the heating dynamics accurately. The simple model is used to adapt a discretized version of a conventional PI controller. Field trials show a significant improvement over computer control based on conventional methods. Research in this field will be continued on ventilation with windows.

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