MODEL BASED DESIGN OF OPTIMAL MULTIVARIABLE CLIMATE CONTROL SYSTEMS

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Abstract

The simulation results are presented of the application of the linear quadratic performance (LQP) control design methodology to a non-linear physical greenhouse climate system. A multivariable greenhouse climate model designed by Bot (1983) is used for controller design and evaluation. First, the non-linear model is linearised around a nominal working point. Then, a LQP controller is designed for the linearized system. Computer simulations, using the original non-linear system equations as pilot plant, demonstrate a very accurate controller behaviour compared to a control algorithm which is used in practice.

1. Introduction

The greenhouse climate is governed by a multivariable process with several inputs and outputs and strongly coupled state variables. The classical approach to the control of a multivariable process is to treat the different subprocesses as if they are not interrelated. Each of these subprocesses is controlled by a single-loop controller. The application of modern control theory in which the multivariable character of the process is taken into account, can result in an improved control performance because more detailed information of the process is used. Not much attention has been payed to the application of modern control science in greenhouse climate control, because of the poor availability of detailed dynamic models of the process. (Udink ten Cate, 1983; Wells et al., 1985)

The last decade a lot of research has been done on the physical processes which determine the greenhouse climate, resulting in a multivariable model (Bot, 1983). This model does not give a description of the real control behaviour of the greenhouse system, because dead times and control valve characteristics are not incorporated in the model. It is felt that, while keeping these shortcomings of the system description in mind, it is possible to demonstrate a controller design methodology based on modern control theory.

2. The control problem

The starting point for the controller design is a multivariable non-linear greenhouse climate model which was derived essentially from thermo-fluidmechanical balance principles. The model is shown in figure 1. This model will not be discussed here, as it has already been described by Bot (1983). The dynamic behaviour of eleven state variables is a function of the states x, two control variables u, six disturbances v and time t and is described by a set of simultaneous non-linear equations:

$$dx(t)/dt = f(x,u,v,t) \quad (1)$$

The state variables are the water vapour pressure of the greenhouse air and the temperatures of respectively the greenhouse roof, the greenhouse air, the crop, and seven soil layers. The control variables are the temperature of the heating system and the opening of the ventilators. The disturbance variables are short wave radiation, windspeed, outside air temperature and watervapour content, sky temperature and the temperature of the eighth soil compartment.
In this study a linear time-invariant deterministic system description is used for the design of the controller. It is assumed that all statevariables x are measurable. By choosing a suitable working point, the non-linear equations (1) are linearized using a Taylor series expansion, which results in a set of linear first order differential equations:

$$dx(t)/dt = Ax'(t) + Bu'(t) + Cv'(t) \quad (2a)$$

where
$x'(t)$, $u'(t)$ and $v'(t)$ are resp. a n-dimensional nominal state vector, a m-dimensional nominal control vector and a k-dimensional nominal disturbance vector,
A, B, C are resp. a (n*n) system matrix, a (n*m) control matrix and a (n*k) disturbance matrix.

Because of modelling errors in (1), linearization errors in (2a) and non-zero disturbances $v'(t)$ the system description is extended with an integral state to improve the controller performance:

$$dq(t)/dt = Dx'(t) + Ew'(t) \quad (2b)$$

where
$q(t)$ is a p-dimensional integral state vector,
$w'(t)$ is a l-dimensional vector containing the setpoints of the controlled variables,
D and E are resp. a (p*n) matrix and a (p*l) matrix.

As stated above the parameters in the A, B and C matrices are not time-dependent and the stochastic character of the disturbances v has not being taken into account.

Before stating the control problem it has to be emphazised that the system equations (1) and (2) do not give a full description of the control behaviour of a real greenhouse climate system. Not included are dead times of the heating system and control valve characteristics.

The controller design is based on the optimal control theory concerning linear quadratic performance (LQP) criteria. The control problem is now to find a control law u(t) which for non-zero setpoints of the control variables minimizes the performance index:

$$J= \int_0^t (x'(t)^T R_1 x'(t) + q'(t)^T R_2 q'(t) + u'(t)^T R_3 u'(t))dt \qquad (3)$$

where

R_1 is a (n*n) state weighing matrix,
R_2 is a (p*p) integral state weighing matrix,
R_3 is a (m*m) control weighing matrix,

and $x'(t)^T$, $q'(t)^T$, $u'(t)^T$ are the transpose of the vectors x'(t), q'(t) and u'(t) respectively.

The optimal control law which minimizes the performance index (3) has the form:

$$u'(t)= K_1*x'(t) + K_2*q'(t) \qquad (4)$$

where

K_1 is a (m*n) state feedback matrix,
K_2 is a (m*p) integral state feedback matrix.

Only the results of the design method are shown. For a thorough description of the theory is referred to Schultz and Melsa (1967), Ogata (1970), Kwakernaak and Sivan (1972).

The model of the controlled process is shown in figure 2.

3. Controller design

The choice of the weighing matrices is quite arbitrary. Computer simulation and evaluation resulted in the choice of the following performance index:

$$J= \int_0^t (500.0*Tair^2 + 0.1*VPair^2 + 0.1*(Tair-Tairs)^2 + 3.0E-8*(VPair-VPairs)^2 + 10.0*Tpipe^2 + 1.0*Window^2)\, dt$$

4. Results and discussion

In figure 3 simulation results are shown. The non-linear system description (1) is used as test process. A standard control algorithm is used to evaluate the performance of the multivariable controller. At t= 500 s the setpoint of the greenhouse air temperature is increased with 2.5 ^oC, while keeping the setpoint of the water vapour pressure of the greenhouse air at the same value. At t= 5000 s one of the disturbances, the short wave radiation, is increased with 50 W/m^2. The figures 3a and 3b show respectively the respons of the greenhouse air temperature and the water vapour pressure of the greenhouse air to these step inputs. Actuator signals, the temperature of the heating system and the ventilator aperture, are shown respectively in the figures 3c and 3d.

Although quite large feedback gains are used, the overshoot of the multivariable controlled air temperature is small compared to the respons of the air temperature using the standard algorithm. The water vapour pressure of the air is more accurate controlled by the multivariable algorithm than by the standard algorithm. Application of the standard algorithm results in a saturation of the heating system. There is no saturation of the actuator signals when the multivariable controller is used.

5. Conclusions

The results of the in this paper demonstrated controller design methodology applied to greenhouse climate control are very promising. The feedback of more process information results in a better controller performance, i.e. a higher accuracy, less overshoot and no saturation of the actuator signals.

Further research must prove the applicability of this theory to a practical greenhouse climate control system. In the future attention will be focused on the following subjects:

- Further development of the dynamic model, especially with regard to the description of the control behaviour of the greenhouse system,
- Determination of the desired control behaviour of the greenhouse system and translation of these goals in design parameters,
- Implementation of the control algorithm in a climate control computer,
- Development of a state estimator.

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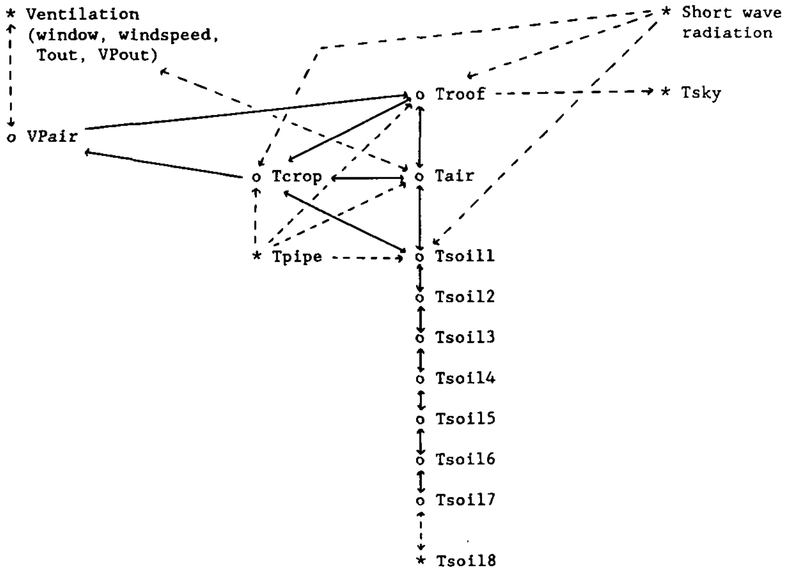

Fig. 1. A multivariable greenhouse climate model; the solid lines indicate the relations between the state-variables (o), the dashed lines indicate the relations between the state-variables (o) and the actuators and disturbances (*).

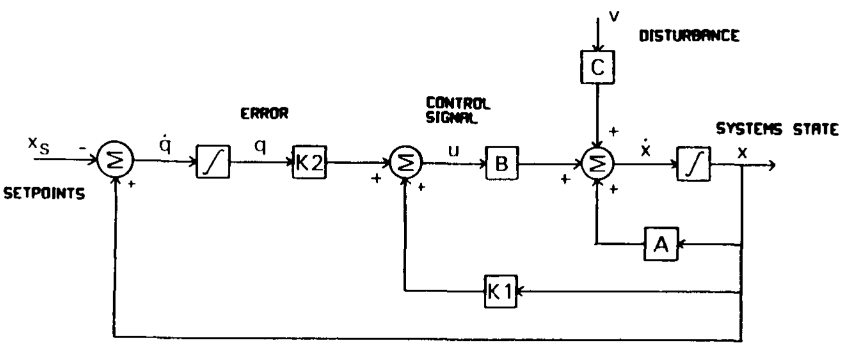

Fig. 2 - The model of the controlled process.

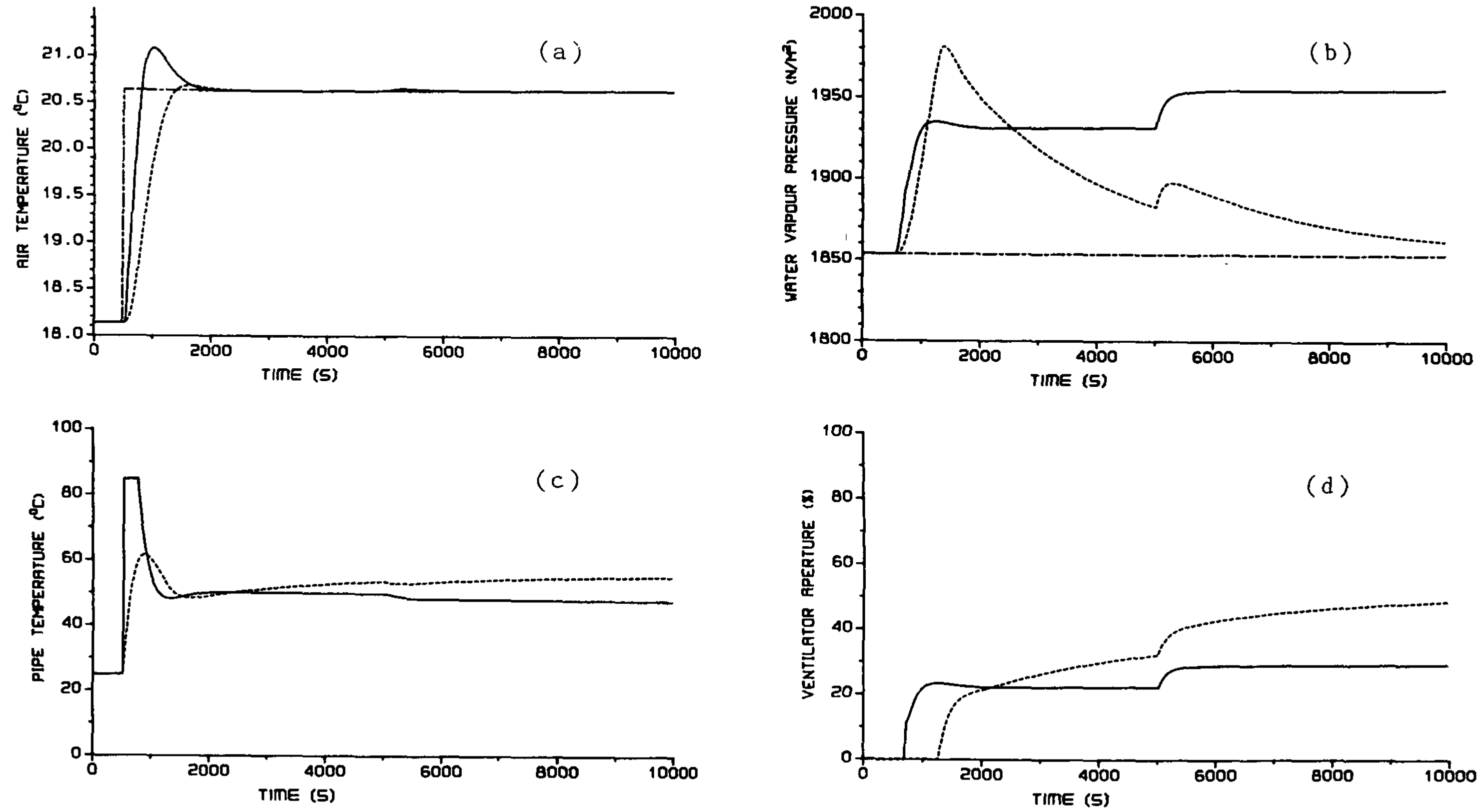

Fig. 3. Simulated responses of the air temperature (a), the water vapour pressure (b), the pipe temperature (c) and the ventilator aperture (d) to a step increase of the air temperature setpoint at t=500 s and a step increase of the short wave radiation at t=5000 s. (——: standard algorithm, -----: multivariable algorithm, —-—: setpoint)