Diurnal greenhouse temperature control with predictive control and online constrains mapping

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Abstract: Greenhouse climate control is a complex task that can be dealt using several control strategies to achieve energy efficiencies. The climatic control problem in greenhouses is characterized by frequent actuator saturation, due to energy source and structure layout characteristics. A model predictive combined with a feedforward compensator is used in this paper to face both disturbance and actuators saturation. Simulation and real tests are shown presenting promising results.

Keywords: GPC, feedforward control, constraing mapping, greenhouses, energy efficiency in agriculture.

1. INTRODUCTION

Due to strong demands over production and diversity, quality and market requirements, agro-food sector needs to use new technologies, where control engineering plays a decisive role. In this sense, the automatic control and the robotic techniques are present in every agricultural production level: seed, production, harvest, postharvest, and transport. Modern agriculture is subject to quality and environmental impact regulations and it is a field where control techniques application has raised considerably (Farkas (2005), King and Sigrimis (2000), Rodríguez (2002), Sigrimis, et al. (2001), Sigrimis and King, (1999), van Straten (2007)).

The main objective of greenhouses crop production is to increment the economic benefits of the farmer by means of finding a trade-off between the improvement of the quality of the horticultural products and the cost of obtaining adequate climatic conditions using new greenhouse structures and automatic control strategies. 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 (Rodíguez et al. (2001)).

The diurnal temperature control problem has been addressed in literature from different points of view, ranging from adaptive control, robust control, predictive control, and non-linear control ideas (Sigrimis et al. (2001), Rodríguez (2002), Moreno et al. (2002), Piñón et al. (2005)). In most of these works, it can be observed that in this control problem the external disturbances strongly influence the air flow, particularity the wind speed, the external air temperature, and radiation. So, it is convenient to include a feedforward term within the feedback control scheme to compensate for disturbances, and even to cancel non-linearities (the energy balance is of non-linear nature). The feedforward controller has been successfully used by the authors in previous works (Rodríguez et al. (2001), Rodríguez (2002), Moreno et al. (2005)).

However, in these previous works the treatment of the input constraints has been addressed by means of antiwindup technique and non optimal constraint management has been considered. Taking care about control signal constraints is very important when dealing with greenhouses climate control problems, because actuators suffer saturation continuously during daily operation. Therefore, this paper is focused on the development of a predictive control algorithm (Generalized Predictive Control –GPC– is used in this case (Camacho and Bordons (2004)) in series with a feedforward controller to regulate the greenhouse inside temperature during the diurnal period. The proposed control scheme allows to compensate process disturbances and adequately manage the input constraints. Since the predictive control algorithm has not direct access to the control signal, because of the feedforwad is placed in series, a constraint mapping strategy (Kurtz and Henson (1996), Roca et al. (2009)) has been also applied to translate the real input constraints to restrictions in the feedforward input, which can be managed by the predictive control algorithm.

This paper is organized as follows. In section 2, greenhouse climate control problem is briefly described focusing on the diurnal temperature control problem. In section 3, the proposed control strategy is analyzed, ranging from the feeforward controller, the predictive control algorithm, and the constrains mapping approach. Simulated and real tests are presented in section 4 showing promising results. Finally, section 5 is devoted to summarize some conclusions and future works.

2. PROCECSS DESCRIPTION

2.1 Climatic control description problem

Crop growing depends mainly on environmental climatic variables and on the amount of water and fertilizers supplied by irrigation. This is the reason why a greenhouse is adequate for growing crops, since it constitutes a closed environment from which climatic variables and fertilization can be controlled so as to allow an optimum crops growing and development. Climate and fertilization are two separated systems with different control problems each one of them. Empirically, water and species nutrients of different crops demands are known and, in fact, first automatized systems were those which controlled these variables. As greenhouses crop production problem is a complex task, a simplification consists in supposing that plants receive the amount of water en fertilizers required all the time. In this way, the problem is reduced to crop growing control subject to climatic conditions. Main elements in order to control greenhouse climate are ventilation and heating systems so as to modify inside air temperature and humidity conditions, shading and artificial light in order to change inside radiation, CO_2 injection so as to influence on photosynthesis, and spraying in order to modify humidity enrichment (Rodríguez et al. (2008)).

2.2 Temperature control using natural ventilation

Natural ventilation determines the air flow exchange inside the greenhouse as a direct consequence of outside and inside temperatures. The control system main objective consists on keeping inside greenhouse air temperature around a reference value. The relation between vents opening and inside air temperature is non-linear, but in this work, a linear controller combined with a non-linear feedforward static mapping maping is used to cope with external disturbances that have a huge influence on air flow, mainly, wind speed and outside air temperature. Thus, the feedforward controller is placed in series with the greenhouse, and then inside air temperature changes will mainly depend on ventilation opening changes (Gruber et al. (2008), Rodríguez et al. (2008)). There exists another alternative to using feedforward controller so as to compensate disturbances which consists on adding disturbances dynamics to GPC during design stage (Camacho and Bordons (2004))). However, the first alternative was only used in this work.

3. MODELING AND CONTROL ISSUES

3.1 Feedforward controller

The greenhouse crop production 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 can treat the physical climate as immediately realisable through the control. In nowadays greenhouse climate control, the emphasis is on achieving a temperature integral for crop growing and development purposes. 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, even leading to dangerous situations (e.g. condensation) as a consequence of the surpassing of temperature or humidity limits. Due to this reason, it is important to minimise the effect of disturbances in the inside conditions of the greenhouse by using adequate feedforward controllers, based on the measurement of disturbances and trying to eliminate their effects before they have created control errors.

Therefore, following the approximation introduced in (Rodríguez et al. (2001), Rodríguez (2002)) for designing feedforward controllers in the greenhouse climate control framework, the relationship can be obtained relating inside temperature with control variables and disturbances. Equation (1) represents the feedforward controller and it will allow to get ventilation signal considering disturbances and reference temperature values (Berenguel et al. (2006), Pérez-Parra et al. (2006), Rodríguez et al. (2001)):

$$U_{ven} = \frac{\sqrt[b]{\left[\frac{c_{r,a} P_{rs,e}}{(X_{t,a} - P_{t,e})}\right] + \left[\frac{c_{cnv,ss-a}(X_{t,ss} - X_{t,a})}{(X_{t,a} - P_{t,e})}\right] - \left[c_{cnv\_cnd,a-e}\right] - \left[\phi_{losses}\right]}}{\sqrt[b]{P_{v,e} a}} \tag{1}$$

where U_{vent} is the aperture percentage in vents, $P_{rs,e}$ is outside global radiation, $P_{t,e}$ outside air temperature, $P_{v,e}$ is wind speed, $X_{t,ss}$ is 3 cm depth floor temperature, ϕ_{losses} is the calculated inherent ventilation leakage due to greenhouse aerodynamics and layout, and $X_{t,a}$ is the reference value. Moreover, there are several coefficients which have to be estimated during a calibration process (Rodríguez et al. (2001), Rodríguez (2002)). In addition, feedforward controller adds a non linear element to the system which allows to make a system gain pseudo-linearization. It also introduces some modelling errors which are compensated by feedback.

However, it is necessary to take into account next considerations:

- Inside air temperature control using natural ventilation with this technique can be only used during daytime periods. Thus, heating convection is not considered.
- Crop respiration is considered as a function of plants state, measured using foliar area index and solar radiation at the greenhouse roof.

3.2 System model

By connecting feedforward controller with the plant in series, it results in a new system formed by both components. Therefore, it is necessary to take into account that GPC control signal will be the feedforward controller reference value ($X_{t,a}$ in (1)), and it will not be the real control signal which arrives to actuators. Fig. 1 shows the combination of both systems.