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Bayesian networks for greenhouse temperature control

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Greenhouse crop production is directly influenced by climate conditions. A Bayesian network is introduced in this paper aimed at achieving adequate inside climate conditions (mainly temperature and humidity) by acting on actuators based on the value of different state variables and disturbances acting on the system. The system is built and tested using data gathered from a real greenhouse under closed-loop control (where several controllers as gain scheduling ones are used), but where growers can also perform control actions independent on the automatic control system. The Bayesian Network has demonstrated to provide a good approximation of a control signal based on previous manual and control actions implemented in the same system (based on predefined setpoints), as well as on the environmental conditions. The results thus show the performance and applicability of Bayesian networks within climate control framework.

1. Introduction

Nowadays, agriculture must meet an increasing number of regulations on quality and environmental impact. The incorporation of new technologies in the agroalimentary sector can serve as an aid for the fulfillment of these requirements. This fact makes it a suitable field for the application of automatic control techniques [30,7,29]. A greenhouse is an enclosure which can maintain constant temperature, humidity and other environmental factors within desired ranges to promote crop growing. Therefore its main aim is to provide near-optimal conditions for a crop at different stages of crop development and even obtaining crop production in other seasons different from normal ones. For that reason, the greenhouse is ideal for farming because variables affecting crop growth can be controlled to achieve optimal growth and plants development [22]. Crops use solar radiation, the CO_2 concentration in the surrounding air, water and nutrients to produce biomass (roots, stems, leaves, and fruits) through the photosynthesis process. Thus, crop development is primarily determined by climatic variables of the environment. So, the greenhouse

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crop growth control problem can be simplified, assuming that plants are healthy and that is provided an adequate water and fertilizer quantity at all times [14]. As result of this simplification, the problem reduces to control the crop growth as a function of climate environmental conditions [23,24,20]. So, the growth may be managed, controlling the main climate variables: temperature, humidity and CO_2 [25]. Furthermore, all the physiological processes are influenced by temperature and humidity, the aim is to control the greenhouse temperature (and indirectly humidity) within appropriate range despite of disturbances.

This paper will be focused on controlling the diurnal air temperature inside the greenhouse. In the mild climate countries, diurnal temperature control is performed by convective air exchange between the outside and inside [2]. Natural ventilation is a mechanism that reduces the greenhouse air temperature. Its control is characterized by the following features: (a) nonlinear relationship of the temperature with the vent position; (b) Disturbances produced by the external weather have a strong influence, by convective air exchange (stack effect and wind effect), and (c) the actuator (vent) has two nonlinear phenomena: saturation (between 0% and 100%) and output resolution (the vent implementation is performed using racks with gears, which permits a vent minimum movement of about 5%). For these non-linear relationship, it is suitable the use of Bayesian networks.

This work presents promising ideas and results about the combination of Bayesian networks and control systems to be applied in greenhouses. As a first approximation, a Bayesian network-based control has been applied for the temperature control problem using the ventilation system. The paper is organized as follows. Section 2 is devoted to describe the greenhouse climate control problem. Afterwards, Bayesian networks and its main uses are briefly described in Section 3. The Bayesian network-based control system is discussed and simulation results are presented in Section 4. Finally, some conclusions are given in Section 5.

2. Greenhouse climate control problem

The term "greenhouse climate" is used to denote the set of environmental physical quantities produced in a greenhouse that affect the growth and development of a crop [3–5,31]. The main purpose of a greenhouse is to help to achieve the optimal conditions for a particular crop and season, based on the needs of the plants. The dynamic behavior of the greenhouse climate is a combination of physical processes involving energy transfer (radiation and heat) and mass balance (water vapor fluxes and CO_2 concentration). These processes are affected by the outlet environmental conditions, structure of the greenhouse, type and state of the crop, and on the effect of the control actuators based on predefined setpoints [3,4]. Also, such processes have a strong relationship among them, as diurnal temperature control is performed by convective air exchange between the outside and inside [2]. This exchange rate coupled with CO_2 taken by the crop during photosynthesis determine the concentration of CO_2 in the greenhouse. Some authors propose different techniques of carbon enrichment in order to overcome these problems and achieve the final increase crop production [27,16]. When the photosynthetic rates are higher, the concentration of CO_2 falls below the atmospheric producing a growth deficit that is increased when the crop reaches its maximum development [26]. Furthermore, photosynthesis rate indirectly affects the humidity content because when the leaves stomata are opened to capture the CO_2, the plant emits water vapor through the transpiration process increasing the humidity inside the greenhouse. These released vapor can be reduced by ventilation [24].

Thus, greenhouse climate (see Fig. 1) is mainly controlled by using ventilation and heating (to modify inside temperature and humidity conditions), shading and artificial light (to modify internal radiation), CO_2 injection (to influence photosynthesis), and fogging/misting (for humidity enrichment). A deeper study about the features of the climate control problem can be found in [3,23]. The approach presented in this paper is focused on the climatic conditions of mild winter in Southern Europe, where the production in greenhouses is made without CO_2 enrichment and there is an increasing demand of quality products. In this geographical area the main variables to control are temperature and humidity, taking into account the greenhouse structures, the commonest actuators, the crop types, and the commercial conditions. The PAR