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Improving automatic climate control with decision support techniques to minimize disease effects in greenhouse tomatoes

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A B S T R A C T

Crop growth in greenhouses is basically determined by the climate variables in the environment and by the amounts of water and fertilizers supplied by irrigation. The management of these factors depends on the expertise of agricultural technicians and farmers, usually assisted by control systems installed within the greenhouse. In this context, decision support features enable us to incorporate invaluable human experience so that we can take quick and effective decisions to ensure efficient crop growth. This work describes a real-time decision support system for greenhouse tomatoes that supports decisions at three stages – the supervision stage identifies climate sensor faults, the control stage maintains climate variables at setpoints, and the strategic stage identifies diseases affecting the crop and changes climate variables accordingly to minimize damage. The DSS was implemented by integrating a real-time rule-based tool into the control system. Experimental results show that the system increases climate control effectiveness, while providing support in preventing diseases which are difficult to eradicate. The system was tested by simulating the appearance of the disease and observing the real system response. The main contribution has been to demonstrate that production rules, which are mature and well-known in the artificial intelligence domain, can act as a shared technology for the whole system. This means that fault detection, temperature control and disease monitoring features are not dealt with in isolation.

1. Introduction

Crop growth is basically determined by the climate variables in the environment and by the amounts of water and fertilizers that can be supplied by irrigation. Therefore, crop growth can be managed by controlling these variables [19]. This makes a greenhouse ideal for growing crops because it is enclosed; and these variables can be manipulated for optimal plant growth and development [3].

Having ideal climatic conditions present in the greenhouse might be optimal for plant growth but they also favor the proliferation of pests and diseases. This is the case with the

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disease caused by the fungus *Botrytis cinerea* [8] (i.e. *Botrytis*), which thrives on humidity in the air. The lack of ventilation in Mediterranean greenhouses [6,4] means that condensation in production processes under plastic is ever-present and, consequently, can cause severe damage [24,17].

Artificial intelligence and decision support systems (DSS) have the potential of being successful methods for analyzing and modeling environmental system activities [12,33,39,31,7]. These systems are becoming a means of integrally managing the necessary decision-making information in specific fields, a real alternative for acquiring the necessary expert criteria and making them accessible in the specific domain [23]. Furthermore, they offer a highly specialized criterion when an expert's opinion is needed, without needing them to attend. [27,2].

Applying DSS to the supervision and control of greenhouse crop growth has come about because it is possible to incorporate these systems into the automation of the growing processes [18,2,42]. Greenhouse climate control systems automate growth using devices installed in the greenhouse which collect sensor data. Most of the advanced commercial climate control systems currently in use contain multiple heuristic rules and usually manage hundreds of defining parameters related to weather trajectories and actuators [17]. Current approaches focus not only on production processes, but also on the agricultural marketing chain (right through from seed germination to consumer sales [32]).

This paper describes a decision support system built for greenhouse horticultural production that has been applied to three decision stages: supervision, control, and strategic. The supervision stage identifies climate sensor faults, the control stage maintains climate variables at setpoints, and the strategic stage identifies diseases affecting the crop and changes the climate variables accordingly to minimize damage. Sensor fault detection [5,25,41,15], greenhouse climate control systems [33,21,35] and disease monitoring [27,2,16,22] are in themselves complex problems that have been widely addressed in the literature. While most of the previous approaches focused on just one of the problems in isolation, the goal of this work is to demonstrate how fault detection and control functionalities can be incorporated into an integrated system using a mature and experienced method, such as rules, as a common design and implementation technology for the whole DSS. The aim is to provide an integrated system for climatic growth control incorporating fault detection, control and expert supervision techniques in order to prove that DSS can supplement automated control systems in intensive knowledge tasks where the variables decisively influence crop growth.

The DSS was evaluated in the greenhouse at the Cajamar Foundation's Experimental Station (in south-east Spain), where the system was tested by simulating the appearance of disease and observing the real system response.

The rest of the paper is structured into four sections. Section 2 describes the study area, the knowledge acquired and the task workflow that defines the system architecture. The subsystems that deal with each stage are described in Section 3. Section 4 includes the main results and validation processes and, finally, Section 5 gathers together the conclusions and possible future research.

2. Materials and methods

2.1. *Study area and host system*

The data used in this research was acquired from the Cajamar Foundation's Experimental Station greenhouses in El Ejido, Almería Province, Spain (2° 43″W, 36° 48″N, and 151 m a.s.l.). The crops grow in a multispan "Parral-type" greenhouse (Fig. 1). The greenhouse is 877 m^2 (37.8 × 23.2 m) and has a polyethylene cover, automated ventilation with windows in the north and south walls, a roof-flap window in each span, 20 × 10 threads × cm^{-1} mesh "bionet" anti-insect screens, and night heating generated by a 95 kW hot-air heater programmed to keep the minimum temperature above 14 °C. The greenhouse orientation is east to west, whilst crop rows are aligned north to south. The growing conditions and crop management are very similar to those in commercial tomato greenhouses. The climate parameters inside the greenhouse are monitored continuously. Outside the greenhouse, a weather station measures air temperature, relative humidity, solar and photosynthetic active radiation (PAR), rain detection, wind direction and speed. The cover temperature sensors were located on the east (two sensors) and west (two sensors) sides. During the experiments, the indoor climate variables were also recorded; in particular, air temperature and relative humidity with a ventilated psychrometer (model MTH-A1, ITC, Almería, Spain), solar radiation with a pyranometer (model MRG-1P, ITC, Almería, Spain), and photosynthetic active radiation (PAR) with a silicon sensor (PAR Lite, Kipp-Zonnen, Delft, The Netherlands).

The adaptive proportional-integral controller (PI controller) manages daylight air temperature and humidity by means of the top and side windows. Potentiometers show the window position at any control instant. The night air temperature and humidity are controlled by the windows and the heating system. The ventilation and heating setpoints are 25 °C and 14 °C, respectively. All the actuators are driven by relays designed for this task. Minute by minute climate data were recorded on a personal computer. The data acquisition system is made up of two National Instrument Compact-Field points connected by an Ethernet protocol.

2.2. *Knowledge acquisition*

Temperature is the climate variable that most influences crop growth. It is also the most controlled variable inside greenhouses in south-east Spain since the existing structures and installed actuation systems make it possible [11]. Due to the favorable weather conditions in this region, the energy necessary to reach the optimal temperature during the day is provided by the sun; thus, it is only under extreme conditions when this needs to be supplemented. The problem for daytime temperature control is keeping the temperature from exceeding the optimal. Of the several available greenhouse cooling approaches [34,1], natural ventilation is the most commonly used actuation system in the area; this promotes air exchange between the greenhouse's interior and exterior. The relationship between the interior and exterior air temperature is known. However, this relationship can undergo wind