# Preface

Modern agriculture is nowadays subject to regulations in terms of quality and environmental impact and thus it is a field where the application of automatic control techniques has increased during the last few years. The greenhouse production agrosystem is a complex of physical, chemical, and biological processes, taking place simultaneously, reacting with different response times and patterns to environmental factors, and characterized by many interactions, which must be controlled to obtain the best results for the grower. Crop growth is the most important process and is mainly influenced by surrounding environmental climatic variables (Photosynthetically Active Radiation—PAR, temperature, humidity, and $CO_2$ concentration of the inside air), the amount of water and fertilizers supplied by irrigation, pests and diseases, and culture labors such as pruning and pesticide treatments, among others. A greenhouse is ideal for crop growing since it constitutes a closed environment in which climate and fertigation can be controlled (with different control problems and objectives). Empirically, the water and nutrients requirements of the different crop species are known and, in fact, the first automated systems were those that control these variables. On the other hand, the market price fluctuations and the environmental rules to improve water-use efficiency or to reduce fertilizer residues in the soil (such as the nitrate contents) are other aspects to be taken into account. Therefore, the optimal production process in a greenhouse agrosystem may be summarized as the problem of reaching the following objectives: an optimal crop growth (bigger production with better quality), reduction of the associated costs (mainly fuel, electricity, and fertilizers), reduction of residues (mainly pesticides and ions in soil), and the improvement of water use efficiency.

Many of these objectives are addressed in this book, where the major topics and key features are:

- Discussion and presentation of the greenhouse crop growth problem and the new challenges related to modeling and control issues, including a state of the art.
- Modeling of the different subsystems involved in the greenhouse crop grow control. Different modeling techniques are described to show how the resulting models can be used for simulation or control design purposes. Furthermore,

suggestions and ideas about how to develop and use physical and/or black-box models for the different subsystems are also described.
- Development of basic and advanced control strategies to control the different variables of the climate and irrigation control problems. First, basic control strategies such as PID control and feedforward compensators (which are widely used in commercial tools) are summarized. Moreover, advanced control techniques, such as event-based, robust, and predictive control, are described to improve the performance of the basic control strategies.
- A multiobjective optimization problem is proposed and tested for greenhouse crop growth management, obtaining tradeoff solutions of three objectives: maximization of economic benefits, fruit quality, and water-use efficiency. This optimization scheme has been integrated into a hierarchical control architecture performing the automatic generation of setpoints for daytime and night-time temperatures and electrical conductivity along a whole crop cycle (using a receding horizon strategy). The obtained results show logical trajectories both in short and long crop cycles.

The book summarizes research performed by the authors on modeling, simulation, control, and optimization of greenhouse crop production during more than 10 years providing real results in an industrial greenhouse. It includes recent research results mainly concerned with greenhouse crop growth problems. It can be useful for a wide range of readers in the academic field, as graduate students working on their Master's or Ph.Ds. in automatic control and agricultural engineering. Furthermore, suggestions are included for the greenhouse management, which will be useful for practitioners and companies.

The book is organized as follows: Chap. 1 gives a brief introduction to the greenhouse crop growth system justifying the need for automation. Furthermore, it is devoted to describe a typical automated greenhouse and the timescales involved: climate, crop growth, weather, and market. Chapter 2 is focused on climate dynamical models, based both on mass and energy balances (fundamental models) and obtained from data. Crop growth models are also developed in Chap. 2, as they play an important role in the optimization problem. In this book, tomato has been selected as representative crop so that the influence of both inside greenhouse climate and irrigation on tomato crop growth are studied. Implementation and disturbance forecast issues are also discussed in terms of parameters identification, and model calibration and validation, including sensitivity analysis. The problem of determining the trajectories to control greenhouse crop growth has traditionally been solved by using constrained optimization or applying artificial intelligence techniques. The economic profit has been used as the main criterion in most research on optimization approaches to obtain adequate climatic control setpoints for the crop growth. This book addresses the problem of greenhouse crop growth through a hierarchical control architecture governed by a high-level multiobjective optimization approach, where the solution to this problem is to find reference trajectories for diurnal and nocturnal temperatures (climate-related setpoints) and electrical conductivity (fertirrigation-related setpoints). The objectives are to maximize profit, fruit quality, and water-use efficiency, these being currently fostered by international rules. Chapter 3 briefly describes control techniques used in the regulation layer of the hierarchical control scheme to cope with climate and irrigation control, including: PID control, feedforward control, gain scheduling control, adaptive control, event-based control, robust control, fuzzy logic control, and model predictive control. Chapter 4 is the core of the book. Taking into account the different models explained in Chap. 2 and the time scales involved, the main hierarchical control problem is introduced. The different control objectives are explained, starting with the solution of the optimization problem based on maximizing profits and afterwards introducing other objectives, such as maximization of water-use efficiency or quality. The solution of the multiobjective optimization problem is explained and also its role in the multilevel hierarchical control architecture is described. Finally, Chap. 5 summarizes some advices and suggestions for greenhouse users.

The text is composed of material collected from articles written by the authors, technical reports and lectures given to graduate students. The book is complemented with an extensive use of illustrations, tables and real examples which are helpful to understand the text. For this reason, the book can be of interest to engineers (agricultural, industrial, chemical, etc.) and process control engineers and researchers, as well as Ph.D. students in the engineering field.

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