Overview

The ever increasing technological demands of today call for very complex systems, which in turn require highly sophisticated controllers to ensure that high performance can be achieved and maintained under adverse conditions. There are needs in the control of these complex systems which cannot be met by conventional controllers and this is primarily due to the lack of precise knowledge about the process to be controlled. Acquisition of adequate system knowledge is often problematic or impractical due to system complexity and the fact that the structure and parameters in many systems change in significant and unpredictable ways over time. Moreover, to reduce design complexity control designers often utilize less detailed models for control than what they have access to. To address the control demands of such highly complex and uncertain systems one can enhance today's control methods using intelligent control systems and techniques.

The area of Intelligent Control is a fusion of a number of research areas in Systems and Control, Computer Science and Operations Research among others, coming together, merging and expanding in new directions and opening new horizons to address the new problems of this challenging and promising area. Perhaps in the not so distant future we will be able to witness control systems which perform many intelligent functions so that they exhibit high degrees of autonomy and hence release us from dangerous or mundane tasks. Intelligent control systems are typically able to perform one or more of the following functions: planning actions at different levels of detail, learning from past experience, identifying changes that threaten the system behavior, such as failures, and reacting appropriately. This identifies the areas of Planning and Expert Systems, Fuzzy Systems, Neural Networks, Machine Learning, and Failure Diagnosis, to mention but a few, as existing research areas that are related and important to Intelligent Control. In addition, there are novel problems raised in the context of machine intelligence and intelligent control, the solution of which requires the development of completely new approaches and methods- such is the case for example in the study of symbolic-numeric / discrete and continuous state systems called "Hybrid Systems."

The Chapters in this book are written by the specialists in the area. They discuss a variety of approaches, theories, solved and unsolved problems, fundamental and advanced methods, and a number of applications. The contributions are grouped into three parts: Part I deals with the theories, fundamentals, architectures and the different ways of looking at Intelligent Control. Part 11 addresses specific classes of problems and suggests particular methods for Intelligent Control such as expert, planning, fuzzy, neural, and learning systems. Part 111 explicitly deals with applications. Applications are in fact diffused throughout the chapters of the book in the form of examples for proof of concept or for illustration of ideas.

Overall, this book provides a solid introduction to the area. Studying the material one is certainly impressed by the gains so far, by the amount of pioneering work which has been, and currently is being performed but also by the enormity of the undertaking. It is quite clear that we are at the very early stages of development in this important and extremely promising field. The difficulties sometimes appear unsurpassed but the rewards are also without precedent, truly fantastic.

It is essential to have a view of the whole area, of the goals, theories, approaches, different views, and architectures. This is presented in the six chapters of Part I. Such an overview of the area, which is in fact a Systems' approach, is very helpful indeed as it provides the framework to build upon. This framework has to be flexible to accommodate new ideas but it must also be firm enough to provide good foundations. The theories presented in Part I are different enough, but also similar enough for one to be able to identify the main concepts and ideas of intelligent control that are common to all.

The first paper in Part I provides an introduction to the field and discusses the main concepts and ideas. A general approach to design and control of intelligent systems is given in chapters two and three. Distributed intelligent control is discussed next while distributed intelligence systems, such as human organizations, are studied in chapter five. Chapter six describes a rather distinct approach to design and control of intelligent systems. We provide a brief overview of each of the chapters below:

Antsaklis and Passino provide an introduction to control systems that incorporate intelligent methods to attain higher degrees of autonomy. An overview of the field of intelligent control is provided, a hierarchical functional architecture is discussed, and the characteristics of such systems are explained. It is emphasized that: (i) the area of intelligent control is interdisciplinary, requiring research in and coordination among many research disciplines, and (ii) there is need for analytical models and methods to study intelligent control systems and recent advances in the area of discrete event and hybrid dynarnical systems do offer significant promise.

Albus describes an architecture for intelligent system design based on his RCSReal time Control System-reference model architecture; in RCS the types of functions that are required in a real time intelligent control system are defined together with how these functions relate to each other, thus providing a structural approach to design. This systematic approach has been used in a variety of applications such as in controlling machining workstations, space station telerobots, autonomous underwater vehicles, and in postal service mail handling.

Zeigler and Chi present a model-based architecture for the design and simulation of high autonomy systems. A model base is at the center of its planning, operation, diagnosis and fault recovery strategies; timing effects are also being considered as they are so important for the correct operation of the system. The general approach is characterized via a "hierarchical encapsulation and abstraction principle". As a proof of concept, this approach is implemented to automate a space-borne laboratory.

Acar and Ozguner, based on distributed control concepts, describe a structure-based hierarchy for the intelligent control of systems; the mathematical foundations are stressed and analytical results are presented. This approach is different in that its organization is based on the physical structure of a system rather than on its functionality. The approach is illustrated on robotics applications.

Levis discusses distributed intelligence systems such as human organizations. He describes an

emerging mathematical theory for the analysis and design of such systems; an information processing and decision making system approach is taken where both human and machine intelligence coexist and interact. The theory is showing that such systems can exhibit a wide variety of not well understood behavior.

Finally nested hierarchical control its foundations and history is presented by Meystel. It is described as a development of theories of multiresolutional image and signal representation into the domain of control theory that enables efficient practice of design and control using nested search in state space.

Part II addresses particular questions and aspects of intelligent control. As it was mentioned earlier one recognizes the research areas of expert and planning systems fuzzy systems neural networks and learning systems as providing several methods for the intelligent control of complex systems. All of these are addressed by the six chapters in Part II. Expert and planning systems are considered in the first two chapters while fuzzy and neural control is the topic of the next chapter. The remaining three chapters all discuss aspects of learning in control reflecting the great importance of learning methods in intelligent control. In particular we provide a brief overview of each of the chapters of Part II below:

Astrom and Arzen describe how to use expert systems to implement control functions. They explain how such expert controllers can automate several tasks normally performed by operators and process and control engineers by emulating their heuristic decision making activities. An overview of the foundations of the area of expert control systems is provided and implementation issues are discussed. It is explained how the expert control framework can be composed of many conventional and intelligent control techniques.

Passino and Antsaklis develop a foundation of fundamental control theoretic concepts for the modeling and analysis of AI planning systems. They introduce the ideas of feedforward and feedback planning systems and highlight the importance of analyzing the dynamical behavior of AI systems. Finally they show that discrete event system theoretic techniques can be used for the modeling and analysis of simple AI planning problems.

Berenji provides an introduction to fuzzy and neural control. He explains the basic architecture and operation of fuzzy controllers and how they implement interpolative reasoning. Hierarchical fuzzy control and applications of fuzzy control are discussed. For neural approaches he explains reinforcement leanzing in control and introduces hybrid fuzzy/neural control via the approximate reasoningbased intelligent controller. A cart-pole balancing problem is discussed for proof of concept.

Farrell and Baker provide an introduction to the area of learning control. They present an extensive overview of the literature and a careful comparison between learning and adaptive systems. They identify the advantages of augmenting conventional control approaches with learning capabilities. In addition they illustrate the application of contemporary learning control approaches to two examples. Finally the authors provide future research directions.

Kokar shows how architectures for adaptive control systems have evolved into ones for learning control. The author emphasizes that learning controllers should be able to learn goals models and control laws. In addition he explains the COPER/IC architecture and overviews his contributions within this framework. Finally he outlines future needs in the area of learning control.

Grant also describes techniques for learning control. In particular he discusses human control passive learning and machine learning. He establishes the heuristics for control of the pole-cart system and studies the acquisition of knowledge for learning controllers. He provides both simulations and results from experiments in learning and neural control.

The emphasis in the last four chapters of the book is on particular applications of intelligent control. It is important to clearly demonstrate that the approaches and ideas which were discussed can successfully address real needs and this is done in Part III. The first two chapters of Part III deal with robotic systems while the last two describe particular applications of intelligent control methods to flight control and fault diagnosis in process control respectively. In particular we provide a brief overview of each of the chapters of Part III below:

Nguyen and Stephanou discuss an intelligent integrated symbolic-numeric technique for dexterous manipulation. In particular the authors use topological models and topological reasoning for a multifingered robot hand. They show that with this approach both the hand posture and functionality can be derived from the high level symbolic requirements and translated into low level numeric joint space variables. The application nicely illustrates the use of multilayer hierarchical intelligent control developed from both symbolic and numeric models/algorithms.

Seetharaman and Valavanis study multi-sensory robotic systems with failure diagnostic capabilities. In particular the authors investigate the problem of recovery from visual failures which occur in multi-sensory robotic systems. In addition they examine problems with sensor fusion in the multi-sensory system. The authors adhere to the classical three level hierarchical approach to intelligent control focus on the function and complexity of the vision system and explain the variety of problems that their approach applies to.

Belkin and Stengel describe an expert system that aids a pilot of an aircraft by automating decision making tasks that are normally the responsibility of the crew. In particular the authors introduce a cooperative rule-based expert systems approach to intelligent flight control. They study the interactions between the expert systems which automate various functions and study the performance of the entire AUTOCREW system in terms of its ability to assist the pilot. Extension of the results to other applications is discussed. The approach provides an illustration of several of the fundamental ideas in intelligent control including the division of responsibilities and coordination of intelligent system activities.

Prasad and Davis study how to enhance the capabilities of process control computers to automate the activity of failure diagnosis. The diagnostic activity is broken down into a set of information-processing tasks and it is explained how such tasks are integrated to form a framework to construct knowledge-based diagnostic systems. Moreover, it is shown how the

approach facilitates the integration of diverse techniques for automated diagnosis. Overall, the work shows how various intelligent control techniques can be integrated to perform a complex task for a difficult problem facing a wide variety of industries today.

This book represents the collective effort of many researchers in the field of intelligent control who thought that such book would be helpful in introducing the major topics in the area and providing a description of the state-of-the-art techniques. We would like to thank all the contributors who dedicated a significant amount of time and effort to make such an enterprise possible. We sincerely hope that the reader finds the study of this book rewarding and sees it as the beginning of many exciting and challenging new endeavors.

Panos Antsaklis, Notre Dame, Indiana also London, England and Athens, Greece

Kevin Passino, Columbus, Ohio