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Neural Network Engineering in Dynamic Control Systems

With 122 Figures

Springer

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Series Editors' Foreword

The series *Advances in Industrial Control* aims to report and encourage technology transfer in control engineering. The rapid development of control technology impacts all areas of the control discipline. New theory, new controllers, actuators, sensors, new industrial processes, computer methods, new applications, new philosophies,...., new challenges. Much of this development work resides in industrial reports, feasibility study papers and the reports of advanced collaborative projects. The series offers an opportunity for researchers to present an extended exposition of such new work in all aspects of industrial control for wider and rapid dissemination.

Within the control community there has been much discussion of and interest in the new Emerging Technologies and Methods. Neural networks along with Fuzzy Logic and Expert Systems is an emerging methodology which has the potential to contribute to the development of intelligent control technologies.

This volume of some thirteen chapters edited by Kenneth Hunt, George Irwin and Kevin Warwick makes a useful contribution to the literature of neural network methods and applications. The chapters are arranged systematically progressing from theoretical foundations, through the training aspects of neural nets and concluding with four chapters of applications. The applications include problems as diverse as oven temperature control, and energy/load forecasting routines. We hope this interesting but balanced mix of material appeals to a wide range of readers from the theoretician to the industrial applications engineer.

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Preface

Neural networks have been seen for some years now as providing considerable promise for application in nonlinear control and systems problems. This promise stems from the theoretical ability of networks of various types to approximate arbitrarily well continuous nonlinear mappings.

This book is based upon a very successful colloquium of the same title held in May 1994 at the Daimler-Benz Systems Engineering Research Centre in Berlin. The aim in this book is to evaluate the state-of-the-art in this very popular field from the engineering perspective. The book covers both theoretical and applied aspects. A major goal of the book is to examine ways of improving the engineering involved in neural network modelling and control, so that the theoretical power of learning systems can be harnessed for practical applications. This includes questions such as: which network architecture for which application? Can constructive learning algorithms capture the underlying dynamics while avoiding overfitting? How can we introduce a priori knowledge or models into neural networks? Can experiment design and active learning be used to automatically create 'optimal' training sets? How can we validate a neural network model?

The structuring of the book into four parts reflects these aims. In part 1 (chapters 1–3) the theoretical foundations of neural networks with specific focus on control systems is examined. Part 2 is the engineering core of the book and consists of chapters 4–6. Here, a variety of very recent constructive learning methods are presented. The main motivation for these techniques is to move towards a systematic engineering design procedure for neural modelling and control systems. Further technical aspects of the learning process are considered in part 3 (chapters 7–9).

In line with the goal of better engineering methods, the book places emphasis on real industrial applications of the technology; Part 4, consisting of chapters 10–13, describes in detail a number of concrete implementations.

Contents Overview

2. **Dynamic Systems in Neural Networks**
   K. Warwick, C. Kambhampati, P.C. Parks and J. Mason
   This contribution considers progress in the understanding of the dynamics of weight adjustment in neural networks when they are used as function approximators. This is seen as a vital step towards the development of a more complete stability analysis for neural control.
3. **Adaptive Neurocontrol of a Certain Class of MIMO Discrete-time Processes Based on Stability Theory**
   J-M. Renders, M. Saerens and H. Bersini
   A stability proof is provided for a class of non-linear multivariable processes controlled by a multilayer neural network. The result is based on a Lyapunov analysis and is local in nature. A simple weight adaptation strategy underlying the stability theorem is discussed.

Part 2: Constructive Training Methods

4. **Local Model Architectures for Nonlinear Modelling and Control**
   R. Murray-Smith and K.J. Hunt
   Local model networks are based upon the interpolation of simple, locally valid dynamic models. This contribution shows how the transparency of the local model network structure supports the integration of existing knowledge and a priori models. Extension of the model structure to local controller networks is described and applied to an automotive control example.
5. **On ASMOD – An Algorithm for Empirical Modelling using Spline Functions**
   T. Kavli and E. Weyer
   This chapter describes the theoretical foundations and principles of the ASMOD algorithm – a spline-based method for building dynamic models based on observed data. An incremental refinement procedure automatically adapts the model to the dependencies observed in the data. Case studies are included.
6. **Semi-Empirical Modeling of Non-linear Dynamic Systems through Identification of Operating Regimes and Local Models**
   T.A. Johansen and B.A. Foss
   Off-line algorithms for automatically determining the structure of local model networks are proposed and discussed. The algorithm searches for an optimal decomposition of the operating space into operating regimes, and local model structures. The transparency of the resulting model and the flexibility with respect to incorporation of prior knowledge is discussed.

Part 3: Further Issues in Network Learning

7. **On Interpolating Memories for Learning Control**
   H. Tolle, S. Gehlen and M. Schmitt
   General aspects of learning control are outlined and discussed. The presentation in this chapter is focussed on interpolating memories, and the CMAC structure in particular. Recent improvements in the approach are presented and results of applications in biotechnology

and automotive control are given. Finally, a critical assessment of the status of learning control is presented.

8. **Construction and Design of Parsimonious Neurofuzzy Systems**
   K.M. Bossley, D.J. Mills, M. Brown and C.J. Harris
   This chapter is concerned with the development of adaptive neural networks which can learn to perform ill-defined and complex tasks. The focus is on neurofuzzy systems where the transparent representation of fuzzy systems is fused with the adaptive capabilities of neural networks. The chapter concentrates on the question of how an appropriate structure for the rule base may be determined directly from the training data.
9. **Fast Gradient Based Off-line Training of Multilayer Perceptrons**
   S. McLoone and G.R. Irwin
   Fast off-line training of multilayer perceptrons using gradient-based algorithms is discussed. The inefficiencies of standard backpropagation algorithms are highlighted and this leads to a discussion of second-order optimisation techniques. Very significant speed-ups can be achieved, depending on problem size and convergence criterion. Parallel implementation of the algorithms is discussed.

Part 4: Applications

10. **Kohonen Network as a Classifier and Predictor for the Qualification of Metal-Oxide Surfaces**
    W. Kessler and R.W. Kessler
    The problem of predicting the future corrosion behaviour of low carbon steel is considered. The approach presented is based upon diffuse reflectance spectroscopy and evaluation of the spectra by a Kohonen self-organising map. This method is fast and reliable and can be applied on-line. Examples of corrosion prediction in car body steel are presented.
11. **Analysis and Classification of Energy Requirement Situations Using Kohonen Feature Maps within a Forecasting System**
    S. Heine and I. Neumann
    The Kohonen network is again applied, this time to the analysis and classification of energy requirements and load forecasting. For such problems a forecast model must be built for each application, and this can be a very demanding procedure. The efficiency of the Kohonen approach in a stepwise automation of model building is discussed by means of two case studies.
12. **A Radial Basis Function Network Model for Adaptive Control of Drying Oven Temperature**
    O. Dubois, J-L. Nicolas and A. Billat
    This contribution describes a neural control scheme for temperature control in a drying oven. The control strategy used is internal model control in which the plant is modelled by a radial basis function network. The process was identified both on- and off-line and experimental results of control trials with a real oven are presented.
13. **Hierarchical Competitive Net Architecture**
    T. Long and E. Hanzevack
    Development of hypersonic aircraft requires a high degree of system integration. Design tools are needed to provide rapid and accurate

calculations of complex fluid flow patterns. This chapter demonstrates that neural networks can be successfully applied to calculation of fluid flow distribution and heat transfer in a six leg heat exchanger panel, of the type envisioned for use in hypersonic aircraft.

Acknowledgements

Most of the contributors to this book came together at the Berlin colloquium in May 1994. We'd like to gratefully acknowledge the Institution of Electrical Engineers and Daimler-Benz Systems Technology Berlin, whose support made this meeting possible. Special thanks are due to Cap'n Natho who managed the local arrangements in Berlin.

Dedication

It is with deep sadness that we note the recent passing of our friend and colleague Professor Patrick C Parks. Patrick gave a presentation at the Berlin colloquium upon which this book is based, and is a co-author of chapter 2. For more than three decades Patrick Parks made fundamental contributions to the theory and stability analysis of nonlinear control systems. In recent years he contributed very actively to neural network applications in this area. As a token of our respect we dedicate this book to his memory.

Kenneth Hunt, George Irwin, Kevin Warwick
Berlin, Belfast, Reading: April 11, 1995

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