APPLICATION OF NEURAL NETWORKS TO MODELLING AND CONTROL

Edited by G. F. Page, J. B. Gomm and D. Williams

INSTITUTE OF MEASUREMENT & CONTROL

CHAPMAN & HALL

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G.F. Page, J.B. Gomm and
D. Williams

School of Electrical and Electronic Engineering,
Liverpool John Moores University,
Liverpool,
UK

CHAPMAN & HALL
London · Glasgow · New York · Tokyo · Melbourne · Madras

Published by Chapman & Hall, 2–6 Boundary Row, London SEI 8HN

Chapman & Hall, 2–6 Boundary Row, London SE1 8HN, UK

Blackie Academic & Professional, Wester Cleddens Road, Bishopbriggs, Glasgow G64 2NZ, UK

Chapman & Hall Inc., 29 West 35th Street, New York NY10001, USA

Chapman & Hall Japan, Thomas Publishing Japan, Hirakawacho Nemoto Building, 6F, 1–7–11 Hirakawa-cho, Chiyoda-ku, Tokyo 102, Japan

Chapman & Hall Australia, Thomas Nelson Australia, 102 Dodds Street, South Melbourne, Victoria 3205, Australia

Chapman & Hall India, R. Seshadri, 32 Second Main Road, CIT East, Madras 600 035, India

First edition 1993

Typeset in 10/12 Times by Interprint Limited, Malta
Printed in England by Clays Ltd, St Ives plc

ISBN 0 412 54760 0

A catalogue record for this book is available from the British Library

Library of Congress Cataloging-in-Publication data.
Application of neural networks to modelling and control/edited by
G.F. Page, J.B. Gomm, and D. Williams.—1st ed.
p. cm.
Includes bibliographical references and index.
ISBN 0-412-54760-0
1. Neural networks (Computer science) 2. Computer simulation.
3. Automatic control. I. Page, G.F. II. Gomm. J.B.
III. Williams, D.
QA76.87.A65 1993
003′.363—dc20 93-14878
CIP

Application of Neural Networks to Modelling and Control

The Institute of Measurement and Control was founded in 1944 as the Society of Instrument Technology and took its present name in 1968. It was incorporated by Royal Charter in 1975 with the object '... to promote for the public benefit by all available means the general advancement of the science and practice of measurement and control technology and its application'. The Institute of Measurement and Control provides routes to Engineering Council status as Chartered and Incorporated Engineers and Engineering Technicians. The Institute of Measurement and Control is a registered charity, number 269815, and is based at 87 Gower Street, London WC1E 6AA. Telephone (071) 387 4949, facsimile (071) 388 8431.

Preface

Interest in artificial neural networks began in the early 1940s when pioneers, such as McCulloch and Pitts and Hebb, investigated networks based on the neuron and attempted to formulate the adaptation laws which applied to such systems. During the 1950s and 1960s several basic architectures were developed and a background body of knowledge was buit up from many diverse disciplines: biology, psychology, physiology, mathematics and engineering. General interest in the subject waned after the analysis of the perceptron by Minsky and Papert highlighted the limitations of several of the models. However, several groups did continue and by the mid 1980s the work of Hopfield and of Rumelhart gave a renewed impetus to the area. Since then the number of papers published, conferences organized and journals devoted exclusively to neural network research has mushroomed.

Neural networks have several important characteristics which are of interest to control engineers:

- Modelling. Because of their ability to be trained using data records for the particular system of interest, the major problem of developing a realistic system model is obviated.
- Non-linear systems. The networks possess the ability to 'learn' non-linear relationships with limited prior knowledge about the process structure. This is possibly the area in which they show the greatest promise.
- Multivariable systems. Neural networks, by their very nature, have many inputs and many outputs and so can be readily applied to multivariable systems.
- Parallel structure. The structure of neural networks is highly parallel in nature. This is likely to give rise to three benefits: very fast parallel processing, fault tolerance and robustness.

The great promise held out by these unique features is the main reason for the enormous interest which is currently being shown in this field.

This book arises from a very successful colloquium that was held in Liverpool and was jointly organized by Liverpool John Moores University and the Merseyside branch of the Institute of Measurement and Control. The colloquium was attended by over 80 delegates from the UK, of whom approximately half were from industry. The book is of particular interest to those currently investigating neural networks and also to practising engineers, for whom the applications may reveal that neural networks could be a useful tool in their field. Also, the book may be suitable to support courses, particularly at postgraduate level, where the course emphasis is on implementation and applications of neural networks. Rapid progression of this field makes it difficult for the text to provide a comprehensive coverage of the subject. However, the book does provide a valuable insight into current reseach activity in artificial neural network applications to modelling and control.

The topics in this book can be split into three parts: (1) a general introduction to the field plus a theoretical discussion; (2) applications of neural networks in process modelling and estimation; and (3) applications of various neural network control strategies. Chapter 1 is for the reader who is either new to, or has limited knowledge of, the area. It gives a gentle introduction to the subject and overviews the configurations which are most applicable to modelling and control. The second chapter deals with the historical evolution of modern non-linear networks. The characteristics of these networks are discussed together with various issues regarding practical applications to estimation and control.

Approaches of applying neural networks to process modelling and estimation are described in Chapters 3, 4 and 5. The first of these deals with the effectiveness of recurrent networks for the identification of linear systems and it demonstrates that to model higher-order systems successfully the basic Elman net has to be modified. Chapter 4 presents a new paradigm for enhancing the training of feedforward networks. The training procedure is described and implications of the training philosophy are discussed. Some results of the technique applied to industrial data are presented to demonstrate the effectiveness of the technique. An interesting feature of the paradigm is that it incorporates a systematic procedure for determining the number of neurons in the hidden layer of the network. The following chapter by Tsaptsinos *et al.* deals with an estimation problem. It compares a conventional identification approach to the modelling of a fermentation process with a neural network technique.

The final three chapters present methodologies for achieving neural control. Evans *et al.* in Chapter 6 bridge the modelling and control aspects and describe a neural modelling procedure which leads to an actual working predictive controller. Chapter 7 introduces the cerebellar model articulation controller (CMAC). This belongs to a class of neural network which consists of a fixed non-linear input layer coupled to an adjustable linear output layer.

The particular CMAC-based adaptive control strategy described here is being developed as part of a project to produce an intelligent controller for aeronautical gas turbine engines. The chapter describes an adaptive control strategy and presents some preliminary results. The last chapter demonstrates the very wide potential applicabiity of the neural network approach by presenting a unique problem which has some very severe constraints. A back-propagation learning paradigm is described which has been developed to control depth of anaesthesia.

Finally, the editors would like to express their gratitude to all the contributing authors, to the staff at the Institute of Measurement and Control and to all at Chapman & Hall who have helped bring this project to completion.

G.F. Page
J.B. Gomm
D. Williams

Contributors

J.T. Evans
Control Systems Research Group
School of Electrical and Electronic Engineering
Liverpool John Moores University
Byrom Street
Liverpool, L3 3AF, UK

J.B. Gomm
Control Systems Research Group
School of Electrical and Electronic Engineering
Liverpool John Moores University
Byrom Street
Liverpool, L3 3AF, UK

C.J. Harris
Aeronautics and Astronautics Department
Southampton University
Highfield
Southampton, SO9 5NH, UK

N.A. Jalel
Industrial Control Centre
Faculty of Engineering and Science
University of Westminster
115 New Cavendish Street
London, W1M 8JS, UK

A.J. Lawrence
Aeronautics and Astronautics Department
Southampton University
Highfield
Southampton, SO9 5NH, UK

J.R. Leigh
Industrial Control Centre
Faculty of Engineering and Science
University of Westminster
115 New Cavendish Street
London, W1M 8JS, UK

D.A. Linkens
Department of Automatic Control and Systems Engineering
University of Sheffield
P.O. Box 600
Sheffield, S1 4DU, UK

P.J.G. Lisboa
Department of Electrical Engineering and Electronics
University of Liverpool
P.O. Box 147
Liverpool, L69 3BX, UK

X. Liu
Intelligent Systems Research Laboratory
School of Electrical, Electronic and Systems Engineering
University of Wales College of Cardiff
P.O. Box 904
Cardiff, CF1 3YH, UK

G.F. Page
Control Systems Research Group
School of Electrical and Electronic Engineering
Liverpool John Moores University
Byrom Street
Liverpool, L3 3AF, UK

C. Peel
Department of Chemical and Process Engineering
University of Newcastle upon Tyne
Newcastle upon Tyne, NE1 7RU, UK

D.T. Pham
Intelligent Systems Research Laboratory
School of Electrical, Electronic and Systems Engineering
University of Wales College of Cardiff
P.O. Box 904
Cardiff, CF1 3YH, UK

H.U. Rehman
Department of Automatic Control and Systems Engineering
University of Sheffield
P.O. Box 600
Sheffield, S1 4DU, UK

M.T. Tham
Department of Chemical and Process Engineering
University of Newcastle upon Tyne
Newcastle upon Tyne, NE1 7RU, UK

Q.S. To
Department of Electrical Engineering and Electronics
University of Liverpool
P.O. Box 147
Liverpool, L69 3BX, UK

D. Tsaptsinos
Industrial Control Centre
Faculty of Engineering and Science
University of Westminster
115 New Cavendish Street
London, W1M 8JS, UK

D. Williams
Control Systems Research Group
School of Electrical and Electronic Engineering
Liverpool John Moores University
Byrom Street
Liverpool, L3 3AF, UK

M.J. Willis
Department of Chemical and Process Engineering
University of Newcastle upon Tyne
Newcastle upon Tyne, NE1 7RU, UK

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Introduction to neural networks 1

J.B. Gomm, G.F. Page and D. Williams

1.1 ABSTRACT

This chapter is intended to provide a general introduction to neural networks for the reader who is either new to, or has limited knowledge in, this area. Concepts of neural networks are introduced, with a background to biological aspects, and their attributes are described. Many types of neural network exist and the configurations that are most applicable to the context of this book, modelling and control, are overviewed. These networks are the multi-layer perceptron, Hopfield network and Kohonen network.

1.2 INTRODUCTION

Artificial neural networks have emerged from studies of how human and animal brains perform operations. The human brain is made up of many millions of individual processing elements, called neurons, that are highly interconnected. A schematic diagram of a single biological neuron is shown in Fig. 1.1 Information from the outputs of other neurons, in the form of electrical pulses, are received by the cell at connections called synapses. The synapses connect to the cell inputs, or dendrites, and the single output of the neuron appears at the axon. An electrical pulse is sent down the axon (i.e. the neuron 'fires') when the total input stimuli from all of the dendrites exceeds a certain threshold [1, 2].

Artificial neural networks are made up of individual models of the biological neuron (artificial neurons or nodes) that are connected together to form a network. The neuron models that are used are typically much simplified versions of the actions of a real neuron. Information is stored in

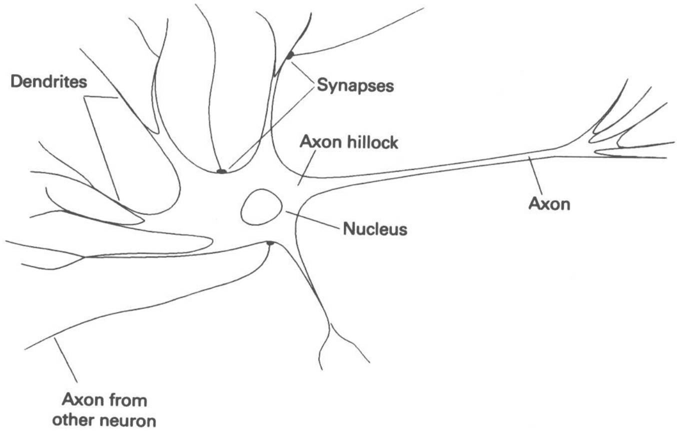

Fig. 1.1 Biological neuron.

the network often in the form of different connection strengths, or weights, associated with the synapses in the artificial neuron models.

Among the numerous attributes of neural networks that have been found in many application areas are [3]:

- inherent parallelism in the network architecture due to the repeated use of simple neuron processing elements. This leads to the possibility of very fast hardware implementations of neural networks.
- capability of 'learning' information by example. The learning mechanism is often achieved by appropriate adjustment of the weights in the synapses of the artificial neuron models.
- ability to generalize to new inputs (i.e. a trained network is capable of providing 'sensible' outputs when presented with input data that has not been used before).
- robustness to noisy data that occurs in real world applications.
- fault tolerance. In general, network performance does not significantly degenerate if some of the network connections become faulty.

Conventional programming techniques are significantly better than humans at performing tasks requiring a high degree of numerical computation and repeatable steps that can be accurately pre-specified. However, humans still far exceed the performance of these methods in applications that are poorly defined, either because the problem is extremely complex or simply that exact solution rules are not known (e.g. speech and image recognition, plant monitoring and fault diagnosis). The above attributes of neural networks indicate their potential in solving these problems. Hence, the considerable interest in neural networks that has occurred in recent years is not only due to significant advances in computer processing power that has enabled their implementation, but also because of the diverse possibility of application areas.

Many different types of neural network are available and only the architectures that are most applicable to the context of this book, modelling and control, are described. The basic building block of these networks, the artificial neuron model, is first introduced. This is followed by overviews of three networks architectures: the multi-layer perceptron, Hopfield and Kohonen networks. General descriptions of training algorithms for these networks are also given.

1.3 ARTIFICIAL NEURON MODEL

The most commonly used neuron model is depicted in Fig. 1.2 and is based on the model proposed by McCulloch and Pitts in 1943 [4]. Each neuron input, $x_1 - x_N$, is weighted by the values $w_1 - w_N$. A bias, or offset, in the node is characterized by an additional constant input of 1 weighted by the value w_0. The output, y, is obtained by summing the weighted inputs to the neuron and passing the result through a non-linear activation function, $f(\ )$:

$$y = f\left(\sum_{i=1}^{N} w_i x_i + w_0\right). \tag{1.1}$$

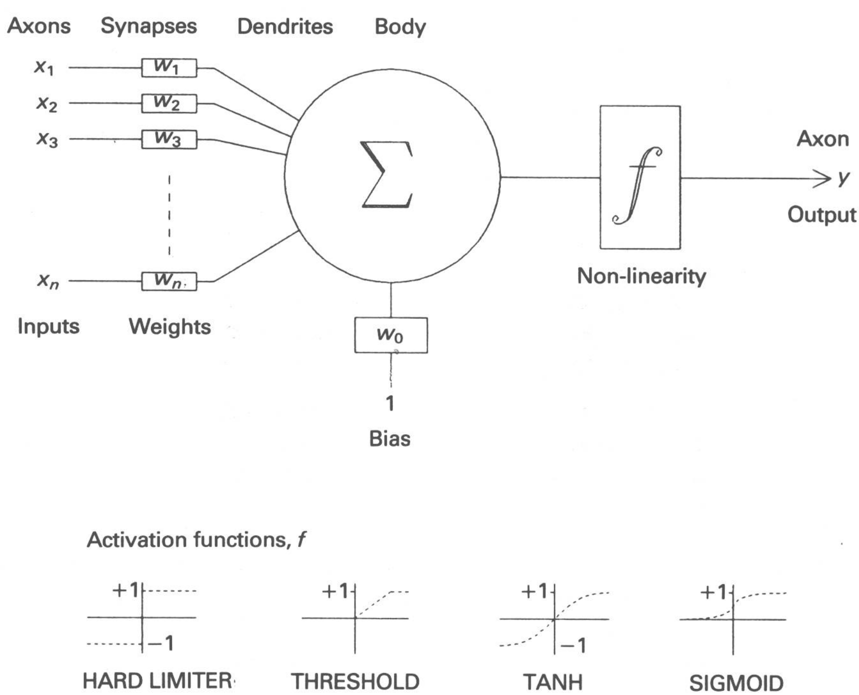

Fig. 1.2 McCulloch–Pitts neuron model.