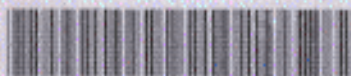


M. Nørgaard, O. Ravn, N. K. Poulsen
and L. K. Hansen

Neural Networks for Modelling and Control of Dynamic Systems

Suranaree University of Technology



31051000616173



Springer

Contents

1. Introduction	1
1.1 Background	1
1.1.1 Inferring Models and Controllers from Data	1
1.1.2 Why Use Neural Networks?	4
1.2 Introduction to Multilayer Perceptron Networks	6
1.2.1 The Neuron	6
1.2.2 The Multilayer Perceptron	7
1.2.3 Choice of Neural Network Architecture	8
1.2.4 Models of Dynamic Systems	9
1.2.5 Recurrent Networks	10
1.2.6 Other Neural Network Architectures	11
2. System Identification with Neural Networks	13
2.1 Introduction to System Identification	13
2.1.1 The Procedure	15
2.2 Model Structure Selection	18
2.2.1 Some Linear Model Structures	18
2.2.2 Nonlinear Model Structures Based on Neural Networks	25
2.2.3 A Few Remarks on Stability	30
2.2.4 Terminology	33
2.2.5 Selecting the Lag Space	34
2.2.6 Section Summary	37
2.3 Experiment	38

2.3.1	When is a Linear Model Insufficient?	39
2.3.2	Issues in Experiment Design	40
2.3.3	Preparing the Data for Modelling	45
2.3.4	Section Summary	46
2.4	Determination of the Weights	47
2.4.1	The Prediction Error Method	49
2.4.2	Regularization and the Concept of Generalization	64
2.4.3	Remarks on Implementation	73
2.4.4	Section Summary	83
2.5	Validation	85
2.5.1	Looking for Correlations	86
2.5.2	Estimation of the Average Generalization Error	88
2.5.3	Visualization of the Predictions	95
2.5.4	Section Summary	99
2.6	Going Backwards in the Procedure	101
2.6.1	Training the Network Again	101
2.6.2	Finding the Optimal Network Architecture	102
2.6.3	Redoing the Experiment	113
2.6.4	Section Summary	113
2.7	Recapitulation of System Identification	114
3.	Control with Neural Networks	121
3.1	Introduction to Neural-Network-based Control	121
3.1.1	The Benchmark System	124
3.2	Direct Inverse Control	125
3.2.1	General Training	127
3.2.2	Direct Inverse Control of the Benchmark System	129
3.2.3	Specialized Training	132
3.2.4	Specialized Training and Direct Inverse Control of the Benchmark System	137
3.2.5	Section Summary	138

3.3	Internal Model Control (IMC)	140
3.3.1	Internal Model Control with Neural Networks	140
3.3.2	Section Summary	142
3.4	Feedback Linearization	142
3.4.1	The Basic Principle of Feedback Linearization	143
3.4.2	Feedback Linearization Using Neural Network Models	145
3.4.3	Feedback Linearization of the Benchmark System	146
3.4.4	Section Summary	146
3.5	Feedforward Control	148
3.5.1	Feedforward for Optimizing an Existing Control System	148
3.5.2	Feedforward Control of the Benchmark System	150
3.5.3	Section Summary	152
3.6	Optimal Control	153
3.6.1	Training of an Optimal Controller	154
3.6.2	Optimal Control of the Benchmark System	156
3.6.3	Section Summary	157
3.7	Controllers Based on Instantaneous Linearization	158
3.7.1	Instantaneous Linearization	159
3.7.2	Applying Instantaneous Linearization to Control	162
3.7.3	Approximate Pole Placement Design	164
3.7.4	Pole Placement Control of the Benchmark System	169
3.7.5	Approximate Minimum Variance Design	172
3.7.6	Section Summary	175
3.8	Predictive Control	176
3.8.1	Nonlinear Predictive Control (NPC)	179
3.8.2	NPC Applied to the Benchmark System	191
3.8.3	Approximate Predictive Control (APC)	192
3.8.4	APC applied to the Benchmark System	197
3.8.5	Extensions to the Predictive Controller	198
3.8.6	Section Summary	199
3.9	Recapitulation of Control Design Methods	200

4. Case Studies	205
4.1 The Sunspot Benchmark	206
4.1.1 Modelling with a Fully Connected Network	207
4.1.2 Pruning of the Network Architecture	208
4.1.3 Section Summary	210
4.2 Modelling of a Hydraulic Actuator	211
4.2.1 Estimation of a Linear Model	212
4.2.2 Neural Network Modelling of the Actuator	214
4.2.3 Section Summary	217
4.3 Pneumatic Servomechanism	218
4.3.1 Identification of the Pneumatic Servomechanism	219
4.3.2 Nonlinear Predictive Control of the Servo	221
4.3.3 Approximate Predictive Control of the Servo	223
4.3.4 Section Summary	226
4.4 Control of Water Level in a Conic Tank	227
4.4.1 Linear Analysis and Control	228
4.4.2 Direct Inverse Control of the Water Level	229
4.4.3 Section Summary	233
References	235
Index	243