Advanced Neural Network Controllers and Classifiers Based on Sliding Mode Training Algorithms

A thesis submitted by

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CERTIFICATE OF AUTHORSHIP/ORIGINALITY

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of the requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

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LIST OF SYMBOLS

N	number of input nodes
K	number of hidden nodes
M	number of output nodes
P	number of patterns in the data set
$\overline{W}_{nk}$	network weight between input node n and hidden node k
W_{km}	network weight between hidden node k and output node m
$\overline{o}_k$	output of hidden node k
o_m	output of output node m
$\mathbf{x}^p$	input vector of pattern p
$\mathbf{d}^p$	target output vector of pattern p
f	activation function
f'	first derivative of the activation function f
E	criterion function of the network error
$\mathbf{w}$	vector of all the network weights
$\dfrac{\partial E}{\partial \mathbf{w}}$	gradient vector
s	sliding function
$\lVert \cdot \rVert$	Euclidean norm for a vector and Frobenius norm for a matrix
$\mathbf{A}$	system matrix
$\mathbf{B}$	input matrix
$\mathbf{C}$	output matrix
$\mathbf{x}$	system state vector
$\mathbf{T}$	transformation matrix
$\mathbf{H}$	parameter vector of the sliding function
$\mathbf{F}, \mathbf{G}$	a pair of controllable canonical matrices
$\mathbf{P}, \mathbf{Q}$	a pair of matrices in the Lyapunov equation
u	control input
r	reference input

Subscripts

ω	speed subsystem
x	tension subsystem

Greek Letters

α	momentum coefficient
η	learning rate
μ	a positive scalar
ε	robust learning rate

LIST OF ABBREVIATIONS

ABP	Adaptive BackPropagation
Adaline	Adaptive linear element
BP	BackPropagation
CFSMBP	Chattering-Free Sliding-Mode BackPropagation
CG	Conjugate Gradient
DBD	Delta-Bar-Delta
DWM	Deterministic Weight Modification
EABPM	Extended Adaptive BackPropagation with Momentum
FNN	Feedforward Neural Network
GA	Genetic Algorithm
GN	Gauss–Newton
GOTA	Globally Optimal Training Algorithm
IAMSS	Iterated Adaptive Memory Stochastic Search
IEEE	the Institute of Electrical and Electronics Engineers
LM	Levenberg–Marquardt
MGFPROP	Magnified Gradient Function Propagation
MLP	MultiLayer Perceptron
NN	Neural Network
QN	Quasi-Newton
QuickProp	Quick Propagation
RMBP	Reach Mode BackPropagation
RPROP	Resilient Propagation
SARPROP	Simulated Annealing Resilient Propagation
SISO	Single-Input Single-Output
SMC	Sliding Mode Control
SuperSAB	Super Self-Adapting Backpropagation
SVC	Static VAR Compensator
TRUST	Terminal Repeller Unconstrained Subenergy Tunnelling
VSS	Variable Structure System

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ABSTRACT

This thesis presents the research undertaken to develop some novel learning algorithms based on the sliding-mode control techniques for the neural network classifiers and controllers. Although the feedforward neural network with the backpropagation learning algorithm is the most widely used approach for classification and control applications, the slow convergence rate, the local minima problem, the difficulties in system identification and the lack of robustness are the issues existing for these neural network-based systems. The combination of the sliding-mode control techniques and the backpropagation algorithm, as described in this thesis, leads to three novel learning algorithms, which offer effective solutions for these problems.

The first learning algorithm, derived from the integration between the chattering-free sliding-mode control technique and the backpropagation algorithm, can obtain fast and global convergence with less computation. Experiment results relating to the head-movement neural classifier for wheelchair control show that the proposed approach considerably improved the convergence speed, global convergence capability and even the generalisation performance of the neural network classifier, in comparison with various popular learning algorithms.

The second learning algorithm, also derived from the integration between the chattering-free sliding-mode control technique and the backpropagation algorithm, can guarantee the stability and robustness of the neural control system with parameter uncertainties. Based on this stable neural controller, a neural control design methodology is developed for a class of uncertain nonlinear systems with transportation lag, wherein a new training procedure is proposed to avoid the difficult choice of the training inputs always associated with the conventional neural network identifier. The implementation results with a real-time Static VAR Compensator system indicate the effectiveness of the proposed method.

The third on-line learning algorithm, developed from the reaching law method combined with the backpropagation algorithm, offers a robust adaptation approach for the neural control systems with parameter uncertainties and disturbances. The neural control approach is further developed to design a novel decentralised neural controller for a class of uncertain large-scale systems with bounds of interconnections and disturbances. The stability and robustness of the neural control system are guaranteed based on the Lyapunov synthesis. Real-time implementation results for a Coupled Electric Drives CE8 system show the effectiveness and feasibility of the proposed approach.