Preface

Artificial Neural Networks (ANNs) are known to excel in control signal generating, pattern recognition, pattern matching and mathematical function approximation. However they suffer from several well known limitations – they can often become stuck in local, rather than global minima, as well as taking unacceptably long times to converge in practice. Of particular concern, especially from the perspective of control and recognition areas, is their inability to handle non-smooth, discontinuous training data, and complex mappings (associations). Another limitation of ANN is a ‘black box’ nature – meaning that explanations (reasons) for their decisions are not immediately obvious, unlike techniques such as Decision Trees. This then is the motivation for developing artificial Higher Order Neural Networks (HONNs), since HONNs are ‘open-box’ models and each neuron and weight are mapped to function variable and coefficient.

In recent years, researchers use HONNs for control signal generating, pattern recognition, nonlinear recognition, classification, and prediction in the control and recognition areas. The results show that HONNs are always faster, more accurate, and easier to explain. This is the second motivation for using HONNs in control and recognition areas, since HONNs can automatically select the initial coefficients, even automatically select the model for applications in control and recognition area.

Giles & Maxwell (1987) published the first paper on HONN. Bengtsson (1990) wrote the first book in the higher order (or higher-order, consistency) neural network area. Higher order correlations in the training data require more complex neuron activation functions (Barron, Gilstrap & Shrier, 1987; Giles & Maxwell, 1987; Psaltis, Park & Hong, 1988). Neurons which include terms up to and including degree-k are referred to as kth-order neurons (Lisboa & Perantonis, 1991). In addition, the increased computational load resulting from the large increase in network weights means that the complex input-output mappings normally only achievable in multi-layered networks can now be realized in a single HONN layer (Zhang & Fulcher, 2004). Currently the output of a kth-order single-layer HONN neuron will be a non-linear function comprising polynomials of up to kth-order. Moreover, since no hidden layers are involved, both Hebbian and Perceptron learning rules can be employed (Shin & Ghosh, 1991).

Several different HONN models have been developed by Zhang and Fulcher, during the past decade or so. A more comprehensive coverage, including derivations of weight update equations, is presented in Zhang & Fulcher (2004). The Neuron-Adaptive HONN (and NAHONN group) leads to faster convergence, much reduced network size and more accurate curve fitting, compared with P(T)HONNs (Zhang, Xu & Fulcher, 2002). Each element of the NAHONN group is standard multi-layer HONN comprising adaptive neurons, but which employs locally bounded, piecewise continuous (rather than polynomial) activation functions and thresholds. Now as with the earlier HONN groups, it is possible to provide a similar general result to that found previously by Hornik (1991) for ANNs – namely that
NAHONN groups are capable of approximating any kind of piecewise continuous function, to any degree of accuracy (a proof is provided in Zhang, Xu & Fulcher, 2002). Moreover, these models are capable of automatically selecting not only the optimum model for a particular time series, but also the appropriate model order and coefficients.

This is the first book which introduces HONNs to people working in the fields of control and recognition. This is the first book which introduces to researchers in the control and recognition areas that HONNs is an open box neural networks tool compare to traditional artificial neural networks. This is the first book which provides opportunities for millions of people working in the control and recognition areas to know what HONNs are, and how to use HONNs in control and recognition areas. This book explains why HONNs can approximate any nonlinear data to any degree of accuracy, and allows researchers to understand why HONNs are much easier to use, and HONNs can have better nonlinear data recognition accuracy than SAS nonlinear (NLIN) procedures. This book introduces the HONN group models and adaptive HONNs, and allows the people working in the control and recognition areas to understand HONN group models and adaptive HONN models, which can simulate not only nonlinear data, but also discontinuous and unsmooth nonlinear data.

Millions of people who are using artificial neural networks and who are doing control and recognition research, in particular, professors, graduate students, and senior undergraduate students in the department related to the control and recognition, as well as the professionals and researchers in the areas related to control and recognition, which should include computer science, computer engineering, information science, information technology, economics, business, materials, mathematics, and so on.

Chapter 1, “Ultra High Frequency Polynomial and Trigonometric Higher Order Neural Networks for Control Signal Generator”, delivers a new nonlinear model, Ultra high frequency Polynomial and Trigonometric Higher Order Neural Networks (UPT-HONN), for control signal generator. UPT-HONN includes UPS-HONN (Ultra high frequency Polynomial and Sine function Higher Order Neural Networks) and UPC-HONN (Ultra high frequency Polynomial and Cosine function Higher Order Neural Networks). UPS-HONN and UPC-HONN model learning algorithms are developed in this chapter. UPS-HONN and UPC-HONN models are used to build nonlinear control signal generator. Test results show that UPS-HONN and UPC-HONN models are better than other Polynomial Higher Order Neural Network (PHONN) and Trigonometric Higher Order Neural Network (THONN) models, since UPS-HONN and UPC-HONN models can generate control signals with error approaching 0.0000%.

Chapter 2, “HONU and Supervised Learning Algorithms in Adaptive Feedback Control Peter Mark Benes”, is a summarizing study of Higher Order Neural Units featuring the most common learning algorithms for identification and adaptive control of most typical representatives of plants of single-input single-output (SISO) nature in the control engineering field. In particular, the linear neural unit (LNU, i.e., 1st order HONU), quadratic neural unit (QNU, i.e. 2nd order HONU), and cubic neural unit (CNU, i.e. 3rd order HONU) will be shown as adaptive feedback controllers of typical models of linear plants in control including identification and control of plants with input time delays. The investigated and compared learning algorithms for HONU will be the step-by-step Gradient Descent adaptation with the study of known modifications of learning rate for improved convergence, the batch Levenberg-Marquardt algorithm, and the Resilient Back-Propagation algorithm. The theoretical achievements will be summarized and discussed as regards their usability and the real issues of control engineering tasks.

Chapter 3, “Novelty Detection in System Monitoring and Control with HONU Cyril Oswald”, reviews two recently introduced adaptive novelty detection algorithms based on supervised learning of HONU with extension to adaptive monitoring of existing control loops. Further, the chapter also introduces a
novel approach for novelty detection via local model monitoring with Self-organizing Map (SOM) and HONU. Further, it is discussed how these principles can be used to distinguish between external and internal perturbations of identified plant or control loops. The simulation result will demonstrate the potentials of the algorithms for single-input plants as well as for some representative of multiple-input plants and for the improvement of their control.

Chapter 4, “Ultra High Frequency Sigmoid and Trigonometric Higher Order Neural Networks for Data Pattern Recognition”, develops a new nonlinear model, Ultra high frequency siGmoid and Trigonometric Higher Order Neural Networks (UGT-HONN), for data pattern recognition. UGT-HONN includes Ultra high frequency siGmoid and Sine function Higher Order Neural Networks (UGS-HONN) and Ultra high frequency siGmoid and Cosine functions Higher Order Neural Networks (UGC-HONN). UGS-HONN and UGC-HONN models are used to recognition data patterns. Results show that UGS-HONN and UGC-HONN models are better than other Polynomial Higher Order Neural Network (PHONN) and Trigonometric Higher Order Neural Network (THONN) models, since UGS-HONN and UGC-HONN models to recognize data pattern with error approaching 0.0000%.

Chapter 5, “Ultra High Frequency SINC and Trigonometric Higher Order Neural Networks for Data Classification, creates a new nonlinear model, Ultra high frequency SINC and Trigonometric Higher Order Neural Networks (UNT-HONN), for Data Classification. UNT-HONN includes Ultra high frequency siNc and Sine Higher Order Neural Networks (UNS-HONN) and Ultra high frequency siNc and Cosine Higher Order Neural Networks (UNC-HONN). Data classification using UNS-HONN and UNC-HONN models are tested. Results show that UNS-HONN and UNC-HONN models are better than other Polynomial Higher Order Neural Network (PHONN) and Trigonometric Higher Order Neural Network (THONN) models, since UNS-HONN and UNC-HONN models can classify the data with error approaching 0.0000%.

Chapter 6, “Integration of higher-order time-frequency statistics and neural networks: Application for power quality surveillance”, is focus on that Higher-order statistics demonstrate their innovative features to characterize power quality events, beyond the traditional and limited Gaussian perspective, integrating time-frequency features and within the frame of a Higher-Order Neural Network (HONN). With the massive advent of smart measurement equipment in the electrical grid (Smart Grid), and in the frame of high penetration scenarios of renewable energy resources, the necessity dynamic power quality monitoring is gaining even more importance in order to identify the suspicious sources of the perturbation, which are nonlinear and unpredictable in nature. This eventually would satisfy the demand of intelligent instruments, capable not only of detecting the type of perturbation, but also the source of its origin in a scenario of distributed energy resources.

Chapter 7, “Adaptive Hybrid Higher Order Neural Networks for Prediction of Stock Market Behavior”, establishes two higher order neural networks (HONN) for efficient prediction of stock market behavior. The models include Pi-Sigma, and Sigma-Pi higher order neural network models. Along with the traditional gradient descent learning, how the evolutionary computation technique such as genetic algorithm (GA) can be used effectively for the learning process is also discussed here. The learning process is made adaptive to handle the noise and uncertainties associated with stock market data. Further, different prediction approaches are discussed here and application of HONN for time series forecasting is illustrated with real life data taken from a number of stock markets across the globe.

Chapter 8, “Theoretical analyses of the universal approximation capability of a class of higher order neural networks based on approximate identity”, studies one of the most important problems in the theory of approximation functions by means of neural networks is universal approximation capability of neural
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networks. In this study, the chapter investigates the theoretical analyses of the universal approximation capability of a special class of three layer feedforward higher order neural networks based on the concept of approximate identity in the space of continuous multivariate functions. Moreover, the chapter presents theoretical analyses of the universal approximation capability of the networks in the spaces of Lebesgue integrable multivariate functions. The methods used in proving our results are based on the concepts of convolution and epsilon-net. The obtained results can be seen as an attempt towards the development of approximation theory by means of neural networks.

Chapter 9, “Artificial Sine and Cosine Trigonometric Higher Order Neural Networks for Financial Data Prediction”, addresses two new nonlinear artificial higher order neural network models. They are Sine and Sine Higher Order Neural Networks (SIN-HONN) and Cosine and Cosine Higher Order Neural Networks (COS-HONN). Financial data prediction using SIN-HONN and COS-HONN models are tested. Results show that SIN-HONN and COS-HONN models are good models for financial data prediction compare with Polynomial Higher Order Neural Network (PHONN) and Trigonometric Higher Order Neural Network (THONN) models.

Chapter 10, “Cosine and Sigmoid Higher Order Neural Networks for Data Simulations”, studies new open box and nonlinear model of Cosine and Sigmoid Higher Order Neural Network (CS-HONN). A new learning algorithm for CS-HONN is also developed from this study. A time series data simulation and analysis system, CS-HONN Simulator, is built based on the CS-HONN models too. Test results show that average error of CS-HONN models are from 2.3436% to 4.6857%, and the average error of Polynomial Higher Order Neural Network (PHONN), Trigonometric Higher Order Neural Network (THONN), and Sigmoid polynomial Higher Order Neural Network (SPHONN) models are from 2.8128% to 4.9077%. It means that CS-HONN models are 0.1174% to 0.4917% better than PHONN, THONN, and SPHONN models.

Chapter 11, “Improving Performance of Higher Order Neural Network using Artificial Chemical Reaction Optimization: A Case Study on Stock Market Forecasting”, discusses Multilayer neural networks are commonly and frequently used technique for mapping complex nonlinear input-output relationship. However, they add more computational cost due to structural complexity in architecture. This chapter presents different functional link networks (FLN), a class of higher order neural network (HONN). FLNs are capable to handle linearly non separable classes by increasing the dimensionality of the input space by using nonlinear combinations of input signals. Usually such network is trained with gradient descent based back propagation technique, but it suffers from many drawbacks. To overcome the drawback, here a natural chemical reaction inspired metaheuristic technique called as artificial chemical reaction optimization (ACRO) is used to train the network. As a case study, forecasting of the stock index prices of different stock markets such as BSE, NASDAQ, TAIEX, and FTSE are considered here to compare and analyze the performance gain over the traditional techniques.

Chapter 12, “Artificial Higher Order Neural Network Models”, introduces the background of HONN model developing history and overview 24 applied artificial higher order neural network models. This chapter provides 24 HONN models and uses a single uniform HONN architecture for ALL 24 HONN models. This chapter also uses a uniform learning algorithm for all 24 HONN models and uses a uniform weight update formulae for all 24 HONN models. In this chapter, Polynomial HONN, Trigonometric HONN, Sigmoid HONN, SINC HONN, and Ultra High Frequency HONN structure and models are overviewed too.

Chapter 13, “A Theoretical Framework for Parallel Implementation of Deep Higher Order Neural Networks”, proposes a theoretical framework for parallel implementation of Deep Higher Order Neural
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Networks (HONNs). First, the chapter develops a new partitioning approach for mapping HONNs to individual computers within a master-slave distributed system (a local area network). This will use a network of computers (rather than a single computer) to train a HONN to drastically increase its learning speed: all of the computers will be running the HONN simultaneously (parallel implementation). Next, the chapter develops a new learning algorithm so that it can be used for HONN learning in a distributed system environment. Finally, the chapter proposes to improve the generalization ability of the new learning algorithm as used in a distributed system environment. Theoretical analysis of the proposal is thoroughly conducted to verify the soundness of the new approach. Experiments will be performed to test the new algorithm in the future.

Chapter 14, “Ant Colony Optimization Applied to the Training of a High Order Neural Network with Adaptable Exponential Weights”, studies that high order neural networks (HONN) are neural networks which employ neurons that combine their inputs non-linearly. The HONEST (High Order Network with Exponential SynapTic links) network is a HONN that uses neurons with product units and adaptable exponents. The output of a trained HONEST network can be expressed in terms of the network inputs by a polynomial-like equation. This makes the structure of the network more transparent and easier to interpret. This study adapts ACO_R, an Ant Colony Optimization algorithm, to the training of an HONEST network. Using a collection of 10 widely-used benchmark datasets, we compare ACO_R to the well-known gradient-based Resilient Propagation (R-Prop) algorithm, in the training of HONEST networks. We find that our adaptation of ACO_R has better test set generalization than R-Prop, though not to a statistically significant extent.

Chapter 15, “Utilizing Feature Selection on Higher Order Neural Networks”, is concerned that Artificial Neural Network has shown its impressive ability on many real world problems such as pattern recognition, classification and function approximation. An extension of ANN, higher order neural network (HONN), improves ANN’s computational and learning capabilities. However, the large number of higher order attributes leads to long learning time and complex network structure. Some irrelevant higher order attributes can also hinder the performance of HONN. In this chapter, feature selection algorithms will be used to simplify HONN architecture. Comparisons of fully connected HONN with feature selected HONN demonstrate that proper feature selection can be effective on decreasing number of inputs, reducing computational time, and improving prediction accuracy of HONN.

Chapter 16, “Some Properties on The Capability of Associative Memory for Higher Order Neural Networks”, describes that higher order neural networks (HONNs) have been proposed as new systems. This paper shows some theoretical results of associative capability of HONNs. As one of them, memory capacity of HONNs is much larger than one of the conventional neural networks. Further, the chapter shows some theoretical results on homogeneous higher order neural networks (HHONNs), in which each neuron has identical weights. HHNNs can realize shift-invariant associative memory, that is, HHONNs can associate not only a memorized pattern but also its shifted ones.

Chapter 17, “Discrete-time decentralized inverse optimal higher order neural network control for a multi-agent omnidirectional mobile robot”, presents a new approach to multi- agent control of complex systems with unknown parameters and dynamic uncertainties. A key strategy is to use of neural inverse optimal control. This approach consists in synthesizing a suitable controller for each subsystem, which is approximated by an identifier based on a recurrent high order neural network (RHONN), trained with an extended Kalman filter (EKF) algorithm. On the basis of this neural model and the knowledge of a control Lyapunov function, then an inverse optimal controller is synthesized to avoid solving the Hamilton Jacobi Bellman (HJB) equation. We have adopted an omnidirectional mobile robot, KUKA
youBot, as robotic platform for our experiments. Computer simulations are presented which confirm the effectiveness of the proposed tracking control law.

Chapter 18, “Higher Order Neural Network for Financial Modeling and Simulation”, concentrates that financial market creates a complex and ever changing environment in which population of investors are competing for profit. Predicting the future for financial gain is a difficult and challenging task, however at the same time it is a profitable activity. Hence, the ability to obtain the highly efficient financial model has become increasingly important in the competitive world. To cope with this, we consider functional link artificial neural networks (FLANNs) trained by particle swarm optimization (PSO) for stock index prediction (PSO-FLANN). Our strong experimental conviction confirms that the performance of PSO tuned FLANN model for the case of lower number of ahead prediction task is promising. In most cases LMS updated algorithm based FLANN model proved to be as good as or better than the RLS updated algorithm based FLANN but at the same time RLS updated FLANN model for the prediction of stock index system cannot be ignored.

Let millions of people working in the control and recognition areas know that HONNs are much easier to use and can have better recognition results than SAS Nonlinear models, and understand how to successfully use HONNs models for nonlinear data control, recognition, and prediction. HONNs will challenge traditional artificial neural network products and change the research methodology that people are currently using in control and recognition areas for the control signal generating, pattern recognition, nonlinear recognition, classification, and prediction.

Currently no book has been published in the control and recognition areas using HONNs. This book will be the first book which collects chapters on HONNs for control and recognition.

After this book has been published, more people in control and recognition can use HONNs for control signal generating, pattern recognition, nonlinear recognition, and system control. More researchers in the control, recognition, economics and business areas can use HONNs for control signal generating, data recognition, and data prediction.

Artificial neural network research is one of the new directions for new generation computers. Current research suggests that open box artificial HONNs play an important role in this new direction. Since HONNs are open box models they can be easily accepted and used by the people working in the information science, information technology, management, economics, and business areas. Researchers in the control, recognition, information systems, and economics and business areas can use HONNs in their studies.