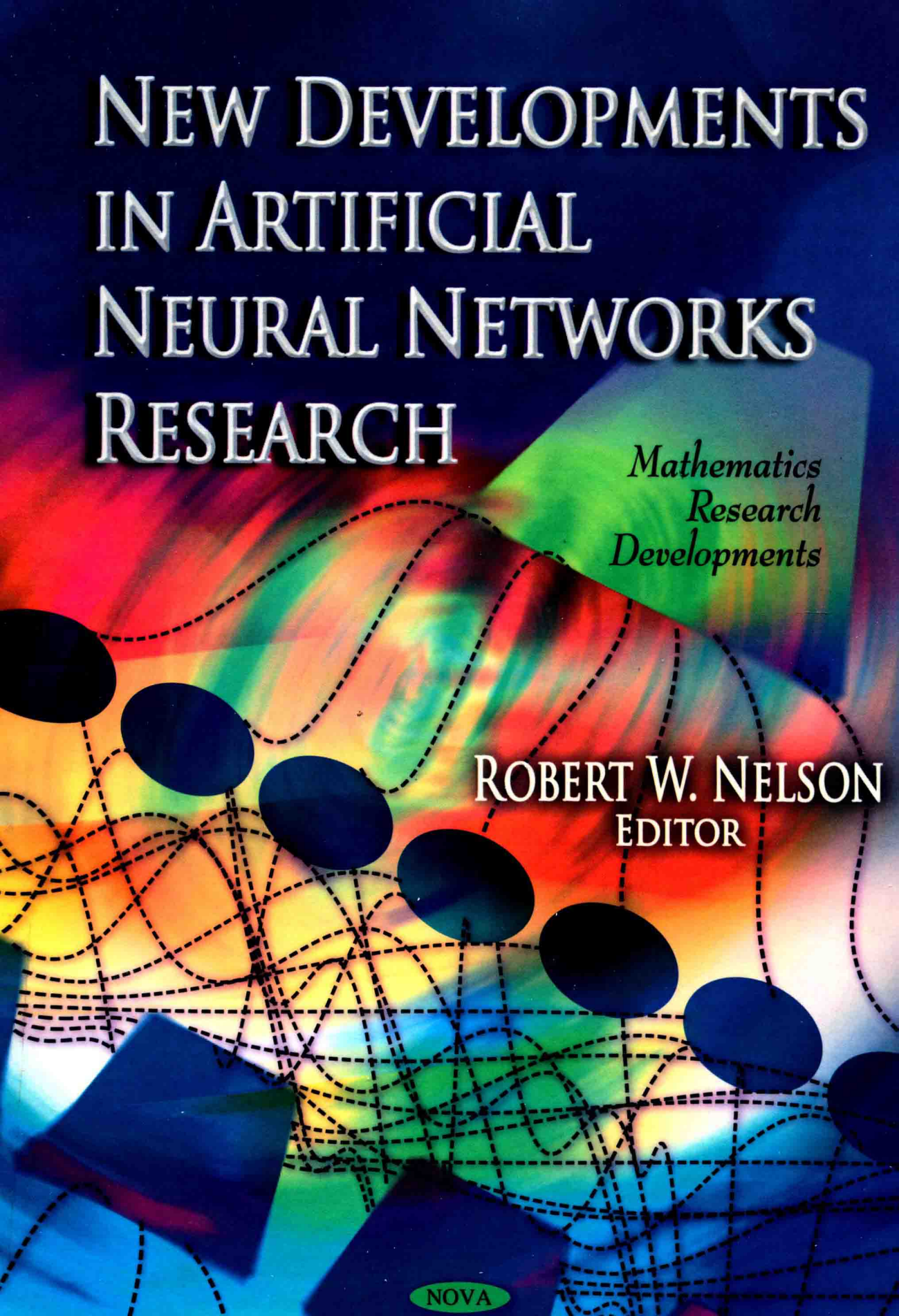
New Developments in Artificial Neural Networks Research

Mathematics Research Developments



Robert W. Nelson
Editor

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MATHEMATICS RESEARCH DEVELOPMENTS

NEW DEVELOPMENTS IN ARTIFICIAL NEURAL NETWORKS RESEARCH

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EDITOR

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PREFACE

This book gathers the most current research from across the globe in the study of artificial neural networks. Topics discussed include a neural network based visual servo system; modeling of computer-assisted learning using artificial neural networks; prediction of hole quality in drilling GFRE using artificial neural networks; ANN-based approaches to study the nanoscale CMOS devices; artificial neural networks in chromatography and spectroscopy; heterogeneous neural networks and tuning differential evolution for artificial neural networks.

Chapter 1 – Robotics arm visual servo system does suffer from a number of issues, as related to speed and complexity. One of which is the complicated kinematics relations, in addition the needed computational time to execute a task. This manuscript highlights a mechanism through which to approximate the inter-related visual kinematics relations that are part of visual servo closed loop system through an artificial neural network system. A main issue that hinders visual servo system is related to the complicated and time variant feature Jacobian matrix. The methodology followed here is based on the concept of integration of ANN with an Image Based Visual Servoing (IBVS) system. Artificial neural networks have been employed here to learn and approximate the relations that relate an object moving to a robotics arm movement through a visual servo. For validating the presented concept, one of the closed loop visual servo system already developed, have been used here to verify the presented concept. A learning Artificial Neural Network has proven to be an effective approach in learning the nonlinear relationships that govern kinematics relations used in robotics arm visual servo. In this respect, this chapter will explore how a trained artificial neural net will be used to achieve a very precise robotics arm movement by extracting the visual information from a moving object.

Chapter 2 – Recycling represents a valid alternative to the disposal of post-consumer materials if it is possible to obtain new materials with good properties. In this chapter, Polypropylene (PP)/waste ground rubber tire powder (WGRT) or waste polypropylene (WPP)/waste ground rubber tire (WGRT) powder composites were studied with respect to the effect of bitumen and maleic anhydride-grafted styrene-ethylene-butylene-styrene (SEBS-g-MA) content by using the design of experiments (DOE) approach, whereby the effect of the four polymers content on the final mechanical properties were predicted. Uniform design method was especially adopted for its advantages. Optimization was done using hybrid artificial neural network-genetic algorithm (ANN-GA) technique. The results indicated that the composites showed fairly good ductibility provided that it had a relatively higher

concentration of bitumen and SEBS-g-MA under the studied condition. A quantitative relationship was presented between the material concentration and the mechanical properties as a set of contour plots, which were confirmed experimentally by testing the optimum ratio.

Chapter 3 – The present work belongs to a rather challenging interdisciplinary issue associated with neuroscience modeling, educational psychology, and cognitive sciences for searching two optimum teaching methodologies at children's classrooms. Firstly, that one associated with trying effectively to find an optimal methodology for "how reading should be taught?" at children's classrooms. However, the second topic is closely related to optimum teaching method for solving long division problems following subsequent mathematical steps such as: divide, multiply, subtract, bring down, and repeat (if necessary). Searching for optimality leaning/teaching educational topics will depend upon comparative assessments and analysis for different experimental educational methodologies that applied at children's classrooms. Herein, presented assessment processes comprise application of visual and/or auditory tutorial materials in addition to the classical classrooms teaching methodologies. The comparative assessment processes are performed by using realistic Artificial Neural Network (ANN) simulation programs, and/or mathematically formulated modeling. In addition, a computer-assisted learning (CAL) module is designed carefully aiming to develop a specified multimedia tutorial material.

Conclusively, it has been shown that optimal teaching methodology performance attained if and only if visual and auditory tutorial materials have been both presented simultaneously to reinforce the retention of learned material topics. Multi-sensory associative memories in addition to Pavlovian classical conditioning theories are applicable, via designed CAL package, at children's classrooms. It is worthy to note that comparative results obtained are interesting, after field application of suggested CAL package, for association tutorials with teacher's voice. Finally, presented study results in high recommendation for application of novel teaching trends aiming to improve learning quality in children's two reading and mathematical topics.

Chapter 4 – The weight and fuel savings offered by composite materials make them attractive not only to the military, but also to the civilian aircraft, space, and automobile industries. In these industries, drilled holes are extensively implemented for structure assembly. The presence of hole defects due to drilling reduces the stiffness and strength of a laminate and hence its load carrying capacity. The main objective of the present work is to develop artificial neural networks (ANNs), with back-propagation training routine, for predicting the machinability parameters in drilling glass fiber reinforced epoxy (GFRE) composites with different machining conditions (feed, speed, and drill pre-wear). Machinability parameters were characterized by thrust force, torque, peel-up and push-out delaminations, and surface roughness of drilled holes.

The inputs to the neural networks used for predicting delamination size and surface roughness are: spindle speed, feed, drill pre-wear, thrust force, and torque. The values of the thrust force and torque that are fed as inputs to the above networks are predicted using ANNs developed for predicting each of them. Several attempts were performed to achieve the best neural network by changing both of network structure (i.e. the number of hidden layers and the number of units within each hidden layer) and the initial values of the connection weights and thresholds. The best obtained network structure for predicting thrust force, torque, peel-up delamination, push-out delamination, surface roughness were 3-5-1, 3-3-1, 5-11-1, 5-7-3-1, and 5-7-3-1, respectively. The developed ANNs predict the machinability parameters

(thrust force, torque, peel-up and push-out delaminations and surface roughness) with acceptable errors for the most confirmation tests.

Chapter 5 – The heart of the liquid desiccant cooling system is the dehumidification process which is influenced by many parameters. Different types of dehumidification equipment have been developed and a variety of analytical models have been employed to analyze the dehumidification process. The dehumidification process involves simultaneous heat and mass transfer and reliable transfer coefficients are required in order to analyze the system. This has been proved to be difficult and many assumptions are made to simplify the analysis.

Artificial Neural Network (ANN) is widely used as an innovative way to tackle complex and ill-defined problems. The present research proposes the use of ANN based model in order to simulate the relationship between inlet parameters and the performance of the dehumidifier. For the analysis, randomly packed dehumidifier is chosen since the packed tower facilitates high mass transfer by providing a large surface area in a relatively small volume. Lithium chloride is selected as the liquid desiccant due to its stability with high performance.

A multilayer ANN is used to investigate the performance of dehumidifier. For training ANN models, data is obtained from analytical equations. The training process implies adjustment of connection weights and biases so that the differences between ANN output and the desired output are minimized. Eight parameters are used as inputs to the ANN, namely: air and desiccant flow rates, air and desiccant inlet temperatures, air inlet humidity, the desiccant inlet concentration, dimensionless temperature ratio, and the inlet temperature of the cooling water. The output of the ANN is the water condensation rate. The predicted water condensation rate by the ANN is validated with experimental data and the value of R^2 is found to be 0.9251. Results and the performance of the developed system are presented in this chapter.

Chapter 6 – In this chapter, the carrying of an object at a workspace, which was perceived by vision, to another location was realized by a robot arm with five axes. Basic image process techniques were used for object recognition and position determination. If the desired object was inside the workspace, the inverse kinematics solution was realized, and then after coordinates of the object's location was sent to the robot arm. The inverse kinematics solution of the robot arm was performed with artificial neural networks (ANN) model (Multi Layer Perceptron-MLP and Radial Basis Function (RBF) Neural Network) based on the forward kinematics solution. For an inverse kinematics solution of the robot, the training data set was created in the ANN method by using the robot's forward kinematics values first and then, ANN modeling was realized. After the robot's inverse kinematics solution was realized, the determined joint angle values were directed to the EDUBOT robot arm and moving the object to the desired location was realized successfully. Experimental results presented in this chapter indicate that RBF is more efficient solution than MLP for inverse kinematic solution of visually guided robot.

Chapter 7 – Over the past three decades, the primary driver of the exponential improvements in integrated circuit performance has been the scaling of transistor dimensions. The inherent benefits of MOSFET scaling are the speed improvement and energy reduction associated with a binary-logic transition. As the MOSFET is scaled below the 100 nm technology node the advantages of MOSFET scaling are diminished by the short channel effects. Ultra-thin film body multigate structures become to be envisaged as a possible

alternative to the conventional devices, due to its enormous potentiality to push back the integration limits to which conventional bulk transistor are subjected [1-4]. The main advantage of this architecture is to offer a reinforced electrostatic coupling between the conduction channel and the gate electrode. In other terms, a multigate structure can efficiently sandwich (and thus very well control, electrostatically speaking) the semiconductor element playing the role of the transistor channel, which can be a Silicon thin layer or nanowire. Moreover, it is known for its higher drive current, improved subthreshold slope, improved short channel effect control and potential circuit design flexibility [1–4]. As shown in Figure 1, with two gates controlling the channel, short-channel effects can be greatly suppressed. Due to the fact that simulation of nanoscale CMOS circuits has been the primary factor driving improvements in integrated circuit performance and cost, which contributes to the rapid growth of the semiconductor industry, there is a need to develop a new theory and modeling techniques that capture the physics of quantum transport accurately to guide the design for nanoscale CMOS circuits.

Chapter 8 – The purpose of this chapter is to demonstrate the application of artificial neural networks in modern chemical investigation, mainly in chromatography and spectroscopy.

The first part of the chapter presents a fast and simple procedure for estimation of steel materials corrosion in artificial sweat solution with usage of artificial neural networks (ANN). For the purpose of the mathematical modeling, optical emission spectroscopy experimental data were used to train and test the most appropriate model of artificial neural networks. Evaluation was performed by comparing the experimental data and values estimated by ANN and by calculating the correlation coefficient and mean absolute error. It was concluded that ANN can be easily applied for estimation of corrosion processes.

The second part of this chapter presents a combination of artificial neural networks and genetic algorithms (GA) in optimization of thin layer chromatographic separation of seven components from their mixture. As a goal of optimization, a resolution factor was calculated for different mixture model solutions. Afterwards the prediction of the same parameter was performed by ANN and GA, and very good correlation between predicted and calculated data was observed. Therefore it can be concluded that the developed combination of ANN and GA may be successfully used in many different chromatography investigations, like high performance liquid chromatography (HPLC), ion chromatography (IC), gas chromatography (GC) and other similar techniques.

Based on their current results the authors expect that artificial neural networks and their combination with other methods (such as genetic algorithms) will be implemented in many different chemical and analytical applications in a near future.

Chapter 9 – In the past decade, there have been many implementations in which artificial neural networks (ANN) successfully applied to many areas of science and engineering. One of these areas is time series forecasting. ANN method has been preferred to conventional time series forecasting models because of its easy usage and providing accurate results. In spite of the fact that ANN produces accurate forecasts in many time series implementations, there are still some problems with using this method. When ANN method is utilized to forecast time series, selection of the components of the method is a vital issue for obtaining good forecast values. These components such as architecture structure, learning algorithm and activation function have important effect on the performance of ANN. An important decision is the selection of architecture structure that consists of determining the numbers of neurons in the

layers of a network. Therefore, to making a good choice for architecture selection, various approaches have been proposed in the literature. Aladag (2009a; 2009b) proposed a method based on tabu search algorithm to determine the best ANN architecture. He showed that accurate forecasts are obtained when the proposed method is employed for architecture selection. In his proposed algorithm, he utilized a candidate list strategy in which six architectures are examined. In this study, the tabu search algorithm proposed by Aladag (2009b) is tried to be improved by defining a new candidate list strategy in which only four architectures are examined. The beer consumption in Austria and the electricity consumption in Turkey time series are forecasted by ANN and the applicability of the proposed strategy is shown.

Chapter 10 – Measured meteorological parameters such as air temperature and relative humidity values recorded between 1998 and 2002 for Abha city in Saudi Arabia were used for the estimation of global solar radiation (GSR) and fraction of diffuse solar radiation (DSR) in future time domain using artificial neural network method. The estimations of GSR and DSR were made using three combinations of data sets namely, (i) day of the year and daily maximum air temperature as inputs and global solar radiation as output, (ii) day of the year and daily mean air temperature as inputs and global solar radiation as output and (iii) time day of the year, daily mean air temperature and relative humidity as inputs and global solar radiation as output. The measured data between 1998 and 2001 was used for training the neural networks while the remaining 240 days' data from 2002 as testing data. The testing data was not used in training the neural networks.

Obtained results show that neural networks are well capable of estimating global and diffuse solar radiation from temperature and relative humidity. Hence the methodology can be used for estimating GSR and DSR for locations where only temperature and humidity data are available.

Chapter 11 – Cementitious materials comprise a great part in construction process of structures such as buildings, bridges, roads and dams. The most expected properties of structural members prepared with cement mortar or concrete, are strength and durability. These structural members are supposed to have strength values determined in the structural analysis and to be durable against aggressive media in their service life. These characteristics are the most effective criteria in civil and material engineering. Therefore, these two parameters depend mainly on the pore structure and its characteristics of structural members. Nowadays, scientists and engineers are using new computer technologies, simulations and experimental techniques try to perform to characterize the inner structure of structural materials in order to define microstructural formations and the effects of microstructural phases such as pores on macro properties.

New image capturing tools and their improved magnification capacity induced researchers to have an expanded view on investigation of microstructures. In addition, the results of these studies are simply not enough to realize the simulation of effects of inner structure. Some numerical and statistical methods performed by computers are needed at this stage. Artificial neural network (ANN) is one of these methods. In last decades, artificial neural network applications have become more considerable issue in engineering applications. In the scope of this chapter, pore area ratio values represent total pore area amount in a polished section of cement mortars were determined. Also, some pore characteristics representing the probability of channels between pores are investigated. The pore amounts and these pore characteristics are related to compressive strength values of

cement mortars in order to establish a microstructure – macro property relationship. Thus, nondestructive methodologies and artificial neural network have been used in the prediction of a macro property, which only be determined by destructive testing techniques.

Chapter 12 – The concept of the drainage divide in a flat country can be taken as a metaphor of health vs disease in a medical setting. In the medical landscape the authors could consider spring location as the equivalent of genetic background at birth. Rivers become people's life trajectories. The seas the rivers ultimately flow into are the outcomes, for example healthy aging vs. premature death due to chronic disease. Depending on the genetic background (starting point), the influence of life events or particular life styles (hills, peaks, ridges) on the fate of the person (river) would be negligible or determinant in inducing a particular trajectory to a specific outcome.

If the principal aim of predictive medicine is to predict the future direction of a person's life in terms of health on the basis of available data, then in this metaphor the problem is to predict what direction the river will take, given its spring location in a particular country and the environmental data available. Two rivers whose "springs" are very close to each other can easily flow in opposite directions.

At present, despite the incredible development of genetic testing technologies, defining the role of genetic predisposition of a subject in determining future outcome still is an elusive target.

In other words, at present, with the exception of extreme situations, the authors are not able to translate efficiently the precise location of individual springs – in the prediction of the river path . The essay discuss how the use of newer mathematical approaches like those inherent to artificial neural networks environment the next future could really offer the chance to trace the health – disease drainage divide. This is the future challenge for predictive medicine.

Chapter 13 – Performance of a treatment plant highly depends on plant's operation and it is generally difficult to predict the performance due to several uncertainties. Also, many of activated sludge processes produce poor effluent quality due to escape of sludge from secondary clarifier as a result of excess filamentous growth. In this context, this study aims at modeling a real scale activated sludge process using a popular artificial neural network (ANN) to make its management easier. Effluent COD, effluent BOD_5 and SVI were used as model output parameters. The developed ANN model was very successful as an excellent to reasonable match was obtained between the measured and the predicted parameters of effluent COD ($R = 0.90$), effluent BOD_5 ($R = 0.83$) and SVI ($R=0.84$). Hence, the ANN based model can be used to predict a full scale wastewater treatment plant performance and to control the operational conditions for improved process performance.

Chapter 14 – This chapter is devoted to solve the positioning control problem of under-actuated robot manipulator. Artificial Neural Networks Inversion technique was used where a network representing the forward dynamics of the system was trained to learn the position of the passive joint over the working space of a 2R under-actuated robot. The obtained weights from the learning process were fixed and the network was inverted to represent the inverse dynamics of the system, and then used in the estimation phase to estimate the position of the passive joint for a new set of data the network was not previously trained for in order to show the success of the control strategy.

Data used in this research are recorded experimentally from sensors fixed on the robot joints in order to overcome whichever uncertainties presence in the real world such as ill-defined linkage parameters, links flexibility and backlashes in gear trains.

The technique was implemented in two phases, the first phase was the forward learning phase that used to obtain the training weights which are used in the second phase which is the inverse estimation phase that is used to estimate the passive joint's position for any set of data the network was not trained for. The results were verified experimentally to show the ability of the proposed technique to solve the problem efficiently.

Chapter 15 – Time series forecasting is a vital issue for many institutions. In the literature, many researchers from various disciplines have tried to improve forecasting models to reach more accurate forecasts. It is known that real life time series has a nonlinear structure in general. Therefore, conventional linear methods are insufficient for real life time series. Some methods such as autoregressive conditional heteroskedastiacity (ARCH) and artificial neural networks (ANN) have been employed to forecast nonlinear time series. ANN has been successfully used for forecasting nonlinear time series in many implementations since ANN can model both the linear and nonlinear parts of the time series. In this study, a novel hybrid forecasting model combining seasonal autoregressive integrated moving average (SARIMA), ARCH and ANN methods is proposed to reach high accuracy level for nonlinear time series. It is presented how the proposed hybrid method works and in the implementation, the proposed method is applied to the weekly rates of TL/USD series between the period January 3, 2005 and January 28, 2008. This time series is also forecasted by using other approaches available in the literature for comparison. Finally, it is seen that the proposed hybrid approach has better forecasts than those calculated from other methods.

Chapter 16 – Evolving Connectionist Systems (ECoS) are a class of constructive artificial neural networks that grow their structure as they learn. They have been widely applied to many problems. Among their advantages are fast, efficient training and a resistance to catastrophic forgetting. An attempt has previously been made to formally describe their operation and behaviour. This formalisation has some objections associated with them. This chapter describes the basic algorithms behind ECoS networks, critiques the previous formalisation and presents a new theory of ECoS networks that overcomes the objections associated with the previous work. Finally, the formalisation is tested on two well-known benchmark data sets.

Chapter 17 – This chapter studies a class of neuron models that computes a user-defined similarity function between inputs and weights. The neuron transfer function is formed by composition of an adapted logistic function with the quasi-linear mean of the partial input-weight similarities. The neuron model is capable of dealing directly with mix- tures of continuous as well as discrete quantities, among other data types and there is provision for missing values. An artificial neural network using these neuron models is trained using a breeder genetic algorithm until convergence. A number of experiments are carried out in several real-world problems in very different application domains described by mixtures of variales of distinct types and eventually showing missing values. This heterogeneous network is compared to a standard radial basis function network and to a multi-layer perceptron networks and shown to learn from with su- perior generalization ability at a comparable computational cost. A further important advantage of the resulting neural solutions is the great interpretability of the learned weights, which is done in terms of weighted similarities to prototypes.

Chapter 18 – The efficacy of an optimization method often depends on the choosing of a num- ber of behavioural parameters. Research within this area has been focused on devising schemes for adapting the behavioural parameters during optimization, so as to alleviate the need for a practitioner to select the parameters manually. But these schemes usually introduce new behavioural parameters that must be tuned. This study takes a different approach in which finding behavioural parameters that yield good performance is con- sidered an optimization problemin its own right and can therefore be attempted solved by an overlaid optimization method. In this work, variants of the general purpose op- timization method known as Differential Evolution have their behavioural parameters tuned so as to work well in the optimization of an Artificial Neural Network. The re- sults show that DE variants using so-called adaptive parameters do not have a general performance advantage as previously believed.

Chapter 19 – The modern drug discovery has entered a realm wherein artificial intelligence plays a pivotal role in handling the huge overflow of the data and extracting vital information related to structure-activity/property relationships and rational drug design. In this communication, the authors present an overview of applications of Artificial Neural Networks (ANN) specifically in the drug discovery arena of Acquired Immunodeficiency Syndrome (AIDS) with special reference to modeling and design of Non-nucleoside Reverse Transcriptase Inhibitors (NNRTIs) of Human Immunodeficiency Virus Type-1 (HIV-1). Although both linear and non-linear techniques are appropriate in distinguishing the biologically active from the inactive compounds, ANN has consistently shown better predictive ability in case of training and test data sets both, thus can serve as an excellent tool for statistical modeling. Also, a comparison of ANN technique with linear and other non-linear techniques is portrayed in brief. Recent trends in application of ANN technique in drug development for AIDS are also discussed in the communication. The flexibility of the neural architecture serves in better understanding of the trained dataset. Since the last two decades, ANN has emerged as a tool to enhance a descriptive model, though the higher computational cost encountered in deriving a neural network compared to linear methods might be of concern, but certainly not a limiting factor.

Chapter 20 – The objective of this paper is to analyze the theme of the application of the intelligent learning systems (such as artificial neural networks, expert systems, fuzzy models and genetic algorithms) in the pricing in banking and finance.

All firms must settle a price for the services or products which they offer. The price is an important element of the marketing mix, being also an important source of income for the firm. As the competition in the financial systems has intensified, nowadays the settlement of correct prices has become an essential element for the marketing strategy of a bank.

The price must not be considered as a purely financial problem, calculated by estimating only the costs to which a margin for profit will be added. The settlement of the price must consider also the stakeholders point of view.

A peculiarity of the pricing in banking is also a partial lack of transparency which make difficult to understand the variables to analyze in order to forecast the phenomenon.

CONTENTS

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Chapter 1

A NEURAL NETWORK BASED VISUAL SERVO SYSTEM: LEARNING VISUAL KINEMATICS OF A SCENE

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ABSTRACT

Robotics arm visual servo system does suffer from a number of issues, as related to speed and complexity. One of which is the complicated kinematics relations, in addition the needed computational time to execute a task. This manuscript highlights a mechanism through which to approximate the inter-related visual kinematics relations that are part of visual servo closed loop system through an artificial neural network system. A main issue that hinders visual servo system is related to the complicated and time variant feature Jacobian matrix. The methodology followed here is based on the concept of integration of ANN with an Image Based Visual Servoing (IBVS) system. Artificial neural networks have been employed here to learn and approximate the relations that relate an object moving to a robotics arm movement through a visual servo. For validating the presented concept, one of the closed loop visual servo system already developed, have been used here to verify the presented concept. A learning Artificial Neural Network has proven to be an effective approach in learning the nonlinear relationships that govern kinematics relations used in robotics arm visual servo. In this respect, this chapter will explore how a trained artificial neural net will be used to achieve a very precise robotics arm movement by extracting the visual information from a moving object.

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I. INTRODUCTION

Visual servo is a technique that is used to control a motion of a robotics system using the visual information to achieve a task. Visionary data is acquired from a camera that is mounted directly on a robot manipulator or on a mobile robot, in which case, motion of the robot induces camera motion. Differently, the camera can be fixed, so that can observe the robot motion. In this sense, visual servo control relies on techniques from image processing, computer vision control theory, kinematics, dynamic and real time computing. Robotics visual servoing has been recently introduced by robotics, AI and control communities. This is due to the significant number of advantages over blind robotic systems. Researchers have been demonstrated that visual servoing is an effective and a robust framework to control robotics systems while relying on visual information as feedback. An image-based scheme task is said to be completely performed if a desired image is acquired by a robotic system. Numerous advances in robotics have been inspired by the biological systems.

Visual servoing aims to control a robotics system through artificial vision in a way as to manipulate an environment, comparable to humans actions. Intelligence-based visual control has also been introduced by research community as a way to supply robotics system even with more cognitive capabilities, [2]. A number of research on the field of intelligent visual robotics arm control have been introduced. Visual servoing has been classified as using visual data within a control loop, enabling visual-motor (hand-eye) coordination. There have been different structures of visual servo systems. However, the main two classes are; Position-based visual servo systems (PBVS), and the Image-based visual servo systems (IBVS). In this chapter, we shall concentrate on the second class, which is the Image-based visual servo systems.

An Image Based Visual Servoing using Takagi-Sugeno fuzzy neural network controller has been proposed by Miao et. al. [3]. In this chapter, a Takagi-Sugeno Fuzzy Neural Network Controller (TSFNNC) based Image Based Visual Servoing (IBVS) method is proposed. Firstly, the eigenspace based image compression method is explored, which is chosen as the global feature transformation method. After that, the inner structure, performance and training method of T-S neural network controller are discussed respectively. Besides, the whole architecture of the TS-FNNC is investigated.

Panwar and Sukavanam in [4] have introduced Neural Network Based Controller for Visual Servoing of Robotic Hand Eye System. For Panwar and Sukavanam, in their paper a neural network based controller for robot positioning and tracking using direct monocular visual feedback is proposed. Visual information is provided using a camera mounted on the end-effector of a robotics manipulator. A PI kinematics controller is proposed to achieve motion control objective in an image plane. A Feedforward Neural Network (FFNN) is used to compensate for the robot dynamics. The FFNN computes the required torques to drive the robot manipulator to achieve desired tracking. The stability of combined PI kinematics and FFNN computed torque is proved by Lyapunov theory.

Luis and Carlos [5], have prsented a research throught which a new control scheme for visual servoing that takes into account the delay introduced by image acquisition and image processing. The capabilities (steady-state errors, stability margins, step time response, etc.) of the proposed control scheme and of previous ones are analytically analyzed and compared. Several simulations and experimental results were provided to validate the analytical results