In this paper, Levenberg–Marquardt inspired sliding mode control theory based adaptation laws are proposed to train an intelligent fuzzy neural network controller for a quadrotor aircraft. The proposed controller is used to control and stabilize a quadrotor unmanned aerial vehicle in the presence of periodic wind gust. A proportional-derivative controller is firstly introduced based on which fuzzy neural network is able to learn the quadrotor's control model on-line. The proposed design allows handling uncertainties and lack of modelling at a computationally inexpensive cost. The parameter update rules of the learning algorithms are derived based on a Levenberg–Marquardt inspired approach, and the proof of the stability of two proposed control laws are verified by using the Lyapunov stability theory. In order to evaluate the performance of the proposed controllers extensive simulations and real-time experiments are conducted. The 3D trajectory tracking problem for a quadrotor is considered in the presence of time-varying wind conditions.
Modeling level change in Lake Urmia using hybrid artificial intelligence approaches

The investigation of water level fluctuations in lakes for protecting them regarding the importance of these water complexes in national and regional scales has found a special place among countries in recent years. The importance of the prediction of water level balance in Lake Urmia is necessary due to several-meter fluctuations in the last decade which help the prevention from possible future losses. For this purpose, in this paper, the performance of adaptive neuro-fuzzy inference system (ANFIS) for predicting the lake water level balance has been studied. In addition, for the training of the adaptive neuro-fuzzy inference system, particle swarm optimization (PSO) and hybrid backpropagation-recursive least square method algorithm have been used. Moreover, a hybrid method based on particle swarm optimization and recursive least square (PSO-RLS) training algorithm for the training of ANFIS structure is introduced. In order to have a more fair comparison, hybrid particle swarm optimization and gradient descent are also applied. The models have been trained, tested, and validated based on lake level data between 1991 and 2014. For performance evaluation, a comparison is made between these methods. Numerical results obtained show that the proposed methods with a reasonable error have a good performance in water level balance prediction. It is also clear that with continuing the current trend, Lake Urmia will experience more drop in the water level balance in the upcoming years.

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Model of car wing active control in order to increase stability of the car on corners of roads

Active wing has the potential to increase the stability of racing cars by down-force as a result of aerodynamics pressure energy. In this paper a novel way of wing modelling and control is introduced. The proposed model is driven by using the second and the third Newton law and is also theoretically calculated by some simple formulation. Moreover, a proof to show how the performance increases is given. There are ways to work on other aspects of the subject because it will be the first step to intelligently control wings in order to increase road-holding without any special features on the road corners. Numerical and analytical arguments are considered to show step by step modeling spoiler. First the history of wing and spoiler is described then some research and improvement in the subject are given. Next the model of the wing plus its legs are discussed in details. Eventually suspension modelling according to wing model are given. The numerical results show the efficacy of the proposed method.

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Sliding mode fuzzy rule base bilateral teleoperation control of 2-DOF SCARA system

In the present study, the control of a bilateral teleoperation system using a fuzzy logic system which operates based on the sliding mode control theory has been considered. Because of intrinsic time delay and uncertainties of this system we choose sliding mode control theory as a robust controller to avoid mentioned side effects. Furthermore, the utilization of some fuzzy rules on the sliding manifold helps to overcome chattering problems which may appear in sliding mode control signals. The rule base controller is derived which results in an admissible outcome in the tracking of master by slave, precisely. The proposed approach is simulated on one of the most commonly used types of robots in industry namely SCARA. Moreover, in the free and contact motion, the stability and transparency of bilateral teleoperation system which is of a great significance is guaranteed in the presence of time delay, parameter uncertainties and system disturbances with a high synchronization performance.

A multi-objective genetic type-2 fuzzy extreme learning system for the identification of nonlinear dynamic systems

The major challenge in the design of Interval type-2 fuzzy logic system (IT2FLS) is to determine the optimal parameters for their antecedent and consequent parts. The most frequently used objective function for the design of IT2FLSs is root mean squared error (RMSE). However, other than RMSE, the maximum absolute error (MAE) for each of identification samples is very important. This paper propose a novel hybrid learning algorithm for the design of IT2FLS. The proposed algorithm benefits from the combination of extreme learning machine (ELM) and non-dominated sorting genetic algorithm (NSGAII) to tune the parameters of the consequent and antecedent parts of the IT2FLS, respectively. The proposed
method is used for forecasting of nonlinear dynamic systems. It is shown that not only the proposed method results in low RMSE, MAE achieved is also satisfactory.

**Comparative analysis of three approaches of antecedent part generation for an IT2 TSK FLS**
Since extreme learning machine is a non-iterative estimation procedure, it is faster than gradient-based algorithms which are iterative. Moreover, the extreme learning machine does not have any design parameters such as learning rate, covariance matrix, etc. The rigorous proof of universal approximation of extreme learning machine with much milder conditions makes it a preferable choice in many different approaches. Although this algorithm is optimal for the parameters which appear linearly in the consequent part of interval type-2 fuzzy logic systems, it is not optimal for the parameters of the antecedent part as it uses random parameters. In this paper, heuristic optimization approaches such as genetic algorithm and artificial bee colony are used to optimize the parameters of the antecedent part of interval type-2 fuzzy logic systems. As these methods are global optimizers, there is less possibility that they will fall in a local minima and are suitable for the selection of the parameters of the antecedent part. A comparative analysis of the optimal parameters with the randomly and manually generated parameters is presented here using noise-free and noisy Mackey-Glass time series data sets and a real world data set. Simulation results support this idea over randomly and manually generated parameters.
Multi objective optimal allocation of fault current limiters in power system

Transmission systems, connection of distributed generation to the grid are increased due to increase in power demands. This fact causes the increase in short circuit level of power networks. The occurrence of fault in such networks leads to large short circuit currents throughout the system, which may exceed the rating of existing circuit breakers and can damage system equipment. There are some approaches to reduce this fault current such as power network reinforcement and utilization of fault current limiter (FCLs) in power systems. Power system reinforcement is too difficult if not impractical. Therefore, the utilization of FCLs can provide an effective way to suppress fault currents. The effectiveness of FCL depends on the number of FCLs and their installation location. In this paper, a novel approach is presented to determine the optimal number and location of FCLs to improve the power network reliability and fault current reduction based on different conflicting objective functions. IEEE 39 BUS system and IEEE 57 BUS system are considered to evaluate the effectiveness and feasibility of the proposed method. The objective functions considered for the optimal allocation are reliability of power system, economic impact and short circuit current reduction. Unlike what has been previously done in literature, in this paper Pareto based optimization algorithms, namely non-dominated sorting algorithm, multiobjective particle swarm optimization and multiobjective evolutionary algorithm based on decomposition, are utilized to deal with this problem. The use of these methods made it possible to obtain the Pareto optimal front in which these objective functions are optimized simultaneously.
Learning Control of Fixed-Wing Unmanned Aerial Vehicles Using Fuzzy Neural Networks

A learning control strategy is preferred for the control and guidance of a fixed-wing unmanned aerial vehicle to deal with lack of modeling and flight uncertainties. For learning the plant model as well as changing working conditions online, a fuzzy neural network (FNN) is used in parallel with a conventional P (proportional) controller. Among the learning algorithms in the literature, a derivative-free one, sliding mode control (SMC) theory-based learning algorithm, is preferred as it has been proved to be computationally efficient in real-time applications. Its proven robustness and finite time converging nature make the learning algorithm appropriate for controlling an unmanned aerial vehicle as the computational power is always limited in unmanned aerial vehicles (UAVs). The parameter update rules and stability conditions of the learning are derived, and the proof of the stability of the learning algorithm is shown by using a candidate Lyapunov function. Intensive simulations are performed to illustrate the applicability of the proposed controller which includes the tracking of a three-dimensional trajectory by the UAV subject to time-varying wind conditions. The simulation results show the efficiency of the proposed control algorithm, especially in real-time control systems because of its computational efficiency.

Artificial bee colony optimization of interval type-2 fuzzy extreme learning system for chaotic data

The major challenge in the design of Interval type-2 fuzzy logic system (IT2FLS) is to determine the optimal parameters for their antecedent and consequent parts. This paper propose a novel hybrid learning algorithm for the design of IT2FLS. The proposed hybrid learning algorithm utilizes the combination of extreme learning machine (ELM) and artificial bee colony optimization (ABC) to tune the parameters of the consequent and antecedent parts of the IT2FLS, respectively. The effective forecasting performance of the proposed hybrid learning algorithm is analyzed by modeling a chaotic data set. It is found that the forecasted errors gradually decrease with decrease in the level of noise in data and vice versa.
A systematic design of interval type-2 fuzzy logic system using extreme learning machine for electricity load demand forecasting

This paper presents a novel design of interval type-2 fuzzy logic systems (IT2FLS) by utilizing the theory of extreme learning machine (ELM) for electricity load demand forecasting. ELM has become a popular learning algorithm for single hidden layer feed-forward neural networks (SLFN). From the functional equivalence between the SLFN and fuzzy inference system, a hybrid of fuzzy-ELM has gained attention of the researchers. This paper extends the concept of fuzzy-ELM to an IT2FLS based on ELM (IT2FELM). In the proposed design the antecedent membership function parameters of the IT2FLS are generated randomly, whereas the consequent part parameters are determined analytically by the Moore-Penrose pseudo inverse. The ELM strategy ensures fast learning of the IT2FLS as well as optimality of the parameters. Effectiveness of the proposed design of IT2FLS is demonstrated with the application of forecasting nonlinear and chaotic data sets. Nonlinear data of electricity load from the Australian National Electricity Market for the Victoria region and from the Ontario Electricity Market are considered here. The proposed model is also applied to forecast Mackey-glass chaotic time series data. Comparative analysis of the proposed model is conducted with some traditional models such as neural networks (NN) and adaptive neuro fuzzy inference system (ANFIS). In order to verify the structure of the proposed design of IT2FLS an alternate design of IT2FLS based on Kalman filter (KF) is also utilized for the comparison purposes.
This paper presents a novel optimization algorithm based on competitive behavior of various creatures such as birds, cats, bees and ants to survive in nature. In the proposed method, a competition is designed among all aforementioned creatures according to their performances. Every optimization algorithm can be appropriate for some objective functions and may not be appropriate for another. Due to the interaction between different optimization algorithms proposed in this paper, the algorithms acting based on the behavior of these creatures can compete each other for the best. The rules of competition between the optimization methods are based on imperialist competitive algorithm. Imperialist competitive
algorithm decides which of the algorithms can survive and which of them must be extinct. In order to have a comparison to well-known heuristic global optimization methods, some simulations are carried out on some benchmark test functions with different and high dimensions. The obtained results shows that the proposed competition based optimization algorithm is an efficient method in finding the solution of optimization problems.

General information
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Adaptive direct fuzzy control of SISO nonlinear systems using a fuzzy reference model
This study presents a novel fuzzy adaptive controller comprising a fuzzy direct model reference mechanism to control uncertain nonlinear SISO systems. The proposed method benefits from a reference model which is itself fuzzy. Since the reference model is fuzzy it has more degrees of freedom to define a more appropriate dynamic behavior for the system to be controlled. The flexibility caused by the fuzzy reference model makes it possible for the system to outperform the case when the reference signal is linear in terms of rise time and settling time. In addition, using the proposed approach, tracking error of the reference system reduces significantly. The direct method of Lyapunov is used to prove the stability of the system. The proposed method is tested on a Duffing oscillator subject to disturbances.

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Optimal parameters of an ELM-based interval type 2 fuzzy logic system: a hybrid learning algorithm

An optimized design of a fuzzy logic system can be regarded as setting of different parameters of the system automatically. For a single parameter, there may exist multiple feasible values. Consequently, with the increase in number of parameters, the complexity of a system increases. Type 2 fuzzy logic system has more parameters than the type 1 fuzzy logic system and is therefore much more complex than its counterpart. This paper proposes optimal parameters for an extreme learning machine-based interval type 2 fuzzy logic system to learn its best configuration. Extreme learning machine (ELM) is utilized to tune the consequent parameters of the interval type 2 fuzzy logic system (IT2FLS). A disadvantage of ELM is the random generation of its hidden neuron that causes additional uncertainty, in both approximation and learning. In order to overcome this limitation in an ELM-based IT2FLS, artificial bee colony optimization algorithm is utilized to obtain its antecedent parts parameters. The simulation results verified better performance of the proposed IT2FLS over other models with the benchmark data sets.

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Optimal design of adaptive type-2 neuro-fuzzy systems: A review

Type-2 fuzzy logic systems have extensively been applied to various engineering problems, e.g. identification, prediction, control, pattern recognition, etc. in the past two decades, and the results were promising especially in the presence of significant uncertainties in the system. In the design of type-2 fuzzy logic systems, the early applications were realized in a way that both the antecedent and consequent parameters were chosen by the designer with perhaps some inputs from some experts. Since 2000s, a huge number of papers have been published which are based on the adaptation of the parameters of type-2 fuzzy logic systems using the training data either online or offline. Consequently, the major challenge was to design these systems in an optimal way in terms of their optimal structure and their corresponding optimal parameter update rules. In this review, the state of the art of the three major classes of optimization methods are investigated: derivative-based (computational approaches), derivative-free (heuristic methods) and hybrid methods which are the fusion of both the derivative-free and derivative-based methods.
This study presents a novel direct model reference fuzzy controller as applied to the control of a nonlinear system over a network subject to variable network induced time delay. The proposed method uses Pade approximation to cope with this condition. Unlike most approaches seen in the literature, which are mostly model based and necessitate the solution of a set of linear matrix inequalities, the proposed approach is online and can be applied to nonlinear systems with a little knowledge about the structure of the system and the values of its parameters. The stability of the proposed method is proved using an appropriate Lyapunov function. The approach is implemented and tested on a dc motor with nonlinear characteristics and nonlinear state-dependent disturbance. It is shown that it is capable of controlling the system over a network subject to variable network-induced time delay with bounded tracking error. In addition, the effect of packet losses is considered in the implementation part and it is seen that the system can be controlled under these conditions too.
A Novel Direct Model Reference Fuzzy Control Approach Based on Observer and Its Applications

This paper aims to introduce a novel direct model reference fuzzy control approach based on observer for nonlinear systems, expressed in the form of a Takagi Sugeno (TS) fuzzy model. Based on this model, a direct model reference fuzzy controller based on adaptive observer is developed to deal with external disturbances. Compared with the adaptive observer based on TS fuzzy control model, the proposed method is robust in the existence of bounded external disturbances and it is capable of tracking a reference signal rather than just regulation. In addition the proposed algorithm does not necessitate the existence of plant parameter estimator any more. The proposed method is then validated on the control of Chua's circuit and it is shown that it is capable of controlling this chaotic system with high performance.
Recruent Interval Type-2 Fuzzy Control of 2-DOF Helicopter With Finite Time Training Algorithm

This study presents the decentralized control of a 2-DOF helicopter by designing a recurrent interval type-2 fuzzy neural network (RIT2FNN). The main aim of the proposed controller is to force the pitch and yaw angles follow a desired trajectory by using a finite time adaptation law. The proposed control signal is composed of two terms: the output of the RIT2FNN and the control signal generated by a conventional proportional-derivative (PD) controller. In the beginning, since the initial conditions of the RIT2FNN are randomly selected and may not be appropriate, the PD controller is responsible for the control of the system. However, the stable adaptation laws, which benefit from sliding mode control theory, train the parameters of the RIT2FNN. Since the adaptation laws are guaranteed to converge in finite time, the parameters of the RIT2FNN converge to their appropriate values. Meanwhile, the PD controller participates less in the control process and the RIT2FNN becomes the dominant controller of the system. The proposed control method is promising when dealing with highly nonlinear real-time systems which have to operate under uncertain working environment.

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Adaptive sliding-mode type-2 neuro-fuzzy control of an induction motor

An innovative adaptive control method for speed control of induction motor based on field oriented control is presented in this paper. The fusion of sliding-mode and type-2 neuro fuzzy systems is used to control this system. An online learning algorithm based on sliding-mode training algorithm, and type-2 fuzzy systems is employed to deal with parametric uncertainties and disturbances, by adjusting the control parameters. The sliding-mode adaptive mechanism tune the parameters of type-2 membership functions (antecedent part) and the consequent part parameters, according to the inputs: speed error and its derivative, in structure of type-2 neuro fuzzy system. Since the parameters of the induction motor may vary, and the information that is used to construct the membership functions and the rules of fuzzy logic system is uncertain, type-2 neuro fuzzy structure is selected as the controller. The results obtained by using this approach are compared with those of type-1 counterpart. The proposed adaptive sliding-mode type-2 neuro-fuzzy controller can control the induction motor with higher performance as it is compared with type-1 neuro-fuzzy systems while it shows more robustness to variations in the parameters and measurement noise.

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A novel type-2 fuzzy membership function (MF) in the form of an ellipse has recently been proposed in literature, the parameters of which that represent uncertainties are de-coupled from its parameters that determine the center and the support. This property has enabled the proposers to make an analytical comparison of the noise rejection capabilities of type-1 fuzzy logic systems with its type-2 counterparts. In this paper, a sliding mode control theory-based learning algorithm is proposed for an interval type-2 fuzzy logic system which benefits from elliptic type-2 fuzzy MFs. The learning is based on the feedback error learning method and not only the stability of the learning is proved but also the stability of the overall system is shown by adding an additional component to the control scheme to ensure robustness. In order to test the efficiency and efficacy of the proposed learning and the control algorithm, the trajectory tracking problem of a magnetic rigid spacecraft is studied. The simulations results show that the proposed control algorithm gives better performance results in terms of a smaller steady state error and a faster transient response as compared to conventional control algorithms.
Adaptive indirect fuzzy sliding mode controller for networked control systems subject to time-varying network-induced time delay

Two major challenges in networked control systems are the time-varying networked-induced delays and the packet losses. To alleviate these problems, this study presents a novel fuzzy sliding mode controller, where a fuzzy system is used to estimate the nonlinear dynamical system online, and the networked-induced delay is handled by Padé approximation. The problem of packet losses is handled by viewing them as large time-varying delays in the system. The sliding mode-based design procedure used ensures the stability and the robustness of the proposed controller in the presence of disturbances and time-varying networked-induced time delays. Using an appropriate Lyapunov function, it is proved that the tracking error converges to the neighborhood of zero asymptotically. Furthermore, since the adaptation laws of the parameters are derived by using of the Lyapunov function, these laws are also found to be stable. Simulation results show that the proposed fuzzy sliding mode controller is capable of controlling nonlinear dynamical systems over a network, which is subject to bounded external disturbances, time-varying network-induced delays, and packet losses with adequate performance.
Controlling the pitch and yaw angles of a 2-DOF helicopter using interval type-2 fuzzy neural networks

Due to not only having strong nonlinear inter-couplings in its model but also being an open-loop unstable system, control of a 2-degree of freedom (DOF) helicopter is a challenging task. This chapter deals with the decentralized control of the Quanser 2-DOF helicopter system by designing an interval type-2 fuzzy neural network for the control of the pitch and yaw angles by using a sliding mode control theory-based training algorithm. The proposed control method is known as feedback error learning in which an intelligent controller, a type-2 fuzzy neural network in this case, works in parallel with a conventional PD controller. In the proposed scheme, on one hand, the conventional PD controller is responsible to maintain the stability of the system until the intelligent controller takes the responsibility of controlling the system. On the other hand, the intelligent controller learns the system dynamics online with a sliding mode control-theory based learning algorithm. The simulation results show that without having neither a priori knowledge about the mathematical model of the system nor its parameters, the proposed control algorithm is able to track the reference signals for both yaw and pitch angles without giving a steady state error. In addition, the simulation results show the superiority of the proposed control scheme over its type-1 counterpart in the presence of noise in the system. In addition to its robustness, the sliding mode control theory-based learning algorithm has additional advantages such as having no matrix manipulations or partial derivatives which makes the overall training and control algorithm computationally simple and fast when compared to other methods, e.g. gradient-descent based methods.

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In order to achieve faster and more robust convergence (particularly under noisy working environments), a sliding-mode-theory-based learning algorithm has been proposed to tune both the premise and consequent parts of type-2 fuzzy neural networks (FNNs) in this paper. Different from recent studies, where sliding-mode-control-theory-based rules are proposed for only the consequent part of the network, the developed algorithm applies fully-sliding-mode parameter update rules for both the premise and consequent parts of type-2 FNNs. In addition, the responsible parameter for sharing the contributions of the lower and upper parts of the type-2 fuzzy membership functions is also tuned. Moreover, the learning rate of the network is updated during the online training. The stability of the proposed learning algorithm has been proved by using an appropriate Lyapunov function. Several comparisons have been realized and shown that the proposed algorithm has faster convergence speed than the existing methods such as gradient-based and swarm-intelligence-based methods. Moreover, the proposed learning algorithm has a closed form, and it is easier to implement than the other existing methods.

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Web of Science (2011): Indexed yes
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Scopus rating (2010): SJR 1.814 SNIP 3.265
Web of Science (2010): Indexed yes
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Observer-based indirect model reference fuzzy control system with application to control of chaotic systems

This paper proposes a novel, observer-based, indirect model reference fuzzy control approach for nonlinear systems, expressed in the form of a Takagi Sugeno (TS) fuzzy model. Based on this model, an adaptive observer based, indirect model reference fuzzy controller is developed to deal with external disturbances. In contrast to what is seen in the literature on adaptive observer based TS fuzzy control systems, the proposed method is robust in the existence of bounded external disturbances and it is capable of tracking a reference signal rather than just regulation. The proposed method is simulated on the control of Chua's circuit and it is shown that it is capable of controlling this chaotic system with high performance.

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In this paper, a novel identification scheme based on wavelet neural network structure is proposed. The objective function for identification considered in this paper is the sum of squared error. In order to optimize this objective, the genetic algorithm (GA) which is a global optimization is used for the parameters which appear nonlinearly in the wavelet structure. Recursive least square algorithm is used for the parameters which appear linearly in the output of wavelet neural network because it is known to be an optimal estimator for these parameters. The proposed training algorithm is used to identify chaotic system and a highly nonlinear dynamical system. Simulation results show that the proposed method identifies input/output data with higher performance in terms of sum of squared error when it is compared to gradient descent method.

Estimation of the parameters of wavelet neural networks using simultaneous use of genetic algorithm and recursive least square

In this paper, a novel identification scheme based on wavelet neural network structure is proposed. The objective function for identification considered in this paper is the sum of squared error. In order to optimize this objective, the genetic algorithm (GA) which is a global optimization is used for the parameters which appear nonlinearly in the wavelet structure. Recursive least square algorithm is used for the parameters which appear linearly in the output of wavelet neural network because it is known to be an optimal estimator for these parameters. The proposed training algorithm is used to identify chaotic system and a highly nonlinear dynamical system. Simulation results show that the proposed method identifies input/output data with higher performance in terms of sum of squared error when it is compared to gradient descent method.

General information

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Hierarchical Fuzzy identification using gradient descent and recursive least square method

In this paper, the parameters of hierarchical fuzzy systems are trained using the simultaneous use of Gradient Descent (GD) for nonlinear parameters and recursive least square (RLS) algorithm for linear parameters. One of the most effective ways to overcome the curse of dimensionality of fuzzy systems is the use of hierarchical fuzzy systems (HFS). Considering the learning abilities of fuzzy systems, two learning algorithms GD and GD+RLS have been used to teach HFS. The results of simulation show that, the use of HFS causes the decrease in the number of rules and results in better performance in identification. In addition, when GD+RLS algorithm is used for learning HFS, it produces better results when it is compared to GD algorithm.

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Sliding mode type-2 fuzzy control of robotic arm using ellipsoidal membership functions

Several papers claim that the performance of the type-2 fuzzy logic systems is superior over their type-1 counterparts, especially under noisy conditions. In order to show the effectiveness of the noise reduction capabilities of the type-2 fuzzy logic systems, a novel type-2 fuzzy membership function, ellipsoidal membership function, has recently been proposed. The novel membership function has certain values on both ends of the support and the kernel, and some uncertain values on the other values of the support. The parameters responsible for the width of uncertainty are decoupled from the parameters responsible for the center and the support of the membership function. In this study, a sliding mode control theory based learning algorithm has been proposed to tune the consequent part parameters tuning of the ellipsoidal type-2 fuzzy membership functions. The applicability of the novel membership function with the proposed novel parameter update rules has been shown on the control of a 2DOF robotic arm. The simulation results show that the type-2 fuzzy neural networks working in parallel with conventional PD controllers have the ability of controlling the robotic arm with a high accuracy especially under noisy conditions.

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Links: http://www.scopus.com/inward/record.url?scp=84886540314&partnerID=8YFLogxK (Link to publication in Scopus)
Extended kalman filter based learning algorithm for type-2 fuzzy logic systems and its experimental evaluation

In this paper, the use of extended Kalman filter for the optimization of the parameters of type-2 fuzzy logic systems is proposed. The type-2 fuzzy logic system considered in this study benefits from a novel type-2 fuzzy membership function which has certain values on both ends of the support and the kernel, and uncertain values on other parts of the support. To have a comparison of the extended Kalman filter with other existing methods in the literature, particle swarm optimization and gradient descent-based methods are used. The proposed type-2 fuzzy neuro structure is tested on different noisy input-output data sets, and it is shown that extended Kalman filter has a better performance as compared to the gradient descent-based methods. Although the performance of the proposed method is comparable with the particle swarm optimization method, it is faster and more efficient than the particle swarm optimization method. Moreover, the simulation results show that the proposed novel type-2 fuzzy membership function with the extended Kalman filter has noise rejection property. Kalman filter is also used to train the parameters of type-2 fuzzy logic system in a feedback error learning scheme. Then, it is used to control a real-time laboratory setup ABS and satisfactory results are obtained.

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Web of Science (2013): Indexed yes
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Control and synchronization of chaotic systems using a novel indirect model reference fuzzy controller

This paper presents a robust indirect model reference fuzzy control scheme for control and synchronization of chaotic nonlinear systems subject to uncertainties and external disturbances. The chaotic system with disturbance is modeled as a Takagi-Sugeno fuzzy system. Using a Lyapunov function, stable adaptation laws for the estimation of the parameters of the Takagi-Sugeno fuzzy model are derived as well as what the control signal should be to compensate for the uncertainties. The synchronization of chaotic systems is also considered in the paper. It is shown that by the use of an appropriate reference signal, it is possible to make the reference model follow the master chaotic system. Then, using the proposed model reference fuzzy controller, it is possible to force the slave to act as the reference system. In this way, the chaotic master and the slave systems are synchronized. It is shown that not only can the initial values of the master and the slave be different, but also there can be parametric differences between them. The proposed control scheme is simulated on the control and the synchronization of Duffing oscillators and Genesio-Tesi systems.

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Scopus rating (2013): SJR 0.857 SNIP 1.454 CiteScore 2
Statistical results to show the superiority of type two fuzzy logic systems over type one counterparts under noisy conditions

In this paper, some statistical quantities of the distortion caused by noise in the rule base of type-2 fuzzy logic systems are calculated. In many papers, the justification of better performance of type-2 fuzzy logic systems over type-1 counterparts in noisy conditions are studied only for some specific cases. In this paper, a simple type-2 fuzzy logic system with the ellipsoidal membership function is considered. Using this fuzzy system, it is possible to statistically study the effect of noise in the rule base of fuzzy systems. Using this statistical analysis, it is shown that the type-2 fuzzy logic systems with ellipsoidal membership function is less influenced in the presence of high level of noise when compared to its type-1 counterparts.
Training fuzzy neural networks using sliding mode theory with adaptive learning rate

This paper proposes an online training method for the parameters of a fuzzy neural network (FNN) using sliding mode systems theory with an adaptive learning rate. The implemented control structure consists of a conventional controller in parallel with a FNN. The former is provided both to guarantee global asymptotic stability in compact space and acts as a sliding surface to guide the states of the system towards zero. The output of the conventional controller is used to update the parameters of the FNN. The output of the FNN gradually replaces the conventional controller. The adaptive learning rate makes it possible to control the system without priori knowledge about the upper bound of the states of the system and their derivatives. An appropriate Lyapunov function approach is used to analyze the stability of the adaptation law of parameters of FNN. Sufficient conditions to guarantee the boundedness of the parameters are derived. The proposed approach is tested on the velocity control of an electro hydraulic servo system in presence of flow nonlinearities and internal friction.

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Analysis of the noise reduction property of type-2 fuzzy logic systems using a novel type-2 membership function

In this paper, the noise reduction property of type-2 fuzzy logic (FL) systems (FLSs) (T2FLSs) that use a novel type-2 fuzzy membership function is studied. The proposed type-2 membership function has certain values on both ends of the support and the kernel and some uncertain values for the other values of the support. The parameter tuning rules of a T2FLS that uses such a membership function are derived using the gradient descend learning algorithm. There exist a number of papers in the literature that claim that the performance of T2FLSs is better than type-1 FLSs under noisy conditions, and the claim is tried to be justified by simulation studies only for some specific systems. In this paper, a simpler T2FLS is considered with the novel membership function proposed in which the effect of input noise in the rule base is shown numerically in a general way. The proposed type-2 fuzzy neuro structure is tested on different input-output data sets, and it is shown that the T2FLS with the proposed novel membership function has better noise reduction property when compared to the type-1 counterparts.

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Direct model reference Takagi-Sugeno fuzzy control of SISO nonlinear systems

This study presents a novel direct model reference fuzzy controller. It relaxes the special conditions on the reference model that is required by some of the approaches described in the literature, as well as covering a more general class of Takagi-Sugeno (T-S) systems. The stability of the proposed method is proved using a proper Lyapunov function. In addition, the effects of modeling errors on the proposed controller are considered, and a robust modification algorithm to alleviate this problem is introduced and analyzed. The proposed method is then simulated on a flexible joint robot in a feedback linearization form and on Chua's chaotic electrical circuit. Finally, it is implemented and tested on a nonlinear dc motor with nonlinear state-dependent disturbance.

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An online training algorithm based on the fusion of sliding mode control theory and fuzzy neural networks with triangular membership functions

This paper proposes an online tuning method for the parameters of a fuzzy neural network using variable structure systems theory. The proposed learning algorithm establishes a sliding motion in terms of the fuzzy neuro controller parameters, and it leads the error towards zero. The Lyapunov function approach is used to analyze the convergence of the weights for the case of triangular membership functions. Sufficient conditions to guarantee the convergence of the weights are derived. In the simulation studies, the approach presented has been tested on the velocity control of an electro hydraulic servo system in presence of flow nonlinearities and internal friction.

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A novel training method based on variable structure systems theory for fuzzy neural networks

Uncertainty is an inevitable problem in real-time industrial control systems and, to handle this problem and the additional one of possible variations in the parameters of the system, the use of sliding mode control theory-based approaches is frequently suggested. In this paper, instead of using a conventional sliding mode controller, a sliding mode control theory-based learning algorithm is proposed to train the fuzzy neural networks in a feedback-error-learning structure. The parameters of the fuzzy neural network are tuned by the proposed algorithm not to minimize the error function but to ensure that the error satisfies a stable equation. The parameter update rules of the fuzzy neural network are derived, and the proof of the learning algorithm is verified by using the Lyapunov stability method. The proposed method is tested on a real-time servo system with time-varying and nonlinear load conditions.
Levenberg Marquardt algorithm for the training of type-2 fuzzy neural systems with a novel type-2 fuzzy membership function

A new training approach based on the Levenberg-Marquardt algorithm is proposed for type-2 fuzzy neural networks. While conventional gradient descent algorithms use only the first order derivative, the proposed algorithm used in this paper benefits from the first and the second order derivatives which makes the training procedure faster. Besides, this approach is more robust than the other techniques that use the second order derivatives, e.g., Gauss-Newton's method. The training algorithm proposed is tested on the training of a type-2 fuzzy neural network used for the prediction of a chaotic Mackey-Glass time series. The results show that the learning algorithm proposed not only results in faster training but also in a better forecasting accuracy.

Model reference fuzzy control of nonlinear dynamical systems using an optimal observer

This paper proposes a novel indirect model reference fuzzy control approach for nonlinear systems, expressed in the form of a Takagi Sugeno (TS) fuzzy model based on an optimal observer. In contrast to what is seen in the literature on adaptive observer-based TS fuzzy control systems, the proposed method is capable of tracking a reference signal rather
than just regulation. Additionally the proposed algorithm benefits from an adaptation algorithm which estimates the parameters of observer optimally. The stability analysis of the adaptation law and the controller is done using an appropriate Lyapunov function. The proposed method is then simulated on the control of Chua's circuit and it is shown that it is capable of controlling this chaotic system with high performance.

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**A novel type-2 fuzzy membership function: Application to the prediction of noisy data**
A novel, diamond-shaped type-2 fuzzy membership function is introduced in this study. The proposed type-2 fuzzy membership function has certain values on 0 and 1, but it has some uncertainties for the other membership values. It has been shown that the type-2 fuzzy system using this type of membership function introduced in this study has some noise reduction property in the presence of noisy inputs. The appropriate parameter selection to be able to achieve noise reduction property is also considered. A hybrid method consisting of particle swarm optimization (PSO) and gradient descent (GD) algorithm is used to optimize the parameters of the proposed type-2 fuzzy system. PSO is a derivative-free optimizer, and the possibility of the entrapment of this optimizer in local minimums is less than the gradient descent method. The proposed type-2 fuzzy system and the hybrid parameter estimation method are then tested on the prediction of a noisy, chaotic dynamical system. The simulation results show that the type-2 fuzzy predictor with the proposed novel membership functions shows a superior performance when compared to the other existing type-2 fuzzy systems in the presence of noisy inputs.

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Identification of interval fuzzy models using recursive least square method

In this paper, we present a new method of interval fuzzy model identification. Unlike the previously introduced methods, this method uses recursive least square methods to estimate the parameters. The idea behind interval fuzzy systems is to introduce optimal lower and upper bound fuzzy systems that define the band which contains all the measurement values. This results in lower and upper fuzzy models or a fuzzy model with a set of lower and upper parameters. The model is called the interval fuzzy model (INFUMO). This type of modeling has various applications such as nonlinear circuits modeling. There has been tremendous amount of activities to use linear matrix inequality based techniques to design a controller for this type of fuzzy systems. The fact that the actual desired data must lie between upper and lower fuzzy systems, introduces some constrains on the identification process of the lower and upper fuzzy systems. We would introduce a cost function which includes the violation of constrains and try to find an adaptation law which minimizes this cost function and at the same time tries to be less conservative.

Subspace identification of dynamical neurofuzzy system using LOLIMOT

In this paper a novel method for identification of dynamical neurofuzzy system is proposed. The proposed method benefits from both LOLIMOT as the premise part optimizer of the system and the subspace identification method of N4SID to optimize the state space parameters of the conclusion part. The resulting neurofuzzy system is a nonlinear dynamical system which is modeled by some locally linear state space models. using this model it is then possible to use different parallel distributed control techniques such as linear matrix inequality to control the identified system. The proposed approach is tested on a flexible robot arm and satisfactory results are generated.
Identification using ANFIS with intelligent hybrid stable learning algorithm approaches and stability analysis of training methods

This paper proposes a novel hybrid learning algorithm with stable learning laws for Adaptive Network based Fuzzy Inference System (ANFIS) as a system identifier and studies the stability of this algorithm. The new hybrid learning algorithm is based on particle swarm optimization (PSO) for training the antecedent part and forgetting factor recursive least square (FFRLS) for training the conclusion part. Two famous training algorithms for ANFIS are the gradient descent (GD) to update antecedent part parameters and using GD or recursive least square (RLS) to update conclusion part parameters. Lyapunov stability theory is used to study the stability of the proposed algorithms. This paper, also studies the stability of PSO as an optimizer in training the identifier. Stable learning algorithms for the antecedent and consequent parts of fuzzy rules are proposed. Some constraints are obtained and simulation results are given to validate the results. It is shown that instability will not occur for the learning rate and PSO factors in the presence of constraints. The learning rate can be calculated on-line and will provide an adaptive learning rate for the ANFIS structure. This new learning scheme employs adaptive learning rate that is determined by input-output data. Also, stable learning algorithms for two common methods are proposed based on Lyapunov stability theory and some constraints are obtained.

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Scopus rating (2014): SJR 1.696 SNIP 2.816 CiteScore 4.29
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 1.579 SNIP 2.684 CiteScore 4.06
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 1.187 SNIP 2.279 CiteScore 3.48
Incremental locally linear fuzzy classifier

Optimizing the antecedent part of neuro-fuzzy system is investigated in a number of documents. Current approaches typically suffer from high computational complexity or lack of ability to extract knowledge from a given set of training data. In this paper, we introduce a novel incremental training algorithm for the class of neuro-fuzzy systems that are structured based on local linear classifiers. Linear discriminant analysis is utilized to transform the data into a space in which linear discriminancy of training samples is maximized. The neuro-fuzzy classifier is built in the transformed space, starting from the simplest form. In addition, rule consequent parameters are optimized using a local least square approach.

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Publication date: 2009
Direct stable adaptive fuzzy neural model reference control of a class of nonlinear systems
In this study, using a model reference adaptation law, a stable fuzzy neural control system is developed. Despite the advantages of Model reference control design technique, which is mainly its power to exactly set trajectories of the system under control, this method is designed for linear system. In this study using fuzzy neural systems, a stable model reference controller for nonlinear systems is developed. Lyapunov method is used to guarantee the stability of fuzzy neural training algorithm and model following of the system under control.

A novel binary particle swarm optimization
Particle swarm optimization (PSO) as a novel computational intelligence technique, has succeeded in many continuous problems. But in discrete or binary version there are still some difficulties. In this paper a novel binary PSO is proposed. This algorithm proposes a new definition for the velocity vector of binary PSO. It will be shown that this algorithm is a better interpretation of continuous PSO into discrete PSO than the older versions. Also a number of benchmark optimization problems are solved using this concept and quite satisfactory results are obtained.

Fuzzy sliding mode control of rotary inverted pendulum
In this study, a fuzzy sliding mode controller for a rotary inverted pendulum is designed. Sliding mode controllers are high performance nonlinear controllers. Not only Sliding mode controller stabilizes the system under control effectively but also it robustly compensates the effect of bounded uncertainties and shows invariance properties in the presence of bounded disturbance. In this study, a fuzzy system is added to the classical sliding mode controller to adaptively estimate the equivalent signal of the sliding mode controller. In addition, using lyapunov theory the stability of the controller and the adaptation law is guaranteed.
In this study, a hybrid learning algorithm for training the Recurrent Fuzzy Neural Network (RFNN) is introduced. This learning algorithm aims to solve main problems of the Gradient Descent (GD) based methods for the optimization of the RFNNs, which are instability, local minima and the problem of generalization of trained network to the test data. PSO as a global optimizer is used to optimize the parameters of the membership functions and the GD algorithm is used to optimize the consequent part's parameters of RFNN. As PSO is a derivative free optimization technique, a simpler method for the train of RFNN is achieved. Also the results are compared to GD algorithm.

This paper presents sliding mode control of Rotary Inverted Pendulum. Rotary Inverted Pendulum is a nonlinear, unstable and non-minimum-phase system. Designing sliding mode controller for such system is difficult in general. Here, first the desired performance is introduced and based on this performance two sliding surfaces are designed, then system is controlled by proper definition of a lyapunov function. The lyapunov function designed puts more emphasis on the control of the inverted pendulum rather than the control of the motor.