REF: J110.284/2007
4 de octubre del 2007

CONACYT
Consejo Nacional de Ciencia y Tecnología

Ingenieria
Acciones de Movilidad: 4
Continuación

DR. ARNULFO ALBORES MEDINA
Secretario Académico
Centro de Investigación y de Estudios Avanzados

Ref: Hierarchical fuzzy neural networks for nonlinear system identification.
Programa: México – China 2007- 2008 2do. Año
Monto: $52,800.00 (CINCUENTA Y DOS MIL OCHOCIENTOS PESOS 00/100 M. N.)

En relación a la solicitud de apoyo presentada por esa Institución a este Consejo, tengo el agrado de comunicarle que se ha acordado asignar la cantidad especificada en la referencia, para las siguientes acciones internacionales del proyecto:

a) 50% *pasaje aéreo* México – China - México para 2 investigadores mexicanos, de conformidad al tabulador vigente para estos conceptos.	$33,000.00
b) 50% *gastos de estancia* para 2 investigadores chinos por 30 dias cada uno, a razón de $330.00 diarios, de conformidad al tabulador vigente para estos conceptos.	$19,800.00

En virtud de lo anterior, me permito solicitarle envíe a esta área a mi cargo el recibo fiscal correspondiente de conformidad con el procedimiento anexo, con el objeto de realizar los trámites administrativos pertinentes para la emisión del cheque respectivo.

En caso de que los recursos proporcionados se destinen para gastos distintos a lo autorizado, se deberá requerir previamente la autorización de este Consejo.

Asimismo, le agradeceré que al finalizar las actividades programadas y dentro de los 30 días posteriores envíe, a esta área a mi cargo, los Informes Financiero y Técnico debidamente requisitados, reportando los beneficios que ha recibido la comunidad científica nacional con esta contribución, de conformidad a los formatos correspondientes.

Hago de su conocimiento que en la documentación y en las publicaciones que se generen a partir de las actividades aprobadas, deberán figurar en forma explícita los créditos de reconocimiento al Consejo Nacional de Ciencia y Tecnología.

Sin otro particular, aprovecho la ocasión para enviarle un cordial saludo.

CLARA MORAN ANDRADE
Subdirectora de Estrategias de Cooperación Bilateral y Multilateral
Dirección de Política y Cooperación Internacional

CONACYT Consejo Nacional de Ciencia y Tecnología
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c.c.p. **Dr. Wen Yu Liu,** Responsable del Proyecto – Departamento de Control Automático
Dr. Efraín Aceves Piña, Director de Política y Cooperación Internacional – **CONACYT**

CONACYT

REF: J110.507/2006
14 de noviembre del 2006

Ingeniería
Acciones de Movilidad: 4
Nuevo

DRA. ROSALINDA CONTRERAS THEUREL
Directora General
Centro de Investigación y de Estudios Avanzados

Ref: Hierarchical fuzzy neural networks for nonlinear system identification.
Programa: México – China 2007- 2008 1er. Año
Monto: $52,800.00 (CINCUENTA Y DOS MIL OCHOCIENTOS PESOS 00/100M. N.)

En relación a la solicitud de apoyo presentada por esa Institución a este Consejo, tengo el agrado de comunicarle que se ha acordado asignar la cantidad especificada en la referencia, para las siguientes acciones internacionales del proyecto:

a) 50% *pasaje aéreo* México – China - México para 2 investigadores mexicanos, de conformidad al tabulador vigente para estos conceptos.	$33,000.00
b) 50% *gastos de estancia* para 2 investigadores chinos por 30 días cada uno, a razón de $330.00 diarios, de conformidad al tabulador vigente para estos conceptos.	$19,800.00

En virtud de lo anterior, me permito solicitarle envie a esta área a mi cargo el recibo fiscal correspondiente de conformidad con el procedimiento anexo, con el objeto de realizar los trámites administrativos pertinentes para la emisión del cheque respectivo. **El recibo deberá ser entregado a más tardar el 17 de noviembre del 2006, de lo contrario el apoyo se cancelará definitivamente.**

En caso de que los recursos proporcionados se destinen para gastos distintos a lo autorizado, se deberá requerir previamente la autorización de este Consejo. Por otra parte, si los gastos efectuados resultasen menores a lo previsto, la diferencia deberá ser reembolsada a CONACYT.

Asimismo, le agradeceré que al finalizar las actividades programadas y dentro de los 30 días posteriores envíe, a esta área a mi cargo, los Informes Financiero y Técnico debidamente requisitados, reportando los beneficios que ha recibido la comunidad científica nacional con esta contribución, de conformidad al formato que también se anexa.

Hago de su conocimiento que en la documentación y en las publicaciones que se generen a partir de las actividades aprobadas, deberán figurar en forma explícita los créditos de reconocimiento al Consejo Nacional de Ciencia y Tecnología.

Sin otro particular, aprovecho la ocasión para enviarle un cordial saludo.

REGISTRADO

CLARA MORAN ANDRADE
Subdirectora de Organismos Multilaterales y Estrategias de Cooperación
Dirección de Política y Cooperación Internacional

c.c. **Dr. Wen Yu Liu**, Responsable del Proyecto – Departamento de Control Automático
Dr. Efrain Aceves Piña, Director de Política y Cooperación Internacional – **CONACYT**

Hierarchical fuzzy neural networks for nonlinear system identification

CONACyT-Bilateral 2006-2008

Introduction

Both neural networks and fuzzy logic are universal estimators, they can approximate any nonlinear function to any prescribed accuracy, provided that sufficient hidden neurons and fuzzy rules are available. Resent results show that the fusion procedure of these two different technologies seems to be very effective for nonlinear systems identification.

In the design of the fuzzy systems is common to use a table look-up approach, which is a time-consuming task. Especially when the number of inputs and membership functions are huge, the number of fuzzy rules increase exponentially. The huge rule base would be overload the memory and make the fuzzy system very hard to implement. Generally n input variables and m membership functions for each variable, neuro-fuzzy systems require m^n rules. This phenomenon is called curse of dimensionality. In order to deal with the rule-explosion problem, a number of low-dimensional fuzzy systems in a hierarchical form are consisted, instead of a single high-dimensional fuzzy system. This is main idea of hierarchical fuzzy systems (HFS) [1]. It has been proven that hierarchical fuzzy systems also universal estimators [2. In [3] a hierarchical prioritized structure are able to introduce exceptions to more general rules by giving them a priority and introducing them to a higher level. The lowest level contains de default rules about the relationship being modeled. The middle level contains rules based on aggregation of exceptions to these default rules. The highest level of the structure contains specific exceptions not accounted for by the rest of the model. In [4] a method using intermediate mapping variables as temporal variables is presented to avoid the designing of intermediate outputs. In [5] a type of HFS, called Hierarchical Classifying-Type Fuzzy System (HCTFS) is used instead of repetitive defuzzification process between subsystem layers, analyzes the computational complexity in terms of the mathematical process and electronic components used.

When we cannot decide the membership functions in prior, we should use the input/output data to train the parameters of the membership function, for example ANFIS [2] and gradient learning [1]. Even for a single fuzzy neural networks, the training algorithm is complex [4]. It is very difficult to realize learning for hierarchical fuzzy neural networks if we use normal learning [5]. By using backpropagation technique, gradient descent algorithms can be simplified for multilayer neural networks training. Can hierarchical fuzzy neural networks be trained by the similar technique?

Gradient descent and backpropagation are always used to adjust the parameters of membership functions (fuzzy sets) and the weights of defuzzification (neural networks) for fuzzy neural networks. Slow convergence and local minimum are main drawbacks of these algorithms [1]. Some modifications were derived in recently published literatures. [3] suggested a robust backpropagation law to resist the noise effect and reject errors drift during the approximation. [Brown] used B-spline membership functions to minimize a robust object function, their algorithm can improve convergence speed. In [6], RBF neural networks were applied to fuzzy systems, a novel approach of determining structure and parameters of fuzzy neural systems was proposed. However the algorithm is complex, and difficult to realize. By using passivity and input-to-state stability (ISS) approaches, we successfully proved that for neural networks with modified gradient descent algorithms were stable and robust to any bounded uncertainties [5]. Do hierarchical fuzzy neural networks have the similar characteristics?

To the best of our knowledge, the training for hierarchical fuzzy neural system was still used the normal gradient algorithm [3] and ISS approach for fuzzy neural system was not still applied in the literature. In this collaborative project, new simple algorithms will be proposed such that the parameters of each sub-block can be trained independently. Input-to-state stability (ISS) approach is applied to system identification via fuzzy neural networks. Two cases are considered: (1) the premise memberships are assumed to be known, predetermined somehow in advance and learning is carried on only on the consequence parameters, and (2) weight update concerns both the premise and the consequent parameters. The new stable algorithms with time-varying learning rates are applied to two types of fuzzy neural models, namely, the traditional Mamdani's type model and TSK model.

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Objectives

In this project we will design a novel hierarchical neuro-fuzzy network to avoid the phomenon of "curse of dimensionality". With this structure the following works will be developed

1) A simple training algorithm for hierarchical fuzzy neural networks. The modelling process can be realized in each sub-block independently.
2) Input-to-state stability (ISS) approach will be applied to prove the stability of identification. Two cases will be considered:
   a) consequent memberships are unknown
   b) neither the premise nor the consequent memberships are known

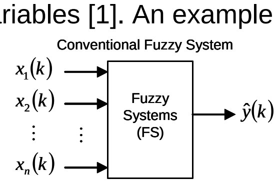
Scientific Metodology

A conventional fuzzy model with one output is presented as a collection of fuzzy rules in the following form (for example, Mamdani fuzzy model [1])

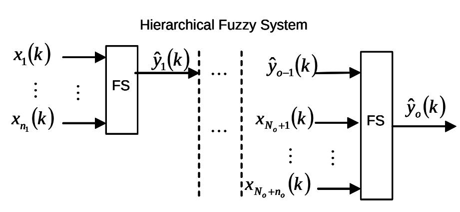
$$\mathrm{R}^i : \text{IF } x_1 \text{ is } A_1^i \text{ and} \cdots \text{and } x_n \text{ is } A_n^i \text{ THEN } \hat{y}_1 \text{ is } B^i$$

We use $l \quad (i = 1, 2, \cdots, l)$ fuzzy IF-THEN rules to perform a mapping from an input linguistic vector $X = [x_1, \cdots, x_n] \in \Re^n$ to an output linguistic $\hat{y}$. $A_1^i, \cdots, A_n^i$ and B^i are standard fuzzy sets. Each input variable $x_j (j = 1, 2, \ldots, n)$ has l_j fuzzy sets. In the case of full connection, $l = l_1 \times l_2 \times \cdots l_n$.

In order to design a conventional fuzzy system (see figure f0.a) with a required accuracy, the number of rules has to increase exponentially with the number of input variables to the fuzzy system. Consider n input variables and m fuzzy sets for each input variable, then the number of rules in the fuzzy system is m^n . When n is large, the number of rules is a huge number. A serious problem facing fuzzy system applications is how to deal with this rule explosion problem. One approach to deal with this difficulty is use hierarchical fuzzy systems. This kind of systems have the nice property that the number of rules needed to construct the fuzzy system increases only *linearly* with the number of variables [1]. An example is shown in the following figure.



(a)



(b)

- The idea of the hierarchical fuzzy systems [2] is to put the inputs variables into a collection of low-dimensional fuzzy systems. Each low-dimensional fuzzy system constitutes a level of this kind of systems.

For n input variables $x_1, x_2, \ldots, x_n$ with M_1 rules in each level

For conventional fuzzy systems, we know from [1], by using product inference, center-average and singleton fuzzifier, the output of the fuzzy logic system can be expressed as

$$\hat{y} = \frac{\sum_{i=1}^{l} w^i \left[\prod_{j=1}^{n} \mu_{A_j^i}\left(x_j\right) \right]}{\sum_{i=1}^{l} \left[\prod_{j=1}^{n} \mu_{A_j^i}\left(x_j\right) \right]} = \sum_{i=1}^{l} w^i \phi^i$$

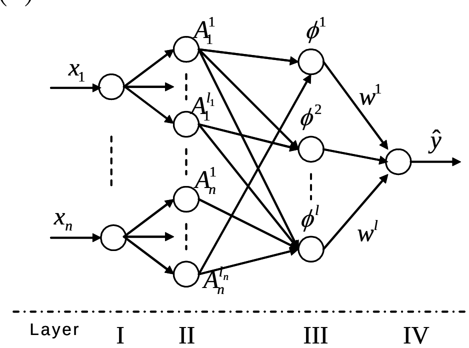
where $\mu_{A_j^i}$ is the membership functions of the fuzzy sets A_j^i, w_i is the point at which $\mu_{B_1^i} = 1$. If we define

$$\phi^i = \prod_{j=1}^{n} \mu_{A_j^i}\left(x_j\right) / \sum_{i=1}^{l} \prod_{j=1}^{n} \mu_{A_j^i}\left(x_j\right)$$

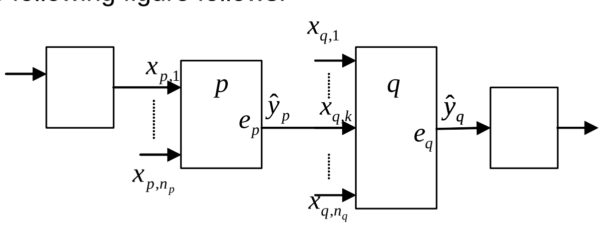
it can be expressed in vector form

$$\hat{y}(k) = W(k)\Phi\left[X(k)\right]$$

where parameter $W(k) = \left[w^1 \quad \cdots \quad w^l\right] \in R^{1\times l}$, data vector $\Phi\left[X(k)\right] = \left[\phi^1 \quad \cdots \quad \phi^l\right]^T \in R^{l\times 1}$. The structure of the fuzzy neural system is shown in Fig.f00. This four layers fuzzy neural networks was discussed in many papers [3]. Each node of layer II represent the value of the membership function of the linguistic variable. Nodes at layer III represent fuzzy rules. Layer IV is the output layer, the links between layer III and layer IV are full connected by the weight vector $W(k)$.



In general case is shown in the following figure follows:



Hierarchical neuro-fuzzy identification can be classified into two groups:

- Fuzzy logic-based hierarchical neural network models: the structure is hierarchical neural networks, but the activation function in some hidden layers are logic functions (AND, OR, XOR), this kind of hierarchical neuro-fuzzy system can identify knowledge and norma nonlinear systems. Stable identification can be studied in two ways:
  - Transform the fuzzy activation into approximated continuous functions. We may apply stability analysis techniques of multimodel neural networks into it.
  - Transform hierarchical neuro-fuzzy system into Takagi-Sugeno models, *i.e.*, several linear local models in neural networks. Then use standard analysis technique.
- Hierarchical Neuro-Fuzzy Network systems. The main structure is fuzzy system, but membership function and rules can be learned via multimodel neural networks. We may combine stable hierarchical fuzzy identification and stable neuro learning approaches.

Feasibility

Teamwork

1) Northeastern University, China
2) CINVESTAV-IPN, Mexico

Laboratories and Equipment:

This project will be executed in the Department of Automatic Control of CINVESTAV and the Department of Information Engineering, Northeastern University, where three laboratories and various types of computers, workstations, operation systems, software and networks can be utilized freely.

Human resource:

1) Dr.Huaguang Zhang has worked on neural networks and fuzzy system for more than 15 years. He has published many excellent papers on these fields. He is working on modelling the forces in a prototype electrostatic conveyor, modelling and control of blimps, modelling of power system faults using neural networks. These can give great help on our project "Hierarchical fuzzy neural networks for nonlinear system identification"
2) Dr. Wen Yu has worked on neural network control and nonlinear system theory for more than 10 years, he has already got some results on neural networks and fuzzy system. This project is also an extend of his privious works.
3) Both Dr. Wen Yu and Dr. Huaguang Zhang are Chinese, they knew each other for a long time ago. Since 2003 we began to cooperate. We have published several papers together in international journals and conferences
4) Dr. Wen Yu and Dr. Huaguang Zhang have met several times in China to discuss some problems of system identification and nonlinear control.

Plan of the work

The project is planed to be realized in 2 years. The activities will be:

1) The two researchers will collect publications about hierarchical fuzzy systems, fuzzy neural networks for identification in their own institute independently.
2) Dr. Wen Yu will visit Dr. Huaguang Zhang in Northeastern University. Within the first, they will write 1-3 papers for international journals.
   a) The first year: Structure design
   b) The second year 1: Stability proof
   c) The second year 2: technical report, perpare some papers

Expected Results

- Two international journal publications and three international conference publications.
- Hierarchical Neuro-Fuzzy Network (HNFN) software package.