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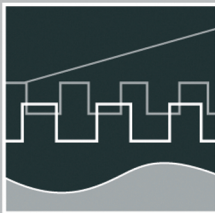
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COMPUTER SCIENCE MEETS AUTOMATION

VOLUME I

Session 1 - Systems Engineering and Intelligent Systems

Session 2 - Advances in Control Theory and Control Engineering

**Session 3 - Optimisation and Management of Complex
Systems and Networked Systems**

Session 4 - Intelligent Vehicles and Mobile Systems

Session 5 - Robotics and Motion Systems



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Preface

Dear Participants,

Confronted with the ever-increasing complexity of technical processes and the growing demands on their efficiency, security and flexibility, the scientific world needs to establish new methods of engineering design and new methods of systems operation. The factors likely to affect the design of the smart systems of the future will doubtless include the following:

- As computational costs decrease, it will be possible to apply more complex algorithms, even in real time. These algorithms will take into account system nonlinearities or provide online optimisation of the system's performance.
- New fields of application will be addressed. Interest is now being expressed, beyond that in "classical" technical systems and processes, in environmental systems or medical and bioengineering applications.
- The boundaries between software and hardware design are being eroded. New design methods will include co-design of software and hardware and even of sensor and actuator components.
- Automation will not only replace human operators but will assist, support and supervise humans so that their work is safe and even more effective.
- Networked systems or swarms will be crucial, requiring improvement of the communication within them and study of how their behaviour can be made globally consistent.
- The issues of security and safety, not only during the operation of systems but also in the course of their design, will continue to increase in importance.

The title "Computer Science meets Automation", borne by the 52nd International Scientific Colloquium (IWK) at the Technische Universität Ilmenau, Germany, expresses the desire of scientists and engineers to rise to these challenges, cooperating closely on innovative methods in the two disciplines of computer science and automation.

The IWK has a long tradition going back as far as 1953. In the years before 1989, a major function of the colloquium was to bring together scientists from both sides of the Iron Curtain. Naturally, bonds were also deepened between the countries from the East. Today, the objective of the colloquium is still to bring researchers together. They come from the eastern and western member states of the European Union, and, indeed, from all over the world. All who wish to share their ideas on the points where "Computer Science meets Automation" are addressed by this colloquium at the Technische Universität Ilmenau.

All the University's Faculties have joined forces to ensure that nothing is left out. Control engineering, information science, cybernetics, communication technology and systems engineering – for all of these and their applications (ranging from biological systems to heavy engineering), the issues are being covered.

Together with all the organizers I should like to thank you for your contributions to the conference, ensuring, as they do, a most interesting colloquium programme of an interdisciplinary nature.

I am looking forward to an inspiring colloquium. It promises to be a fine platform for you to present your research, to address new concepts and to meet colleagues in Ilmenau.



Professor Peter Scharff
Rector, TU Ilmenau



Professor Christoph Ament
Head of Organisation

Table of Contents

CONTENTS

	Page
1 Systems Engineering and Intelligent Systems	
A. Yu. Nedelina, W. Fengler DIPLAN: Distributed Planner for Decision Support Systems	3
O. Sokolov, M. Wagenknecht, U. Gocht Multiagent Intelligent Diagnostics of Arising Faults	9
V. Nissen Management Applications of Fuzzy Control	15
O. G. Rudenko, A. A. Bessonov, P. Otto A Method for Information Coding in CMAC Networks	21
Ye. Bodyanskiy, P. Otto, I. Pliss, N. Teslenko Nonlinear process identification and modeling using general regression neuro-fuzzy network	27
Ye. Bodyanskiy, Ye. Gorshkov, V. Kolodyazhniy, P. Otto Evolving Network Based on Double Neo-Fuzzy Neurons	35
Ch. Wachten, Ch. Ament, C. Müller, H. Reinecke Modeling of a Laser Tracker System with Galvanometer Scanner	41
K. Lüttkopf, M. Abel, B. Eylert Statistics of the truck activity on German Motorways	47
K. Meissner, H. Hensel A 3D process information display to visualize complex process conditions in the process industry	53
F.-F. Steege, C. Martin, H.-M. Groß Recent Advances in the Estimation of Pointing Poses on Monocular Images for Human-Robot Interaction	59
A. González, H. Fernlund, J. Ekblad After Action Review by Comparison – an Approach to Automatically Evaluating Trainee Performance in Training Exercise	65
R. Suzuki, N. Fujiki, Y. Taru, N. Kobayashi, E. P. Hofer Internal Model Control for Assistive Devices in Rehabilitation Technology	71
D. Sommer, M. Golz Feature Reduction for Microsleep Detection	77

F. Müller, A. Wenzel, J. Wernstedt A new strategy for on-line Monitoring and Competence Assignment to Driver and Vehicle	83
V. Borikov Linear Parameter-Oriented Model of Microplasma Process in Electrolyte Solutions	89
A. Avshalumov, G. Filaretov Detection and Analysis of Impulse Point Sequences on Correlated Disturbance Phone	95
H. Salzwedel Complex Systems Design Automation in the Presence of Bounded and Statistical Uncertainties	101
G. J. Nalepa, I. Wojnicki Filling the Semantic Gaps in Systems Engineering	107
R. Knauf Compiling Experience into Knowledge	113
R. Knauf, S. Tsuruta, Y. Sakurai Toward Knowledge Engineering with Didactic Knowledge	119
2 Advances in Control Theory and Control Engineering	
U. Konigorski, A. López Output Coupling by Dynamic Output Feedback	129
H. Toossian Shandiz, A. Hajipoor Chaos in the Fractional Order Chua System and its Control	135
O. Katernoga, V. Popov, A. Potapovich, G. Davydau Methods for Stability Analysis of Nonlinear Control Systems with Time Delay for Application in Automatic Devices	141
J. Zimmermann, O. Sawodny Modelling and Control of a X-Y-Fine-Positioning Table	145
A. Winkler, J. Suchý Position Based Force Control of an Industrial Manipulator	151
E. Arnold, J. Neupert, O. Sawodny, K. Schneider Trajectory Tracking for Boom Cranes Based on Nonlinear Control and Optimal Trajectory Generation	157

K. Shaposhnikov, V. Astakhov The method of ortogonal projections in problems of the stationary magnetic field computation	165
J. Naumenko The computing of sinusoidal magnetic fields in presence of the surface with bounded conductivity	167
K. Bayramkulov, V. Astakhov The method of the boundary equations in problems of computing static and stationary fields on the topological graph	169
T. Kochubey, V. Astakhov The computation of magnetic field in the presence of ideal conductors using the Integral-differential equation of the first kind	171
M. Schneider, U. Lehmann, J. Krone, P. Langbein, Ch. Ament, P. Otto, U. Stark, J. Schrickel Artificial neural network for product-accompanied analysis and control	173
I. Jawish The Improvement of Traveling Responses of a Subway Train using Fuzzy Logic Techniques	179
Y. Gu, H. Su, J. Chu An Approach for Transforming Nonlinear System Modeled by the Feedforward Neural Networks to Discrete Uncertain Linear System	185
3 Optimisation and Management of Complex Systems and Networked Systems	
R. Franke, J. Doppelhammer Advanced model based control in the Industrial IT System 800xA	193
H. Gerbracht, P. Li, W. Hong An efficient optimization approach to optimal control of large-scale processes	199
T. N. Pham, B. Wutke Modifying the Bellman's dynamic programming to the solution of the discrete multi-criteria optimization problem under fuzziness in long-term planning	205
S. Ritter, P. Bretschneider Optimale Planung und Betriebsführung der Energieversorgung im liberalisierten Energiemarkt	211
P. Bretschneider, D. Westermann Intelligente Energiesysteme: Chancen und Potentiale von IuK-Technologien	217

Z. Lu, Y. Zhong, Yu. Wu, J. Wu WSReMS: A Novel WSDM-based System Resource Management Scheme	223
M. Heit, E. Jennenchen, V. Kruglyak, D. Westermann Simulation des Strommarktes unter Verwendung von Petrinetzen	229
O. Sauer, M. Ebel Engineering of production monitoring & control systems	237
C. Behn, K. Zimmermann Biologically inspired Locomotion Systems and Adaptive Control	245
J. W. Vervoorst, T. Kopfstedt Mission Planning for UAV Swarms	251
M. Kaufmann, G. Bretthauer Development and composition of control logic networks for distributed mechatronic systems in a heterogeneous architecture	257
T. Kopfstedt, J. W. Vervoorst Formation Control for Groups of Mobile Robots Using a Hierarchical Controller Structure	263
M. Abel, Th. Lohfelder Simulation of the Communication Behaviour of the German Toll System	269
P. Hilgers, Ch. Ament Control in Digital Sensor-Actuator-Networks	275
C. Saul, A. Mitschele-Thiel, A. Diab, M. Abd rabou Kalil A Survey of MAC Protocols in Wireless Sensor Networks	281
T. Rossbach, M. Götze, A. Schreiber, M. Eifart, W. Kattanek Wireless Sensor Networks at their Limits – Design Considerations and Prototype Experiments	287
Y. Zhong, J. Ma Ring Domain-Based Key Management in Wireless Sensor Network	293
V. Nissen Automatic Forecast Model Selection in SAP Business Information Warehouse under Noise Conditions	299
M. Kühn, F. Richter, H. Salzwedel Process simulation for significant efficiency gains in clinical departments – practical example of a cancer clinic	305

D. Westermann, M. Kratz, St. Kümmerling, P. Meyer Architektur eines Simulators für Energie-, Informations- und Kommunikationstechnologien	311
P. Moreno, D. Westermann, P. Müller, F. Büchner Einsatzoptimierung von dezentralen netzgekoppelten Stromerzeugungsanlagen (DEA) in Verteilnetzen durch Erhöhung des Automatisierungsgrades	317
M. Heit, S. Rozhenko, M. Kryvenka, D. Westermann Mathematische Bewertung von Engpass-Situationen in Transportnetzen elektrischer Energie mittels lastflussbasierter Auktion	331
M. Lemmel, M. Schnatmeyer RFID-Technology in Warehouse Logistics	339
V. Krugljak, M. Heit, D. Westermann Approaches for modelling power market: A Comparison.	345
St. Kümmerling, N. Döring, A. Friedemann, M. Kratz, D. Westermann Demand-Side-Management in Privathaushalten – Der eBox-Ansatz	351
 4 Intelligent Vehicles and Mobile Systems	
A. P. Aguiar, R. Ghabchelloo, A. Pascoal, C. Silvestre , F. Vanni Coordinated Path following of Multiple Marine Vehicles: Theoretical Issues and Practical Constraints	359
R. Engel, J. Kalwa Robust Relative Positioning of Multiple Underwater Vehicles	365
M. Jacobi, T. Pfützenreuter, T. Glotzbach, M. Schneider A 3D Simulation and Visualisation Environment for Unmanned Vehicles in Underwater Scenarios	371
M. Schneider, M. Eichhorn, T. Glotzbach, P. Otto A High-Level Simulator for heterogeneous marine vehicle teams under real constraints	377
A. Zangrilli, A. Picini Unmanned Marine Vehicles working in cooperation: market trends and technological requirements	383
T. Glotzbach, P. Otto, M. Schneider, M. Marinov A Concept for Team-Orientated Mission Planning and Formal Language Verification for Heterogeneous Unmanned Vehicles	389

M. A. Arredondo, A. Cormack SeeTrack: Situation Awareness Tool for Heterogeneous Vehicles	395
J. C. Ferreira, P. B. Maia, A. Lucia, A. I. Zapaniotis Virtual Prototyping of an Innovative Urban Vehicle	401
A. Wenzel, A. Gehr, T. Glotzbach, F. Müller Superfour-in: An all-terrain wheelchair with monitoring possibilities to enhance the life quality of people with walking disability	407
Th. Krause, P. Protzel Verteiltes, dynamisches Antriebssystem zur Steuerung eines Luftschiffes	413
T. Behrmann, M. Lemmel Vehicle with pure electric hybrid energy storage system	419
Ch. Schröter, M. Höchemer, H.-M. Groß A Particle Filter for the Dynamic Window Approach to Mobile Robot Control	425
M. Schenderlein, K. Debes, A. Koenig, H.-M. Groß Appearance-based Visual Localisation in Outdoor Environments with an Omnidirectional Camera	431
G. Al Zeer, A. Nabout, B. Tibken Hindernsvermeidung für Mobile Roboter mittels Ausweichecken	437
5 Robotics and Motion Systems	
Ch. Schröter, H.-M. Groß Efficient Gridmaps for SLAM with Rao-Blackwellized Particle Filters	445
St. Müller, A. Scheidig, A. Ober, H.-M. Groß Making Mobile Robots Smarter by Probabilistic User Modeling and Tracking	451
A. Swerdlow, T. Machmer, K. Kroschel, A. Laubenheimer, S. Richter Opto-acoustical Scene Analysis for a Humanoid Robot	457
A. Ahranovich, S. Karpovich, K. Zimmermann Multicoordinate Positioning System Design and Simulation	463
A. Balkovoy, V. Cacenkin, G. Slivinskaia Statical and dynamical accuracy of direct drive servo systems	469
Y. Litvinov, S. Karpovich, A. Ahranovich The 6-DOF Spatial Parallel Mechanism Control System Computer Simulation	477

V. Lysenko, W. Mintchenya, K. Zimmermann 483
Minimization of the number of actuators in legged robots using
biological objects

J. Kroneis, T. Gastauer, S. Liu, B. Sauer 489
Flexible modeling and vibration analysis of a parallel robot with
numerical and analytical methods for the purpose of active vibration damping

A. Amthor, T. Hausotte, G. Jäger, P. Li 495
Friction Modeling on Nanometerscale and Experimental Verification

Paper submitted after copy deadline

2 Advances in Control Theory and Control Engineering

V. Piwek, B. Kuhfuss, S. Allers 503
Feed drivers – Synchronized Motion is leading to a process optimization

Y. Gu / H. Su / J. Chu

An Approach for Transforming Nonlinear System Modeled by the Feedforward Neural Networks to Discrete Uncertain Linear System

ABSTRACT

In this paper, an approach for transforming a state-space or input-output representation nonlinear system modeled by feedforward NN to a discrete uncertain linear system is presented. First, The dynamics of the feedforward NN model are represented by linear difference inclusions (LDI's). Then, the LDI's are interpreted as discrete linear system with norm-bounded or polytopic time-varying uncertainties. Finally, we use some simulation results of a typical continuous stirred tank reactor (CSTR) to elaborate on the details of the above approach.

1. Introduction

Nonlinear system modeling and control is still an open problem now. Though nonlinear system modeling based on Neural Networks (NN) has made a great progress in recent years, the nonlinear controller synthesis for nonlinear system modeled by NN is still hard to be realized online due to the heavy computational burden and the difficulty in convergence. As a result, the most practical strategies recently are to linearize the involved NN model in the model based controller synthesis. In most cases, the uncertainties caused by linearization could not be neglected. Otherwise, the stability and performance characteristics of the nonlinear control system are not easy to be assessed. In the last few years, the research on robust stability and performance of linear systems with norm-bounded or polytopic uncertainties have achieved a lot^[1]. So we want to build a bridge between the NN model and the uncertain linear system to integrate the nonlinear system control with NN into robust control^{[2],[3]}. In this paper, a bridge between the feedforward NN and linear systems with norm-bounded or polytopic uncertainties is proposed.

2. Preliminaries

Usually, discrete nonlinear system could be described as state-space form or input-output form:

State-space form:

$$\begin{aligned} x(k) &= f[x(k-1), u(k-1)] \\ y(k) &= Cx(k) \end{aligned} \quad (2.1)$$

Input-output form:

$$y(k) = g[y(k-1), \dots, y(k-n), u(k-1), \dots, u(k-n)] \quad (2.2)$$

where f and g are nonlinear functions. f and g could be modeled by the Feedforward Neural Networks(FNN), which is sufficient to uniformly approximate arbitrary nonlinear mapping.

And, we describe some specific families of LDI's that we often encounter in robust control study:

Norm-bounded LDI's:

$$x(k+1) = (A_0 + \Delta A)x(k) + (B_0 + \Delta B)u(k) \quad (2.3)$$

$$y(k) = Cx(k)$$

$$[\Delta A \quad \Delta B] = DF(k)[E_1 \quad E_2] \quad (2.4)$$

where $\Delta A \in R^{n \times n}$ and $\Delta B \in R^{n \times m}$ represent time-varying parameter uncertainties in the system model. $D \in R^{n \times r}$, $E_1 \in R^{l \times n}$ and $E_2 \in R^{l \times m}$ are known real constant matrices. $F(k)$ is an unknown time varying matrix, satisfying

$$N = \{F(k) \in R^{r \times l} : F^T(k)F(k) \leq I\} \quad (2.5)$$

Polytopic LDI's:

$$x(k+1) = A(k)x(k) + B(k)u(k)$$

$$y(k) = Cx(k) \quad (2.6)$$

$$[A(k) \quad B(k)] \in \Omega$$

where Ω is polytope, $\Omega = Co\{[A_1 \quad B_1], [A_2 \quad B_2], \dots, [A_L \quad B_L]\}$ where Co devotes to the convex hull.

According to a simple extension from [1], there are two corollaries as the following:

Corollary 2.1 State-space form (2.1) could be described as the uncertain linear system as follows:

$$\begin{aligned} \bar{x}(k) &= A(k)\bar{x}(k-1) + B(k)\bar{u}(k-1) \\ y(k) &= Cx(k) \end{aligned} \quad (2.7)$$

$$[A(k) \quad B(k)] \in Co\left[\frac{\partial f}{\partial x(k-1)}, \frac{\partial f}{\partial u(k-1)}\right] \quad (2.8)$$

where, $\bar{x}(k) = x(k) - \tilde{x}(k)$, $\bar{u}(k) = u(k) - \tilde{u}(k)$. $[\tilde{x}(k) \quad \tilde{u}(k)]^T$ could be a known equilibrium trajectory.

Corollary 2.2 For input-output form (2.2), denote

$$p(k) = [y(k-1), \dots, y(k-n), u(k-1), \dots, u(k-n)]$$

then (2.2) could be described as the uncertain linear system as follows:

$$\bar{y}(k) = H(k)\bar{p}^T(k) \quad (2.9)$$

$$H(k) \in Co \left[\frac{\partial g}{\partial y(k-1)}, \dots, \frac{\partial g}{\partial y(k-n)}, \frac{\partial g}{\partial u(k-1)}, \dots, \frac{\partial g}{\partial u(k-n)} \right] \quad (2.10)$$

where $\bar{y}(k) = y(k) - \tilde{y}(k)$, $\bar{p}(k) = p(k) - \tilde{p}(k)$. $[\tilde{y}(k) \ \tilde{p}(k)]^T$ could be a known equilibrium trajectory.

Since most robust control theory focus on state-space model, we now consider the state-space observer realization of (2.9):

$$\begin{aligned} x(k+1) &= A(k)x(k) + B(k)\bar{u}(k) \\ \bar{y}(k) &= Cx(k) \end{aligned} \quad (2.11)$$

$$A(k) = \begin{bmatrix} 0 & \dots & 0 & A_n(k) \\ I & \dots & 0 & A_{n-1}(k) \\ \vdots & \ddots & \vdots & \vdots \\ 0 & \dots & I & A_1(k) \end{bmatrix} \quad B(k) = \begin{bmatrix} B_n(k) \\ B_{n-1}(k) \\ \vdots \\ B_1(k) \end{bmatrix} \quad (2.12)$$

$$C = [0 \ 0 \ \dots \ I]$$

$$\text{where, } A_i(k) = \frac{\partial g}{\partial y(k-i)}, \quad B_i(k) = \frac{\partial g}{\partial u(k-i)}$$

3. Transforming FNN to Discrete Uncertain Linear System

In this section, we discuss the problem of the formulation for transforming weights of FNN to parameter matrices of norm-bounded uncertain linear system and vertexes of polytopic uncertain linear system. The active function in the neuron of FNN is Tansig function. The output value of Tansig function is bounded in (-1,1).

3.1 Norm-bounded Uncertainties

3.1.1 System(2.1) modeled by a single hidden layer FNN

Consider the nonlinear function f in system(2.1), which is modeled by a single hidden layer FNN. The Jacobian matrix of the FNN is as the following:

$$J = \begin{bmatrix} \frac{\partial f}{\partial x(k-1)} & \frac{\partial f}{\partial u(k-1)} \end{bmatrix} = W_2 \times \text{diag}(1 - a \times a) \times W_1 \quad (3.1)$$

where $a = f(W_1 \times p + B_1)$, is output vector of the hidden layer, \times represent the array multiplication. $\text{diag}(a_{s \times 1})$ denotes a square diagonal matrix with $a(1), \dots, a(s)$ on the main diagonal. W_1 is the matrix of connecting weights between the input-layer and the hidden-layer, W_2 is that between the hidden-layer and the output-layer.

According to Corollary 2.1, system (2.1) could be transformed to (2.7). Hence,

$$[A(k) \ B(k)] = W_2 \times \text{diag}(1 - a \times a) \times W_1 \quad (3.2)$$

Then system (2.1) could be further transformed to (2.3). The nominal model is the linearization model on an equilibrium.

$$[A_0 \quad B_0] = W_2 \times \text{diag}(1 - a_0 \times a_0) \times W_1 \quad (3.3)$$

The uncertainties are as the following:

$$[\Delta A(k) \quad \Delta B(k)] = W_2 \times \text{diag}(a_0 \times a_0 - a \times a) \times W_1 \quad (3.4)$$

$$D = W_2, \quad [E_1 \quad E_2] = W_1, \quad F(k) = \text{diag}(a_0 \times a_0 - a \times a) \quad (3.5)$$

And the value of each element in the diagonal matrix $F(k)$ is in $(-1, 1)$, so obviously the norm-bounded condition (2.5) is satisfied.

3.1.2 System(2.2) modeled by a single hidden layer FNN

Consider the nonlinear function g in system(2.2), which is modeled by a single hidden layer FNN with the input vector $p(k) = [y(k-n), \dots, y(k-1), u(k-n), \dots, u(k-1)]$.

According to Corollary 2.2, system (2.2) could be transformed to (2.9), and further transformed to state-space model (2.11), (2.12) . Then we have,

$$[A_n(k), \dots, A_1(k), B_n(k), \dots, B_1(k)] = W_2 \times \text{diag}(1 - a \times a) \times W_1 \quad (3.6)$$

We get W_1 partitioned with appropriate dimensions, and substituted the partitioned W_1 in (2.12) to get:

$$A(k) = \begin{bmatrix} 0 & \dots & 0 \\ I & \dots & 0 & W_{1A}^T \times \text{diag}(1 - a \times a) \times W_2^T \\ \vdots & \ddots & \vdots \\ 0 & \dots & I \end{bmatrix} \quad (3.7)$$

$$B(k) = W_{1B}^T \times \text{diag}(1 - a \times a) \times W_2^T \quad (3.8)$$

The nominal model could be set to the linearization model on one equilibrium.

Then (3.7),(3.8) could be transformed to(2.3),(2.4):

$$A_0 = \begin{bmatrix} 0 & \dots & 0 \\ I & \dots & 0 & W_{1A}^T \times \text{diag}(1 - a^0 \times a^0) \times W_2^T \\ \vdots & \ddots & \vdots \\ 0 & \dots & I \end{bmatrix} \quad (3.9)$$

$$B_0 = W_{1B}^T \times \text{diag}(1 - a^0 \times a^0) \times W_2^T \quad (3.10)$$

$$[\Delta A(k) \quad \Delta B(k)] = DF(k)[E_1 \quad E_2] \quad (3.11)$$

$$\text{where } F(k) = \begin{bmatrix} F_A(k) \\ F_B(k) \end{bmatrix}, \quad D = [D_A \quad D_B], \quad E_1 = \begin{bmatrix} E_A \\ 0 \end{bmatrix}, \quad E_2 = \begin{bmatrix} 0 \\ E_B \end{bmatrix} \quad (3.12)$$

$$D_A = W_{1A}^T, \quad D_B = W_{1B}^T, \quad F_A(k) = F_B(k) = \text{diag}(a^0 \times a^0 - a \times a), \quad (3.13)$$

$$E_A = \begin{bmatrix} 0 & \cdots & 0 \\ 0 & \cdots & 0 & W_2^T \\ \vdots & \ddots & \vdots \\ 0 & \cdots & 0 \end{bmatrix}, E_B = W_2^T \quad (3.14)$$

Since the output value of Tansig function in hidden neuron is in $(-1,1)$, so obviously $F^T(k)F(k) < I$ is satisfied.

3.2 Polytopic Uncertainties

The above norm-bounded LDI's are all diagonal norm-bounded LDI with an uncertain diagonal matrix $F(k)$. And the diagonal norm-bounded uncertainties could be described as polytopic uncertainties^[1]. The vetexes are the linear nominal models when the elements of $F(k)$ take their extreme value. The number of the vetexes is obtained according to permutation and combination. There are two corollaries as the following:

Corollary 3.1 The nonlinear system modeled by a single hidden-layer feedforward NN could be represented by a polytopic uncertain system with 2^s vetexes at most, where s is the number of nodes of the hidden-layer.

Corollary 3.2 The nonlinear system modeled by a double hidden-layers feedforward NN could be represented by a polytopic uncertain system with $2^{s+t} - 2^s - 2^t + 2$ vetexes at most, where s is the number of nodes of the first hidden-layer, and t is that of the second one.

4. An Example

Let's consider a typical CSTR process^[4] now. The single hidden layer FNN for modelling the CSTR is first identified by the input-output data. The topology structure of the FNN is 3-4-2.

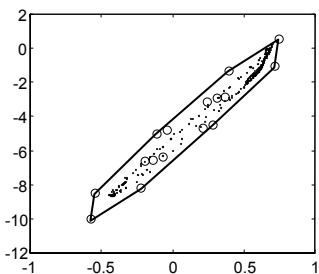


Fig. 4.1 a_{11} and a_{21} of $A(k)$

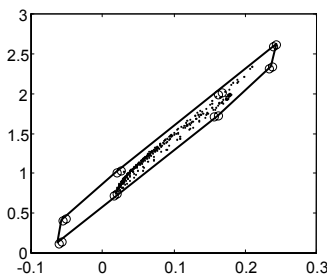


Fig.4.2 a_{12} and a_{22} of $A(k)$

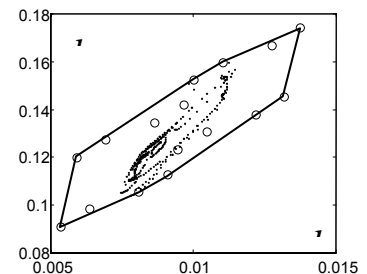


Fig. 4.3 b_1 and b_2 of $B(k)$

Then, the FNN could be transformed to an uncertain linear system (3.2)~(3.5). where $A(k) \in R^{2 \times 2}$, $B(k) \in R^{2 \times 1}$, and the equilibrium is selected as the middle unstable equilibrium(0.447, 2.751, 0). We group every two elements of the matrices $A(k), B(k)$

and project the uncertainties of the elements to the Fig. 4.1~4.3. The dots in the figures are obtained by the equations (3.3) on every input-output sampling data. According to Corollary 3.1, the polytopic uncertain system has $2^4 = 16$ vertices at most. The circles in the figures are the potential vertices.

5. Conclusion

Based on the above work, the robust control strategies could be applied to the nonlinear controller synthesis incorporating the feedforward NN model. And, the robust stability and robust performance of the corresponding nonlinear control system is convenient to be assessed. Then a systematic procedure for nonlinear process control could be provided with our contribution. We could firstly model the real process with the feedforward NN model just based on the input and output data. Secondly, the resulted NN would be transformed to uncertain linear system with the approach in this paper. Thirdly, many robust control strategies could be attempted to analyse and synthesis the uncertain linear system. Finally, the derived controller is applied to the real process with some anticipative stability and performance. It is noted that uncertain linear system is always conservative compared with the feedforward NN. The conservatism has direct impact on the successful implementation of this procedure. Then how to reduce the conservatism in this procedure will be further studied in the future.

References

- [1] Boyd, S. et al. 1994. Linear Matrix Inequalities in systems and control theory. SIAM.
- [2] Tanaka, K. 1996. An Approach to Stability Criteria of Neural Network Control Systems. IEEE Trans. on Neural Networks, 7(3): 629-642.
- [3] Limanond, S. and Si, J. 1998. Neural Network-Based Control Design: An LMI Approach. Proceeding of ACC, Philadelphia, Pennsylvania, June, 970-974.
- [4] Uppal, A., Ray, W.H. and Poore, A.B. 1974. On the Dynamic Behavior of Continuous Stirred Tank Reactors. Chem. Eng. Sci. Vol.29: 967-985.

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