INTELLIGENT CONTROL AND SUPERVISION AT CENTRO DE INFORMÁTICA E SISTEMAS DA UNIVERSIDADE DE COIMBRA

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Abstract. The CISUC- Centro de Informática e Sistemas da Universidade de Coimbra is a research center founded by the Portuguese Ministry of Science and Technology, developing research in the fields of Computer Science and Engineering. The Automation and Control Group develops actually research activities concerning Intelligent Control and Supervision that are briefly presented in this paper. The research focuses on the three common levels in industrial control in complex systems framework: real-time control (the main concern is on-line learning tasks), supervision and diagnosis (analog fault detection and prevention), coordination and management (production and energy optimization, global optimization).

1. Introduction

Important limitations of Intelligent Control architectures still remain to be solved. The on-line learning tasks are limited by dimensional problem of Neural Networks (NN) (Yingwei and coll.,1997). Recurrent Neural Networks (RNN) have the advantage to allow to built control structures mixing NN (for nonlinear tasks) with control methods issued from linear systems; however the memory size of the RNN is fixed by construction; this is a limitation when the controlled process has time-varying dynamics, a current situation in industrial conditions. Self (re)configuration of fuzzy systems and controllers is still a very active domain (Lin and Kan (1998)). Neuro-fuzzy structures, for modeling, prediction and control can be made by a big variety of architectures and funcionalities, but when the process is of high order, the computational complexity remains unsolved. Research of bridges among the several paradigms of modeling and automatic control (Tanaka and coll. (1997) , Ma and coll. (1998), Heister (1999)) is very important, in order to converge to a unified theory of systems and control. The work being developed is intended to give a contribution to the solution of these problems, through the following projects:

A) To develop and generalize a neuro-fuzzy architecture with variable dynamic memory and its corresponding learning (training) algorithms, to be used as a predictor in industrial processes.
B) To develop intelligent adaptive controllers in a neuro - fuzzy framework, exploiting the structural similarity between Radial Basis Function Neural Networks and fuzzy systems for constructive transparent methods. One main objective is to maintain the dimension of the neuro-fuzzy system compatible with its practical use; other is to obtain nonlinear parametric models with dynamic (time changing) memory. It may also allow to combine linguistic fuzzy rules (pre-existent knowledge) and numerical data and achieve transparency of models.
C) To develop mixed control structures for nonlinear systems, where some parts are based on neural networks (to take account of nonlinearities) and other parts are based on conventional control techniques and their theoretical analysis for convergence and robustness. Conditions for robust stability of the recurrent network training will be investigated. It is intended to find and explore some ways to use the classical linear control techniques (pole placement, optimal control, multivariable decoupling control, etc.) in a nonlinear context, where the nonlinearities are managed by neuro and neuro-fuzzy systems. Another approach to be exploited is the constrained non-linear model predictive control with neural networks as the modeling tool, with on-line learning, stability and robustness studies.

Concerning supervision and diagnosis, application of soft-computing to the development of a robust control system, with fault tolerance is the main objective. The control system will have to be constituted mainly by the following modules: a Residual Generator, a Supervision Sub-system and a Knowledge based Sub-system and should allow to detect, identify, classify different types of faults (in sensors, actuators or in the plant parameters), to generate performance signals (man-machine interface, alarms, ...) and to allow to control the plant with an acceptable performance in presence of faults. Particularly, the control system should detect and distinguish either abrupt faults either incipient faults (soft faults). In this situation, the system must be able to diagnose incipient faults before they are manifested as problems requiring either human operator or automatic system intervention. Prompt indication of incipient faults can give enough information to the control system and time to take decisive actions to prevent any serious failure in the system.

For coordination and management the main issue is to develop effective decision support systems for production and energy management in industrial complexes. This involves the solution of ill-structured large-scale optimization problems. Genetic algorithms are being used for that, with an effort to reduce the computational time and to look for in hybrid optimization structures integrating several approaches to the problem.

In the following paragraphs some more details are given about some of these projects.

2. Recurrent Neural Networks for Modelling and Control of Non-linear Systems

In the last few years several works have shown and emphasise that recurrent neural networks are quite effective in modelling either linear or non-linear dynamical systems [Jin, 1995]. The critical issues in this purpose are not only the choice of specific network architecture and the number of neurones, but also the type of neurones, the location of feedback loops and, most of all, the development of a suitable and fast training algorithm in order to enable on-line identification.

The work that has been carried out in regards the neural modeling takes advantage of recurrent Elman networks together with the truncated back-propagation through time algorithm for learning [Williams, 95].

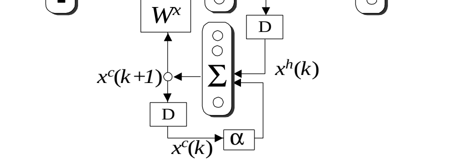

Figure 1 – Elman network.

Considering the neural model of the plant several control strategies have been developed and applied. One of these strategies consists in the design of a standard pole placement controller and internal model controller using a linear description of the plant derived from the non-linear neural model. Another technique is a mixed structure involving the incorporation of the neural description either linear or non-linear within a predictive control framework. The sequence of control actions is computed on-line at each time step by solving an open loop optimization problem leading this way to a closed loop control technique.

Experimental results on several plants not merely demonstrate the viability of utilizing neural networks and on-line learning within a control framework but also, given their inherent adaptive features, they are a remarkable choice, particularly, for those systems having unmodelled dynamics.

Future work is devoted mainly to the improvement of learning methodologies in two particular research directions envisioning intelligent control techniques. In one research program it is intended to derive new training approaches using both the RLS and EKF methods. Another direction consists in the incorporation of additional knowledge stemming from the first principle modeling into the neural model.

3. Neuro-Fuzzy modeling and prediction

In this work, several fuzzy structures are analyzed, namely Takagi-Sugeno systems and linguistic systems. Two major concerns of fuzzy identification are studied: structure learning and parameter learning. Referring to the first item, clustering techniques receive a deeper attention, especially subtractive clustering. Still in the same point, the questions related to relevant input selection are addressed. As for parameter learning, this task is carried out after the determination of a structure, based on the training of a fuzzy neural network via error backpropagation. In some situations, hybrid learning schemes are also utilized, which result from the combination of both linear and nonlinear optimization algorithms. In the point of parameter learning, the problem of online learning is also addressed.

A relevant matter in the context of fuzzy identification relates to the use of their potential in terms of model transparency. In this way, some studies are performed, regarding the construction of interpretable fuzzy models, which are based on similarity measures and restricted parameter learning.

4. Supervision for Robust Fault Tolerant Intelligent Control Systems

Many authors consider fault tolerance, as one of the characteristics of intelligent systems. For instance, according to Stengel (1991): "*By design or implementation, failure-tolerant control systems are* *intelligent systems*". Actually, modern control systems are becoming more and more complex and control algorithms more and more sophisticated. Consequently, the issues of availability, cost efficiency, reliability, operating safety and environmental protection are of major importance. These requirements are important to, not only normally accepted safety-critical systems, but also other advanced systems employed in many plants.

A fault tolerant control system should be designed to retain some portion of its control integrity in the event of a specified set of possible component faults or large changes on the system operating conditions that resemble these faults. This can only be done if the control system has built in an element of automatic reconfiguration, once a malfunction has been detected and isolated. Fault diagnosis plays an important rule in the fault-tolerant control, as before any control law reconfiguration is possible, the fault must be reliably detected, isolated and identified, and the information should be passed to a supervision module to make proper decision, as can be seen in Figure 2.

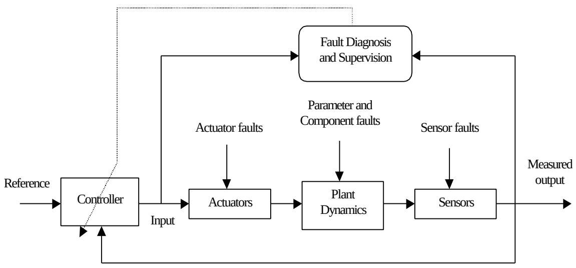

Figure 2: Fault Diagnosis, Supervision and Controller's Reconfiguration.

One of the most frequently used diagnosis method, is to monitor the level of a particular signal, using a mathematical model of the supervised system, and tacking action when the signal reach a given threshold. To overcome the difficulties introduced by modelling uncertainty, because a perfectly accurate and complete mathematical model of a physical system is never available, a model-based FDI has to be made robust, i.e. insensitive or even invariant to modelling uncertainty, noise or disturbances.

The model-based fault detection and isolation (FDI) considers the analytical redundancy inherent in the dynamic relationships between inputs and outputs of a system. Usually, a mathematical model is used to derive a residual quantity, which is supposed to be “small” for an unfaulty plant and “large” whenever a fault occurs. Faults could then be detected if the residual exceeds a given threshold. In order to achieve fault isolation, a number of residuals could be used, each one indicating a different fault. Recent surveys can be found for instance in (Frank, 1997), (Patton, 1997) and (Chen and Patton, 1999).

Robustness against disturbances, process uncertainty and modelling errors are an important subject in FDI research. Unsatisfactory diagnostic performance due to neglected interaction between the controller and the FDI module should be avoid. To overcome this problem, an integrated approach using the robust control formulation can be used, where the controller and the model-based fault detection filter are designed simultaneously.

This methodology has been studied and implemented in our laboratory plants as the Inverted Pendulum or the Three-Tank-System.

Future work consists mainly on the supervisor design using techniques based on soft-computing methodologies in order to obtain an efficiently and robust isolation and identification of either abrupt or incipient faults. The reconfiguration issue is other aspect to be considered and developed in the supervisor framework.

5. Some recent publications of the group

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Conclusions

This paper describes some of the research activities concerning intelligent systems and control developed at the CISUC. They are intended to give a contribution particularly in on-line learning and adaptation and oriented towards industrial applications. The purpose of this paper is to create opportunities for scientific and technical cooperation, stressing the needs for experience exchange with other groups and laboratories at international level.

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