# POSSIBILITY OF USING NEURAL NETWORK BASED IDENTIFICATION IN ADAPTIVE CONTROLLERS

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## ABSTRACT

This paper deals with possibility of a neural network identification applicable in adaptive (self-tuning) controllers. The reason is a long sample time necessary for a proper function of the classical identification methods (recursive least square especially) that results improper behaviour of the whole control system. Typical neural networks used to process modelling and applicable in this adaptive control are introduced. Regular identification requirements are discussed. Properties and special cases of the various neural types are introduced. The most extended neural networks are compared in conclusion.

## 1 INTRODUCTION

Many industrial processes are nonlinear systems which parameters vary with time and operating conditions. Suitable designed controller sufficient to align with these changes is necessary.

Adaptive controller with continuous modification of its parameters is discussed in this paper. The process model (ARX) is estimated of actual process inputs and outputs and its parameters are then made use of updating the controller parameters and controller action. The model and controller parameters are updated in every sample time.

Although the world research gives attention to these adaptive controllers the distribution in the practice fails.

The process modelling is a general part of the self-tuning controller on which controller action depends. Therefore, it is necessary to choose a long sample time with respect to the identification part. The long sample time works as a disturbance and noise filter but it results insufficient control behaviour by disturbance cancelling and it introduces unintentional additional dynamics [1].

Classical identification methods based mainly on recursive least square method fail to resolve this problem. Hence it is appropriate to find new identification methods. This paper focuses on neural networks and on their usage by process modelling.

## 2 NEURAL NETWORK IDENTIFICATION

To the neural networks advantages fall their ability continuously change their properties to approximate nonlinear time-varying complex systems. The goal is their generalization property. The disadvantages of the neural networks are unpredictable results (they work as “black-boxes”), necessity to be learned (sufficient training sets must be chosen), the proper choice of the layer number, the number of neurons in a layer, of the learning rate, the transfer function…

The most commonly used network architectures for process modelling include the feedforward network, the radial basis function network and the autoassociative network. Advanced network architectures are the dynamic, fuzzy, recurrent and wavelet networks. Recent developments include stacked networks for improving model accuracy and robustness and for addressing the problem of limited training data.

The neural network used as an identification part of the self-tuning controller has to be able to estimate process parameters as

- linear ARX model: $$y(k) = \theta^{\mathrm{T}}(k)\varphi(k) + e_{\mathrm{s}}(k) \qquad (2.1)$$

where $\theta^{\mathrm{T}}(k) = [a_1 \ \ldots \ a_{\mathrm{na}} \ b_1 \ \ldots \ b_{\mathrm{nb}}]$ is the parameter vector, $\varphi^{T}(k) = [-y(k-1) \ \ldots \ -y(k-na) \ u(k-1) \ \ldots \ u(k-nb)]$ the regressor based on measured input-output signals up to time $k-1$ and $e_s(k)$ is unmeasured noise,

- nonlinear NARX model: $$y(k) = \mathrm{f}(\theta^{\mathrm{T}}(k), \varphi(k)) + e_{\mathrm{s}}(k) \qquad (2.2)$$

where f is generally nonlinear function.

In the linear case the controller is commonly designed assuming the ARX model to represent deterministic part of process model using the certainty equivalence principle. The NARX model cannot be divided in two separate parts as its linear counterpart (the ARX model). If the identified NARX model is used as a process model for controller design, one might get poor results.

More requirements are presented here:

- On-line training algorithm – the process varies its properties continuously
- Necessity a priori weight initialization – it’s the on-line training algorithm effect
- A fast, simple but robust and effective neural network

The types of neural network suitable for model identification and satisfactory are further presented.

## 3 TYPES OF NEURAL NETWORKS

### 3.1 LINEAR NEURON (ADALINE)

This neuron is similar to the perceptron but its transfer function is linear. Name ADALINE is given by Widrow and Hoff [2].

This neuron can be trained to find a linear approximation to a nonlinear function – the linear ARX model in this case.

A linear network cannot be made to perform a nonlinear computation. They use the LMS (Least Mean Squares) learning rule, which is much more powerful that the perceptron learning rule. The Widrow-Hoff learning rule can be used for this neural network [3].

## 3.2 FEEDFORWARD NEURAL NETWORKS

The feedforward neural network (the multilayer perceptron) is the most used and studied neural network architecture today. A number of papers has shown that a two-layered feedforward network has the ability to approximate any nonlinear continuous function by arbitrary degree of exactness, provided that the hidden layer contains sufficient neurons. The problem of determining the network weights is essentially a nonlinear optimisation task. A rich collection of different learning paradigms has been developed. The back-propagation method which is a distributed gradient descent technique is the most popular training algorithm.

These methods would normally be used for on-line training. For small and medium size networks with condition of enough memory, the Levenberg-Marquardt algorithm can be used. If memory is a problem, then there are a variety of other fast algorithms available. For large networks the Scaled Conjugate Gradient algorithm (the only conjugate gradient algorithm that requires no line search, it is very good general purpose training algorithm), the Recursive Error Backpropagation or the Recursive Prediction Error Method (this method is a variant of the recursive Gauss-Newton algorithm, more details Koivisto, Ruoppila and Koivo (1992)) are proposed [3, 4].

The benefits of these advanced methods are faster adaptation and better results. The methods are computationally heavier, mainly nonparallel and require some level of expertise to implement.

## 3.3 LOCAL NEURAL NETWORKS

A RBF neural network is the most popular member of the local neural networks. Such networks have 3 layers, the input layer, the hidden layer with the RBF nonlinearity and a linear output layer. A RBF is a function which has built on a distance criterion with respect to a centre. The most popular choice for the non-linearity is the Gaussian. The RBF networks construct a local approximation of multi-input multi-output function analogous to fitting least squares splines through a set of data points using basis functions. The RBF networks have the advantage of not being locked into local minima as do the feedforward networks.

Special type of the RBF networks is a RBF-ARX network whose idea is that the modeling problem of smooth nonlinear systems that can be linearized for small excitations around all possible operating points without resorting to on-line parameter estimation. A global NARX model (RBF-ARX model) has a basic structure of the linear ARX model and whose coefficients are composed of signal-dependent sets of Gaussian radial basis function is proposed to characterize the systems. The highlight of the RBX-ARX model is the advancing of an efficient nonlinear optimization method for the parameter estimation. Case studies on a nonlinear chemical reaction process and a nonlinear electroencephalogram (EEG) time series show that the RBF-ARX model estimated by using the proposed optimization algorithm in [5] has much better performance than general the Hammerstein model or the RBF neural network.

The Rectangular Local Linear Model (RLLM) networks belong to this group and they can be made to estimate process model. This approach is based on a principle of the approximation of a nonlinear function with piece-wise linear mappings. The RLLM is used to identify the plant as the NARX model. The construction of the RLLM involves three layers: the input layer, the hidden layer consists of local linear units that are connected directly with all of the neurons in the input layer and the linear output layer. The learning algorithm developed for online training of this network, in addition to determining the optimum number of local linear models in the hidden layer, estimates the parameters of each linear model using the Recursive Least Squares algorithm. Great advantage is that the learning algorithm can be started with any initial form of the lattice. More [6].

### 3.4 DYNAMIC NEURAL NETWORK

The feedforward network performs a nonlinear transformation of input data in order to approximate output data. This results in a static network structure. The most straightforward way to extend this essentially steady state mapping to the dynamic domain is to adopt an approach similar to that taken in the linear ARMA modelling. Past process inputs and outputs can be used to predict the present process outputs. Important characteristics such as system delays can be accommodated for by utilising only those process inputs beyond the dead time. Although perhaps the most concise network representation of a dynamic system is obtained by using network inputs comprising of past input and output data, the requirement to model processes over a wide dynamic range can result in large network structures leading to network training and convergence problems.

The recurrent Jordan or Elman neural network are the members of dynamic neural network [8].

## 4 CONCLUSIONS

Some reasons for finding the new identification methods for adaptive control were discussed. Several types of the neural networks applicable to the model estimation in adaptive control are introduced. A lot of principles and training method were derived. This paper focuses in the widely used neural networks.

Most extensive neural networks for modelling are the feedforward and the RBF neural network. A nonlinear global approximation scheme like the feedforward neural network is not the most suitable for adaptive purposes because the model is not linear as well the parameters. This makes the adaptation slower than in the linear case. There are also several precautions when applying recursive methods, like sensitivity to the initial weights and in the nonlinear case also sensitivity to the data presentation order which may lead to different local minimums. Furthermore, all the aspects and experience gained applying linear self-tuning control must be taken into account.

Local approximation (the RBF network) is an efficient method for low dimensional tasks (input vector dimension 1 to 3). For higher dimensional tasks several difficulties are encountered and the suitability depends heavily on the application [4].

Compared to the feedforward neural network, the RBF network is simpler for implementing, needs less computational memory, converges faster, and global minimum convergence is achieved even if operating conditions change [7].

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