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Technical Report Number 1787 January 1994

The block regularised parameter estimator and its parallel implementation*

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Abstract

Kulhavý's regularised parameter identification concept protects the adaptive recursive estimation of a linear regression model from numerical difficulties associated with standard exponential weighting in cases where the processed data is not sufficiently exciting. A parameter time updating model based on a modified quadratic cost function is used, thus enriching the conventional adaptive recursive least squares method by the general concept of regularisation.
This paper presents a block regularised parameter estimator, compatible with the requirements of implementation on a parallel architecture. Due to the accumulated regularisation in blocks the achieved throughput of estimator is an order of magnitude higher in comparison with the general framework of Kulhavý and it is only half as fast as the standard recursive least squares systolic array. The processing cells operate at almost 100 % efficiency and are only connected to their nearest neighbours by one–directional connections.

Keywords: Identification; least-squares estimation; adaptive systems; forgetting; recursive algorithms.

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Lattice Feedback Regularised Identification *

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Abstract

The paper describes a normalised parallel identification algorithm. This normalised recursive information filter allows a highly modular and numerically safe implementation of the recursive least square identification with a minimal latency. All normalised parameters and internal variables of the modular triangular array have the guaranteed range $[-1, 1]$. Consequently, a significant part of the algorithm is suitable for implementation on a fast, parallel, low-cost, fixed-point hardware, based on look-up memory tables.
The algorithm is equipped with a block regularisation. It avoids the eventual difficulties of the standard least squares algorithms caused by insufficient excitation.
The final specification of the regularisation method for the autoregression models attracts the parameter estimates to parameters with guaranteed stability. The stable parameters are generated periodically as the unit impulse response of a Linear Prediction Coding Lattice filter, driven by the normalised coefficients from the Ladder part of the array.

This is an extended version of the conference paper submitted for the IFAC SYSID 94, Copenhagen, Denmark.

Keywords: Recursive identification; regularisation; lattice; parallel algorithms; systolic array; stability; fixed point processors.

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The Block Regularised Linear Quadratic Optimal Controller*

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Abstract

In this paper we will show how a sample interval of $N * O(1)$ for the LQ adaptive controller may be achieved using a pipelined parallel implementation.
We will present:

- A novel adaptive parameter estimator, whose data sample speed is $O(1)$ and generates the parameter estimates for the controller with a speed of $O(n)$ on $O(n^2)$ processing elements.
- An LQ control designer, whose speed is $N * O(1)$ on $O(n^2)$ processing elements.
- A systolic implementation of the control action computation, generating the control signal with a speed of $O(1)$ on $O(n)$ processing elements.

* This work has been partially supported by the research grant No. 102/93/0897 of the Grant Agency of the Czech Republic: Systolic Arrays of Processors for Identification of Systems with Variable Structure

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Structure Determination and Tracking for Radial Basis Function based Nonlinear Networks*

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Abstract

The paper proposes the concept of an array for structural estimation of nonlinear systems modelled by Radial Basis Functions. The proposed systolic array incorporates estimation of different modes in parallel and provides an estimate of the probabilities of these models. The array can be interpreted as a neural network type architecture, based on the systolic square–root, recursive least–squares algorithm.

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Transputer Implementation of Block Regularized Filtering*

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Abstract

A novel approach to parallel transputer implementation of a regularised exponential parameter tracking is described.
The proposed block regularised exponential algorithm allows to define and automatically adjust mean value of an alternative covariance of the estimated parameters in the boundaries of blocks of processed data. The alternative mean tracks in blocks the current parameter estimates. That is why the influence of the regularisation on the parameter estimates is reduced, and the algorithm remains compatible with the completely pipelined parallel transputer implementation.

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The Cell Level Description of Systolic Block Regularised QR Filter

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Abstract

Adaptive recursive parameter estimation is a fundamental concept in control and signal processing. The standard regularisation of identification protects the square root adaptive recursive estimation from numerical difficulties (associated with not sufficiently exciting data). But an ad-hoc regularisation can affect the quality of estimation unpredictably.

This was one of the reasons why Kulhavý has proposed a generalised parameter tracking in. In his concept the standard exponential weighting method is extended by the addition of an alternative weighted quadratic term, enriching the conventional exponentially weighted RLS method by an general concept of regularisation.

This paper presents the detailed, cell-level description of a compacted systolic array implementation of the block regularised parameter estimator. The regularisation avoids the potential numerical problems, caused by overparametrisation or poor data, which can eventually affect the classical QR recursive least squares systolic arrays without regularisation. The array provides periodically the regression parameter estimates (weights). It is shown in detail, how to implement the QR type of the processing cells.

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In the presented array an additional column of processors realize a feedback associated with the periodical adjustment of the new position of the regularising cost function on the boundaries of blocks. This position follows (with delay) the current parameter estimates. The array is compatible with the pipelined implementation if the length of blocks is chosen at least equal to the number of identified parameters.

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Regularized Lattice-Ladder Adaptive Filter*

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Abstract

A novel regularised algorithm is presented for the adaptive recursive least-squares Ladder-Lattice prediction and filtering. The design of the filter is based on formulating the Lattice section as a special implementation of the factorised recursive least-squares algorithm, assuming the data and the parameter tracking method meet certain specific criteria.
The proposed estimator provides on a linear array of n processors a data throughput comparable with the triangular systolic implementation of the recursive square root information filters on $n(n-1)/2$ processors.
Unlike the standard Recursive Least Squares Lattice-Ladder algorithm the proposed regularised estimator parameter tracking technique can be interpreted as introduction of a set of forgetting factors tuned to control the character of the adaptation. The estimator reduces considerably the numerical problems related to overparametrisation or poor data.

Keywords: Identification; least-squares estimation; adaptive systems; forgetting; recursive algorithms

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Automatic Prior Design of LQG Adaptive Controllers

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Abstract

The results achieved in preparation of computer tools for the automatic commission of a multivariate LQG adaptive controller are reported, i.e. *unified theory* and a set of cooperating *algorithms* needed. The paper points out the general conception of the underlying practical project, refers to ready solutions of partial tasks and formulates the remaining problems to be solved.

Keywords: Multivariate LQG adaptive control

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Bayesian Pooling of Expert Opinions

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Abstract

The quantification and exploitation of prior knowledge in control design becomes important for improving control efficiency. The paper presents results gained in extracting the common knowledge contained in different experts' opinions. A special case of the standard Bayesian formulation is given which is believed to reflect specific features of technical systems, namely,

- availability of a parametrized system model;
- possibility to quantify particular information items;
- availability of objective data complementing the subjective opinions of experts;
- preference of conservative opinion pooling (overconfidence is more dangerous).

The general formulation is applied to the technically important specific classes of ARX models and Markov chains.

Keywords: prior information, Bayesian statistics, expert opinions, ARX model.

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The Pseudo-Givens Rotation*

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Abstract

A pseudo-Givens rotation is a two by two real matrix that has the following properties. First, it zeros an element in an arbitrary column vector from the left, while its inverse zeros an element in an arbitrary row vector from the right. Second, the remaining degrees of freedom are subject to a minimization that is invariant to inversion and proper orthogonal transformation. One of its interesting properties is that the pseudo-Givens rotation is the Givens rotation in the event that the row vector with an element to be zeroed is the transpose of the column vector with an element to be zeroed. Another is that the pseudo-Givens rotation belongs to the set of matrices with determinant equal to one. In this respect, it is similar to the Givens rotation and the Hyperbolic rotation.

Keywords: Orthogonal transformations, Similarity transformations, Givens rotations, Hyperbolic rotations, Non-symmetric matrices.

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Bayesian Estimation, Large Deviations, and Incomplete Data

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Abstract

Can the Bayesian estimation be modified so to cope with compressed, aggregated or partially missing data? Naturally, the best answer would be to make inference conditional on just information given. But, this is rarely feasible so we have to look for a suitable approximation. The paper shows that the conditional distribution can be approximated so to keep the key features of the optimal solution. First, under weak assumptions, we get the same asymptotic behaviour, only with a lower rate of convergence. Second, the less information we get from data, the more uncertain our inference is. The properties follow essentially from the large deviation theorem and the elementary properties on the informational (Kullback-Leibler) divergence.

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Approximation and Uncertainty in Parameter Estimation

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Abstract

Except for simple models, limited computer resources necessarily make parameter estimation more uncertain or less precise compared to the theoretical ideal. However obvious this implication is, there seems to be no formal expression of it in the theory. The paper looks for an estimation scheme close to the Bayesian one that would make the approximation an integral part of inference.

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Numerical Analysis of a Normalized RLS Filter Using a Probability Description of Propagated Data*

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Abstract

The normalized version of the QR algorithm for recursive least squares estimation and filtering is presented. An understanding of the numerical properties of a normalized RLS algorithm is attempted using a global probability analysis.

Keywords: Systolic array, normalization, fixed point, probability.

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Direct Software Bridge Matlab–Transputer Boards*

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Abstract

Presented software toolbox "PARAbridge" connects the new PC MS Windows 3.1 based MATLAB 4 with 3L Parallel C on Inmos B004 compatible transputer boards. This combination enables the running of data-parallel transputer applications from within MATLAB for the verification and testing of systolic array algorithms. The MATLAB user can program the transputer application, which may use MATLAB as a programmable high level graphical interface. This can significantly reduce the development time of transputer based applications.

Keywords: Systolic array, normalization, fixed point, probability.

* This work has been partially supported by the research grant No. 102/93/0897 of the Grant Agency of the Czech Republic: "Systolic Arrays of Processors for Identification of Systems with Variable Structure" and by the SERC Grant "Algorithm Engineering for Concurrent Control" (UK). J. Kadlec is with Control Engineering Research Centre, Department of Electrical and Electronic Engineering, The Queen's University of Belfast, Ashby Building, Stranmillis Road, Belfast BT9 5AH, Northern Ireland.

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Parallel Normalized Identification Algorithm with Lattice Feedback Regularization*

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Abstract

The paper describes a normalized parallel identification algorithm. This normalized recursive information filter allows a highly modular and numerically sound implementation of the recursive least squares identification with minimal latency. All normalized parameters and internal variables of the modular triangular array have the guaranteed range $[-1, 1]$. Consequently, a significant part of the algorithm is suitable for implementation on fast, parallel, low-cost, fixed-point hardware.
The algorithm is equipped with block regularization which avoids the eventual difficulties experienced by standard least squares algorithms caused by insufficient excitation.
The regularization method is specified for autoregression models and attracts the parameter estimates to stable projections. These stable parameters are periodically adjusted using unit impulse response of a linear prediction coding lattice filter, driven by coefficients from the normalized array.

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The computer simulations demonstrate the performance of a 14-bit fixed point implementation of the lattice feedback regularized array and shows that it compares favorably with the standard recursive least squares algorithms without regularization implemented in double precision floating point arithmetic.

Keywords: Identification, regularization, parallel algorithms, stability, fixed point arithmetics.

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