New Complex Models in Fuzzy Systems

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***Abstract**: Soft Computing, especially fuzzy model based operation proved to be very advantageous in power plant control where the high complexity, nonlinearity, and possible partial knowledge usually limit the usability of classical methods. By this, a model-based anytime control methodology can be suggested which is able to keep on continuous operation using non-exact, approximate models of the plant, thus preventing critical breakdowns in the operation. In this paper, an anytime modelling method is suggested which makes possible to use complexity optimized fuzzy models in control and can determine the near optimal non-exact model of the plant considering the available time and resources. The model by building is in new information without complexity explosion.*

***Keywords**: intelligent control; anytime modelling; fuzzy modelling; Singular Value Decomposition-based complexity reduction; time critical systems*

1 Introduction

Embedding fuzzy models in anytime systems extends the advantages of the Soft Computing (SC) approach with the flexibility with respect to the available input information and computational power. There are mathematical tools, like Singular Value Decomposition (SVD), which offer a universal scope for handling the complexity problem by anytime operations. In this paper, we deal with the applicability of fuzzy models in dynamically changing, complex, timecritical, anytime systems. The analyzed models are generated by using (Higher Order) Singular Value Decomposition ((HO)SVD). This technique provides a uniform frame for a family of modeling methods and results in low (optimal or nearly optimal) computational complexity, easy realization, and robustness. The accuracy can also easily and flexibly be increased, thus both complexity reduction and the improvement of the approximation can be implemented.

2 Anytime Processing

In recourse, data, and time insufficient conditions, anytime algorithms, models, and systems (Zilberstein, 1996) can be used advantageously. They are able to provide guaranteed response time and are flexible with respect to the available input data, time, and computational power. The main goal of anytime systems is to keep on the continuous, near optimal operation through finding a balance between the quality of the processing and the available resources. Iterative algorithms/models are popular tools in anytime systems. Unfortunately, the usability of iterative algorithms is limited. Because of this limitation, a general technique for the application of a wide range of other types of models/ computing methods in anytime systems has been suggested in Várkonyi-Kóczy, et al. 2001, however at the expense of lower flexibility and a need for extra planning and considerations.

3 Value Decomposition

The Singular Value Decomposition based complexity reduction algorithm is based on the decomposition of any real valued matrix

$$\underline{\underline{F}}_{(n_1 \times n_2)} = \underline{\underline{A}}_{1,(n_1 \times n_1)} \underline{\underline{B}}_{(n_1 \times n_2)} \underline{\underline{A}}^{T}_{2,(n_2 \times n_2)} \tag{1}$$

where , k=1,2 are orthogonal matrices, and B is a diagonal matrix containing the singular values of in decreasing order. The singular values indicate the signif icance of the corresponding columns of Ak. The matrices can be part i t ioned in the fol l o wing way:

$$\underline{\underline{A}}_{k} = \left| \underline{\underline{A}}^{r}_{k,(n_k \times n_r)} \quad \underline{\underline{A}}^{d}_{k,(n_k \times (n_k - n_r))} \right|$$

$$\underline{\underline{B}} = \left| \begin{matrix} \underline{\underline{B}}^{r}_{(n_r \times n_r)} & 0 \\ 0 & \underline{\underline{B}}^{d}_{((n_1 - n_r) \times (n_2 - n_r))} \end{matrix} \right|, \tag{2}$$

where r denotes "reduced" .For n-dimensional cases, Higher Order Singular Value Decomposition based reduction can be made in n steps, in every step one dimension of matrix, containing the consequences is reduced.

4 Complex Reduction

The complexity of the control can be tuned both by evaluating only a degraded model (decreasing the granulation) and both by improving the existing model (increasing the granulation) in the knowledge of new information.

Reducing the Complexity of the Model

For creating anytime models, first a practically "accurate" fuzzy system is to be constructed. In the second step, the redundancy of this model is reduced by (HO)SVD. The (non-exact) anytime models can be obtained either by applying the iterative transformation algorithm described in Takács et Várkonyi-Kóczy, 2004 or in the general frame of modular architecture (for details, see Várkonyi-Kóczy et al., 2001). The SVD based reduction finds the optimum, i.e., minimum number of parameters which is needed to describe the system.

Improving the Approximation of the Model

A very important aim is not to let to explode the complexity of the compressed model when the approximation is extended with new points. Thus, if approximation *A* is extended to *B* with a new set of approximation points and basis, then the question is how to transform *Ar* to *Br* directly without decompressing *Ar*, where *Ar* and *Br* are the reduced forms of *A* and *B*. In the paper, an algorithm is summarized for the complexity compressed increase of such approximations. The crucial point is to inject new information, given in the original form, into the compressed one. How to apply those extra points taken from a large sampled set to be embedded, which have no new information on the dimensionality of the basis, but carry new information on the approximation?

Fitting of two approximations into a common

basis system:

- use the rational general form

$$y=\frac{\sum_{j_1=1}^{e_1}\cdots\sum_{j_n=1}^{e_n}\prod_{i=1}^{n}\mu_{i,j_i}(x_i)\,f_{j_1,\cdots,j_n}(x_1,\cdots,x_n)}{\sum_{j_1=1}^{e_1}\cdots\sum_{j_n=1}^{e_n}\prod_{i=1}^{n}\mu_{i,j_i}(x_i)\,w_{j_1,\cdots,j_n}} \qquad (3)$$

Wich can always be transformed into the form

$$y=\frac{\sum_{j_1=1}^{e_1^r}\cdots\sum_{j_n=1}^{e_n^r}\prod_{i=1}^{n}\mu_{i,j_i}^r(x_i)\,f_{j_1,\cdots,j_n}^r(x_1,\cdots,x_n)}{\sum_{j_1=1}^{e_1^r}\cdots\sum_{j_n=1}^{e_n^r}\prod_{i=1}^{n}\mu_{i,j_i}^r(x_i)\,w_{j_1,\cdots,j_n}^r} \qquad (4)$$

where $$f^{r}_{i_1,\cdots,i_n}(x_1,\cdots,x_n) = \sum_{t=1}^{m} b^{r}_{i_1,\cdots,i_n,t}\phi(x_1,\cdots,x_n)$$

- find the minimal common basis:

1, determine the minimal unified basis in the *i*-th dimension.

2, transform of the elements of matrices and to the common basis.

Embedding the new approximation A into the

reduced form of O.

1, filter out the redundancy of approximation *A* by applying HOSVD

2, Define the merged basis of *Or* and *Ar* in all, except the *k*-th, dimensions (*k*-th dimension where the approximation is increased).

3, fit *A* and *O* in the *k*-th dimension

4, filter out the redundancy (linear dependance)

4 Anytime TS Fuzzy Control

There are numerous successful applications of anytime control which affect on the analysis and design of anytime control systems. The previously discussed ideas can fruitfully be applied in plant control if Takagi-Sugeno (TS) fuzzy modeling and Parallel Distributed Compensation (PDC) based controller design is used (Tanaka et Wang, 2001) (Fig. 1). If the model approximation is given in the form of TS fuzzy model, the controller design and Lyapunov stability analysis of the nonlinear system reduce to solving the Linear Matrix Inequalities (LMI) problem (Tanaka et al., 1999). This means that first of all we need a TS model of the nonlinear system to be controlled. The construction of this model is of key importance. This can be carried out either by identification based on input-output data pairs or we can derive the model from given analytical system equations. The PDC offers a direct technique to design a fuzzy controller from the TS fuzzy model. This procedure means that a local controller is determined to each local model. This implies, that the more complex the system model is, the more complex controller will be obtained. According to the complexity problems outlined in the previous sections we can conclude that when the approximation error of the model tends to zero, the complexity of the controller explodes to infinity. This pushes us to focus on possible complexity reduction and anytime use.

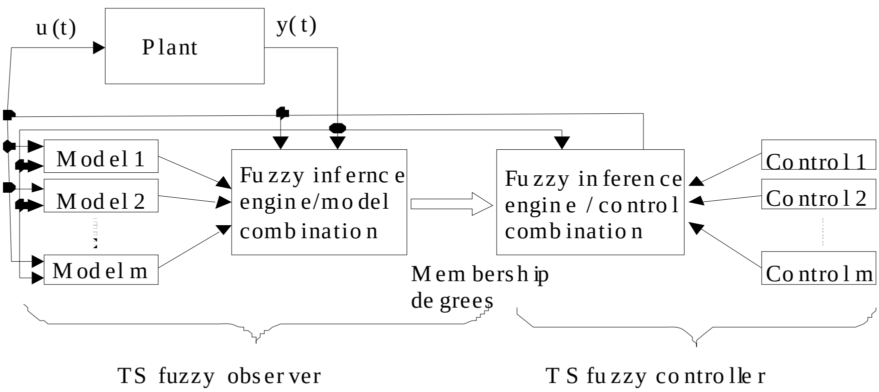

Figure 1
TS fuzzy observer based control scheme

SVD-based complexity reduction can be applied on two levels in the TS fuzzy controller. First, we can reduce the complexity of the local models (local level reduction). Secondly, it is possible to reduce the complexity of the overall controller by neglecting those local controllers, which have negligible or less significant role in the control (model level reduction). Both can be applied in an anytime way, where we take into account the "distance" between the current position and the operating point, as well. The model granularity or the level of the iterative evaluation can cope with this distance: the further we are, the more rough control actions can be tolerated. Although, approximated models may not guarantee the stability of the system, this can also be ensured by introducing robust control.

Conclusions

In this paper, the applicability of (Higher Order) Singular Value Decomposition based anytime fuzzy models in control is analyzed. It is proved that the presented technique can be used for both complexity reduction and for improving the approximation without complexity explosion. The introduced anytime models can advantageously be used in many types of time critical applications during resource and data insufficient conditions.

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