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博 士 論 文 概 要

論　文　題　目

Study on Identification of Nonlinear Systems Using Quasi-ARX Models

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System identification can be used to construct a model to represent a given system, and it plays an important role in system analysis, control and prediction. From the view of application, conventional nonlinear black-box models are imperfect since an easy-to-use model is to interpret the properties of the nonlinear process, rather than treated as vehicles for adjusting the fit to the data. Therefore, some careful modeling is needed for certain applications, and prior knowledge from the system is inspired to be combined with formal properties of the model.

Quasi-linear autoregressive with exogenous inputs (quasi-ARX) modeling scheme provides an effective approach to extend well-studied and user-friendly linear techniques to nonlinear applications. It constructs models consisting of two parts: a macro-part and a core-part. The macro-part owns a useful interface to introduce some properties favorable to specific applications, and the core-part is a flexible nonlinear model to parameterize complicated coefficients of the macro-part. To this end, an ARX-like linear structure is constructed as the macro-part by using Taylor expansion; while the coefficients are parameterized by a multi-input-multi-output (MIMO) nonlinear model in the core-part.

Nevertheless, it is no easy solution to identify nonlinear systems using the quasi-ARX models, though it is equipped with a useful structure. Followed by requirement of real applications, the identification is expected to interpret properties of the nonlinear system and hold the principle of simplicity. One effective approach to this challenge is to divide the model parameters into two parts: the nonlinear parameters and the linear parameters. The nonlinear parameters mean those interpretable ones, such as translation and dilation parameters of wavelet basis function, which can be determined by using prior knowledge. When the nonlinear parameters are fixed, the quasi-ARX model can be transformed linear in parameters. These linear parameters are the ones to fit the data, which can be estimated by linear regression methods. Furthermore, the quasi-ARX model is meaningful to nonlinear polynomial system identification, which often contains a big number of candidate monomial terms. The identified quasi-ARX model inspires a pre-processing approach to evaluate significance of each monomial term, which is helpful to reduce the candidate pool efficiently. In this thesis, investigations are firstly made on nonlinear parameter estimation with clustering partition and grid partition method, where wavelet network (WN) and neurofuzzy network

(NFN) are included as the core-part of the model, respectively. Then the linear parameters are estimated by means of kernel method, where radial basis function network (RBFN) is incorporated. Finally, neural network (NN) is embedded in the quasi-ARX model, which is identified and provides a pre-screening scheme for polynomial system identification.

Chapter 1 firstly introduces background of system identification and the quasi-ARX models. Challenges and obstacles of nonlinear system identification using the quasi-ARX model are analyzed, and main contributions of each chapter are outlined.

Chapter 2 identifies the quasi-ARX model by incorporating WN into the model core-part, and clustering partition method is proposed to obtain prior knowledge of data distribution. The input-output space is partitioned into reasonable number of clusters, then translation and dilation parameters of each wavelet basis function are estimated with the help of heuristic guides in the associated subspace. In this way, the interpretable parameters of the quasi-ARX model can be determined and fixed by using prior knowledge efficiently. It is meaningful not only from the aspect of nonlinear system identification but also in nonlinear adaptive control, where the quasi-ARX WN predictor is utilized by using the proposed identification method. Reference signal can be tracked quickly since only linear parameters are needed to be adjusted, even a sudden change is happened on the system.

Chapter 3 identifies the quasi-ARX model using grid partition method to obtain prior knowledge. Typically, the partition is made on each input dimension, which can be explained in the manner of fuzzy membership partition, and the generated fuzzy rules work as the prior knowledge to unveil the system properties. To this end, NFN is incorporated into the quasi-ARX model, where a set of linguistic fuzzy rules are represented by neurofuzzy basis functions in the NFN. However, it suffers from curse-of-dimensionality, which may result in over-fitting by redundant fuzzy rules. Heuristically, the quasi-ARX model input variables which are linear with the output, are sufficient to describe the input-output relationship by linear expression, thus are less important to parameterize coefficients of the ARX-like linear structure. Based on this fact, fuzzy rules are reduced by using only necessary inputs for the incorporated NFN, where correlation between model inputs and output are included in the form of a modified Bayesian information criterion

(BIC) to trade off between model accuracy and complexity. It works as a fitness function of genetic algorithm (GA) for an optimal subset.

Chapter 4 identifies the quasi-ARX model using kernel learning method, where the model is transformed to a support vector regression (SVR) with composite kernel. The SVR based identification introduces robust performance for linear parameter estimation. Moreover, it provides an efficient approach to cope with curse-of-dimensionality when grid partition is utilized. Instead of estimating the big number of linear parameters directly, a dual form of quadratic programming (QP) optimization is implemented, where the complexity of representation by support vectors is independent of input dimension. At the same time, explicit and physically meaningful kernel mapping is proposed, which is learnt by means of the quasi-ARX modeling with prior knowledge. It leads to appropriate high-dimensional feature space, where the nonlinearity of mapping can be adjusted according to complexity of the model core-part. In this way, the associated kernel function is called quasi-linear kernel, which is categorized into composite kernels with nonlinearity between linear and certain nonlinear kernel function.

Chapter 5 identifies the quasi-ARX model for nonlinear polynomial systems, which are often composed of a huge monomial candidate pool, while a parsimonious model structure is finally expected. In most cases, it is difficult and time-consuming for optimization based method to search the optimal subset directly. Consider the fact that the quasi-ARX NN model provides impressive fitting performance and can prevent the training from local minima, it is applied to provide an index in pre-screening selection, which may improve identification efficiency by reducing the candidate term pool to an reasonable size. In the pre-screening step, a quasi-ARX NN model is identified to approximate the system under study initially; then a Taylor expansion of the identified model is performed, and the importance of each monomial term is evaluated according to variance of the term with its coefficient. In the following step, multi-objective evolutionary algorithm (MOEA) is used to determine appropriate model structure in the reduced searching space efficiently. Both model approximation ability and complexity are optimized simultaneously.

Chapter 6 concludes this work, summarizes the thesis and gives some potential topics for our further research.