Software Engineering for Identification of Nonlinear Dynamical Systems Using Volterra Model

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Abstract: This thesis presents a software of identification "input-output" nonlinear dynamic systems based on the Volterra approximation model using multi-impulse and multistep test signals, taking into account measurement errors of responses. To ensure computational stability of the identification method it is used regularization method of ill-posed problems and procedures for noise reduction based on wavelet transformation. Researching the effectiveness of computational algorithms that implement identification method.

Keywords: Software Engineering, Software Design, Nonlinear Dynamical Systems, Volterra Model, Multidimensional Volterra Kernels, Multi-Impulse Test Signals, Multistep Test Signals, Wavelet Transformation, Computational Stability.
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Introduction
Mathematical modeling methods and experiments are main tools for researching of complex nonlinear dynamical systems (NDS). To describe NDS it’s often used integro-powered Volterra series [Doyle and oth. 2001]. At that nonlinear and dynamical properties of systems are completely characterized by sequence of multidimensional weight functions – Volterra kernels. The problem of identification – building a model in form of Volterra series – is a determination of Volterra kernels based on data of experimental exploration of “input-output” NDS. Identification in essence is related to inverse problems, during the solving of which there are difficulties of computation kind, caused by ill-posed problems. Obtained solutions are unstable to errors of input data – measurements of identifiable NDS’s responses. However, so far known applied identification algorithms of NDS based on Volterra series still does not allow fully use a power of this mathematical tool [Giannakis and oth. 2001]. It is caused by several reasons, the most important of which are: absence of accounting of significant effect of measurements errors on result of identification in algorithms of experimental determination of Volterra kernels, that limits their use in the real world; insufficient elaborated software for identification of NDS based on Volterra series. The aim is developing of efficient computational algorithms and software tools for estimation of Volterra kernels under incomplete a priori information about identifiable object.

Identification methods and computational algorithms
In this work is used methods of the theory of nonparametric identification based on Volterra model using test pulse and step signals:

- method for building approximation model
- method of differentiation of responses by parameter-amplitude of test signals [Pavlenko and oth. 2014].

During implementation of identification methods used computational methods and numerical methods of processing empirical data:

- methods of wavelet-transformation [Pavlenko and oth. 2014]
- regularization methods of ill-posed problems [Pavlenko and oth. 2015]

During developing the tools used methods of software engineering, and during the solving test and applied problems, analysis of accuracy and noise stability of Volterra kernels’ estimation used methods of the theory of computational experiments.
To verify the reliability of obtained theoretical results used tools of imitation modeling in environment MATLAB/Simulink.

3 Software tools

In MATLAB/Simulink was developed the Identification Tools of Nonlinear Dynamical Objects – a kit for identification of NDS based on Volterra model in time domain, in which was implemented computational algorithms for model building. To simplify the management of modeling and identification processes in MATLAB was created GUI that hides the details of computational processes. A block diagram is shown in figure 1.

![Block Diagram of the Kit](image)

Figure 1: A block diagram of the kit

The interface consists of separate independent modules:

- Modeling module;
- Identification module;
- Configurator;
- Denoise modules.

Structure hierarchy of interface’s files is shown in figure 2, in which: start.* – main executable file of interface; config – configurator; denoise – denoise modules; models – modeling module; ident – identification module; results – identification results; utils – helper functions.

From the main (start) window (figure 3) one can access to all modules.
Modeling module consists of: *modeling.* – main executable file of module; *inputs* – directory with input signals (*.mdl files, schemes with 1 output); *objects* – directory with researched objects (*.mdl files, schemes with 1 input and 1 output); *simres* – directory with modeling results (*.mat files with information about modeling time, input and output signals); *etalons* – directory with etalon Volterra kernels for comparing with identification results (*.m files, functions, input of which are order of kernel and time vector, and output is an array with values of kernel’s estimation).

Identification module consists of: *identification.* – main executable file of module; *methods* – folder with files that implements identification methods (*.m files, functions, input of which are time vector, input and output signals, kernel order and additional parameters, and output is an estimation of kernel); *noise* – folder with noise generators for modeling of noised signals (*.m files, functions, input of which are responses of objects, noise value and additional parameters, and output is a noised signal).

Modeling window (figure 4) is used for selecting of modeling parameters. Result is a file which consists of responses of selected object on selected input signal. One can set next parameters: type of test input signal for object (1 – Input); object (2 – Object); modeling time (3 – $t_{max}$); modeling step (4 – $dt$);
computational step \((5 – \text{dtsim})\); additional parameters for models \((6)\), if unchecked.

![Figure 4: Modeling window](image)

Identification window (figure 5) is used for evaluating of Volterra kernels’ estimations of researched object. Approximation and interpolation methods are used. One can set next parameters: name of file with responses of selected object \((1 – \text{Output})\); noise type \((2 – \text{Noise})\) and it value \((3 – \text{Value})\); identification method \((4 – \text{Method})\); order of evaluated object’s kernel \((5 – n)\); etalon values of object’s kernel \((6 – \text{Compare with})\).

Denoise window is used for denoise of signals. Used next methods: denoising using FFT, denoising using polynomial, wavelet-filtration.

Configurator (figure 6) is used for setting of default values of input signals, researched objects, noise types and identification methods. One can set parameters of object required for modeling: name of block \((\text{Element})\), parameter name of block \((\text{Attribute})\) in Simulink, parameter name – alias for user \((\text{Name})\), parameter value \((\text{Value})\).
Conclusion

On the basis of theoretical and experimental researches was developed new efficient computational algorithms for deterministic identification of nonlinear dynamical systems in time domain, and the corresponding software tools, which provide a building of objects’ models in a form of Volterra kernels' sequence based on experimental data of observations “input-output” with taking into account measurements errors. To simplify the processes of modeling and identification in MATLAB was created GUI for developed software tools.
List of References


