Software development rapid synthesis of nonlinear robust adaptive control systems of complex dynamic objects

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Abstract

The paper deals with the problem computer-aided design of nonlinear control systems. It is proposed to pass from the problem of synthesis of nonlinear control systems related to various theoretical complexities of the problem of parameterization and reduction of the mathematical model of control object to the required form. The developed software achieves the synthesis of control laws in symbolic form, and sends for further analysis, simulation in Matlab. The methods of synthesis used the method of exact linearization via nonlinear feedback, adaptive, robust algorithms based on Lyapunov functions and direct compensation scheme.

1 Introduction

Modern controlled objects are characterized by a high degree of complexity to the factors which are multi-dimensionality, nonlinearity, uncertainty, mathematical models and, etc. Software computational tools can to accelerate synthesis control system and to reduce the volume of routine work of designer. For today the majority modern research on the synthesis and design of automatic control laws is carried out using mathematical packages and specialized programming languages. With increasing dimension of problems, even the use of software computational tools does not reduce difficulty the synthesis and simulation, the developer substantially limits the possibilities computer-aided design [1]

The obvious solution specific problem is a decrease impact by designer on the process of building control laws, by applying a formal analytical method. These methods allow by mathematical model of control object, recorded in analytical or symbolic form, obtain the control law in the analytical or symbolic form too. Ideal variant is a situation where the synthesis of control laws in symbolic form is fully automatic.

The paper considers a variant of algorithm is fully automatic synthesis. Use two contour control system, based on the method of feedback linearization [1,5], adaptive synthesis algorithms based on Lyapunov functions and the scheme direct compensation [6,3]. Not looking some restrictions of the proposed approach, greater value is the speed construction of a workable control laws which insure the motion control object along the required trajectory.

Important to note that the strategy of synthesis of control systems, as a rule, is in a preliminary study of the control object. At this stage is performed the numerical simulation of the motion along the desired trajectories. The developed software complex gives the designer a tool to quickly go from a mathematical model to the simulated results. In the next stage designer can start to the synthesis higher quality control laws in manual or automatic modes, based on radically different methods of synthesis, or by optimizing the algorithm which is automatically synthesized at the before stage.

2 Description of software

The developed software package has a modular, linear principle. Stage of the synthesis is carried out with the use of library functions that are implemented in the language of Maple. Stage modeling is performed in Matlab, a numerical experimental doing on basis of generated during the synthesis of Matlab's files containing the model and control laws.

Working with the software on the synthesis stage is to write a program in Maple, using the developed functions.The initial data for the synthesis of a mathematical model of control object, which is written in an analytical, symbolic form. After entering the model, the designer run a series of function to perform. The structure of the software complex with a sequence of functions of run is shown in Figure 1.

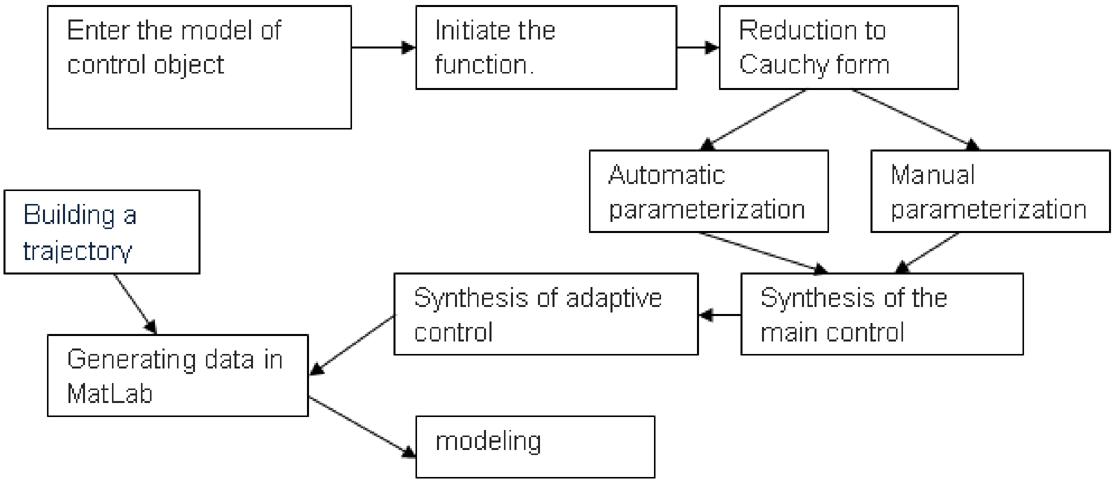

Figure 1: The functional structure of the software system.

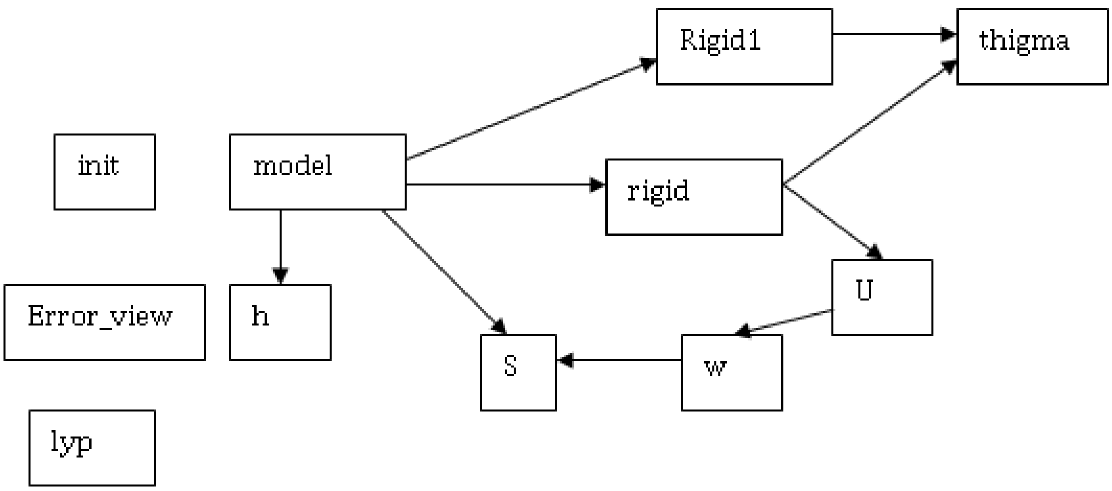

Figure 2: Scheme function calls Matlab-files.

The final stage of using of the Maple is the generation of the system files for simulate closed control system in the environment of MatLab (Fig. 2). Simulation in Matlab is by running the file "model" or by constructing block model in the environment Simulink.

The major file is “rigid1” or “rigid”, which are inserted into the standard solver of ordinary differential equations (ODE) as the called functions calculating of the next step.

The proposed scheme generation matlab-file is more flexible. In fact, the researcher immediately after synthesis system receives all the graphs of the simulated signals the control system. It may itself configure the Matlab simulation environment, depending on the desired results. Among the important configurable selected parameters: a method of solving an ODE step solving - greatly determine the speed and precision of simulation.

3 Algorithms for the main and adaptive control contour

In this paper used the strategy of direct adaptive control - direct compensation scheme, and a group gradient algorithm, called adaptive algorithms with Lyapunov functions [6]. The model of uncertain dynamic control object is represented by the following equation:

$$\dot{x} = f(x) + g(x)(u + \omega(x,t)^T\theta(x,u,t)) + \delta(t), \tag{1}$$

where $\dot{x} = (x_1, ...x_n)^T$, $u = (u_1, ...u_m)^T$ are the state and control vectors, respectively, $\omega(x,t)$ - matrix (regressor) of dimension $(n \times q)$, $\theta(x,u,t) = (\theta_1, ...\theta_q)^T$ - vector of uncertainty parameters, $\delta(t) = (\delta_1, ...\delta_n)^T$ - vector of unmeasured external disturbances. Feature of the model (1) is that all the uncertainty of the object control, including parametric, signaling, structural uncertainty is concentrated in the vector θ In accordance with the principle of direct compensation form the control law as:

$$u = U_0 - \omega(x,t)^T\hat{\theta}, \tag{2}$$

$$\hat{\theta} = \Theta(x, \hat{\theta}, t), \tag{3}$$

where $\hat{\theta}$ - estimate vector undefined parameters, If found by the regulator (3) estimate of the vector equal to actual value $\hat{\theta} = \theta$, then the law (2) provides the full compensation of the disturbing influence of uncertainty θ (without δ) and model (1) can be written as:

$$\dot{x} = f(x) + g(x)U_0, \tag{4}$$

Regulator (2), (3) can be designed with adaptive, adaptive-robust and robust nonlinear control laws:

$$\hat{\theta} = \hat{\theta}_S + \hat{\theta}_I, \tag{5}$$

$$\dot{\hat{\theta}}_S = \mu\omega\frac{\partial V}{x}(x)g(x), \tag{6}$$

$$\dot{\hat{\theta}}_I = \gamma\omega\frac{\partial V}{x}(x)g(x) - \sigma\hat{\theta}_I, \tag{7}$$

where $\mu > 0$, $\gamma > 0$ and $\theta >)$ - constant, $V(x)$ - a Lyapunov function that guarantees the stability of the model (4), (5) - nonlinear robust control, (6) - adaptive and robust control. Synthesis of the main control U_0 is using the method of feedback linearization is described in details [1,4]:

$$U_0 = \frac{1}{L_g L_f^{r-1} h}(-L_f^r + \tilde{u}), \tag{8}$$

where r - vector relative degree, $h(x)$ - additional output of the system (1).Going to the synthesis of an additional control $\tilde{u}$, we use the method of inverse dynamics problems [5], we write the control as follows:

$$\tilde{u} = (y^*)^r + k_r e_y^{r-1} + ... + k_1 e_y, \tag{9}$$

$$e_y = y^* - h(x), \tag{10}$$

where y^* - required trajectory. Control (7), (8) provide a tracking the output $y \to y^*$. If $h(x) = x$, then the problem is solved by tracking the state vector $x \to x^*$ or the problem of stabilizing $x \to 0$.

4 Final comments

Practical results using of the software show the effectiveness the approach proposed rapid synthesis of control systems. Testing was carried out on systems of various degrees of complexity and uncertainty of the mathematical model of the object controls, in particular, examined three-tier manipulators, mobile underwater vehicles, 3-phase motors with a maximum size of the ODE to 30.

Speed of symbolic synthesis is almost independent of the complexity of the mathematical model and is less than 1 minute. Speed of simulation depends on the chosen parameters of ODE solver, can be varied from minutes to hours depending on the complexity of the problem. During symbolic synthesis can be run special procedures of optimization of computational complexity of control laws which essentially accelerate the phase of the simulation.

From the standpoint of the quality of the obtained control laws, the use of 2 independent circuits requires careful selection of the coefficients of the laws (5) (6). During numerical experiments to ensure an acceptable amplitude and frequency of the control laws signal applied strategy to gradually tuning of the coefficients. In general, the simulation results show the stability of the synthesized control system obtained control laws can be immediately applied in practice in the implementation of control systems.

References

[1] B.R. Andrievsky, A. L. Fradkov Elements of mathematical modeling in software environments Matlab and Scilab. St. Petersburg. Science, 2001.

[2] H. Nijmeijer, A. Van der Schaft Nonlinear Adaptive Feedback Linearization of Systems. New York: Springer-Verlag, 1990.

[3] P.V. Kokotovic, placeI. Kanellakopoulos, A.S. Morse Adaptive Feedback Linearization of Nonlinear Systems. Foundation of Adaptive Control. Berlin: Springer-Verlag, 1991.

[4] A. A. Dyda, S. Di Gennaro Adaptive trajectory control for underwater robot. Proc. OCEANS-94 Osates, Brest, 1994.

[5] D. P. Kim The theory of automatic control. V.2. Multi-dimensional, nonlinear, optimal and adaptive systems. Moscow, Phismathlit, 2004.

[6] I. V. Miroshnik, V. O. Nikiforov, A. L. Fradkov Nonlinear and adaptive control of complex dynamic systems. St. Petersburg. Science, 2000.

[7] A. Isidori Nonlinear Control Systems. Berlin: Springer-Verlag, 1995.

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