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Adaptive Control Systems with Reference Models

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ABSTRACT

The synthesis of adaptive control systems for continuous technological objects is a critical scientific problem with both theoretical and practical significance. This article focuses on formalizing the problem of synthesizing adaptive control for complex objects using reference models. The direct approach involves adjusting the system based on a predefined standard, minimizing discrepancies between the standard and the actual system. Additionally, the article explores methods for constructing regulators based on concepts from the theory of direct adaptive systems.

Keywords: Adaptive control systems,Continuous technological objects,Synthesis,Reference models,Direct approach,Discrepancies,Constructing regulators,Theory of direct adaptive systems

Introduction

The field of adaptive systems theory is rapidly expanding within management theory. Diverse perspectives, approaches, and methods contribute to its growth. When developing adaptive systems with a reference model, analyzing engineering methods from self-adjusting control systems theory proves highly effective. In the modern context, the term "adaptive control system" encompasses self-adjusting systems within the broader category of adaptive systems.

In the context of adaptive control with a reference model, the control algorithm typically comprises two interconnected parts: the control algorithm itself and the adaptation algorithm. These algorithms work together. The control object (CO) and the controller form the primary circuit of the adaptive system, while the feedback circuit – including the adapter – constitutes the adaptation circuit. Notably, these systems adjust only the controller parameters, which represent a finite set of numerical values.

Materials and methods

For indicating the main theoretical results in this field in the most concise form, we turn mainly to the works of recent years, in which we found a generalization, development and modern interpretation of the main results obtained earlier. Methods of the theory of optimal and adaptive control, as well as their constructive parts, containing the corresponding algorithms and their software are given. Methods for the synthesis of adaptive systems with a reference model are given. Method for constructing adaptive control systems with a reference model, the objects of which are affected by an unknown external disturbance in the form of a sum of an unlimited number of harmonics, was translated. This adaptive control provides a given accuracy of tracking the output of the object for the output of the reference model.The problem of constructing adaptive control systems with a reference model based on the idea of parametric negative feedback is considered. The proposed synthesis method uses three options for determining parametric control algorithms: direct estimation of deviations of control system parameters from model values, a modified gradient method, and the second Lyapunov method. The method does not require the fulfillment of the hypothesis about the quasi-stationarity of the parameters of the control object; it is used for the synthesis of algorithms for adapting the parameters of linear and nonlinear nonstationary systems. The resulting algorithms may contain proportional, integral, differential, relay and power components, the combination of which determines the speed of the adaptation loop. An adaptive control system for a linear single-channel plant in a scheme with two reference models, which is operable under conditions of a priori uncertainty, both in parameters and in the structure of the control object, is considered.

Formulation of the problem

The scheme of adaptive systems with a reference model, which captures the essential properties of a closed control system, is depicted in Figure 1. Here's how it works:

1. The output signal *z(t)* from the reference model is compared with the actual system's output signal *z(t)*.
2. Any deviation *g(t)* resulting from this comparison becomes the input signal for the self-adjusting circuit.
3. The self-adjusting circuit modifies the controller parameters to eliminate the deviation *g(t)*.
4. This structure represents a direct approach to synthesizing adaptive systems (AS).

The key step in AS synthesis involves developing a self-adjusting circuit algorithm to reduce or eliminate deviations. Currently, the Lyapunov's direct method is widely recognized for estimating control system stability.

Let's delve into the basic principles of AS synthesis using the Lyapunov's direct method. For clarity and logical completeness, we'll focus on a second-order system. Consider a real control system described by the equation:

$$\dot{z} + c_1 \dot{z} + c_2 z = k(t) a \epsilon(t) \quad (1)$$

where:

c1 and c2 are constant parameters of the control object (CO). k(t) represents the time-varying amplification coefficient of the CO.

a is the transfer coefficient of control devices.

The model equation has the form:

$$\ddot{z}_m + c_1 \dot{z}_t + c_2 z_m(t) = k_m(t) e(t)\,) \quad (2)$$

It is necessary to find such a process of changing the a coefficient, which will lead to the elimination of the mismatch between the output signals of the control object (OC) and the model and ensure the asymptotic stability of the AS.

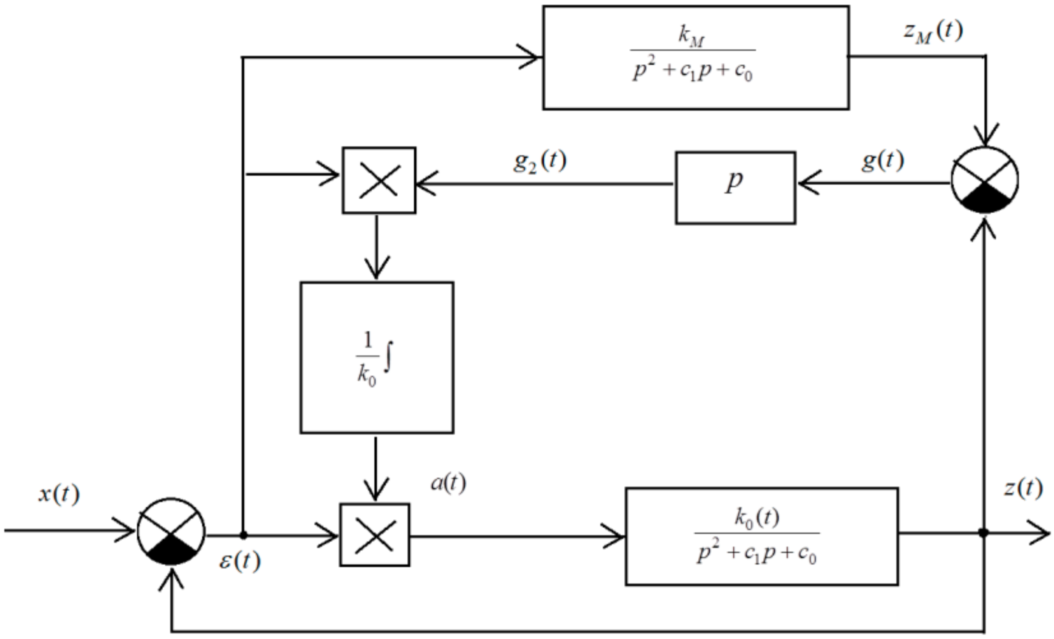

Figure 1. Algorithm of self-adjusting

$$\dot{a}(t) = (1/k_0)g_2(t)\varepsilon(t) \tag{3}$$

$$\ddot{a}(t) = (1/k_0)\int_0^t g_2(t)\varepsilon(t)\,dt \tag{4}$$

The self-adjusting algorithm (Algorithm 4) corresponds to the scheme of the self-adjusting algorithm within the adaptive system (AS), as shown in Figure 1. However, Algorithm 4 is effective only under the assumption that the amplification coefficient of the control object (CO) changes insignificantly and slowly relative to the nominal value. In previous works and other related research, it has been indicated that this principle can serve as the foundation for constructing AS of arbitrary orders, even in scenarios with multiple adjustable parameters as part of the control devices. The conditions and challenges associated with this generalization have also been thoroughly analyzed.

Conclusion

Unlike systems with customizable models, systems with a reference model share a common goal for both control and adaptation: ensuring that the system's behavior closely aligns with a predefined reference model. This reference model encapsulates the desired behavior of the system. In such systems, the problem of parametric optimization within the main control loop, considering adjustable parameters, is also addressed. Notably, the use of searchless optimization methods replaces the traditional optimization problem with an algebraic one. Solving this algebraic problem yields the desired relationship between observation results and controller parameter settings. Additionally, the tuning functional itself serves as a measure of the parametric deviation between the main circuit and its reference model. In certain cases, this approach simplifies the incorporation of technical requirements for adaptive control systems.

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