Models of Adaptive Control System Design for Nonlinear Dynamic Plants Based on a Neural Network

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Abstract—The present work is dedicated to the control problem of nonlinear dynamic plants with an incomplete mathematical description. The authors consider a synthesis method of adaptive neural networks based on some analytic design principles. The adaptation law is defined via the stabilization condition of the closed-loop system by Lyapunov’s second method.

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1. INTRODUCTION

Today, the design problem of adaptive control systems functioning in uncertain conditions is among most important ones of cybernetics and information science. Direct analysis of the recent publications indicates that a series of significant results were obtained in adaptive control theory. In addition to traditional approaches, artificial intelligence theory finds more and more applications in the field of automatic control systems (ACSs) intellectualization. For instance, some methods of embedding artificial intelligence elements in adaptive ACSs were studied in [1–8]. However, their usage in control problems for complex nonlinear dynamic plants faces substantial obstacles.

This paper aims at suggesting an analytic design method for adaptive control systems of complex dynamic objects with nonlinear links based on a neural network. The constructed control systems meet the requirements imposed on their performance (bounded response time, overshoot, control error, etc.). Moreover, the developed method allows designing controllers for plants with an inaccurate mathematical description. The synthesized controller demonstrates good performance under external and internal random disturbances.

2. THEORETICAL ANALYSIS

As is well-known, analytic design methods serve for constructing optimal controllers in the sense of some performance criterion only for plants with a given mathematical description and invariable parameters during system functioning. We emphasize that, in many situations, realization of the obtained control laws is accompanied by certain difficulties due to the necessity of solving partial differential equations. In some cases, when a plant incorporates links with a nonlinear static characteristic suffering from discontinuities of the first kind, control signal calculation appears even impossible.
On the other hand, researchers develop adaptive control systems for plants with varying parameters and uncertain descriptions. Nevertheless, analysis of design principles applied in traditional adaptive ACSs reveals a series of problems appreciably hampering the synthesis procedure of such systems. The presence of an identification unit for the dynamics of plants makes the ACS structure complex. Identification errors impair control performance or even cause unstable operation of the ACS. The adaptation laws of controller’s parameters can be derived by existing methods only in special cases. In other words, the universal synthesis method of adaptation laws takes no place.

Almost all known design methods of the parameter adaptation algorithms for controllers in nonstationary plants based on a reference model proceed from the hypothesis of quasistationary plant parameters during controller tuning. In fact, most real plants do not satisfy this requirement. As a result, we possibly substantial deviations of the actual performance characteristics from the desired ones and, furthermore, the instability of parameter adaptation procedures.

The existing design methods do not yield parameter adaptation algorithms in the case when all coefficients in the differential equation of the plant dynamics vary with time. The book [12] proposed a design method of the parameter adaptation algorithms for a controller under all varying parameters of an associated plant; however, this method requires accessing a summation unit within the plant. At the same time, the synthesized adaptation algorithms have a rather cumbersome structure causing difficulties in their implementation. Thus and so, we acknowledge the inherent complexity of adaptation algorithms for most adaptive systems. This explains the topicality of creating analytic design methods of adaptive control systems for nonlinear dynamic plants with simpler structure and uncomplicated implementation of corresponding computational procedures.

The classical design methods of control systems employ the well-developed apparatus of integral and differential calculus (introduced by Newton about three centuries ago) and the Laplace transform. Artificial neural networks (ANNs) represent a modern branch of automatic control theory, which exists for several years and suggests an alternative solution approach to this problem [1, 3, 6, 10, 11].

The key role in implementing artificial neural networks in control field belongs to S. Narendra, see the paper [9]. Artificial neural networks have found a wide application in the problems of identification and control of dynamic plants owing to the following properties:

- the capability for learning and accumulation of information;
- the approximation capability;
- the capability for parallel signal processing.

In control systems these networks can be used as controllers and identifiers. Controller and identifier design mostly involves multi-layer direct propagation neural networks, where information moves between layers in the direction of signal propagation (backward motion is prohibited). Such ANNs are widespread as they have a simple structure, high performance owing to parallel data processing, numerous network learning algorithms and standard software of their implementation.

The approximation capabilities of neural networks with dynamic learning algorithms describe complex nonlinear dynamic plants in the form of direct and inverse models based on “input-output” measurements.

2.1. The Suggested Design Method of Adaptive Control Systems

For stating the major idea of the approach, consider a dynamic plant with the mathematical description

\[ \dot{x}_i = f_i(x) + bu_j, \quad i = \overline{1,n}; \quad j = \overline{1,m}, \] (1)