Adaptive Controller for a Multi-Mode Object

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Abstract—We consider an adaptive controller for a single-mode object and study the possibility of using it for a multi-mode object. We propose an enhanced adaptive control algorithm for a multi-mode object. We study the influence of the quantization effect in DA and AD converters on the results of adaptive control. We study the influence of test signal amplitudes on identification results and show the findings of experimental studies for an adaptive controller with improved algorithms.

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1. INTRODUCTION

There are several research directions in the field of adaptive control theory where external disturbance is an unknown bounded function.

One of such directions is related to the notion of a reference model. Characteristic results of this direction can be found, for instance, in [1, 2]. The fundamental idea of this direction is easy to understand on the example of [1], where the authors solve an $LQ$-optimization problem for an object with unknown coefficients. Solving this problem with Riccati equations, they substitute quasiestimates constructed with the gradient method as true object coefficients. Such quasiestimates may significantly differ from true values under the influence of external disturbances. In [3], other possibilities this approach provides are discussed, possibilities that do not use quasiestimates.

One characteristic feature of the method of recurrent objective inequalities [4, 5] is the formulation of an adaptive control objective as admissible residues for the deviations of the established object output under the influence of arbitrary bounded disturbances. In [6, 7], solution of the $l_1$-optimization problem is generalized to the case of unknown object coefficients. In these works, the authors use a variation of the gradient method in such a way that the resulting quasiestimates for object coefficients ensure minimal deviation of the system output. However, numerical implementation for this method becomes more complicated.

Therefore, a number of works have been devoted to a more narrow class of external disturbances. For instance, in [8] the external disturbance is assumed to be a piecewise constant function with a given frequency range, while estimates of object coefficients can be found with a test signal and an adaptive observer.

In frequency adaptive control [9], the control objective is a given accuracy in object output, and the external disturbance can be an arbitrary bounded function. The method of finite–frequency identification [10] employs a test signal in the form of a finite sum of harmonics. Implementation of this approach began with the controller FAC-1 [11] and has undergone a number of modifications over the last two decades, including algorithms for tuning the amplitudes, frequencies, and duration of adaptation.

This work is organized as follows. In Section 2, we give the problem setting. Section 3 contains an exposition of known results for the problem’s solution in the single-mode case and a description of the testbed. In Section 4, we describe the direct reconstruction method and propose a technique
for suppressing noises caused by level quantization in the digital-analog (DA) and analog-digital (AD) converters together with a way to design an implementable controller with this property. In Section 5 we present numerical studies of the proposed controller that take into account the presence of a DA or AD converter in the system. In Section 6, we discuss the results of seminatural experimental studies. Appendices contain derivations of main expressions and the proof of the statement.

2. PROBLEM SETTING

Consider an object given by a difference equation

\[ y(k) + d_1^m y(k-1) + \ldots + d_n^m y(k-n) = k_1^m u(k-1) + \ldots + k_n^m u(k-n) + f(k), \quad k = 0, 1, 2, \ldots, \quad m = 1, 2, \ldots, \]

where \( y(k) \) is the object output measured at time moment \( t = kh \) (\( h \) is the discretization interval of this object); \( u(k) \), the control; \( f(k) \), unmeasured external disturbance which is an unknown bounded function \( |f(k)| \leq f^* \), where \( f^* \) is a given number); \( m \), index of the object operation mode; \( n \), a known number. Object coefficients \( d_j^m \) and \( k_j^m \) are unknown numbers that change at time moments \( t^m_{cm} \) and are constant on time intervals \([t^m_{cm}, t^{m+1}_{cm}]\), \( m = 1, 2, 3, \ldots, t^{[1]}_{cm} = 0 \). Time moments \( t^m_{cm} \), \( m = 2, 3, 4, \ldots \) are known or can be found in the adaptation process. The object is asymptotically stable on each of the operation modes \( m \).

The control comes from a controller:

\[ u(k) + g_1^m u(k-1) + \ldots + g_n^m u(k-n) = r_0^m y_\psi(k-\psi - 1) + r_1^m y_\psi(k-\psi - 2) + \ldots + r_{n-1}^m y_\psi(k-\psi), \quad m = 1, 2, 3, \ldots, \]

where \( y_\psi(k) \triangleq y(k) - v(k), v(k) \) is the identifying signal, \( r_j^m = [r_0^m, \ldots, r_n^m] \), \( g^m = [g_1^m, \ldots, g_n^m] \) are controller coefficients, \( \psi \geq n - 1 \) is a given number. Coefficients \( r_j^m \), \( g^m \) are found by the time moment \( t^m_{cm} + \Delta t^{[m]}_{adap} \), where \( t^m_{cm} \) is the moment when the \( m \)th operational mode begins at the object, \( \Delta t^{[m]}_{adap} \) is the duration of adaptation on mode \( m \). In the first mode (for \( m = 1 \)), object parameters are unknown, and as the control signal we give a test signal \( u(k) = v(k) \). On subsequent modes on time intervals \([t^m_{cm}, t^m_{cm} + \Delta t^{[m]}_{adap}]\) controller (2.2) operates with coefficients \( r_{[m-1]}^m \), \( g^{[m-1]} \).

Transition function of the controller (2.2) has the following form:

\[ w_{\text{cntr}}(q) = \frac{r_0^m q^{-n+1} + r_1^m q^{-n+2} + \ldots + r_{n-1}^m q^\psi}{1 + g_1^m q + \ldots + g_n^m q^\psi}, \]

where the shift operator \( q \) is defined as \( q^* x(k) \triangleq x(k - i) \).

The problem is to find, for every \( m = 1, 2, 3, \ldots \), the controller coefficients \( r_j^m \), \( g^m \) such that controller (2.2) meets the following conditions on accuracy:

\[ |y(k)| \leq y^*, \quad k > k^*_m, \]

where \( y^* \) is a given number, \( k^*_m \) is such that the time moment \( t^*_m = k^*_m h \) lies inside the time interval \( t^{[m]}_{cm} < t < t^{[m+1]}_{cm} \), \( m = 1, 2, 3, \ldots \). We make the following assumptions: