OPTIMAL AND ROBUST SLIDING MODE CONTROL FOR LINEAR SYSTEMS WITH MULTIPLE TIME DELAYS IN CONTROL INPUT

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ABSTRACT

This paper presents the optimal regulator for a linear system with multiple time delays in control input and a quadratic criterion. The optimal regulator equations are obtained using the duality principle, which is applied to the optimal filter for linear systems with multiple time delays in observations. Performance of the obtained optimal regulator is verified in the illustrative example against the best linear regulator available for linear systems without delays. Simulation graphs and comparison tables demonstrating better performance of the obtained optimal regulator are included. The paper then presents a robustification algorithm for the obtained optimal regulator based on integral sliding mode compensation of disturbances. The general principles of the integral sliding mode compensator design are modified to yield the basic control algorithm oriented to time-delay systems, which is then applied to robustify the optimal regulator. As a result, the sliding mode compensating control leading to suppression of the disturbances from the initial time moment is designed. The obtained robust control algorithm is verified by simulations in the illustrative example.

KeyWords: Linear system, multiple delays, optimal control, filtering, sliding mode regulator.

I. INTRODUCTION

Although the optimal control (regulator) problem for linear system states was solved, as well as the filtering one, in 1960s [15,22], the optimal control problem for linear systems with delays is still open, depending on the delay type, specific system equations, criterion, etc. Such complete reference books in the area as [7,10,20,21,25] note, discussing the maximum principle [19] or the dynamic programming method [26] for systems with delays, that finding a particular explicit form of the optimal control function might still remain difficult. A particular form of the criterion must be also taken into account: the studies mostly focused on the time-optimal criterion (see the paper [27] for linear systems) or the quadratic one [9,13,34]. Virtually all studies of the optimal control in time-delay systems are related to systems with delays in the state (see, for example, [1]), although the case of delays in control input is no less challenging, if the control function should be causal, i.e., does not depend on the future values of the state. A considerable bibliography existing for the robust control problem for time delay systems (such as [12,24]) is not discussed here.

The first part of this paper concentrates on the solution of the optimal control problem for a linear system with multiple time delays in control input and a quadratic criterion, which is based on the duality principle in a closed-form situation [3] applied to the optimal filter for linear systems with multiple time delays in observations recently obtained in [5]. Taking into account that the optimal control problem can be solved in the linear case [22] applying the duality principle to the solution of