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On Delay Robustness Improvement Using Digital Smith Predictor for Networked Control Systems

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Abstract

This paper presents a study on delay robustness improvement ability of a digital Smith predictor based delay compensator for networked control systems with bounded network induced time-varying delays and packet losses. The compensator is considered to be implemented in digital form with time-driven controller and event-driven actuator configuration. The uncertain system model is represented in polytopic form and Lyapunov method is used for stability analysis in terms of linear matrix inequalities. The performance of the digital predictor in terms of delay-tolerability is then tested on two numerical examples and verified with simulation using TrueTime simulator. It is found that the selection of predictor delay can be made based on bounds of network delays to improve the performance of the controller.

Keywords: Networked control system, Smith predictor, Delay, Packet loss, LMI.

1. Introduction

In modern remote control perspective, the plant and its command are situated away from each other but connected with a communication network (e.g. LAN, WAN and Internet). This forms the so called Networked Control Systems (NCSs). The use of communication networks is advantageous due to less cost, easy installation and ready availability while using non-dedicated networks. These are widely used in automobiles, manufacturing plants, aircrafts and spacecrafts [1, 2]. However, inserting such networks into an NCS usually induces time-delays and packet losses that degrades the closed-loop system performance [3]. Analysis and design of controllers for such NCS are important due to their wide and potential applications, but are complex due to the uncertain delays and packet losses.

A block-diagram representation of general type of NCS is shown in Figure 1. The output measurement data is communicated to the controller via a network. After control input computation, the control signal is again sent via the same network, but to the plant. Available literature considers, the communications either be time-driven, i.e. the signals are sent or updated at constant sampling intervals, or be event-driven, for which the receiver signal is updated once a new data arrives.

In general, the sensor node in an NCS is time-driven at the transmitting end. Based on the protocol used, receivers at both the controller and the actuator ends are either time- or event-driven. Both the controller and the actuator are considered to be event-driven in [4, 5, 6, 7]. If a node (controller or actuator) is time-driven, the delay is ceiled to integer multiples of the sampling interval since data is received/updated at sampling instants only. On the other hand, for a event-driven receiver node, the delay is not an integer multiple and thereby a time-varying one. Further discussions on these aspects can be found in [8].

For network-induced delays that are variable integer multiple of sampling interval (for time-driven node), the system may be represented as a switched one with multiple models corresponding to all possible variable data update on intervals [9, 10, 11]. Then the stability analysis can be carried out employing Lyapunov analysis for switched systems. However, for event-driven case, delays take continuous values. One way to tackle such a case is by discretizing the system and treating the network-induced time-varying delays as uncertainties in the system [5, 12, 13].

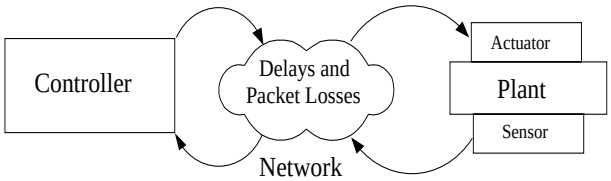

Figure 1: A general representation of NCS

Due to the involvement of uncertain delays and packet losses, predictive controllers is commonly employed in NCSs for performance improvement. For example, delay compensating performances of a class of predictive controllers have been studied in [14, 15, 16]. In these works, the non-delayed output is predicted using a Luenberger-type observer based predictor. The classical Smith Predictor (SP) has also been studied for delay effect compensation in NCSs [17]. In [18], a modified SP

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