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Plantwide process control with asynchronous sampling and communications

Shichao Xu, Jie Bao*

School of Chemical Engineering, The University of New South Wales, UNSW, Sydney, NSW 2052, Australia

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ABSTRACT

The need for economic efficiency has driven the development of large and complex chemical plants. These plants typically contain a large number of process units, often with different time scales, interacting with each other due to the use of recycle streams and heat integration. This causes considerable difficulties in plantwide control. This paper aims to address this issue by developing a flexible networked-based plantwide control approach. In this approach, a plantwide process is modeled as a network of process units which is controlled by a network of autonomous controllers. The controllers within the network operate with different sampling rates and communicate with each other asynchronously, to allow cost-effective control designs and efficient utilization of communication bandwidth. This networked control approach ensures the plantwide stability even when communications between controllers breakdown. Using the concept of dissipative systems, the effects of different local controller sampling rates and information exchange rates on the stability and performance of the entire plant are represented by a set of dissipativity conditions. The conditions that individual local controller has to satisfy to achieve the plantwide stability and user specified performance are derived. Autonomous controllers can then be designed individually to form a controller network. This effectiveness of the proposed approach is demonstrated by an illustrative example of a process network that consists of a reactor and a multi-stages distillation column.

1. Introduction

Complex process plants increasingly appear in modern chemical industry (*e.g.*, bio-chemical processes, reaction networks and membrane filtration systems) due to the considerable economic efficiency that complex and interactive process designs can offer [1]. These plants, which often have more than a hundred process units, are highly interactive due to the wide use of material recycle and heat integration. As a result, this may lead to significant control difficulties. For example, centralized multivariable control approaches, which rely on the complete model of the entire plantwide process, is generally difficult, if not entirely impossible to implement when the plant size is very large [2]. On the other hand, decentralized control approaches which require weak coupling between process units, do not often provide adequate control performance when interactions within the plant is strong [3–5]. To address the above problems, a plantwide distributed control approach, which is somewhere between the fully decentralized and centralized approaches, has emerged in recent years (e.g. [6–9]). In this approach, a plant-wide process is divided into a number of subsystems and controlled by a number of geographically distributed controllers which communicate with each other and sensors located locally or plant-wide via a communication network. For example, Vadigepalli and Doyle [10] studied distributed and decentralized estimation and control (DDEC) for large scale systems, which was further extended to distributed model predictive control (DMPC) [11]. Camponogara et al. [12] investigated a communication based approach to coordinate multiple MPCs with different individual cost functions. Rawling and Stewart [13] developed a cooperative approach to DMPC where a global objective function is used in all MPCs. Sun and El-Farra [14,15] proposed a quasi-decentralized approach that requires minimal cross communications between controllers by using models of neighboring units to recreate the states of those units. Baldea and Daoutidis [16,17] investigated the effects of time-scale separation in the dynamical behavior of process networks on system analysis and controller network design. In the meantime, much research has been carried out on the communication media (the communication network of sensors, actuators and controllers) which is referred to as Network Control Systems (NCS) by researchers from electrical and computer engineering. This includes studies on the network protocols for control area network [18], real-time communication jitter and delays [19–22] and software implementation of networked control approaches [23]. A network approach to plantwide process control was developed in our previous work [24,25]. Different to other distributed control methods, this approach views a complex

* Corresponding author. Tel.: +61 2 9385 6755; fax: +61 2 9385 5966.
E-mail address: j.bao@unsw.edu.au (J. Bao).

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