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On-line optimization of fedbatch bioreactors by adaptive extremum seeking control

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ABSTRACT

In this paper, we present an adaptive extremum seeking control scheme for fed-batch bioreactors with Haldane kinetics. The proposed adaptive extremum seeking approach utilizes the structure information of the process kinetics to derive a seeking algorithm that drives the system states to the desired setpoints that maximize the biomass production. It assumes that only the substrate concentration is available for on-line measurement. Lyapunov stability is used in the design of the extremum seeking controller structure and the development of the parameter learning laws. The performance of the approach is illustrated via numerical simulations.

1. Introduction

Fed-batch bioreactors represent an important class of bioprocesses, mainly in the food industry (e.g. yeast production) and in the pharmaceutical industry (like the production of penicillin [18] or of the vaccine against the Hepatitis B [3]) but also e.g. for biopolymer applications (PHB) [5] and for wastewater treatment (for instance in sequential batch reactors (SBR's) [2]). It is also very much involved in the field of enzyme production which has been developed over the past decade due to the recombinant DNA technology and via the use of filamentous micro-organisms.

One of the key issues in the operation of fed-batch reactors is to optimize the production of synthesis product (e.g. penicillin, enzymes, etc.) or biomass (e.g. baker's yeast). They are therefore a priori ideal candidates for optimal control strategies. An intensive research activity has been devoted to optimal control of (fed-batch) bioreactors mainly in the seventies and in the eighties (see e.g. [4,14,16,17]). Yet in practice, because of the large uncertainty related to the modelling of the process dynamics [1], poor performance may be expected from such control strategies, and although a priori attractive, optimal control has not been largely applied to industrial bioprocesses. Alternative approaches have been proposed that are aimed at handling the process uncertainties with an adaptive control scheme [6].

The task of extremum seeking is to find the operating setpoints that maximize or minimize an objective function. Since the early research work on extremum control in the 1920s [13], several applications of extremum control approaches have been reported, e.g. [7,19,22]. Krstic et al. [10,11] presented several extremum control schemes and stability analysis for extremum-seeking of linear unknown systems and a class of general nonlinear systems [10–12]. The implications for the chemical and biochemical industries are clear. In these sectors, it is recognized that even small performance improvements in key process control variables may result in substantial economic benefits.

In this paper, we investigate an alternative extremum seeking scheme for fed-batch bioreactors. The proposed scheme utilizes explicit structure information of the objective function that depends on system states and unknown plant parameters. The scheme presented in this paper is based on Lyapunov's stability theorem. As a result, the global stability is ensured during the seeking of the extremum of the nonlinear continuous stirred tank bioreactors. It is also shown that once a certain level of persistence of excitation (PE) condition is satisfied, the convergence of the extremum seeking mechanism can be guaranteed.

A similar approach has been considered for a simple microbial growth model with Monod kinetics in continuous stirred tank reactors [23]. In the present paper, we consider a fed-batch reactor and the Haldane model as the process kinetics model. The present approach results in a structure of the extremum seeking algorithm which is rather different. The innovative aspects of the present extremum seeking controller are basically threefold. First, the optimization problem to be handled is different: in [23], the problem is

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