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A weighted variable gain super-twisting observer for the estimation of kinetic rates in biological systems

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ABSTRACT

The knowledge of kinetic reaction rates is important for monitoring and controlling biotechnological processes. However, the lack of on-line sensors for this purpose and the inherent problems with numerical differentiation make observers indispensable. In this work, we propose the use of a weighted variable gain super-twisting observer (WVGSTO), applicable to a class of second-order nonlinear systems that include a measurable weight on the unmeasured variable and the possibility of bounding the perturbations with measurable functions. This estimation method is illustrated with an academic example and then applied to a fed-batch bioprocess.

1. Introduction

Biotechnological processes, including also the biodegradation used in the wastewater treatment, have become an important part of modern life, and its appropriate control, optimization and supervision is clearly a fundamental issue. The increasing incentive to develop Process Analytical Technologies (PAT) [1] has also boosted the implementation of on-line instrumentation, and in turn the interest in designing software sensors, which blend the information from a process model and from available on-line measurement signals to reconstruct other, non measured, variables.

These tasks are particularly challenging since the dynamical models of bioprocesses are highly uncertain and there is a lack of reliable and/or economical sensors for key variables. This explains the interest in the last decades for developing estimation strategies for the states and the (specific) reaction rates in bioprocess models [2].

An approach to deal with model variability and uncertainty is to consider known ranges for the parameter values within a simplified model. For example, interval observers [3,4] do not provide an estimate of the system trajectory but rather upper and lower bounds for this trajectory. The extended Kalman filter or other robust linear observers may deal with some degree of parameter uncertainty or signal noise, but they rely heavily on the model.

Asymptotic observers (AO) [2,5] are highly robust, since they are able to estimate the states of a bioreactor without the knowledge of the reaction rates. However, this requires the measurement of at least as many state variables as the number of reaction rates and usually the convergence of the observer cannot be assigned. The properties of AOs can be explained by using the theory of unknown input observers [6].

For the estimation of the (specific) reaction rates, considered as unknown inputs, high-gain observers (HGO) [7,8] have been successfully used [9–11]. A drawback of HGOs, and in general of any continuous observer, is that they are unable to estimate without error the reaction rates, even in the absence of measurement noise. This is due to the lack of knowledge of the velocity of variation of the reaction rate, and this uncertainty cannot be completely compensated by continuous observers. In order to reduce the estimation error the high gain of a HGO has to be increased, but this increases the sensitivity to measurement noise of the estimator [12].

An important feature of discontinuous observers, and in particular of higher order sliding-mode observers [13–15] is that they are able to estimate an unknown input *exactly and in finite time* despite the lack of knowledge of the rate of change of the signal. In particular, for the reaction rate estimation in bioreactors, the use of observers based on the super-twisting algorithm (STA), a second

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