Observability Analysis of a Microalgae Culture Model

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Abstract

Microalgae cultures have a wide range of applications ranging from wastewater treatment to biofuel production. For advanced control and monitoring purposes, it is required to have full state measurements. However, in bioprocess and in particular in microalgae cultures, it is not always possible to measure on-line all the process states either because the sensors are too expensive or simply because some variables, such as the internal quota cannot be sensed online. In that context, a wide variety of observers have been developed [1] in order to reconstruct the evolution of the unmeasured states by combining partial information from hardware sensors and the predictive capability of a dynamic model of the process.

The model (1) is an extension of the Droop model [2] introduced by [3] accounting for photo-acclimation and photo-inhibition phenomena where X is the Biomass concentration, S the Substrate concentration, Q the internal Quota concentration and I^* is a conceptual variable representing the light to which the cells are photo-acclimated, D the dilution rate, $\rho(S,Q)$ the substrate uptake rate and $\mu(Q,I^*)$ the growth rate. Q_0 is the minimal cell quota and Q_1 the maximal cell quota. Parameters were identified by [4] for cultures of Scenesdesmus obliquus.

$$\begin{cases} \dot{X} &= \mu X - DX - RX \\ \dot{S} &= -\rho X + D(S_{in} - S) \\ \dot{Q} &= \rho - \mu Q \\ \dot{I}^* &= \delta\mu(\bar{I} - I^*) \end{cases} \quad (1)$$

With:

$$\begin{aligned} \mu(Q,I^*) &= \bar{\mu}(Q,I^*)(1-\tfrac{Q_0}{Q}) \\ \rho(S,Q) &= \rho_m\left(\tfrac{S}{K_S+S}\right)\left(1-\tfrac{Q}{Q_1}\right) \end{aligned}$$

The aim of this paper is to provide an observability analysis of a model recently identified for cultures of Scenesdesmus obliquus [4] and to study the sensitivity of the unmeasured states to the measured ones. The results highlight conditions under which observability losses occur during the culture, when using only biomass measurements. Fortunately, using both biomass and medium substrate concentration measurements alleviates these issues. Moreover, the sensitivity of the unmeasured states to the measured ones is affected by the dilution rate. This analysis is confirmed by the application of an extended Kalman filter to experimental data.

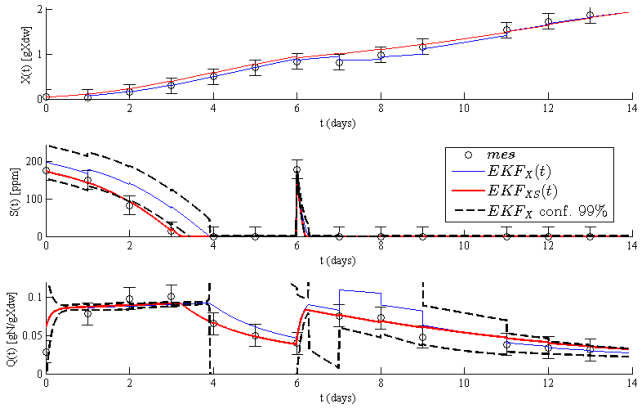

Figure 1: Internal quota estimation with EKF using only Biomass measurements and both Biomass and Substrate measurements (Experimental Data)

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