

Model-Based Identification and Control on Baker's Yeast Fed-Batch Fermentation

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Abstract

A laboratory set-up constituted by a PC-based simulator of non-linear multiple-input multiple-output dynamic systems and by a Control Computer is employed for studies concerning the on-line identification and control of a virtual baker's yeast fed-batch fermentation. The 'Control Computer' receives, optionally in 'real time' or in 'simulation time', the 'measured' state variables generated by the 'Process Computer', performs the estimation, computes the control action and sends the command to the process. The state observer, the observer-based kinetic estimator and the linearizing controller show a robust behaviour under different situations where process parameters, operating variables and measuring characteristics (noise and delays) are changed in the process computer.

The Process-Baker's yeast

- The dynamical model is obtained from a mass balance on the components considering that: the reactor is well mixed, the yield coefficients are constant and known, the dynamics of the gas phase can be neglected.
- The kinetic model assumes the existence of three pathways: respiratory growth on glucose, fermentative growth on glucose and respiratory growth on ethanol.
- It is supposed that the fermentative growth on glucose and the respiratory growth on ethanol pathways are competitive.
- This competition is governed by the instantaneous oxygen uptake capacity of the cells which can or cannot meet the oxygen needs for the total glucose uptake by the respiratory pathway.

Control Algorithm

- The algorithm is constituted by three elements: an Luenberger-type asymptotic observer, an Observer-based estimator and an exact linearizing control law. The design is based on two partial models representing two possible process states (ethanol production and ethanol consumption) from which arises two different algorithms.

- The difference between both algorithms is reflected in the formulation of the specific growth rate vector and of the yield coefficient matrix.
- The detection of the proper process state is based on the kinetics estimation. The transition between the two sets of algorithms consists on swapping the yield coefficients matrix and the kinetics vector.
- With this approach, only two measured variables are needed.

Case Study

Control Objective-

ethanol regulation for a set point of $E^*=0.5$ g/l.

Initial conditions-

$X(0)=0.1$ g/l, $S(0)=0.5$ g/l, $E(0)=0.25$ g/l

$C(0)=0.0066$ g/l, $V(0)=3.5$ g/l, $S_{in}(0)=10$ g/l

Final volume: 10 l

Measured variables - dissolved oxygen (C) and dissolved carbon dioxide (G).

Estimated variables - biomass (X), glucose (S), ethanol (E); kinetics.

Controlled variable - Glucose feed-rate.

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$$\frac{d\xi}{dt} = K\phi(\xi) - D\xi + U$$

$$\xi^T = [\xi_1^T, \xi_2^T]$$

state variable vector

$$K^T = [K_1^T, K_2^T]$$

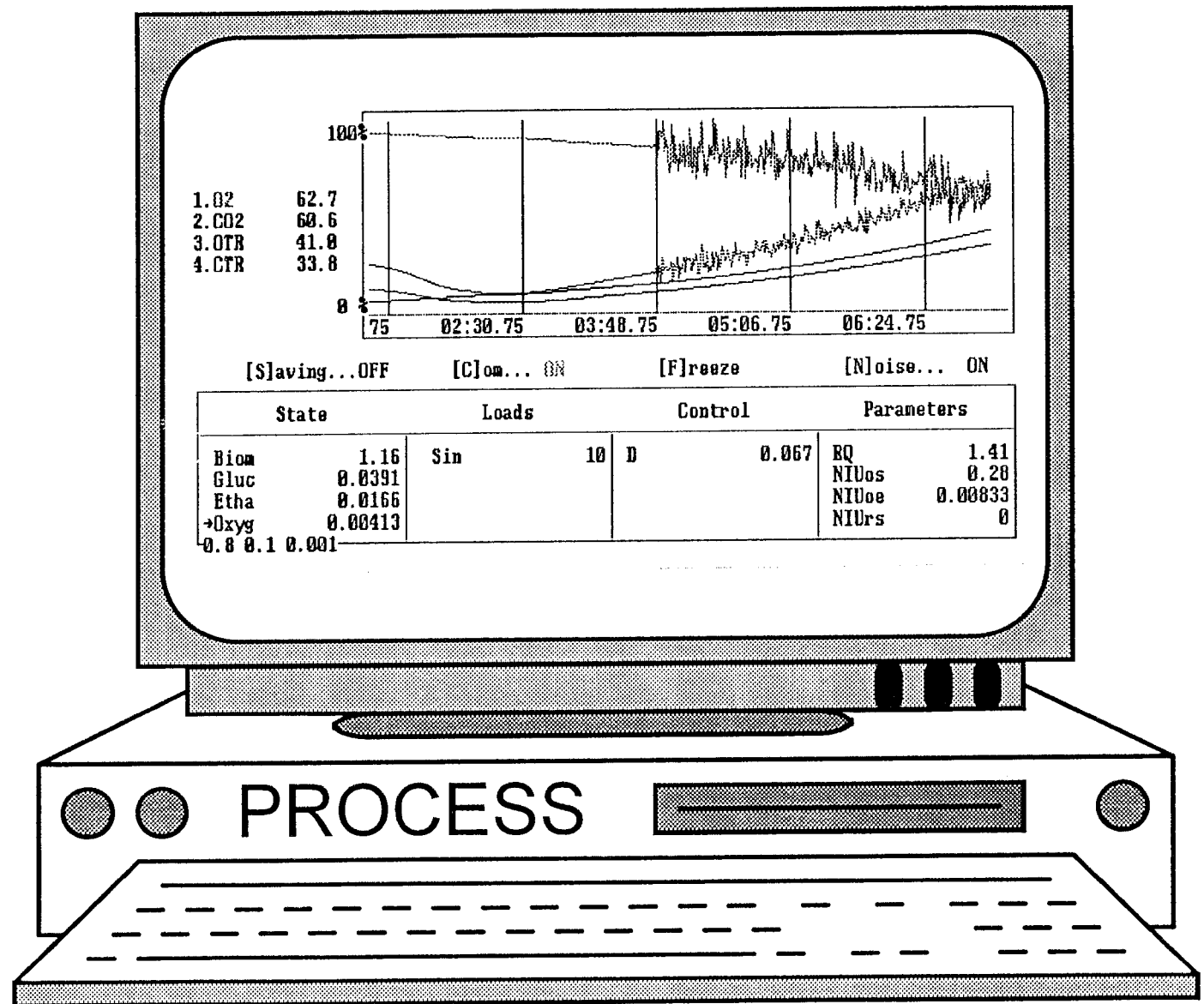
Yield coefficient matrix

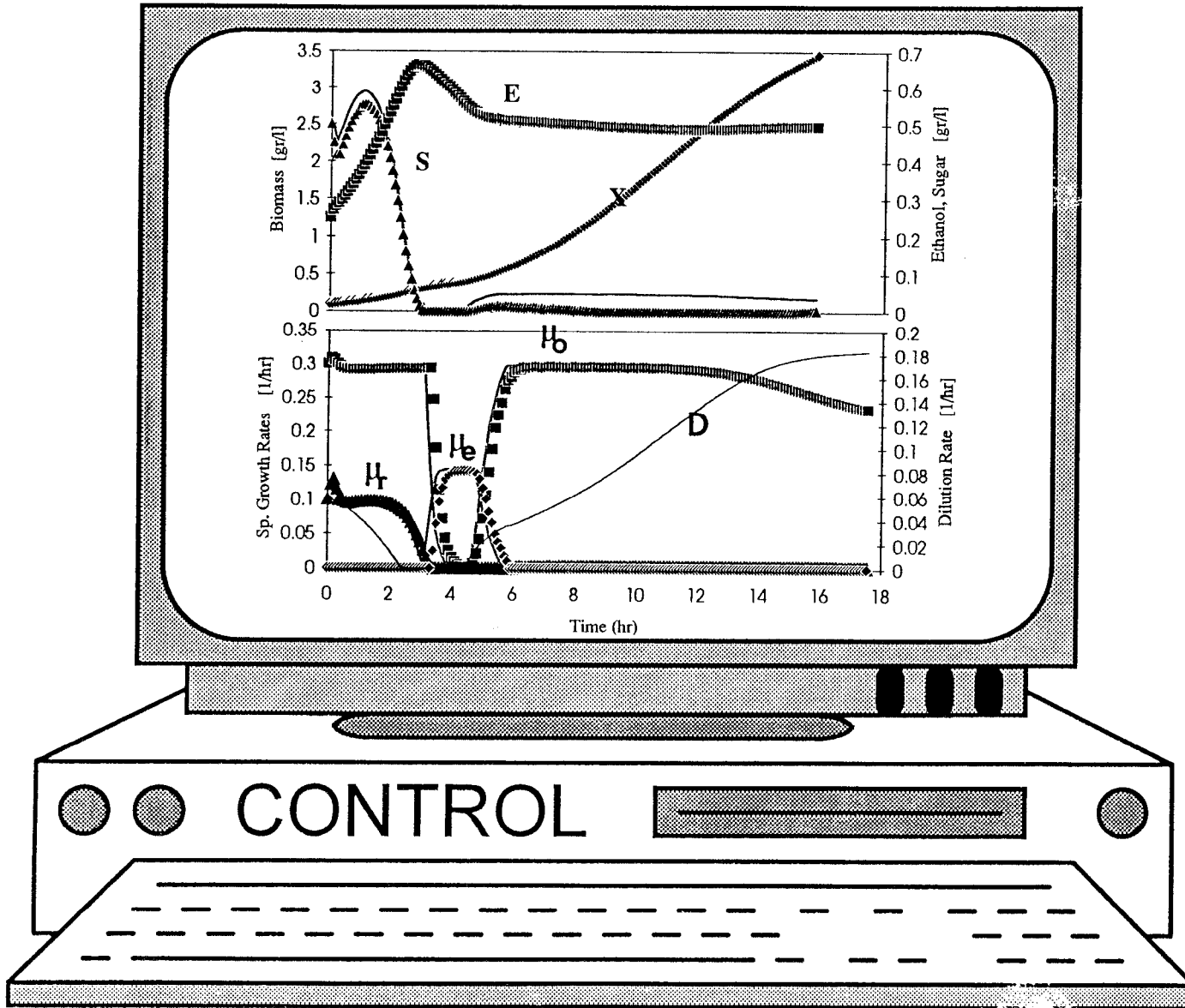
$$U^T = [U_1^T, U_2^T]$$

Net flow vector

index 1- refers to the state partition related with the measured variables.

index 2- refers to the state partition related with the non-measured variables





State observer

$$Z = \xi_2 - K_2 K_1^{-1} U_1$$

$$\frac{dZ}{dt} = -DZ + U_2 - K_1^{-1} K_2 U_1$$

$$\hat{\xi}_2 = Z + K_2 K_1^{-1} \xi_1$$

Kinetic estimator

$$\psi = K_1^{-1} \xi_1$$

$$\frac{d\hat{\psi}}{dt} = \mu X - D\hat{\psi} + K_1^{-1} U_1 + \Omega(\psi - \hat{\psi})$$

$$\frac{d\hat{\mu}}{dt} = \Gamma(\psi - \hat{\psi})X$$

Control law

$$D = \frac{\lambda_1(E^* - E) + \theta_1(CTR) - \theta_2(OTR)}{\theta_3 \text{Sin} - E}$$