ADAPTIVE CONTROL FOR MAXIMUM PRODUCTIVITY OF CONTINUOUS BIOPROCESSES

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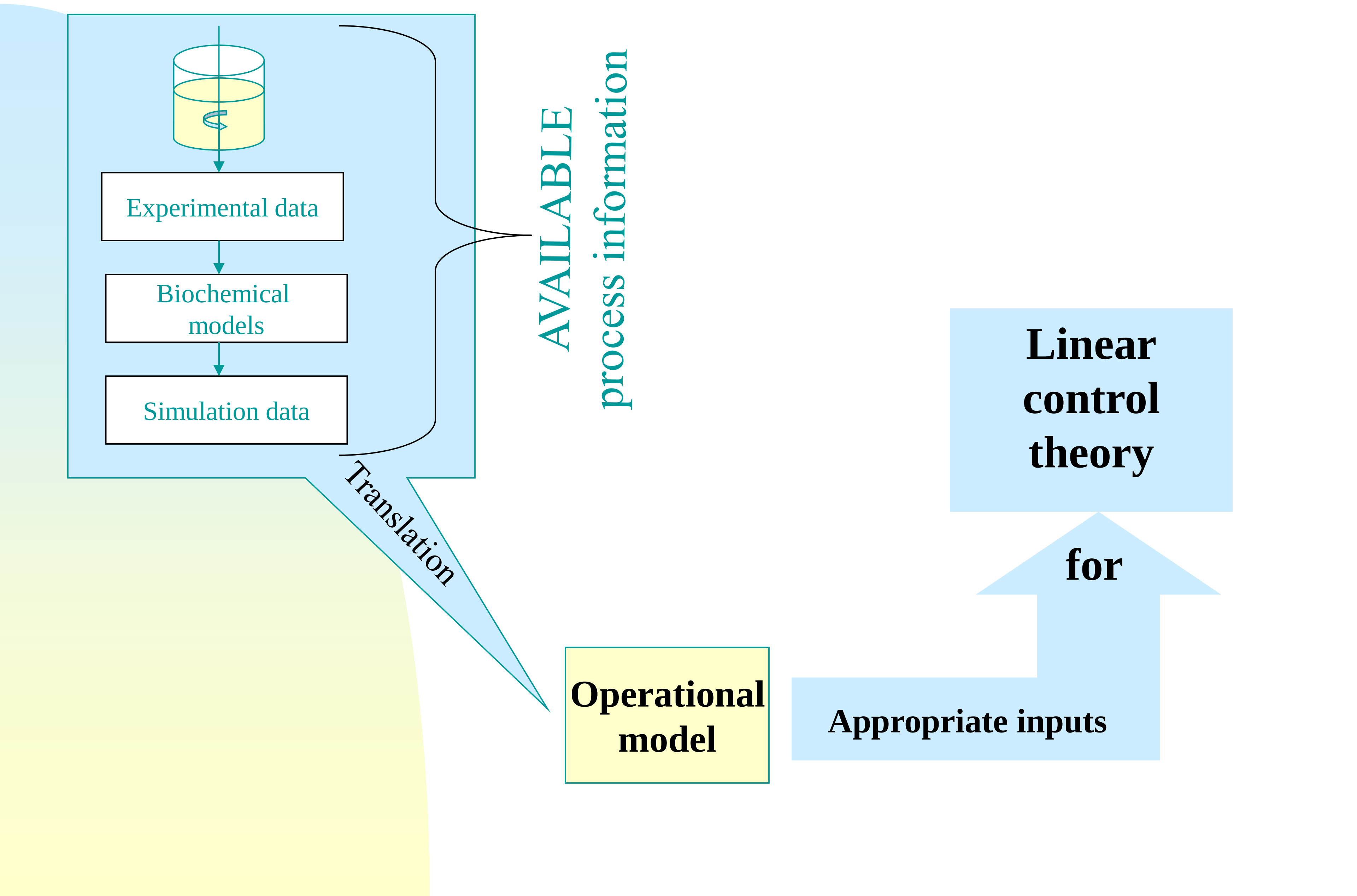
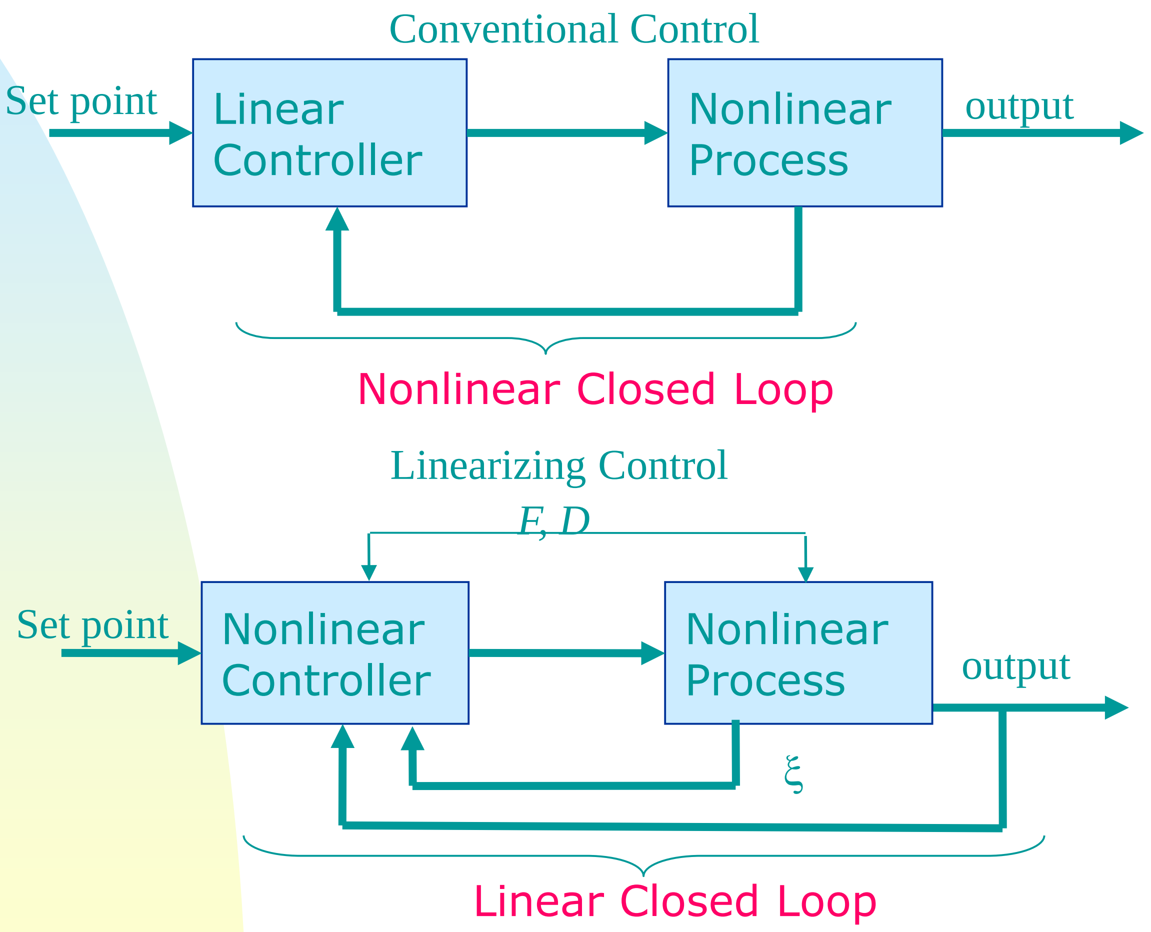
Model-based control



Conventional and Linearizing Control Schemes



Initial information of gluconic acid fermentation

$$\frac{dX}{dt} = R_x;$$

$$\frac{dG}{dt} = -R_x - R_{GOT};$$

$$\frac{dGOT}{dt} = R_{GOT} - R_{GA};$$

$$\frac{dGA}{dt} = R_{GA};$$

$$\frac{dO}{dt} = -R_{GOT} + 0.5R_{H_2O_2} + K_L a(O_2^* - O_2);$$

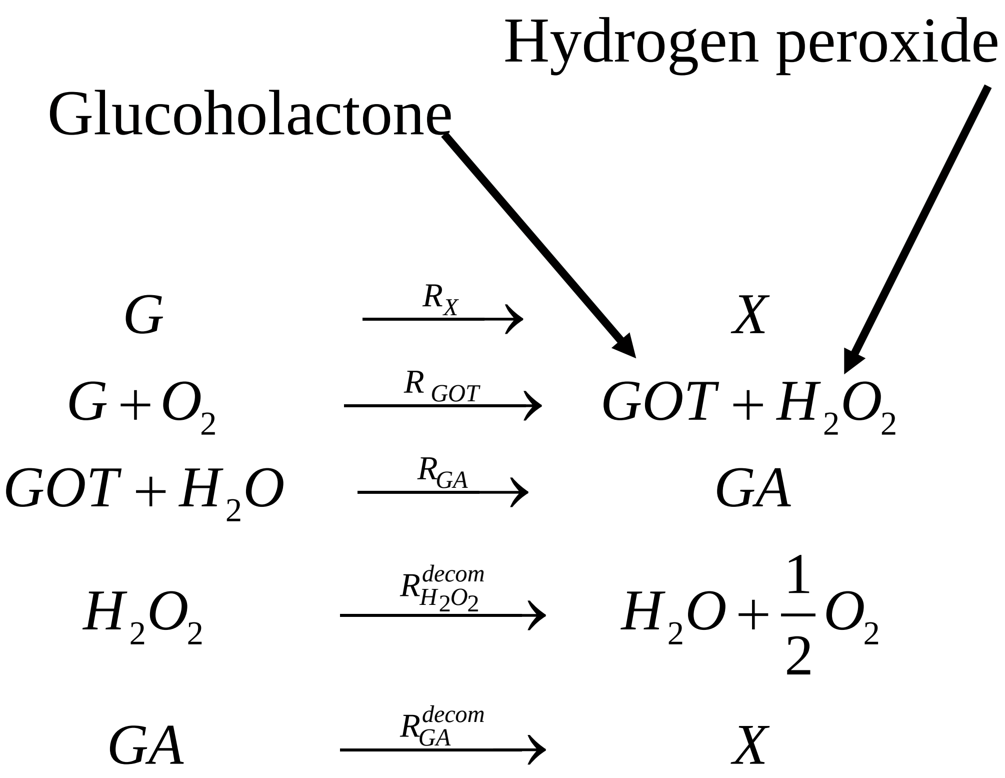
$$\frac{dH_2O_2}{dt} = -R_{H_2O_2};$$

where

$$R_{H_2O_2} = R_{GOT} - R_{H_2O_2}^{decom};$$

$$R_x = \mu_{\max} X \frac{k - X}{k};$$

$$R_{GA} = \mu_{GA} GA \frac{(k_{GA} - GA)}{k_{GA}};$$



Biochemical model and reaction scheme reduction

$$G \xrightarrow{R_X} X$$

$$G + O_2 \xrightarrow{R_{GOT}} GOT + H_2O_2$$

$$GOT + H_2O \xrightarrow{R_{GA}} GA$$

$$H_2O_2 \xrightarrow{R_{H_2O_2}^{decom}} H_2O + \frac{1}{2}O_2$$

~~$GA \xrightarrow{R_{GA}^{decom}} X$~~

$$G \xrightarrow{R_X} X$$

$$G + O_2 \xrightarrow{R_{GA}} GA$$

Reducted biochemical model

$$\frac{dX}{dt} = R_x;$$

$$\frac{dG}{dt} = -R_x - R_{GOT};$$

$$\frac{dGOT}{dt} = R_{GOT} - R_{GA};$$

$$\frac{dGA}{dt} = R_{GA};$$

$$\frac{dO}{dt} = -R_{GOT} + 0.5R_{H_2O_2} + K_L a(O_2^* - O_2);$$

$$\frac{dH_2O_2}{dt} = -R_{H_2O_2};$$

where

$$R_{H_2O_2} = R_{GOT} - R_{H_2O_2}^{decom};$$

$$R_x = \mu_{\max} X \frac{k - X}{k};$$

$$R_{GA} = \mu_{GA} GA \frac{(k_{GA} - GA)}{k_{GA}};$$

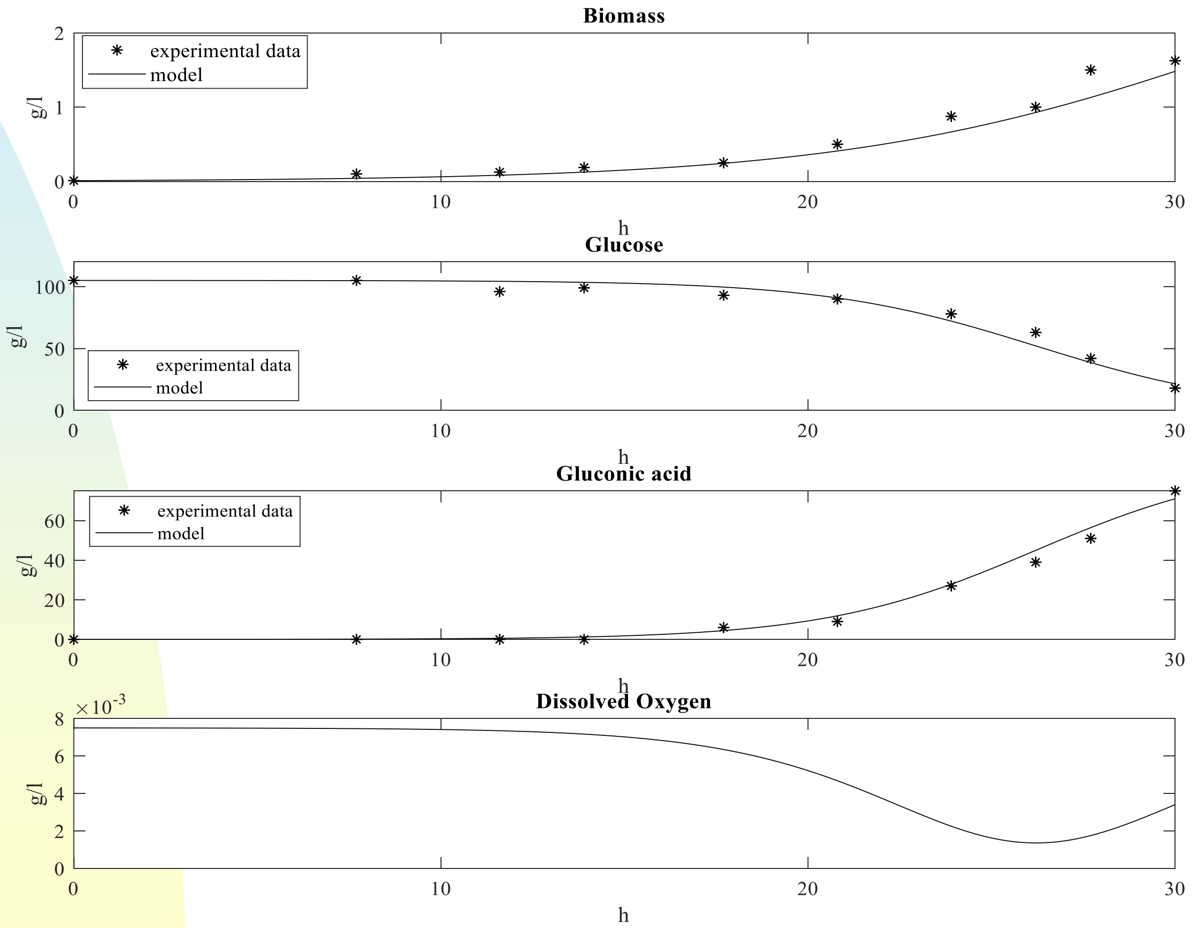
$$\frac{dX}{dt} = R_x;$$

$$\frac{dG}{dt} = -R_x - R_{GA};$$

$$\frac{dGA}{dt} = R_{GA};$$

$$\frac{dO}{dt} = -0.5R_{GA} + K_L a(O_2^* - O_2),$$

Reducted model simulation



General dynamical model derivation

Bastin, G. and D. Dochain (1990). *On-line estimation and adaptive control of bioreactors*, Amsterdam, Oxford, New York, Tokyo: Elsevier.

Dochain, D. and P. A. Vanrolleghem (2001). *Dynamical Modelling and Estimation in Wastewater Treatment Processes*, IWA Publishing

$$G \xrightarrow{\varphi_1} X$$

$$G + O_2 \xrightarrow{\varphi_2} GA$$

$$\frac{d\xi}{dt} = \sum_i (\pm) k_i \varphi_i - D\xi + F_i$$

General Dynamical Model

Process kinetics

Transport dynamics

$$d\xi/dt = K\varphi - D\xi + F$$

KNOWN!

Model transformation

$$\dot{\xi}_a = K_a\varphi - D\xi_a + F_a$$

measured

$$\dot{\xi}_b = K_b\varphi - D\xi_b + F_b$$

unmeasured

$$Z = A_0\xi_a + \xi_b$$

Auxiliary state variable State partition

$$\dot{\xi} = K_a\varphi - D\xi_a + F_a$$

$$\dot{Z} = A_0F_a - D\xi_b + F_b$$

Biomass and gluconic acid observers

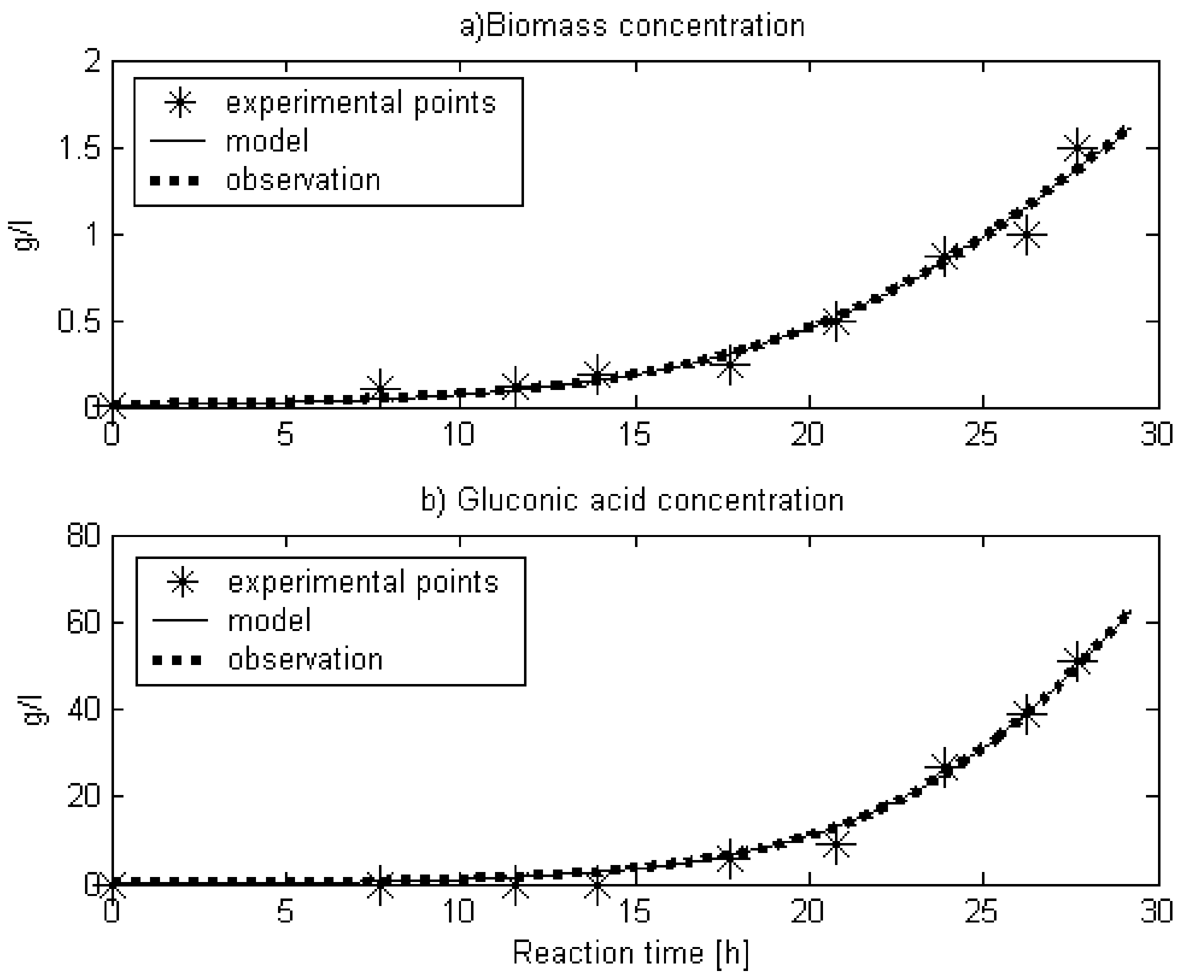
$$\dot{Z}_1 = -DZ_1 + DG_{in};$$

$$\dot{Z}_2 = -DZ_2 + K_L a(O_2^* - O_2);$$

$$X_e = \frac{1}{k_1} Z_1 - \frac{k_2}{k_1 k_3}(Z_2 - O_2) - \frac{1}{k_1} G$$

$$GA_e = \frac{1}{k_3}(Z_2 - O_2)$$

Observers cross validation



Adaptive linearizing control design for continuous process

Reaction scheme

$$G \xrightarrow{\varphi_1} X$$

$$G + O_2 \xrightarrow{\varphi_2} GA$$

General model

$$\dot{X} = \varphi_1 - DX$$

$$\dot{G} = -k_1\varphi_1 - k_2\varphi_2 - D(G - G_{in})$$

$$\dot{O}_2 = -k_3\varphi_2 - DO_2 + K_L a(O_2^* - O_2)$$

$$\dot{GA} = \varphi_1 - DGA$$

Reaction rates

$$\varphi_1 = GX\alpha_1$$

$$\varphi_2 = GO_2\alpha_2$$

General model in linear regression form

$$dX_e / dt = X_e G\theta_1 - DX_e$$

$$dG / dt = -X_e G\theta_2 - GO_2\theta_3 - D(G - G_{in})$$

$$dO_2 / dt = -GO_2\theta_4 - DO_2 - K_L a(O_2^* - O_2)$$

$$dGA_e / dt = GO_2\theta_5 - DGA_e$$

Input (***D***)/output(***GA***) model

Reference model for the regulation error

$$\frac{d(GA^* - GA_e)}{dt} + \lambda(GA^* - GA_e) = 0$$

$$\frac{dG^*}{dt} = 0$$

$$\lambda(GA^* - GA_e) = \frac{dGA_e}{dt}$$

$$D = \frac{-\lambda(GA^* - GA_e) + GO_2\theta_5}{GA_e}$$

Estimator of new kinetics parameters

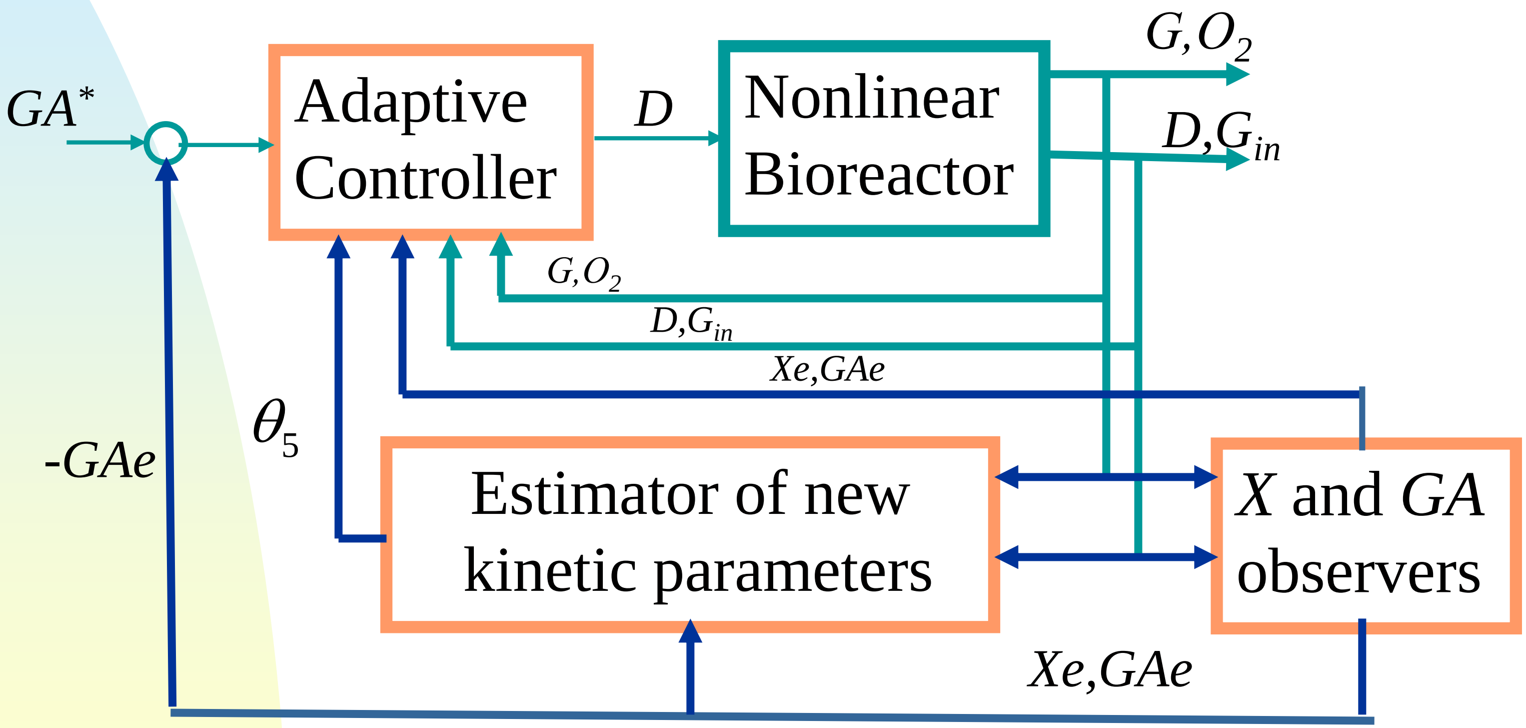
$$\dot{\hat{G}} = -X_e G \hat{\theta}_2 - GO_2 \hat{\theta}_3 - D(G - G_{in}) + \omega_2 (G - \hat{G})$$

$$\dot{\hat{\theta}}_2 = -X_e G \gamma_2 (G - \hat{G})$$

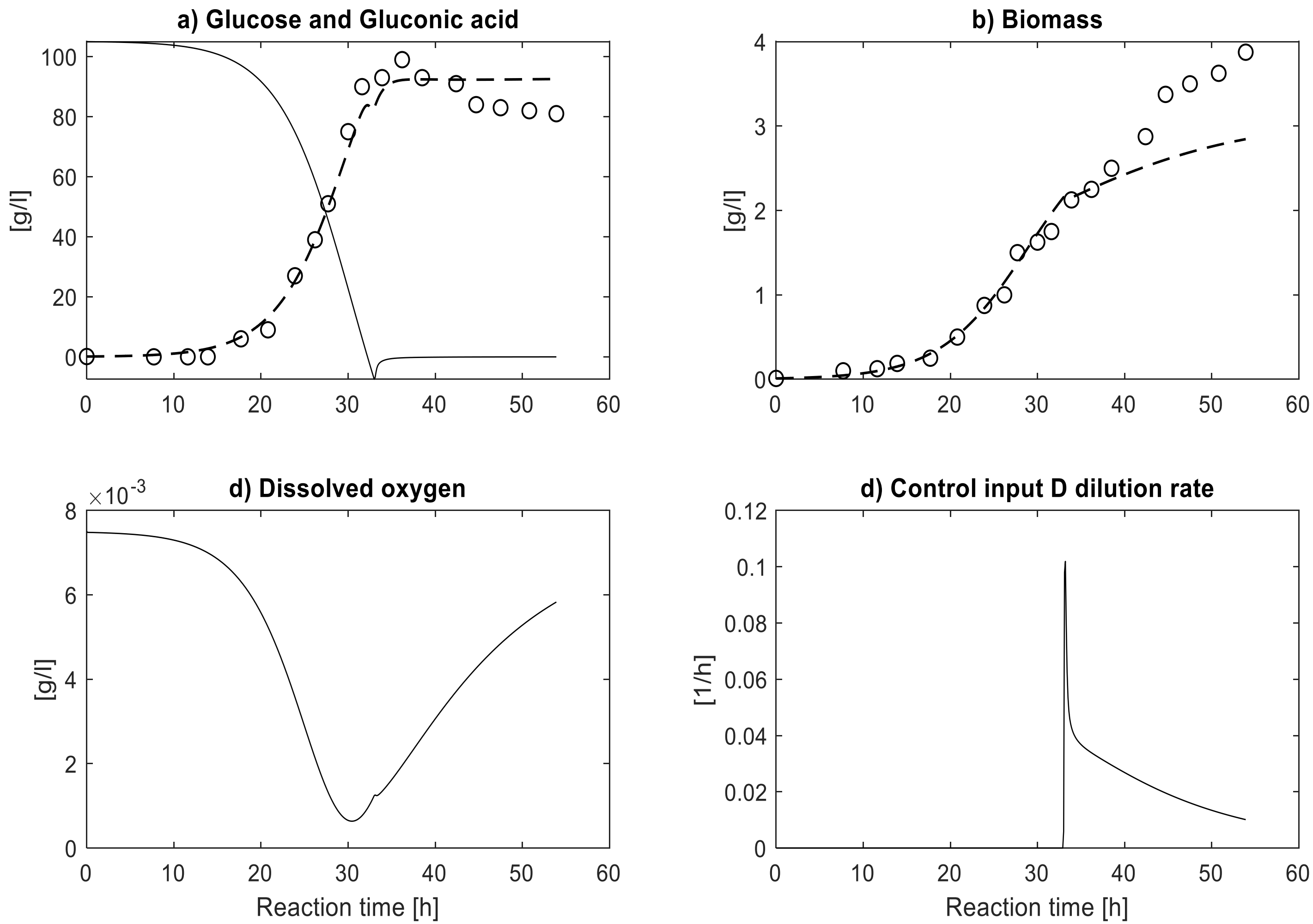
$$\dot{\hat{\theta}}_3 = -GO_2 \gamma_2 (G - \hat{G})$$

$$\gamma_2 = \omega_2^2 / 4[(XeG)^2 + (GO_2)^2];$$

Control scheme



Simulation of the control scheme



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Thanks for your attention