Adaptive Estimator for Biological Clock of Crassulacean Acid Metabolism

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Outline

- Background
- Objectives of this paper
- The minimal CAM model
- Estimator of the tonoplast order
- Simulation results
- Conclusion

Background

- Crassulacean acid metabolism (CAM)

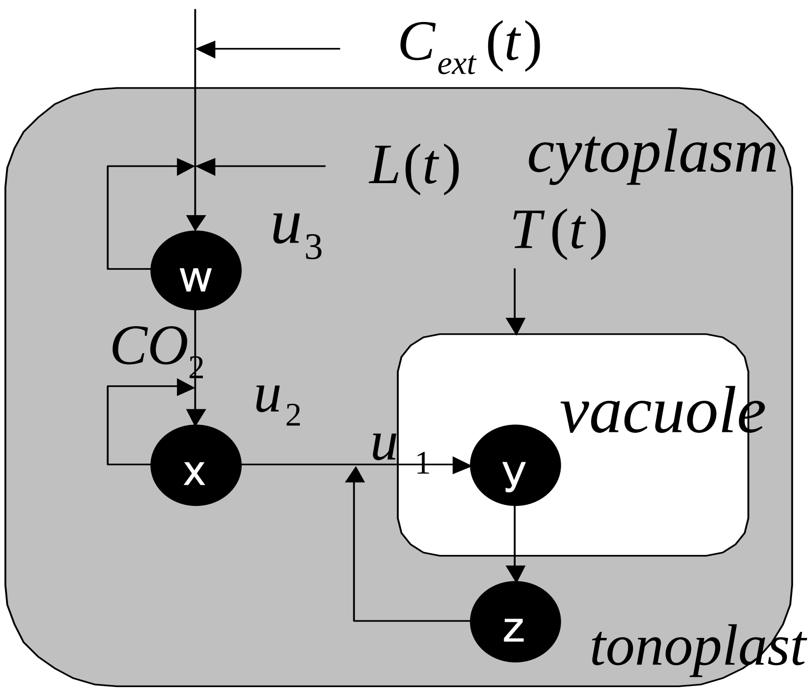
CAM is a special mode of photosynthesis providing a mechanism for plants to concentrate CO_2 and economize water use.

Blasius et.al. used throughout continuous time differential equations.

Objective of this paper

We present an adaptive observer to estimate the state and the nonlinear function in the dynamics of the tonoplast order assuming that the available signal is only the internal CO_2 concentration.

The Minimal CAM Model



$$\epsilon \dot{w} = -u_2 + u_3$$
$$\epsilon \dot{x} = -u_1 + u_2$$
$$\dot{y} = u_1$$
$$\tau \dot{z} = g(z, T) - y$$

w: internal CO_2 concentration.

x: malate concentration in the cytoplasm.

y: malate concentration in the vacuole.

z: a variable that describes the ordering of the lipid molecules in the tonoplast membrane.

$$u_1 = cx - \frac{y}{z}$$
$$u_2 = \frac{w}{x} - x$$
$$u_3 = c_J \frac{C_{ext}(t) - w}{\exp(\alpha w)} - L(t)w + c_R \frac{L_K}{L(t) + L_K} \frac{w_1}{w + w_1}$$

u_1:the difference between malate influx and efflux into and out of the vacuole,modeled with the dynamics hysteresis.

u_2:the difference between malate production from CO_2 fixation by Phosphoenolpyruvate carboxylase (PEPC) and its depletion by decarboxylation.

u_3:CO_2 uptake from outside,$C_{ext}(t)$, minus CO_2 consumption by photosynthesis,$L(T)$,plus CO_2 production by respiration.

The CAM model can be regarded as a nonlinear dynamical system that consists of

input variables : T, L, C_{ext}

state variables : w, x, y, z

small time constants : ϵ, τ

constant parameters : $c, c_J, c_R, L_K, w_1, \alpha$

nonlinear function : $g(z, T)$

Estimator of the tonoplast order

Fuzzy identifier of nonliner function and states with available signal w, x, y and T

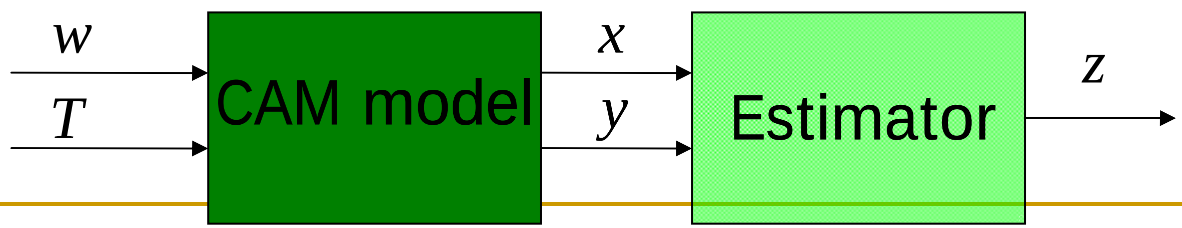
Problem

Estimate the tonoplast order z

$$\lim_{0\to\infty}\{z(t)-\widehat{z}(t)\}=0$$

Assumption

- w, x, y, T **are available**
- $g(z, T)$ **is known**



- w, x, y, T **are available**
- **Nonlinear function $g(z, T)$ is known**

The model to be estimated

$$\dot{z} = \frac{1}{\tau}\{g(z, T) - y\}$$

$$\dot{y} = cx - \frac{y}{z}$$

observer-type dynamic estimator

$$\dot{\hat{z}} = \frac{1}{\tau}\{g(\hat{z}, T) - y\} + k(y - \hat{y})$$

$$\dot{\hat{y}} = cx - \frac{\hat{y}}{\hat{z}}$$

- w, x, y, T **are available**
- **Nonlinear function** $g(z,T)$ **is unknown**

Approximated nonlinear function

$$\widehat{g}(z,T) = \widehat{\theta}^T \zeta(z,T)$$

ζ : **Known basis function**

$\widehat{\theta}$: **estimate of Deployment function**

Adaptive identifier of nonlinear function

$$\begin{aligned}\dot{\hat{z}} &= \frac{1}{\tau}\{g(\hat{z},T) - y\} + k(y - \hat{y}) \\ &= \frac{1}{\tau}\left\{\widehat{\theta}^T \zeta(\hat{z},T) - y\right\} + k(y - \hat{y})\end{aligned}$$

$$\begin{aligned}\dot{\hat{y}} &= cx - \frac{\hat{y}}{\hat{z}} \\ \dot{\hat{\theta}} &= -\gamma\zeta(\hat{z},T)(\hat{y} - y) - \alpha\hat{\theta}\end{aligned}$$

Fuzzy identifier of nonliner function and states with avilable signal w and T

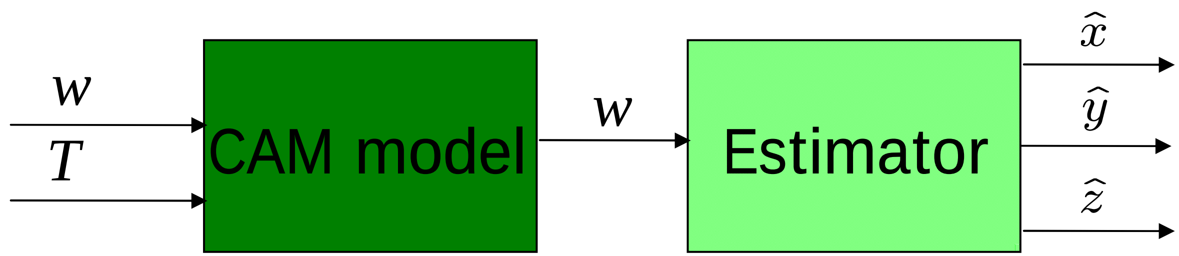
Problem

Estimate the tonoplast order

$$\lim_{t\to\infty}\{\hat{z}(t)-z(t)\}=0$$

Assumption

- w, T **are available**
- $g(z,T)$ **is known**



Approximated nonlinear function

$$\widehat{g}(z,T) = \widehat{\theta}^T \zeta(z,T)$$

observer-type dynamic estimator

$$\begin{aligned}
\dot{\widehat{w}} &= \widehat{f}_1 + k_w(w - \widehat{w}) \\
\dot{\widehat{x}} &= \widehat{f}_2 + k_x(w - \widehat{w}) \\
\dot{\widehat{y}} &= \widehat{f}_3 + k_y(w - \widehat{w}) \\
\dot{\widehat{z}} &= \frac{1}{\tau}\{\widehat{g}(\widehat{z},T) - \widehat{y}\} + k_z(w - \widehat{w})
\end{aligned}$$

k_w, k_x, k_y, k_z:observer gains

$\widehat{f}_1, \cdots, \widehat{f}_4$ are defined as

$$\begin{aligned}
\widehat{f}_1 &= \frac{1}{\epsilon}\{\widehat{u}_2 + u_3\} \\
\widehat{f}_2 &= \frac{1}{\epsilon}\{\widehat{u}_1 + \widehat{u}_2\} \\
\widehat{f}_3 &= \widehat{u}_1 \\
\widehat{f}_4 &= \frac{1}{\tau}\{\widehat{g}(\widehat{z},T) - \widehat{y}\} \\
\widehat{u}_1 &= c\widehat{x} - \frac{\widehat{y}}{\widehat{z}} \\
\widehat{u}_2 &= \frac{w}{\widehat{x}} - \widehat{x}
\end{aligned}$$

Adaptive identifier of nonlinear function

$$\dot{\widehat{\theta}} = -\gamma\zeta(\widehat{z},T)(\widehat{w} - w) - \alpha\widehat{\theta}$$

Simulation results

Simulation parameters(Blasius et al.)

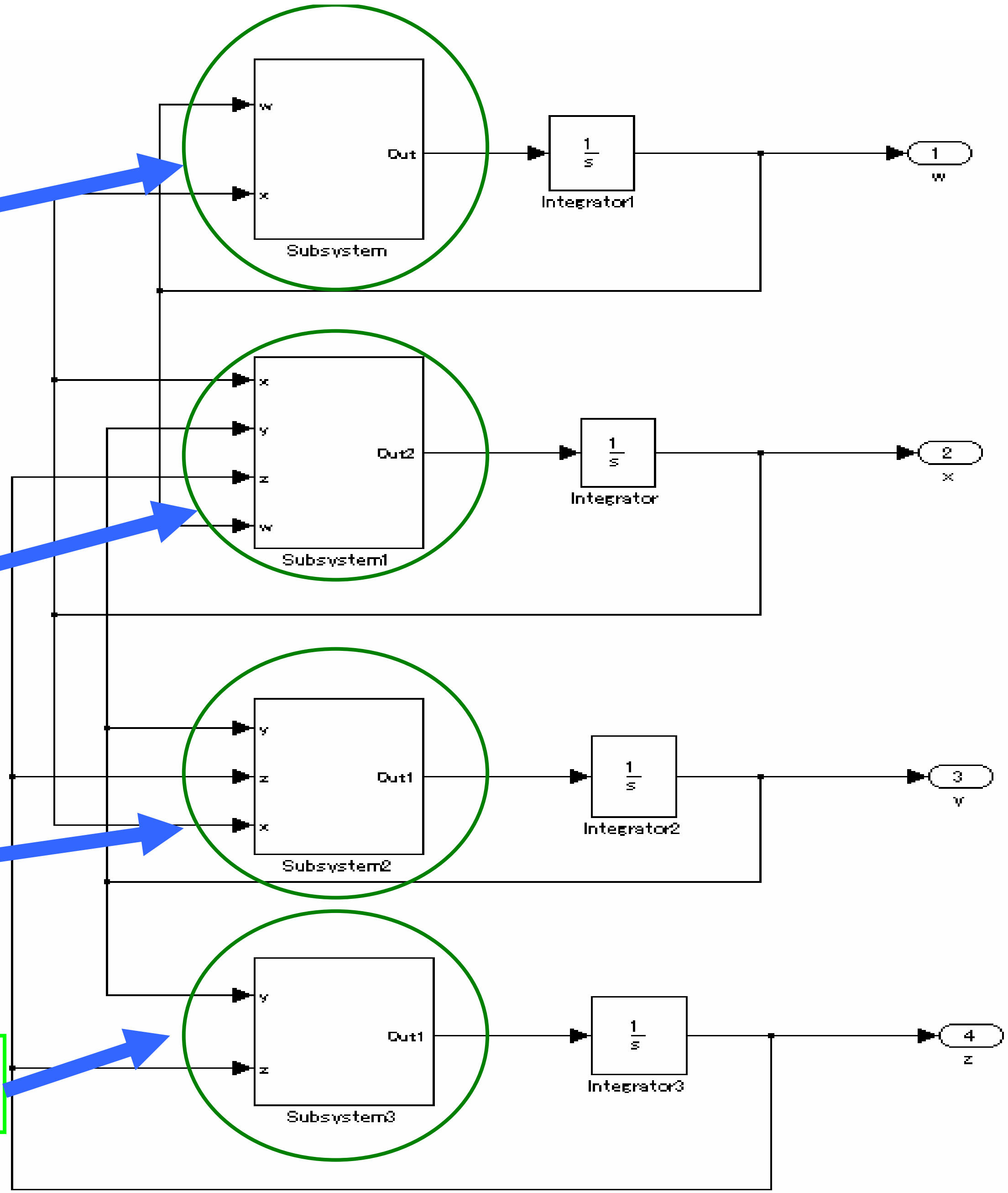
$$C_{ext} = 0$$
$$L(t) = 1$$
$$T = 0.2238, 0.2242, 0.2246, 0.2250, 0.2254$$
$$c = 5.5$$
$$c_J = 1$$
$$c_R = 1$$
$$\epsilon = 0.001$$
$$\tau = 0.35$$
$$\alpha = 1.5$$
$$w_1 = 0.1$$
$$L_K = 0.5$$
$$R = 0.1$$

$$\epsilon \dot{w} = -u_2 + u_3$$

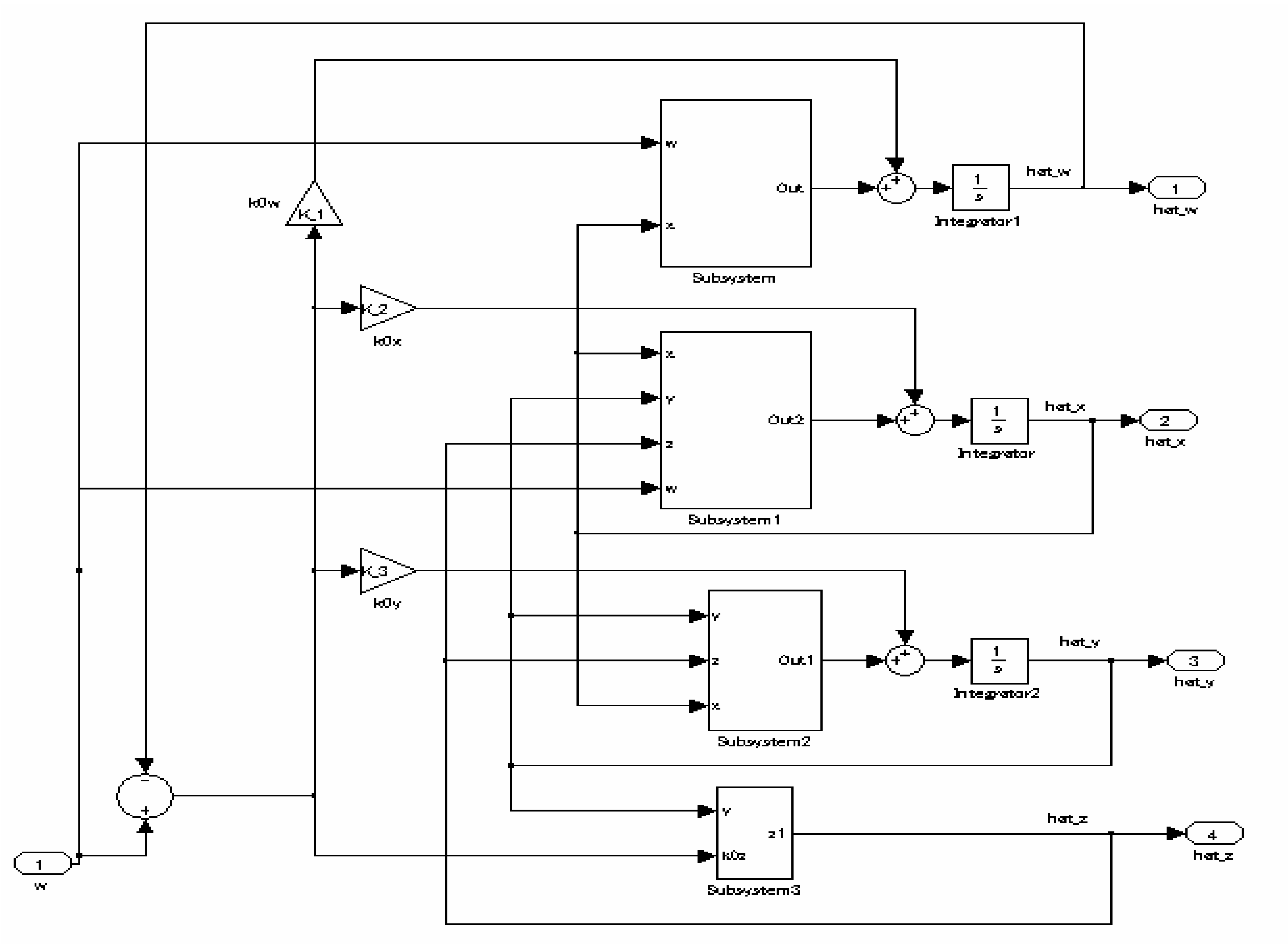
$$\epsilon \dot{x} = -u_1 + u_2$$

$$\dot{y} = u_1$$

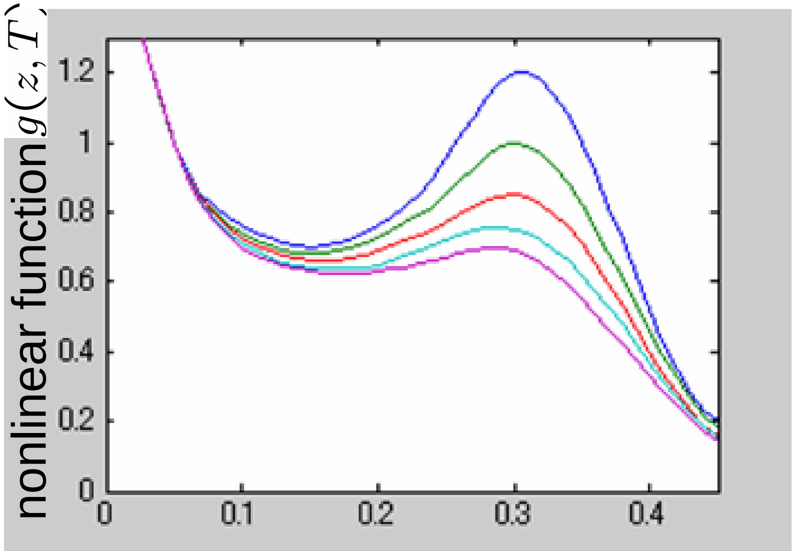
$$\tau \dot{z} = g(z, T) - y$$



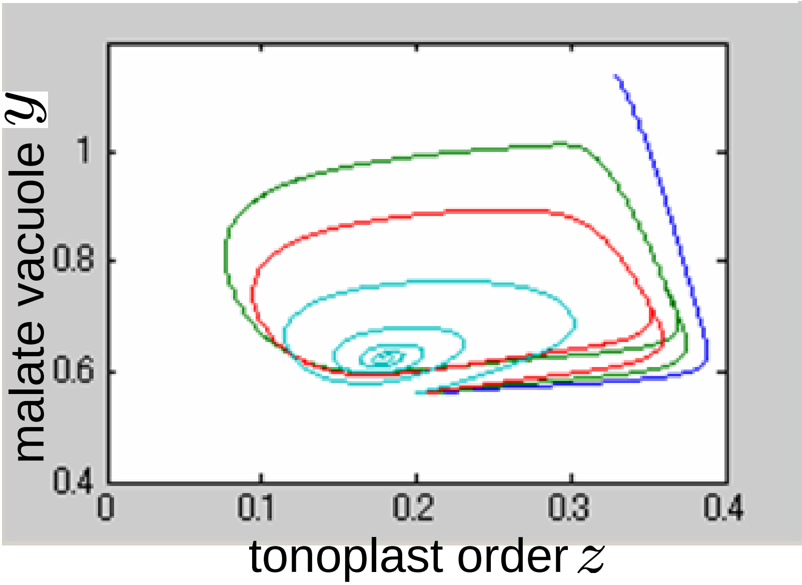
Simulink configuration of a CAM model



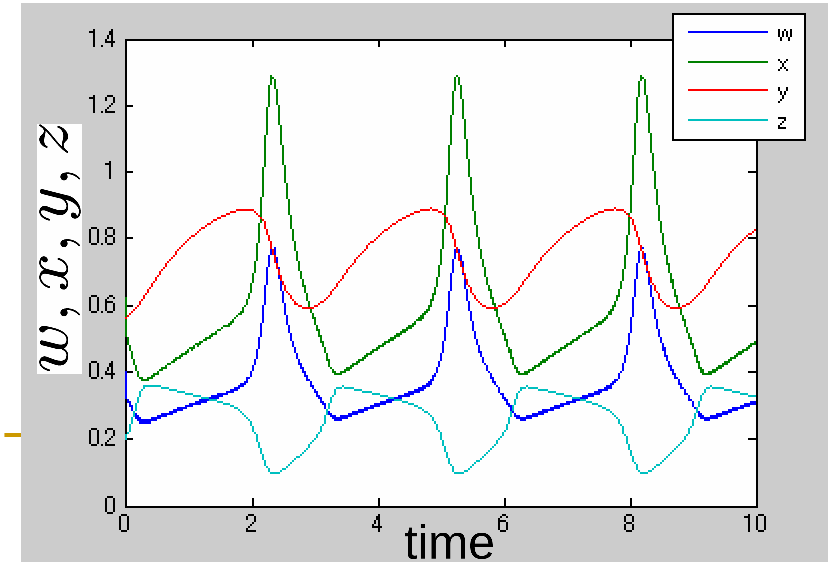
Simulink configuration of the adaptive observer g(z,T) when T = 0.2238 to 0.2254.



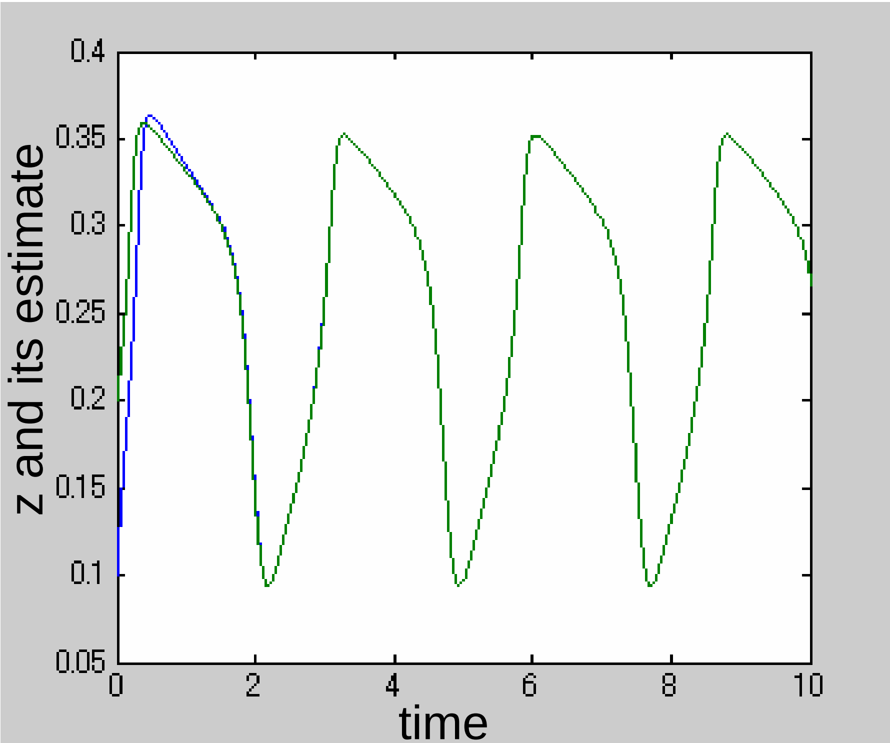
Dynamic behavior in continuous light in phase space for difference relative temperatures



Time responses of sustained endogenous rhythms in continuous light

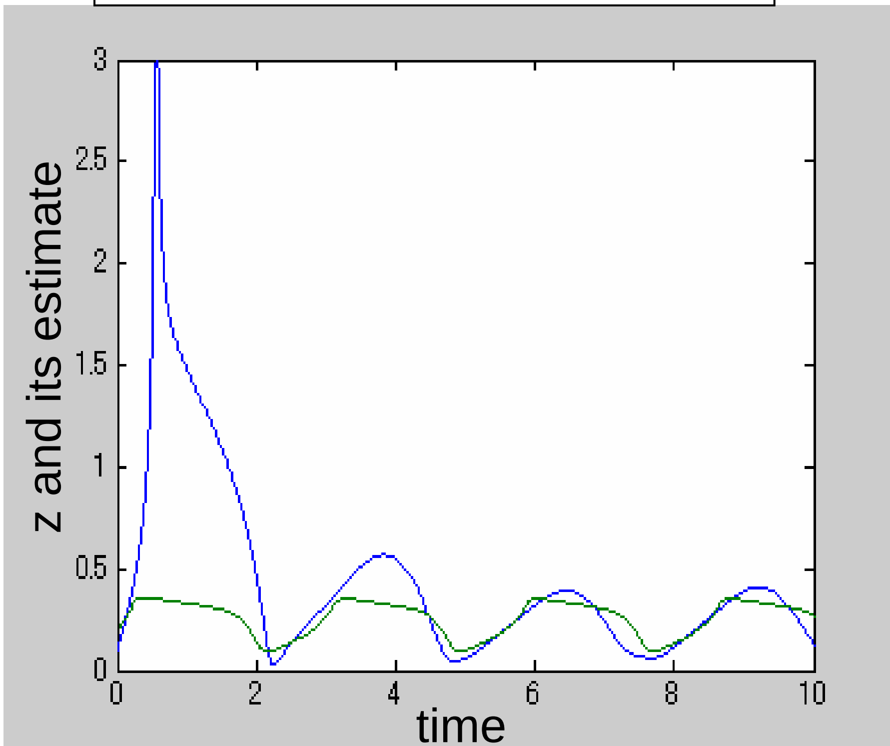


Time responses of z and $\hat{z}$ via observer ($T = 0.2246$)



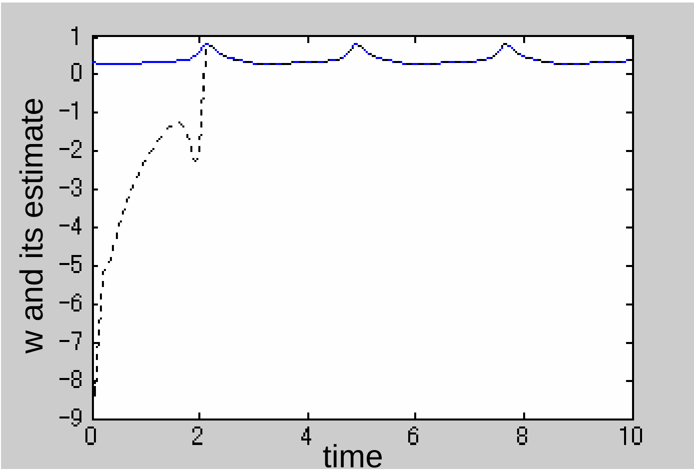
Nonlinear function $g(z, T)$ is known

Time responses of z and $\hat{z}$ via adaptive identifier ($T = 0.2246$)

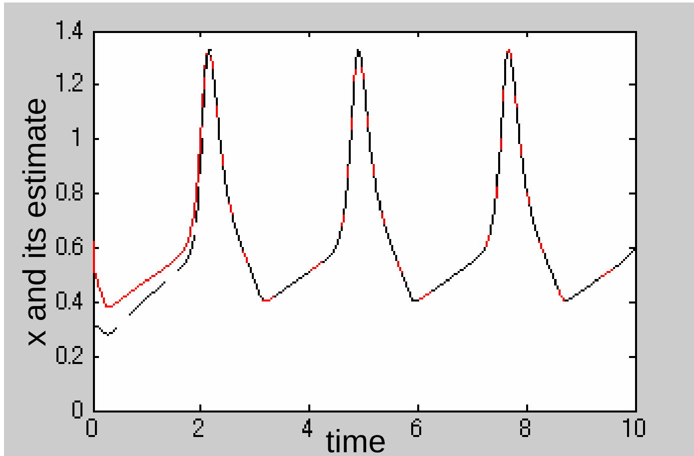


Nonlinear function $g(z, T)$ is unknown

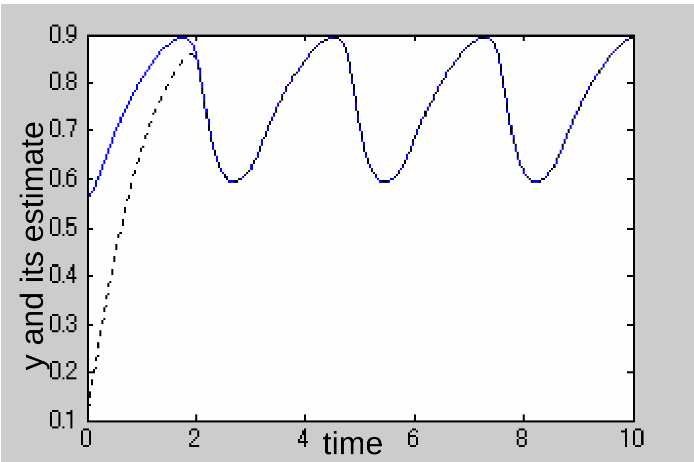
time responses of the observer-type estimator (T = 0.2246, w^(0)=0.1, x^(0)=0.1,y^(0) = 0.1,z^(0) = 0.1, kw=68,kx=0,ky=0,kz=-2.3.)



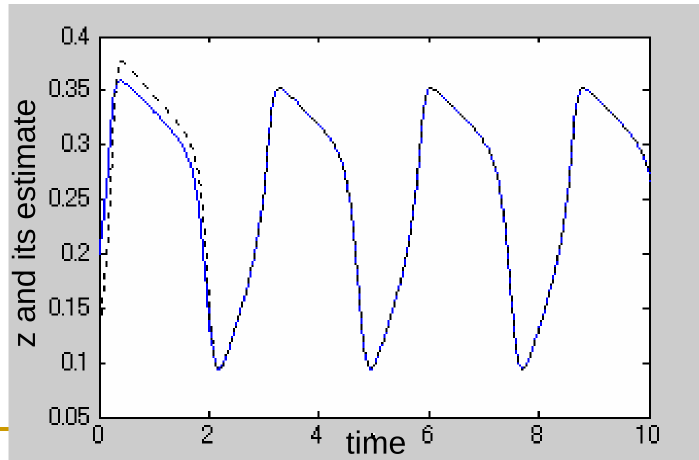
Time responses of w *and its estimate* $\hat{w}$



Time responses of x *and its estimate* $\hat{x}$



Time responses of y *and its estimate* $\hat{y}$



Time responses of z *and its estimate* $\hat{z}$

Conclusion

- We presented an adaptive observer of the CAM model to estimate the tonoplast order z and its nonlinear function g(z,T) .
- We are trying to design a controller such that the closed-loop system has a desired energy.