Comparison of Multiple Model Based Controller Coordination

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Agenda

- Motivation
- Methods
  - Proposed controller coordination method
  - Comparative method (Dougherty *et al.*, 2003)
- Case Study
  - Comparison of control capabilities
- Summary

Motivation

Multiple model based controller coordination
A new control method for …

- Nonlinear systems
- Hybrid systems (COE meeting in last summer)
- Large-scale systems

In this presentation

- The method is applied to Nonlinear systems
- Compare to another method (Dougherty *et al.* 2003)

Method - basic ideas of proposed method

Global modeling of complicated systems is difficult.

- A local model is used instead of a global model.
  - The local model can only work at the corresponding operational range.
  - The local controller based on the local models cannot work around the wide operational range.

Using multiple controllers:
Control system works well in the wide operational range.

Methods - Over view of controller coordination

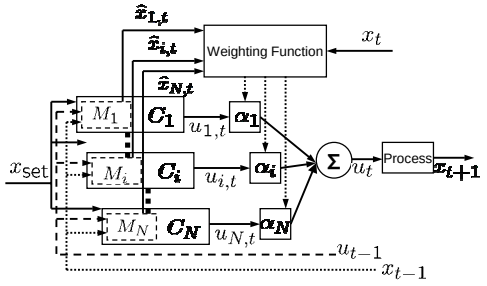


Image of multiple model based controller coordination

Methods - Dougherty & Cooper (2003)

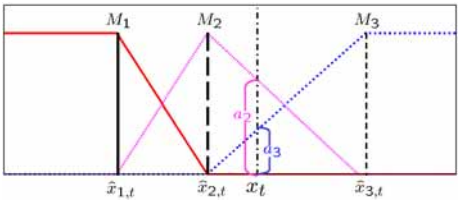
Weighting function (3 local models):

$$\begin{cases} \text{If } x_t \geq \hat{x}_{3,t}, & \text{then } \{\alpha_{1,t}, \alpha_{2,t}, \alpha_{3,t}\} = \{0, 0, 1\} \\ \text{If } \hat{x}_{3,t} > x_t \geq \hat{x}_{2,t}, & \text{then } \{\alpha_{1,t}, \alpha_{2,t}, \alpha_{3,t}\} = \left\{0, 1-\alpha_{3,t}, \frac{x_t - \hat{x}_{2,t}}{\hat{x}_{3,t} - \hat{x}_{2,t}}\right\} \\ \text{If } \hat{x}_{2,t} > x_t > \hat{x}_{1,t}, & \text{then } \{\alpha_{1,t}, \alpha_{2,t}, \alpha_{3,t}\} = \left\{1-\alpha_{2,t}, \frac{x_t - \hat{x}_{1,t}}{\hat{x}_{2,t} - \hat{x}_{1,t}}, 0\right\} \\ \text{If } \hat{x}_{1,t} \geq x_t, & \text{then } \{\alpha_{1,t}, \alpha_{2,t}, \alpha_{3,t}\} = \{1, 0, 0\} \end{cases}$$

- If-Then rules
- No tuning parameters

If the number of models is changed,
the algorithm must be changed.

Methods - Image of Dougherty's function



weights:
$\begin{cases} \alpha_1 = 0 \\ \alpha_2 = a_2 \\ \alpha_3 = a_3 \end{cases}$

The Image of Dougherty's weighting function using 3 local models.

- Coordination weights are decided by linear functions.
- Two of most suitable controllers are selected.
- No tuning parameters, Weights are decided uniquely.

Methods - Proposed weighting function

Weighting function:

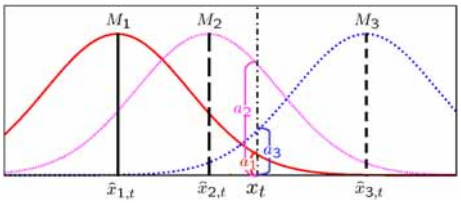
$$\alpha_{i,t} = \frac{\exp(-\beta\|\hat{x}_{i,t} - x_t\|^2)}{\sum_{i=1}^{N} \exp(-\beta\|\hat{x}_{i,t} - x_t\|^2)}$$

- Gaussian functions are normalized
- Introducing parameter β for tuning
- Summation of $\alpha_{i,t}$ is 1

$$\sum_{i=1}^{N} \alpha_{i,t} = 1$$

⇨ Process input is calculated as an affine combination of local controller outputs.

Methods - Image of proposed function



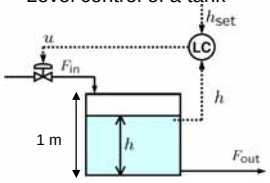
weights:
$\alpha_i = \frac{a_i}{\sum_{k=1}^{3} a_k}$

The Image of proposed weighting function using 3 local models.

- Controller weights are decided by Normalized Gaussian.
- Weights of inadequate controllers becomes small.
- Tuning parameter changes the distribution of Gaussian, weight can be changed for the control in various situations.

Case Study - Process

Level control of a tank



Process dynamics:

$$\frac{dh}{dt} = \frac{F_{max}\ u - c\sqrt{h}}{A}$$

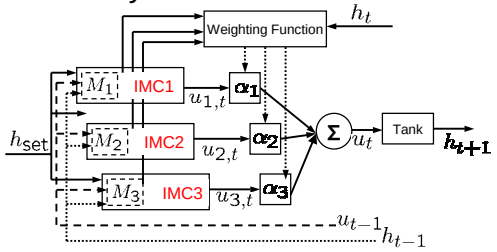
A	:	cross section
c	:	outflow constant
h	:	liquid level (output)
u	:	valve travel (input)
F_{max}	:	maximum of F_{IN}

Nonlinear system

Control problem:

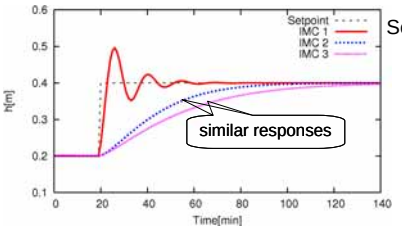
Tracking liquid level h to setpoint h_{set} without overshoot.

Control System



- Three models (M_1:0.001 m, M_2:0.5 m, M_3:0.999 m) is prepared.
- Local IMC (Internal model controller) are constructed.
- Each local IMC is tuned without causing overshoot in each local operational range.

Result - control responses of local controllers

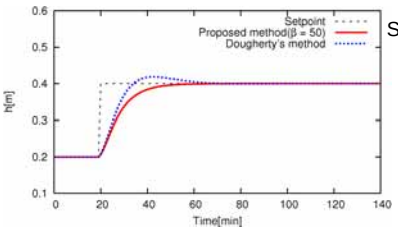


Setpoint h_{set} changes
0.2 m → 0.4 m

- IMC 1 (0.001 m) doesn't work well in this operational range.
- Convergence is slow in the case of IMC 2 & 3.

Each local controller cannot work well without combination of other controllers.

Result - control responses of both methods



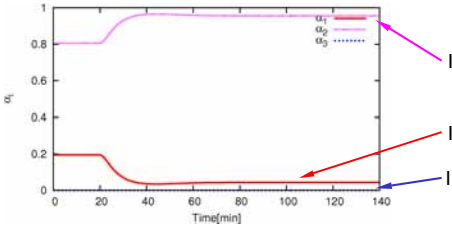
Setpoint h_{set} changes

$0.2\ \mathrm{m} \rightarrow 0.4\ \mathrm{m}$

- Control capabilities of both methods are better than that of local controllers.
- Dougherty's method shows a overshoot.
- Proposed method shows a good tracking without overshoot.

Proposed method shows a best control performance.

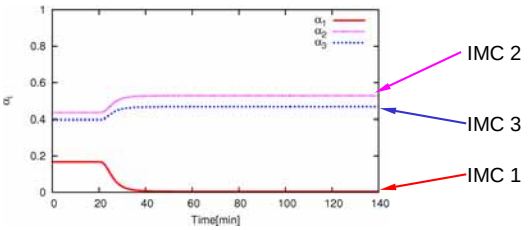
Time series of Weights - Dougherty's method



- IMC 3 is not used ($\alpha_3 = 0$), 2 of most suitable controllers are selected.
- α_1 doesn't change to 0 although IMC 1 doesn't work well around this range.

Dougherty's method can't decide effectual weights.

Time series of Weights - proposed method



- All controllers are used. (The response of IMC 2 & 3 was similar.)
- IMC 1 is not used ($\alpha_1 \fallingdotseq 0$) after 40 min.

Proposed method decides effectual weights.

Summary

- Multiple model based controller coordination method is compared with comparative method proposed by Dougherty *et al.*
- Our method shows a good control capability in a control.
- The method will be applied to another complicated systems in future.