Multiple Model Predictive Control for a Hybrid System

D1 Yoshiyasu Sakakura

Systems and Control Lab.

Outline

- Motivation
- Hybrid dynamical systems
- Final goal of the research
- Predictive control using multiple models
- Case Study
- Summary
- Future work

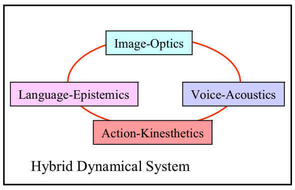
Motivation

Hybrid dynamical systems :

- The systems are both continuous and discrete

Examples

- Human behavior
- Mechanical systems
- Sequence control
- Industrial systems
- Transportation systems
- Communication systems



The future of COE Program

Many subjects of research in COE program also can be modeled as a hybrid dynamical systems.

- To establish the new control method for hybrid dynamical systems contribute for COE program.

Hybrid dynamical systems

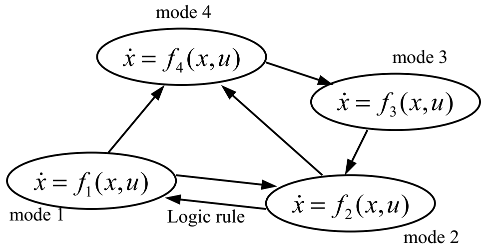


Image of hybrid dynamical systems.

There are multiple modes and logic rules in Hybrid Dynamical systems.

- Each mode is described as Differential Algebraic Equations (DAEs)
- Logic rules associate each mode.

Final goal of the research

Conventional control approaches for hybrid dynamical systems:

- huge computation time
- custom-built
- heuristics

Final goal of the research

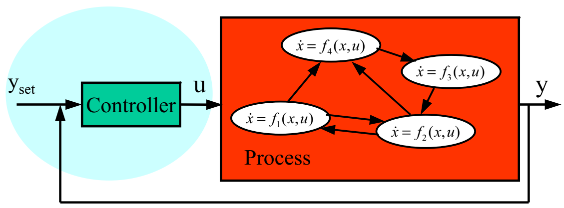
To propose new systematic controller for hybrid dynamical systems.

- Model predictive control with Multiple models.
- Model predictive control with Mixed Logical Dynamical System model. ⇒ Future work

In this presentation

- Model predictive control with multiple models is proposed.
- Application to chemical process.

Considering problem

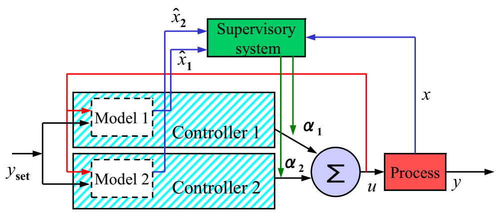


Control scheme for the hybrid dynamical system.

- Process has multiple modes and logic rules.
- How to handle modes and rules in controller

We use multiple model predictive control.

Our approach for hybrid dynamical systems

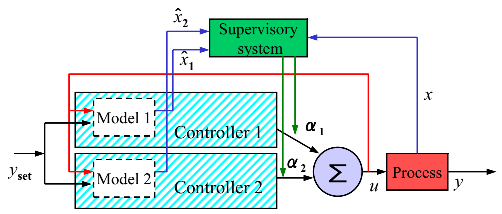


Our approach for hybrid dynamical systems is...

1. Prepare the models for every mode of the process.
2. Calculate controller outputs for every mode by using prepared models.
3. Every controller output is combined by supervisory systems.

How to design control input u is a key point of our approach.

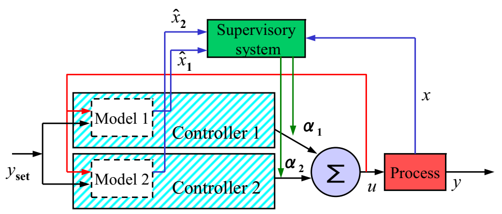
Design of control input



Design procedure of conrtol input $u(t)$

- State estimate $\hat{x}_i$ is calculated using precedent input $u(t-1)$ and models corresponding to every mode of the process.
- Norms of estimation errors $\|\hat{x}_i(t-1) - x(t-1)\|$ are defined.
- Local output weights α_i are designed adequately according to the norms of estimation errors.
- Summation of weighted local controller outputs is control input $u(t)$.

Summary of our approach



Our Approach :

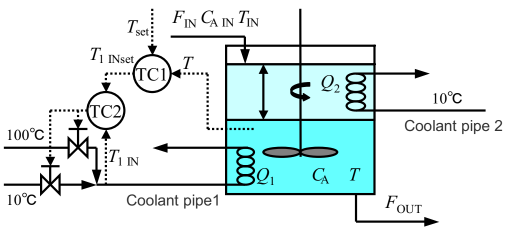
- Control input u are designed according to the norms of every estimation error.

Features of our approach:

- Mode changes of the process are handled implicitly in controller.
- Process input is designed to be optimum approximately.

The method is applied to the case study plant in next section .

Case study (liquid phase exothermal reaction)

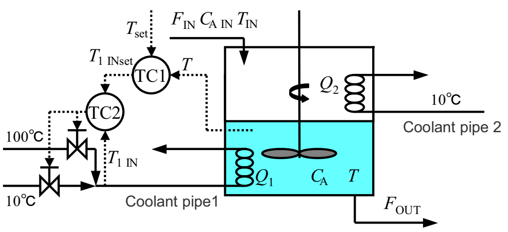


Case study plant (CSTR).

- Highly nonlinear reaction kinetics
- 2 modes depending on liquid level H.

$T_{1\ IN}$: Continuous input variable
F_{IN} : Oscillated and causes mode changes
T : Controlled variable

Case study (liquid phase exothermal reaction)

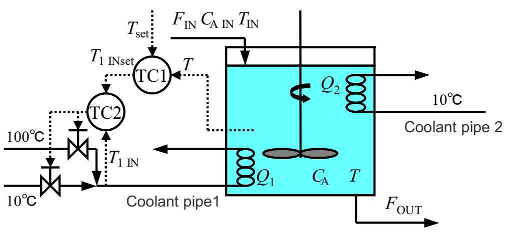


Mode 1.

$$\begin{cases} Q_T = Q_1(T_{1\ \mathrm{IN}}) & \text{if } H \le 1\ \mathrm{m}\ \text{(mode 1)} \\ Q_T = Q_1(T_{1\ \mathrm{IN}}) + Q_2[\text{const.}] & \text{if } H > 1\ \mathrm{m}\ \text{(mode 2)} \end{cases}$$

Q_T : Coolant capacity of total system
Q_1 : Coolant capacity of pipe 1
Q_2 : Coolant capacity of pipe 2

Case study (liquid phase exothermal reaction)



Mode 2.

$$\begin{cases} Q_T = Q_1(T_{1\ \mathrm{IN}}) & \text{if } H \le 1\ \mathrm{m}\ \text{(mode 1)} \\ Q_T = Q_1(T_{1\ \mathrm{IN}}) + Q_2[\text{const.}] & \text{if } H > 1\ \mathrm{m}\ \text{(mode 2)} \end{cases}$$

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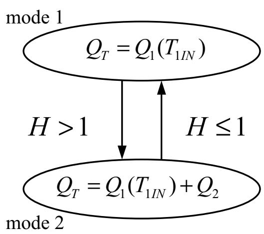
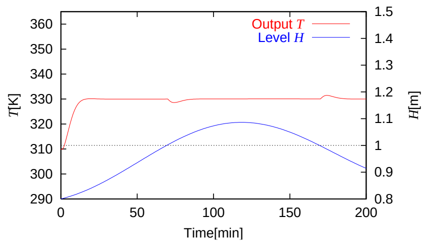
Diagram of the plant



Multiple modes and logic rules of the case study plnat are modeled.

- Modes are changed according to liquid level H.
- Each mode is described as a different dynamics.

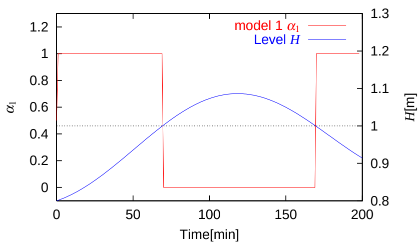
Simulation result



Set point of the reactor temperature is changed from 310 K to 330 K. Liquid level is oscillated and causes mode changes.

- Proposed method has good performance capability in a control of nonlinear hybrid systems.

Operational mode changes and local controller weight α_1



When liquid level is blow 1 meter (mode 1), controller with model 1 is used.

- Weight parameter α changed adequately according to mode chages.

Summary

- We proposed a new control method for a hybrid dynamical systems.
  - Control structure without considering mode changes explicitly.
  - Good control performance is shown for case study.

Issue

- Theoretical analysis about stability is difficult.

Future work

I'm now involved in :
Model Predictive Control with Mixed Logical Dynamical System model

Mixed Logical Dynamical Systems.

Hybrid Dynamical Systems

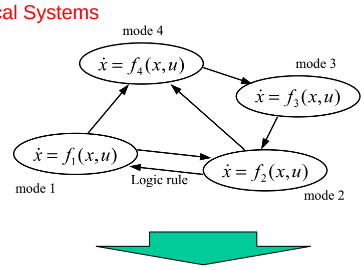
- Physical laws
- Logic rules
- Constraints

↓ (are described)
Mixed Logical Dynamical Systems

- Linear equation
- Inequalities involving continuous and integer variables

Mixed Logical Dynamical Systems

Hybrid Dynamical Systems



Mixed Logical Dynamical Systems

$$x(k+1) = Ax(k) + B_1u(k) + B_2\delta(k) + B_3z(k)$$
$$E_2\delta(k) + E_3z(k) \le E_1u(k) + E_4x(k) + E_5$$

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More systematic control systems may be able to realize by using MPC with MLDS model.