Model-Driven PID Control System, its properties and multivariable application

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Outline

- Introduction
- Model Driven PID Control System
  - structure and properties
- Multivariable Model Driven PID Control System
  - structure and simulations
- Conclusions
PID control system: widely used as a basic control technology, however, is not always easy tuning and has control limitation for long dead-time processes.

What is a simple, widely applicable process controller with easy to tune? Based on the motif, we developed Model Driven PID Control System by extending the Model Driven control concept proposed by Kimura.

Firstly, Model Driven PID Control System, its structure, properties.

Secondary, the Model Driven PID Control System for multivariable processes on regulatory control level and simulation results.
Model Driven PID Control System

Model Driven Control Concept

Model Driven PID control system

Structure and Properties
Model-Driven Control Concept

Definition:
A control system architecture which uses a model of the plant as a principal component of Controller is called a model-driven control.

Kimura (CDC2000 Sydney)

Features of MDC
- Simple Structure
- Easy Tuning
- Proven Stability and robustness

$$\text{imm}$$

Controller

Plant

Model
Structure of Model Driven PID Control System

- PD Feedback
- Main control:
  Gain, second order Q-filter and normalized first order delay model with dead-time for inner loop

Set-point filter

Main Controller

Model

Set Point Filter

Process

PD Feedback
Step 1 PD Feedback $F(s)$

Compensate inner loop dynamics $G(s)$ to a first order system with dead time by using PD feedback $F(s)$.

Design methods: partial model matching method, frequency region method, pole placement, simulation.

Wide applicability, for not only first order delay process with dead time but also integral process, oscillatory process and unstable process.
Example: A integral process can be converted to a first order delay system with dead time.

\[ P(s) = \frac{\exp(-10s)}{10s} \]

\[ F(s) = K_f = 0.25 \]

\[ G(s) = \frac{4\exp(-10s)}{\exp(-10s) + 40s} \]

\[ \hat{G}(s) = \frac{4\exp(-11.8s)}{1 + 28.4s} \]
Design steps (continued)

Step 2: Main controller and set-point filter

1) \( K_c = 1/K \)
2) \( T_c = T \)
3) \( L_c = L \)

Step 3: TDOF property by adjusting \( \alpha \) and \( \beta \).

\[
y = \frac{\exp(-L_c s)}{1 + \lambda T_c s} r + \frac{\exp(-L_c s)}{K_c (1 + T_c s)} \left[ 1 - \frac{(1 + \alpha T_c s)(1 + T_c s)}{(1 + \lambda T_c s)^2} \right] d
\]

\[
Q(s) = \frac{(1 + T_c s)(1 + \alpha T_c s)}{(1 + \lambda T_c s)^2} \quad \frac{1 + \lambda T_c s}{1 + \alpha T_c s}
\]

\( \alpha \): response speed \hspace{1cm} \( \beta \): Disturbance regulation
Adjustable response speed by

\[ G(s) = \frac{1}{1+5s} e^{-10s} \]

\[ y = \frac{e^{-L_1s}}{1+\lambda T_c s} r + \frac{e^{-L_2s}}{K_c (1+T_c s)} \left( 1 - \frac{(1+\alpha T_c s)e^{-L_2s}}{(1+\lambda T_c)^2} \right) \]
Adjustable Disturbance regulation speed by 

\[
G(s) = \frac{1}{1 + 5s} e^{-10s}
\]

\[
y = \frac{e^{-L_c s}}{K_c (1 + T_c s)} \left\{ 1 - \frac{(1 + \alpha T_c s)e^{-L_c s}}{(1 + \lambda T_c)^2} \right\} d
\]
Robustness

Nyquist curves

P(s) = \frac{\exp(-20s)}{1+50s}

F(s) = 0.4

G(s) = \frac{0.714\exp(-21s)}{1+28.7s}

MD-PID(EV-->PV)
Gain Omega = 0.09
Gain Margin = 12.12dB
Phase Margin = 69.94deg

MD-PID(DV-->MV)
Gain Omega = 0.09
Gain Margin = 10.09dB
Phase Margin = 60.64deg
Upper compatibility

\[ \frac{1 + \lambda T_c s}{1 + \alpha T_c s} \]

Set Point Filter

\[ K_c \]
Gain

\[ \frac{(1 + T_c s)(1 + \alpha T_c s)}{(1 + T_c s)^2} \]
Q Filter

\[ \frac{1}{1 + T_c s} e^{-L_c s} \]
Model

\[ \frac{K_f (1 + T_f s)}{1 + k T_f s} \]
Process

PD Feedback

\[ P(s) \]

Main Controller

\[ u \]

\[ r \]

\[ v \]

\[ G(s) \]

\[ d \]

PI Control: \( K_f = T_f = 0, \lambda = \alpha = 1, L_c = 0 \)

PI-PD Control: \( \lambda = \alpha = 1, L_c = 0 \)

PID \[ d \] Control: \( K_f = T_f = 0, \lambda = \alpha = 1 \)

IMC: \( K_f = T_f = 0, \alpha = 1 \)
1. Wide Applicability

PD feedback

\[ G(s) = \frac{K_{\exp}(-Ls)}{1 + Ts} \]

\[ F(s) = \frac{K_t(1 + T_is)}{(1 + ?T_is)} \]

2. Two degree of freedom characteristics

\[ K_c = \frac{1}{K} \quad T_c = T \quad L_c = L \]

\[ \bigcirc \text{tuning: Response speed,} \quad \bigcirc \text{tuning: Disturbance regulation speed} \]

3. Robustness can be examined by well-known nyquist chart

4. Upper compatibility from conventional PID control systems
Reported reduce operator’s over-riding actions and fuel cost, obtain high quality of product though some field applications.
Multivariable Model Driven PID Control System

Model 1
\[ \frac{e^{-L_1 s}}{1 + T_{c1}s} \]

Model 2
\[ \frac{e^{-L_2 s}}{1 + T_{c2}s} \]

Decoupler
\[ K = \begin{bmatrix} K_{d11} & K_{d12} \\ K_{d21} & K_{d22} \end{bmatrix} \]

PD Feedback 1
\[ K_{f1}(1 + T_{f1}s) \]

PD Feedback 2
\[ K_{f2}(1 + T_{f2}s) \]

MIMO Process

\[ P(s) \]
Design steps

1. Decoupler ($K_{\text{dec}}$)

$$P(s) = \begin{bmatrix} \frac{K_{11}}{1+T_{11}s} e^{-L_{11}s} & \frac{K_{12}}{1+T_{12}s} e^{-L_{12}s} \\ \frac{K_{21}}{1+T_{21}s} e^{-L_{21}s} & \frac{K_{22}}{1+T_{22}s} e^{-L_{22}s} \end{bmatrix} \Rightarrow K_{\text{dec}} = P(0)^{-1} = \begin{bmatrix} K_{11} & K_{12} \\ K_{21} & K_{22} \end{bmatrix}^{-1}$$

the control process

A decoupler

2. Other MD control systems

$$K_{\text{dec}} P(s) = \begin{bmatrix} \hat{P}_{11} & \hat{P}_{12} \\ \hat{P}_{21} & \hat{P}_{22} \end{bmatrix}$$

Designed for the diagonal element of $K_{\text{dec}} P(s)$
Simulation

Controlled object: Shell heavy oil fractionator

\[
P(s) = \frac{4.05 e^{-27s}}{1 + 50s} + \frac{1.77 e^{-28s}}{1 + 60s} + \frac{5.39 e^{-18s}}{1 + 50s} + \frac{5.27 e^{-14s}}{1 + 60s}
\]

IEEE Control System Magazine
Shell heavy oil fractionator
By Daniel E. Rivera

Step responses
Design results

1. Distributed MD PID Control

\[ \text{Decoupler} = \begin{bmatrix} 0.4465 & -0.1500 \\ -0.4567 & 0.3431 \end{bmatrix} \]

\[ \text{model1} = \frac{1}{1+50s} e^{-27s}, \text{model2} = \frac{1}{1+60s} e^{-14s} \]

2. Decoupling PID Control by Model-matching method by Kitamori

\[ K_p = \begin{bmatrix} 0.2982 & -0.2618 \\ -0.3455 & 0.7372 \end{bmatrix} \]

\[ T_i = \begin{bmatrix} 45.1015 & 47.6909 \\ 51.1015 & 58.6909 \end{bmatrix} \]
Modelling error 0%

Green: Decoupling PID
Blue: MD-PD

$y_1$

$u_1$

$y_2$

$u_2$
Modelling error 25%

Green: Decoupling PID
Blue: MD-PD
Conclusions

- We discussed a Model Driven PID control system, its properties and a multivariable application.
- PD feedback give us wide applicability of controlled processes:

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<thead>
<tr>
<th></th>
<th>Delay with dead time</th>
<th>Zero</th>
<th>Oscillation</th>
<th>Integral</th>
<th>Unstable</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Small L/T</td>
<td>Large L/T</td>
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<tr>
<td>PID</td>
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<td>MD-PID</td>
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- MD-PID control system shows Good control performances like a TDOF control system with easy tuning.
- MD- PID control system has upper compatibility from conventional PI, IMC, PID and PI-PD
- Multivariable MD PID Control system shows useful results in spite of simple control structure.