From PID to MPC

Control Theory Introduction

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Control theory?

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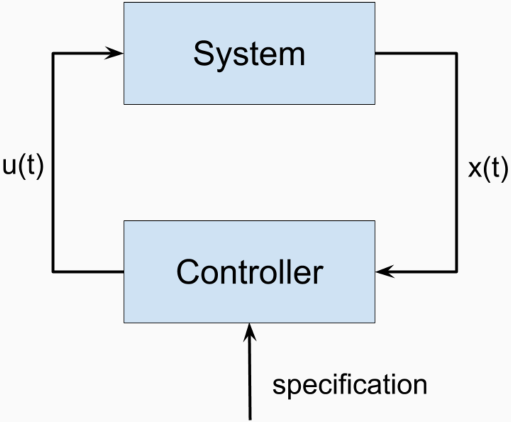
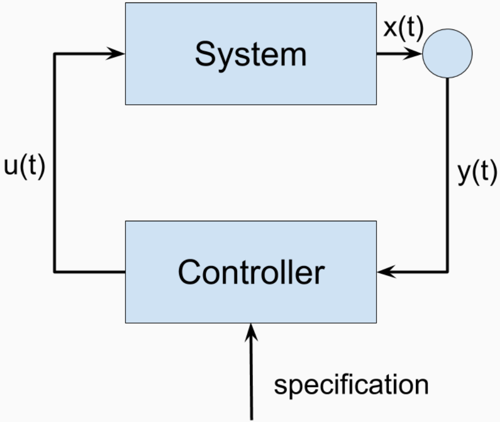
Goals:

- increase product throughput,
- yield of high valued products,
- decrease energy consumption & pollution,
- improve safety,
- improve operability,
- etc.

Principles



Principles



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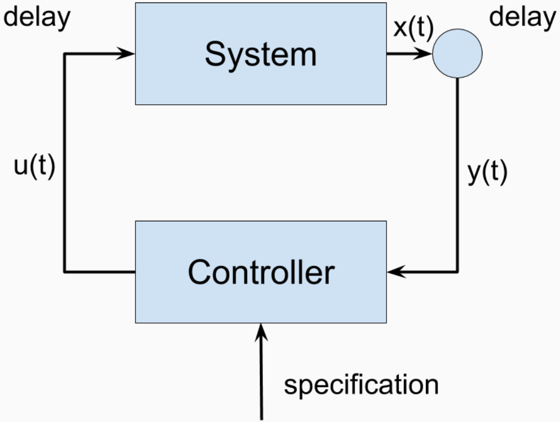

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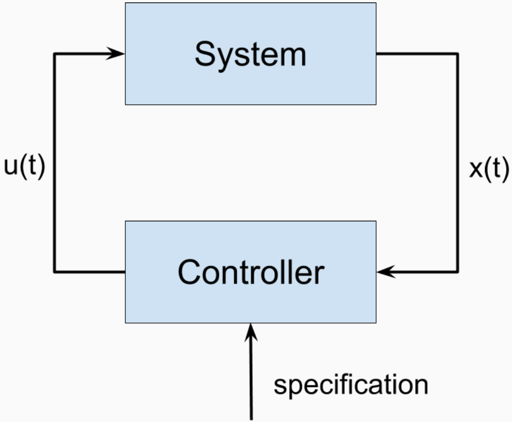


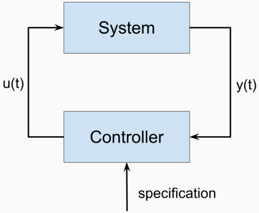
PID controller

Proportional-Integral-Derivative controller.

$$u(t) = k_p e(t) + k_i \int_0^t e(\tau)\, d\tau + k_d \frac{de}{dt}$$

$$e(t) = sp(t) - y(t)$$

- $e(t)$ – error
- $sp(t)$ – set point
- $y(t)$ – observed system output



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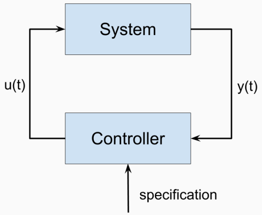


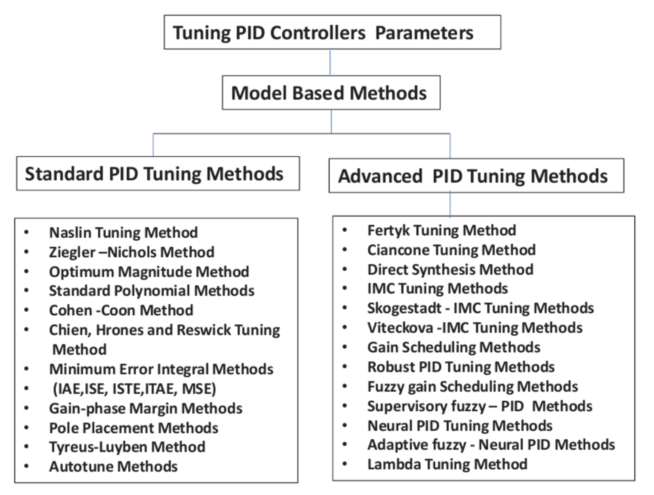
The main advantages of PID

- reduced number of controller **parameters**,
- only **minimal knowledge** about the controlled process is required,
- well-established tuning rules for optimal computation of PID controller parameters,
- good performance and stability of many real controlled processes,
- PID controllers (in continuous and digital form) are versatile and robust.

The main disadvantages of PID

- controller acts only **after** the process feels the upset,
- does not work well with large **time delays**,
- in some applications the controlled variable cannot be measured online and consequently feedback control is not suitable and feasible,
- does not provide predictive control action to compensate for the effects of known or measurable **disturbances**.

Tuning PID Controllers Parameters



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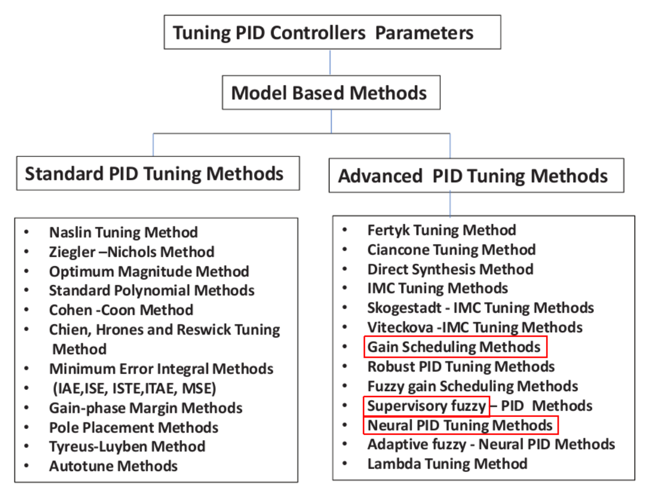


Gain scheduling methods

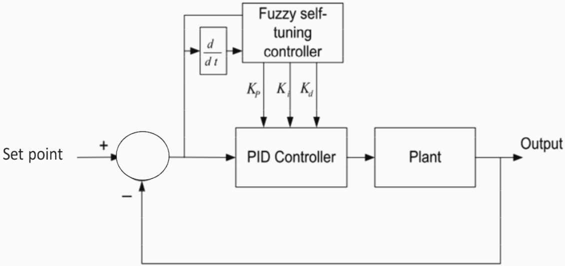
Idea: change controller parameters by monitoring operating conditions of the process.

- very useful technique for reducing effects of parameter variations
- e.g. Split-range controllers:
    - different sets of parameters for different ranges of the process output
    - tuned for any number of operating ranges
- particularly appropriate for processes that speed up or slow down as the process variable rises and falls

Gain scheduling can be viewed as a feedback control system in which the feedback gains are adjusted by using feed forward compensation.

Fuzzy supervisor PID control structures and methods

Existing tuning methods cannot be effectively applied with systems which have fast changing parameters because it would require the change of PID parameters in time.



Fuzzy supervisor PID control structures and methods

The fuzzy supervisor

- the supervisor modifies PID tuning parameters online according to rules
- one or more input variables, usually set point, error and/or actual control action.

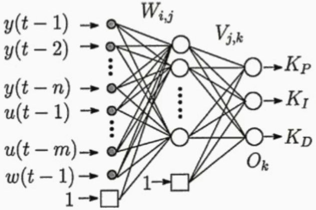
(A set of rules can be obtained from experts to adjust the controllers parameters.)

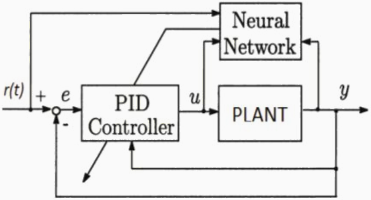
Advanced Neural Net based PID Controller

Neural network control – combination of neural network and control theory, and has become one of the forefront subjects in the intelligent control field.

$$\mathbf{u} = [u(t-1), u(t-2), \cdots, u(t-m)]$$
$$\mathbf{y} = [y(t-1), y(t-2), \cdots, y(t-n)]$$

$$\begin{aligned} u(t) = {} & u(t-1) + K_I e(t) - K_P\{y(t) - y(t-1) \\ & - K_D\{y(t) - 2y(t-1) + y(t-2)\}, \end{aligned}$$





Neural network control

First group

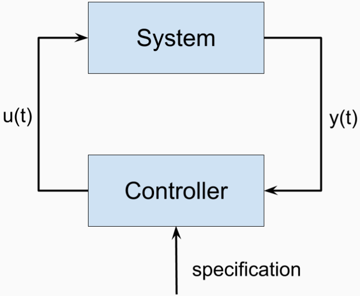
- control action is directly computed by the neural network from the process output.

Second group

- computation of controller parameters (PID gains) are generated in outputs layer of the ANN network.

Model Predictive Control

– the current control action is obtained by solving a finite horizon open-loop optimal control problem at each sampling instant, using the current state of the plant as the initial state.



MPC

- Model-based approach – mathematical model of the controlled process,
- Digital control algorithm – development and implementation on a computer,
- Predictive techniques,
- Optimal control – goals of process control are expressed as a performance function to be minimized,
- Online optimization approach – at each sampling time, a search for a sequence of future control actions is conducted,
- Receding horizon – only the first element of the control sequence is applied to control the process,
- Optimization algorithm for computing control actions is repeated at next sampling instant.

PID vs. MPC

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- PID controller is not able to deal with constraints. (???)
- PID controller does not require a model of the plant.
- MPC controller is a more advanced method of process control used for MIMO (multiple input–multiple output) systems.

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- MPC is a systematic model-based approach.
- MPC can be designed both for SISO and MIMO linear and nonlinear processes.
- Tuning techniques for MPC controller are based on modern numerical optimization algorithms.

References

[Štefan Kozák]
From PID to MPC: Control engineering methods development and applications (2016)
doi:10.1109/CYBERI.2016.7438634