Universität Hamburg
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PID Control

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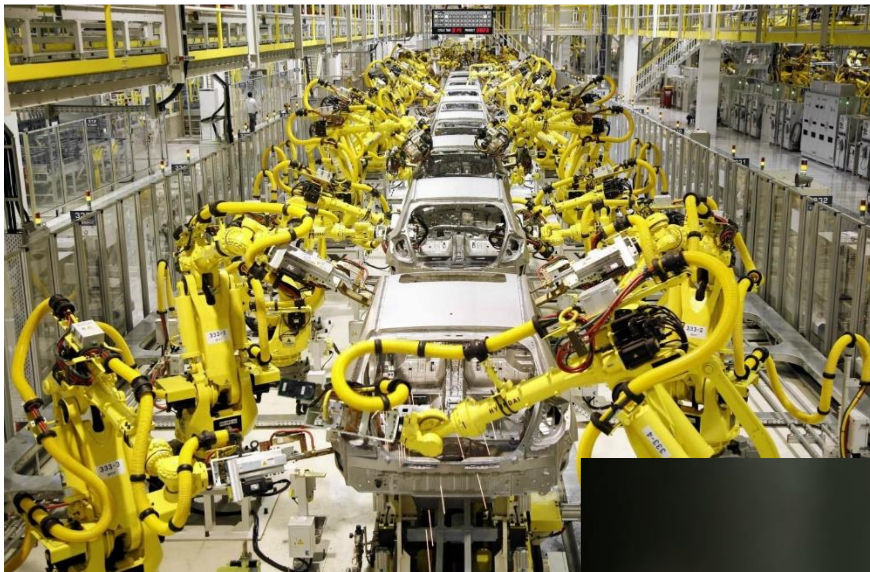
Motivation

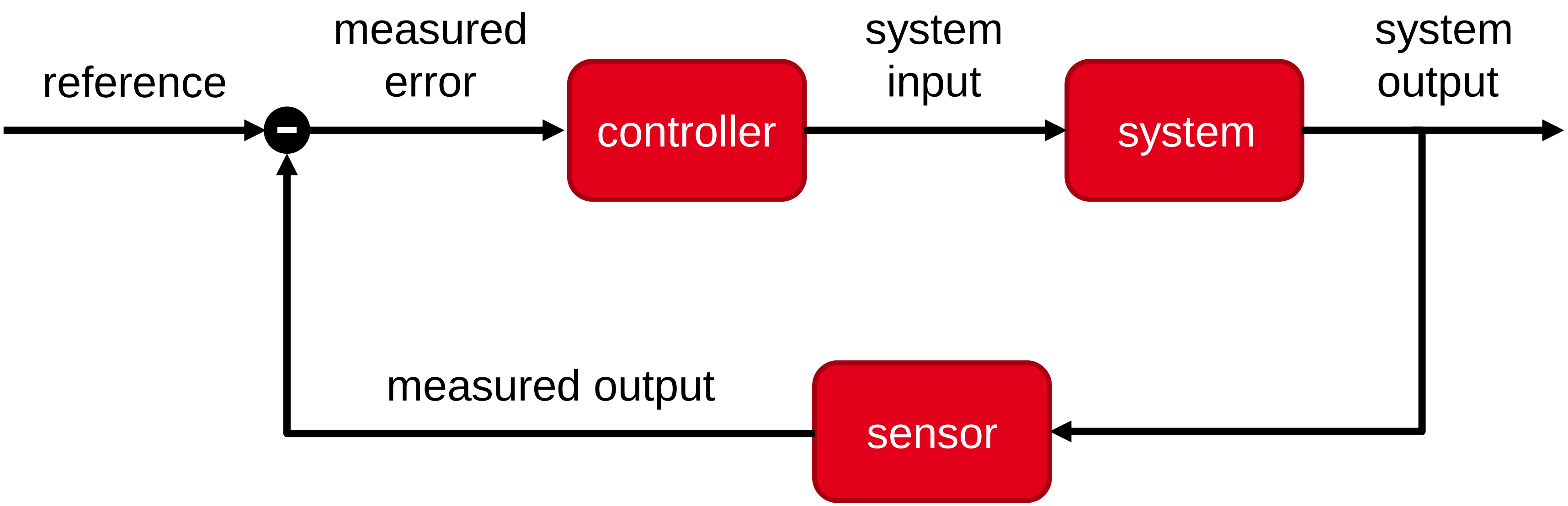


http://www.australianroboticsreview.com

http://www.robotshop.com

https://www.youtube.com
KUKARobotGroup

Control loop



Components of a PID Controller

- Proportional term

$$u_P(t) = K_P e(t)$$

- Integral term

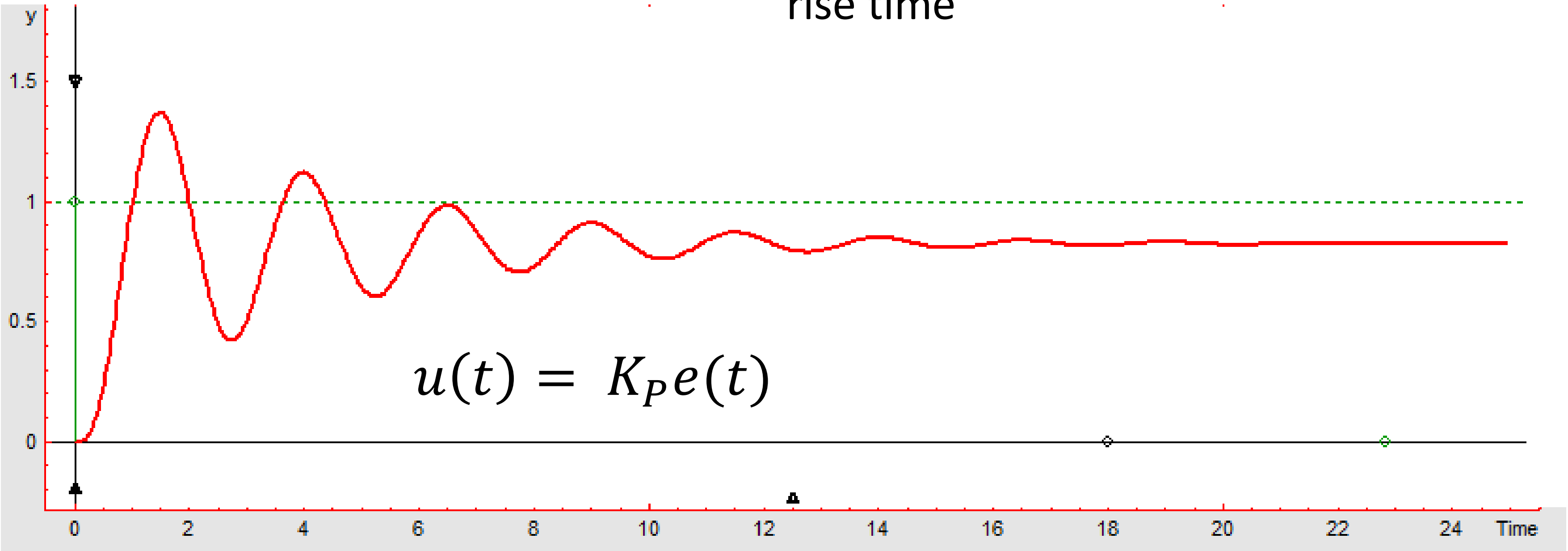
$$u_I(t) = K_I \int_0^t e(\tau) d\tau$$

- Derivative term

$$u_D(t) = K_D \frac{de(t)}{dt}$$

P-Controller

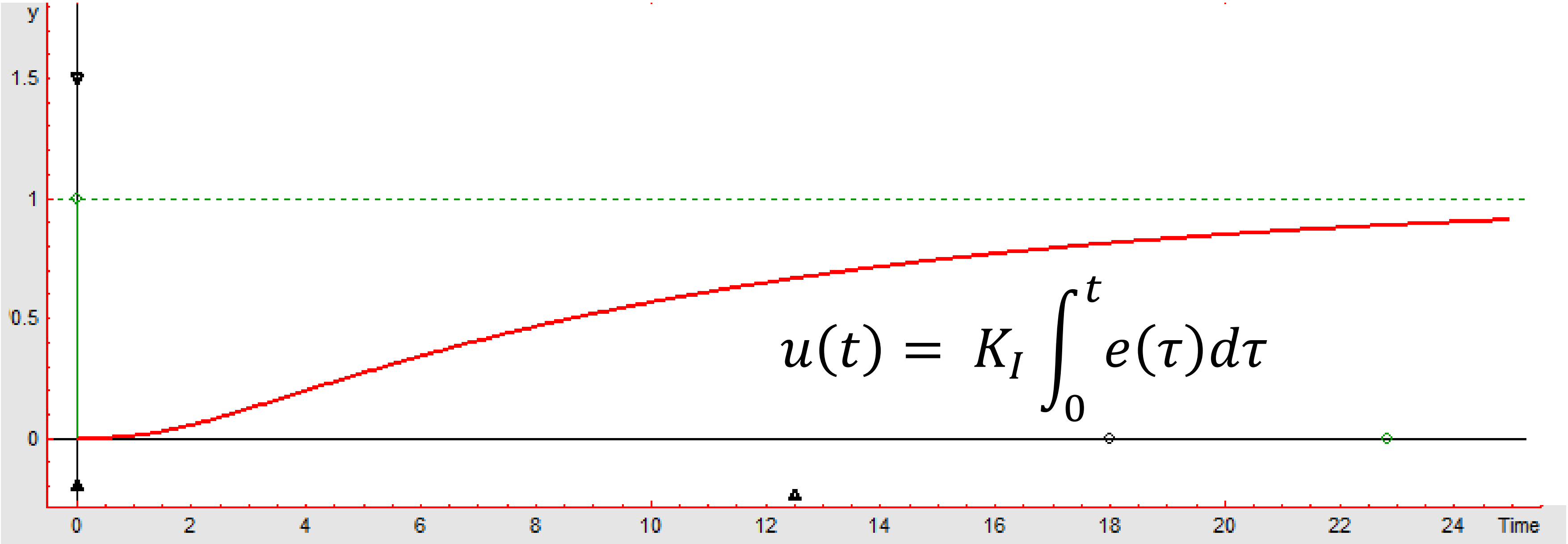
- steady state error
- medium rise time
- oscillates when reducing SSE and rise time



$$u(t) = K_P e(t)$$

I-Controller

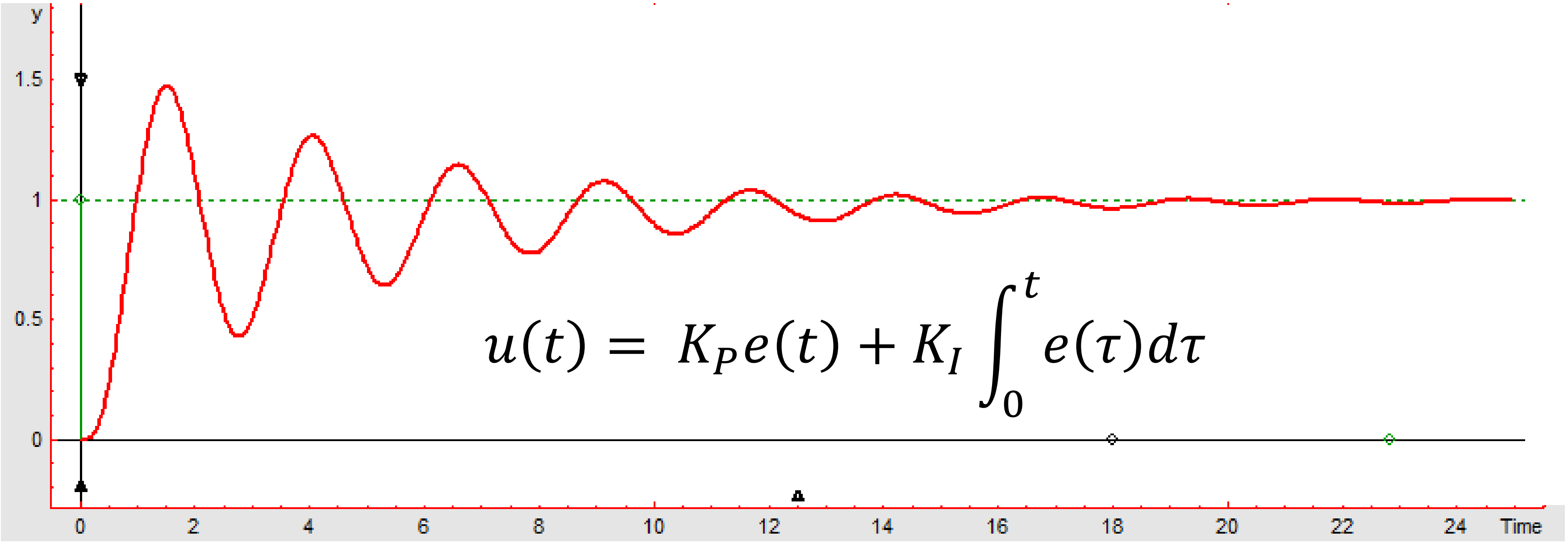
- no steady state error
- very long rise time
- oscillates when reducing rise time



$$u(t) = K_I \int_0^t e(\tau) d\tau$$

PI-Controller

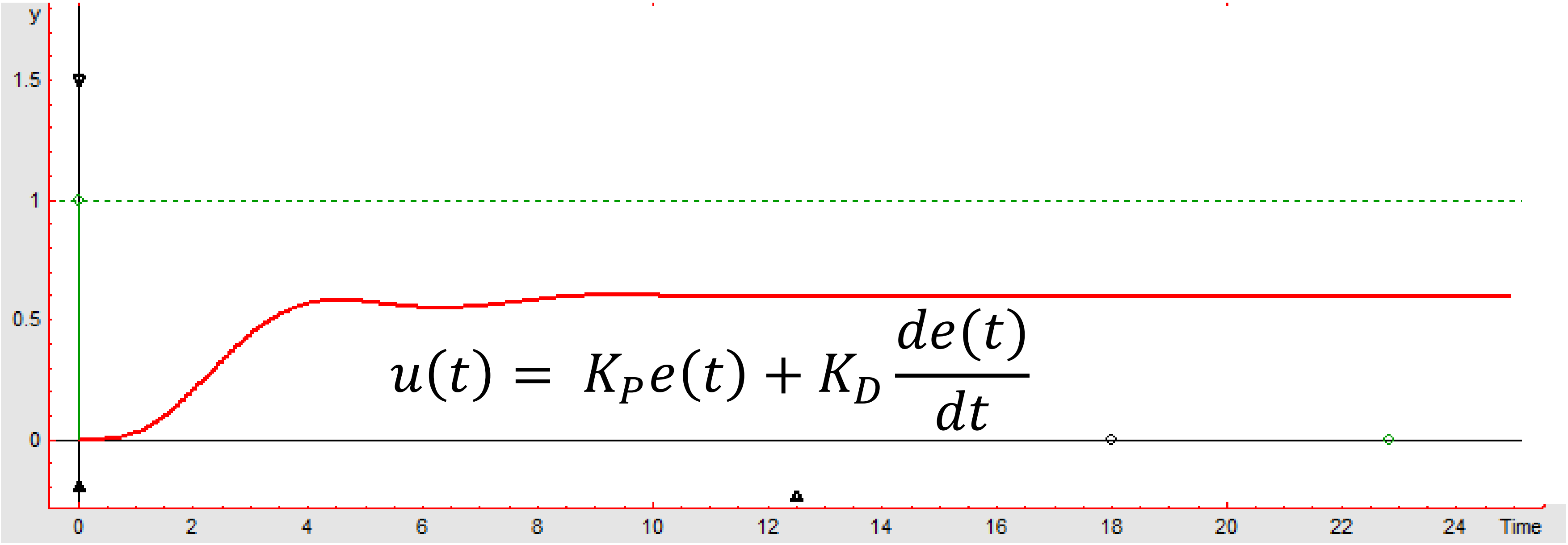
- no steady state error
- medium rise time
- oscillates when reducing rise time



$$u(t) = K_P e(t) + K_I \int_0^t e(\tau) d\tau$$

PD-Controller

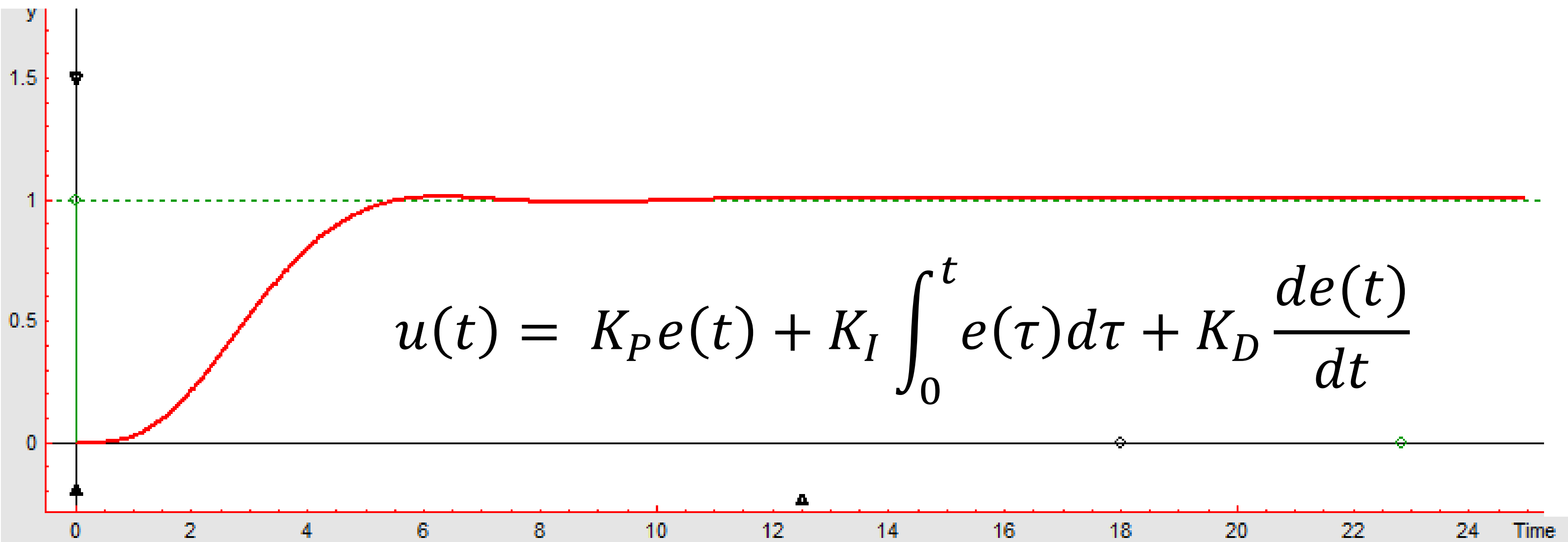
- steady state error
- low rise time
- oscillates when reducing SSE



$$u(t) = K_P e(t) + K_D \frac{de(t)}{dt}$$

PID-Controller

- no steady state error
- low rise time



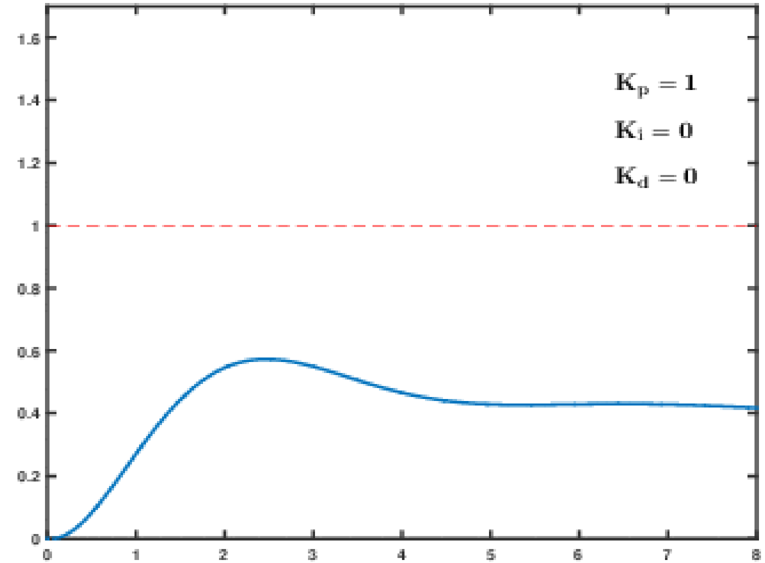
$$u(t) = K_P e(t) + K_I \int_0^t e(\tau)d\tau + K_D \frac{de(t)}{dt}$$

Tuning

parameter	steady state error	rise time	oscillation
K_P	decrease	decrease	increase
K_I	eliminate	small decrease	increase
K_D	no effect	no effect	de-/increase

Tuning with trial and error:

1. Set $K_P = K_I = K_D = 0$
2. Rise K_P until oscillation begins
3. Rise K_I until SSE is eliminated
4. Rise K_D until oscillation is eliminated



https://en.wikipedia.org/wiki/PID_controller

Tuning

$$u(t) = K_P e(t) + K_I \int_0^t e(\tau) d\tau + K_D \frac{de(t)}{dt}$$

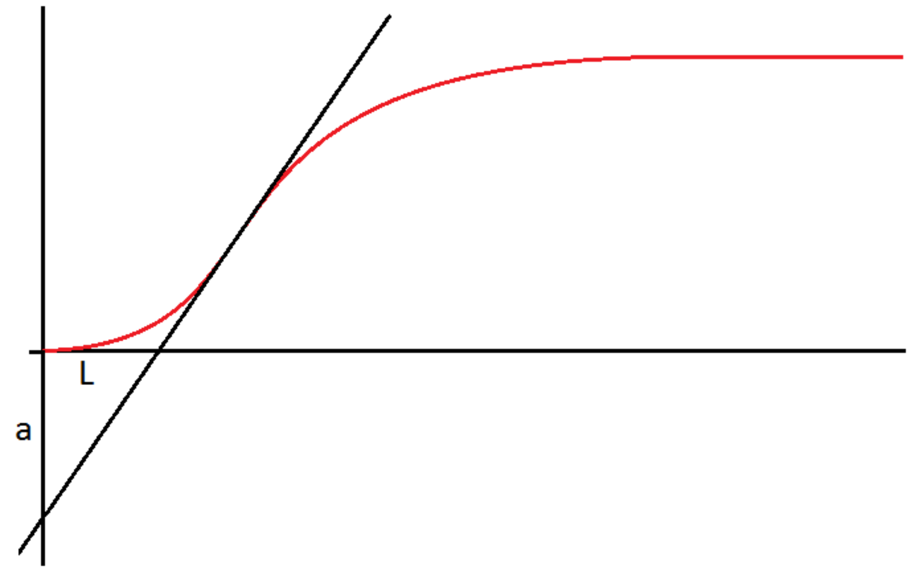
With $K_I = \frac{K_P}{T_i}$ and $K_D = K_P + T_d$

$$u(t) = K_P(e(t) + \frac{1}{T_i} \int_0^t e(\tau) d\tau + T_d \frac{de(t)}{dt})$$

Tuning with Step Response Method

by Ziegler and Nichols

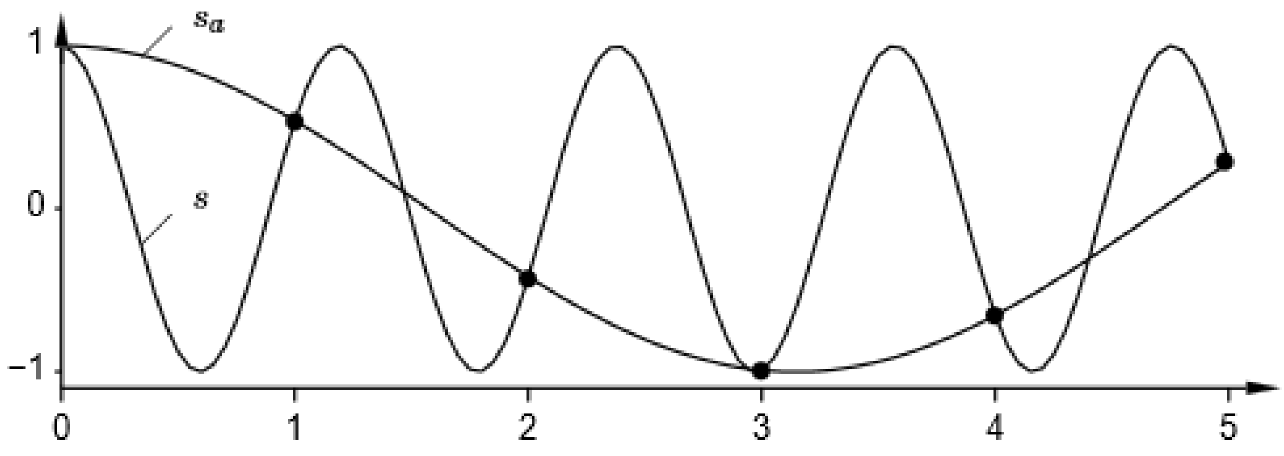
Controller	K	T_i	T_d	T_p
P	1/a			4L
PI	0.9/a	3L		5.7L
PID	1.2/a	2L	L/2	3.4L



- Simple System
- Not optimal
- Too little process information

Noise effects

- Derivative term sensitive to high frequency noise
  - Low-pass filter
- Aliasing
  - Analog low-pass filter



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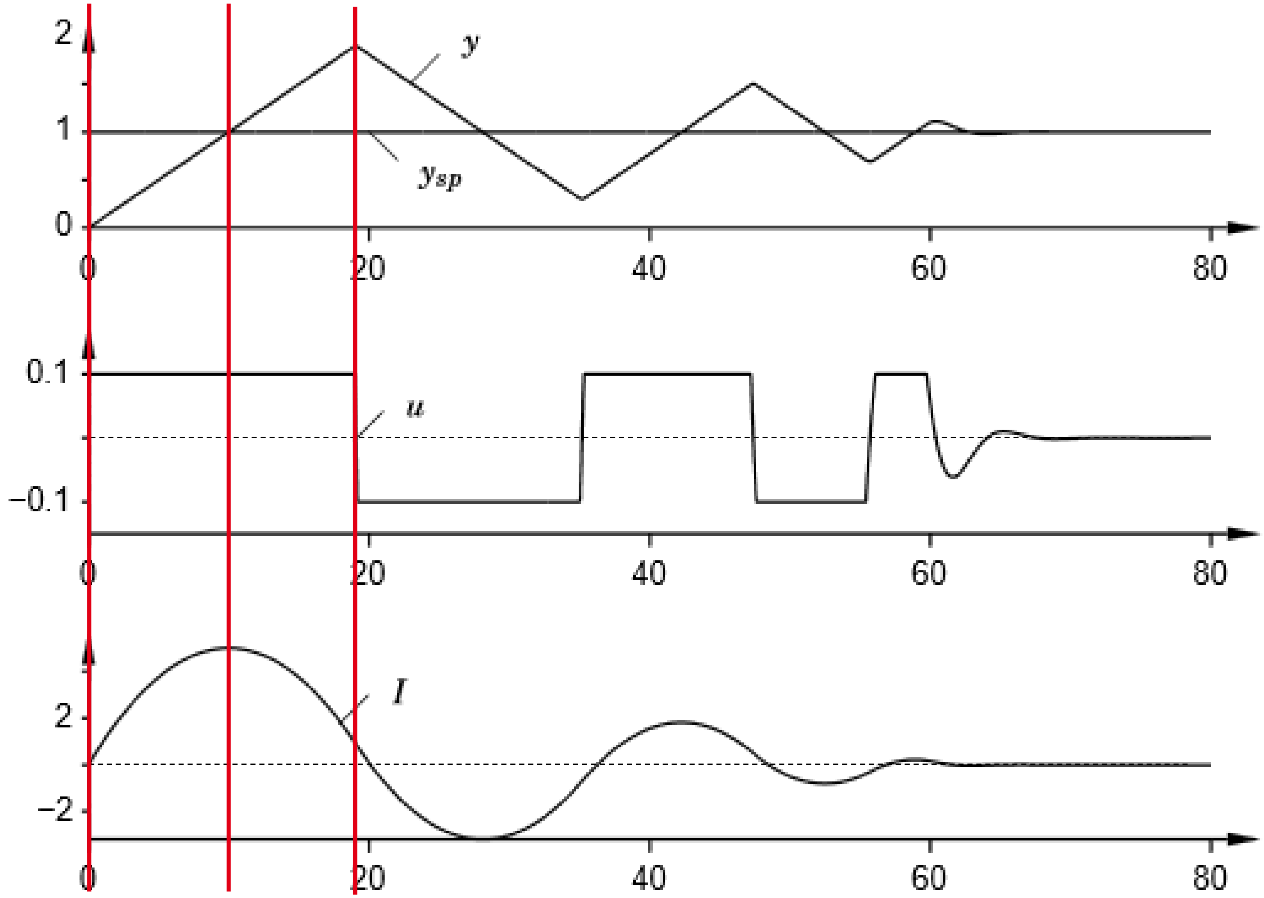
Windup



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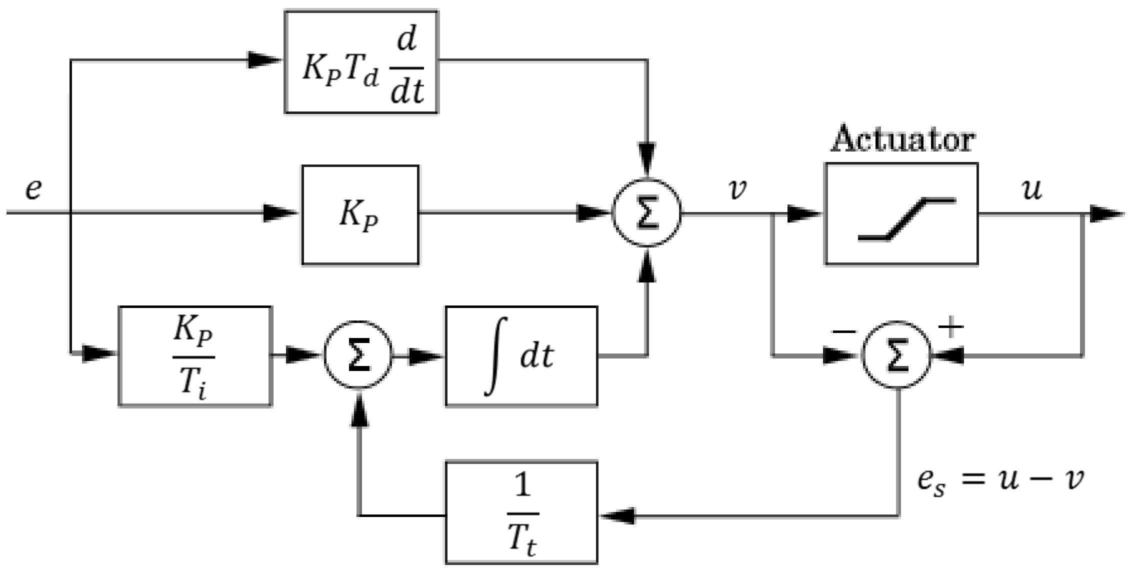
Setpoint Limitation

- Poor performance
- No effect on disturbance

Back-Calculation

- Comparison of controller output and actuator output
- Additional feedback for integral term



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Back-Calculation

integrator input:

$$\frac{1}{T_t}e_s + \frac{K_P}{T_i}e$$

target:

$$\frac{1}{T_t}e_s + \frac{K_P}{T_i}e = 0$$

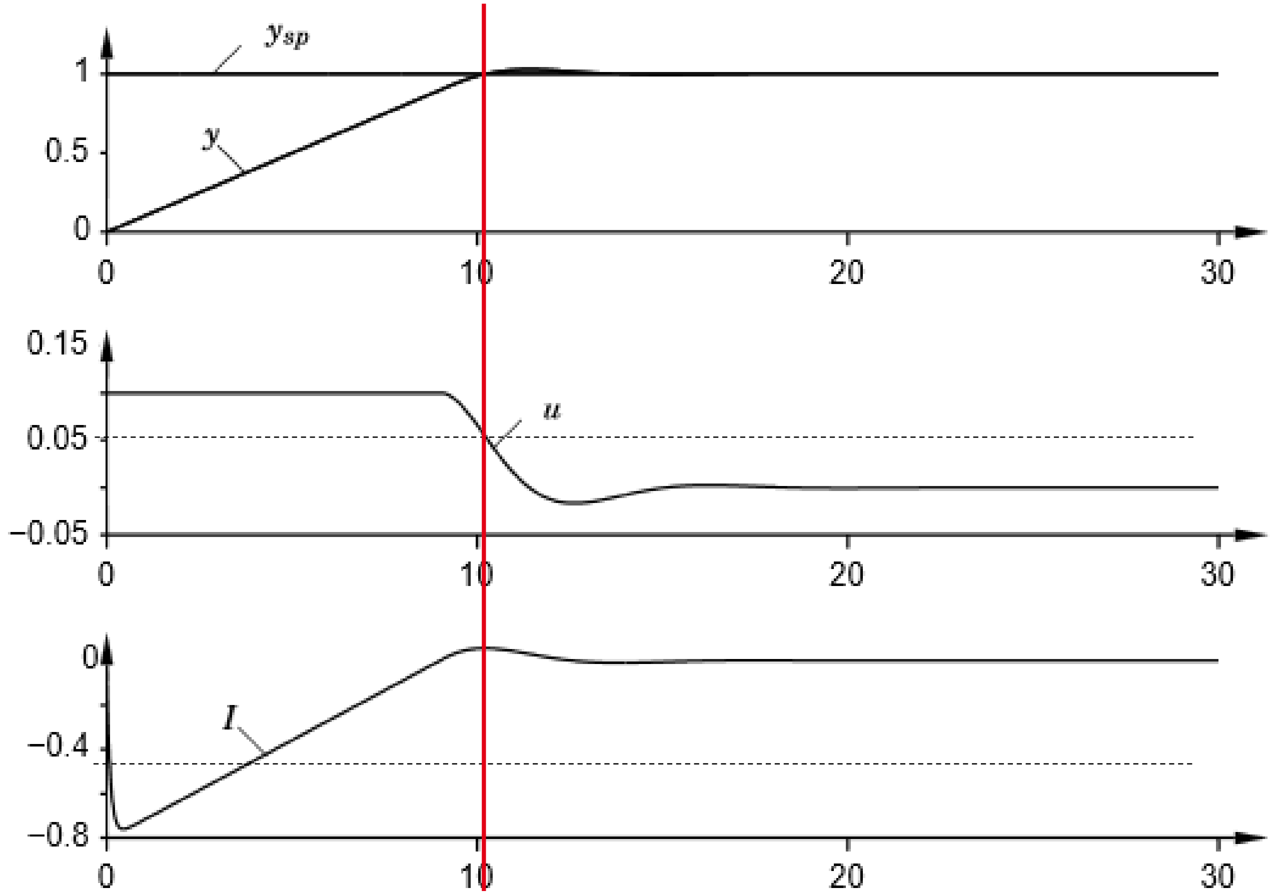
error signal:

$$e_s = -\frac{K_P T_t}{T_i}e$$

with $e_s = u_{lim} - v$:

$$v = u_{lim} + \frac{K_P T_t}{T_i}e$$

Back-Calculation



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Practical application for a robotic arm

- Arm with multiple links or elastic links is not linear
- In an ideal system the type of actuator is not a factor

- P-term is always needed
- Rise I-term if the arm has to carry heavy weight
- Lower I-term if the arm tends to become instable
- Rise D-term if the arm has to react fast on changing target values and disturbances
- Lower D-term if you have a noisy input

Comparison to other approaches

PID Control	Fuzzy Control
Analytical approach	Imitates a human expert
Good for linear systems	Suitable for non-linear systems
Sensitive to variations in system parameters	Does not need precise information about the system
better able to control and minimize the steady state error of the system	Not good to control steady state errors
Fast calculation	Bigger computation effort

Quotations of references

- [1] Pratumsuwan, P., S. Thongchai and S. Tansriwong, 2010. A Hybrid of Fuzzy and Proportional-Integral-Derivative Controller for Electro-Hydraulic Position Servo System. Energy Res. J., 1: 62-67.
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