

Advanced process control

Introduction

Sigurd Skogestad

2025

“The goal of my research is to develop simple yet rigorous methods to solve problems of engineering significance”

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"The overall goal of my research is to develop simple yet rigorous methods to solve problems of engineering significance"

"We want to find a self-optimizing control structure where close-to-optimal operation under varying conditions is achieved with constant (or slowly varying) setpoints for the controlled variables (CVs). The aim is to move more of the burden of economic optimization from the slower time scale of the real-time optimization (RTO) layer to the faster setpoint control layer. More generally, the idea is to use the model (or sometimes data) off-line to find properties of the optimal solution suited for (simple) on-line feedback implementation"



"News"...

- 27 Nov. 2023: [Welcome to the SUBPRO Symposium at the Britannia Hotel in Trondheim](#)
- Aug. 2023: Tutorial review paper on "Advanced control using decomposition and simple elements". Published in Annual reviews in Control (2023). [[paper](#)] [[tutorial workshop](#)] [[slides from Advanced process control course at NTNU](#)]
- 05 Jan. 2023: Tutorial paper on "Transformed inputs for linearization, decoupling and feedforward control" published in JPC. [[paper](#)]
- 13 June 2022: Plenary talk on "Putting optimization into the control layer using the magic of feedback control", at ESCAPE-32 conference, Toulouse, France [[slides](#)]
- 08 Dec. 2021: Plenary talk on "Nonlinear input transformations for disturbance rejection, decoupling and linearization" at Control Conference of Africa (CCA 2021), Magaliesburg, South Africa (virtual) [[video and slides](#)]
- 27 Oct. 2021: Plenary talk on "Advanced process control - A new look at the old" at the Brazilian Chemical Engineering Conference, COBEQ 2021, Gramado, Brazil (virtual) [[slides](#)]
- 13 Oct. 2021: Plenary talk on "Advanced process control" at the Mexican Control Conference, CNCA 2021 (virtual) [[video and slides](#)]
- Nov. 2019: Sigurd receives the "Computing in chemical engineering award from the American Institute of Chemical Engineering (Orlando, 12 Nov. 2019)"
- June 2019: Best paper award at ESCAPE 2019 conference in Eindhoven, The Netherlands
- July 2018: PID-paper in JPC that verifies SIMC PI-rules and gives "Improved" SIMC PID-rules for processes with time delay ($\tau_{\text{aud}}-\theta/3$)
- June 2018: Video of Sigurd giving lecture at ESCAPE-2018 in Graz on how to use classical advanced control for switching between active constraints
- Feb. 2017: Youtube videos of Sigurd giving lectures on PID control and Plantwide control (at University of Salamanca, Spain)
- 06-08 June 2016: IFAC Symposium on Dynamics and Control of Process Systems, including Biosystems (DYCOPS-2016), Trondheim, Norway.
 - [Videos and proceedings from DYCOPS-2016](#)
- Aug 2014: Sigurd receives IFAC Fellow Award in [Cape Town](#)
- 2014: Overview papers on "control structure design and "economic plantwide control"
- [OLD NEWS](#)



Books...

- Book: S. Skogestad and I. Postlethwaite: [MULTIVARIABLE FEEDBACK CONTROL](#)-Analysis and design. Wiley (1996; 2005)
- Book: S. Skogestad: [CHEMICAL AND ENERGY PROCESS ENGINEERING](#) CRC Press (Taylor&Francis Group) (Aug. 2008)
- Book: S. Skogestad: [PROSSESTEKNIKK](#)- Masse- og energibalanser Tapir (2000; 2003; 2009).

More information ...

- Publications from my [Google scholar](#) site
- Download publications from my official [publication list](#) or look [HERE](#) if you want to download our most recent and unpublished work
- [Proceedings from conferences](#) - some of these may be difficult to obtain elsewhere
- [Process control library](#) - We have an extensive library for which Ivar has made a nice [on-line search](#)
- [Photographs](#) that I have collected from various events (maybe you are included...)
- [International conferences](#) - updated with irregular intervals
- [SUBPRO \(NTNU center on subsea production and processing\)](#) [[Annual reports](#)] [[Internal](#)]
- [Nordic Process Control working group](#) - in which we participate
- [5-year Master program in Chemical and Biochemical Engineering at NTNU \(MT&I\)](#) - Sigurd Skogestad is Program Leader 2019-2025.



Course Summary NTNU

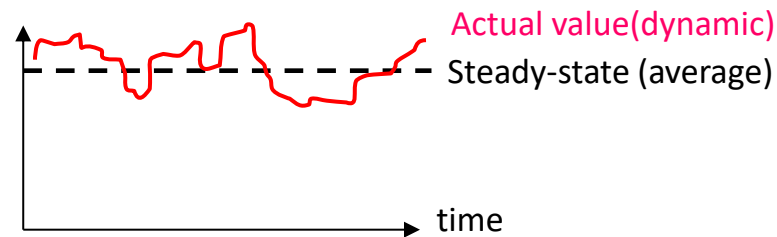
This course is about how to operate and control complete chemical plants

- Part 1: Introduction and motivation
- Part 2 : Plantwide control
- Part 3 : Self-optimizing control
- Part 4 : PID tuning (SIMC rules)
- Part 5 : Inventory control and TPM, Supervisory control and switching
- Part 6 : ARC elements
- Part 7: More on switching and regulatory control
- Part 8: Nonlinear steady-state models: Transformed inputs, RTO and Extremum seeking control.

Part 1: Introduction and motivation

Why do we need control?

- *Operation*



In practice steady state doesn't happen:

- Feed changes
 - Startup
 - Operator changes
 - Failures
 -
- } "Disturbances" (d's)

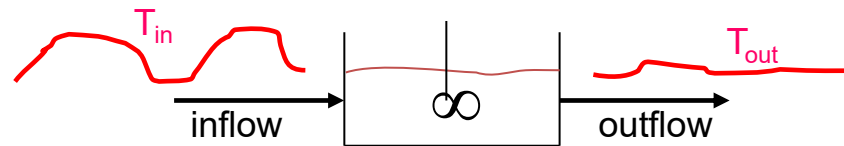
- Control is needed to reduce the effect of **disturbances**
- 30% of investment costs are typically for instrumentation and control

Countermeasures to disturbances

I. Eliminate/reduce the disturbance

(a) Design process so it is insensitive to disturbances

- Example: Use buffer tank to dampen disturbances



(b) Detect and remove source of disturbances

- “Statistical process control”
- Example: Detect and eliminate variations in feed composition

Countermeasures to disturbances

II. Process control

Do something (usually manipulate a valve) to

counteract the effect of the disturbance



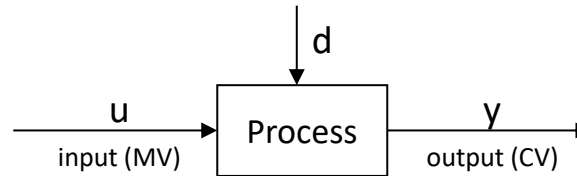
- (a) Manual control: Need operator
- (b) Automatic control: Need measurement + automatic valve + computer

Goals automatic control:

- Smaller variations
 - » more consistent quality
 - » More optimal
- Smaller losses (environment)
- Lower costs
- More production

Industry: Still large potential for improvements!

Classification of variables



Independent variables (“the cause”):

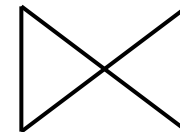
- (a) Inputs (MV, u): Variables we can adjust (valves)
- (b) Disturbances (DV, d): Variables outside our control

Dependent (output) variables (“the effect or result”):

- (c) Primary outputs (CVs, y_1): Variables we want to keep at a given setpoint
- (d) Secondary outputs (y_2): Extra measurements that we may use to improve control

Inputs for control (MVs)

- Usually in process control: Inputs (MVs) are valves.
 - Physical input is valve position (z), but we often simplify and say that flowrate (q) is input



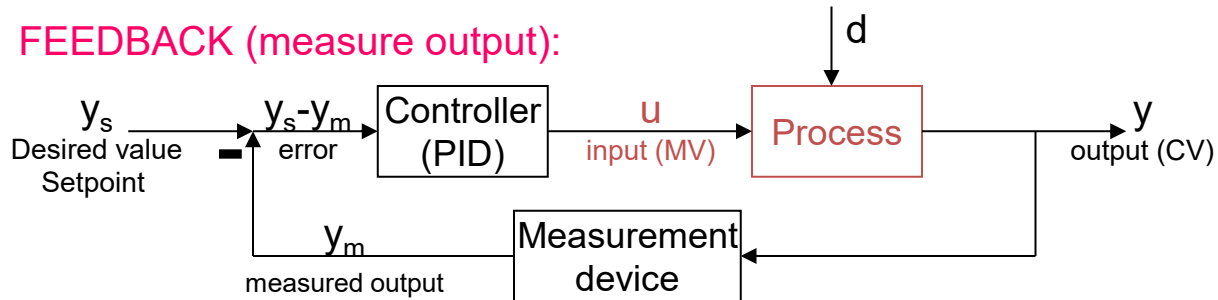
- Valve equation: $q \left(\frac{m^3}{s} \right) = c_v f(z) \sqrt{\Delta p / \rho}$
 - Δp = pressure drop over valve (disturbance; can be counteracted with flow controller)

We use two kind of diagrams

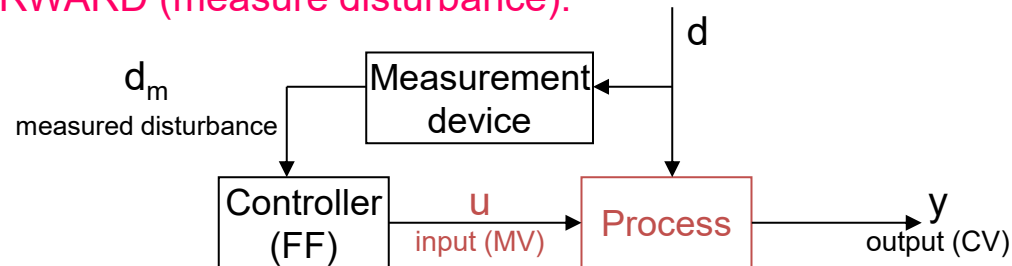
- **Block diagram (information)**
 - Used by control engineers
- **Flowsheet** (piping & instrumentation diagram, P&ID)
 - Used by process engineers

BLOCK DIAGRAMS

FEEDBACK (measure output):

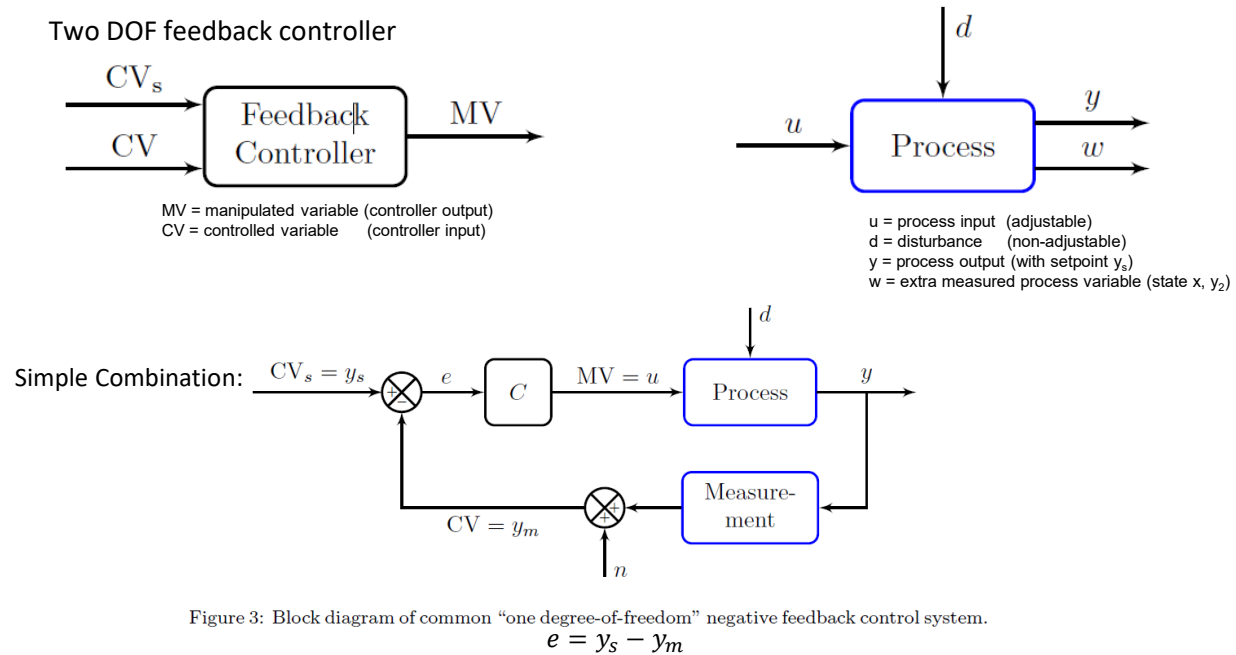


FEEDFORWARD (measure disturbance):



- All lines: Signals (information)
- Blocks: controllers and process
- Do not confuse block diagram (lines are signals) with flowsheet (lines are flows); see below

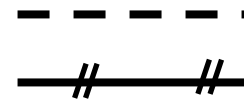
BLOCK DIAGRAMS



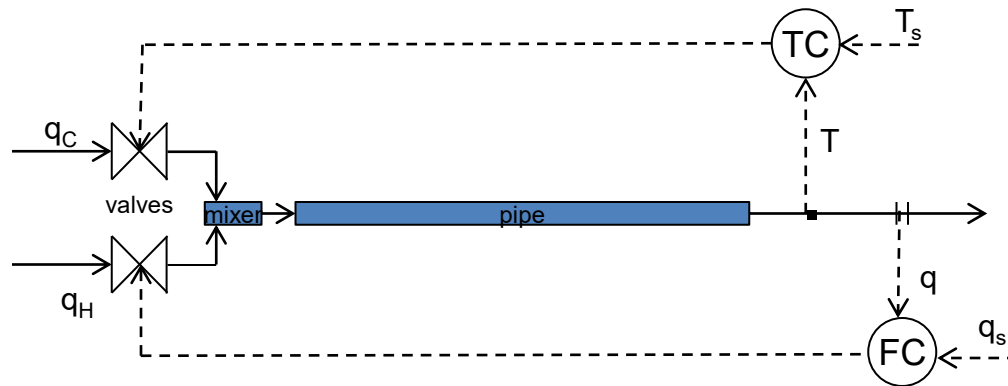
Block diagrams: All lines are signals (information)

Piping and instrumentation diagram (P&ID) (flowsheet)

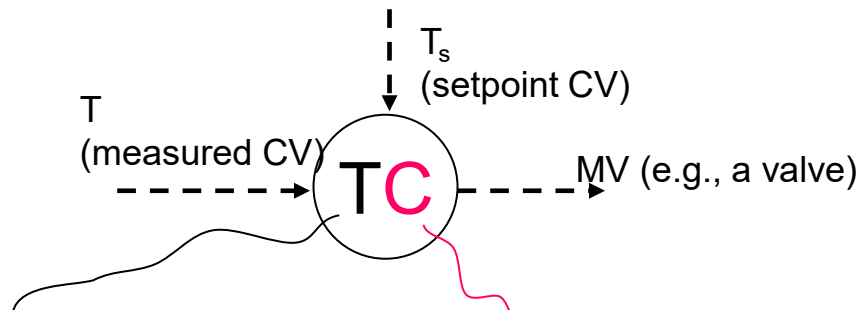
- Solid lines: mass flow (streams) ———
- Dashed/colored lines: signals (control)



Example: Shower



Notation feedback controllers (Flowsheet = P&ID)



1st letter: Controlled variable (CV)

T: temperature

F: flow

L: level

P: pressure

DP: differential pressure (Δp)

A: Analyzer (composition)

C: composition

X: quality (composition)

H: enthalpy/energy

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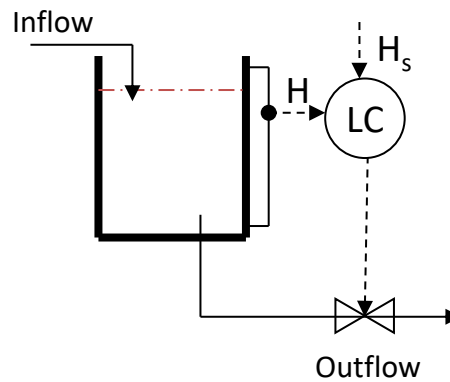
2nd letter:

C: controller

I: indicator (measurement)

T: transmitter (measurement)

Example flowsheet: Level control



INPUT (u): OUTFLOW (Input for control!)

OUTPUT (y): LEVEL

DISTURBANCE (d): INFLOW

Scaling

- Variables ($u=MV, y=CV, d=DV$) are usually scaled
 - Simplifies interpretation and tuning
 - Make sure that valves actually go to fully open or closed
- Linear systems (block diagrams): Variables usually «shifted» with 0 as nominal value, Typical scaled range: -1 to 1
 - where -1 is min. value, 1 is max. value
- Industry (flowsheets): Usually scaled 0-1 or 0-100%.
 - where 0 is min. value (e.g., closed valve)
 - 1 or 100% is max. value (fully open valve)
 - Usually no nominal value