

Model Identification and Predictive Control of a Laboratory Binary Distillation Column

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Motivation



Motivation



Distillation



Distillation



Ján Drgoňa (STU)

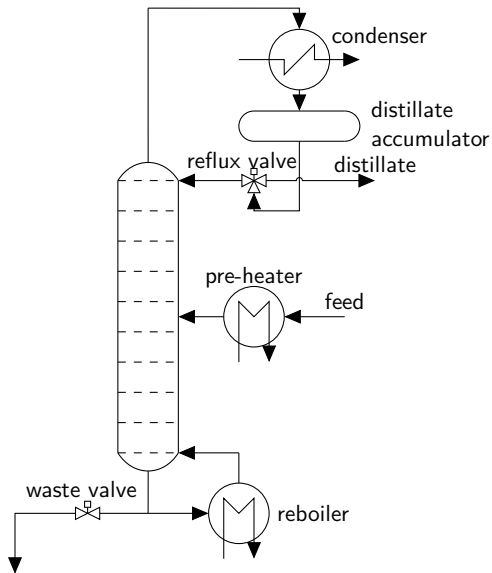


Distillation Control

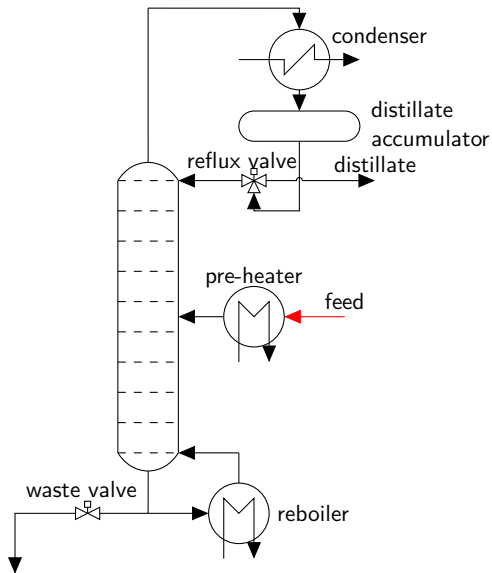
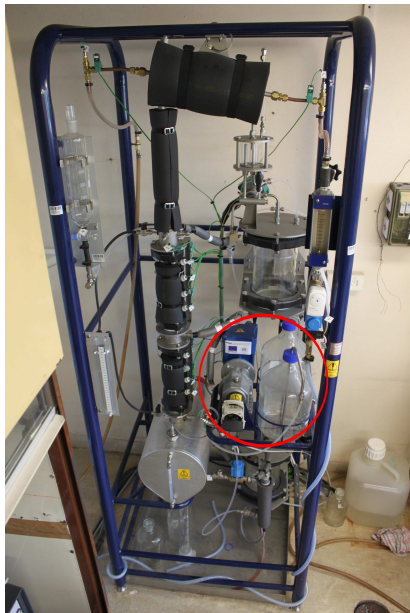
Distillation



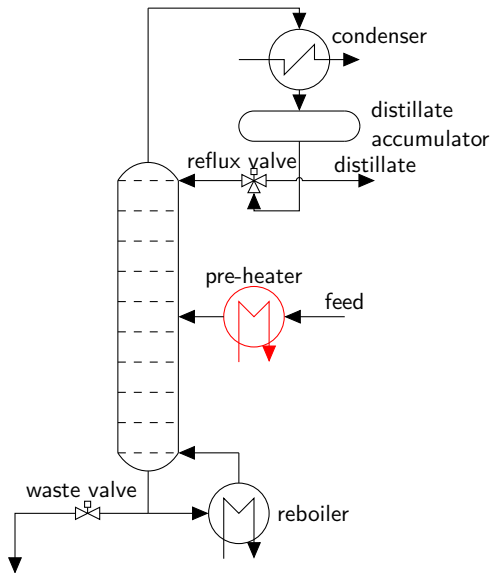
Distillation Column – Process Unit



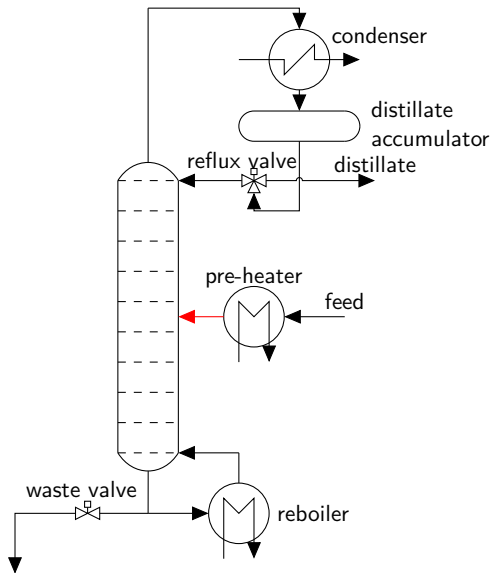
Distillation Column – Process Unit



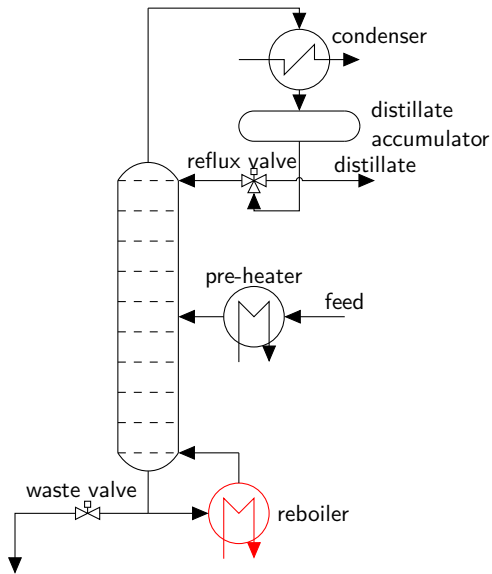
Distillation Column – Process Unit



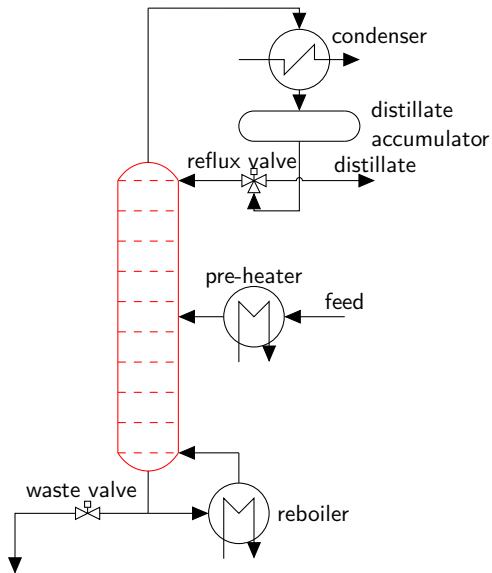
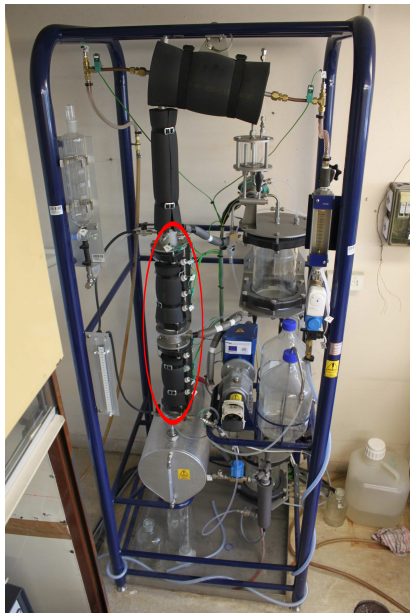
Distillation Column – Process Unit



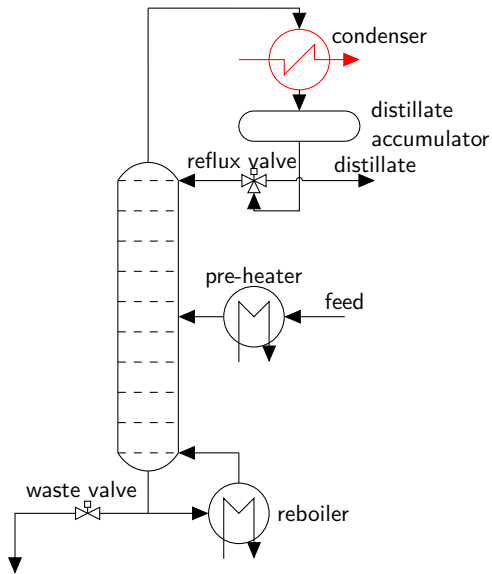
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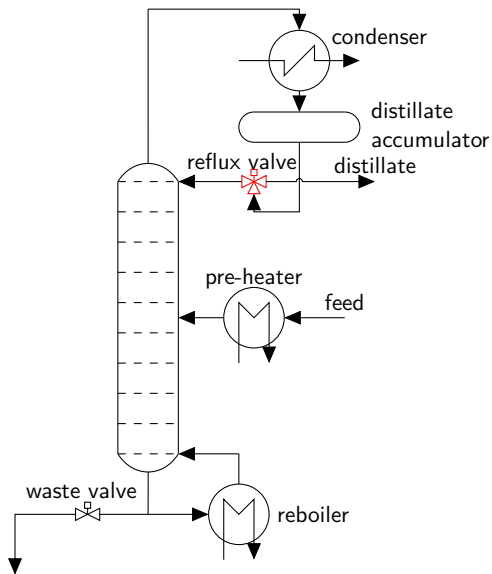
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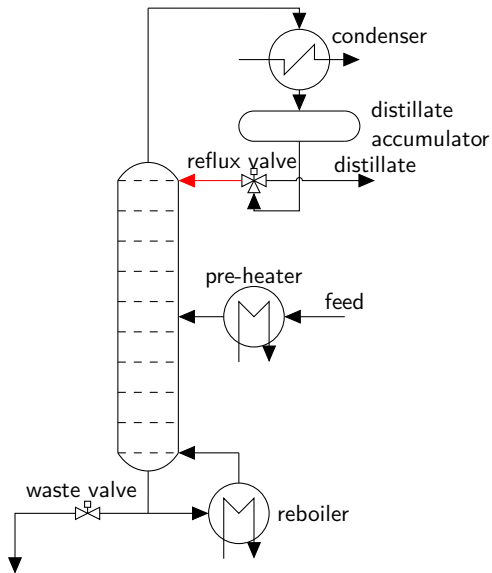
Distillation Column – Process Unit



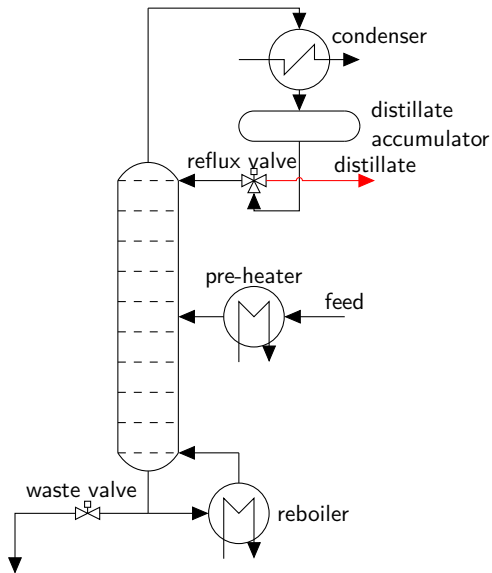
Distillation Column – Process Unit



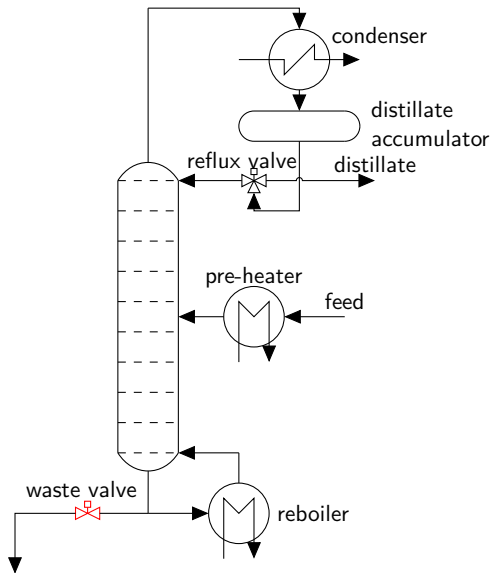
Distillation Column – Process Unit



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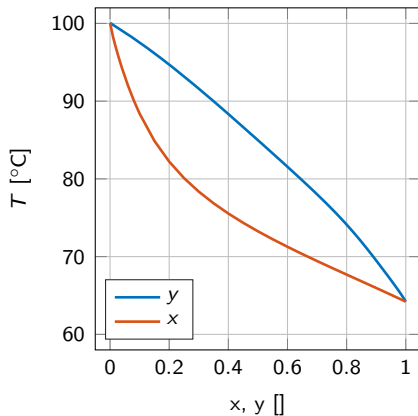


Distillation Column – Process Unit



Aims

- Concentration via temperature control



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Challenges

- Hardware setup
- Nonlinearities
- Disturbances
- Plant-model mismatch

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- Concentration via temperature control

Challenges

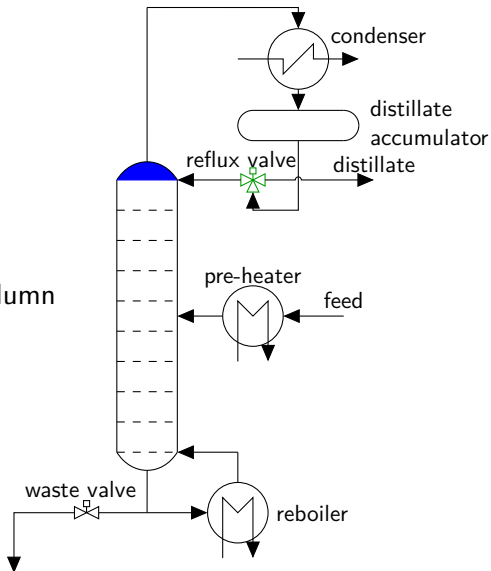
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- Nonlinearities
- Disturbances
- Plant-model mismatch

Tools

- Model identification
- Model predictive control

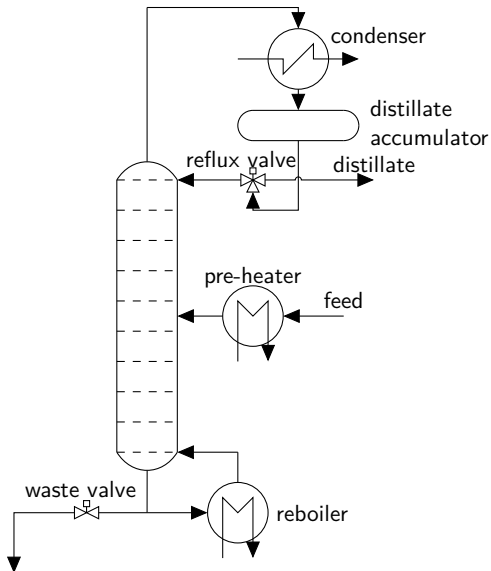
Distillation Column – Variables

- 1 **Process variable:**
Temperature at top of the column
- 2 **Manipulated variable:**
Reflux ratio



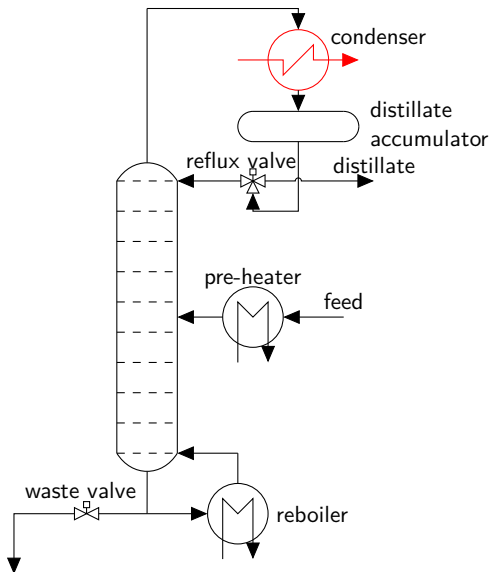
Control Challenges – Hardware

- 1 Oversized condenser
- 2 PWM signal
- 3 Feed temperature control



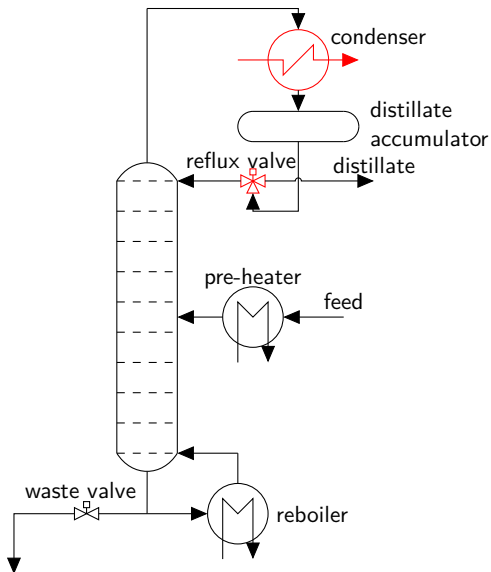
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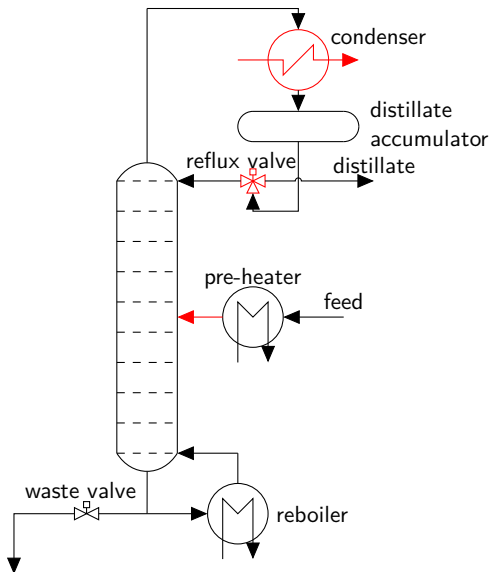
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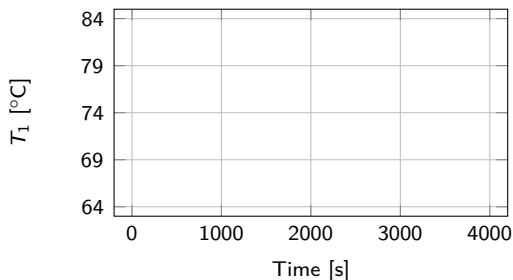
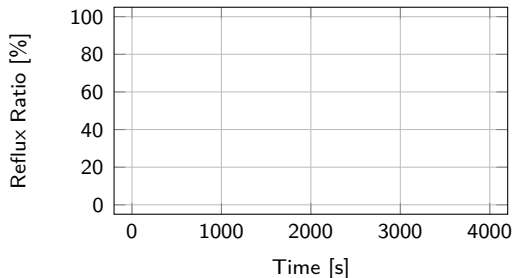


Model Identification

1 Step changes

2 Responses

3 Identified model

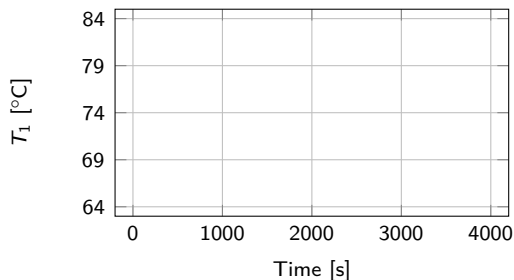
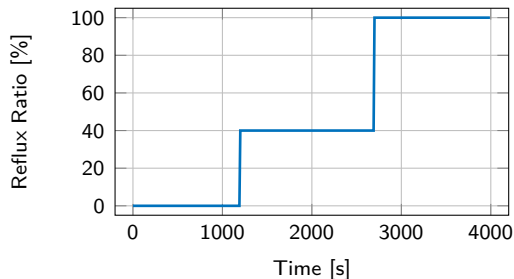


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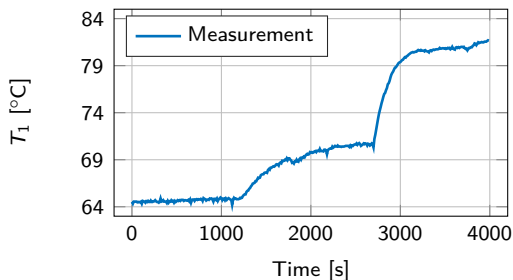
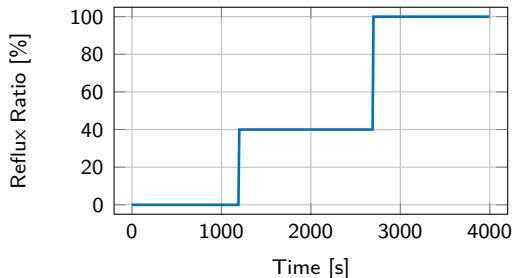


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Model Identification

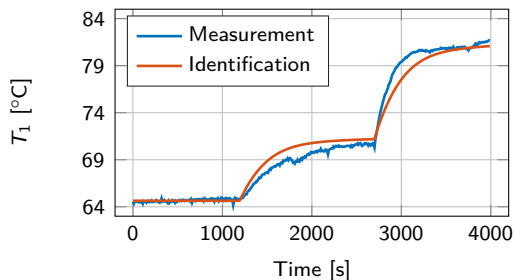
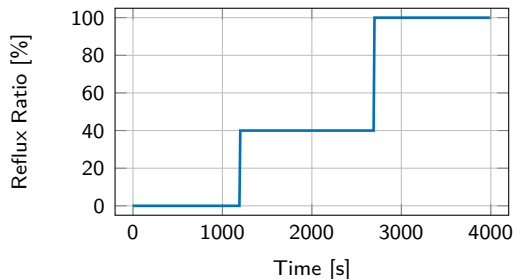
1 Step changes ✓

2 Responses ✓

3 Identified model ✓

$$x_{k+1} = Ax_k + Bu_k$$

$$y_k = Cx_k$$



Common Assumption

Design model

is equal

Plant

Design model

~~is equal~~

Plant

Plant-model mismatch

Design model

~~is equal~~

Plant

Origins of Offset in Control

- 1 Plant-model mismatch
- 2 Unmeasured disturbances
- 3 Incomplete state information

- 1 Disturbance modelling
- 2 Estimation of variables
- 3 Model predictive control

Design model:

$$x_{k+1} = Ax_k + Bu_k$$

$$y_k = Cx_k$$

Augmented design model:

$$x_{k+1} = Ax_k + Bu_k$$

$$d_{k+1} = d_k$$

$$y_k = Cx_k + d_k$$

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Luenberger observer:

$$\begin{bmatrix} \hat{x} \\ \hat{d} \end{bmatrix}_{k+1} = \begin{bmatrix} A & 0 \\ 0 & I \end{bmatrix} \begin{bmatrix} \hat{x} \\ \hat{d} \end{bmatrix}_k + \begin{bmatrix} B \\ 0 \end{bmatrix} u_k + L(y_{m,k} - \hat{y}_k)$$

$$\hat{y}_k = \begin{bmatrix} C & I \end{bmatrix} \begin{bmatrix} \hat{x} \\ \hat{d} \end{bmatrix}_k$$

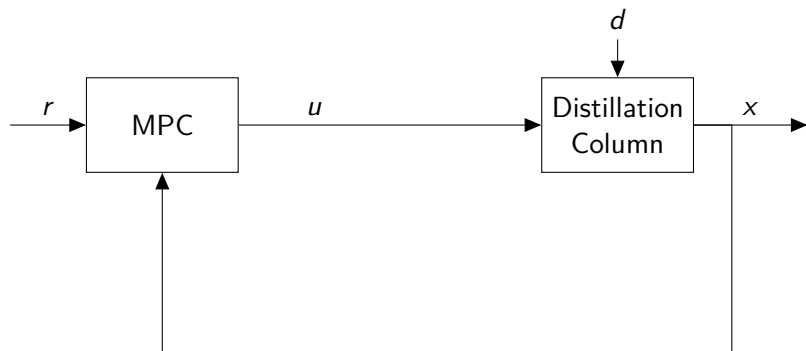
Reference tracking MPC:

$$\begin{aligned} \min \quad & \sum_{k=0}^{N-1} \left((y_{k+1} - r)^2 + \lambda (\Delta u_k)^2 \right) \\ \text{s.t.} \quad & x_{k+1} = Ax_k + Bu_k \quad k = 0, \dots, N-1 \\ & y_k = Cx_k + d_0 \quad k = 0, \dots, N \\ & \Delta u_k = u_k - u_{k-1} \\ & u_{\min} \leq u_k \leq u_{\max} \\ & x_0 = \hat{x}(t) \\ & d_0 = \hat{d}(t) \end{aligned}$$

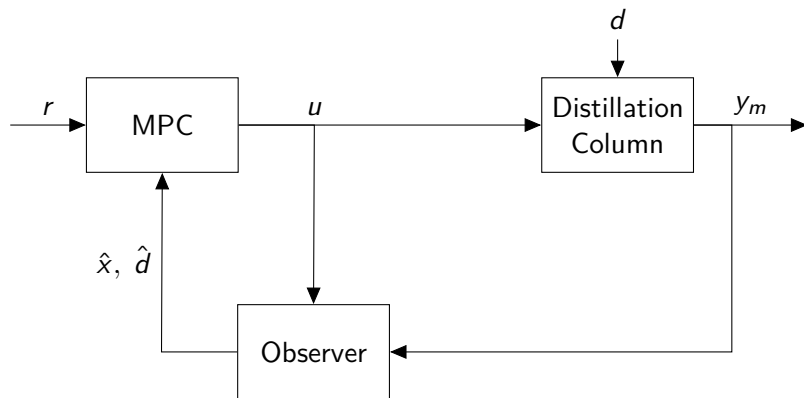
Offset-free Control Tools

- 1 Disturbance modelling ✓
- 2 Estimation of variables ✓
- 3 Model predictive control ✓

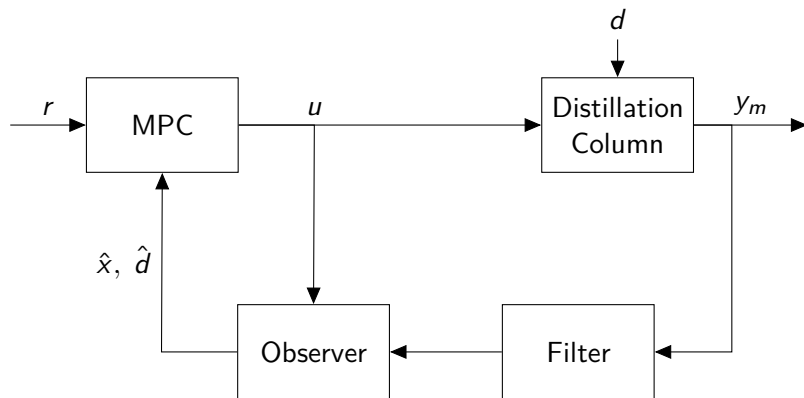
Control Scheme



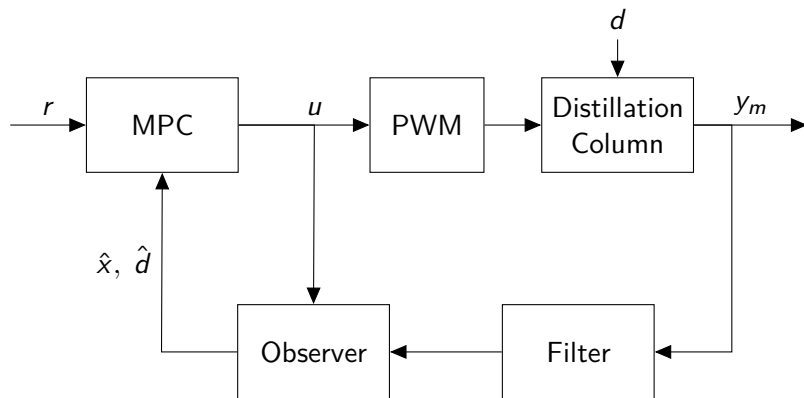
Control Scheme



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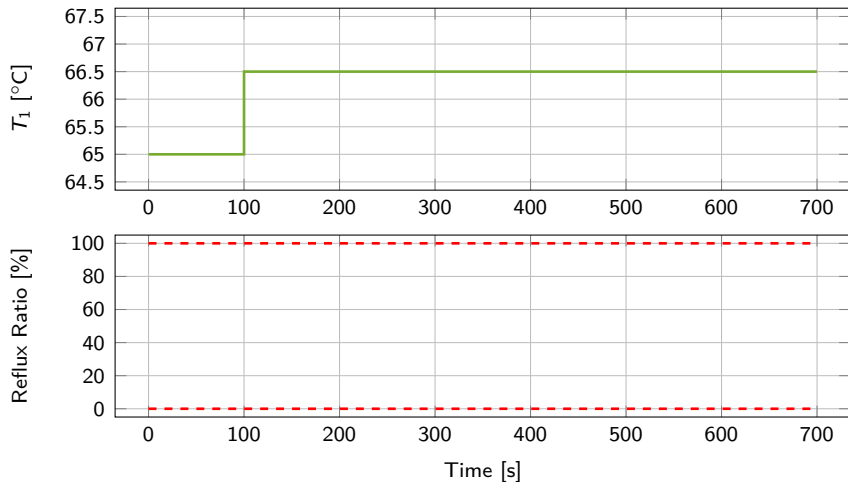


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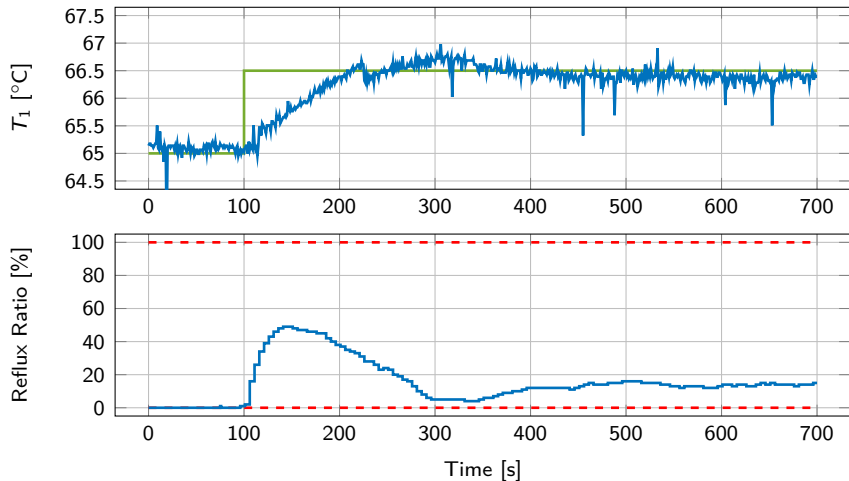
Experimental Results

$T_s = 5$ seconds , $N = 50$ samples , $\lambda = 10^{-2}$



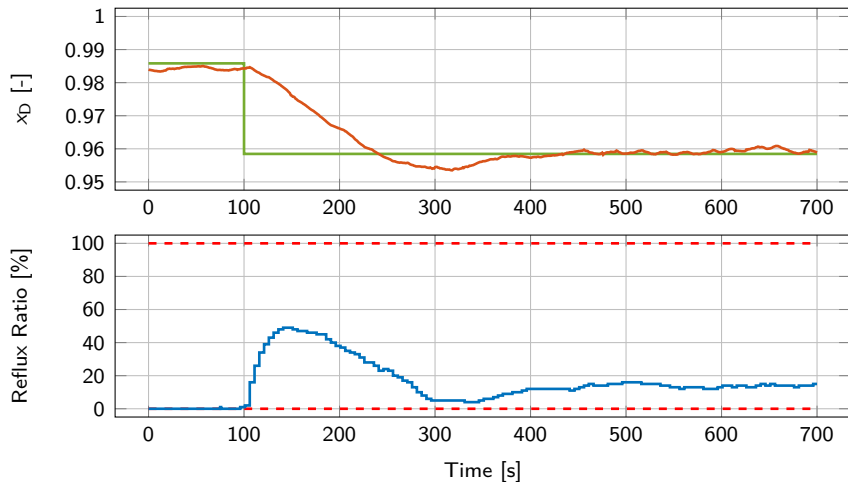
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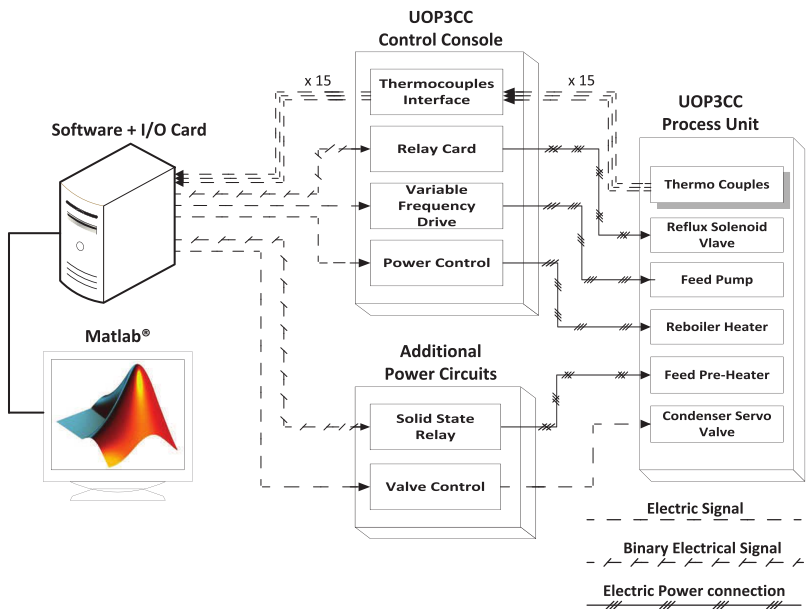
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Backup: Distillation Column – Hardware Solution



Backup: Effect of Disturbances

