

Integrated Control and Sensing for Sustainable Operation of Flexible Intensified Processes

Fabian Claus Schweers¹, Sebastian Engell¹

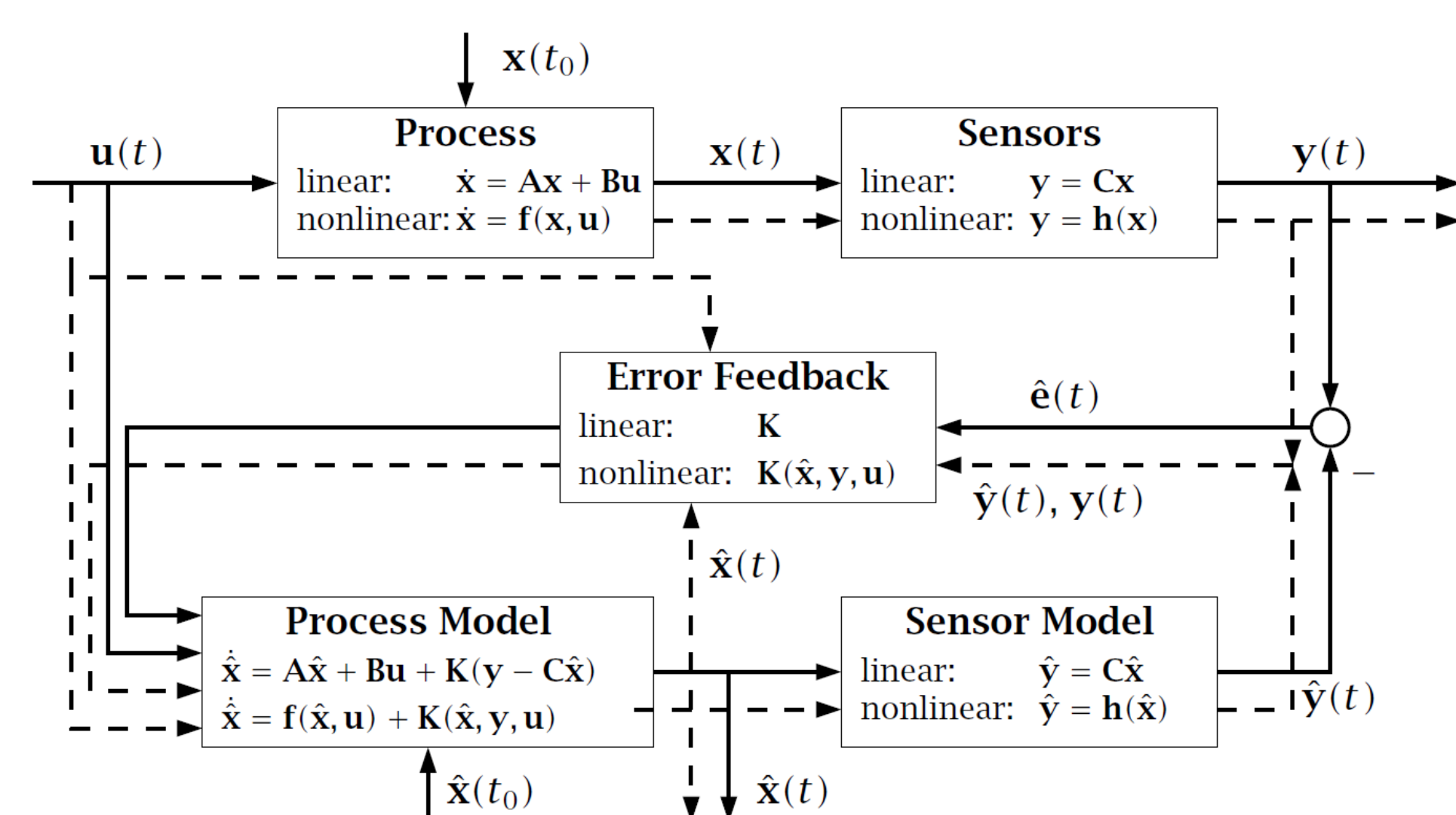
¹ Process Dynamics and Operations Group, TU Dortmund, Germany

Motivation

Challenges in Chemical Industry:

Nowadays there are tight quality requirements that must be met to be competitive on the global market. These quality requirements require the integration of novel PAT-based measurements integrated into monitoring and control systems. The provided information by PAT-sensors can be combined with the information from other sensors to obtain insight into the processes and to detect quality problems early.

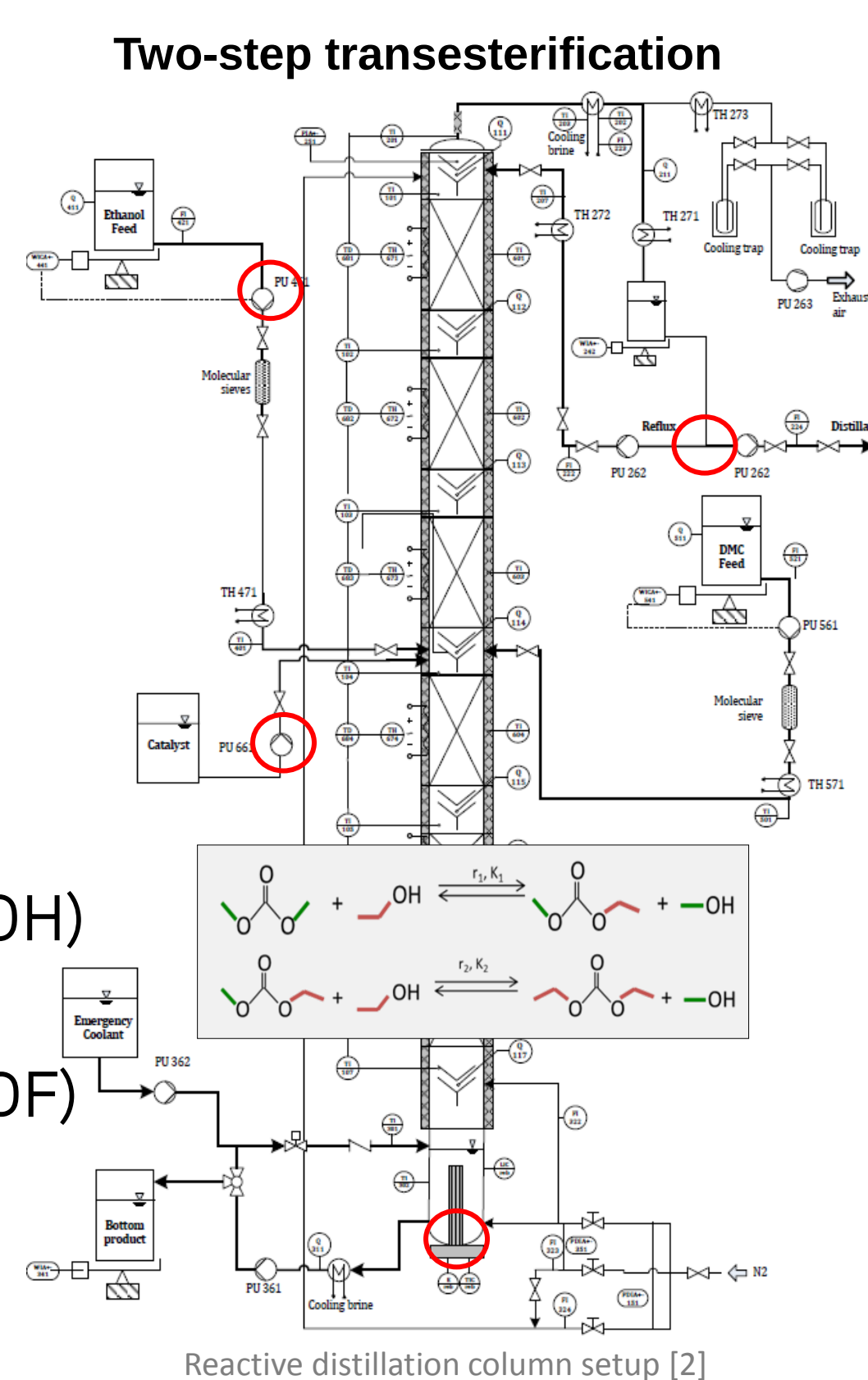
- Full state information is required for Advanced Control Methods
- State Estimation Algorithms needs to be performed to gather full state information
- PAT-based sensors deliver information with unequal sampling rates (e.g. concentration, viscosity, ...)
- Goal: Integration of multi-rate sensor information into control algorithms



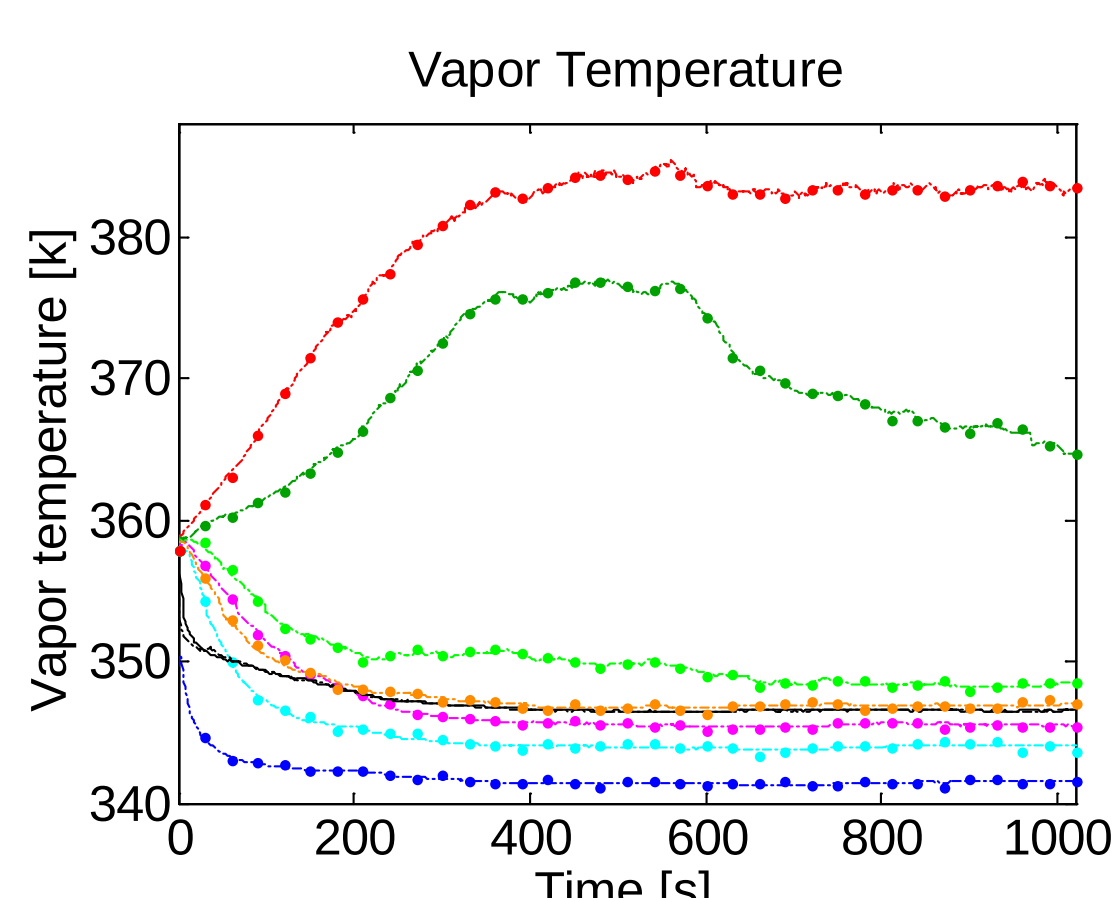
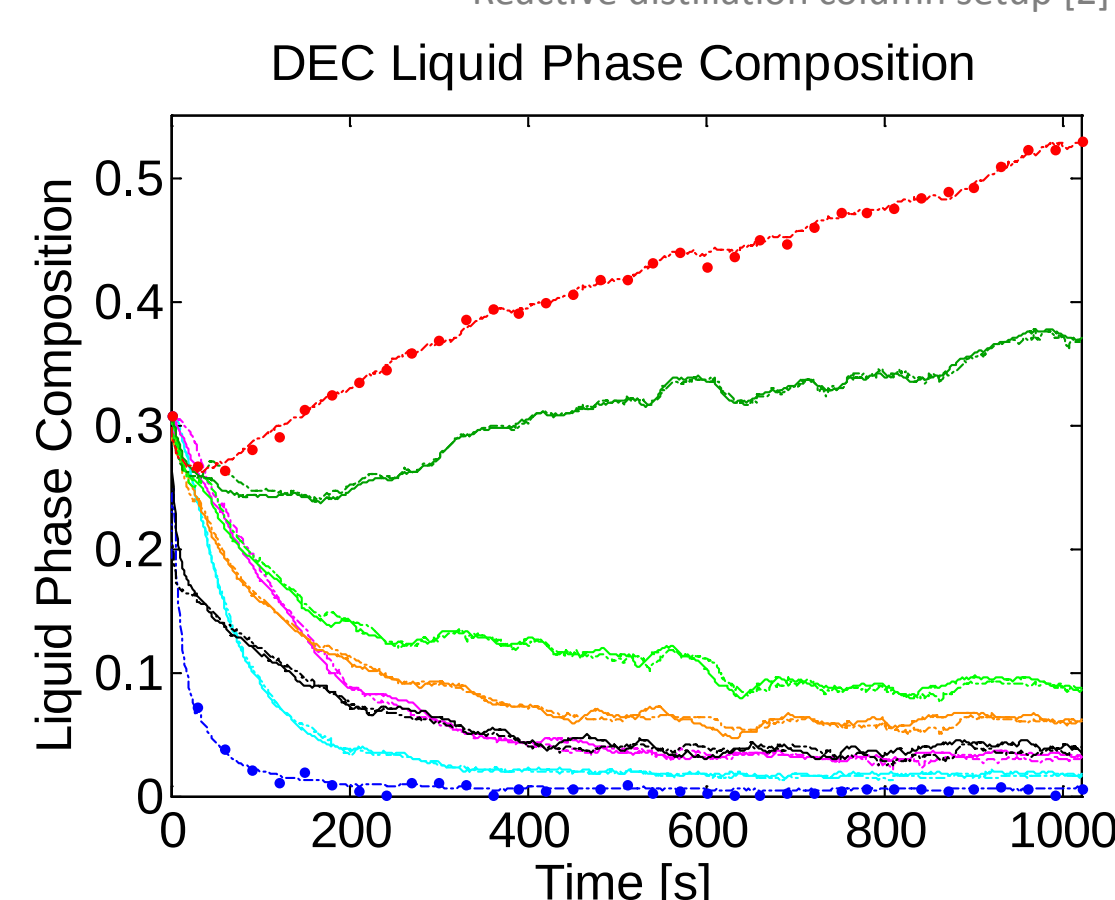
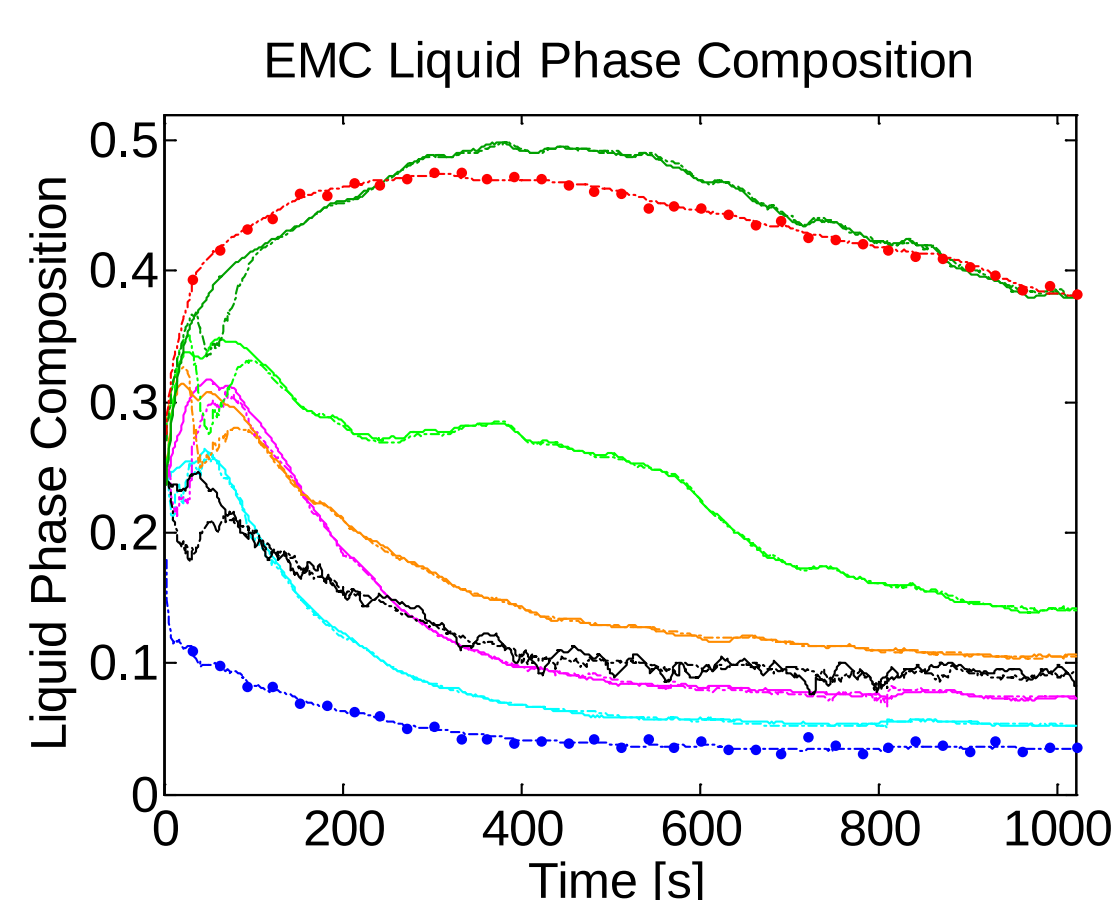
Overview of State Estimation Structure with Process, Process-Model, Sensors and Sensor-Model [1]

Application of multi-rate EKF State Estimation

- Multi-rate EKF is applied to a reactive distillation column process
- The estimated states converge quick to the true plant states of the process
- Operating conditions are defined by:
 - Feed flow-rate (EtOH, DMC)
 - Molar fraction of catalyst (diluted in EtOH)
 - Reflux ratio (RR)
 - Boil-up or distillate-to-feed ratio (B or DF)



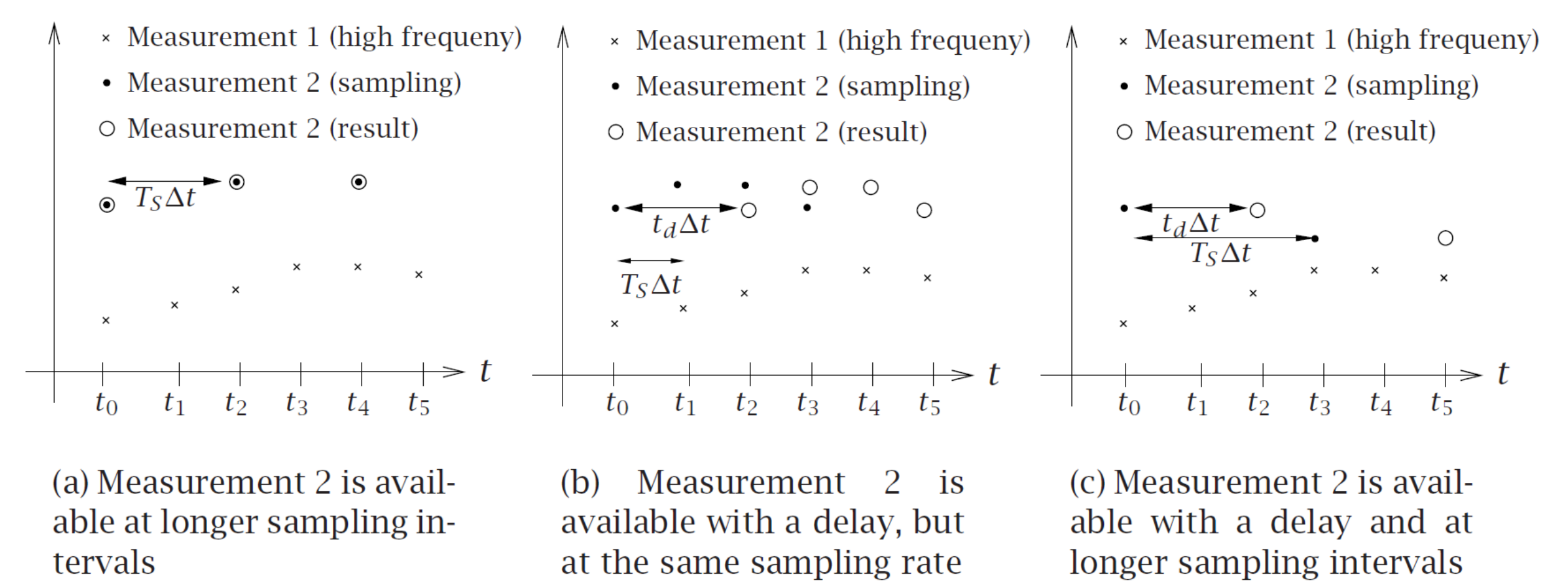
Reactive distillation column setup [2]



Distributor	Color
Liquid Distributor 1	Blue
Liquid Distributor 2	Cyan
Liquid Distributor 3	Magenta
Feed Distributor	Black
Liquid Distributor 4	Orange
Liquid Distributor 5	Green
Liquid Distributor 6	Dark green
Reboiler	Red

DAE-EKF on the case study [2]

Multi-rate Sensor Information Integration



Visualization of Multi-Rate Sensor Measurements [1]

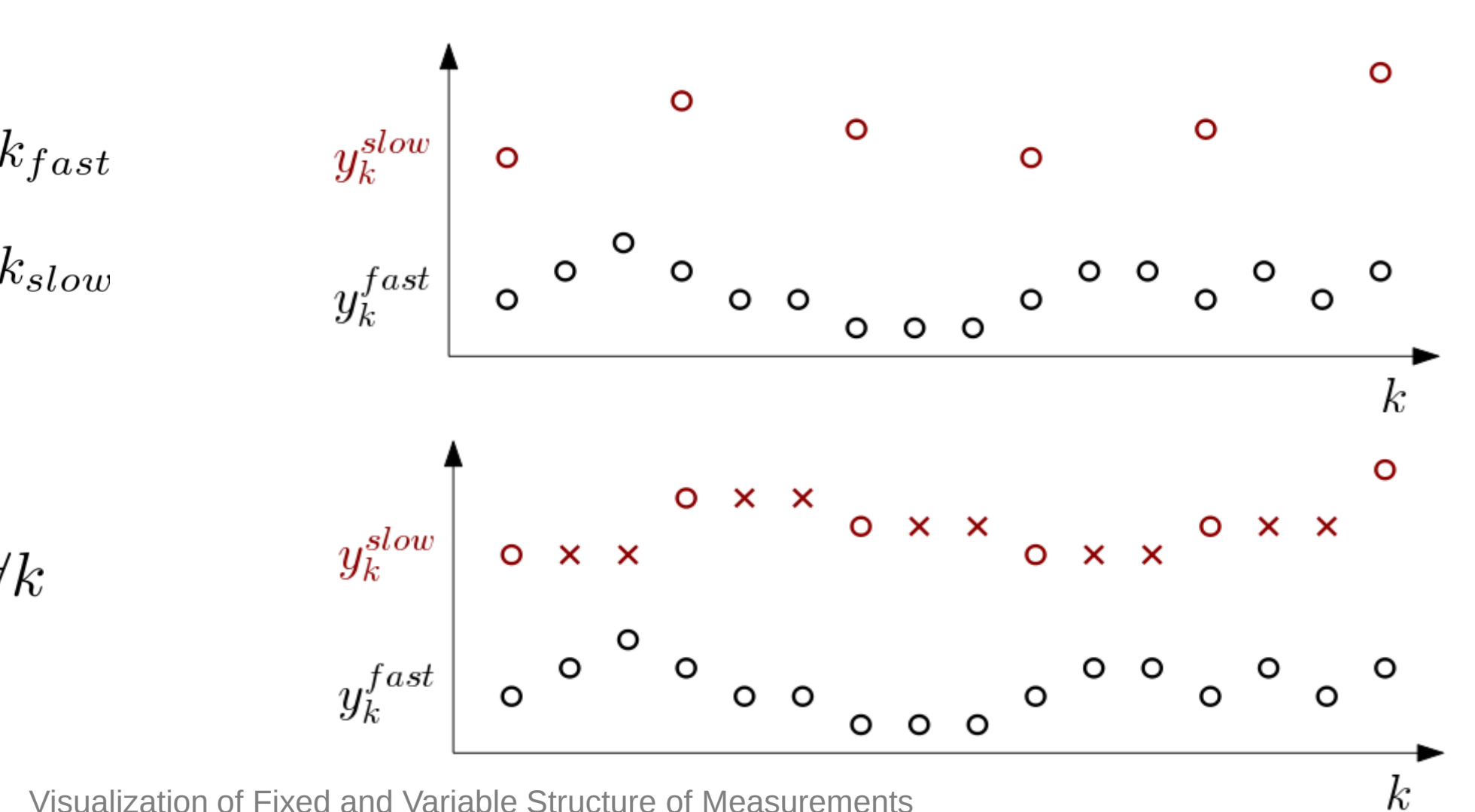
- PAT-sensors have commonly longer sampling intervals than standard sensors (e.g. concentration vs. temperature)
- Some PAT-sensors (e.g. NMR-spectroscopy) have usually delays due to the measurement setup (feed line) and the applied techniques (e.g. algorithms)
- These issues need to be considered and handled appropriately within state estimation techniques
- Estimation results can be improved

Variable Structure:

$$y_k = \begin{cases} y_k^{fast} & \forall k_{fast} \\ y_k^{slow} & \forall k_{slow} \end{cases}$$

Fixed Structure:

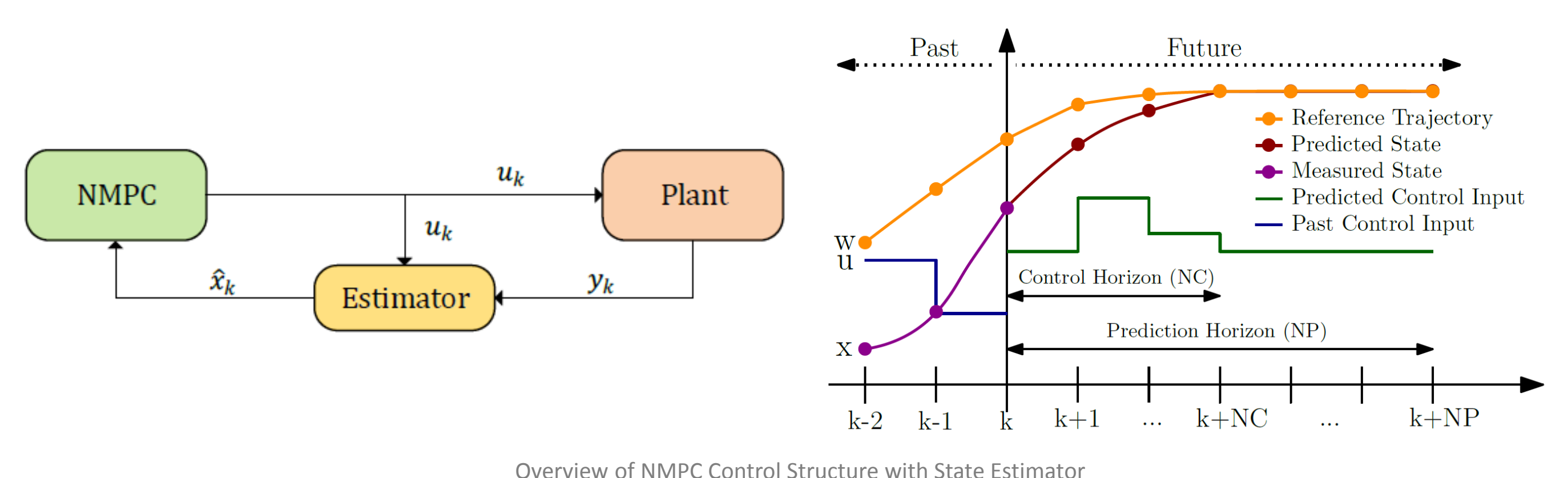
$$y_k = \begin{bmatrix} y_k^{slow} \\ y_k^{fast} \end{bmatrix} \quad \forall k$$



Visualization of Fixed and Variable Structure of Measurements

Novel PAT-based Control Strategies

- Novel PAT-based, adaptive, closed-loop control:
 - Nonlinear model-predictive control based on rigorous process models
- Economic optimization:
 - Iterative set-point optimization
- State and parameter estimation:
 - Combined parameter and state estimation using multi-rate PAT-sensor data



Overview of NMPC Control Structure with State Estimator

References and Acknowledgements

- "Heat Balance Calorimetry and Multirate State Estimation Applied to Semi-Batch Emulsion Copolymerisation to Achieve Optimal Control", Dr.-Ing. Stefan Krämer, Dissertation, Dortmund, 2005, published by Shaker, Aachen.
- "Simulation Study of the Particle Filter and the EKF for State Estimation of a Large-scale DAE-system with Multi-rate Sampling", Daniel Haßkerl, Momin Arshad, Reza Hashemi, Sankaranarayanan Subramanian, Sebastian Engell, Dortmund, 2016, published by Elsevier Ltd. in IFAC PapersOnLine, Volume 49, Issue 7, 2016, p. 490–495, Trondheim, Norway.



This project has received funding from the European Union's Horizon 2020 research and innovation program under the grant agreement N° 636942.

www.consens-spire.eu

This document reflects only the view of the author(s) and the European Commission cannot be held responsible for any use which may be made of the information contained herein. This document is provided with no warranties whatsoever, including any warranty of merchantability, non-infringement, fitness for any particular purpose, or any other warranty with respect to any information, result, proposal, specification or sample contained or referred to herein. Any liability, including liability for infringement of any proprietary rights, regarding the use of this document or any information contained herein is disclaimed. No license, express or implied, by estoppel or otherwise, to any intellectual property rights is granted by or in connection with this document. This document is subject to change without notice.