Process Tomography Under Nonstationary Velocity Fields

Antti Lipponen[1], Aku Seppänen[1], and Jari P. Kaipio[1,2]
[1] Department of Physics and Mathematics, University of Eastern Finland
[2] Department of Mathematics, University of Auckland, New Zealand

Finnish Centre of Excellence in Inverse Problems Research

UNIVERSITY OF EASTERN FINLAND

Introduction

- Process tomography refers to a variety of imaging techniques used in process industry
- Typical applications include monitoring, control and design of mixing and foaming processes, mass transport in pipelines, and chemical reactors
- Imaging modalities are based, for example, on the use of ultrasound, radiation, or electric currents
- Image reconstruction problem is usually ill-posed inverse problem and therefore additional prior information of the target is needed
- In this study, we employ Bayesian state estimation approach for image reconstruction

State estimation

- Conventional stationary reconstruction methods include assumption of slowly varying or stationary targets
- In cases of rapidly time-varying targets, the use of stationary reconstructions can lead to poor reconstructions, see Figure 1

Figure 1. Conventional stationary EIT reconstruction. See Figure 4 for true concentration distribution and state estimate.

- Seppänen et al. introduced a state estimation approach for reconstructing time-varying targets in process tomography [1]

Approximation errors

- Approximation error approach is a technique to statistically model and compensate the errors due to inaccurate or incomplete models [2]
- For example, in case of process tomography, errors due to coarse discretization and unknown velocity field can be compensated with approximation error approach [3]

References

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[2] J.P. Kaipio and E. Somersalo, *Statistical and Computational Inverse Problems*. Springer-Verlag, New York, 2005.

[3] A. Lipponen, A. Seppänen, and J.P. Kaipio. Nonstationary inversion of convection-diffusion problems – recovery from unknown nonstationary velocity fields. *Inverse Problems*, 2009. In review.

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Results

Concentration estimation, experimental study

We experimentally evaluate the state estimation approach in concentration estimation. Electrical impedance tomography (EIT) is used as imaging modality. Approximation errors due to sparse discretization, truncated computational domain, and unknown velocity field are taken into account with approximation error approach. Snapshots showing the target moving towards the electrodes are depicted in Figure 2, and approximation error approach reconstructions in Figure 3.

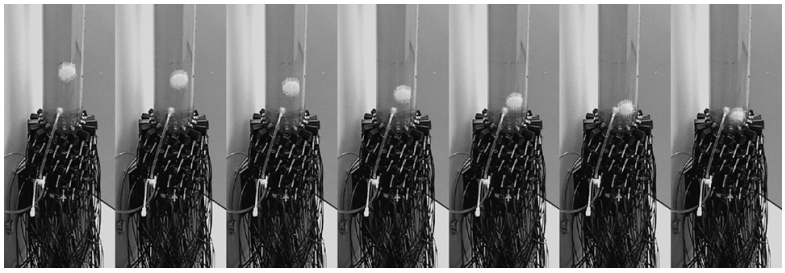

Figure 2. Target moving towards the segment of pipe surrounded by the measurement electrodes.

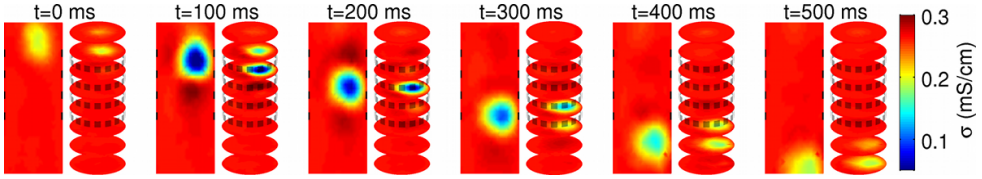

Figure 3. State estimates of rapidly time-varying target computed with approximation error approach.

Velocity field estimation, simulation study

We consider simultaneous estimation of concentration distribution and velocity field with state estimation approach. EIT is used as imaging modality, and convection-diffusion equation with reduced order Navier-Stokes as evolution model. Reduced order approximations both in observation and evolution models are compensated with approximation error approach. See [4] for more details. Reconstructions are shown in Figure 4.

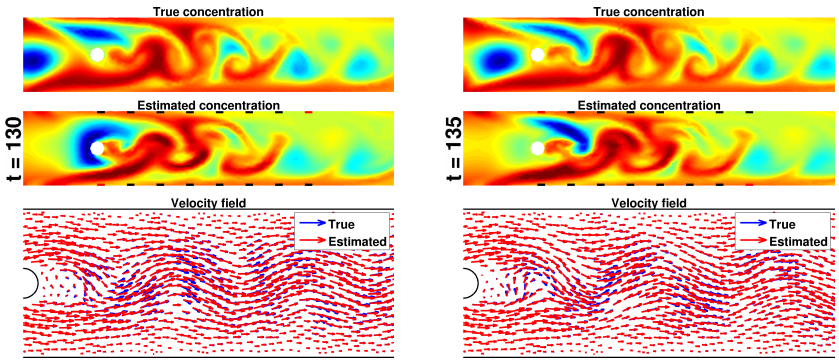

Figure 4. Reconstructions of concentration distribution and velocity field at times $t = 130$ and $t = 135$.

Conclusions

- State estimation approach makes accurate imaging of industrial processes possible even in cases of rapidly varying targets where conventional stationary reconstruction methods fail
- Approximation error approach can be employed to compensate the errors caused by inaccurate models
- With tomographic techiques, such as EIT, and state estimation it is also possible to reconstruct velocity fields which makes process tomography a promising tool for verifying, for example, CFD results

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