Applying Ray Tracing Based Reconstruction to Particle Image Velocimetry Measurements of Gaseous Flow in Packed Beds

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Flow field measurement in packed beds

- Gaseous flow strongly impacts on processes inside packed beds: heat and mass transfer, turbulence
- Intrusive measurement methods change the flow field
Introduction

Flow field measurement in packed beds

- Gaseous flow strongly impacts on processes inside packed beds: heat and mass transfer, turbulence
- Intrusive measurement methods change the flow field
- Transparent geometries for optical measurement techniques introduce distortions
  → Incorrect results e.g. for velocity calculation via PIV
Flow field measurement in packed beds

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**Solution:** correct distorted particle images using ray tracing

**Application to more complex measurement setting**
Experimental Setup

Bulk Reactor

- Optical access through transparent material (acrylic glass and N-BK7 40mm spheres as packing material)
- Body centred cubic packing (bcc)
- Flow inlet conditions defined by a diffusor, honeycombs, irregular 4mm glass sphere packing and a 4mm hole pattern
Experimental Setup

PIV Setup

- **R** - Bulk reactor (bcc)
- **C** - Imager LX 8M camera
- **L** - Nd:YAG PIV-laser
- **T** - 3D-traversing unit
- **M** - Mirror
- **O** - Light sheet optics
- **DEHS tracer**
Image Acquisition - Calibration

Calibration Image

- Commercial calibration target in the measurement plane for calculation of initial pinhole calibration parameters

Calibration target Type 106-10 from LaVision

Ray Tracing Reference Images

- Custom made target (checkerboard pattern/ ArUco marker) in background and measurement plane
- Allows for pose estimation and optical verification of simulation setup

Ray tracing reference image

ArUco Marker
Calibration

- Best results when using a combination of commercial software (DaVis) and OpenCV library:
  - Commercial calibration target to determine focal length and optical centre
  - Ray tracing reference target for distortion parameters and pose estimation (orientation)

All Parameters known to simulate the 3D scene

Marker detection on the ray tracing reference target
Sanity Check

Good Agreement between simulation and acquired image

1st Int. Workshop on Reacting Particle-Gas Systems
Image Acquisition - Particle Fields

Tracer Particle Field Images

- Double frame images of tracer particles in the flow illuminated in the measurement plane behind two spheres by a light sheet
  - Distortion effects behind the spheres are clearly visible

Apply correction to the particle fields

Particle field image (one frame)
Ray Tracing Based Reconstruction – Image Correction

Image Correction

- Reconstruct light field on the investigation plane
- Use ray differentials as weighting for samples
Image Correction

- Reconstruct light field on the investigation plane
- Use ray differentials as weighting for samples
- Backward ray tracing step to remove distortions
Ray Tracing Based Reconstruction – Image Correction

Particle field image (one frame)

Corrected particle field image (one frame)

Artefact
Vector Field Calculation

**Processing**

- Reimport of corrected images to PIV-software (DaVis)
- Application of masks and time filters to remove areas where no evaluation is possible (reflections, no measurement signal, no reconstruction)
- Vector field calculation by a classical cross-correlation method with decreasing interrogation windows, 50% overlap and post processing

Averaged flow field of the main velocity component above 17 layers of spheres for particle Reynolds number 200 to 500 after ray tracing based reconstruction
Validation

Results

- No significant influence of the correction on the results for the freeboard flow
  - Averaged relative differences between uncorrected and corrected freeboard flow results do not exceed 0.08%, especially in the rim region, due to incorrect mask function
- Distorted region is corrected and matches well the freeboard flow
- Perspective applied to centred sphere allows for correction of rim region
Conclusion and Outlook

Conclusion

- Application of ray tracing PIV on the surface of a bcc spherical packing
- Presentation of a complete correction routine
- Extension of previously used correction method
- Successful validation by comparison between the flow field of the free board and distorted regions behind the top layer spheres

Outlook

- Application of the method to volumetric measurement techniques
- Access to the interstices inside the packed bed
- Investigation of perspective to recover highly distorted regions
- Further optimization and enhancement of the ray tracing based correction routine
Thank you for your attention!

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