Real-time Image-based Reconstruction of Pipes Using Omnidirectional Cameras

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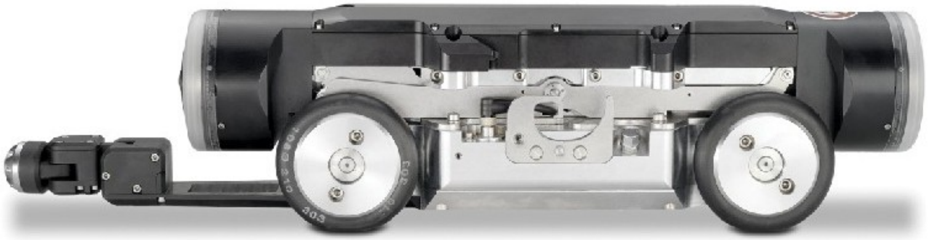
In cooperation with

IBAK Helmut Hunger GmbH & Co. KG, Kiel

Motivation

Quelle: http://www.kanalinspekteure.de

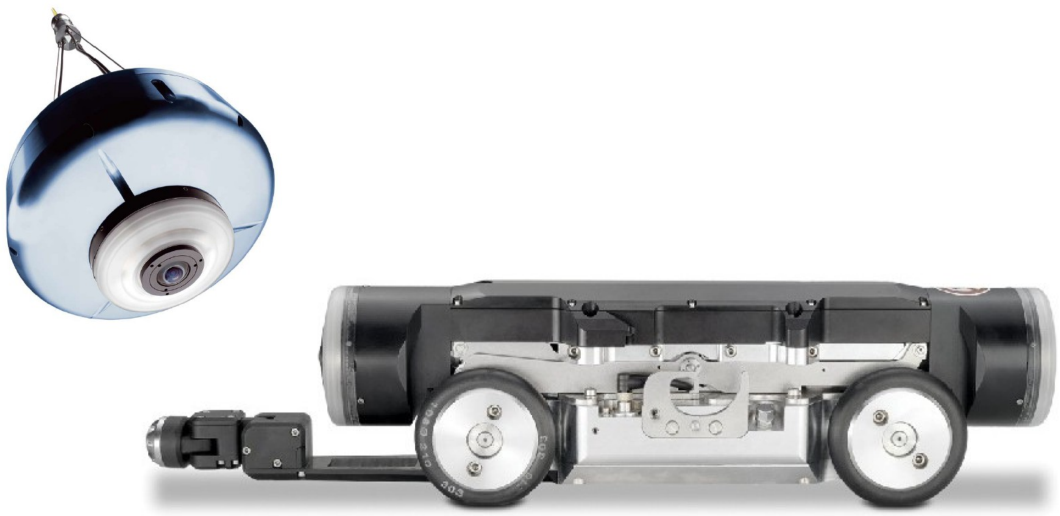
Quelle: http://www.ibak.de



Sewer inspection systems

- Inspection of sewer shafts and pipes with mobile camera systems
- Manual evaluation of videos by expert

Task: Create 3d reconstruction for visualization and measuring



Contents

Image acquisition for sewer pipe inspection

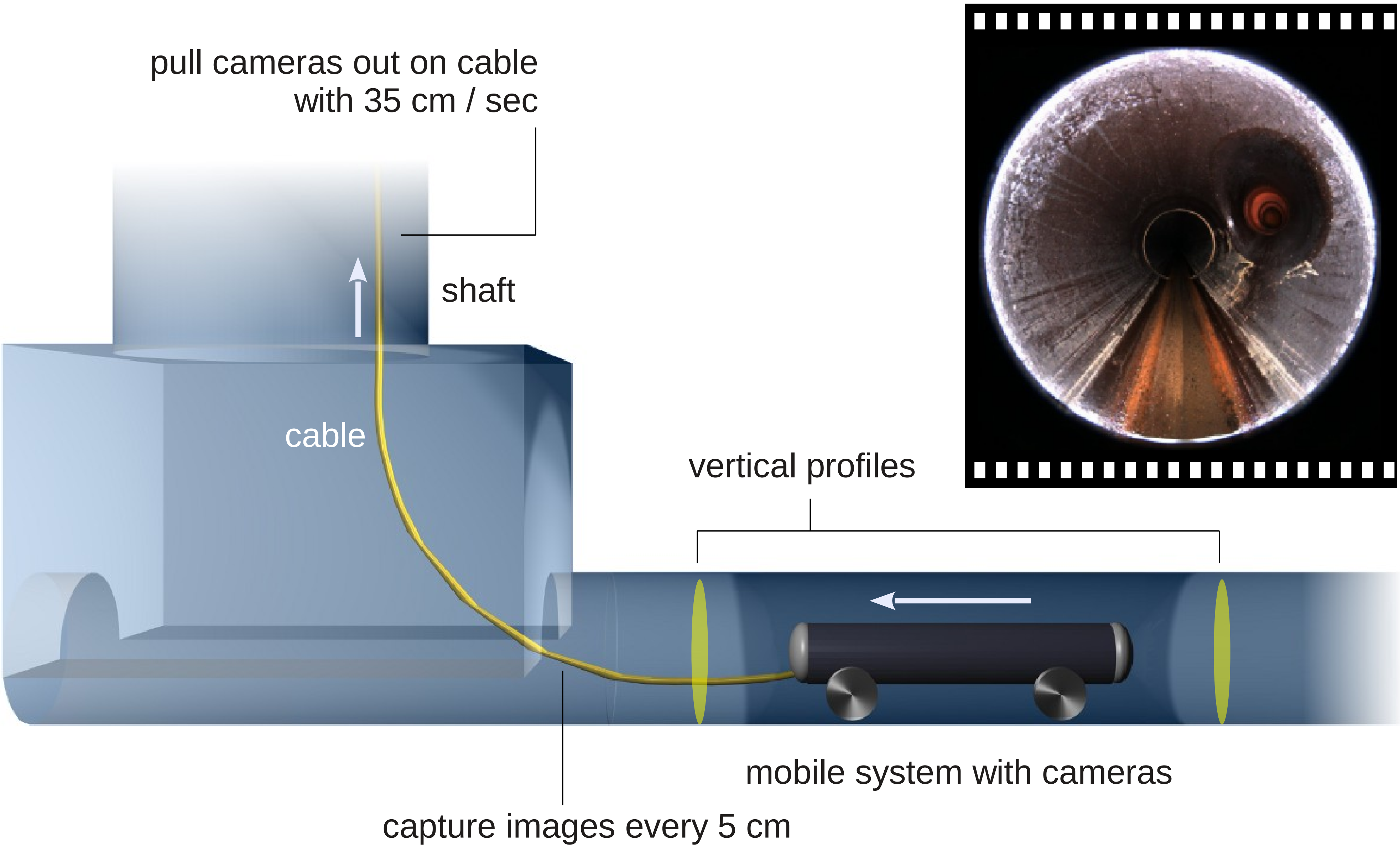
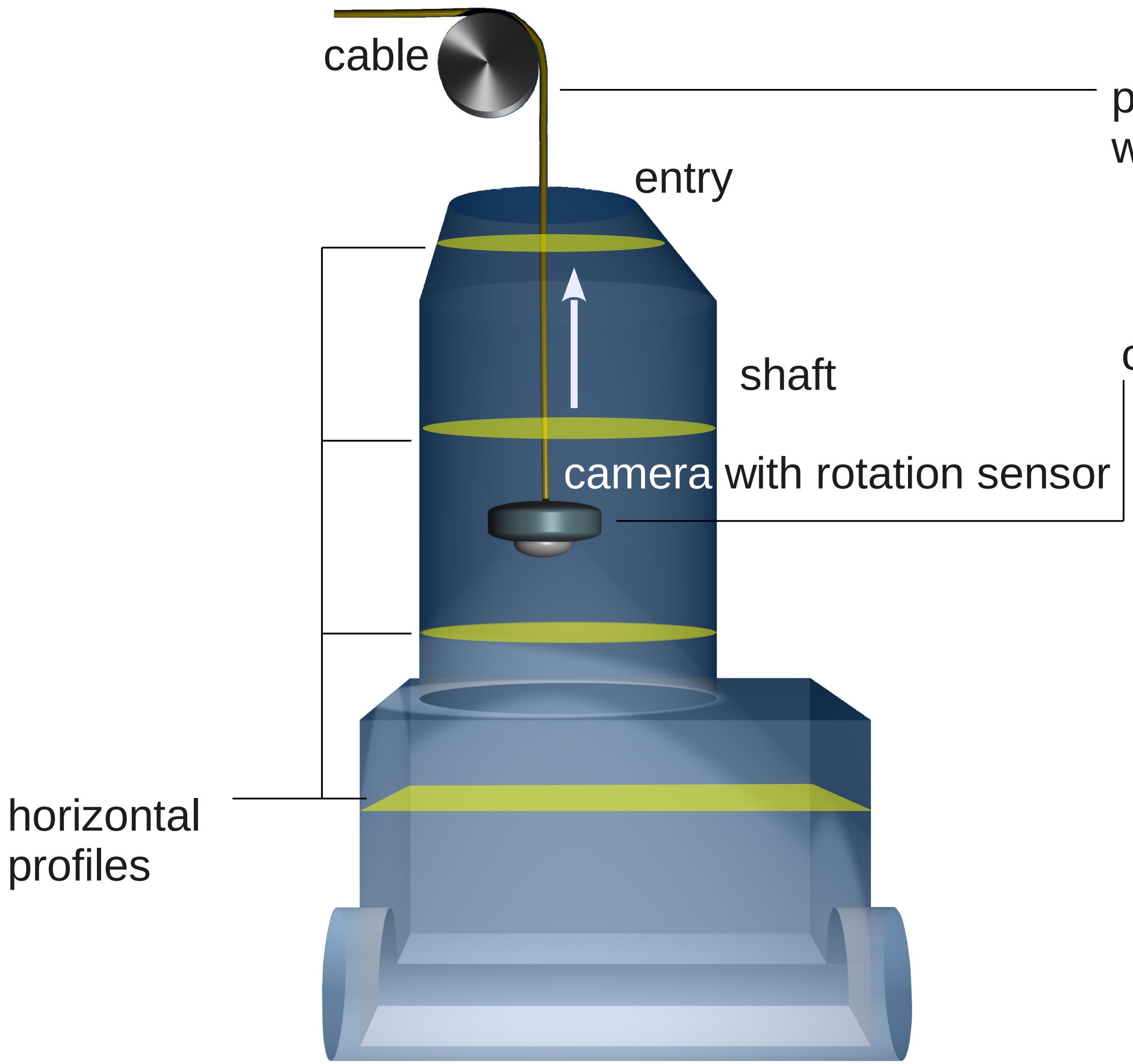
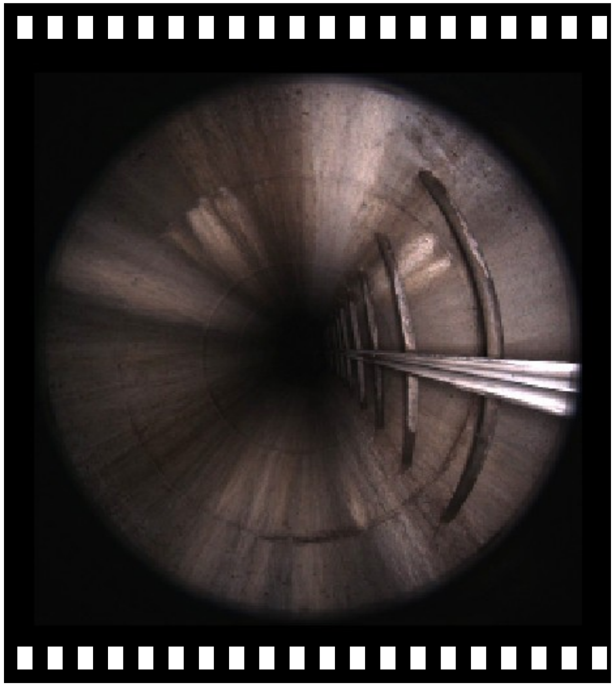


Image acquisition for sewer shaft inspection

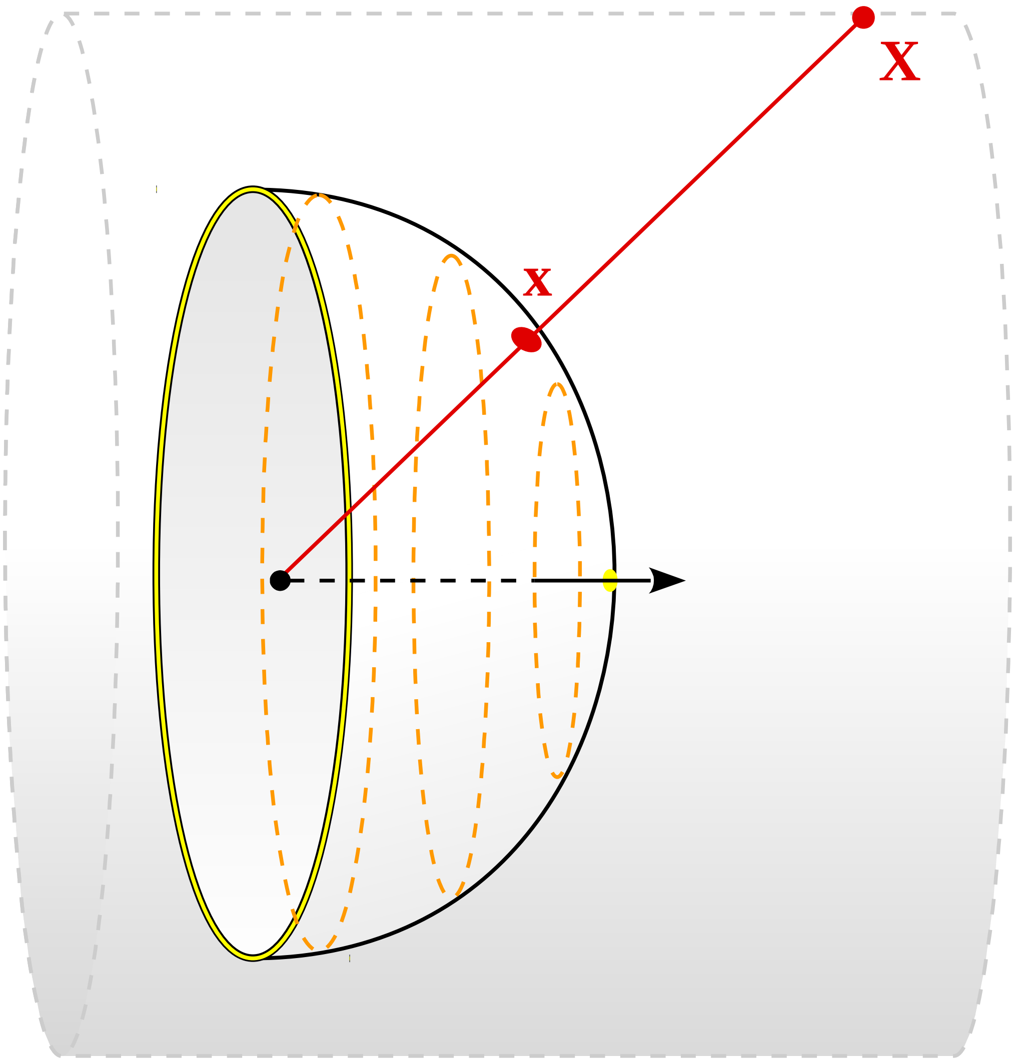


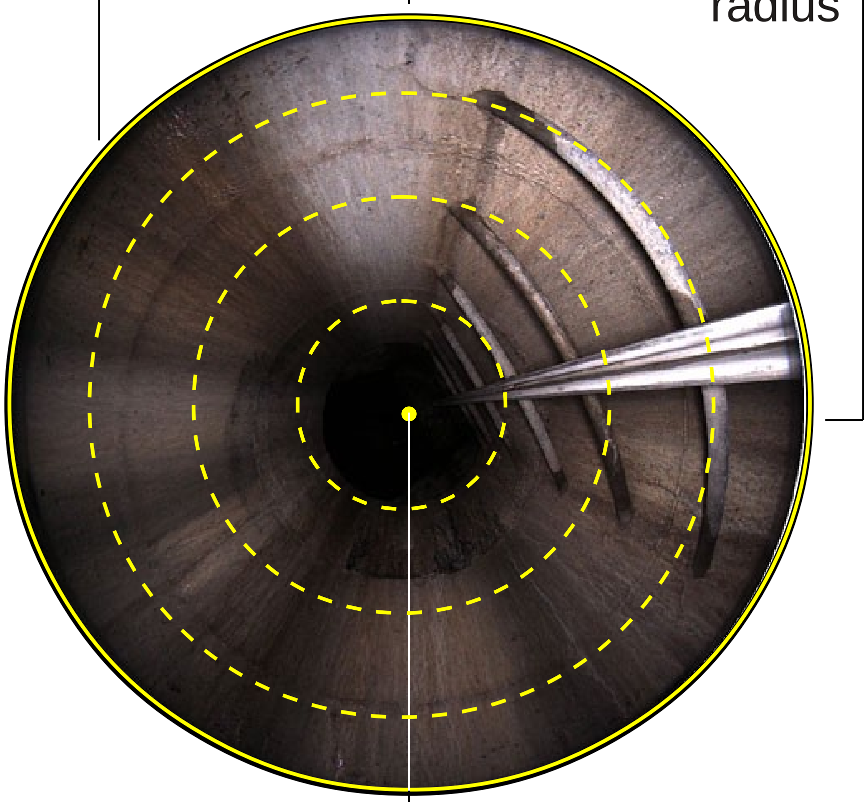
pull camera up on cable
with 35 cm / sec

capture image every 5 cm



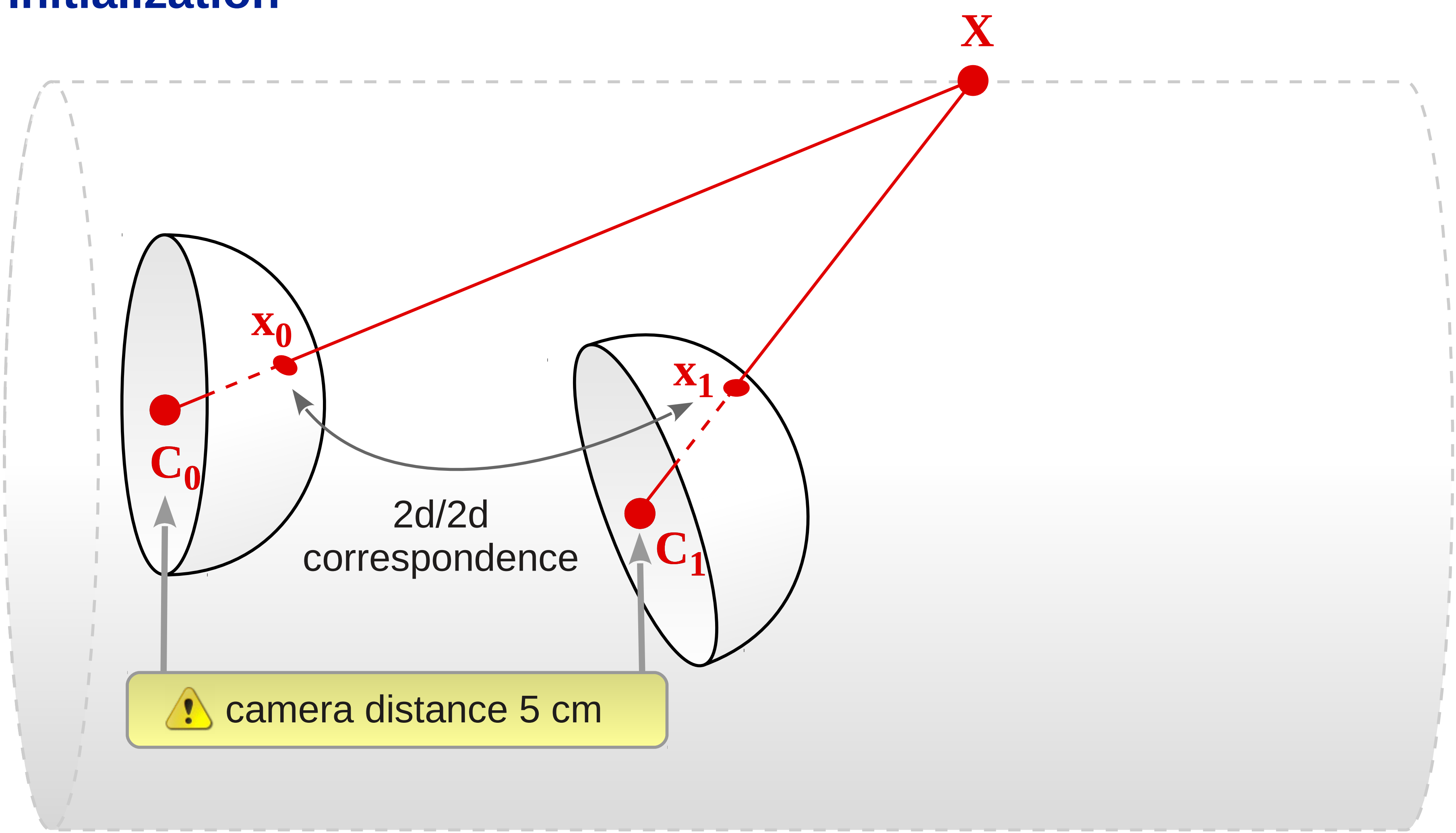
Spherical camera model





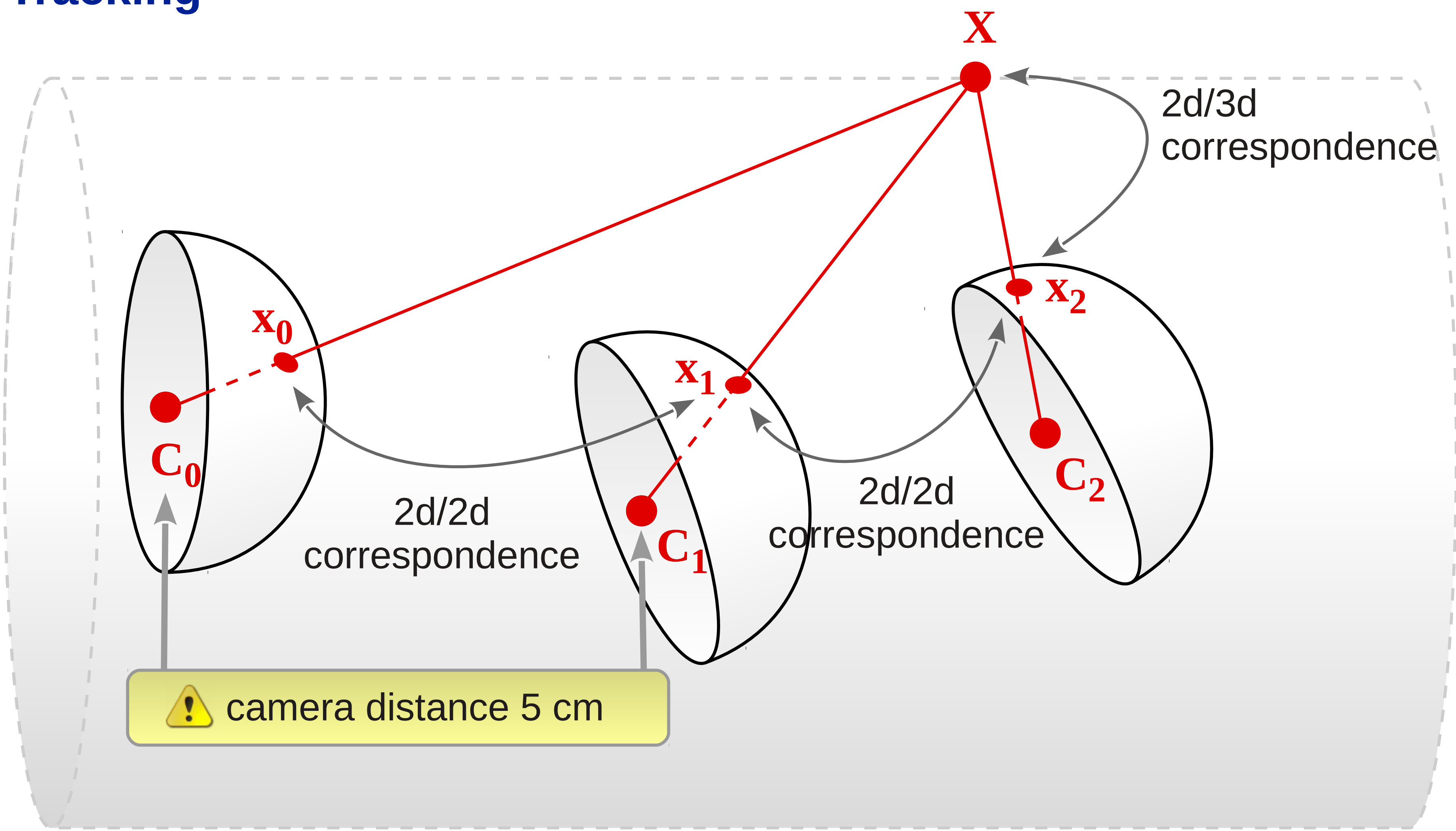
Structure from Motion

Initialization



Structure from Motion

Tracking



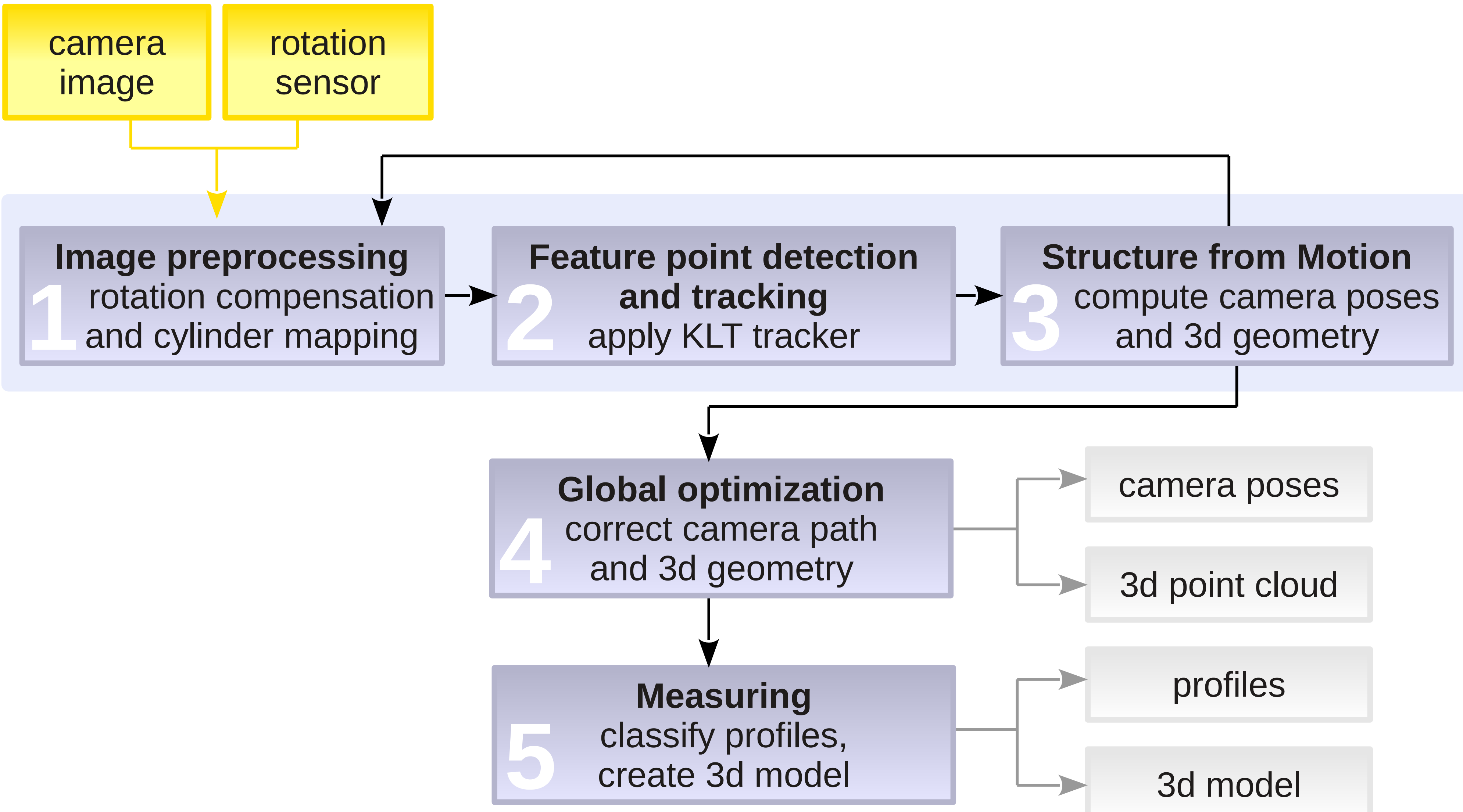
3d reconstruction – Problems and challenges

- Challenging lighting conditions and depth of view
- Strong image distortions
- Brief feature point visibility, large frame-to-frame translation
- Inaccurate camera calibration
- Demands for real-time processing: min. 7 Hz

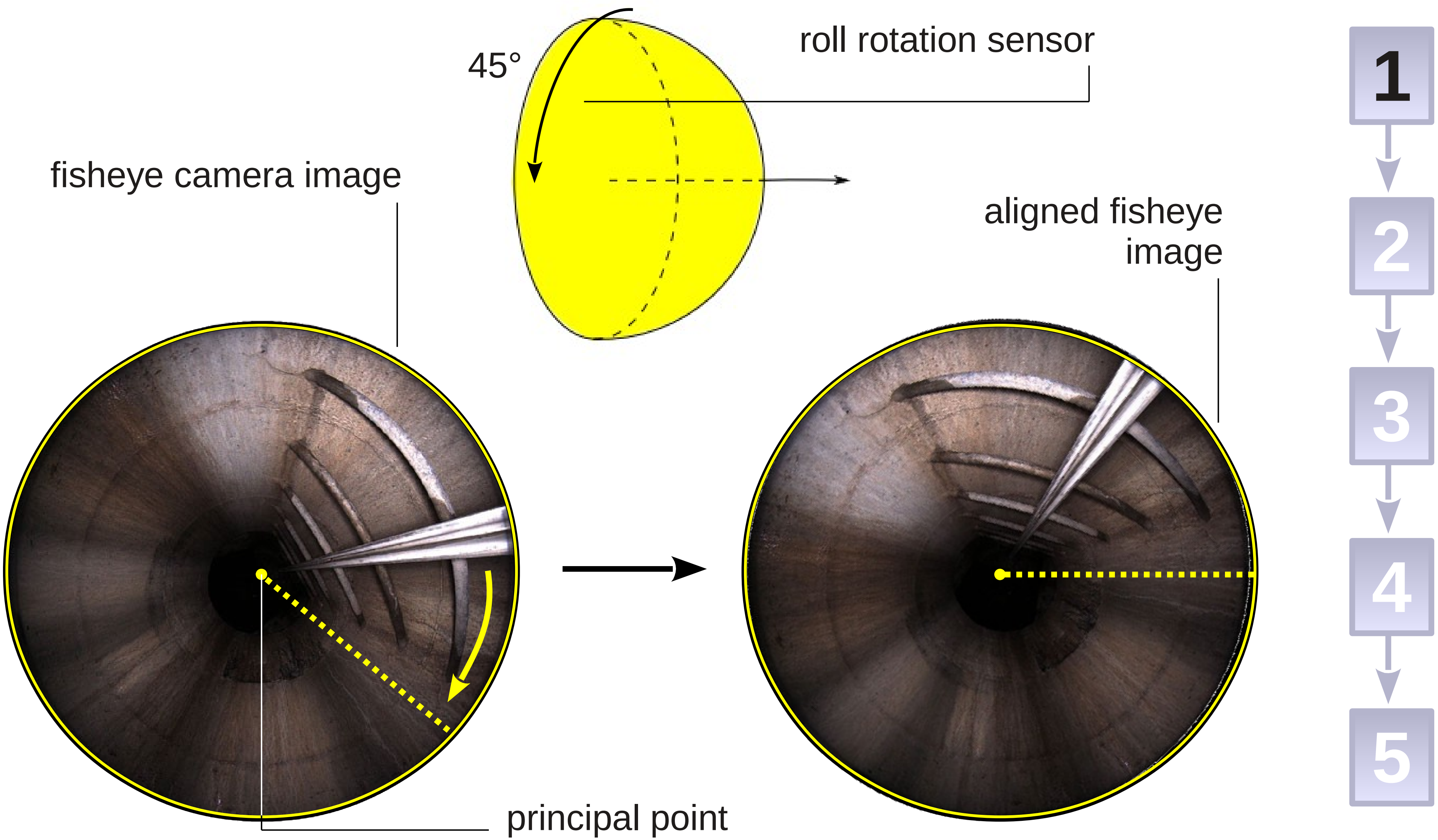
Our approach

- Image Acquisition and Structure from Motion
- Our reconstruction approach
  - Cylinder mapping
  - Global geometric correction
  - Profile fitting and model creation
- Tests and applications
- Conclusion

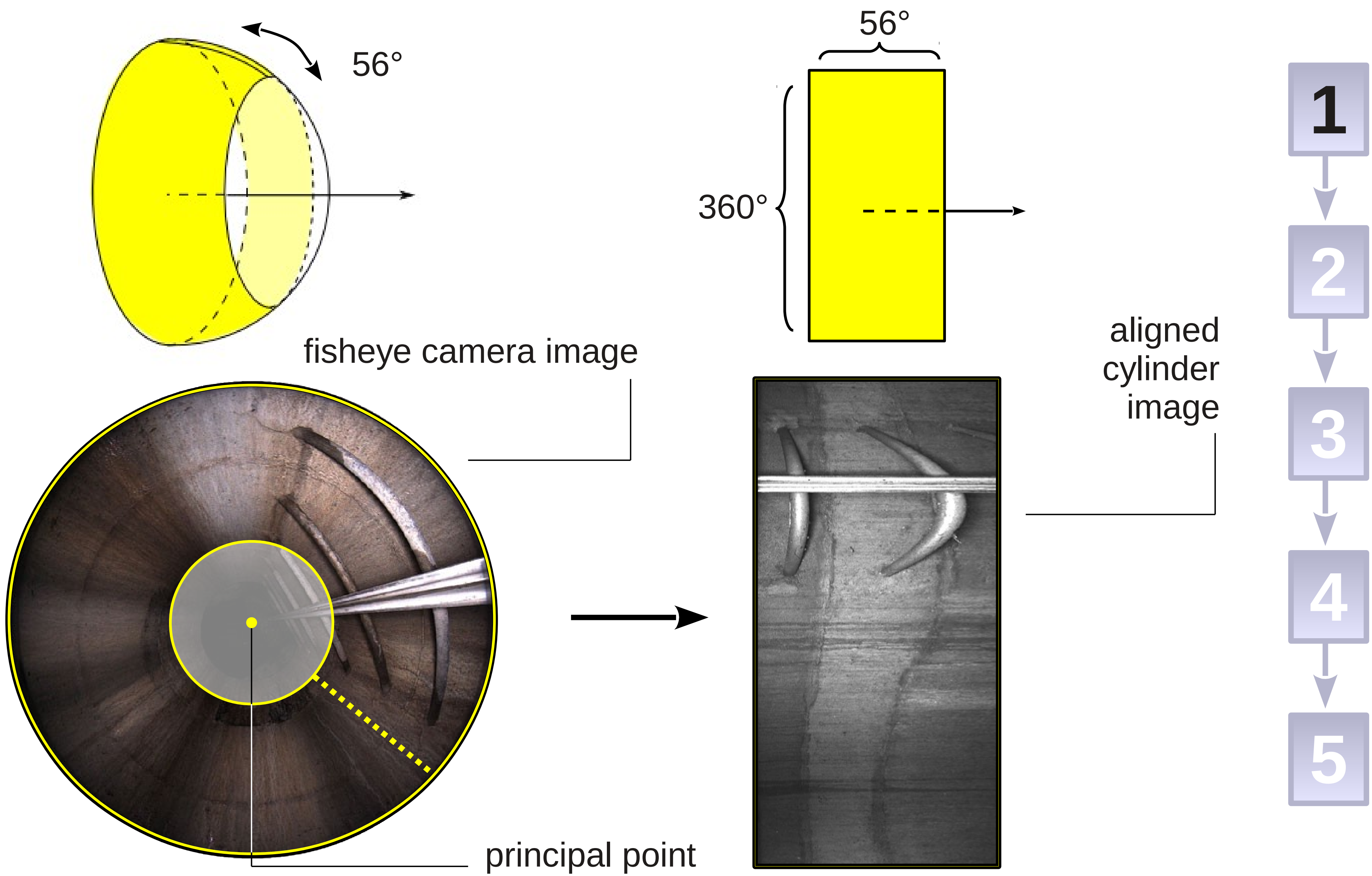
Overview of our approach



1. Image preprocessing: Roll rotation compensation

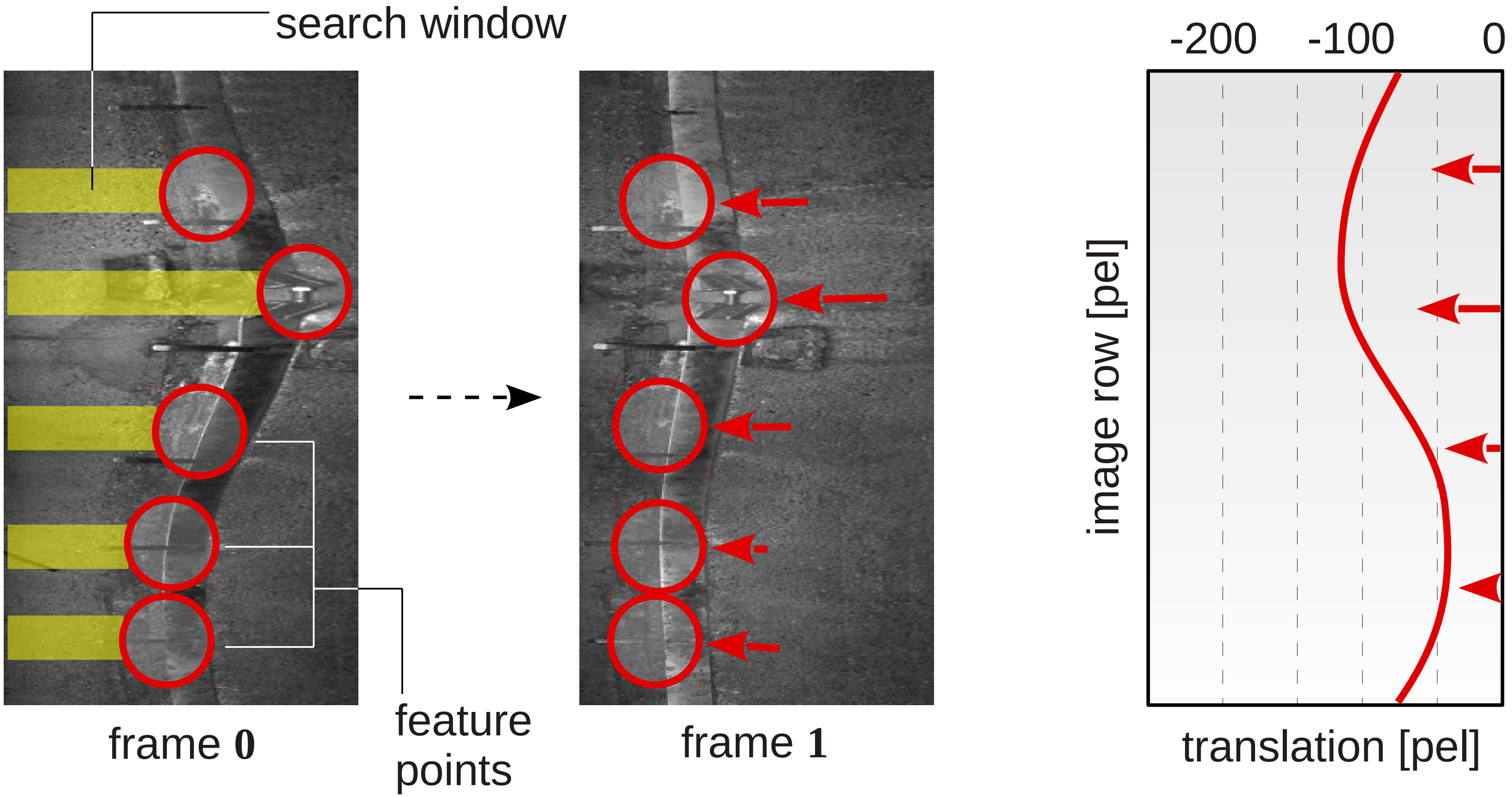


1. Image preprocessing: Cylinder mapping



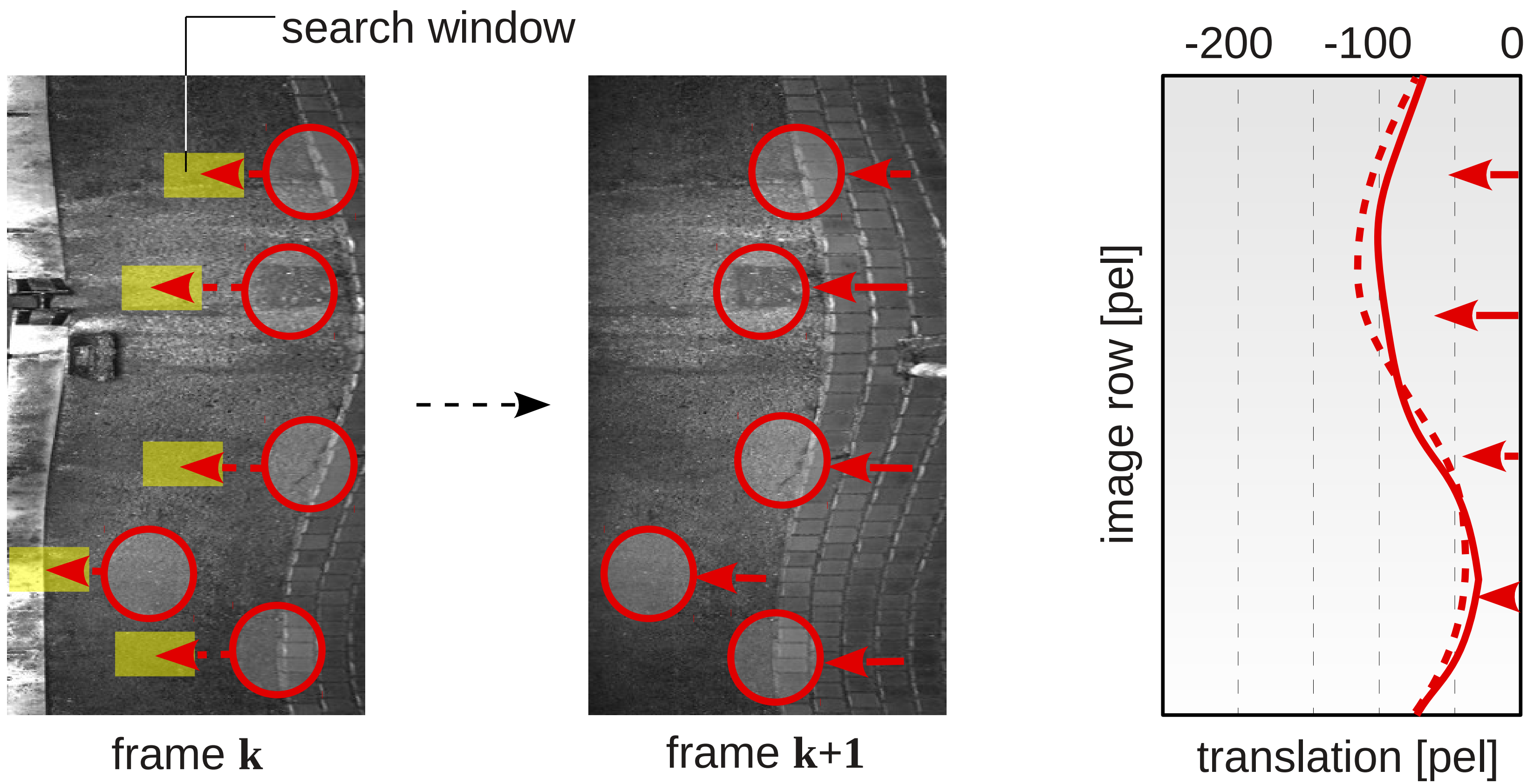
2. Feature point tracking

- **Initialization:** Detect KLT feature points
- Find correspondences along image rows
- Create row-dependent horizontal translation function



2. Feature point tracking

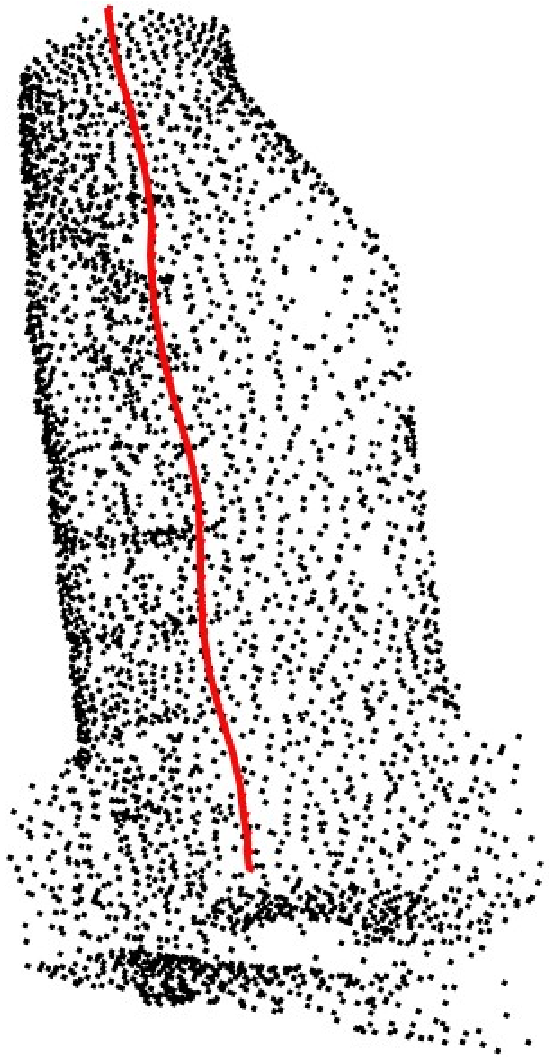
- **Tracking:** Predict new position with translation function
- Use small search window around target position
- Update horizontal translation function



3. Structure from Motion

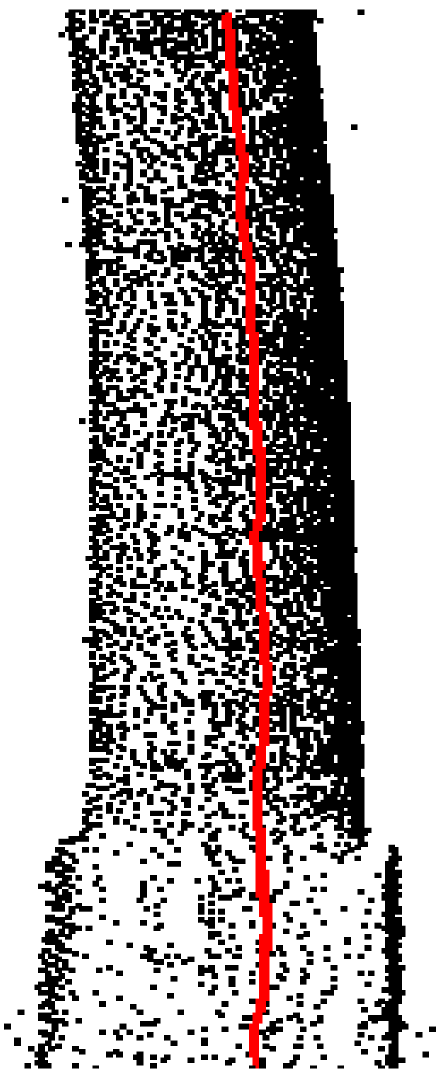
Output:

- Computed 3d point cloud
- Computed camera poses for each frame (position + rotation)
- Robust estimation using RANSAC



4. Global optimization

- Error accumulation
- Inaccurate camera calibration
- Bent and conical 3d reconstruction
- Global optimization needed
- Bundle Adjustment not useful for real-time application

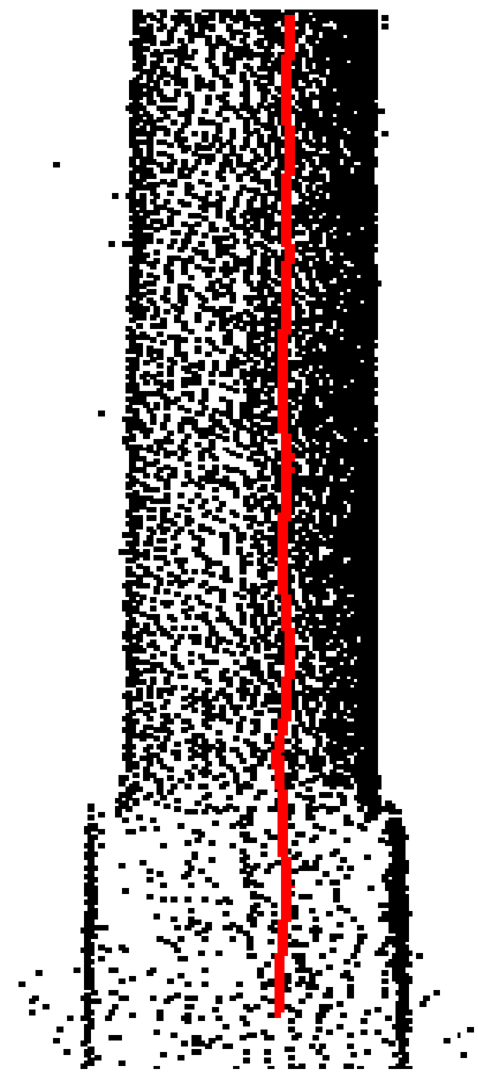


4. Global optimization

- Correct 3d reconstruction using geometric constraints:
  - Average camera path is known

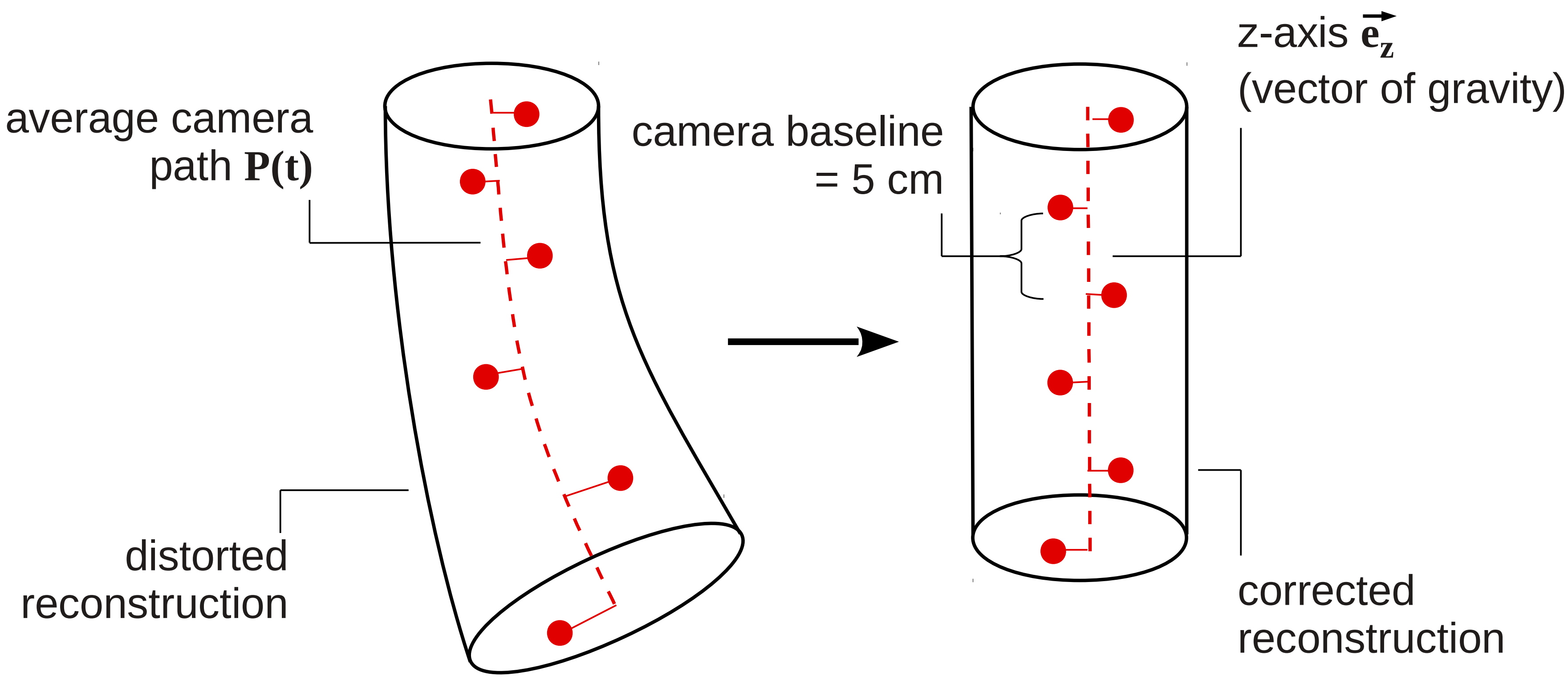
    (vector of gravity = z-axis)
  - Camera baseline between frames

    is known (approx. 5 cm)



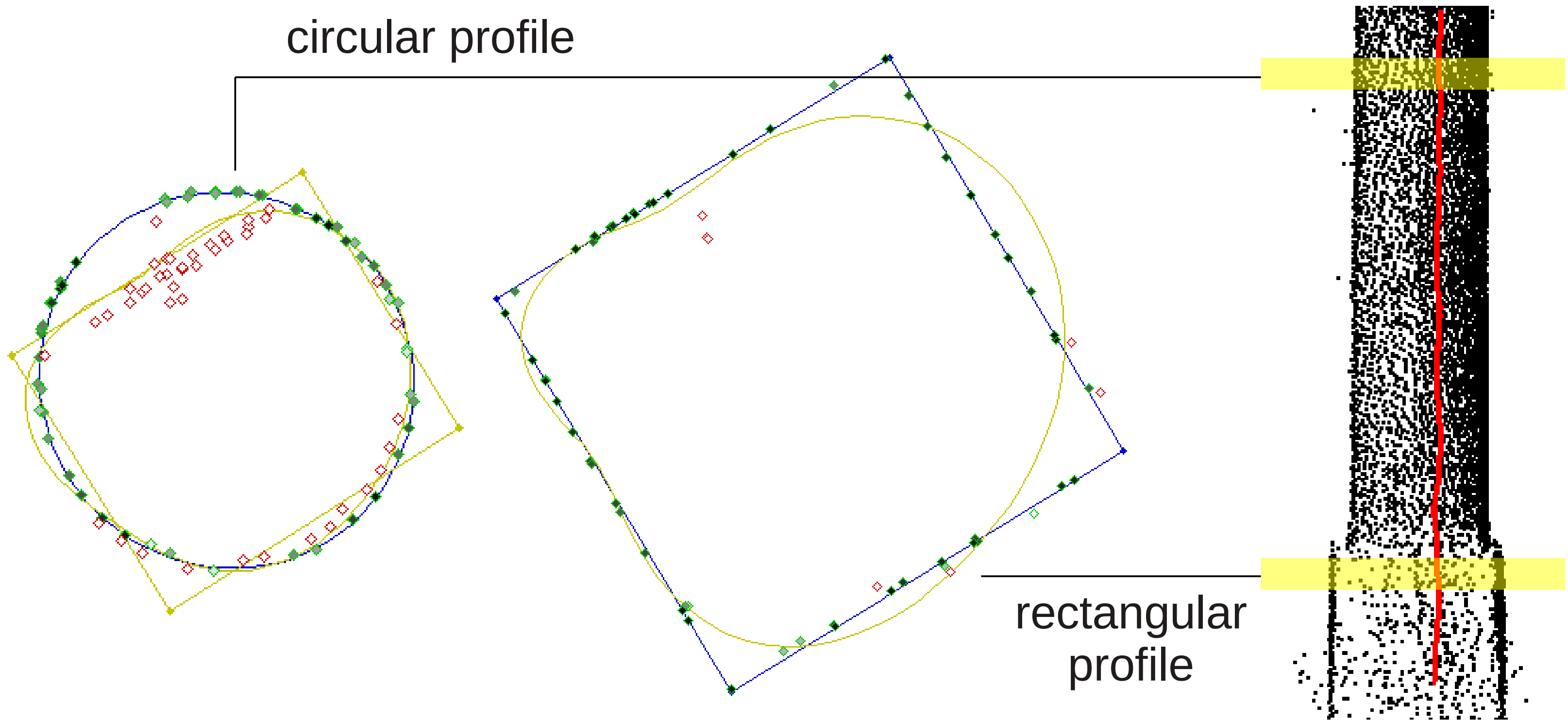
4. Global optimization

- Fit polynomial $\mathbf{P(t)}$ to average camera path
- Transform 3d points and camera poses
  via mapping of $\mathbf{P(t)}$ onto corrected path $\mathbf{P^*(t)} = 5\text{ cm} \cdot \mathbf{t} \cdot \vec{\mathbf{e}}_z$



5. Measuring profile shapes

- Classification of horizontal shaft / vertical pipe profiles
- Robust shape estimation from 3d points within slice



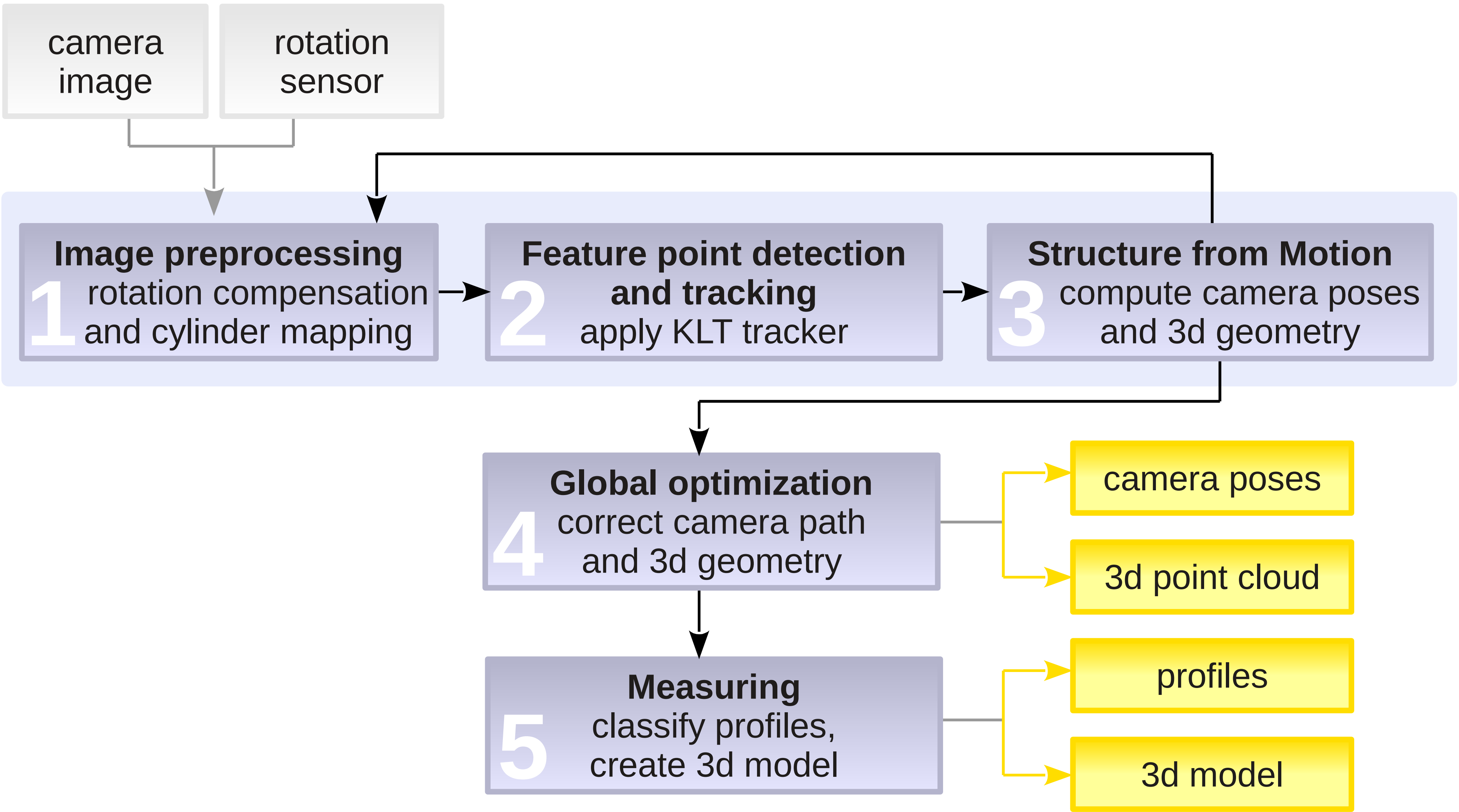
5. Creating 3d models for visualization

- Classify profile shapes in 3d points
- Connect subsequent contours of the same shape class
- Brightness alignment of images
- Optional 3d geometry fitting

Output:

- Profile shapes
- Wire-frame model
- Textured model

Output of our approach



Tests and applications

- Image Acquisition and Structure from Motion
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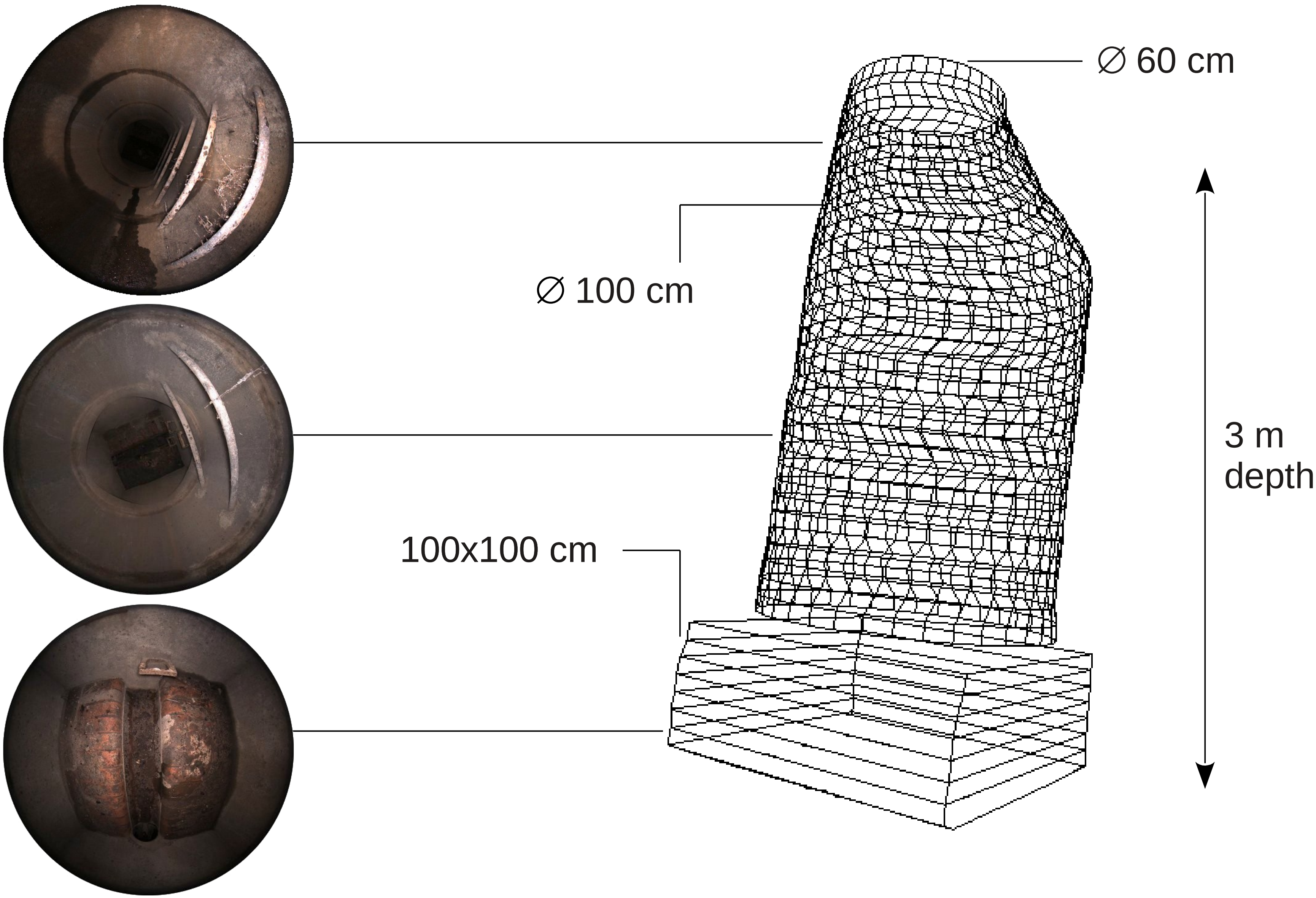
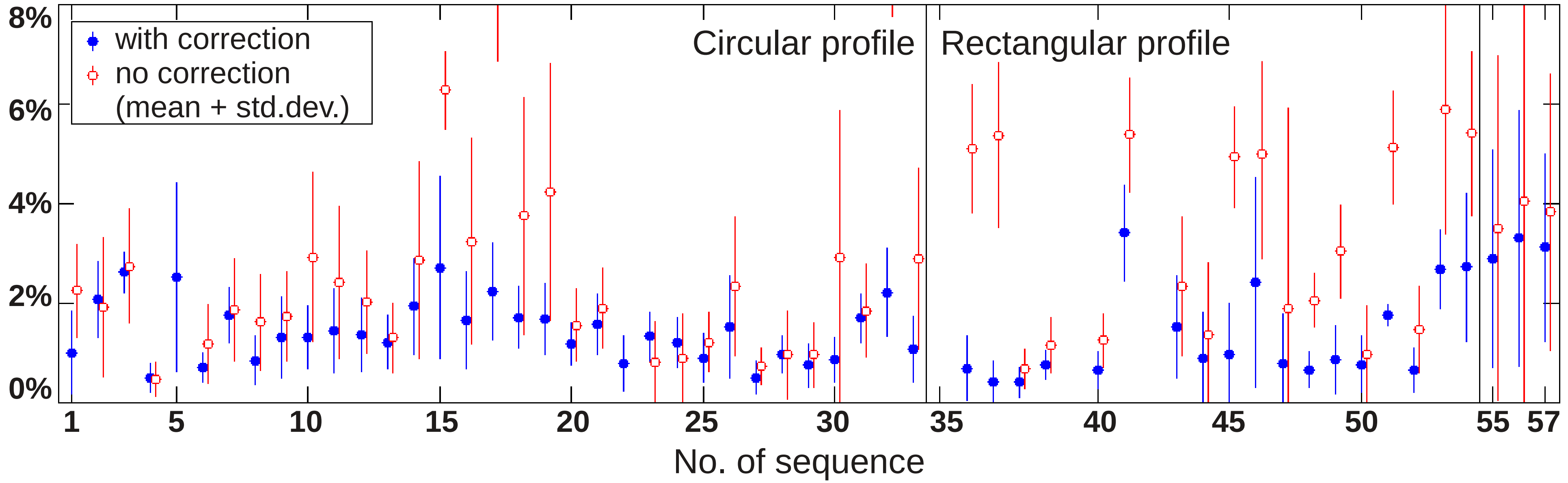
Example test sequence for shaft reconstruction

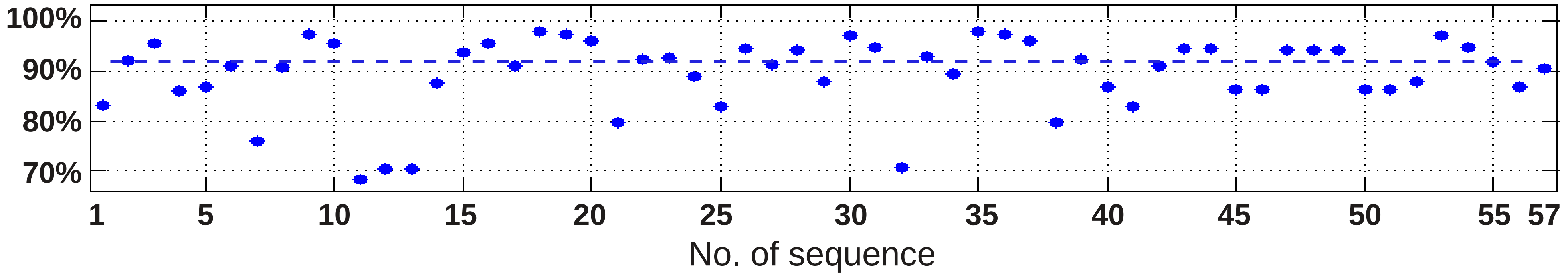


Evaluation of profile measurements

Average diameter estimation error for 57 sequences



Success rate of diameter estimation

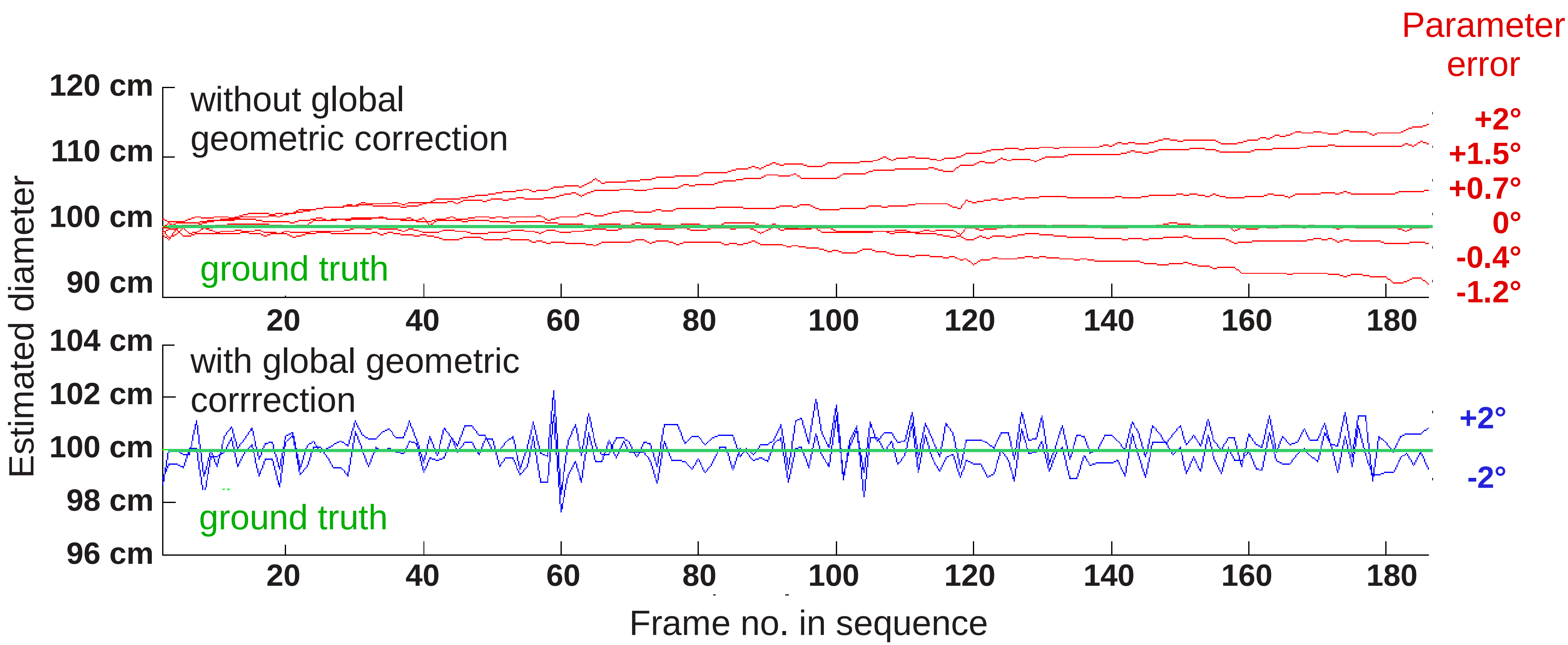


Evaluation of global geometric correction

- Variate intrinsic camera parameters (here: max. angle ± 2°)

➪ Systematic reconstruction error (here: up to 15 cm)

➪ Compensation by global geometric correction

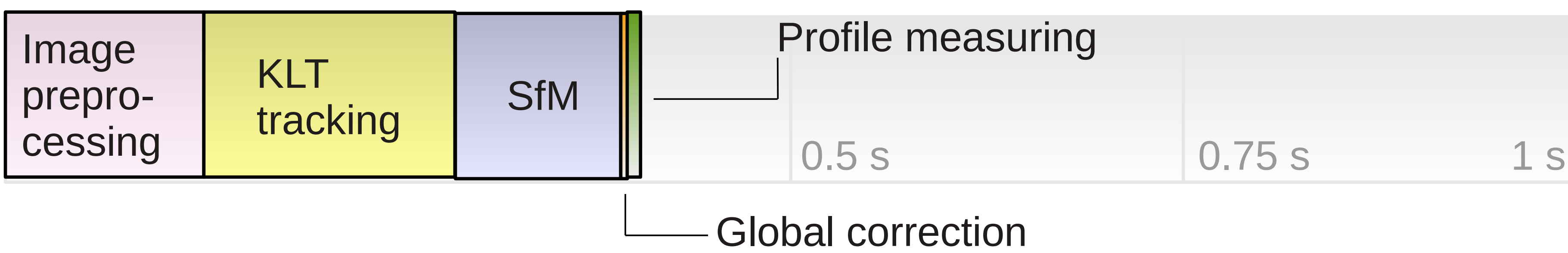


Runtime evaluation (offline)

- Original application (offline) ⇨ 2 – 3 frames per second
- Computation on CPU
- RANSAC with many iterations needed for robustness

Initialization: ~800 ms / frame

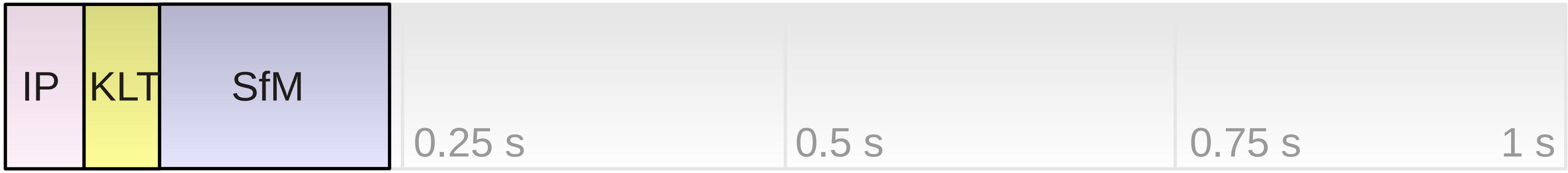
Tracking: ~380 ms / frame



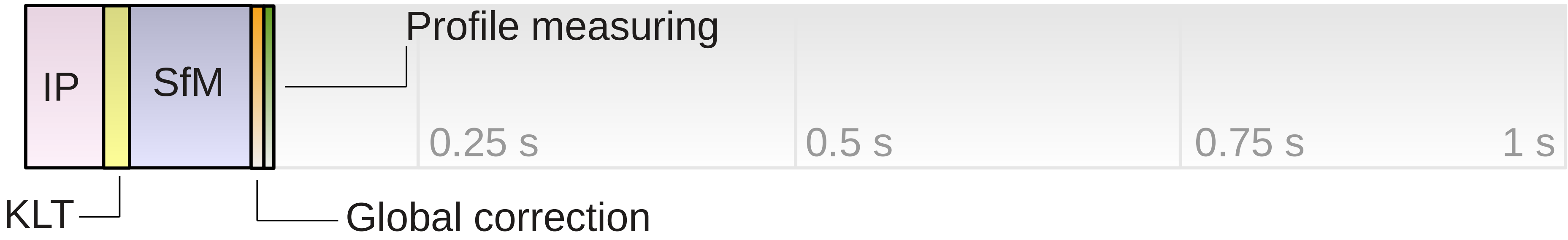
Runtime evaluation (realtime)

- Realtime application (on site) ⇨ ~7 frames per second
- Image preprocessing and KLT tracking on GPU
- Use *PreemptiveRANSAC* instead of RANSAC

Initialization: ~240 ms / frame

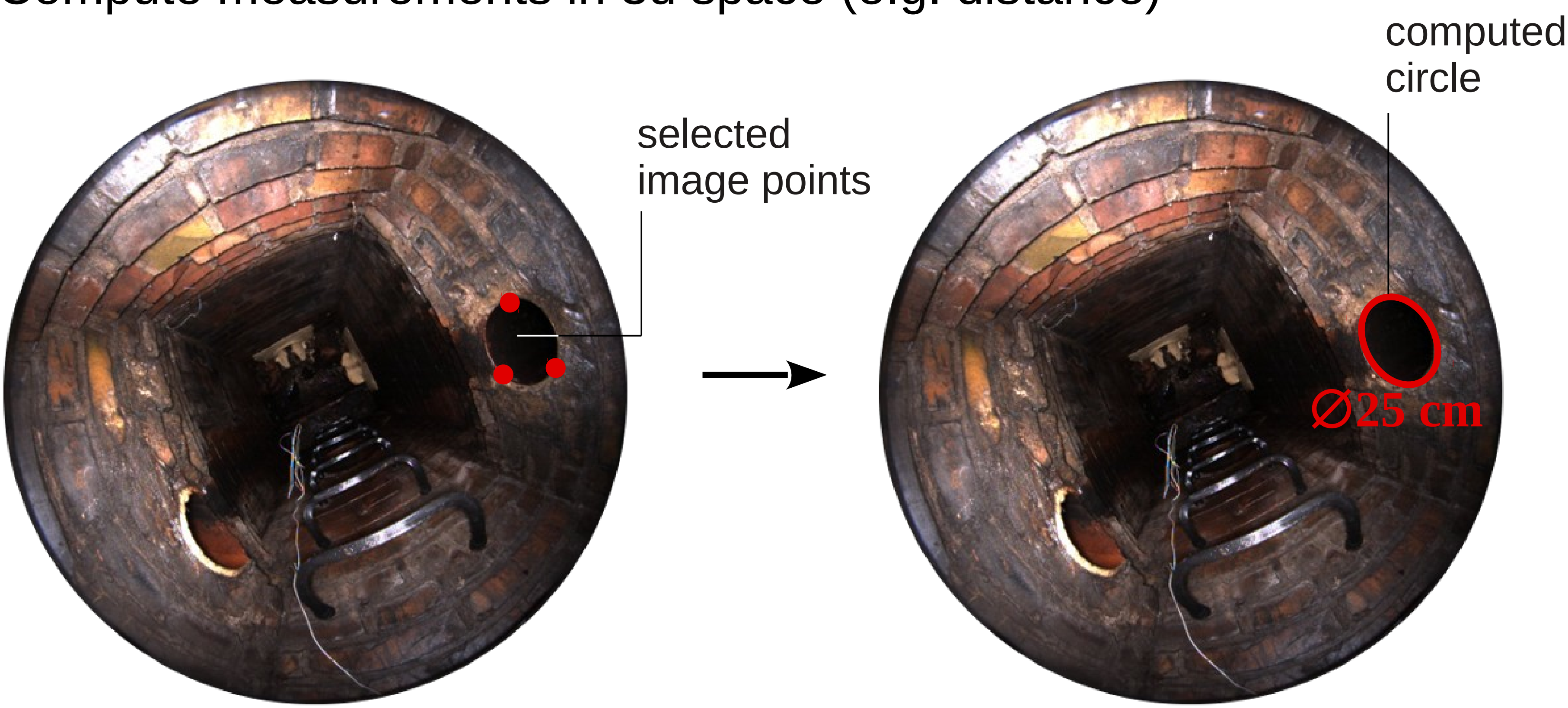


Tracking: ~140 ms / frame



Use camera poses for manual measuring

- Manual selection of measuring points in camera image
- ⇨ Automatic correspondence search in subsequent image
- ⇨ Triangulation of 3d point using known camera poses
- ⇨ Compute measurements in 3d space (e.g. distance)



Visualization of 3d models

Kiel Elmschenhagen #3

Kiel Hürth #1

Kiel Nordmarksportfeld #1

Conclusion

- Image Acquisition and Structure from Motion
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  - Cylinder mapping
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Conclusion

- Robust automatic approach for image-based 3d reconstruction of sewer pipes and shafts with IBAK Panoramo / SI
- Simple geometric correction replaces Bundle Adjustment
- Creation of 3d models for visualization
- Manual measuring in camera images using computed camera poses
- Real-time capability to use on-site
- Successful application to practise

Thank you for your attention!

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Wirtschaft
Investition in Ihre Zukunft

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