Visual SLAM with Multi-Fisheye Camera Systems

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Contents

- Application of Visual Multi-fisheye SLAM for Augmented Reality applications

Components of Visual SLAM

- Calibration and basic image data
- Initialization using virtual 3D model
- Egomotion determination, Tracking

- Integration with image based measurement system

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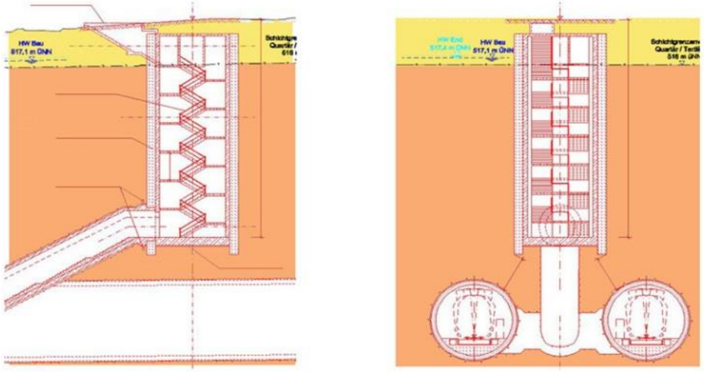
Application:

Planning of new Underground railway tracks

- Support for different planning phases
- Investigation of different tracks
- Localization of emergancy tunnels
- etc

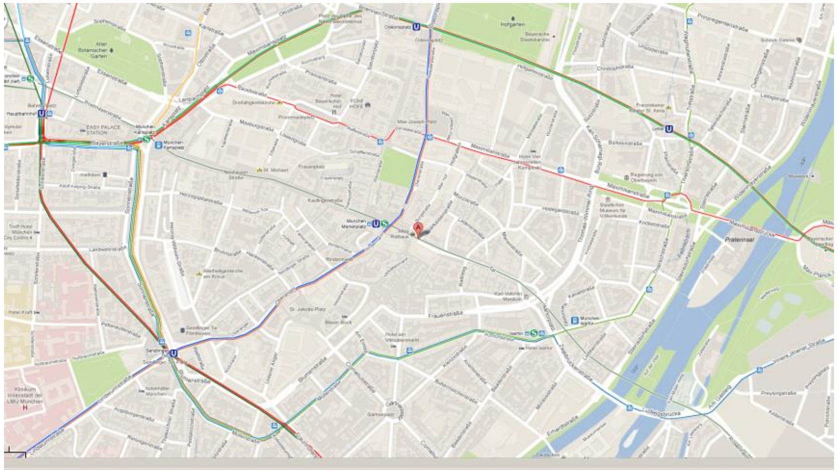
Rettungsschacht mit schräg verlaufendem seitlichen Zugang

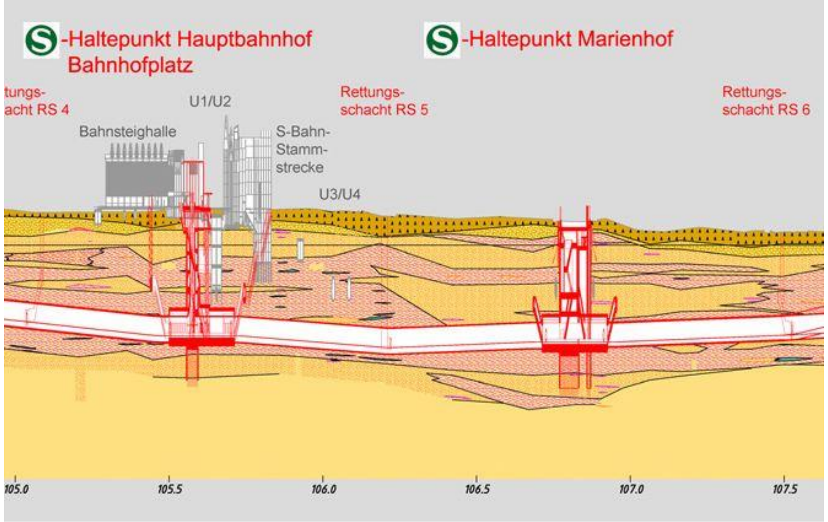


Längsschnitt Rettungsschacht

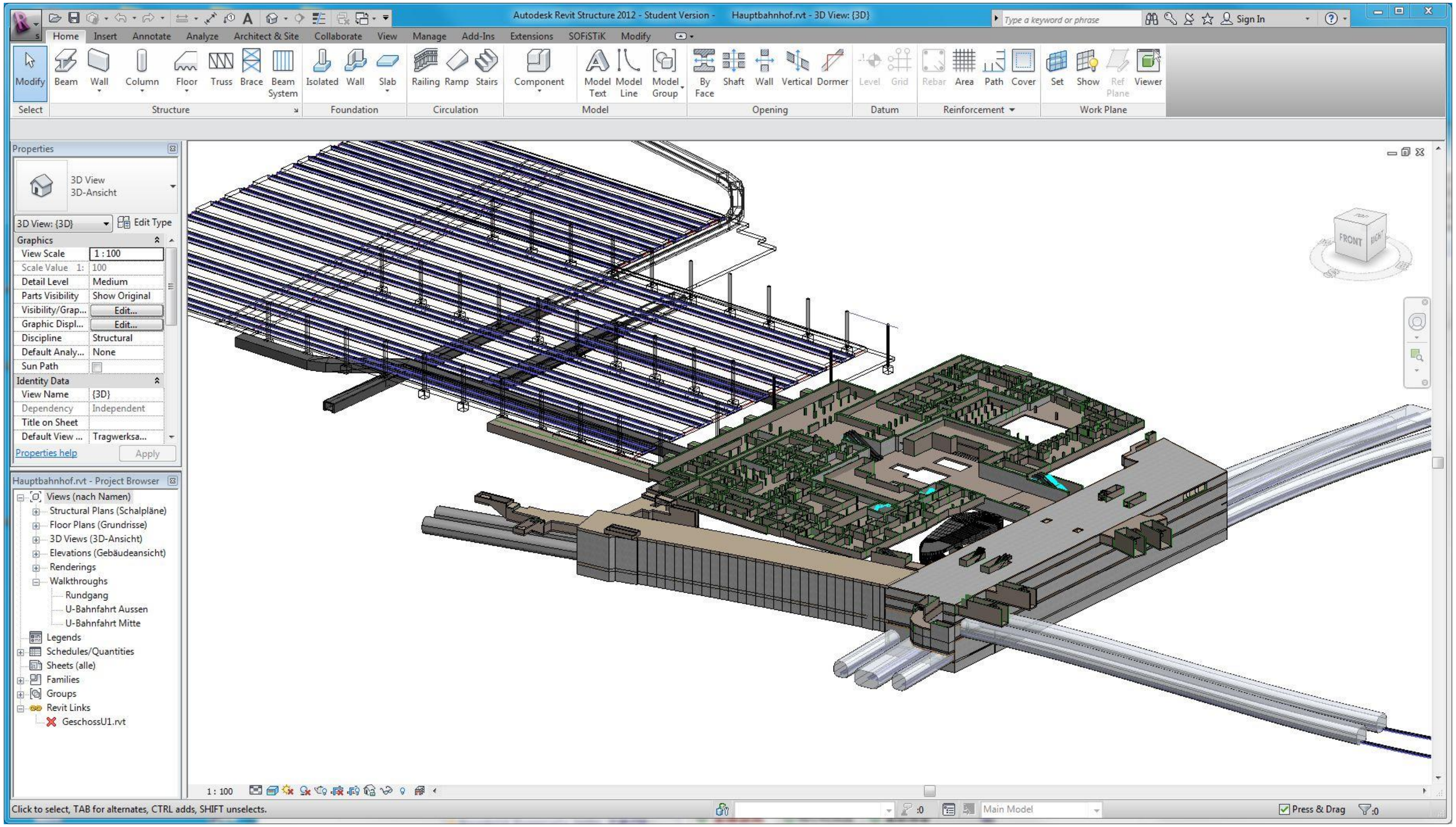
Querschnitt Rettungsschacht

Quelle: Deutsche Bahn AG

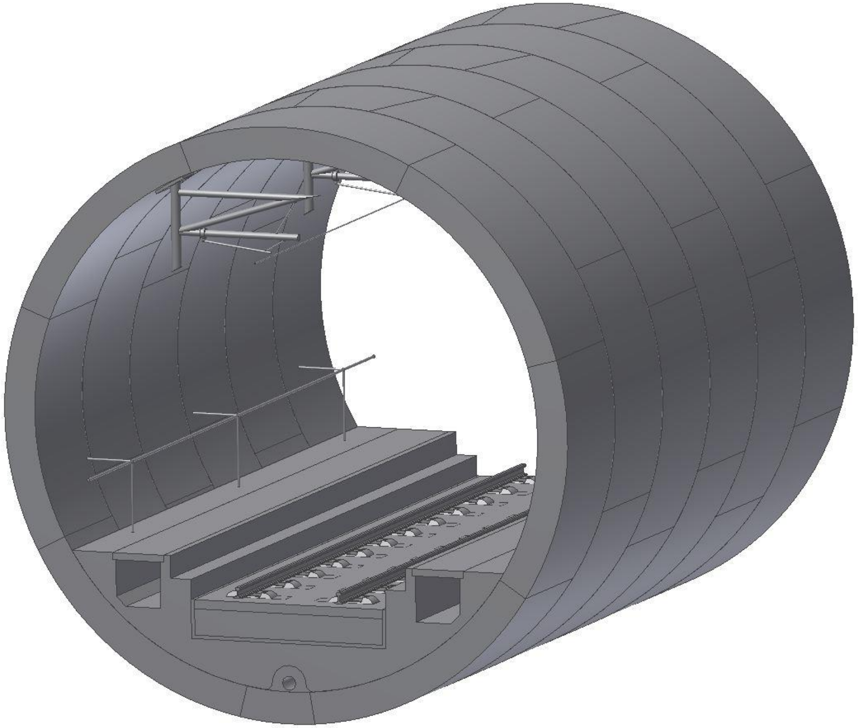


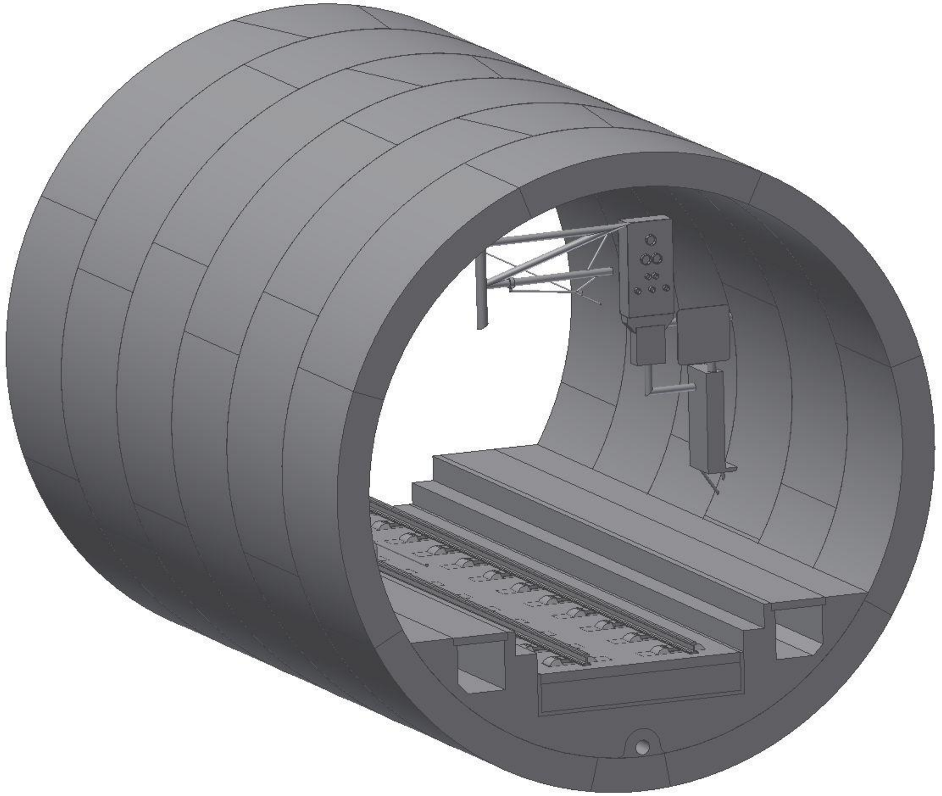


Virtual 3D plans available

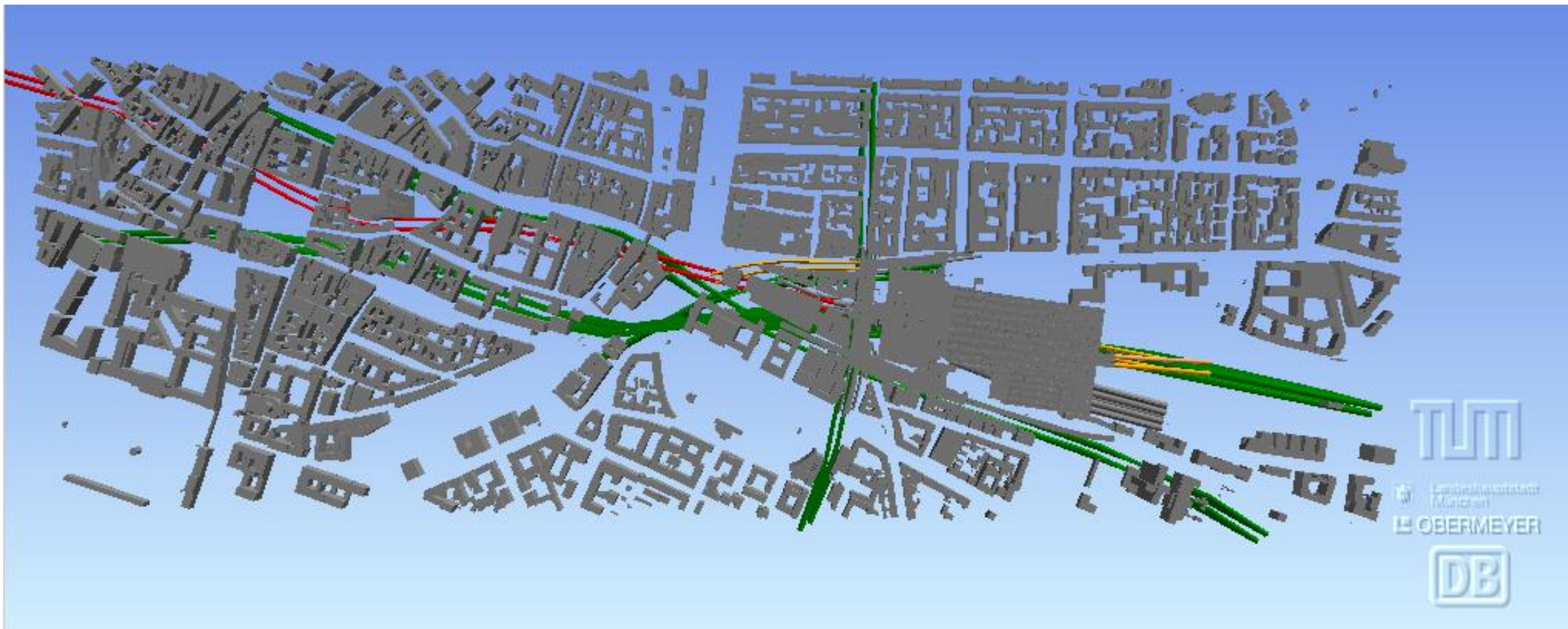


Different resolutions, different level of details



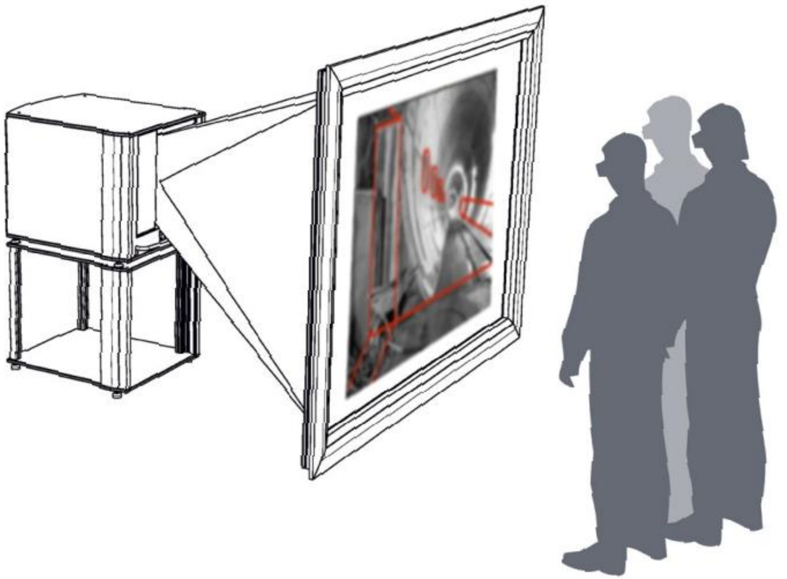


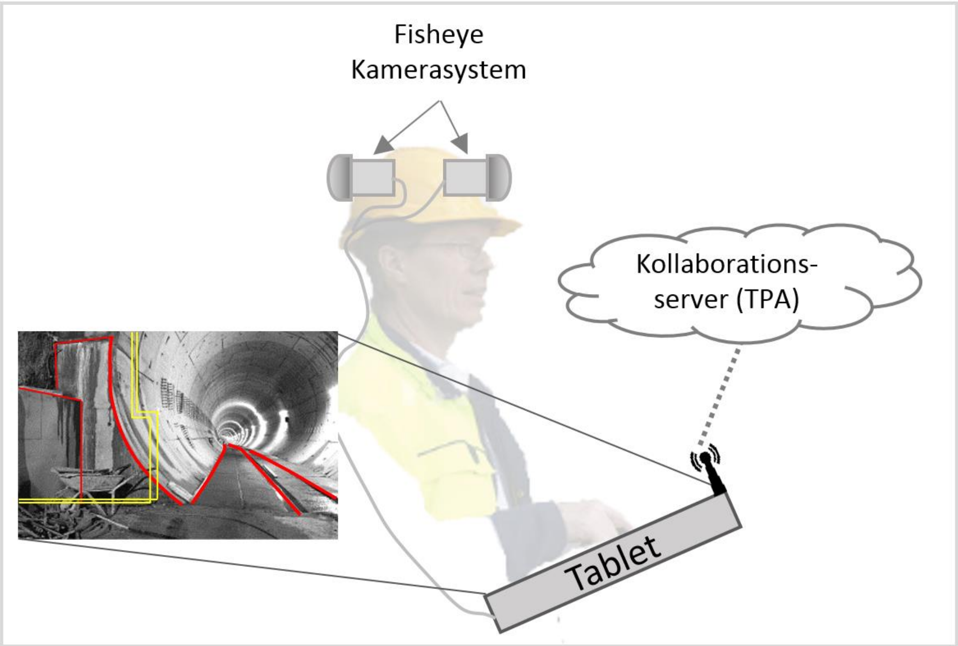
GIS as background information



Augmented Reality System

- Development of a mobile AR-System
- Support of co-operative tunnel/track planning:
  - Overlay of planned and already existing objects
  - Analysis of geometric deviations and missing objects
  - In-situ visualization
  - Documentation



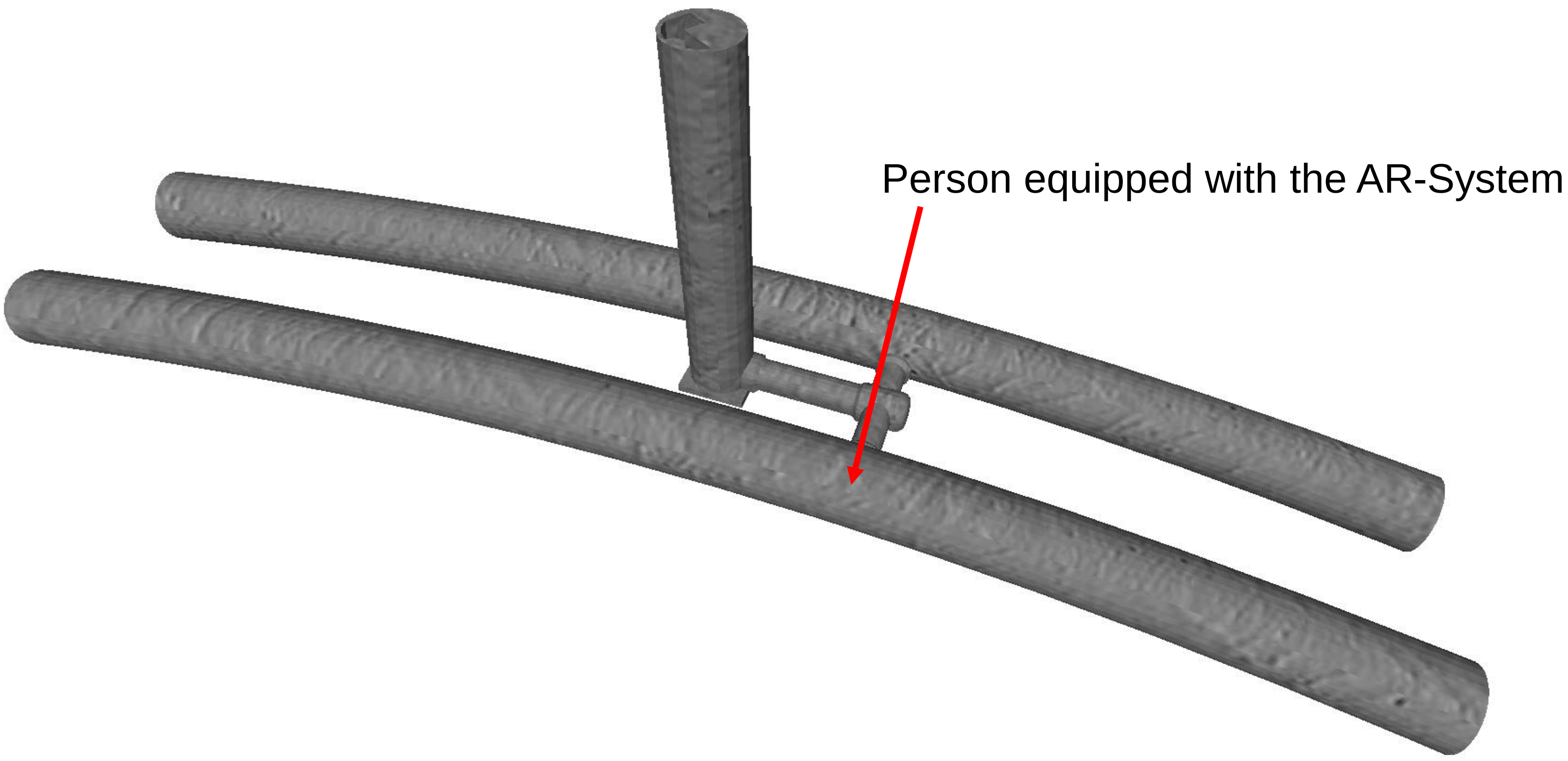


➡ **3D-geocoded and annotated images**

➡ **Platform / camera pose needed**

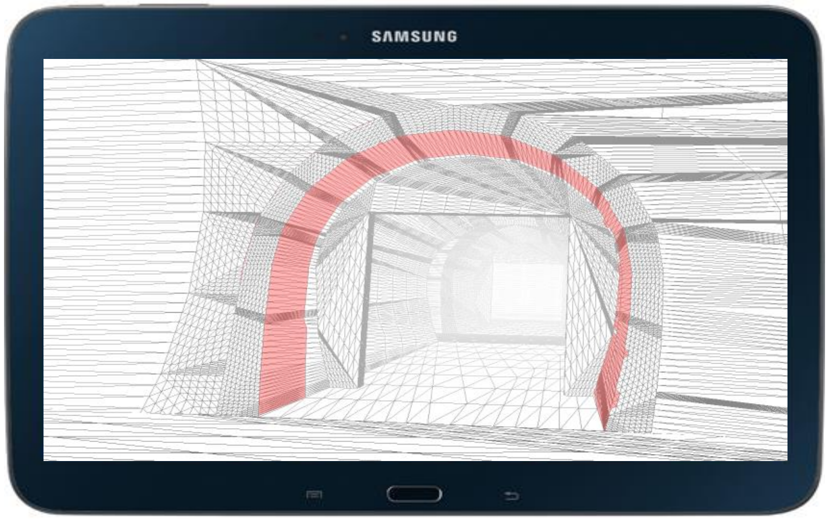
Augmented Reality System

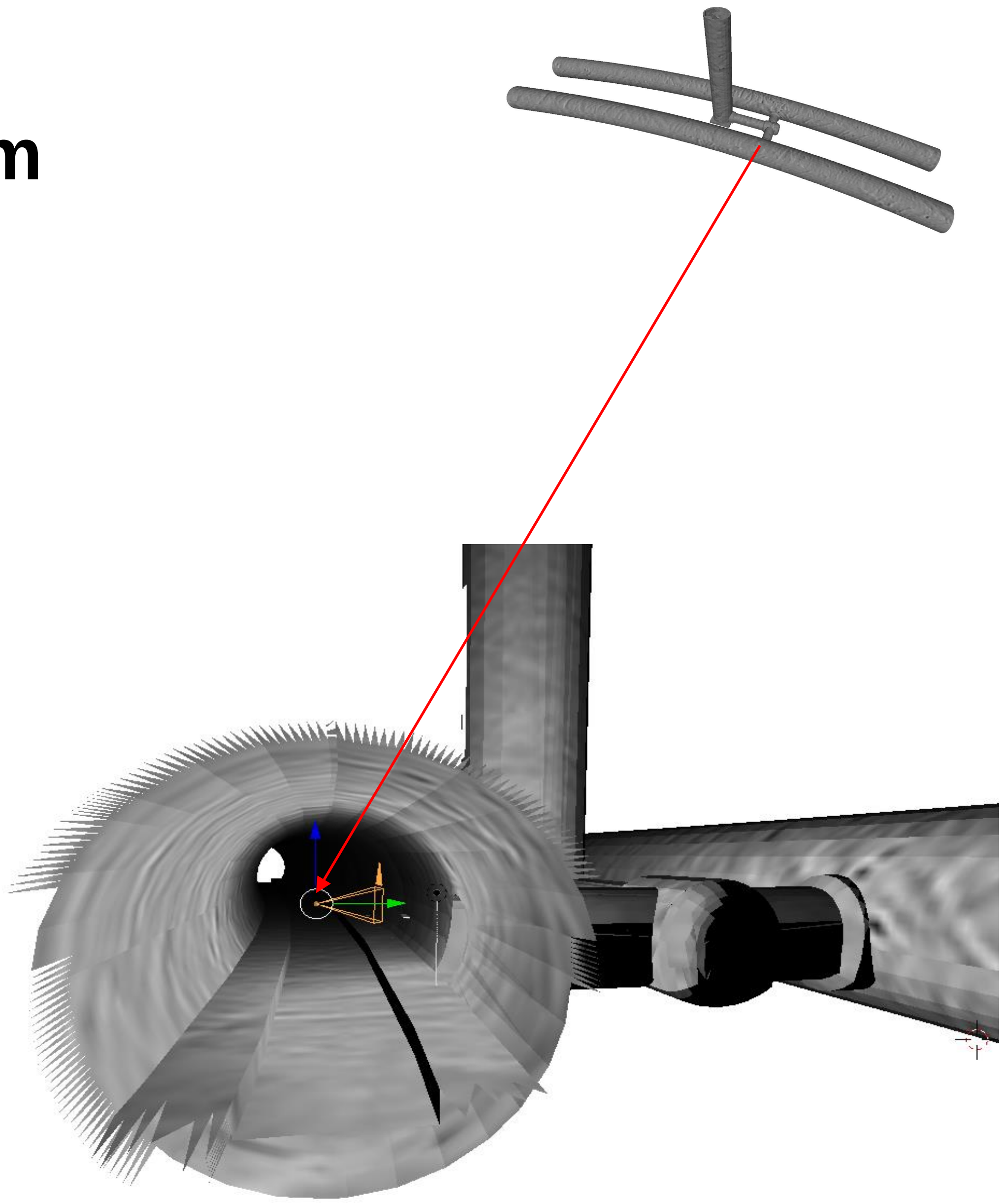
- Example: Emergancy tunnel



Augmented Reality System

- Example: Emergancy tunnel



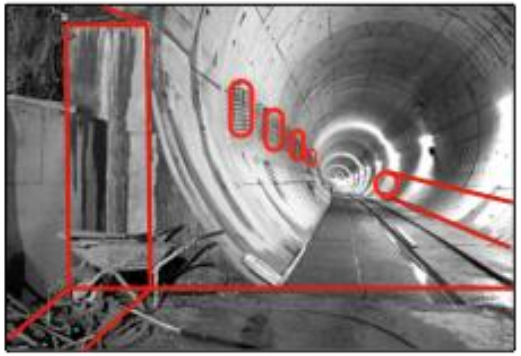


System concept

Explicit 3D Model
(Collaboration Server)

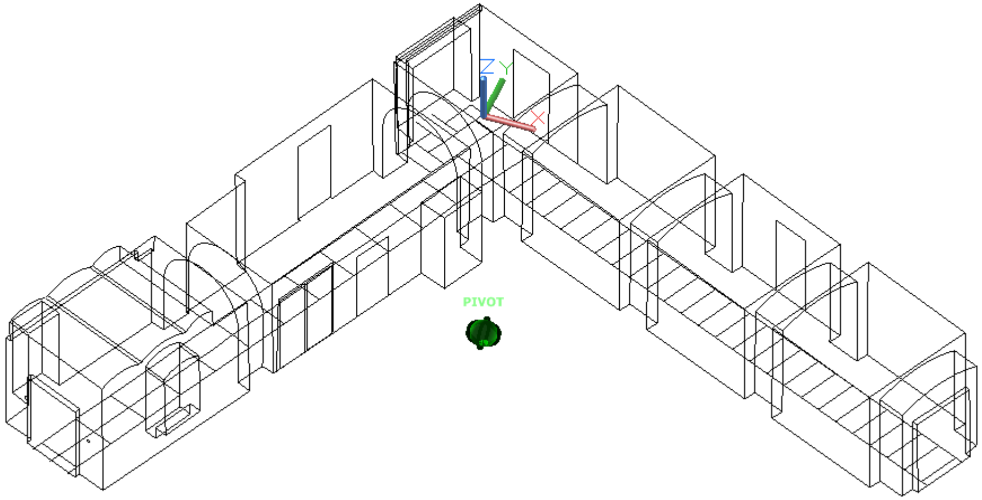
Mulit-fisheye System
(mounted at helmet)

Tablet camera system



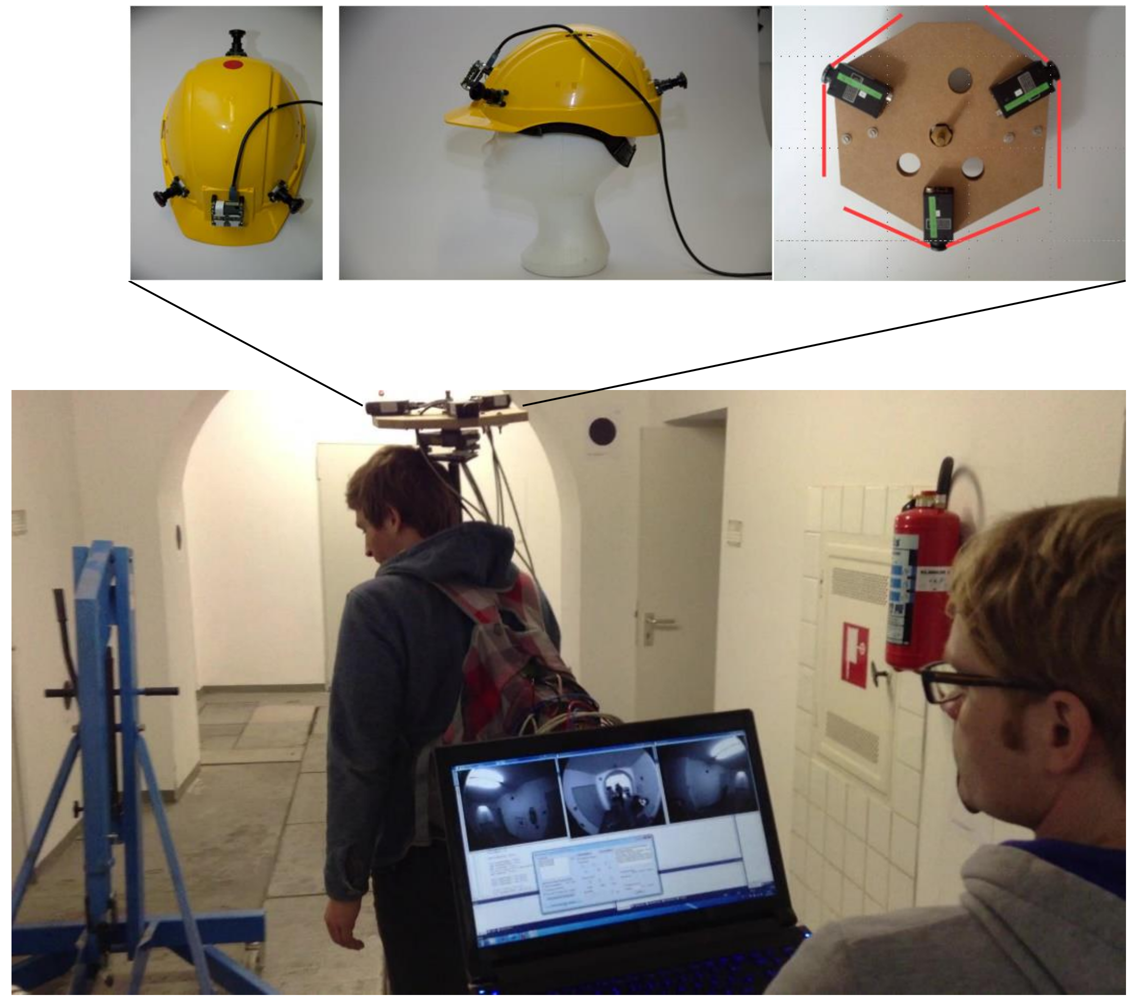
System concept

- Constraints:
  - Indoor/underground → no GPS/GNNS available
  - Bad illumination conditions
  - Narrow and „cluttered“ environment
  - Many occlusions



System concept

- Mobile AR-System
    - Prototype
        - 3 Fisheye cameras
        - Complete coverage
        - Robust estimation of position (and tracking)
    - Visualization unit



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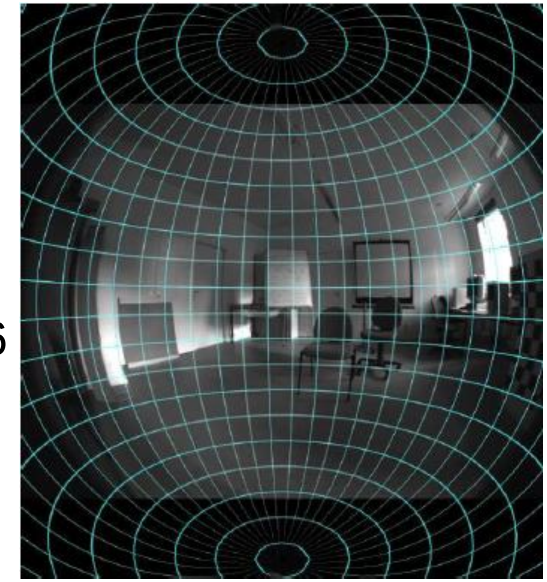
Camera Calibration



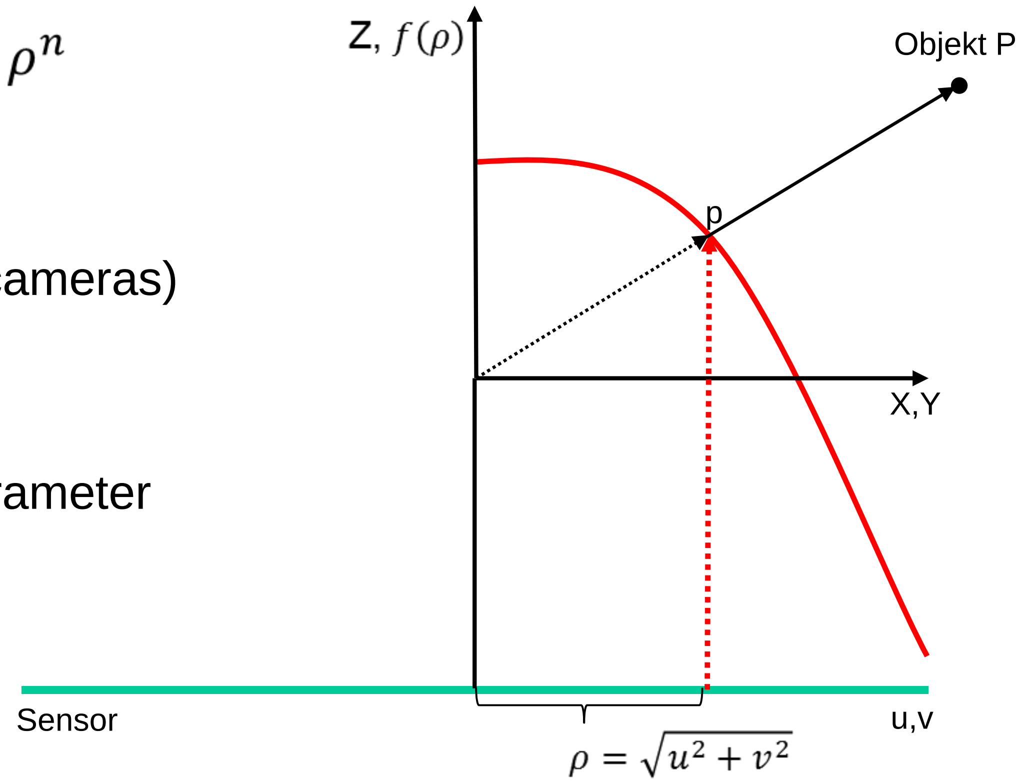
- Basics: Model for fisheye project of Scaramuzza et al. 2006

$$P = \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \alpha \begin{bmatrix} u \\ v \\ f(\rho) \end{bmatrix} = \alpha p$$

with $f(\rho) = a_0 + a_2\rho^2 + \cdots + a_n\, \rho^n$

- Extensions
  - Multiple collinearity equations (3 cameras)
  - Robust bundle approach
  - Simultaneous estimation of all parameter

Improvement in terms of speed and geometric quality by factor 2 - 4

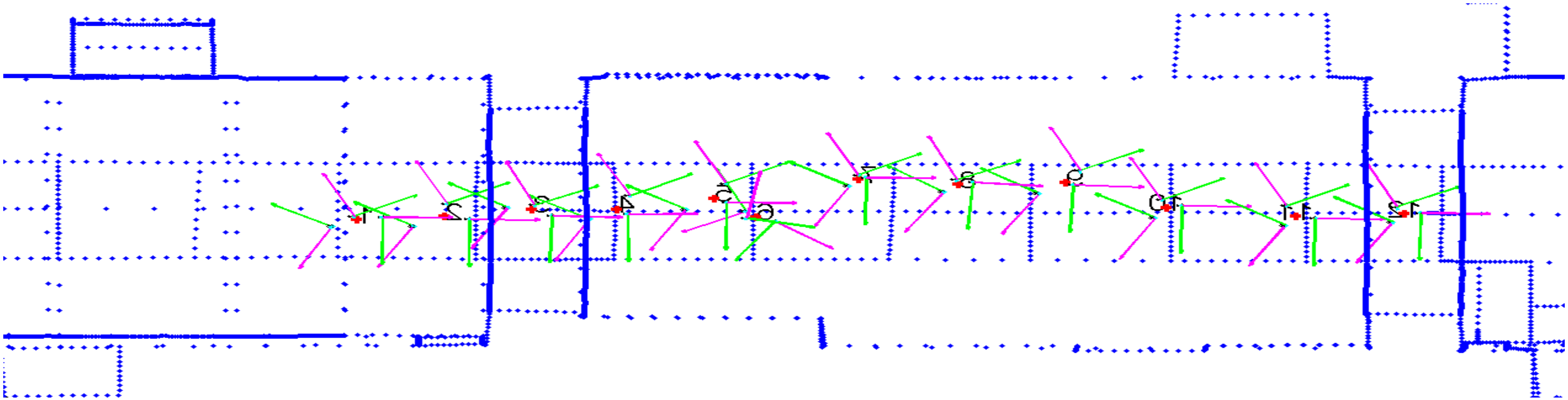


Validation

- Calibration using 3D-Model
- Ground-truth (tachymeter)
- Accuracy:

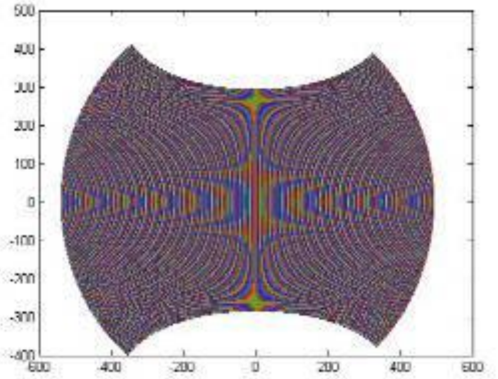
  Position: 0.4-1.5cm

  orientation 0.35-2.6mrad



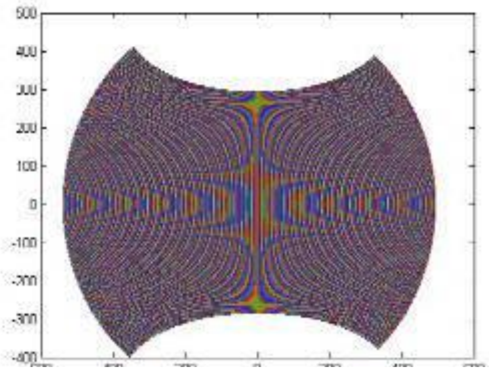
Basic image data (1): Multi-Fisheye Panorama

- No homography anymore
- Mapping onto cylinder
  (using the relative orientation)

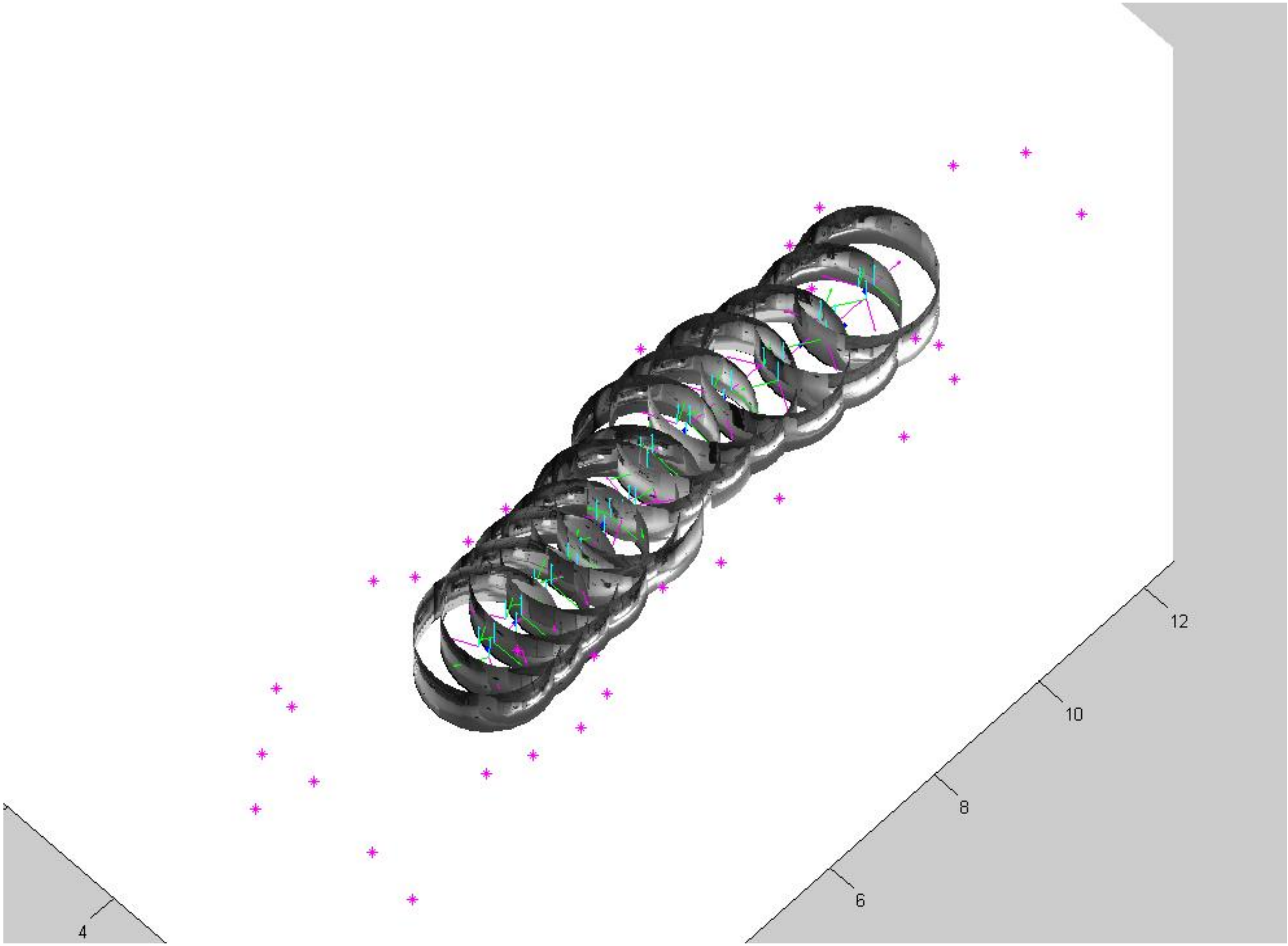


Basic image data (1): Multi-Fisheye Panorama

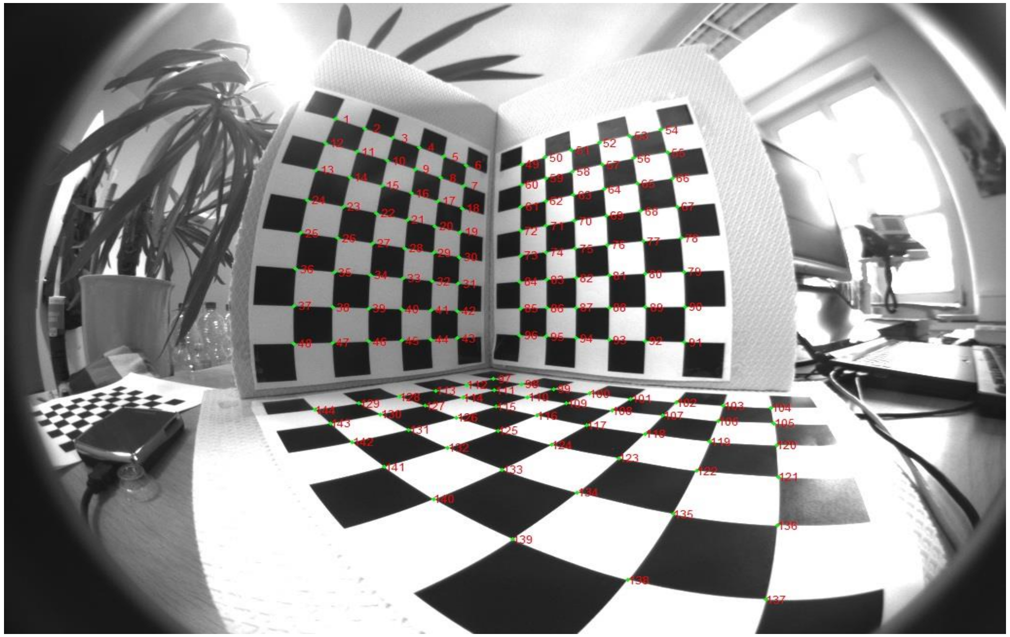
- No homography anymore
- Mapping onto cylinder
  (using the relative orientation)
- Transformation into coordinate system of 3d-model

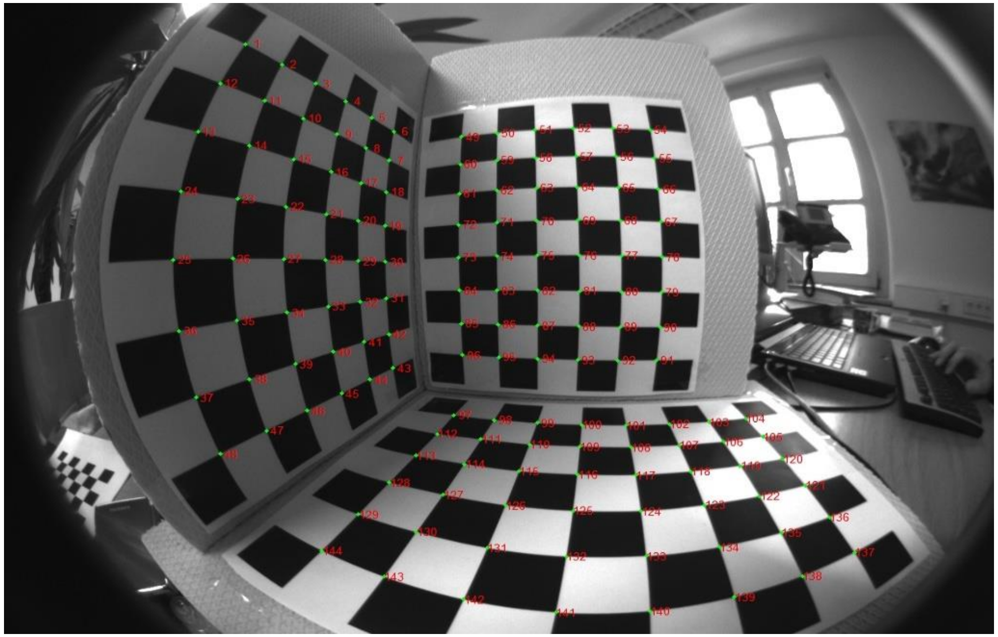


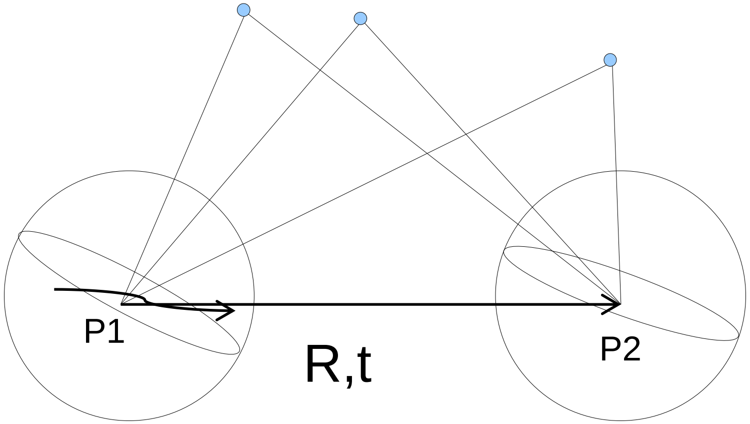
Panorama trajectory



Basic image data (2): Fisheye Stereo





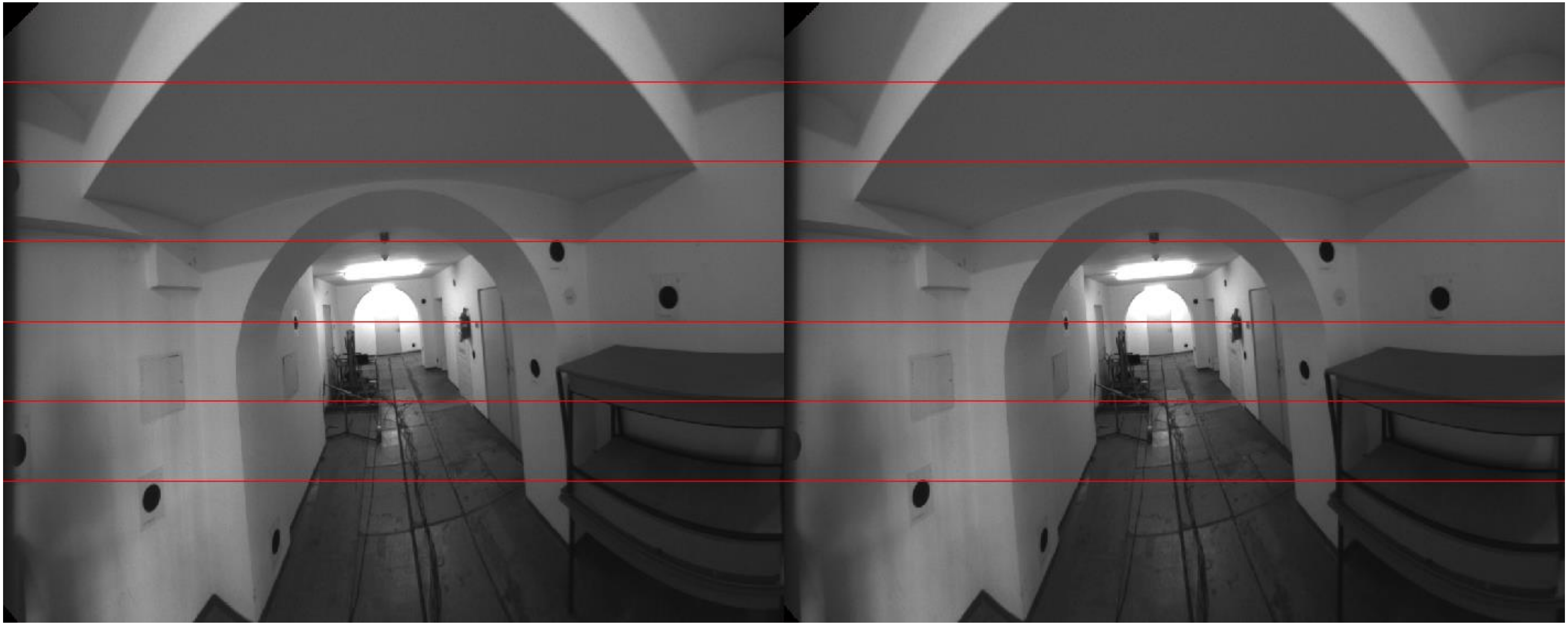


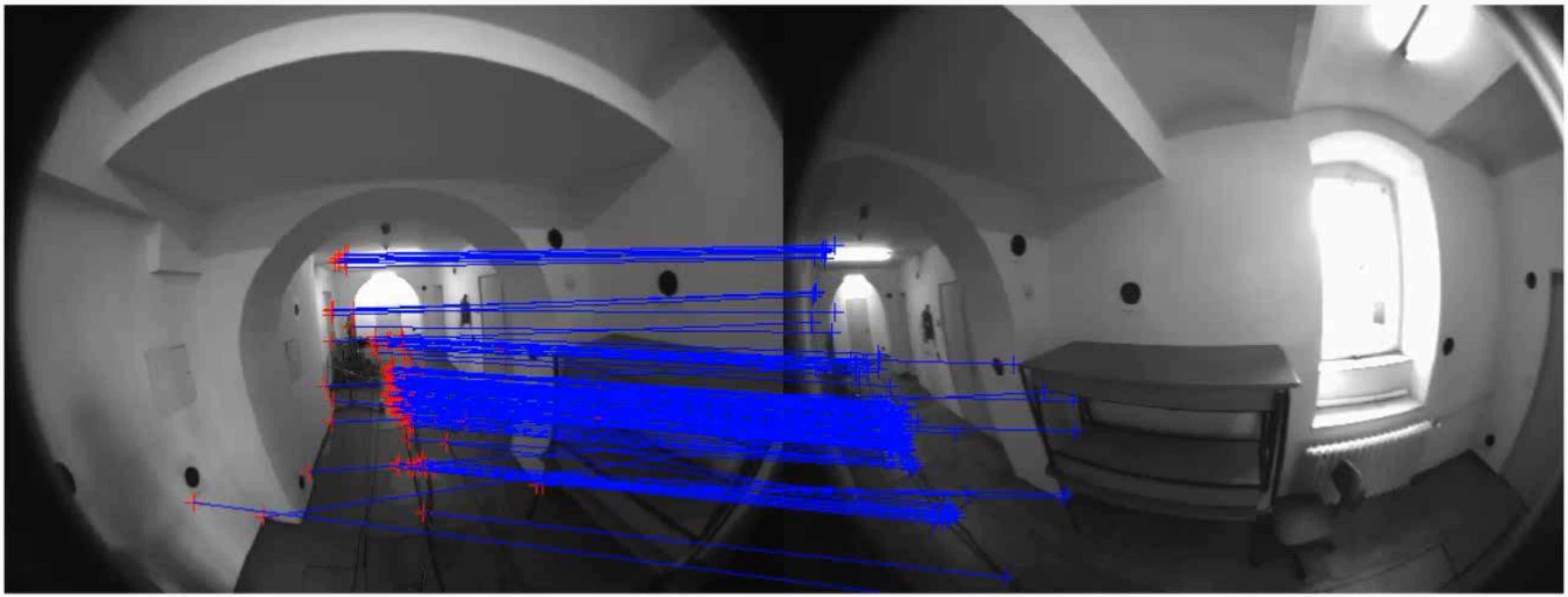
Basic image data (2): Fisheye Stereo

Rectification (via mapping onto cylinder)
Transformation into epipolar geometry

=> limited accuracy of 3D points

=> useful for initial 3D description of imaged environment





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Self-localization / Initialization of AR-System

- Challenges:
  - no GPS → no absolute position
  - Many potential initial positions → many hypotheses to start tracking inside 3D-model

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  - Many potential initial positions → many hypotheses to start tracking inside 3D-model
  - Many clutter and objects not included in virtual 3D model
  - Many discrepancies between images and virtual 3D model

Self-localization / Initialization of AR-System

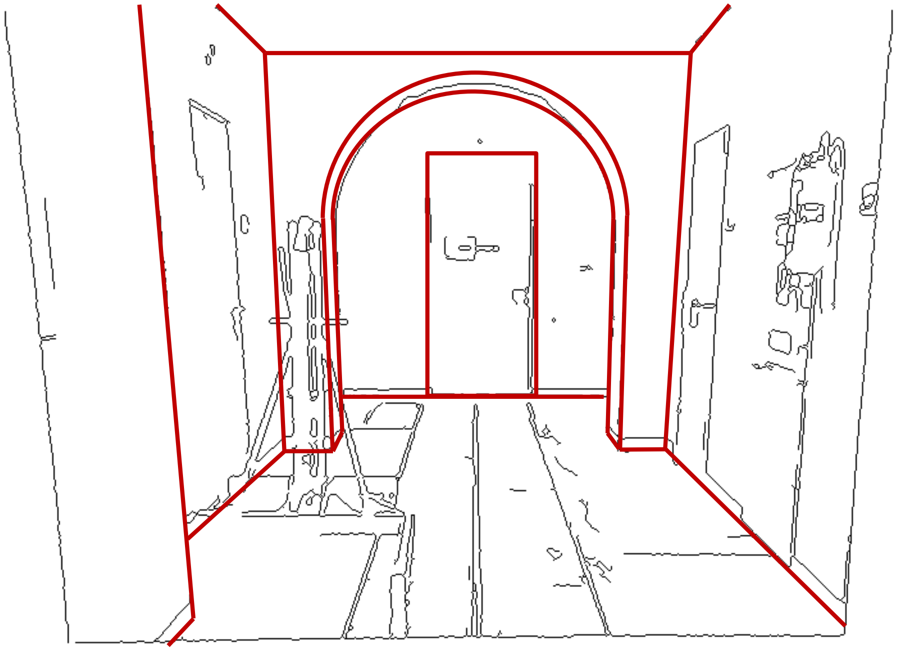
- Challenges:
  - no GPS → no absolute position
  - Many potential initial positions → many hypotheses to start tracking inside 3D-model
  - Many clutter and objects not included in virtual 3D model
  - Many discrepancies between images and virtual 3D model
  - Virtual 3D model is not textured => less features for maching
  - Real-time requirements

    → Indexing (search trees), GPU processing (Rendering), Parallel processing

Model-based Initialization

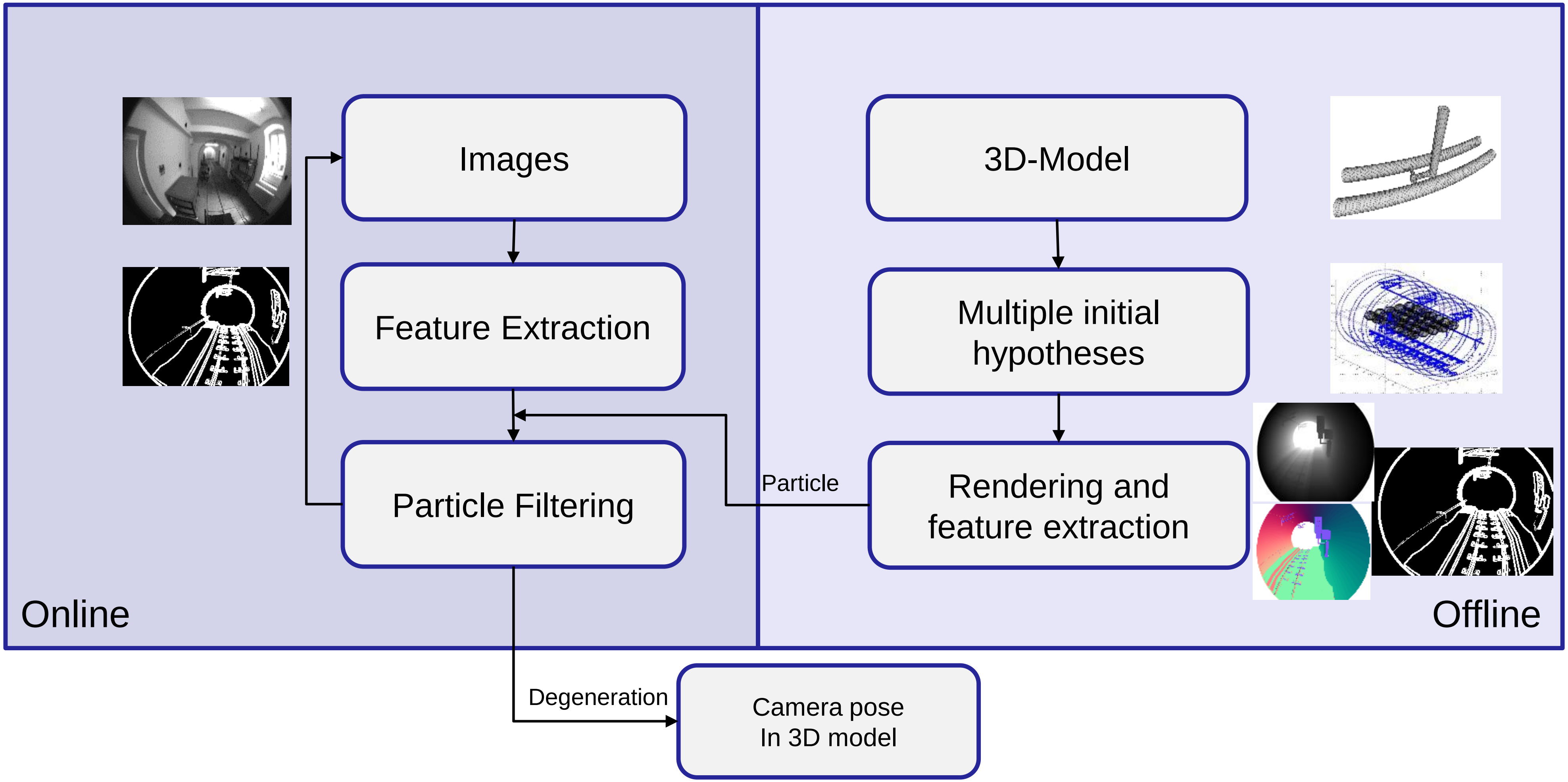
("Model" = 3D Modell)

Task:

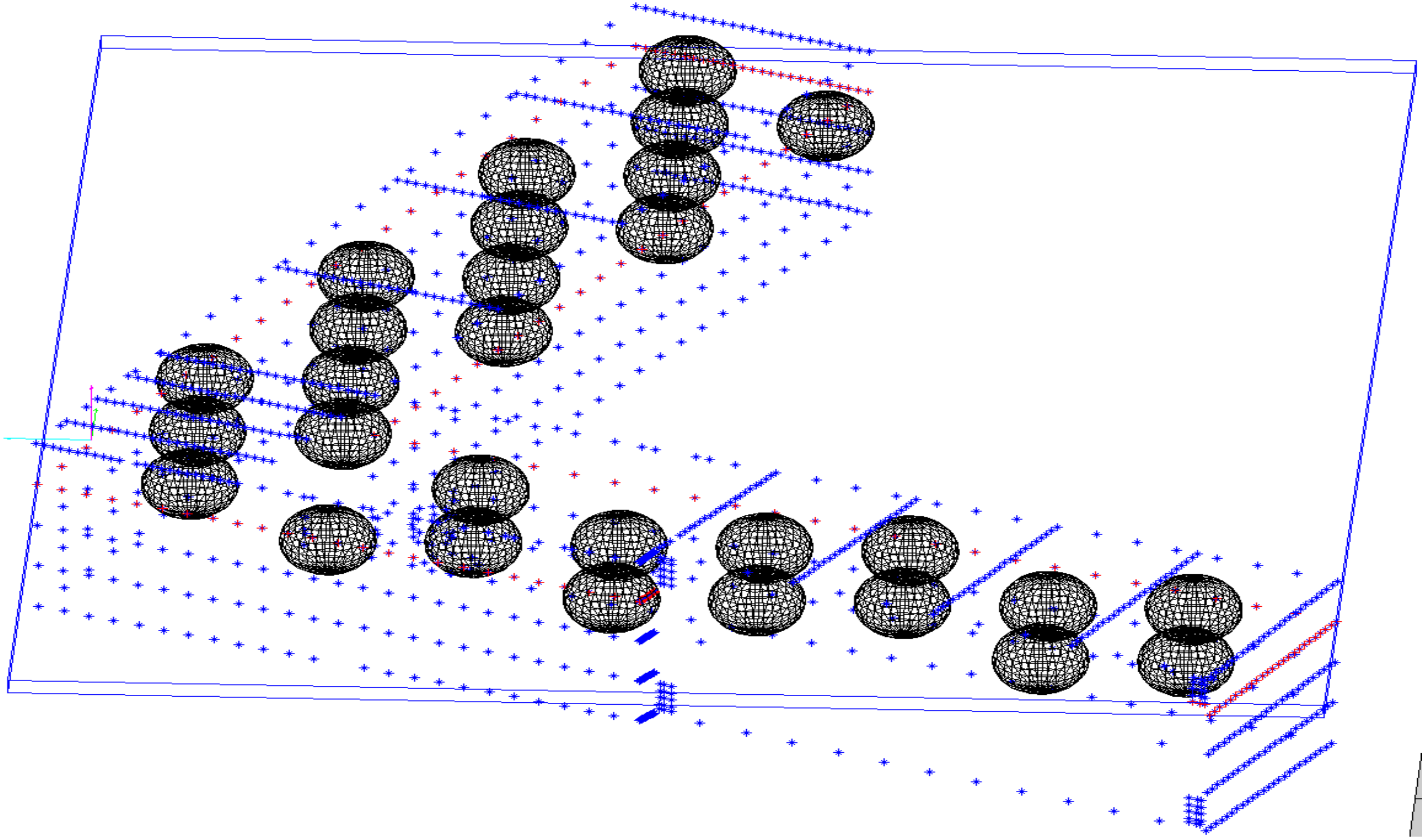


Model-based Initialization

("Model" = 3D Modell)

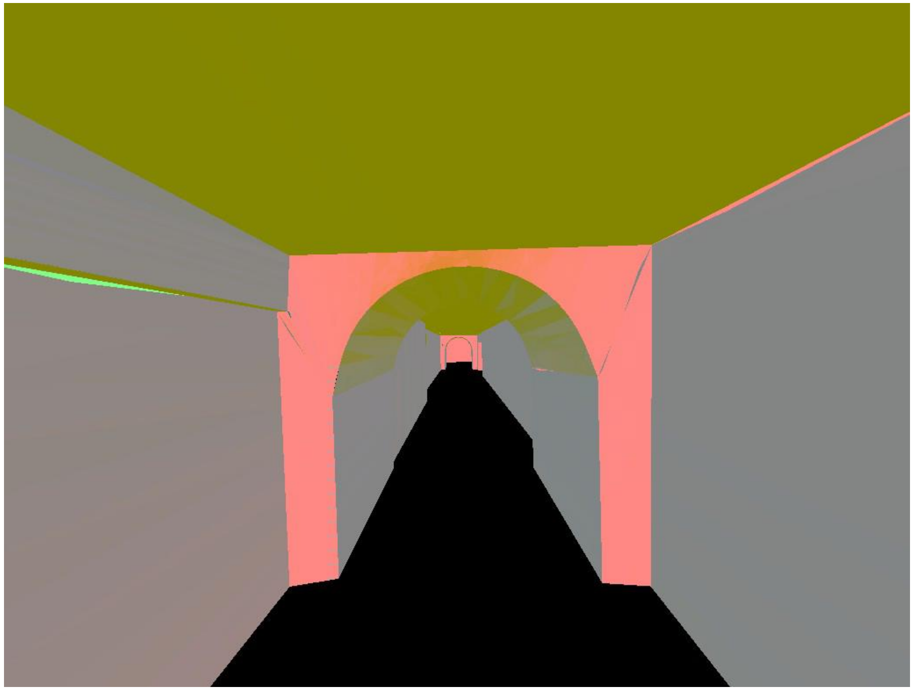


Simulation of virtual camera poses



Features: Extraction of visible 3D-Model edges

- Using already determined fisheye distortion
- Rendering mit “Vertex Shadern”



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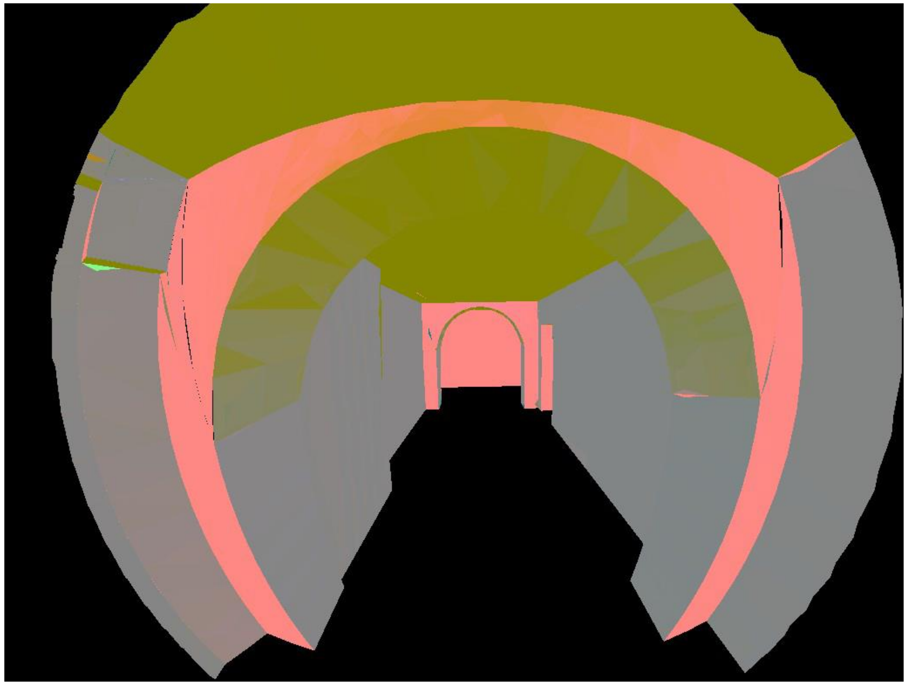
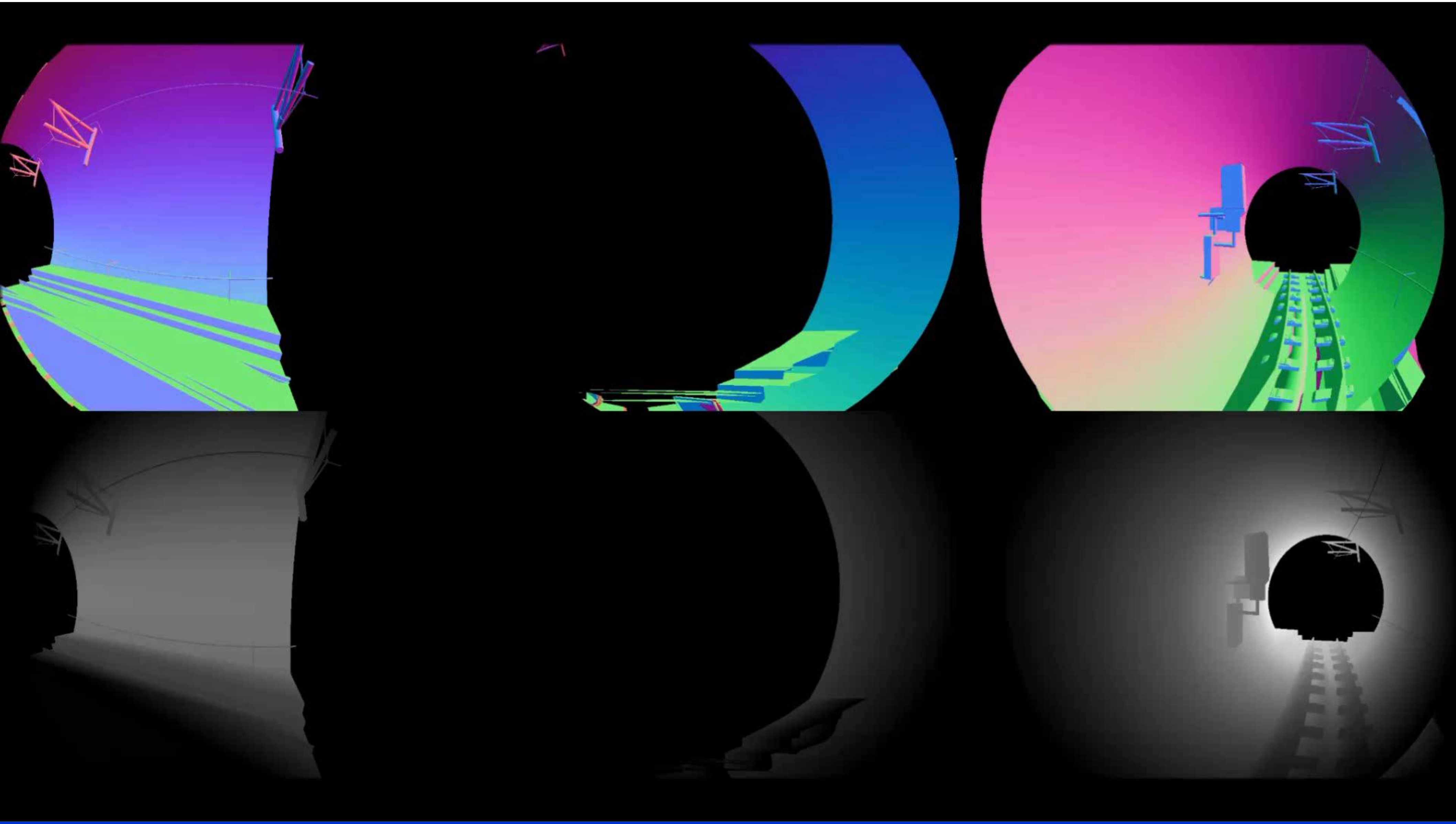
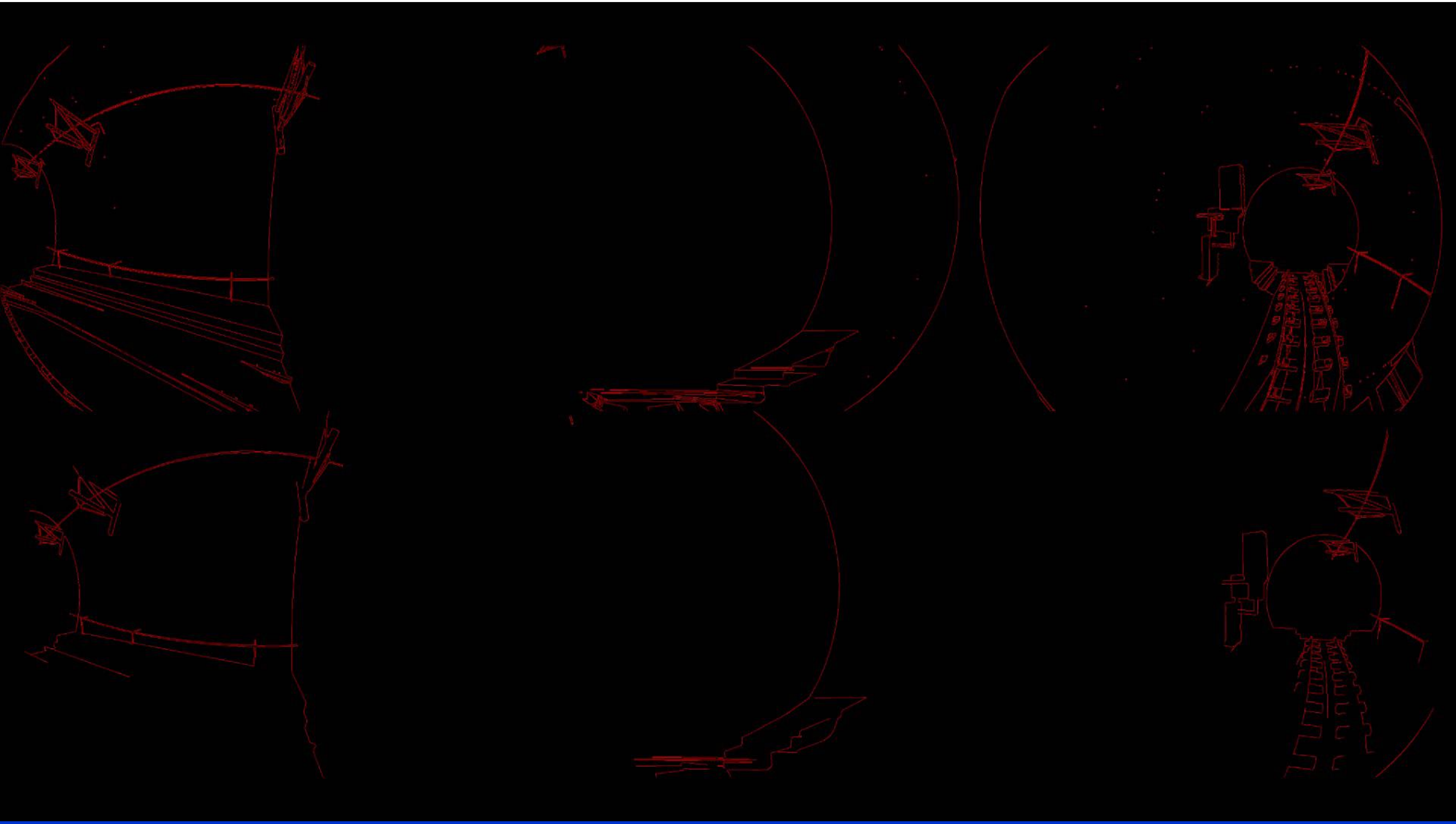


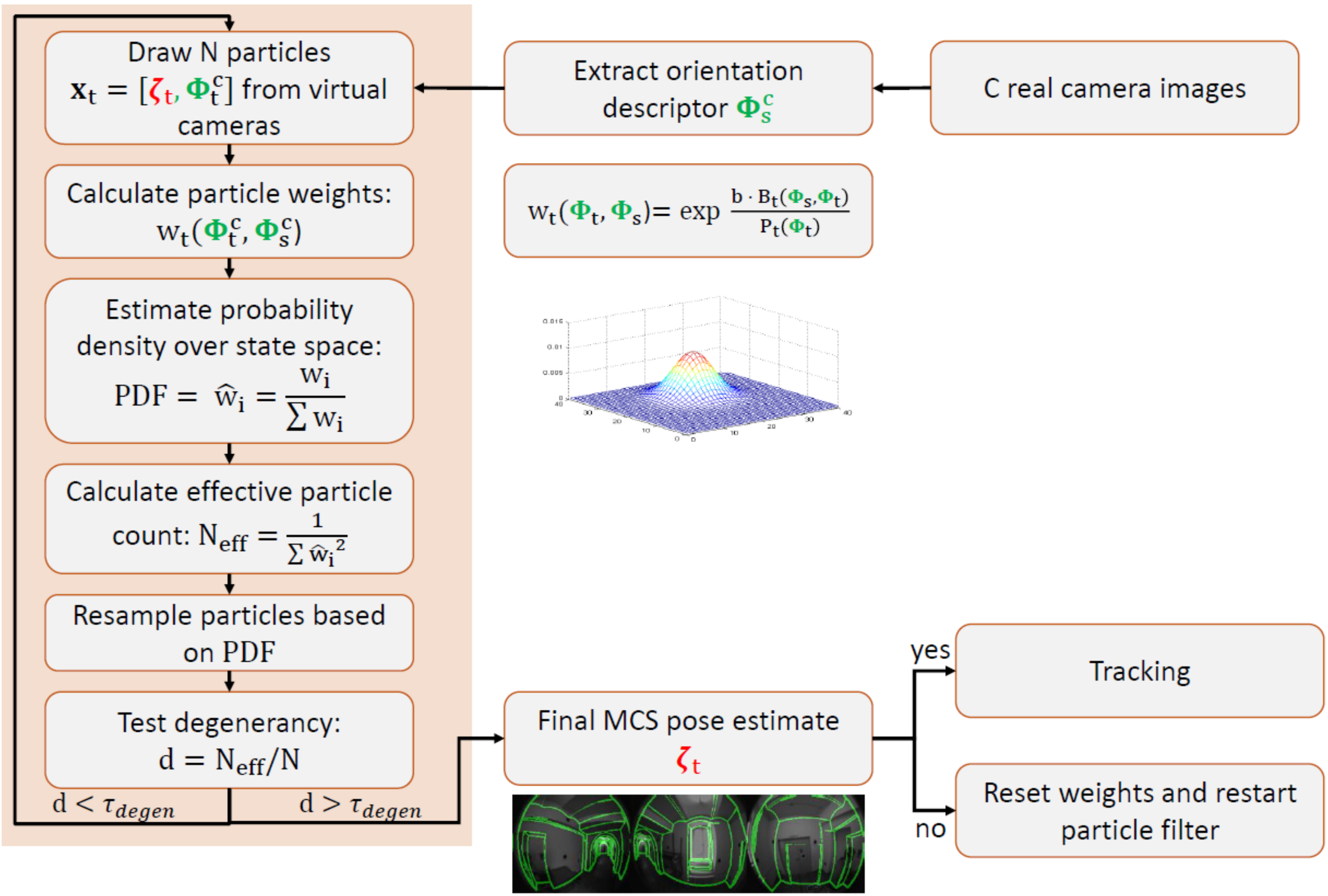
Example



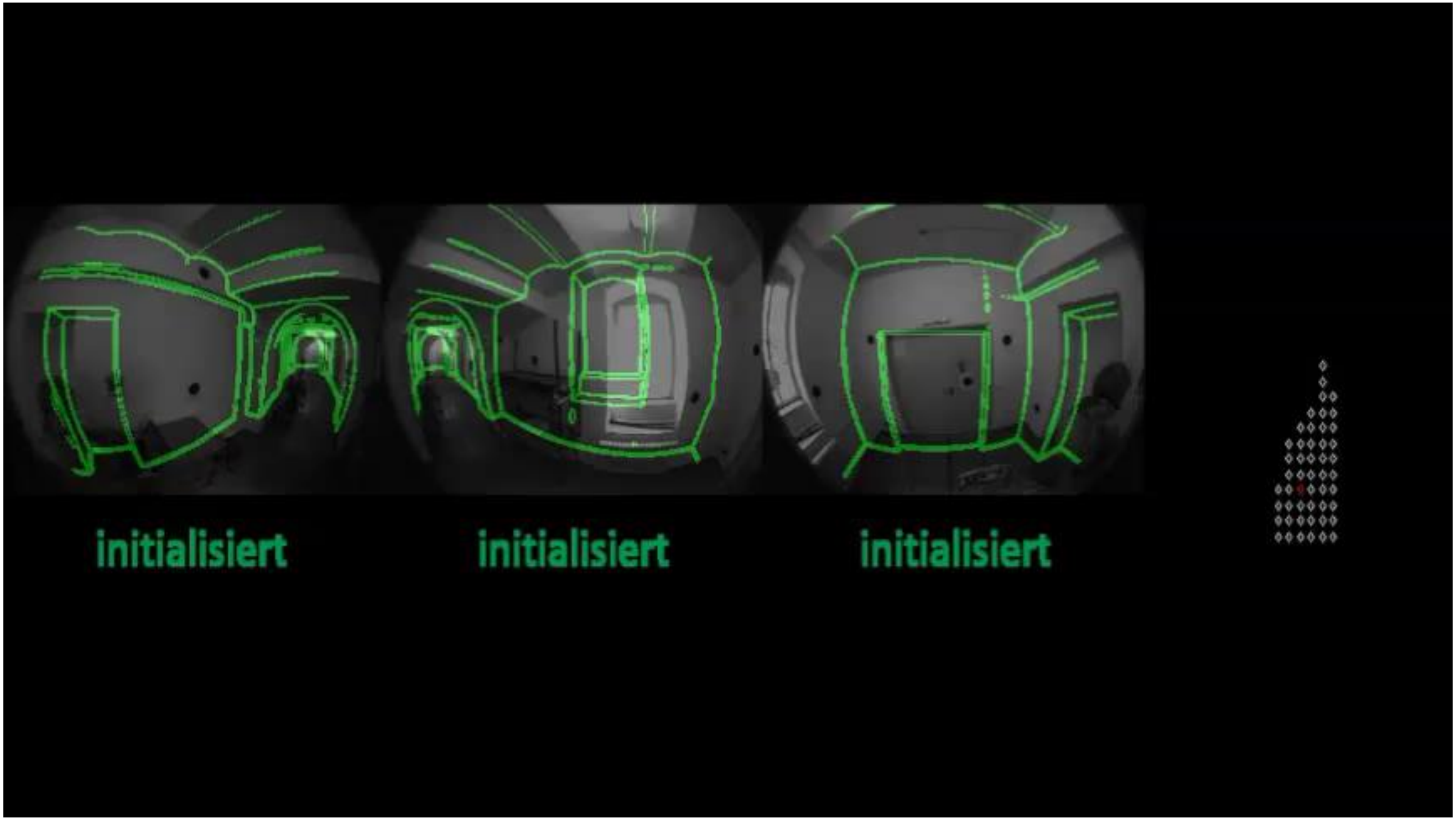
Example: visible edges



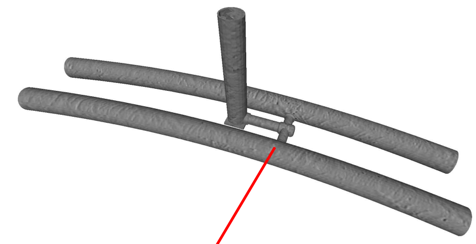
Self-localization: estimation by particle filtering

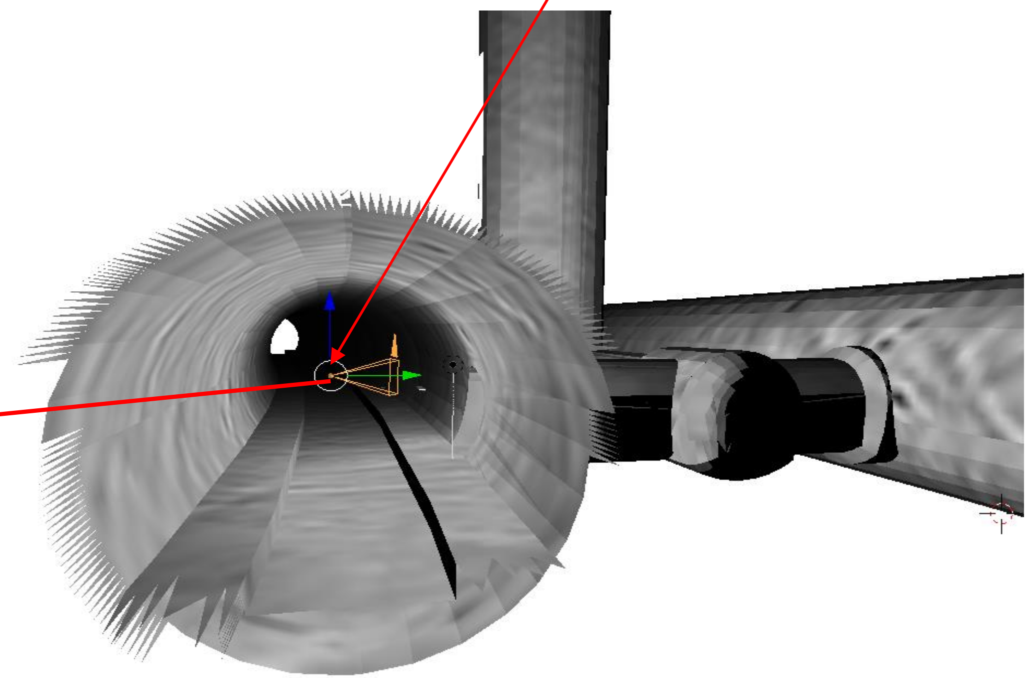


Self-localization

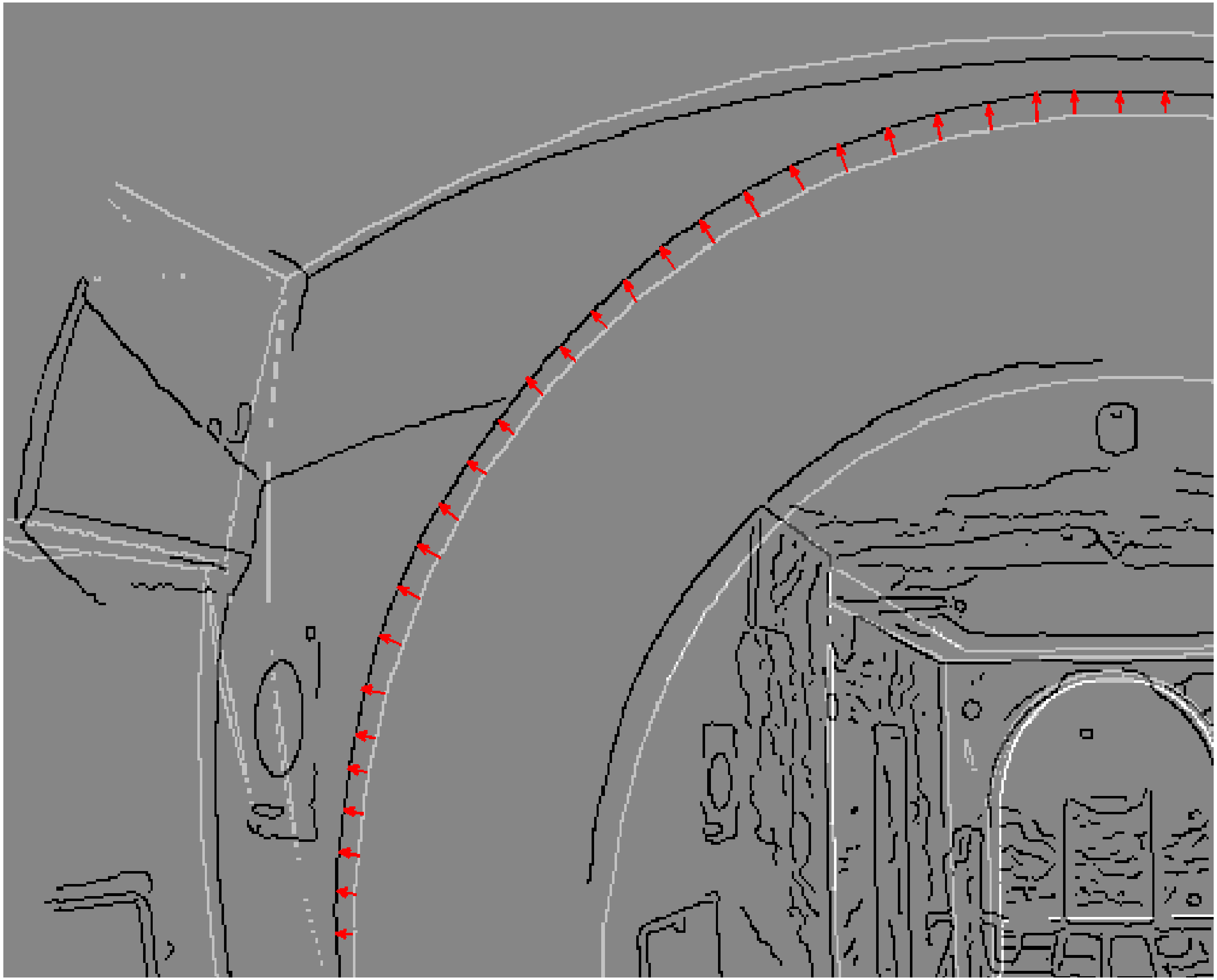


Self-localization: Examples





- Fine registration



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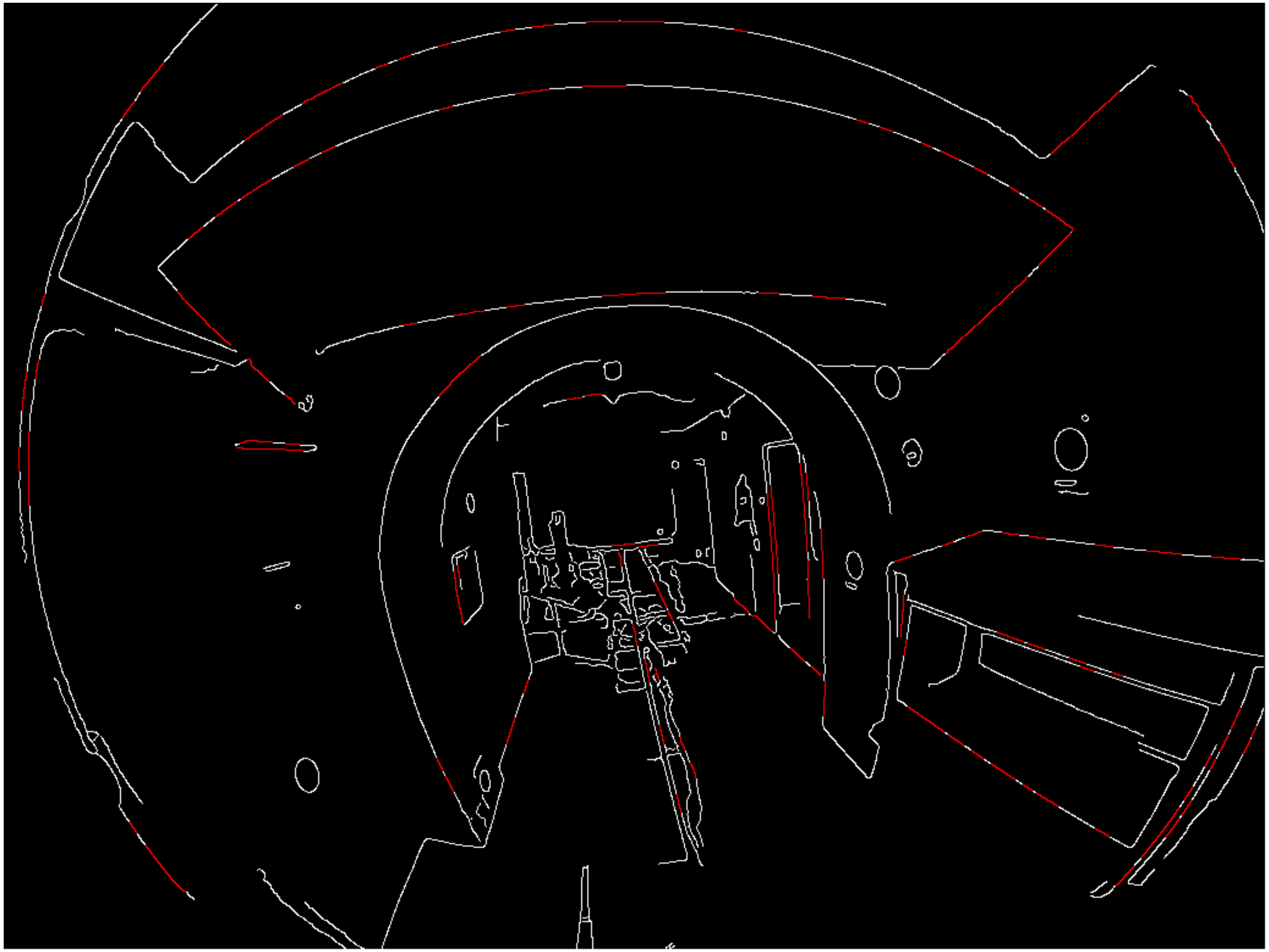

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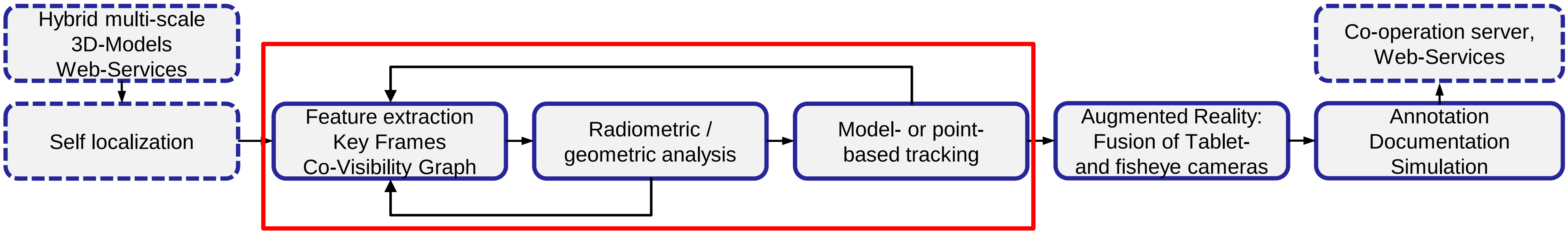
Egomotion determination / Tracking

- Extension of conventional visual SLAM algorithm (ORB-SLAM)

⇒ Multi-Fisheye cameras

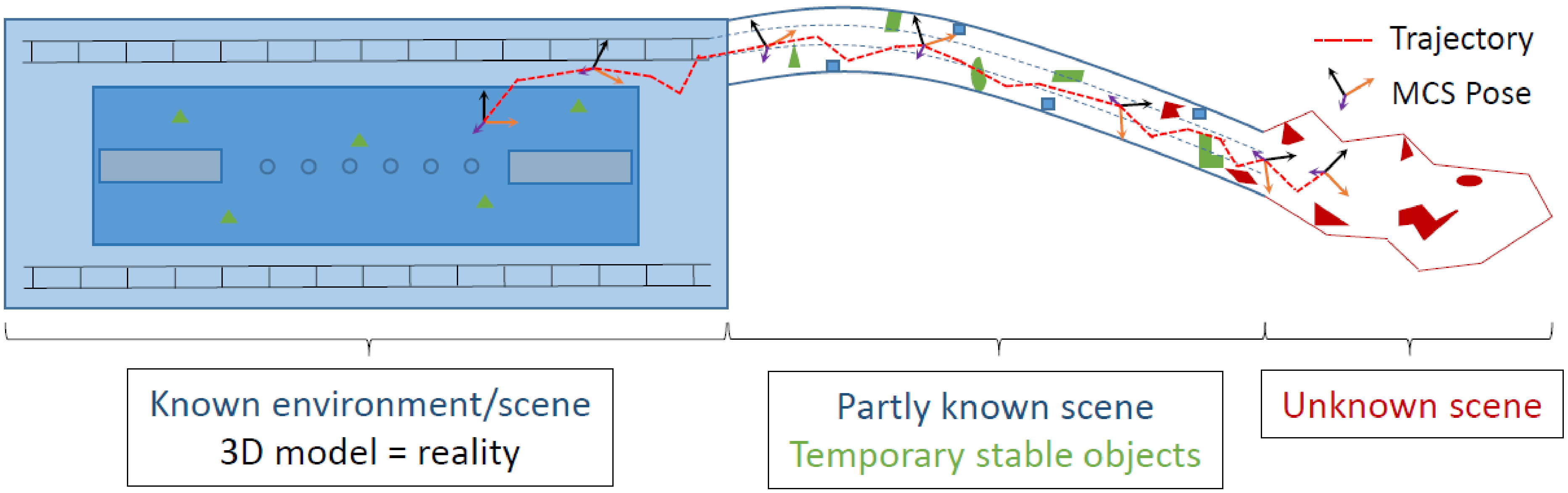
⇒ Optional: support of virtual 3D modell



Egomotion determination / Tracking

Challenges:

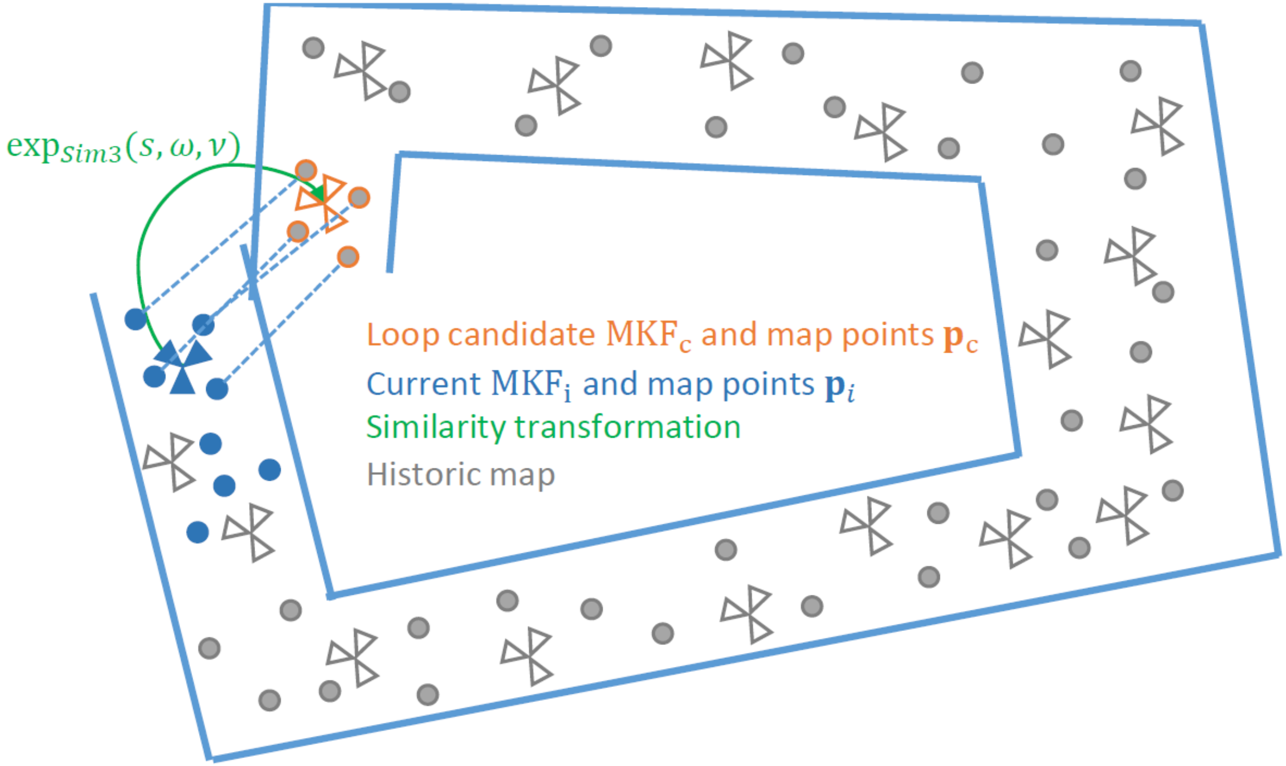
- Fusion of piont- und model-based tracking



Egomotion determination / Tracking

Challenges:

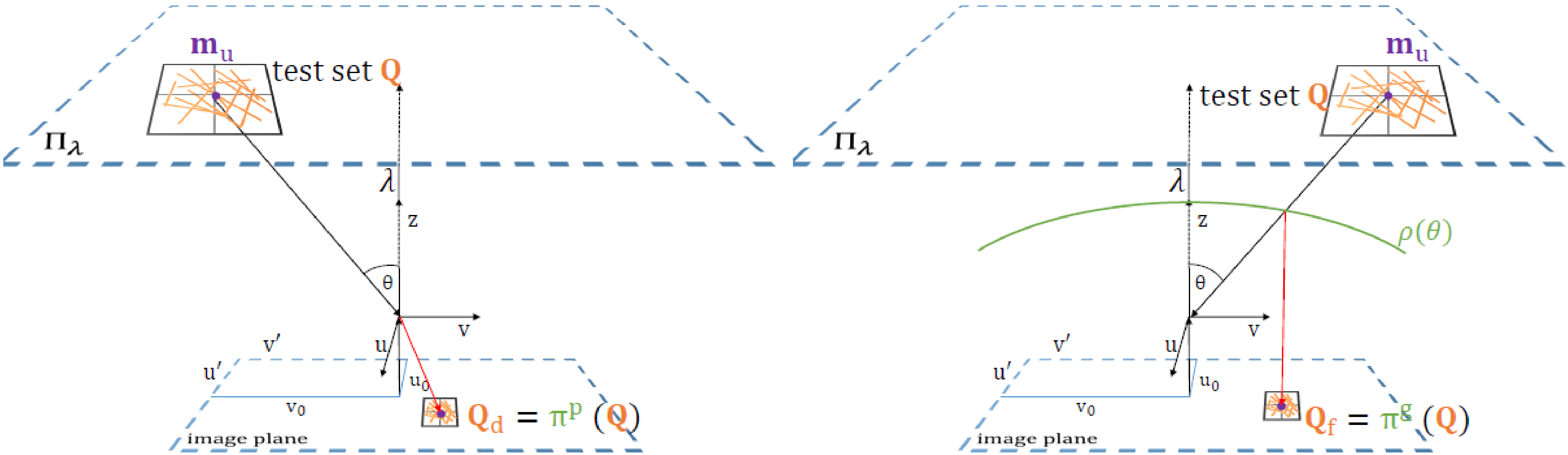
- Fusion of piont- und model-based tracking
  => Multi-colinearity SLAM with refinement of keyframes



Egomotion determination / Tracking

Challenges:

- Fusion of piont- und model-based tracking
  => Multi-colinearity SLAM with refinement of keyframes
- Feature extraction and self-calibration adapted to fisheye projections
  => mdBRIEF with online learning



Egomotion determination / Tracking

Challenges:

- Fusion of piont- und model-based tracking
  => Multi-colinearity SLAM with refinement of keyframes
- Feature extraction and self-calibration adapted to fisheye projections
  => mdBRIEF with online learning
- Distinction of static, moving and re-locatable object points
  => Co-visibility graph, robust estimation

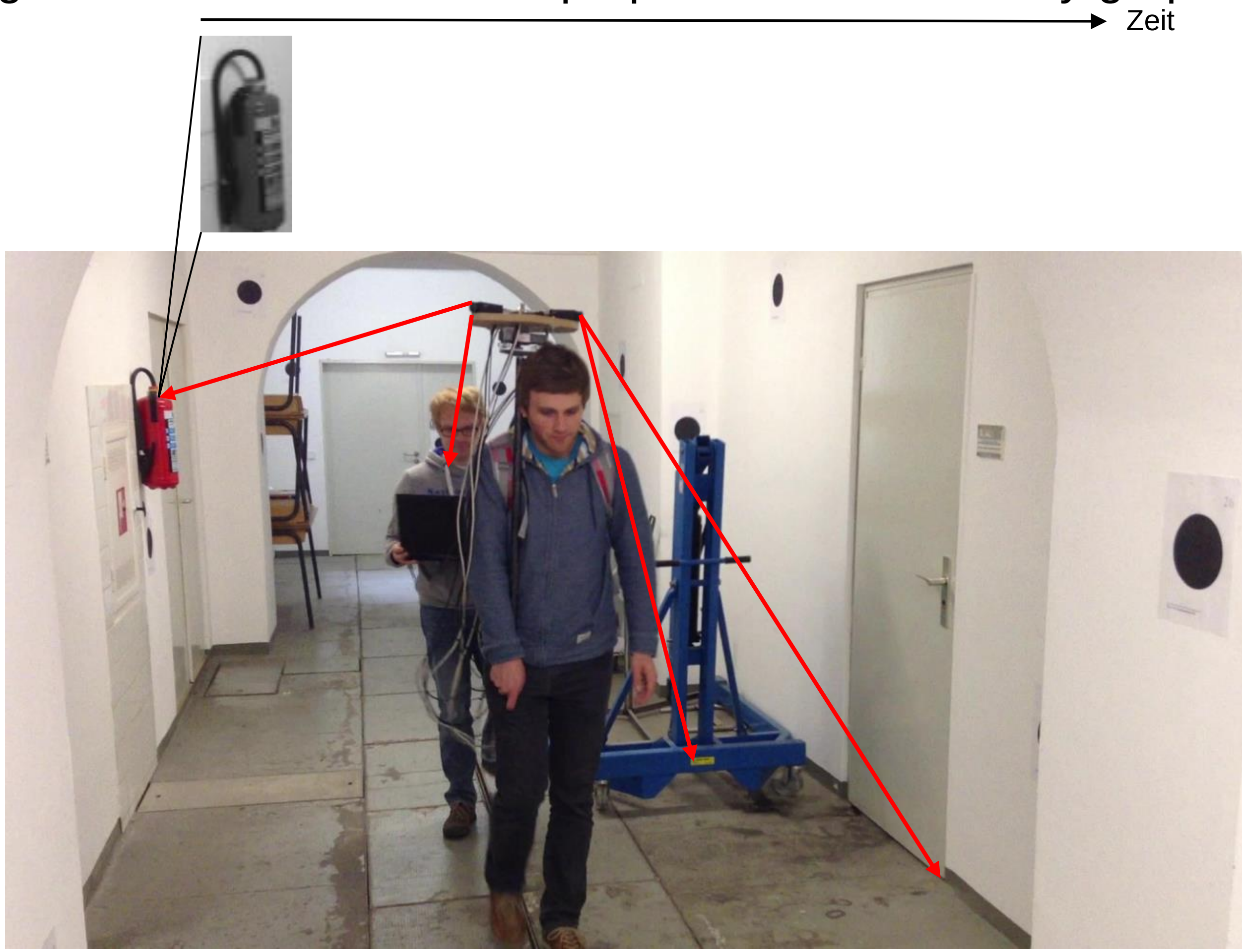
(not yet: utilization of uncertainties of 3D model)

Egomotion determination / Tracking

- Learning of geometric and radiometric properties for co-visibility graph

Radiometry:

Geometry

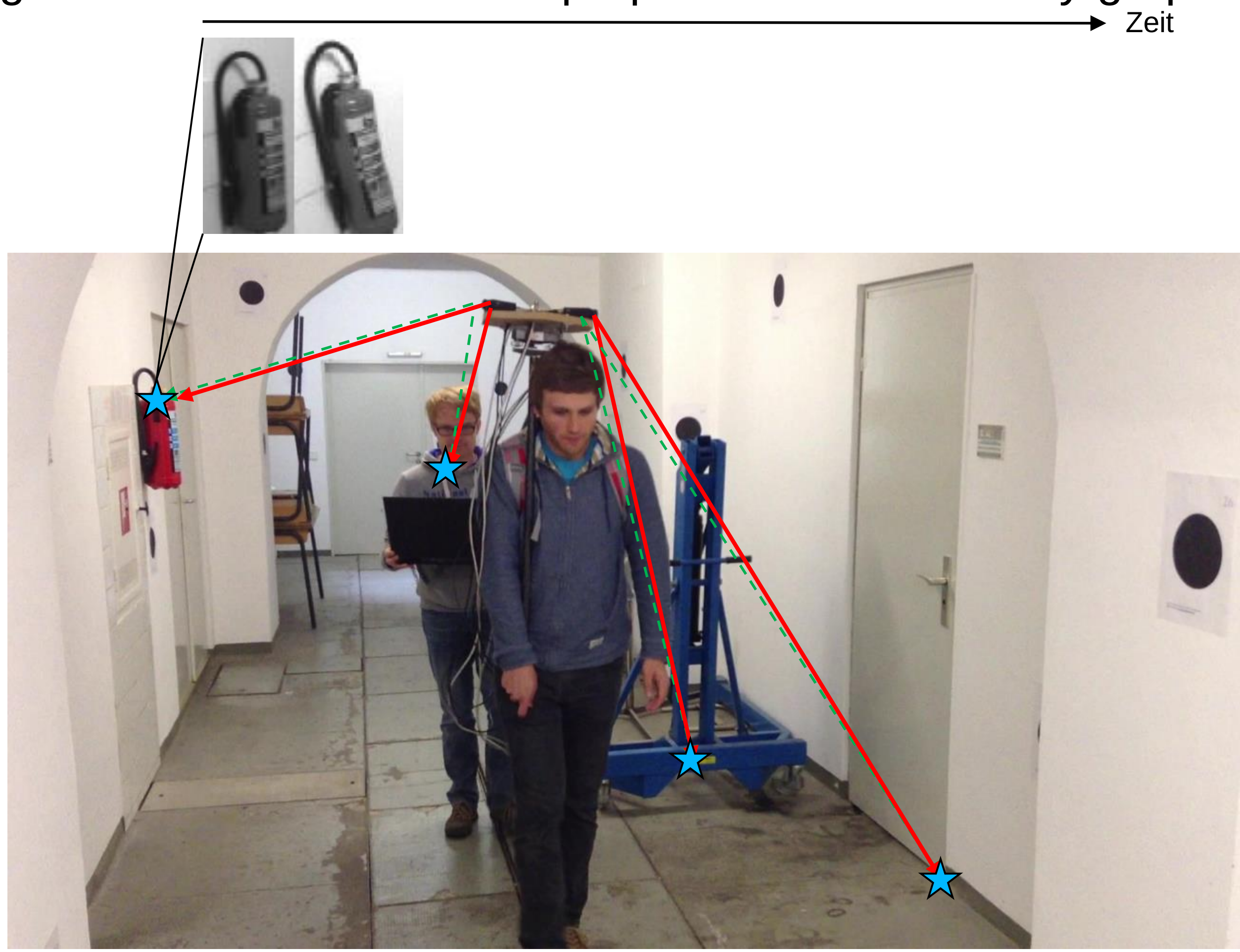


Egomotion determination / Tracking

- Learning of geometric and radiometric properties for co-visibility graph

Radiometry:

Geometry:

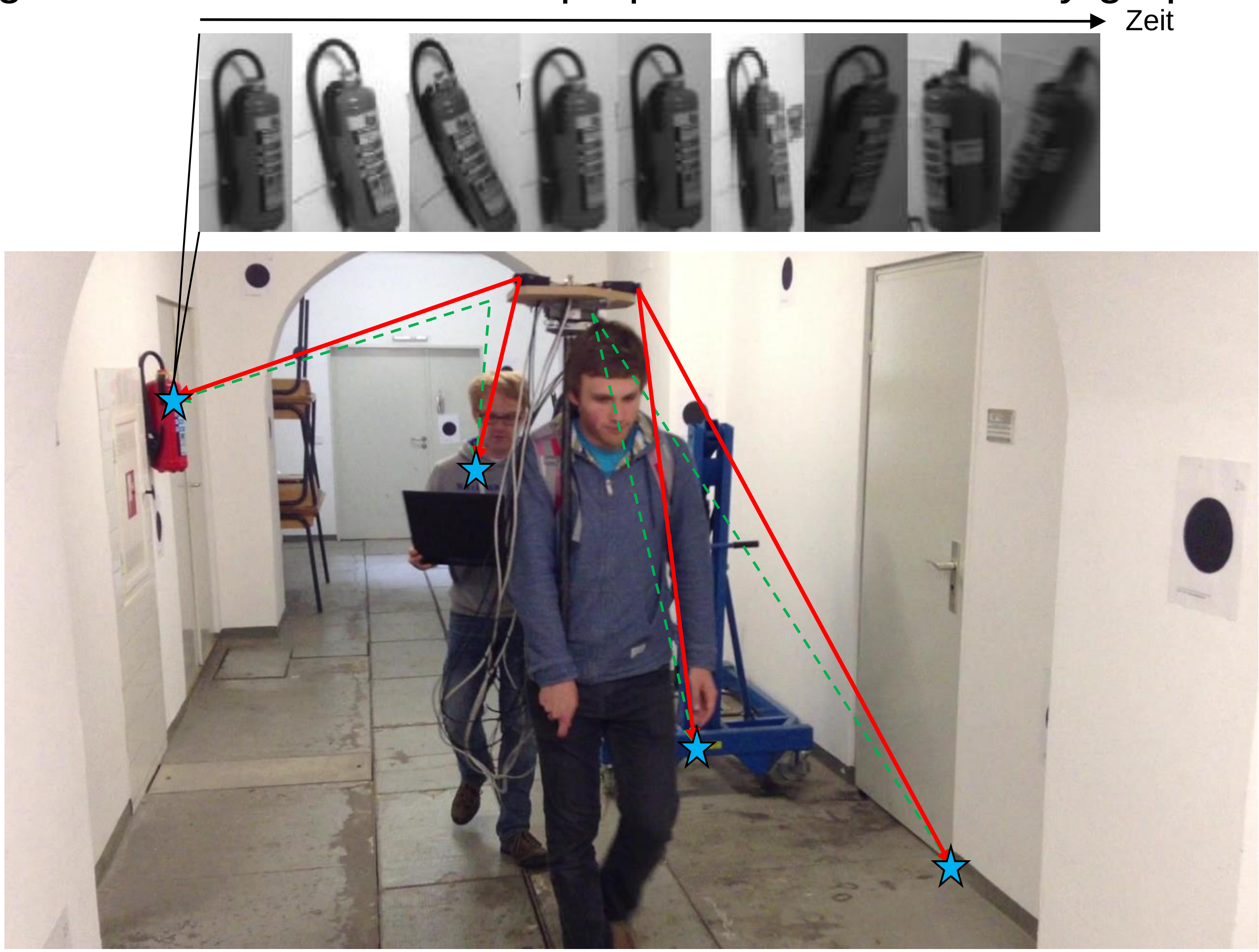


Egomotion determination / Tracking

- Learning of geometric and radiometric properties for co-visibility graph

Radiometry:

Geometry:



Egomotion determination / Tracking

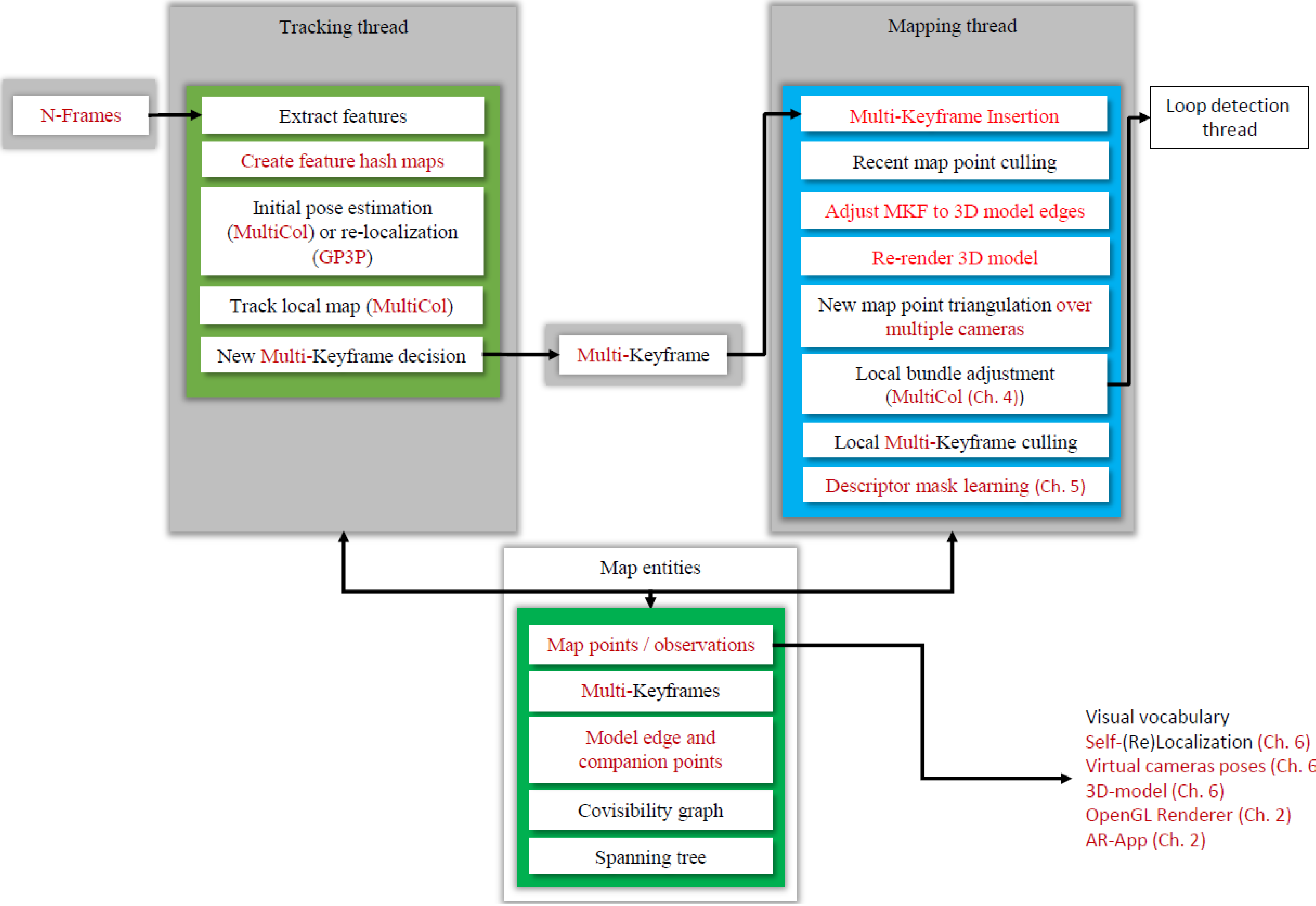
- Weighting of points (geometric restrictions)
- Testing of radiometric invariances
- Efficient selection and indexing (Wuest et al. 2007)

Static – useful

Relocatable – temporary useful

Moving – not useful

Tracking: „MulitCol SLAM“


Tracking thread
N-Frames
Extract features
Create feature hash maps
Initial pose estimation (MultiCol) or re-localization (GP3P)
Track local map (MultiCol)
New Multi-Keyframe decision
Multi-Keyframe
Mapping thread
Multi-Keyframe Insertion
Recent map point culling
Adjust MKF to 3D model edges
Re-render 3D model
New map point triangulation over multiple cameras
Local bundle adjustment (MultiCol (Ch. 4))
Local Multi-Keyframe culling
Descriptor mask learning (Ch. 5)
Loop detection thread
Map entities
Map points / observations
Multi-Keyframes
Model edge and companion points
Covisibility graph
Spanning tree
Visual vocabulary
Self-(Re)Localization (Ch. 6)
Virtual cameras poses (Ch. 6
3D-model (Ch. 6)
OpenGL Renderer (Ch. 2)
AR-App (Ch. 2)

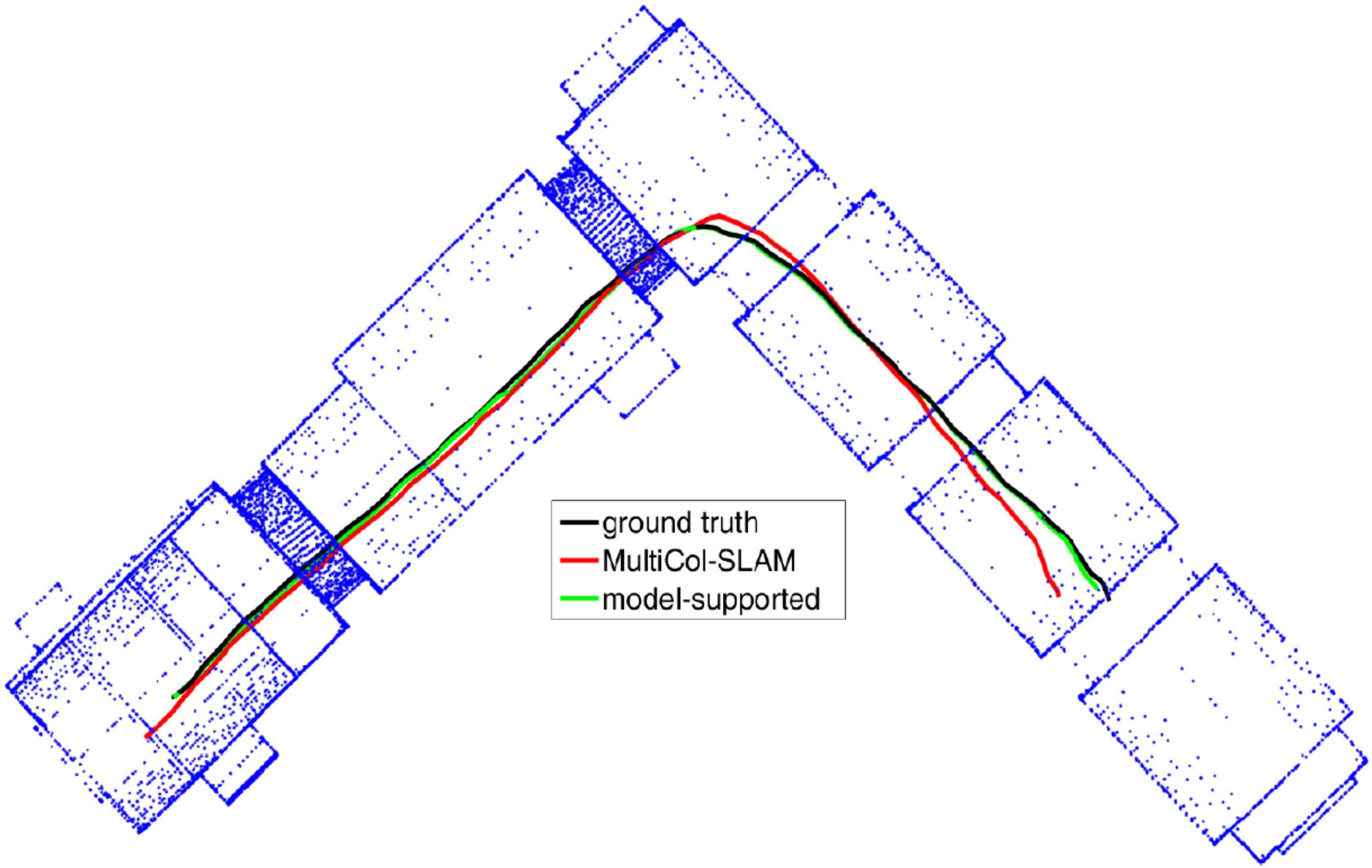
Multi-Fisheye SLAM (Self-localization and mapping)

MultiCol-SLAM

Steffen Urban, Stefan Hinz

Institute of Photogrammetry and Remote Sensing (IPF)

Tracking: „MulitCol SLAM“



Tracking: „MulitCol SLAM“

- Some numbers

	Single fisheye camera			Multi-fisheye camera system		
	ORB	dBRIEF	mdBRIEF	ORB	dBRIEF	mdBRIEF
	% tracked	% tracked	% tracked	% tracked	% tracked	% tracked
Laser 1	88.4	89.7	89.7	88.6	88.7	88.7
Laser 2 fast	86.7	92.9	93.7	69.8	93.2	93.6
Indoor 1 stat. env.	95.2	91.5	96.9	95.5	98.8	98.7
Indoor 2 dyn. env.	91.8	95.1	95.1	97.5	98.7	99.0
Outdoor 1 dyn. env.	31.0	32.0	34.1	93.0	93.0	90.1

Tracking: „MulitCol SLAM“

- Even more numbers (ATE)

	Single fisheye camera			Multi-fisheye camera system		
	ORB	dBRIEF	mdBRIEF	ORB	dBRIEF	mdBRIEF
	[cm]	[cm]	[cm]	[cm]	[cm]	[cm]
Laser 1	31.0	33.0	33.0	1.4	1.3	1.5
Laser 2 fast	28.1	25.3	25.5	(X)	7.0	5.3
Indoor 1 stat. env.	32.4	11.2	3.3	2.1	2.7	2.5
Indoor 2 dyn. env.	13.3	14.7	14.2	1.8	2.5	2.7
Outdoor 1 dyn. env.	(X)	(X)	(X)	3.6	17.1	13.4

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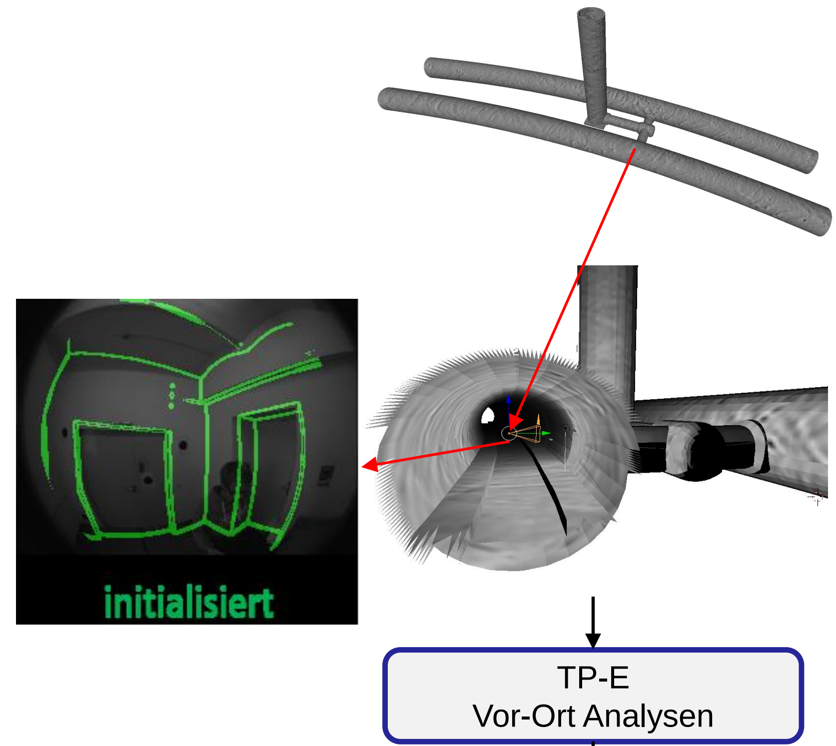
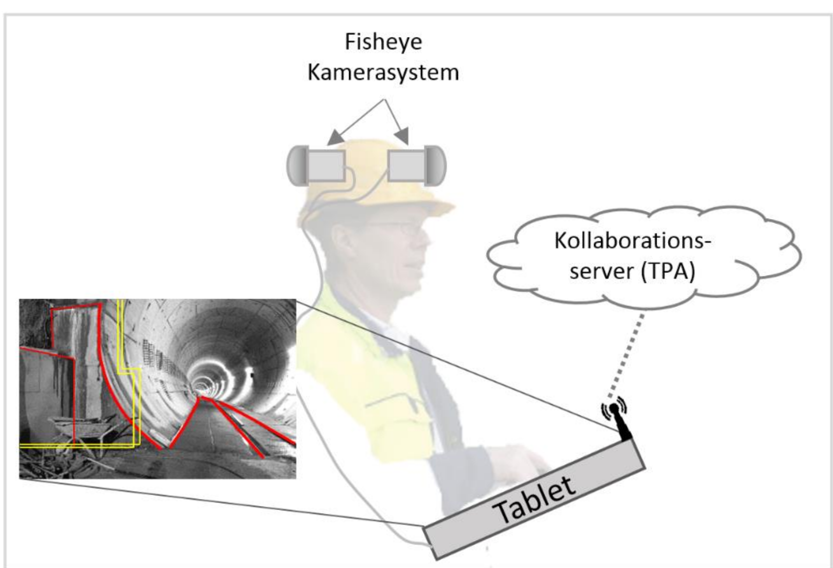
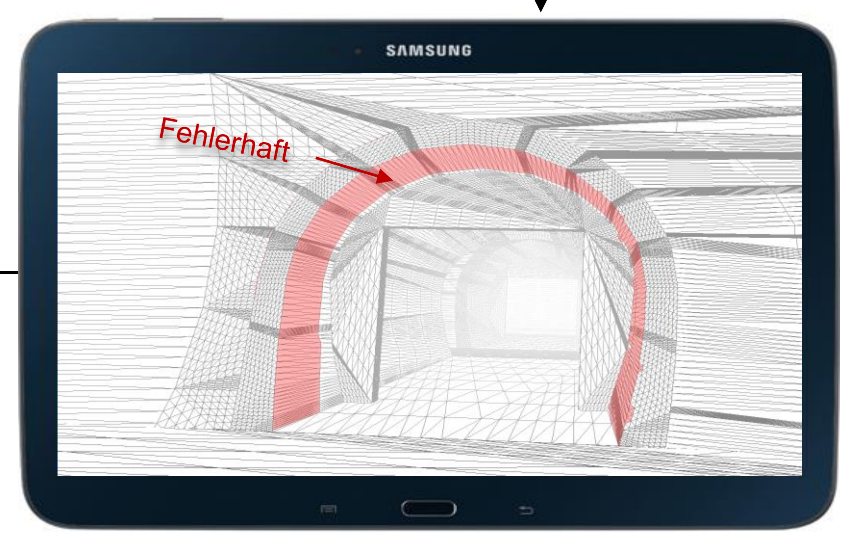
Appendix:
Fusion with Tablet-System

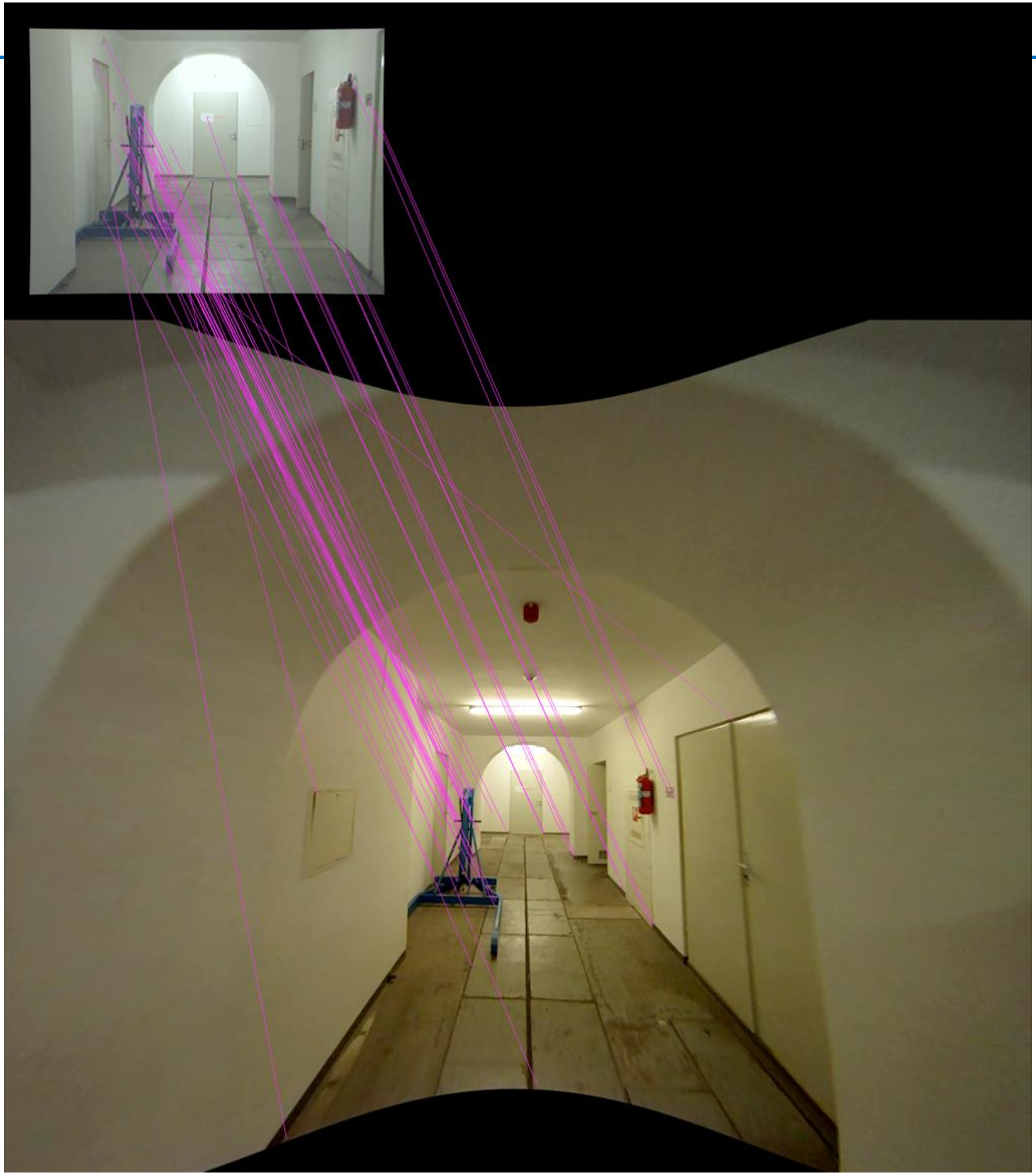
- Image to image matching
- In-situ analysis
  - Dokumentation
  - Annotation







Correction of distortion and matching



Result

Thank you for your attention…

Thank y ntion…

and many thanks to Dr. Steffen Urban

Further readings:

Urban, Leitloff, Hinz (2015): Multi-fisheye camera calibration. ***ISPRS Journal***

Urban, Leitloff, Wursthorn, Hinz (2016): Multi-fisheye tracking. ***Int. Journal of Computer Vision***

Urban, Weinmann, Hinz (2017, to appear): mdBrief… . ***Computer Vision and Image Understanding***