Technical University of Munich

Change detection of urban objects using 3D point clouds (1)

Uwe **STILLA**

TUM - Photogrammetry and Remote Sensing

University of Twente - NCG seminar on point clouds

2020-JUN-11

NCG

Technische Universität München

Photogrammetry and Remote Sensing

Change detection using 3d point clouds

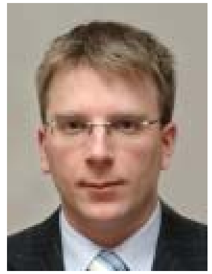
- Change detection as subject of PhD work at TUM-PF
  - Mobile thermal mapping of buildings (terrestrial) [Zhu et al., 2019]
  - Airborne thermal mapping of buildings [Hoegner & Stilla, 2018]
  - **Change detection of urban areas by oblique ALS (Helicopter)**
  - Photogr. construction site monitoring using BIM [Tuttas et al., 2017]
  - Change detection of construction sites from point clouds [Huang, 2019]
  - Street canyon mapping by MLS [Gehrung et al., 2019][Zhu et al., 2020]
  - Pedestrian tracking in MLS point clouds [Borgmann et al., 2019]
  - Bathymetric change detection of river beds [Boerner et. al, 2019]
  - Change detection by space-borne SAR [Vilamill & Stilla, 2019]
  - Laser-based indoor mapping and IndoorGML [Tessema et al., 2019]
  - Photogrammetric indoor mapping and BIM [Meyer, 2019]
  - Reconstruction and monitoring of urban trees [Hirt, 2019]
  - Rock fall monitoring in alpine regions [Dinkel et al., 2020]

Change detection using 3d point clouds

- Automatic **change detection** is of general interest of monitoring dynamic processes which show a confusing situation for human observers
- Independent on sensors (e.g. photogrammetry, laser scanning, RADAR) the 3D geometry of urban structures is often represented by **point clouds**

Challenges

- Detection of **small** changes on-the-fly in **extended** urban areas showing complex structures
  - **Example I: Comparison of point clouds [Hebel & Stilla]**
- Change detection of "**objects of interest**" in a **rapidly** changing environment --> **construction sides**
  - Example II: Progress monitoring – Comparison of point clouds and building information models (BIM) [Tuttas & Stilla]



M. Hebel

Research project:

Comparison point cloud-to-point cloud

Change detection of urban areas by oblique ALS (Helicopter)

- Hebel M, Stilla U (2012) Simultaneous calibration of ALS systems and alignment of multiview LiDAR scans of urban areas. IEEE Transactions on Geoscience and Remote Sensing, 50(6): 2364-2379
- Hebel M, Arens M, Stilla U (2013) Change detection in urban areas by object-based analysis and on-the-fly comparison of multi-view ALS data. ISPRS Journal of Photogrammetry and Remote Sensing 86 (2013): 52–64

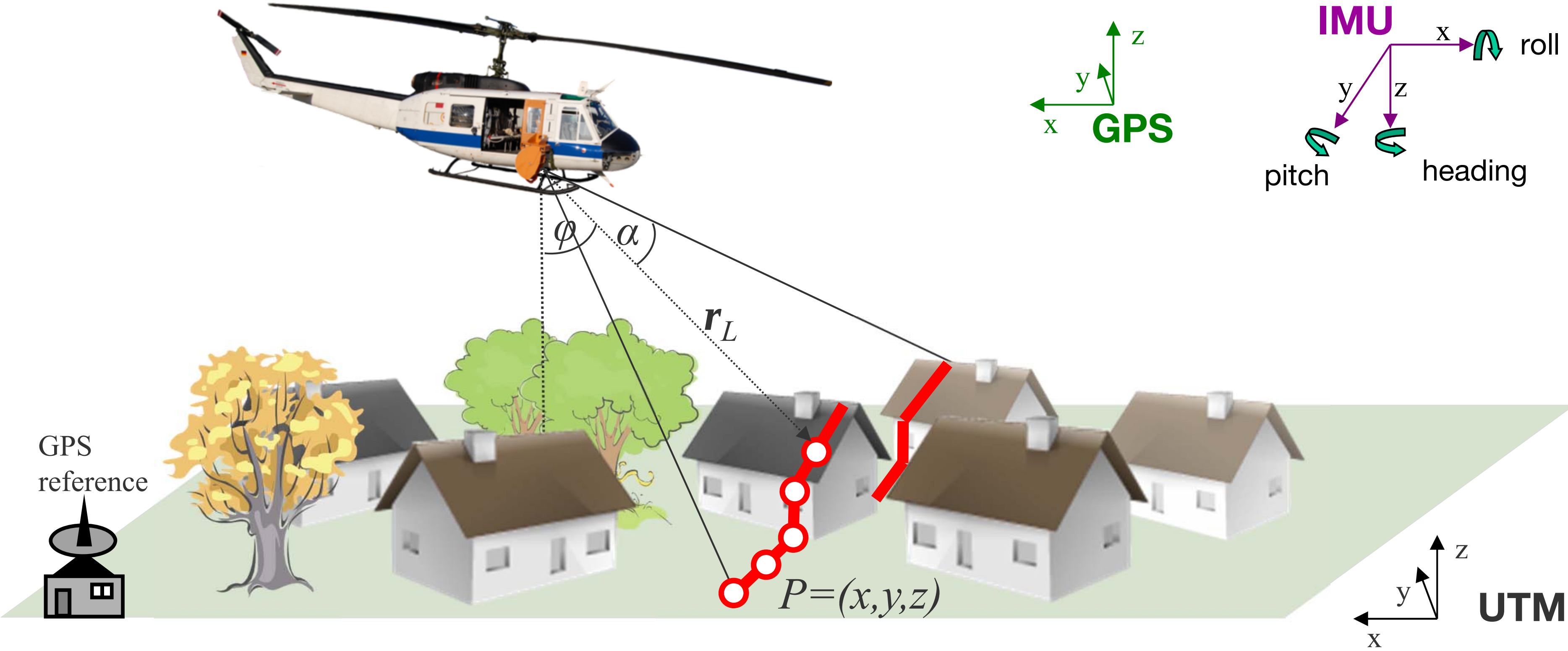
ALS, experimental setup, direct georeferencing

RIEGL LMS-Q560

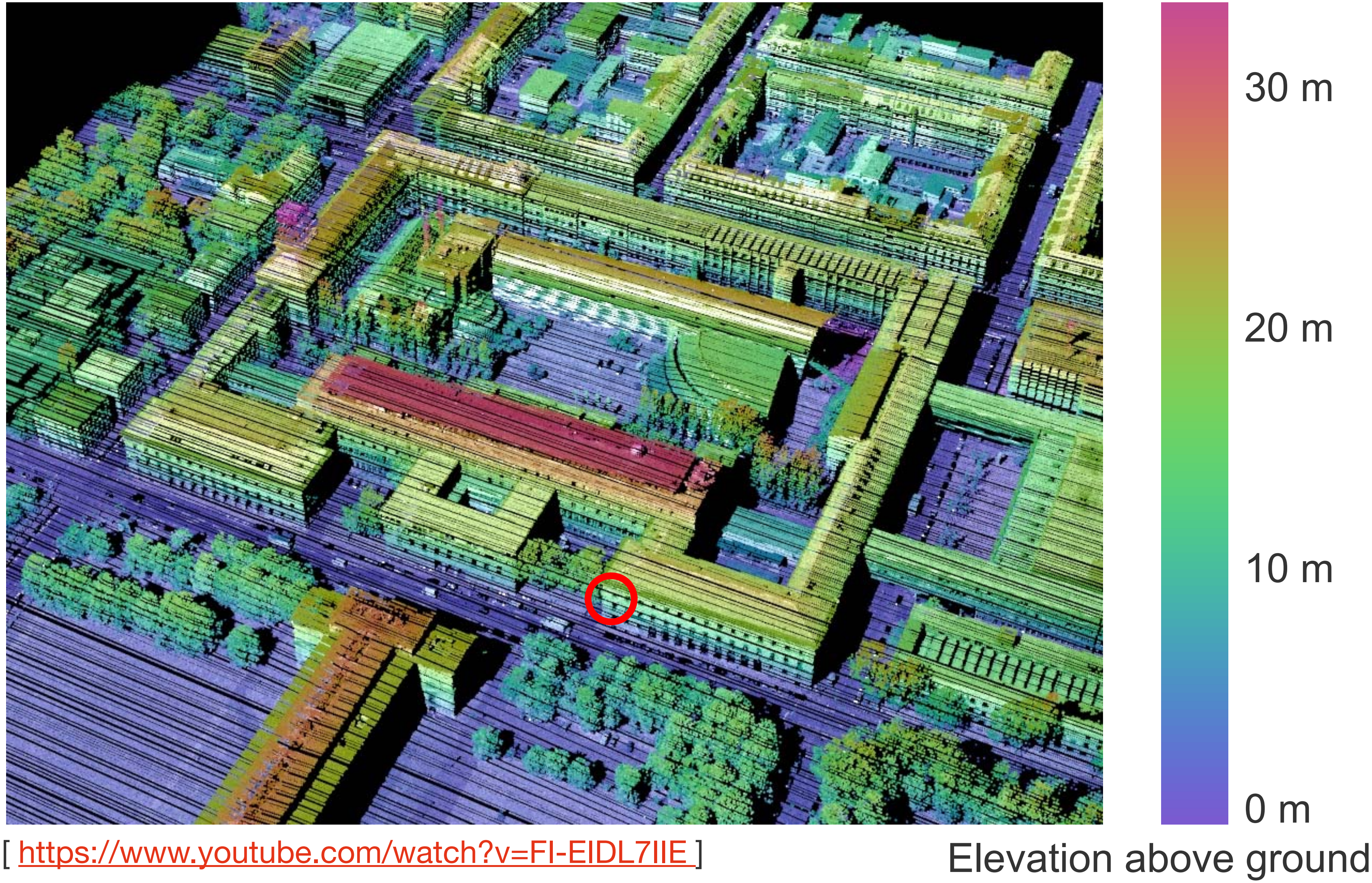
- full waveform
- polygon mirror
- scan-lines

Applanix POS AV 410

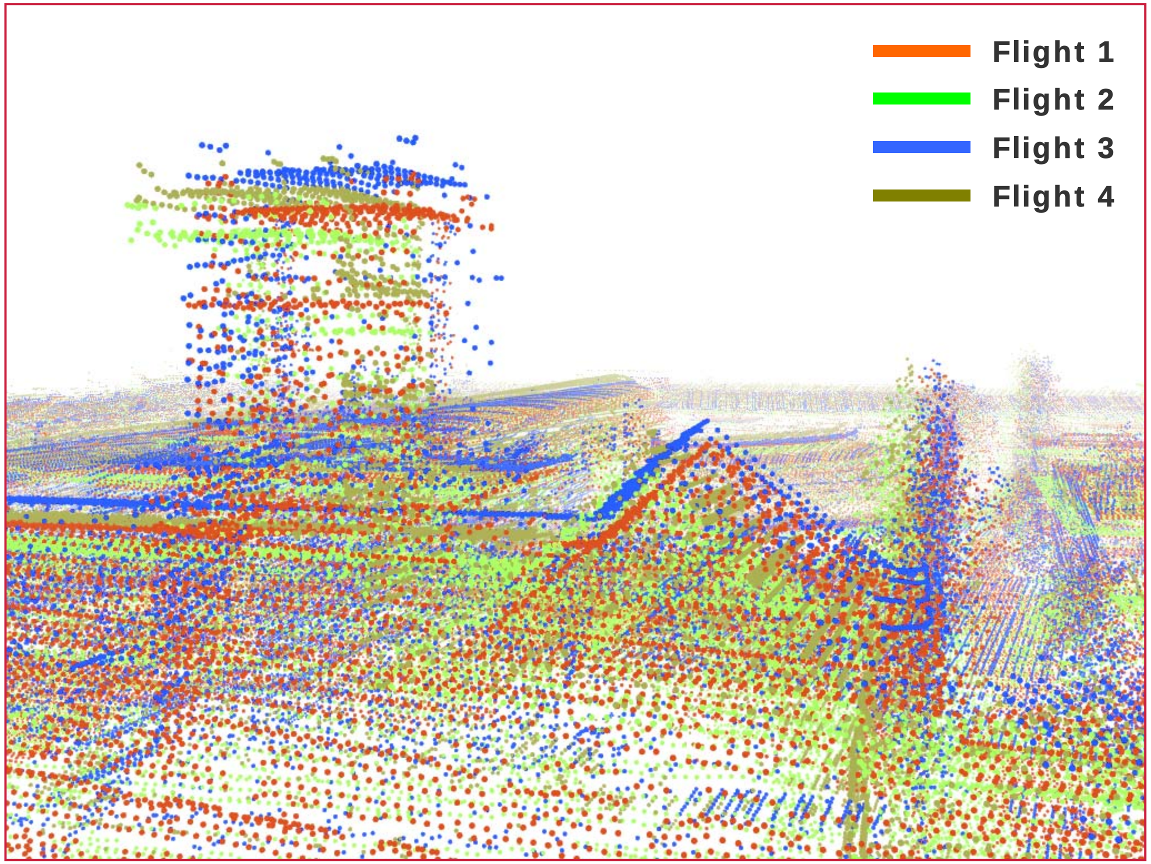
- time (UTC)
- position (GPS)
- orientation (IMU)

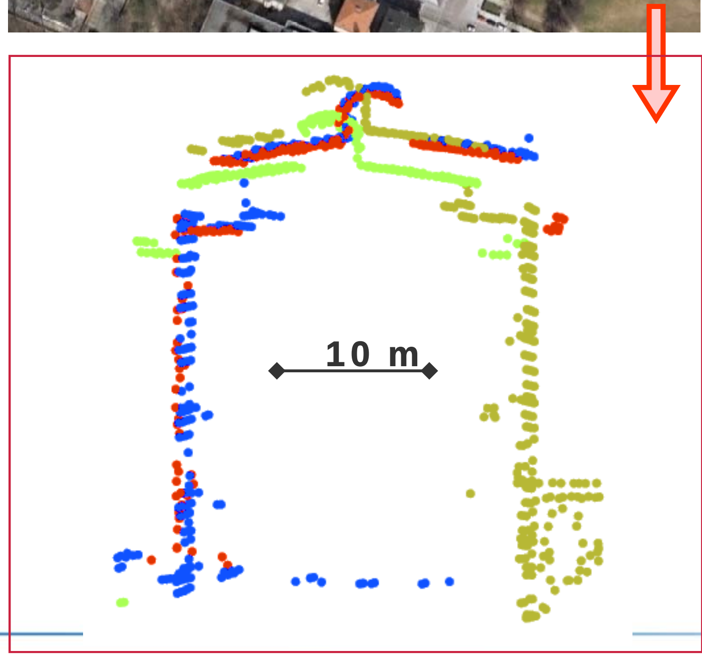


Example: ALS-Flight TUM City Campus 2006



[https://www.youtube.com/watch?v=FI-EIDL7IIE]

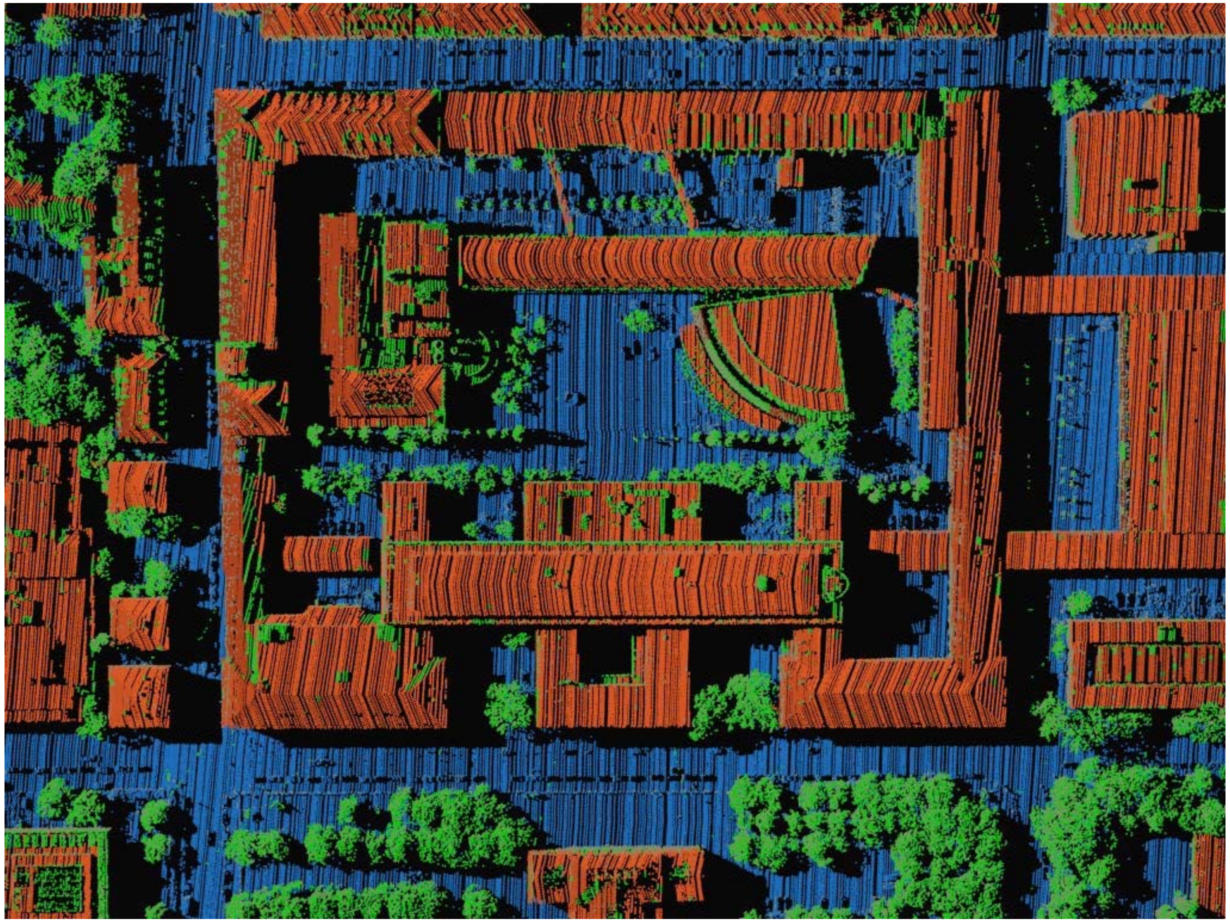




Displacement mainly caused by:

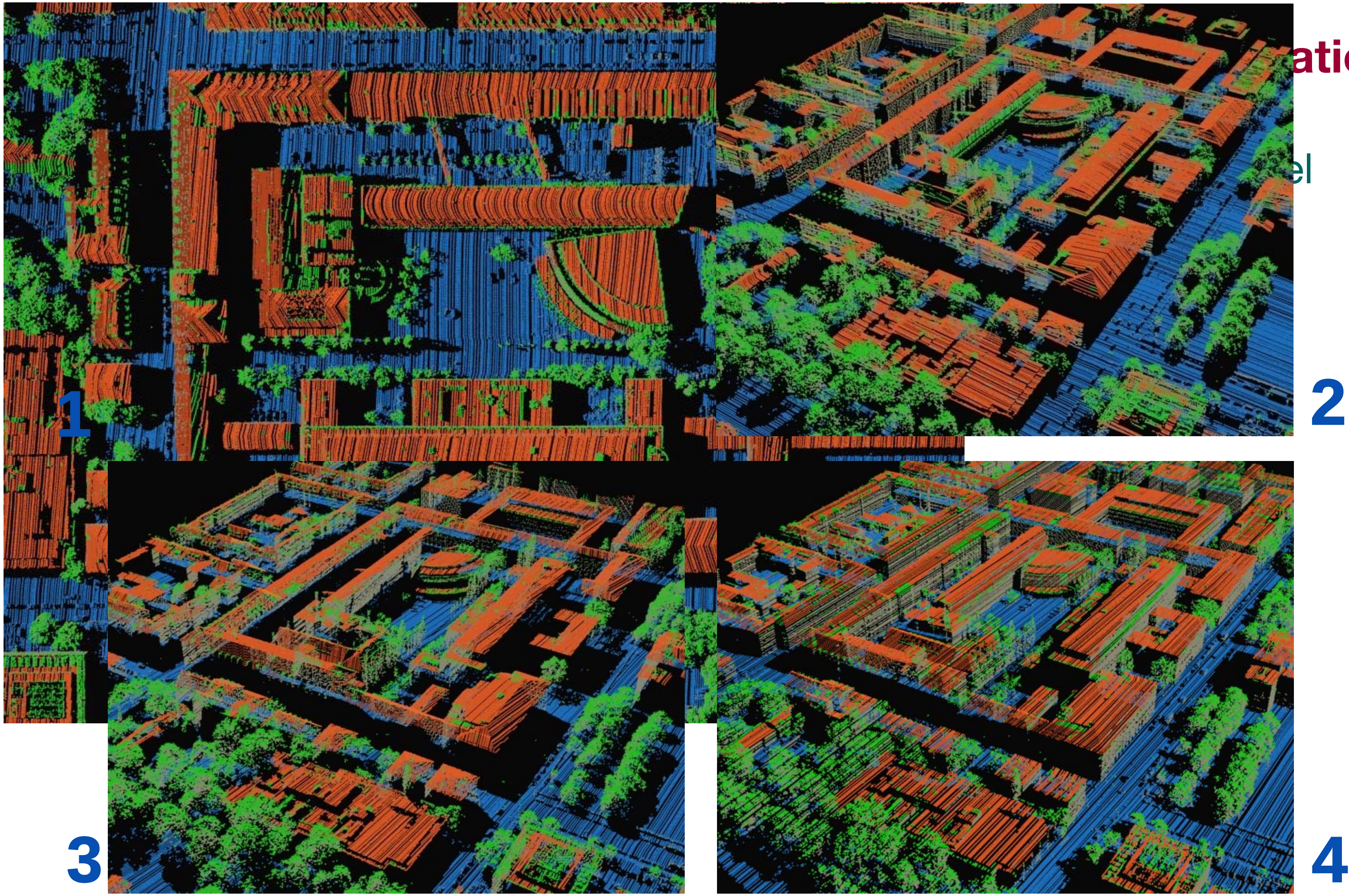
- Inaccurate relative sensor position
- Errors in the navigational data

Classification of the scene



- **"Classification"**

  - Ground level
  - Facades
  - Vegetation
  - Rooftops



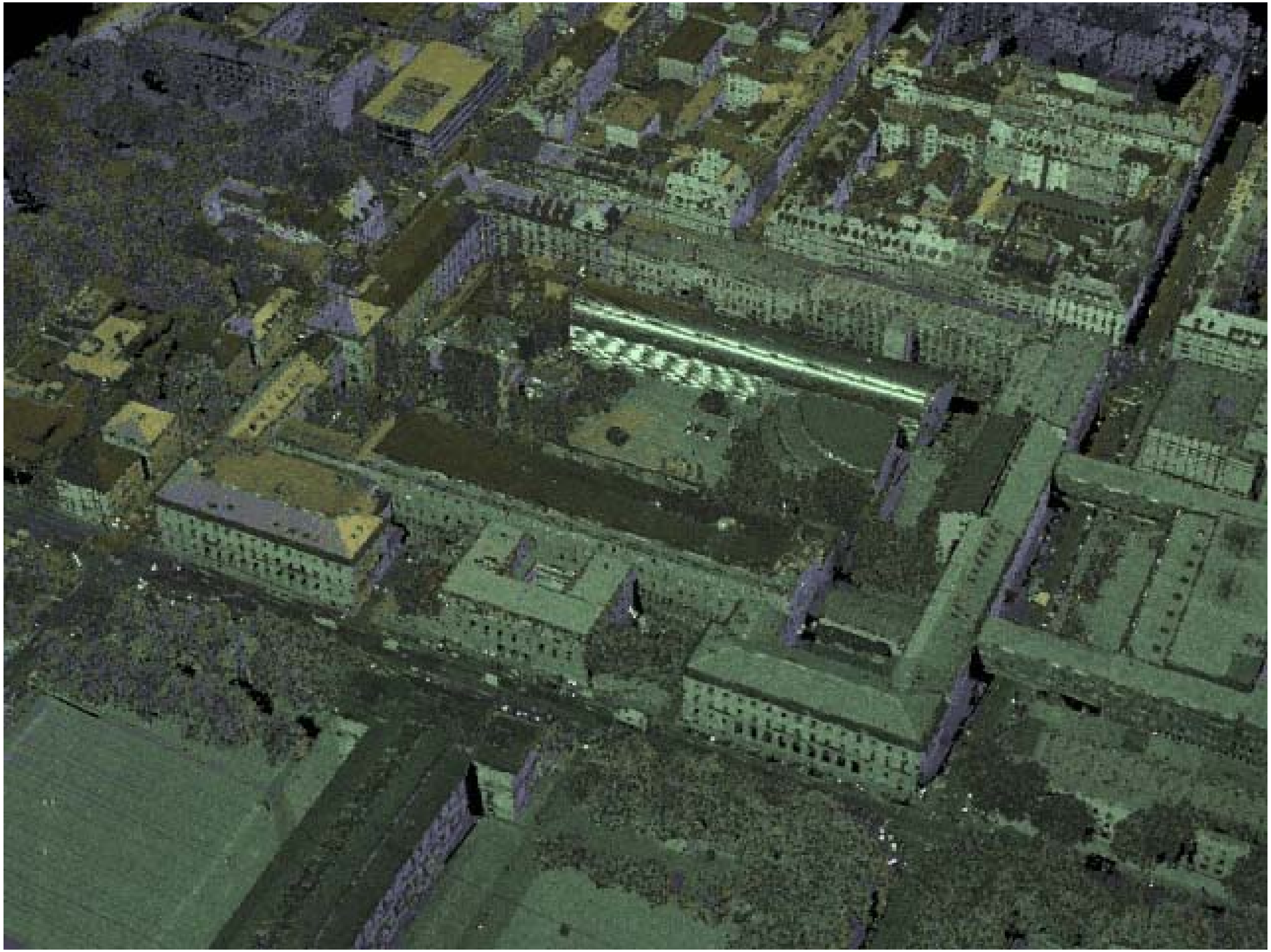
ation”

el

Composed scans after co-registration

[https://www.youtube.com/watch?v=203b-zWlsZ4]

3D Point cloud TUM



[https://www.youtube.com/watch?v=OxV02RqIlpY]

Different operating modes

Generation of a database: t_1

- Not time-critical
- Multiple scans of the relevant urban area
- Calibration
- Off-line data processing
- Analysis of the combined (full 3D) point cloud

Database

Helicopter/UAV mission: t_2

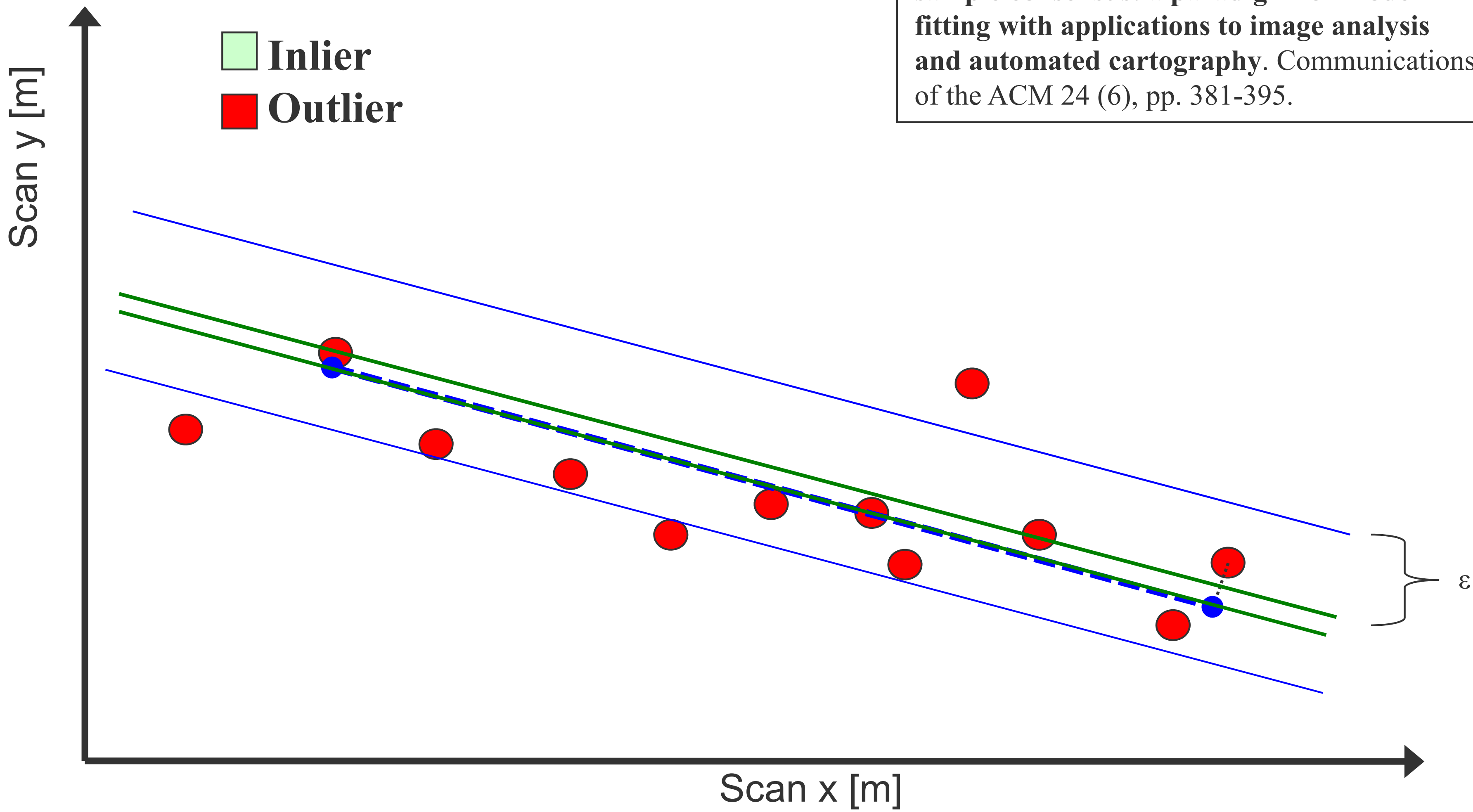
- Oblique forward-looking sensor (obstacle avoidance)
- Degraded GPS accuracy
- Scan-line methods
- Data alignment, terrain referenced navigation

Current ALS data

Comparison,
change detection

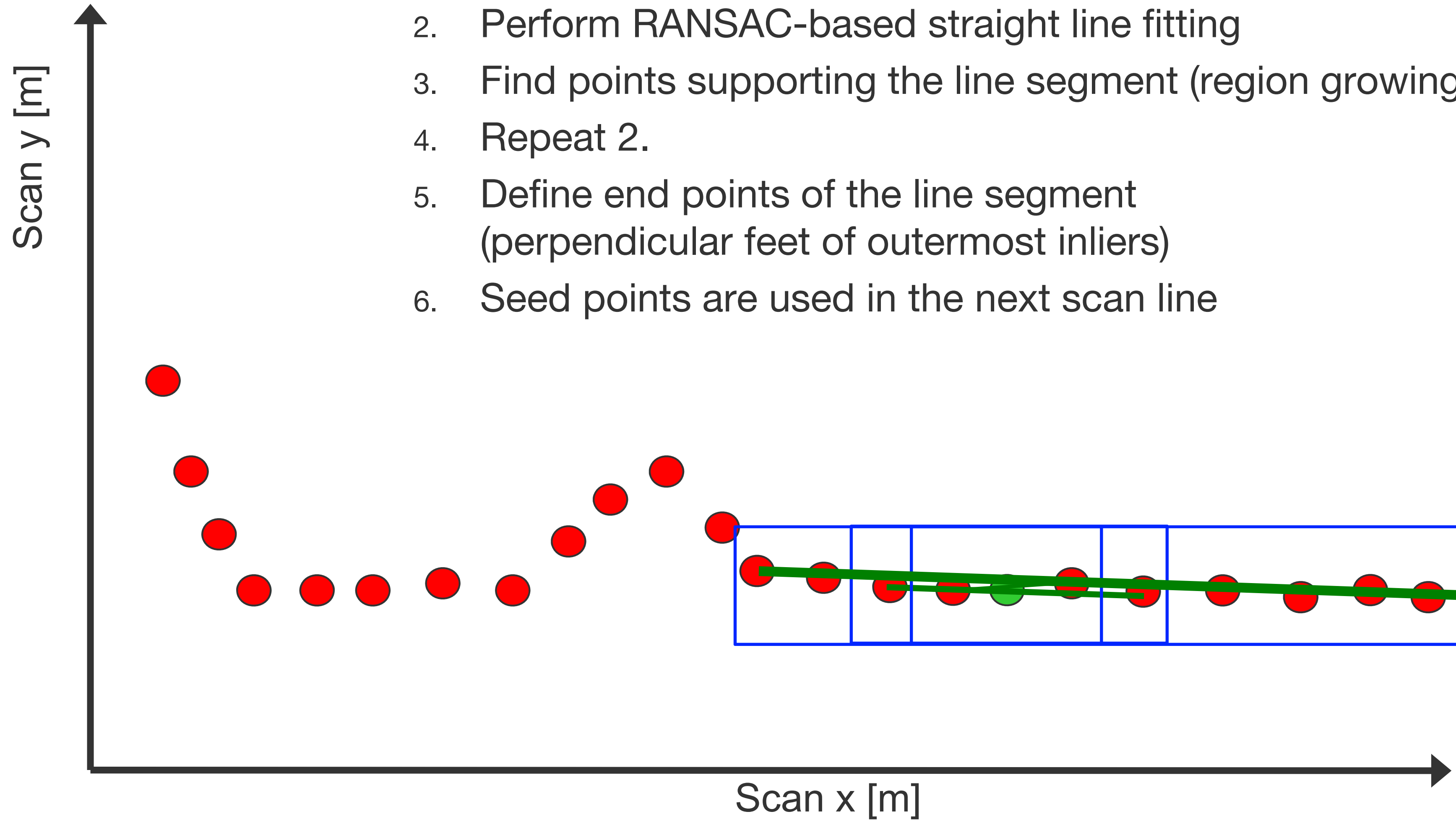
Segmentation of straight line segments

Fischler, M.A., Bolles, R.C., 1981. **Random sample consensus: a paradigm for model fitting with applications to image analysis and automated cartography**. Communications of the ACM 24 (6), pp. 381-395.

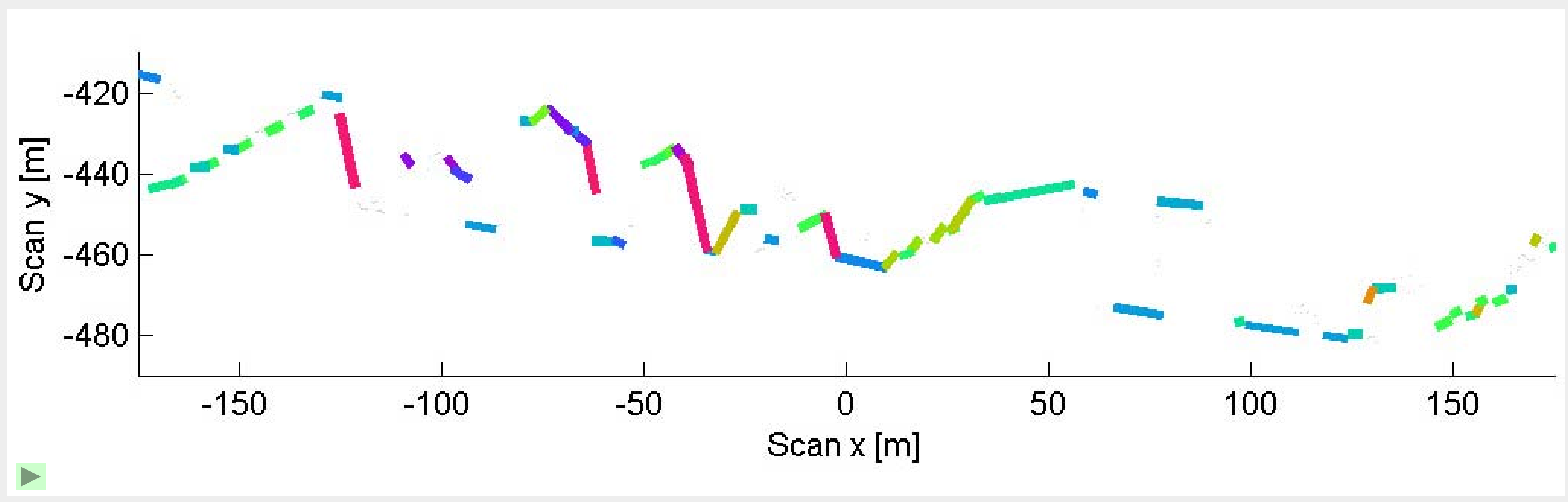


Segmentation of straight line segments

1. Choose position in scan line data
2. Perform RANSAC-based straight line fitting
3. Find points supporting the line segment (region growing)
4. Repeat 2.
5. Define end points of the line segment (perpendicular feet of outermost inliers)
6. Seed points are used in the next scan line

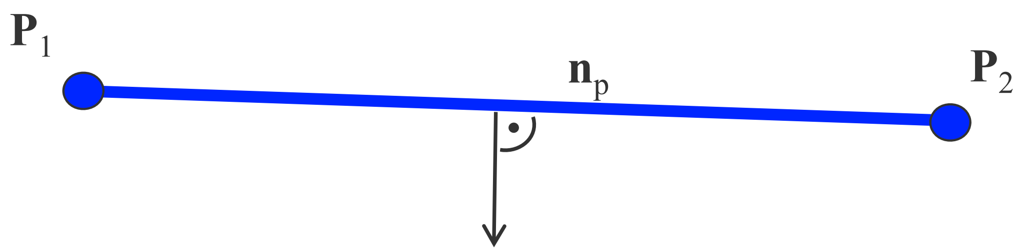


Example: Detected straight line segments

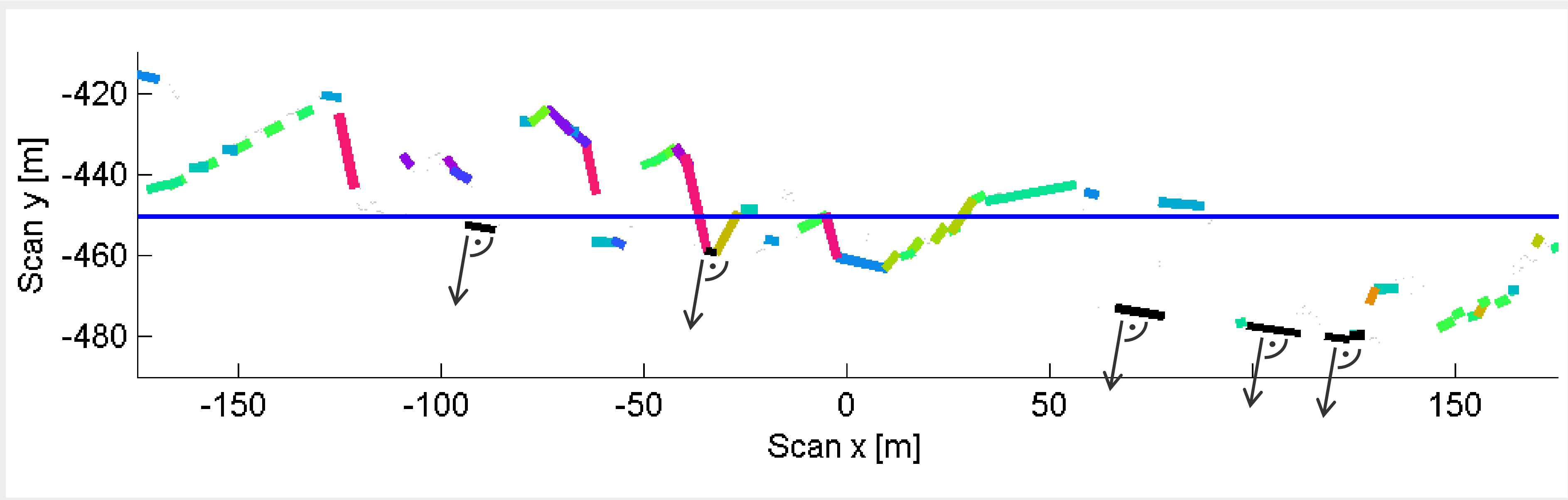


Each line segment:

End points $\mathbf{P}_1$, $\mathbf{P}_2$
2D normal direction $\mathbf{n}_p$

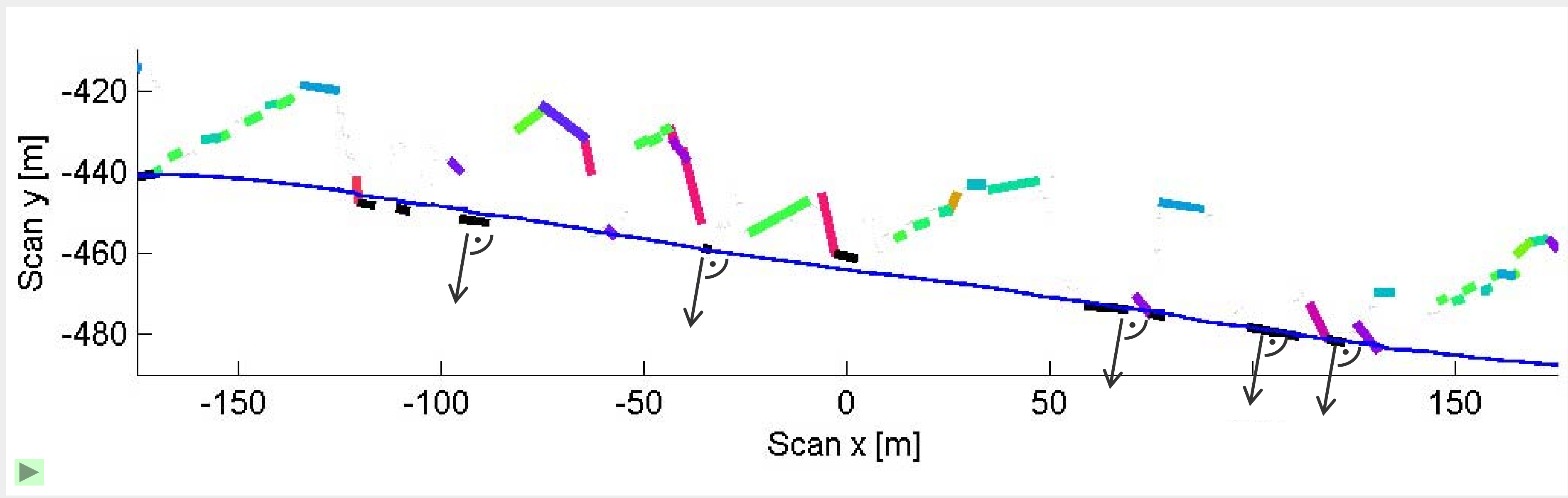


Detection of the ground level



- **Candidates:** No points lying beneath the line segment
- **Ground level** is initialized as average distance to the sensor
- **Candidates contribute** to the estimated ground level
- **Moving average** in time refines ground level
- **Only few initial scan lines** to get a good estimation of the ground level

Detection of the ground level



- **Candidates:** No points lying beneath the line segment
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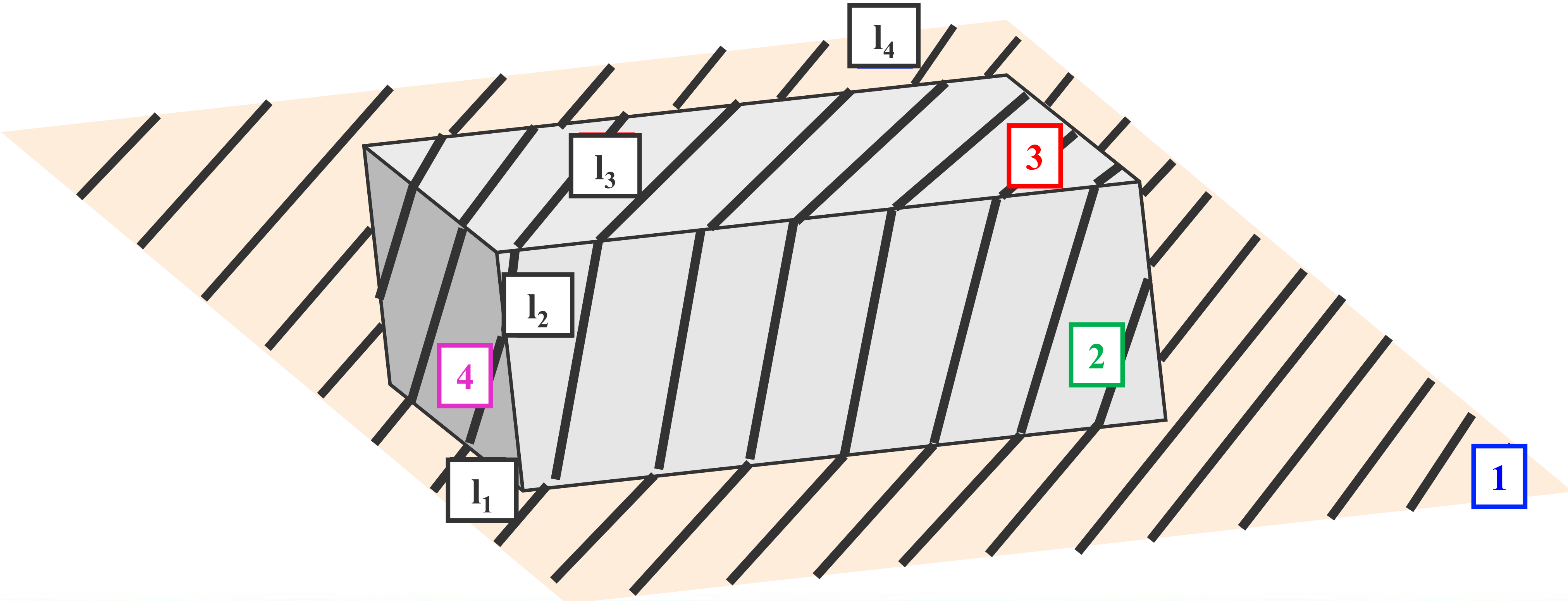
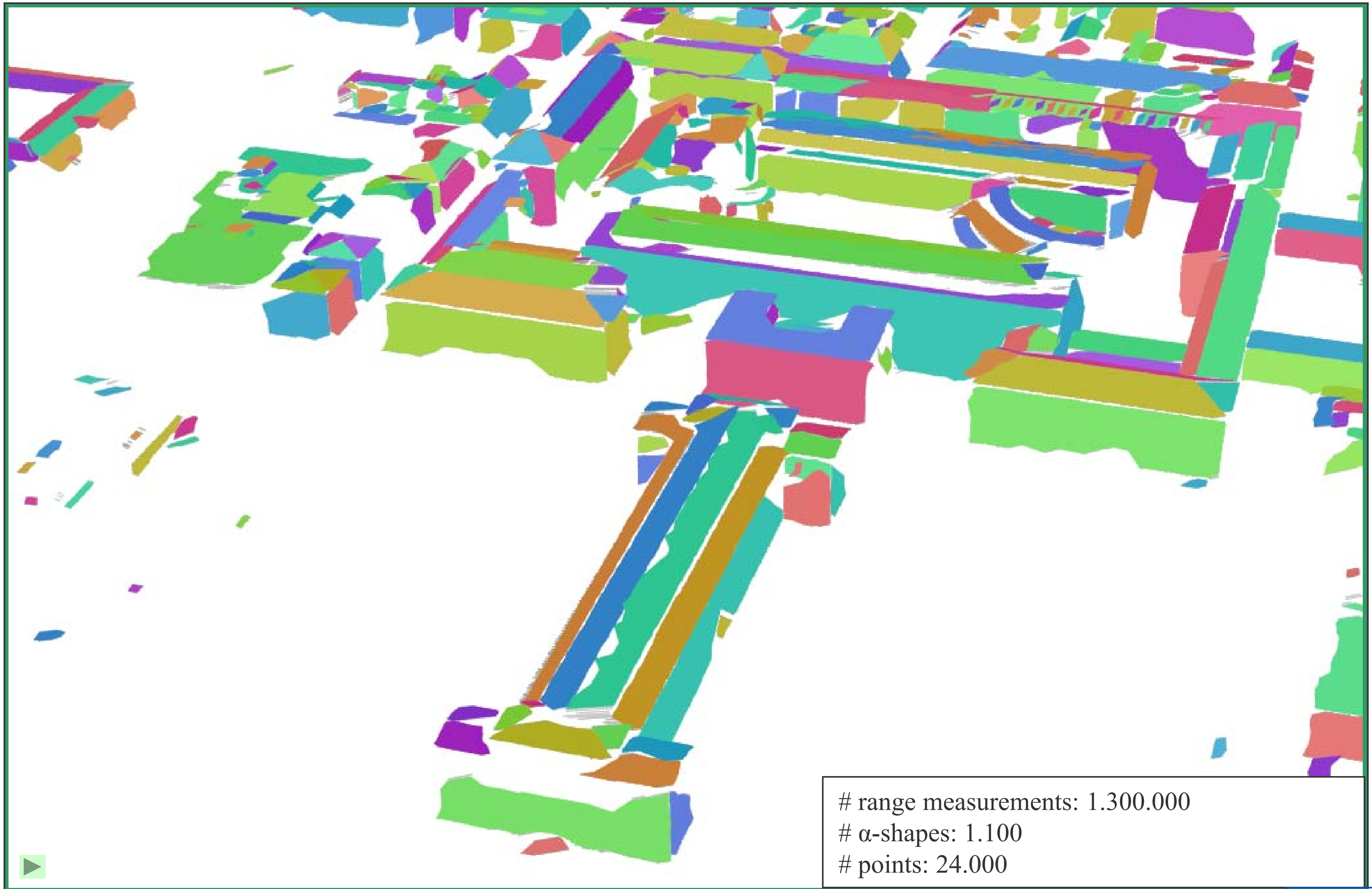
Grouping of line segments over scan lines

- Initialize each new line segment with an increasing unique labeling number
- Check older line segments in the last n (e.g. n=5) scan lines for proximity and coplanarity ($d_3 < \varepsilon_3$, $d_4 < \varepsilon_4$)
- Coplanar line segments are linked (minimum labeling number)
- Repeat until labeling numbers don't change anymore



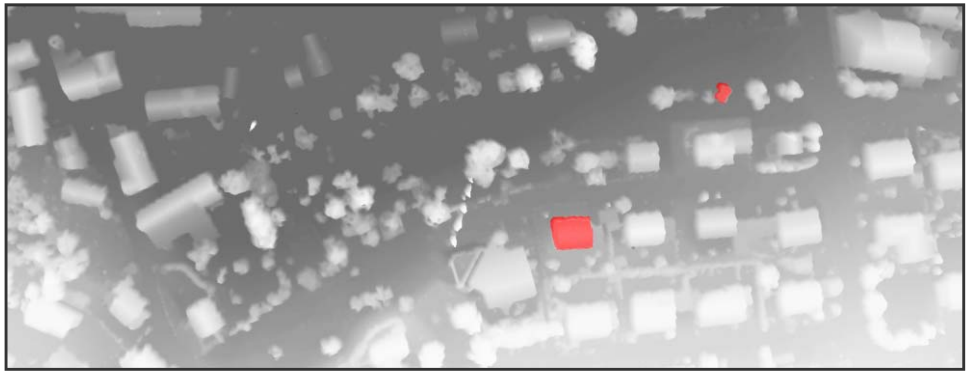
Detected shapes, on-line processing



range measurements: 1.300.000
α-shapes: 1.100
points: 24.000

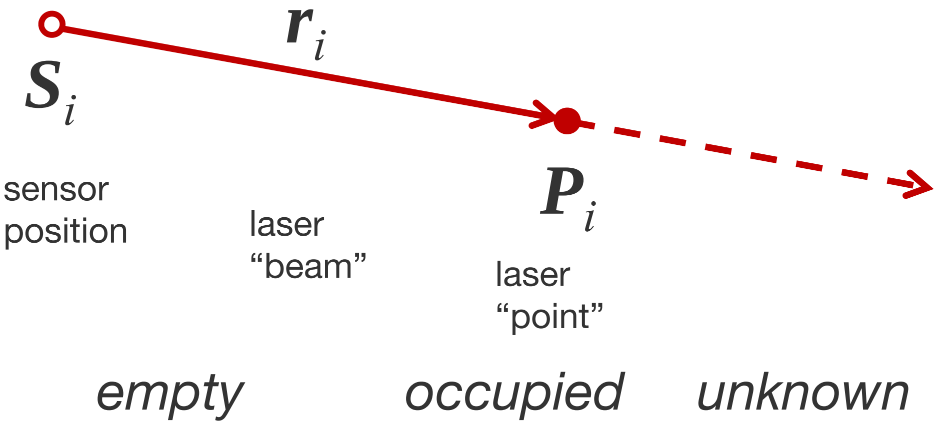
Change detection

❒ Common approach: Comparison (difference) of DSMs



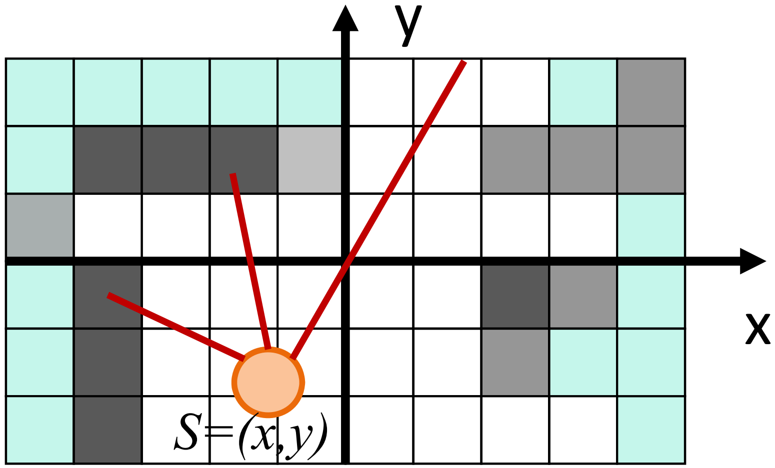
- Interpolation onto 2D grid
- Works best with nadir views (no occlusions)
- e.g., update of maps
- Comparison of point clouds, other information is lost

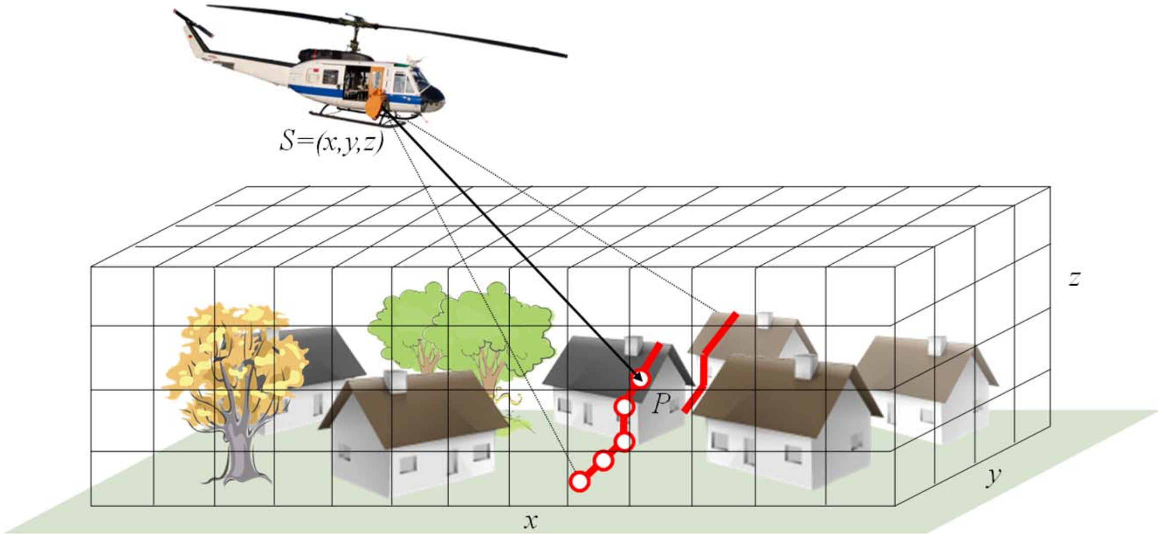
Our method: Analysis of conflicts between **empty** and **occupied** space



- Occlusions and changes are handled implicitly
- Works well with multi-view data
- Evaluation of single range measurements (real-time capable)

Occupancy grids





Well known similar approach:

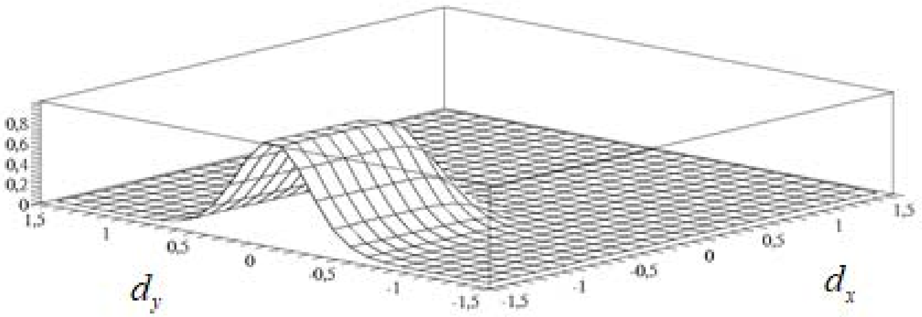
- 2D robot mapping
- Different methods for information fusion:
  - Probabilistic (Bayes)
  - **Dempster-Shafer theory**

Our approach:

- 3D grid used for search operations
- Cell size comparatively wide
- Occupancy evaluated at the position of the laser points (no interpolation)

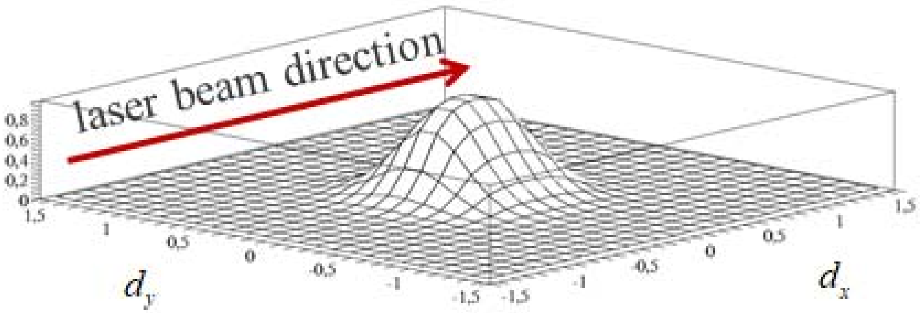
Belief assignment caused by a single laser “beam”

$m_{q,p}(\{emp\})$



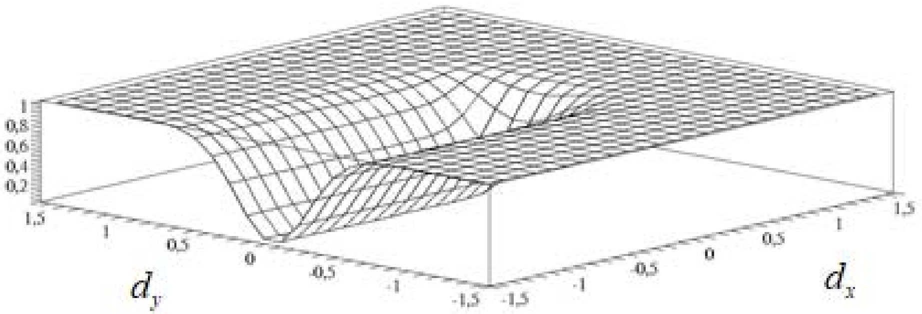
$$\left(1-\frac{1}{1+e^{-\lambda d_x - c}}\right)\cdot e^{-\kappa d_y^2}$$

$m_{q,p}(\{occ\})$



$$\left(\frac{1}{1+e^{-\lambda d_x - c}}-\frac{1}{1+e^{-\lambda d_x + c}}\right)\cdot e^{-\kappa d_y^2}$$

$m_{q,p}(U)$

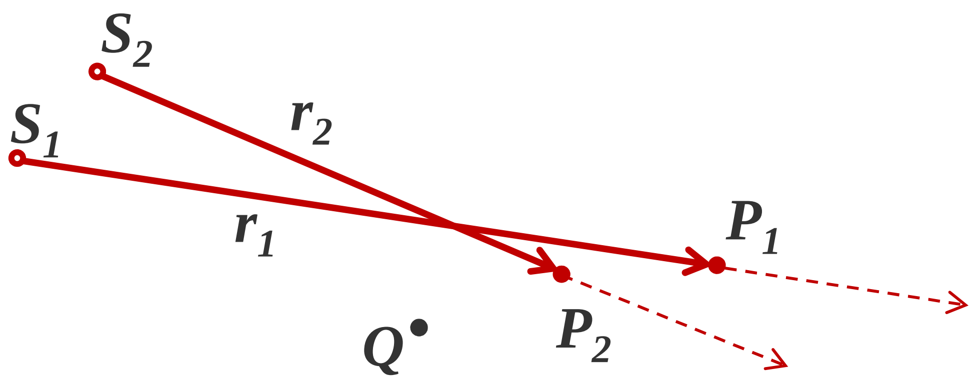


$$1-m_{q,p}(\{emp\})-m_{q,p}(\{occ\})$$

“degree of ignorance”

Parameters (λ, c, κ): laser footprint, point positioning accuracy

Combination of evidence



m_1: belief assignment at Q caused by P_1

m_2: belief assignment at Q caused by P_2

- *Belief masses at a position* $\mathbf{q}$ *caused by laser measurements* $\mathbf{p}_1$ *and* $\mathbf{p}_2$
- *Conflicting evidence:* $C = m_1(emp)\,m_2(occ) + m_1(occ)\,m_2(emp)$
- **Dempster's rule of combination**

$$m(e) = \frac{m_1(e)\,m_2(e) + m_1(e)\,m_2(U) + m_1(U)\,m_2(e)}{1-C}$$

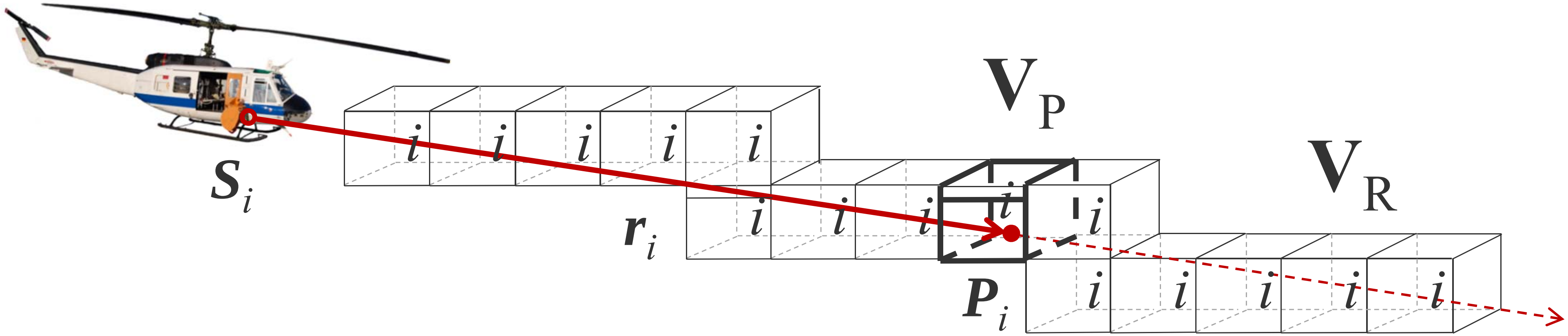
$$m(o) = \frac{m_1(o)\,m_2(o) + m_1(o)\,m_2(U) + m_1(U)\,m_2(o)}{1-C}$$

$$m(U) = \frac{m_1(U)\cdot m_2(U)}{1-C} \qquad m(\varnothing) = 0$$

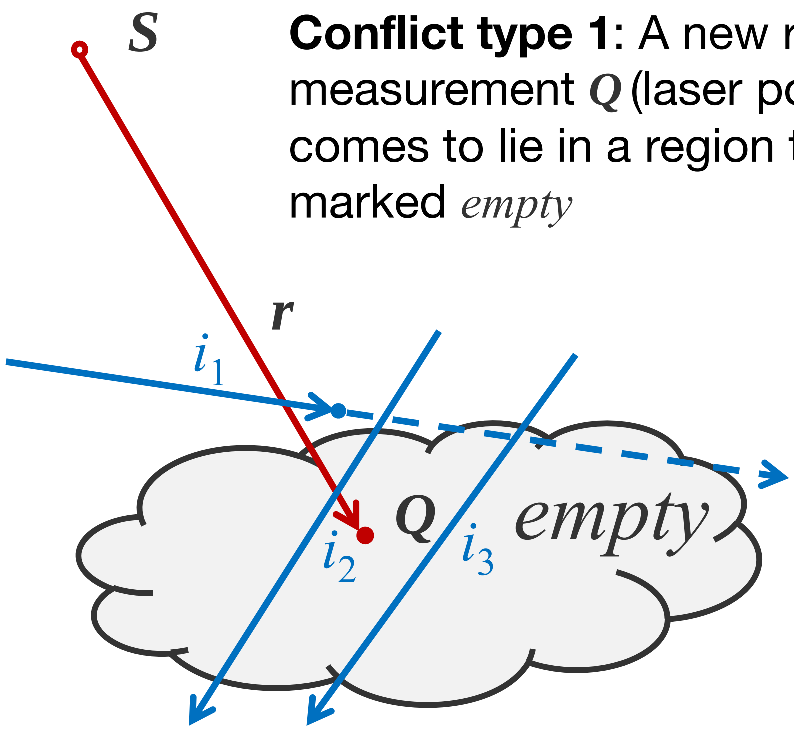
$$m = m_1 \oplus m_2$$

$\oplus$ is commutative and associative

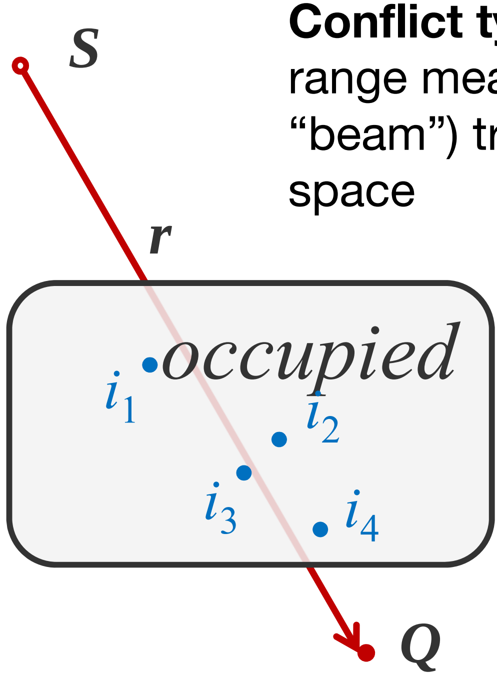
Idea: **Changes** correspond to **conflicting evidence**



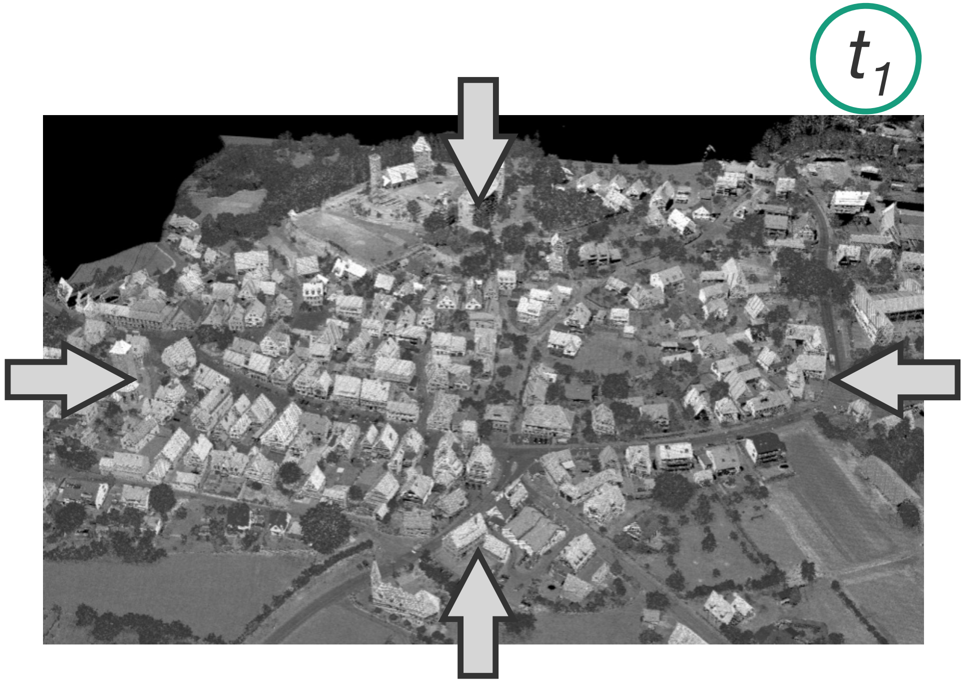
Conflict type 1: A new range measurement Q (laser point) comes to lie in a region that is marked *empty*

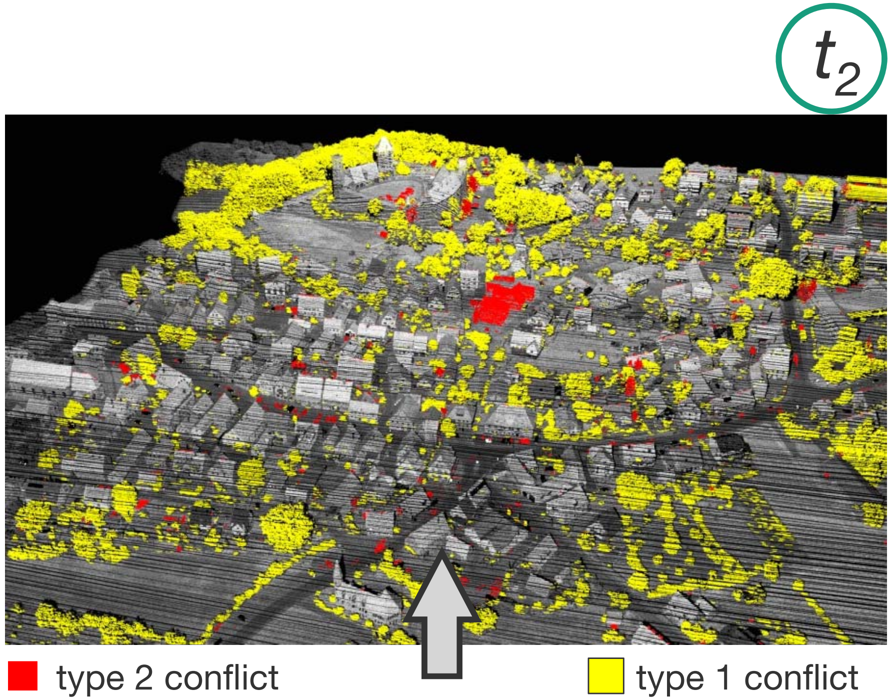


Conflict type 2: A new range measurement Q (laser "beam") traverses *occupied* space



Experiments and results





Abenberg 04/18/2008:

- combination of 4 views / aspects (45° oblique view)
- 5,400,000 points
- 500 x 600 x 90 m
- V_R, V_P cell size 2 x 2 x 2 m³

Abenberg 08/31/2009:

- one strip (south-to-north)
- 1,500,000 points
- type 1 conflicts can be ascribed to seasonal changes (April / August)

[https://www.youtube.com/watch?v=GA2UFRDVyD8]

ALS Flights: Test area abenberg (1)

Testdata find here: [https://www.pf.bgu.tum.de/en/pub/tst.html]

2008

2009

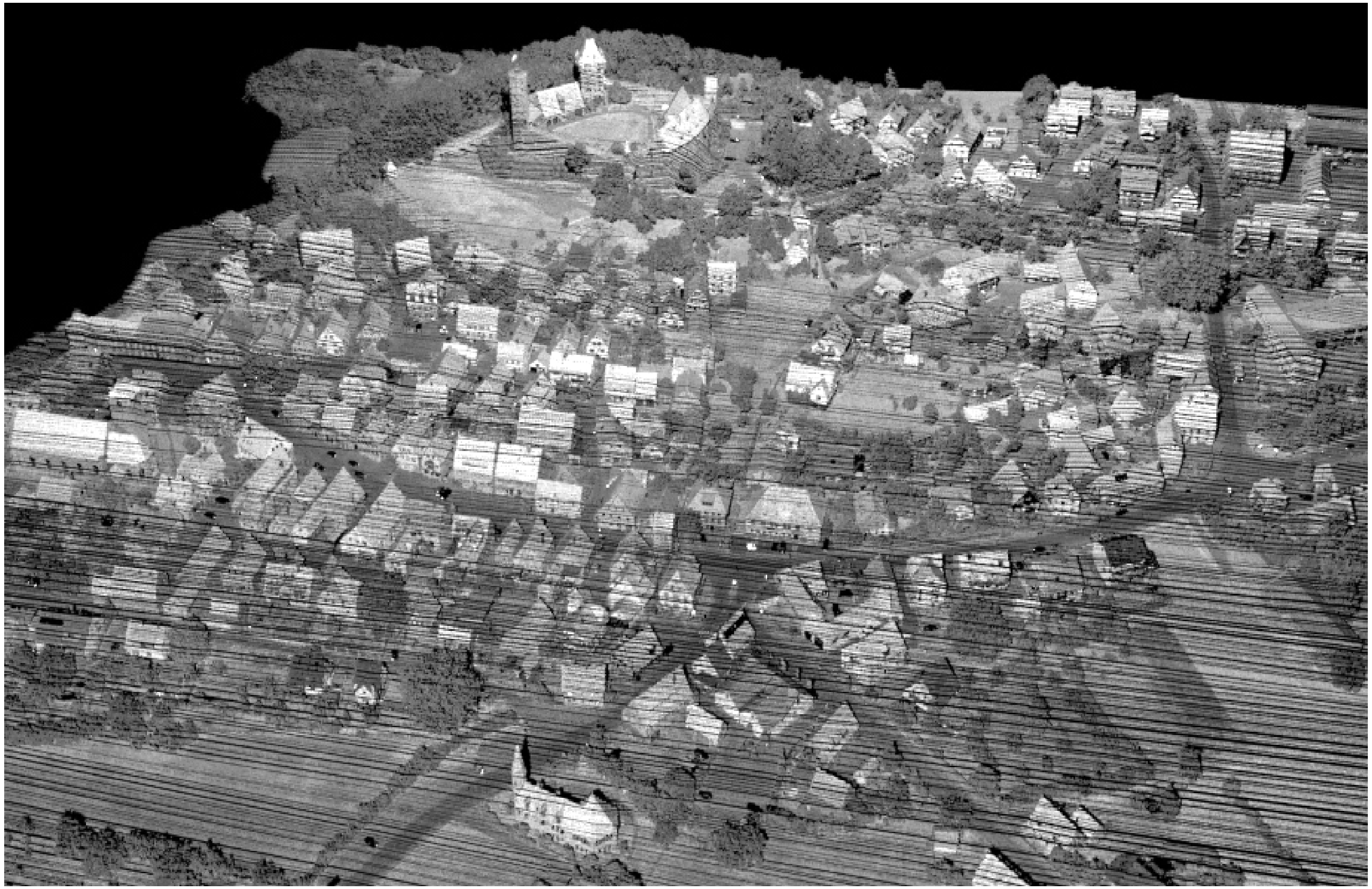
The detecion principle allows an assessment during the flight

[https://www.youtube.com/watch?v=t6npBcHvl3o]

ALS Flights: Test area abenberg (2)

Testdata find here: [https://www.pf.bgu.tum.de/en/pub/tst.html]

2009



The detecion principle allows an assessment during the flight
[https://www.youtube.com/watch?v=t6npBcHvl3o]

ALS Flights: Test area abenberg (3)

Direct comparision

- Typ 1 Conflict
- Typ 2 Conflict
- confirmed planar area
- unchanched ground
- unchanged surface

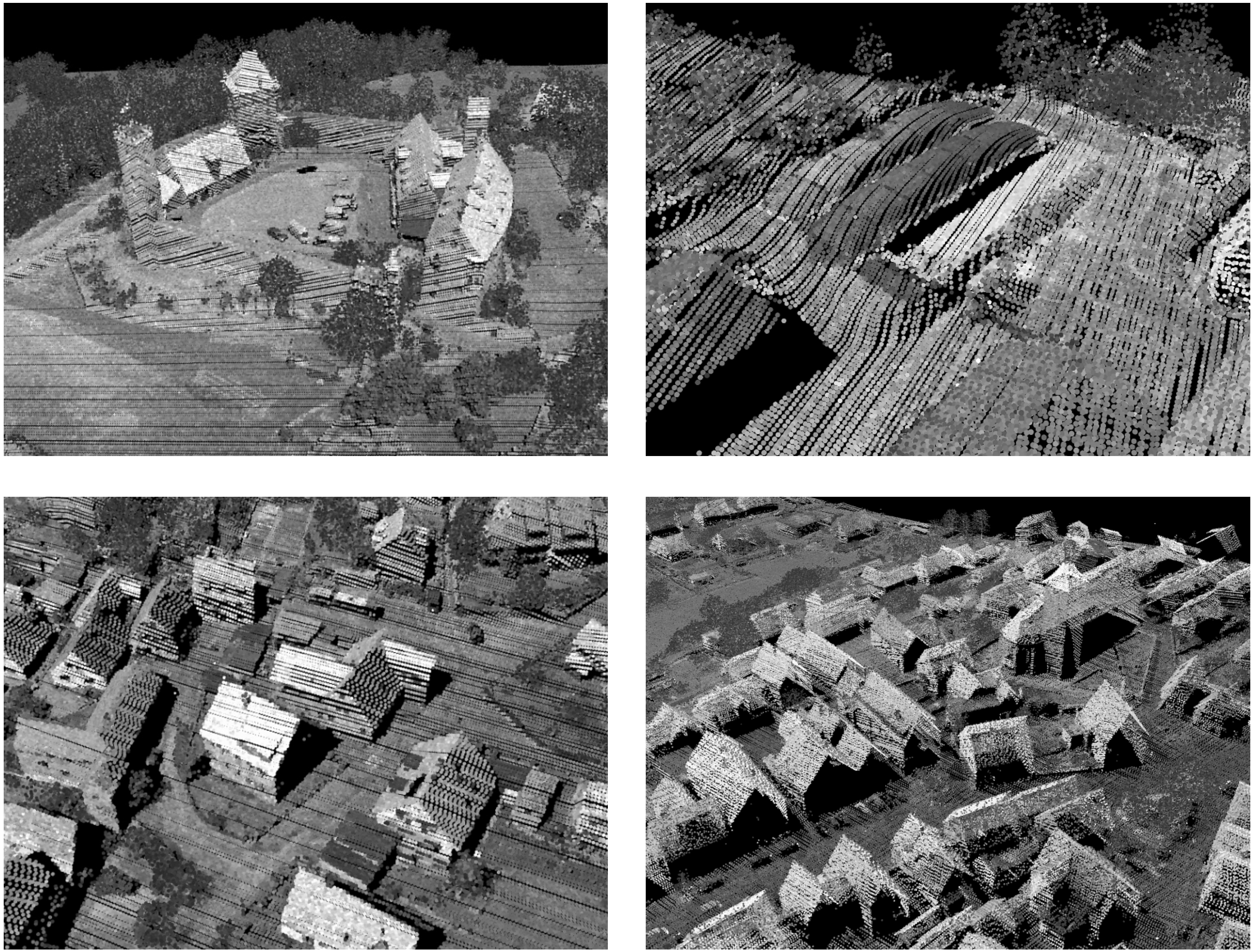
2009

The detecion principle allows an assessment during the flight
[https://www.youtube.com/watch?v=t6npBcHvl3o]

Selected details of the results

2008

- Typ 1 Conflict
- Typ 2 Conflict
- confirmed planar area
- unchanched ground
- unchanged surface
- unveränderte Vegetation



Selected details of the results

2009

- Typ 1 Conflict
- Typ 2 Conflict
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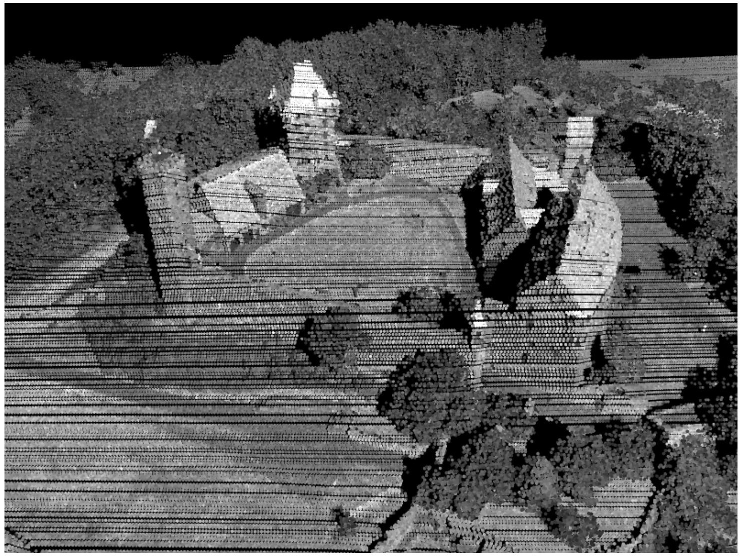
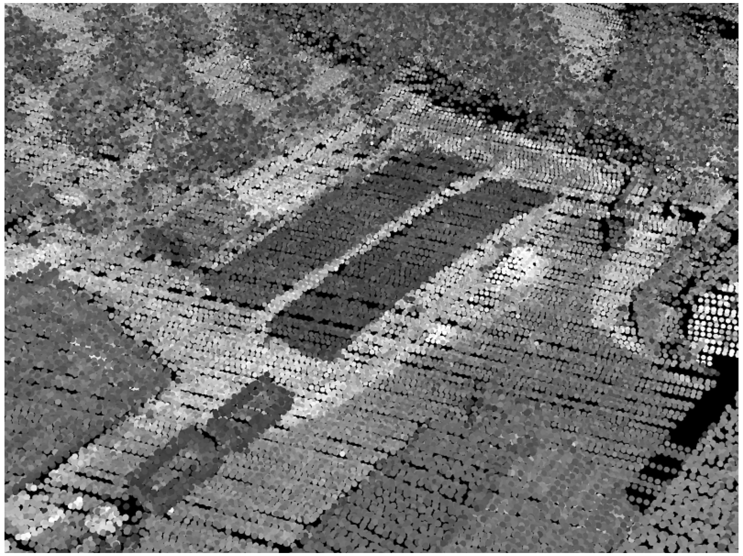
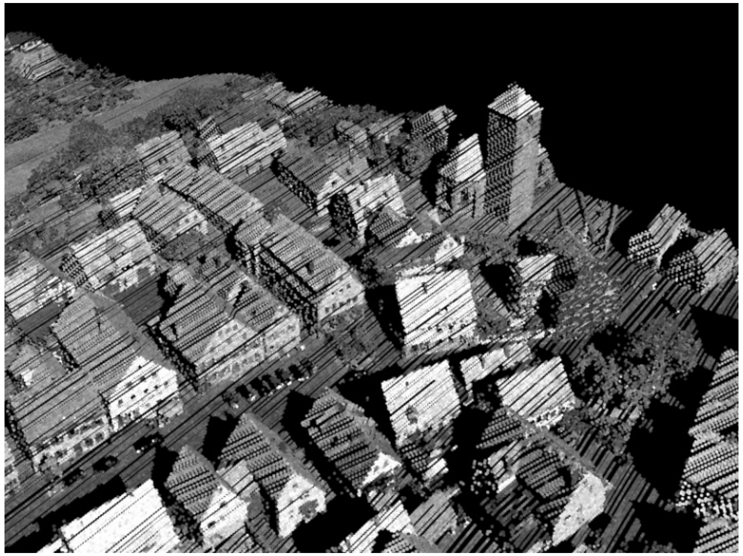


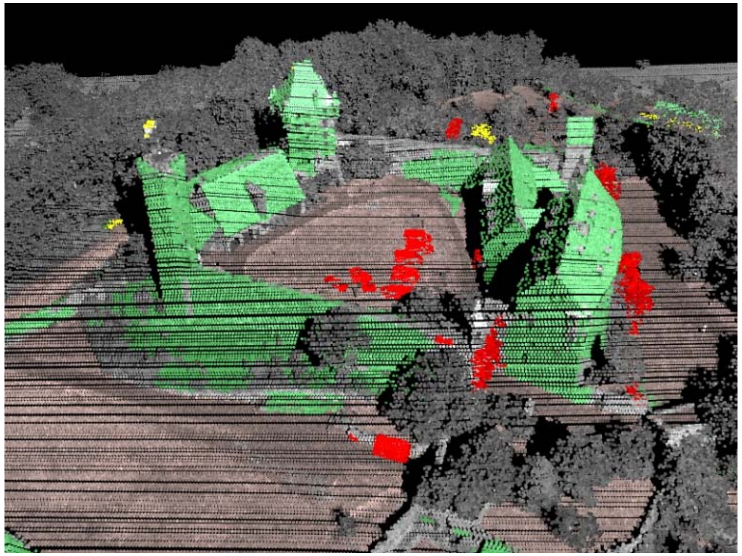


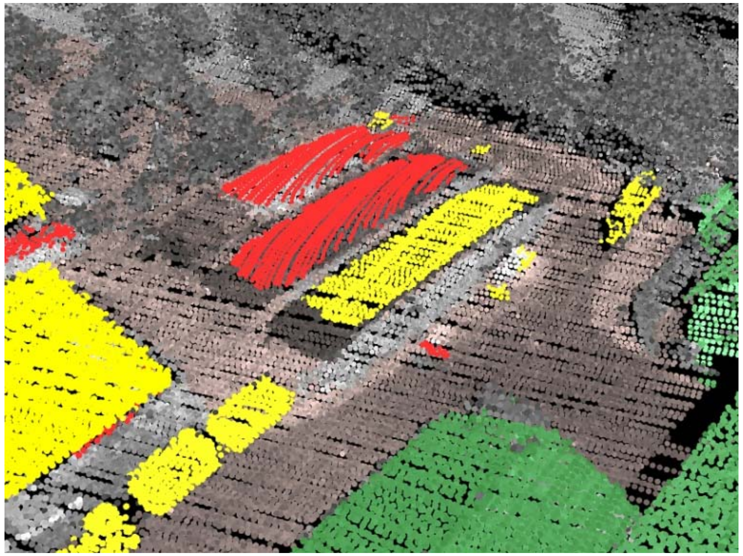


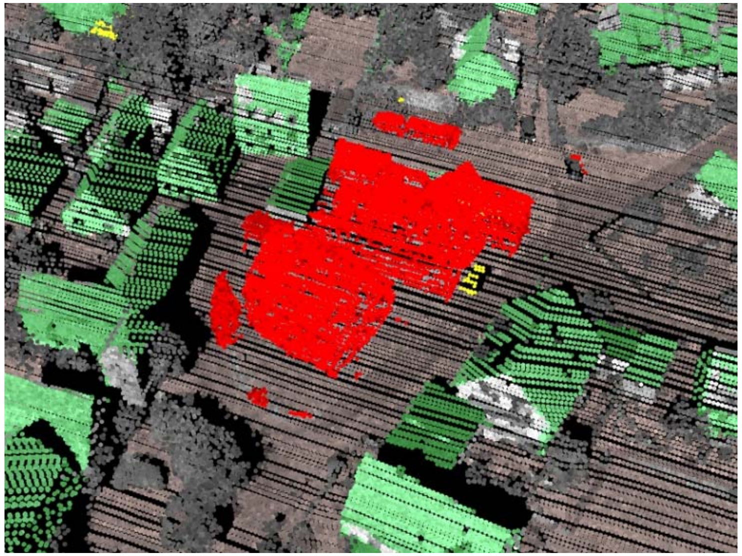
Selected details of the results

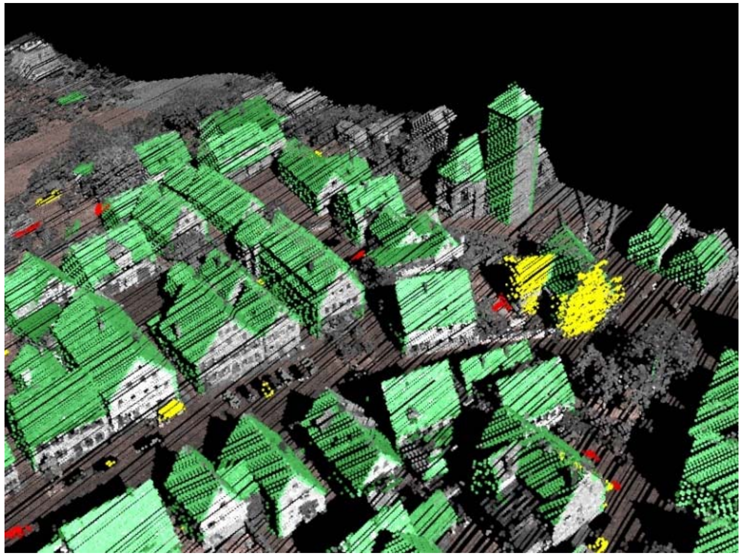
Changes

- Typ 1 Conflict
- Typ 2 Conflict
- confirmed planar area
- unchanched ground
- unchanged surface
- unveränderte Vegetation







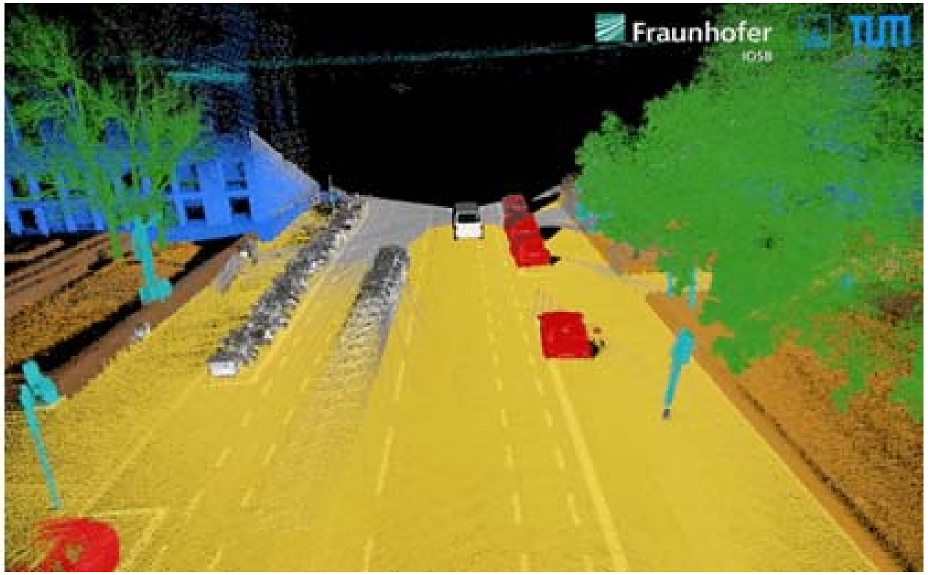


TUM-MLS-2016: An annotated mobile LiDAR dataset

- **Open Access:** Test data set **TUM-MLS-2016** [**https://www.pf.lrg.tum.de/en/pub/tst.html**]

[https://www.pf.lrg.tum.de/img/div/tum_pf_tst_mls_scn1.gif]

Longer version on YouTube:
[https://www.youtube.com/watch?v=JMm54vOqwbY]



[https://www.pf.lrg.tum.de/img/div/tum_pf_tst_mls_lab1.gif]

Longer version on YouTube:
[https://www.youtube.com/watch?v=vUvrfQYeCZg]

Description of the test dataset **TUM-MLS-2016** :

- Zhu J, Gehrung J, Huang R, Borgmann B, Sun Z, Hoegner L, Hebel M, Xu Y, Stilla U (2020) TUM-MLS-2016: An annotated mobile LiDAR dataset of the TUM city campus for semantic point-cloud interpretation in urban areas. Remote Sensing, 12(11): 1875 [https://doi.org/10.3390/rs12111875]

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Reference list with links to papers → [https://www.pf.lrg.tum.de/sta/stilla/pub.html]

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