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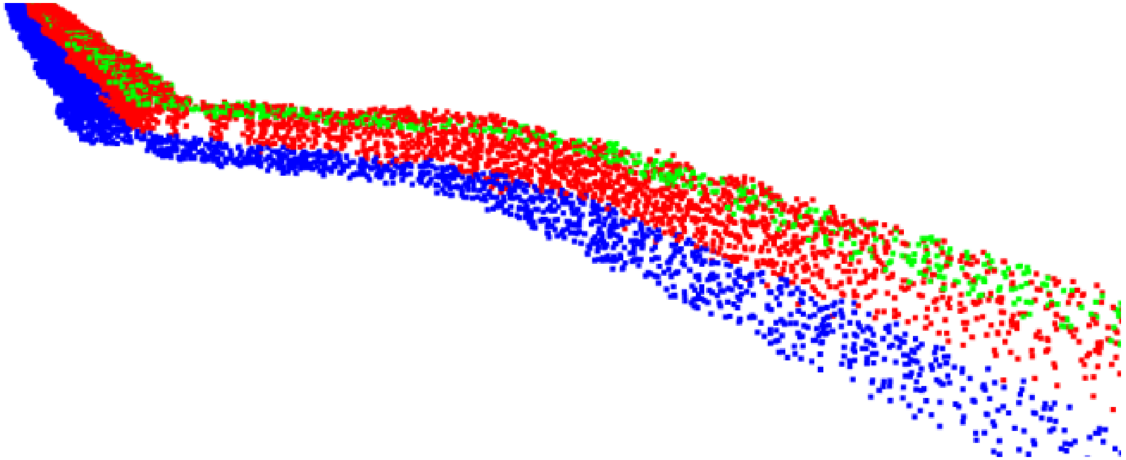

Bordsteinerkennung und Höhenbestimmung in 3D LiDAR-Daten mittels eines mobilen Kartierungssystems

Oldenburger 3D-Tage 2024

Oldenburg, 31. Januar 2024

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Content

What is the issue?

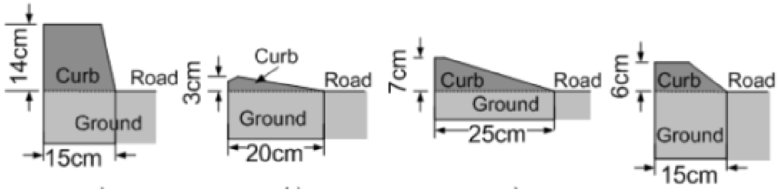

Figure 1: Curbs [Romero et al. 2021]

Curbs …

- separate the roadway from adjacent sidewalks
- directly affects accessibility and safety [Matthews et al. 2003, Sieger et al. 2008]

- ➢ different user groups with conflicting interests
- ➢ curb information is cruicial and could serve as data for **barrier-free person navigation** [Sobek & Miller, 2006, Kasemsuppakorn & Karimi 2009]

Research gap …

- lack of flexible mapping solution
- lack of curb (height) data

Point Cloud Acqusition – Sensor OS1-128

Data acquisition should be flexible, simple and accurate …

- **UAV** needs flight planing and permits are required
- **TLS** has low frequeny and static position
- **high frequency LiDAR** mounted to a helmet to provide cost-effective mobile mapping

Figure 2: Mounted OS1-128 sensor

Feature	Value
Channels	128
Points per line	1024
Frequency	20 Hz
VFov	45 degree
HFov	360 degree

Precision	Range accuracy
0.3 -1 [m]: ±0.7 [cm]	±3 [cm] for lambertian targets
1 - 20 [m]: ±1.0 [cm]	±10 [cm] for reflectors
20 - 50 [m] ±2 [cm]	
50 [m]: ±5 [cm]	

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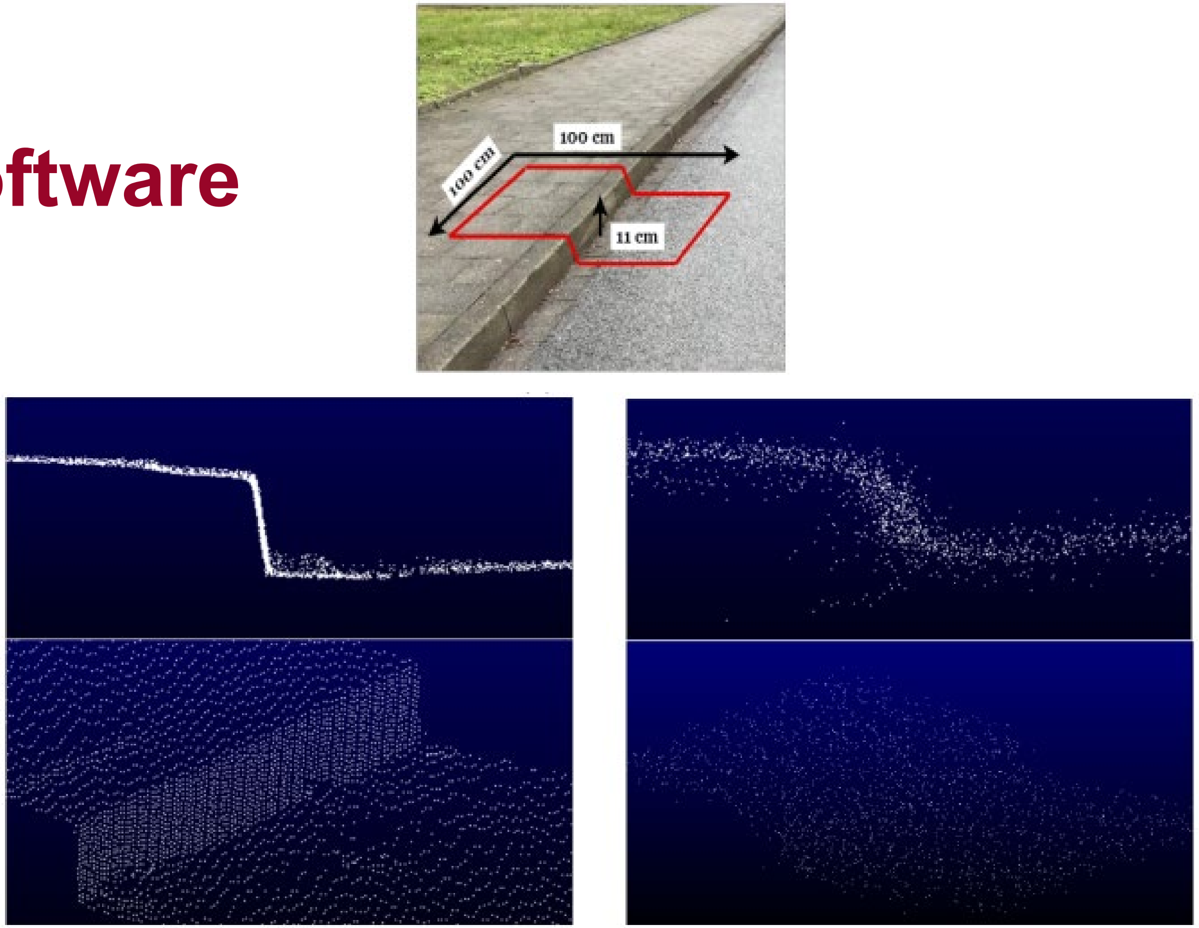
Point Cloud Acqusition - Software

- Co-registration performed by **HATSDF SLAM** from autonomous robotics group (in ROS) [Eisoldt et al. 2022, Gaal 2022]
  - Initial estimate agents trajectory with TSDF
  - Post-registration using VGICP

- LiDAR data processing in Open3D and Python



(b) RIEGL TLS

(c) HATSDF SLAM and OS1-128

Figure 3: Qualitative comparison

Related Work

- Two decades of research
- Multi-stage algorithms or pipelines

Sensor →
- LiDAR
  - 2D, 3D
- Camera

Preprocessing →
- Noise removal
- Ground segmentation

Candidate Points →
- Regions likely to contain curbs

Features
- Height steps
- Normal orientation
- Hough Transform
- Ring Compression

Methodology

Concept …

- Based on Belton and Bae's idea
  [Belton and Bae 2010]
- Differences in point density, accuracy and alignment of the coordinate system

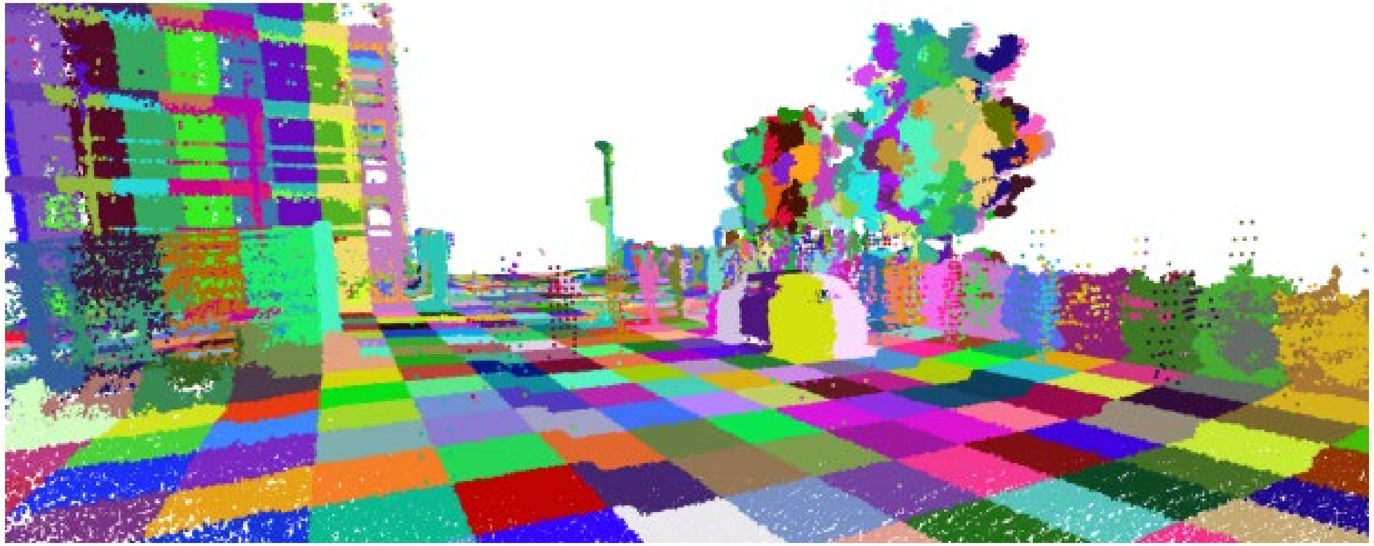
➢ adapt and expand method using different techniques

1. Point cloud organization
2. Filter for ground and non-ground
3. Region growing and finding road region
4. Edge detection to find regions likely to contain curbs
5. Curb detection and height estimation

Methodology - Organization

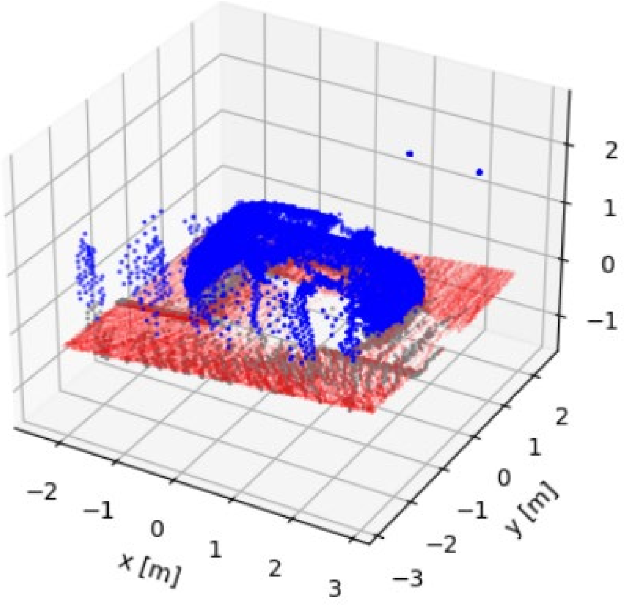
- Primarily horizontal 2D relationship
- Point-based gridding to deal with 3D data in 2D space
- Access through sorted indexing

$$grid\_num\_x_i = \frac{x_i - mod(x_i, s)}{s}$$
$$grid\_num\_y_i = \frac{y_i - mod(y_i, s)}{s} \quad (4.1)$$

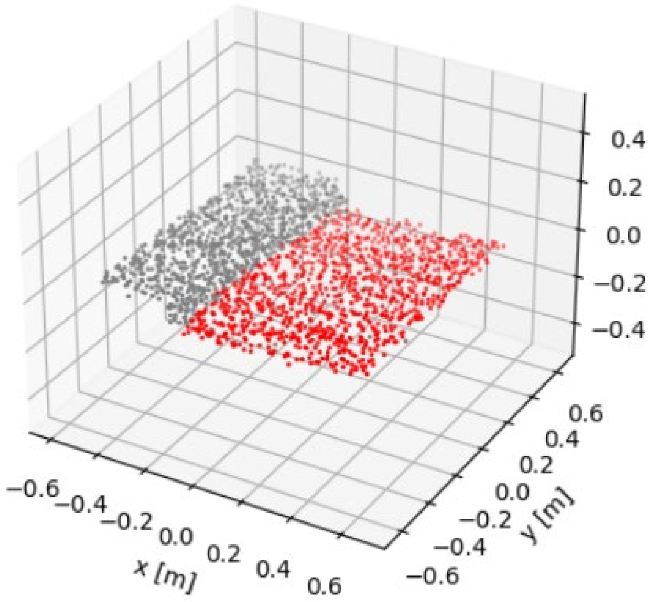


Methodology – Ground segmentation

- Segment into ground and non-ground to get rid of obstacles
- Cellwise roughly selection of lower points
- Plane-based fitting using RANSAC with tight distance threshold



(a)

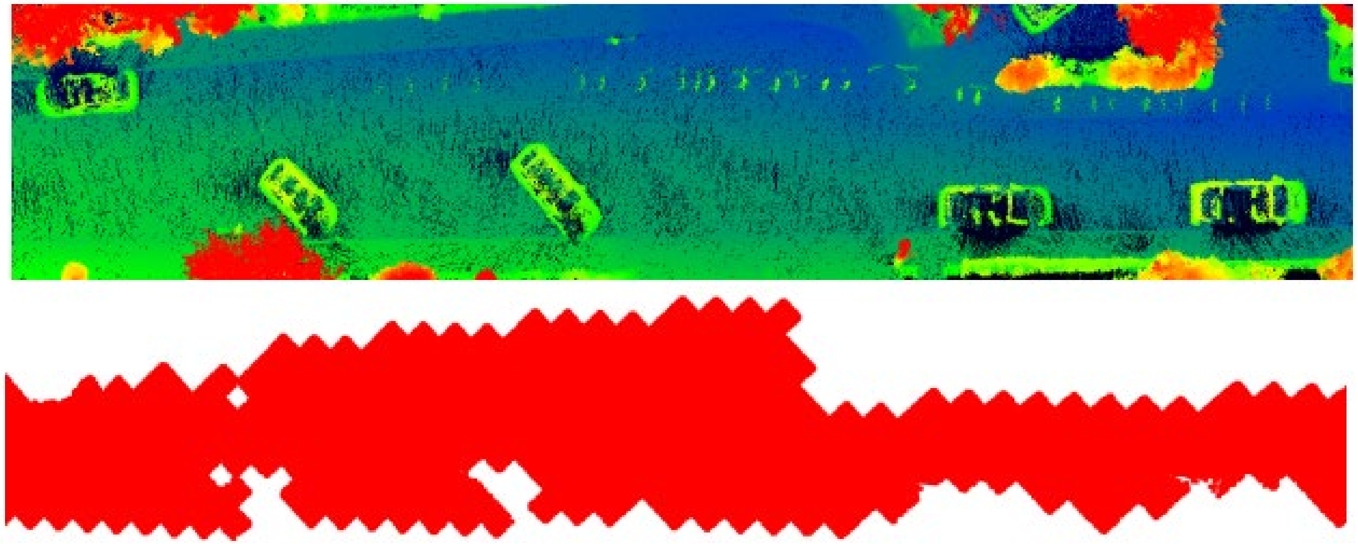


(b)

Methodology – Road detection

- Simple region growing algorithm compares the alignment of ground points with respect to adjacent cells
- **Criteria**: similar normal directions and nominally alignment of ground points
- Selecting biggest region

$$r_j = (\mu_j - \mu_i) \bullet \vec{n_i}$$
$$r_i = (\mu_i - \mu_j) \bullet \vec{n_j}$$



Methodology – Road detection

- Label ground points in road cells as road
- All cells that are not marked as a road but are adjacent to at least one road cell are examined with respect to the properties of the ground points in adjacent road cells

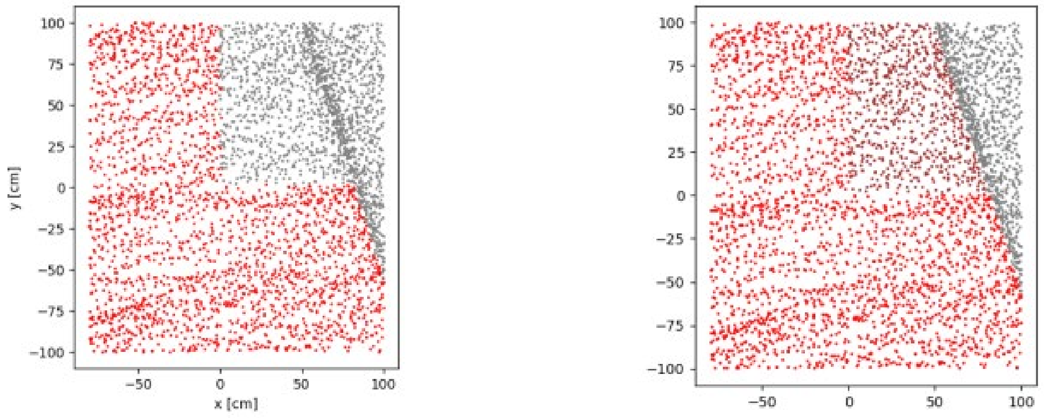


Figure 12: Refine road cellwise

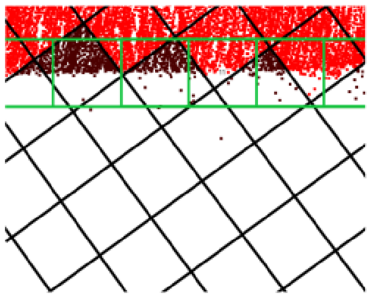
Figure 13: Road points

Methodology – Candidate Points

- Regions that are likely to contain points sampled from a curb → road boundary

- Exact boundary → fewer disturbing obstacles → minimizes errors

- 3D boundary detection is difficult
  - transfer into binary image
  - canny edge detection
  - transfer back into 3D coordinates



(c) Best case selection

Figure 14: Candidate region selection

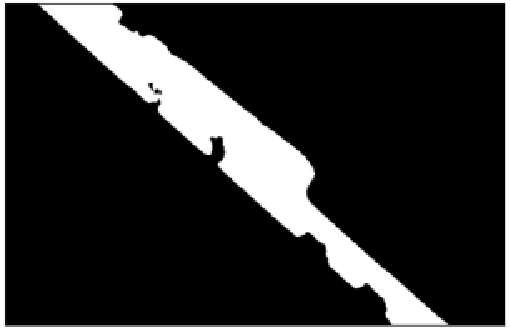


Figure 15: Binary image

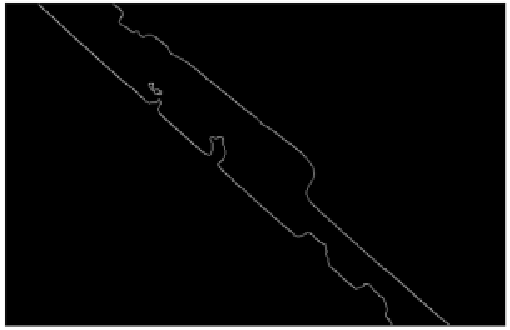


Figure 16: Canny edge detection

Figure 17: Candidate regions

Methodology – Curb detection and height estim.

- Find plane that bisect curb
- Select points along plane
- Project them into 2D cross section

- Not working with oblique cells
- ➢ Align cells that road points become parallel to world xy-plane

- Height measurement in 2D CS

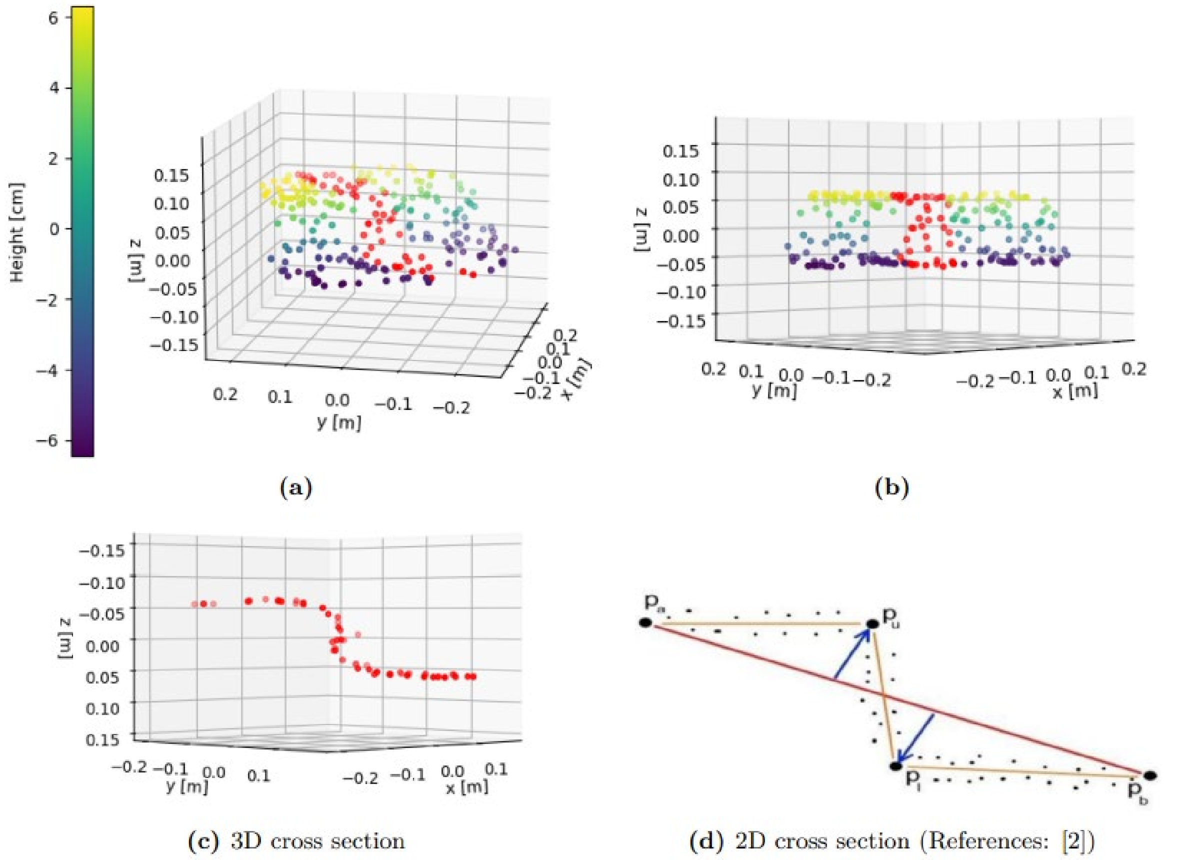


Figure 18: 3D and 2D cross-sections

Methodology – Curb detection and height estim.

- Since this procedure was developed for high-precision terrestrial lidar data in [2], the procedure seems to be too complex for the noisy lidar data and the application in this thesis
- **Alternative**: height estimation trough the average of the z-values of the street points and the average of the z-values of the sidewalk points inside each radius-buffer

$$h = \bar{z}_{sidewalk} - \bar{z}_{road}$$

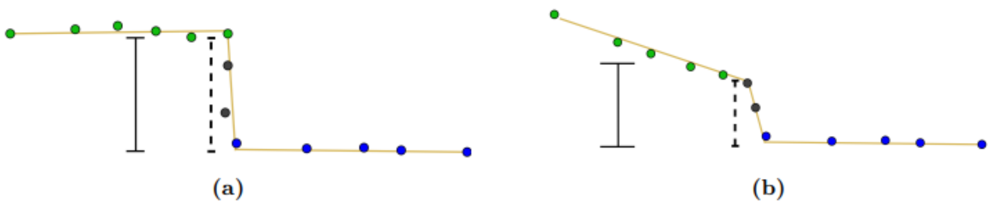


Figure 19: Proposed height estimation

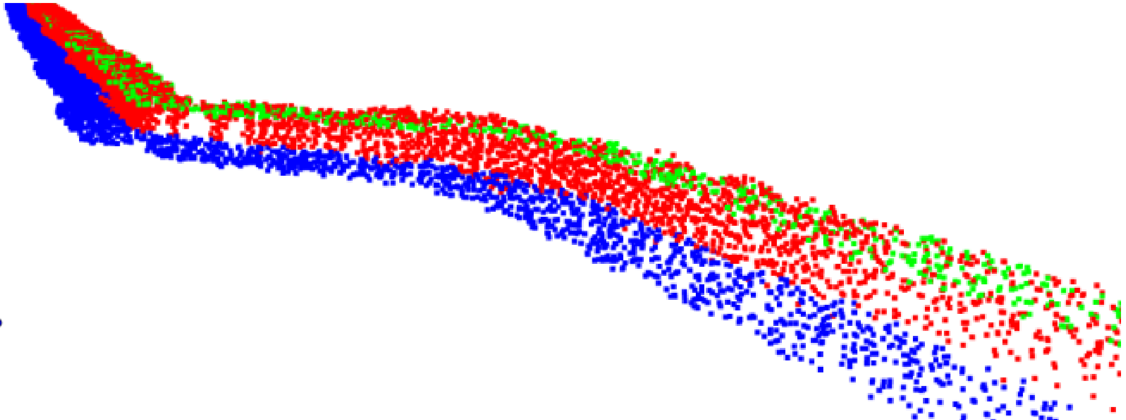


Figure 20: Classified Point Cloud

Experimental Setup – Ground Truth Data

Figure 21: Field Instrument

Data covers …

- >3000m curb (flat to high, different profiles, conditions, textures)
- asphalt, paving-stones, cobblestone
- horizontal and inclined roads
- different road and sidewalk sizes
- Front gardens and vegetation adjacent to road
- Moving pedestrians or cars, static obstacles like parked cars

Ground Truth

- digitalized polylines in recorded point cloud
- height measurements in field

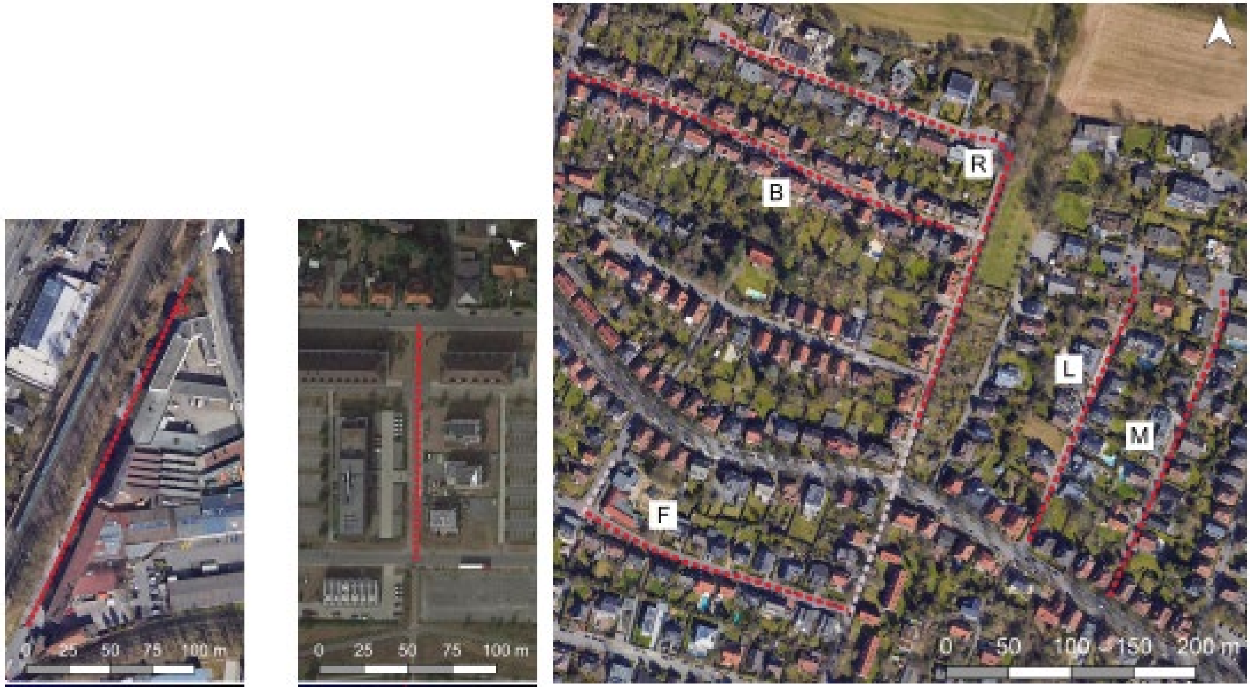


Figure 22: Research area

Experimental Setup – Accuracy Assessment

Metrics for curb detection

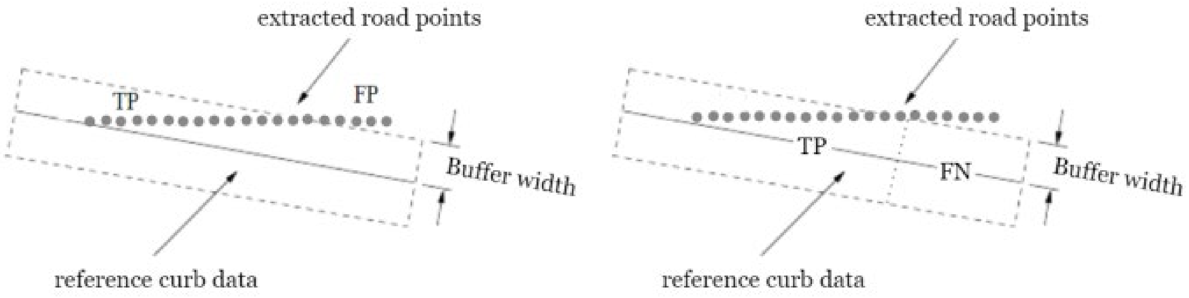


Figure 23: Matching principle (modified, Heipke et al. 1997)

$$correctness = \frac{number\ of\ matched\ curbpoints}{number\ of\ curbpoints} = \frac{TP}{TP + FP}$$

$$correctness \in [0;1]$$

$$completeness = \frac{length\ of\ matched\ reference}{length\ of\ reference} = \frac{TP}{TP + FN}$$

$$completeness \in [0;1]$$

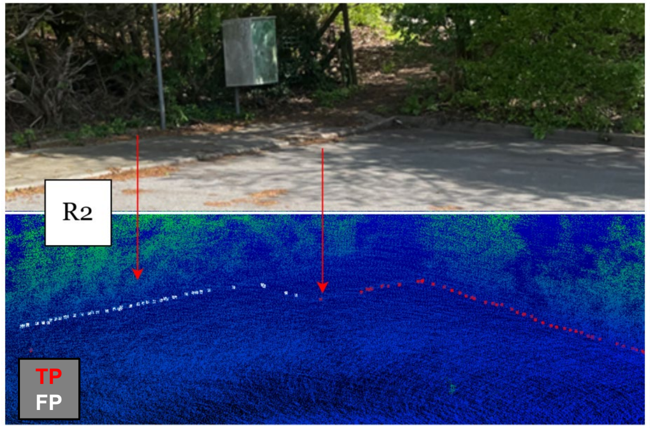
Metric for height estimation (categories)

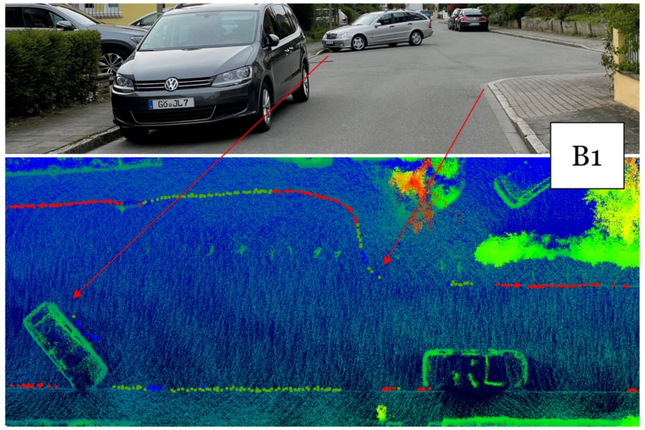
- < 3 cm low
- 3-7 cm medium
- 7-15 cm high

$$correctness\ of\ height = \frac{number\ of\ correct\ estimated\ height\text{-}categorie}{number\ of\ estimated\ height\text{-}categorie}$$

Results – Curb detection

- Adjacent front garden, hedges, vegetation,
- Curved roads and dynamic pedestrians
- Different curb heights, profiles and unevenness





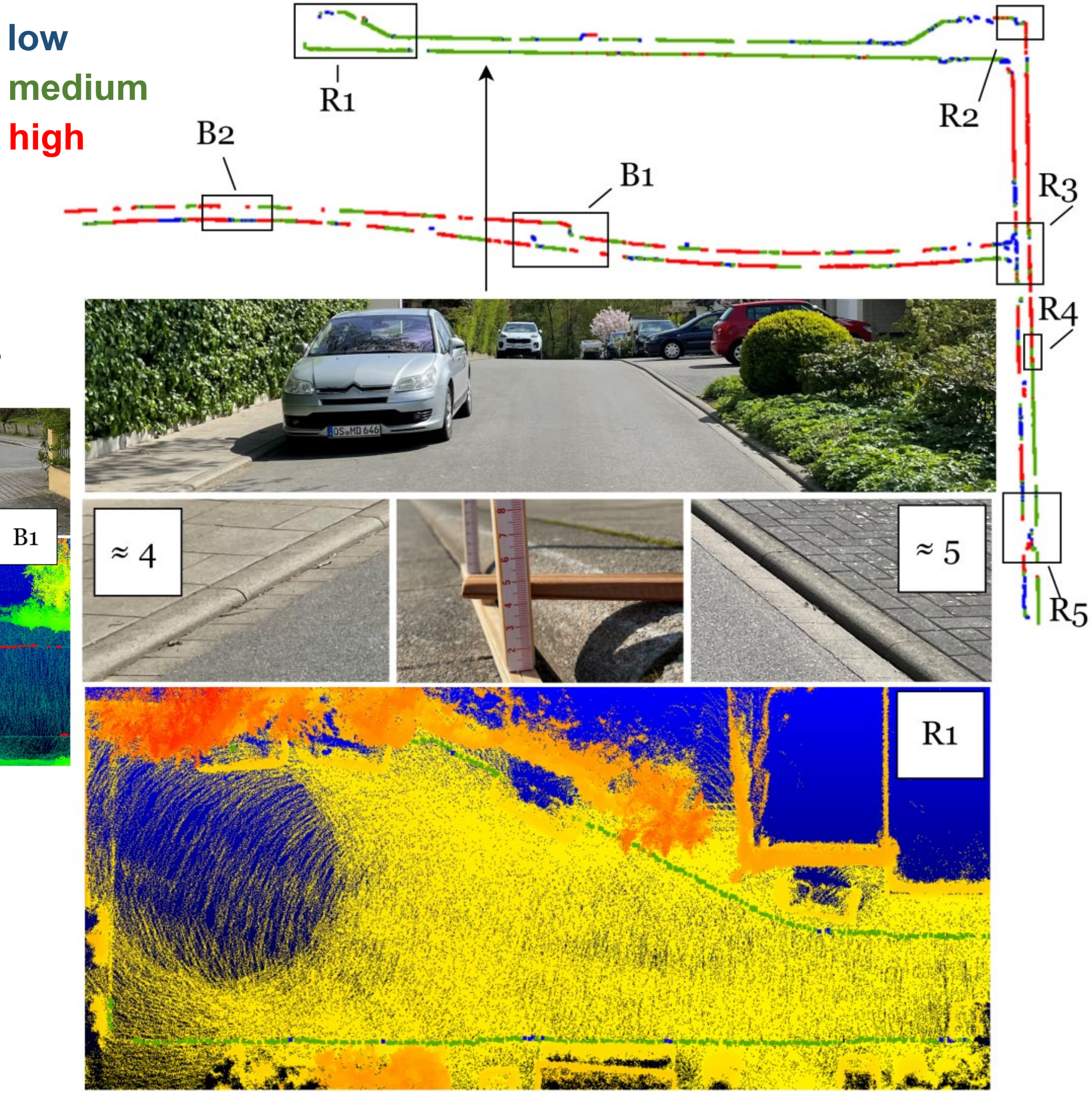


Figure 24: Results for proposed curb detection and height estimation

Results – Curb detection

- Uneven road surface
- Parked cars on sidewalk and on the road

low
medium
high

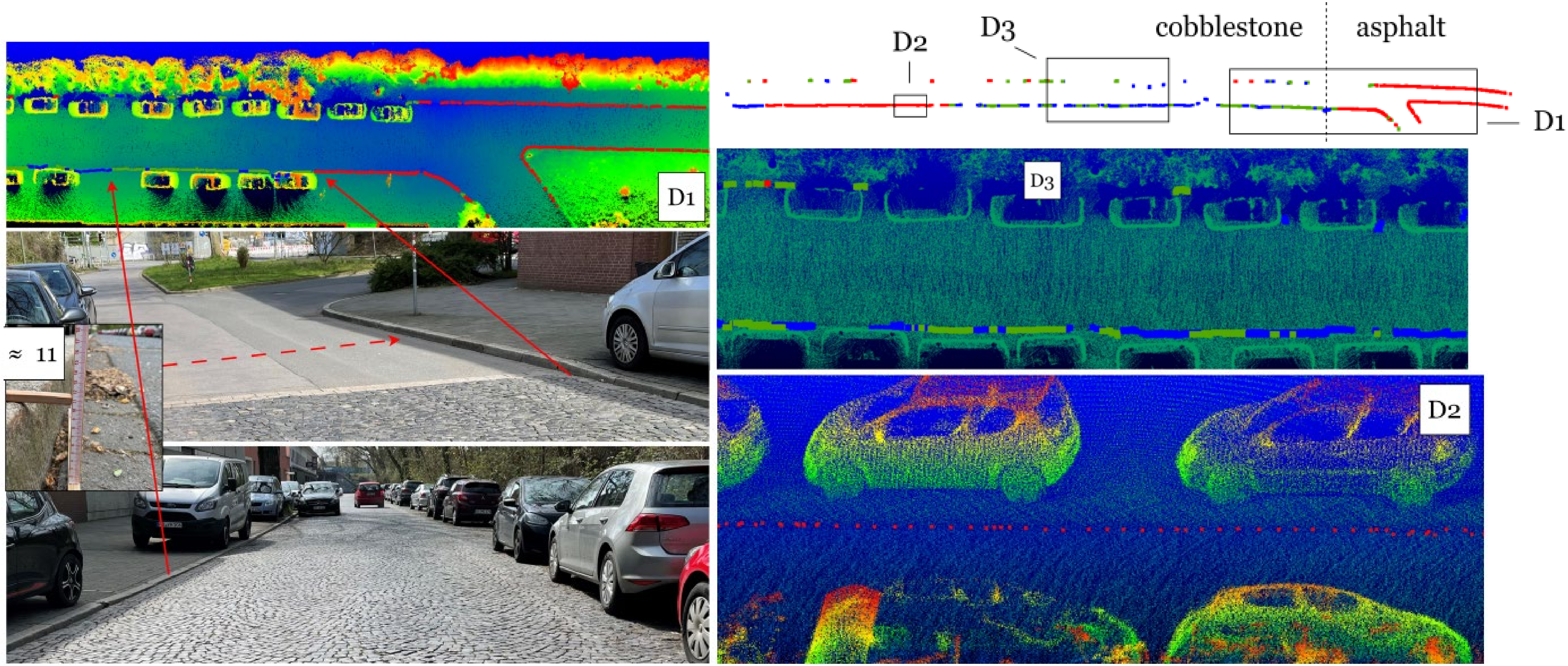


Figure 25: Results for proposed curb detection and height estimation

Results – Curb detection

	Completeness [%]	Correctness [%]	Description
Richardstraussweg	**89.19**	**92.45**	Mostly >8 cm
Beethovenstraße	92.54	97.97	Rough, uneven curbs and sidewalks
Mendelssohnweg	93.65	**98.91**	Up to 9% slope, several cars
Loeweweg	93.35	97.71	Up to 5% slope
Dammstraße	89.98	95.78	Rough, cobblestone, filled with cars
Flohrstraße	**96.26**	96.38	Frontgardens, hedges, walls, 20 cm sidewalk strip
Winkelhausenstraße	94.72	94.79	New construction, smooth, constant
Mean	**> 92%**	**> 96%**	

Table 2: Accuracy of proposed curb detection

Results – Height estimation

- High curb category | 98 % (both methods)
- Ideal, smooth surfaces and wide sidewalk with clear height differences

low
medium
high

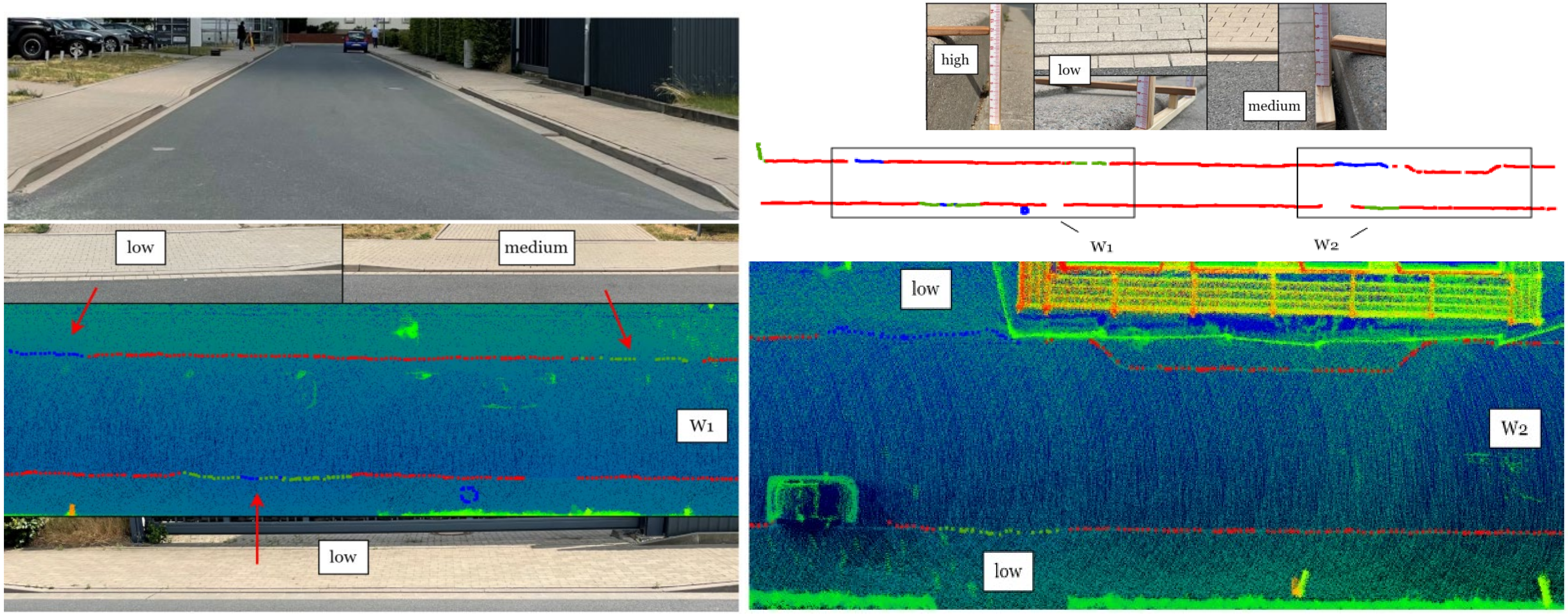
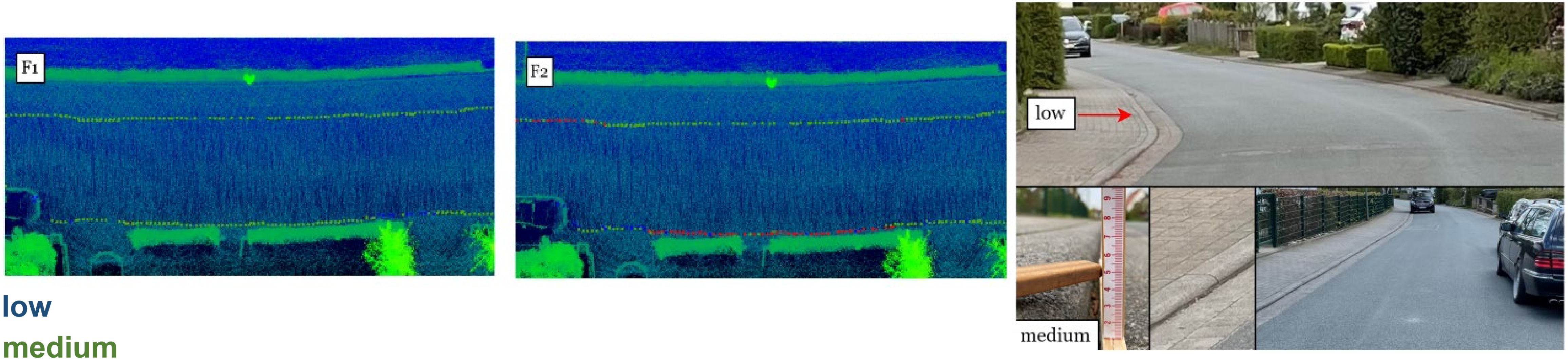


Figure 26: Results for proposed curb detection and height estimation

Results – Height estimation

- Medium curb category | 70% and 90% for 2D CS and Proposed
- Narrow sidewalk (-strips) with adjacent garden fences and vegetation

➢ The 2D CS method overestimates the height for curbs without an adjacent sidewalk significantly more than the proposed method



low
medium
high

Figure 27: Results for proposed curb detection and height estimation

Results – Height estimation

	Correctness in [%]		
	2D CS Method	**Proposed Method**	**Height categorie**
Winkelhausenstraße	**98**	**98**	High curbs (7-15 cm)
Mendelssohnweg	86	**95**	High curbs (7-15 cm)
Flohrstraße	70	**90**	Medium curbs (3-7 cm)

Table 3: Accuracy of proposed height estimation

Discussion

- Curb detection is comparable in accuracy to state-of-the-art methods
- Additionally, reliably high and medium curb height categories
- Flexible and unique lidar setup for curb detection

	Correctness [%]	*Completeness* [%]	*Datasets*
Proposed	96.36	92.81	Seven research spec. datasets
Yang et al. [57]	98.09 95.98	95.13 95.13	Two research spec. datasets of residential and downtown area
Ye et al. [59]	95.61 92.91	96.32 95.06	Two research spec. datasets
Wang et al. [54]	92.00 89.62	77.98 81.37	Ubudan and Kitty dataset
Borja et al. [46]	93.2 90.76	94.2 93.52	Two research spec. datasets
Zhang et al. [61]	85.07	82.87	Research spec. dataset

Discussion - Strengths and Advantages

- Successfully detects even the most flat curbs, which is a common challenge for other algorithms.
- Overcomes the weaknesses of Belton and Bae’s ground point segmentation. Capable of handling noisy data effectively.
- Demonstrates high robustness on uneven surfaces and obstacles.
- Applies alignment, enabling
  - simple height measurement in the coordinate system
  - handling of inclined roads
- Successfully tested the algorithm's transferability to the point cloud of a terrestrial LiDAR scanner.

Discussion - Disadvantages and Limitations

- Both height estimations faces challenges with sloping curbs and adjacent vegetation etc., leading to potential overestimation.

- Distinguishing between low and medium curbs is difficult, compounded by variations in actual height around three centimeters.

- Successful region growing is necessary for curb detection and height estimation. Challenges:
- ➢ Non-deterministic nature of normals computed using RANSAC → variable output
- ➢ Tradeoff between
  - tight thresholds (ri & rj) to handle completely flattened curbstones that seamlessly merge with the street
  - and loose thresholds to ensure that the road is not split into parts

Discussion – Future Work

- Georeferencing.
- Adding results to OSM
- Evaluate on other data sets

The End.

Questions?