Near real-time automatic registration of terrestrial scan data

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EuroCOW
June 8th, 2017
Hannover, Germany

contents

- **registration of scan data from static laser scanning**
- description of laser scanning system
- spectral registration – phase-only matched filtering
- automated workflow
- examples

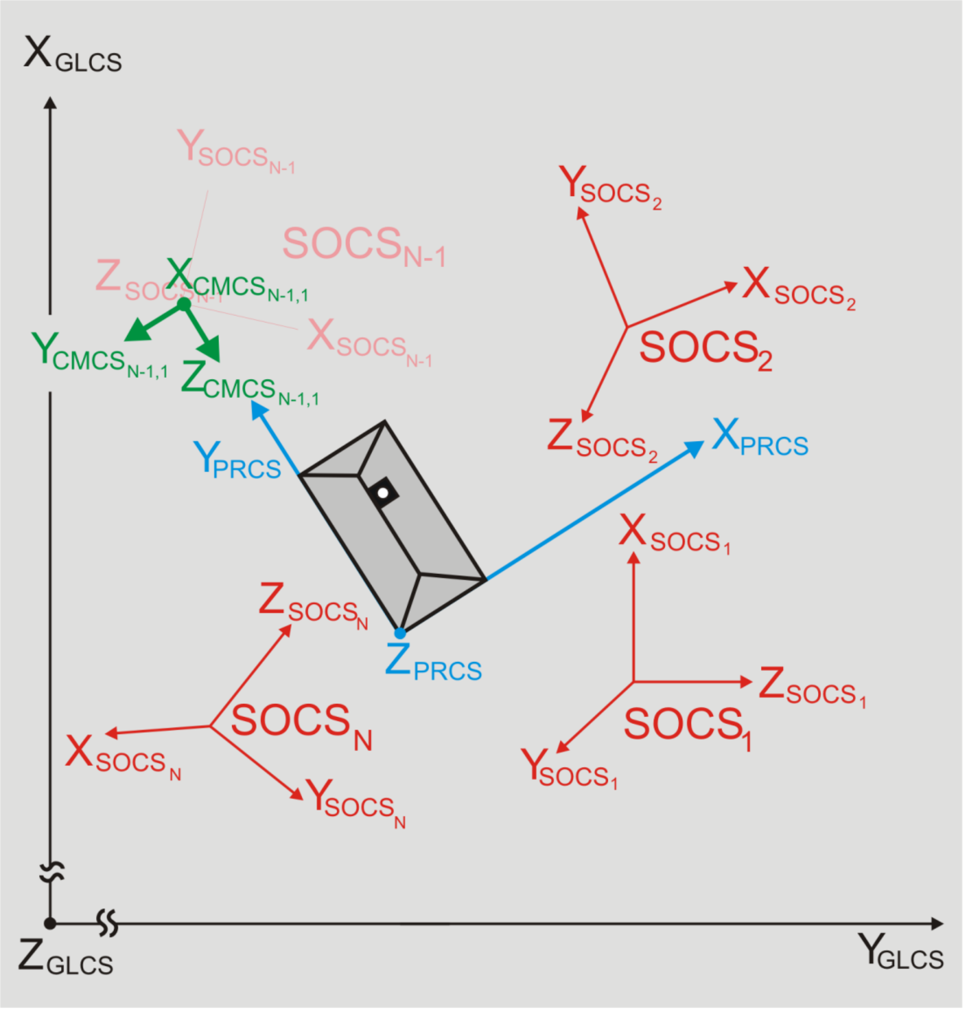
coordinate systems

CMCS
Ca**M**era **C**oordinate **S**ystem

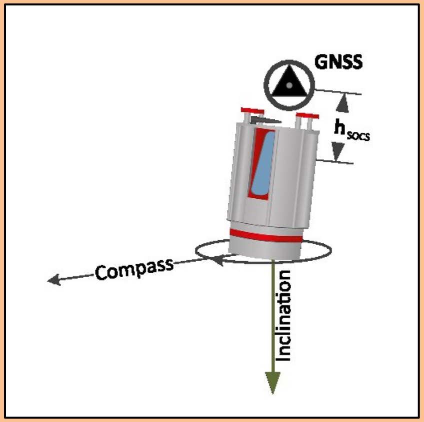
SOCS
Scanner's **O**wn **C**oordinate **S**ystem

PRCS
PRoject **C**oordinate **S**ystem

GLCS/CRS
GLobal **C**oordinate **S**ystem

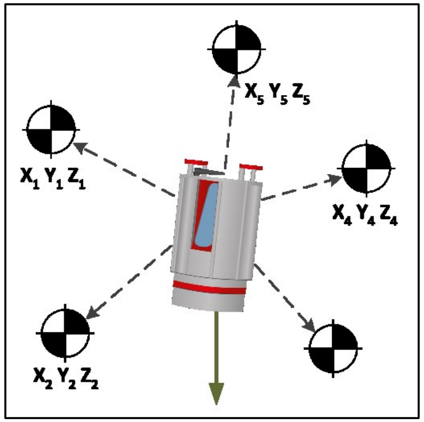


registration methods

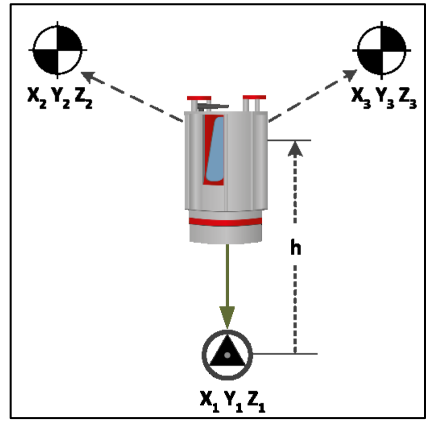


DirectGeoreference

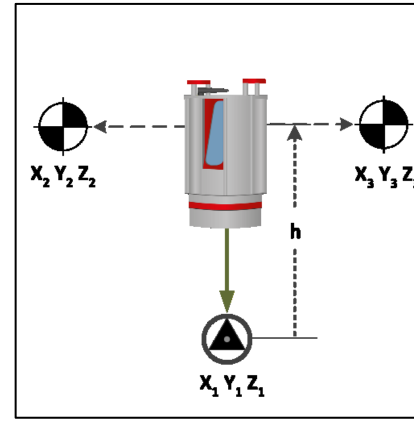
+ point clouds with overlap



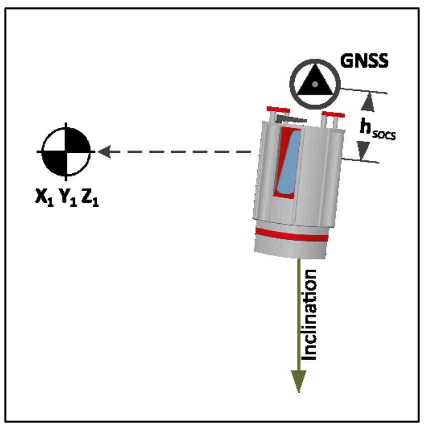
Freestation



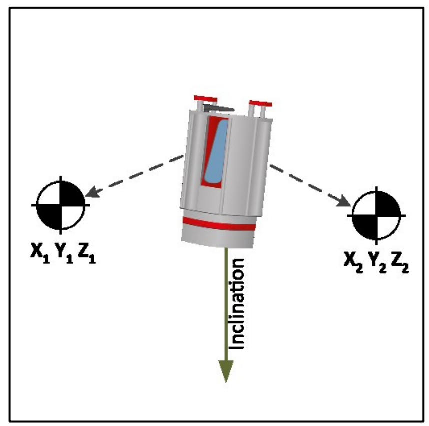
3 Point Solution



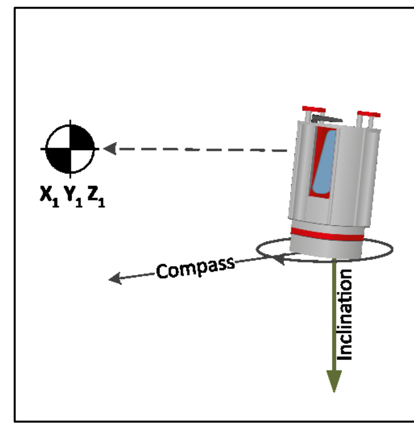
Traverse



Backsight



2 Point Resection



1 Point Reference

contents

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RIEGL VZ-400i – TLS LIDAR System

LIDAR engine
- echo digitization
- online waveform processing

data storage, interfacing
- internal storage, external storage
- data transfer, reporting

add-on camera
- up to 37Mpix

GNSS receiver
- integrated L1 receiver
- external L1/L2 receiver

pose sensors
- tilt sensors, compass, gyros, barometric

post-processor
- real-time data post-processing
- e.g. data conversion, registration

RIEGL VZ-400i – specification

Technical Data *RIEGL* VZ®-400i

Laser Product Classification — Class 1 Laser Product according to IEC 60825-1:2014

CLASS 1 LASER PRODUCT

Range Measurement Performance [1]

Measuring Principle / Mode of Operation — time of flight measurement, echo signal digitization, online waveform processing, multiple-time-around processing, full waveform export capability (optional) / single pulse ranging

Laser Pulse Repetition Rate PRR (peak) [2] [3]	100 kHz	300 kHz	600 kHz	1200 kHz
Effective Measurement Rate (meas./sec) [2]	42,000	125,000	250,000	500,000
Max. Measurement Range [4]				
natural targets $\rho \geq 90$ %	800 m	480 m	350 m	250 m
natural targets $\rho \geq 20$ %	400 m	230 m	160 m	120 m
Minimum Range	1.5 m	1.2 m	0.5 m [5]	0.5 m [5]
Max. Number of Targets per Pulse	15	15	8	4

Accuracy [6] [8]	5 mm
Precision [7] [8]	3 mm
Laser Wavelength	near infrared
Laser Beam Divergence	0.35 mrad [9]

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spectral registration basics

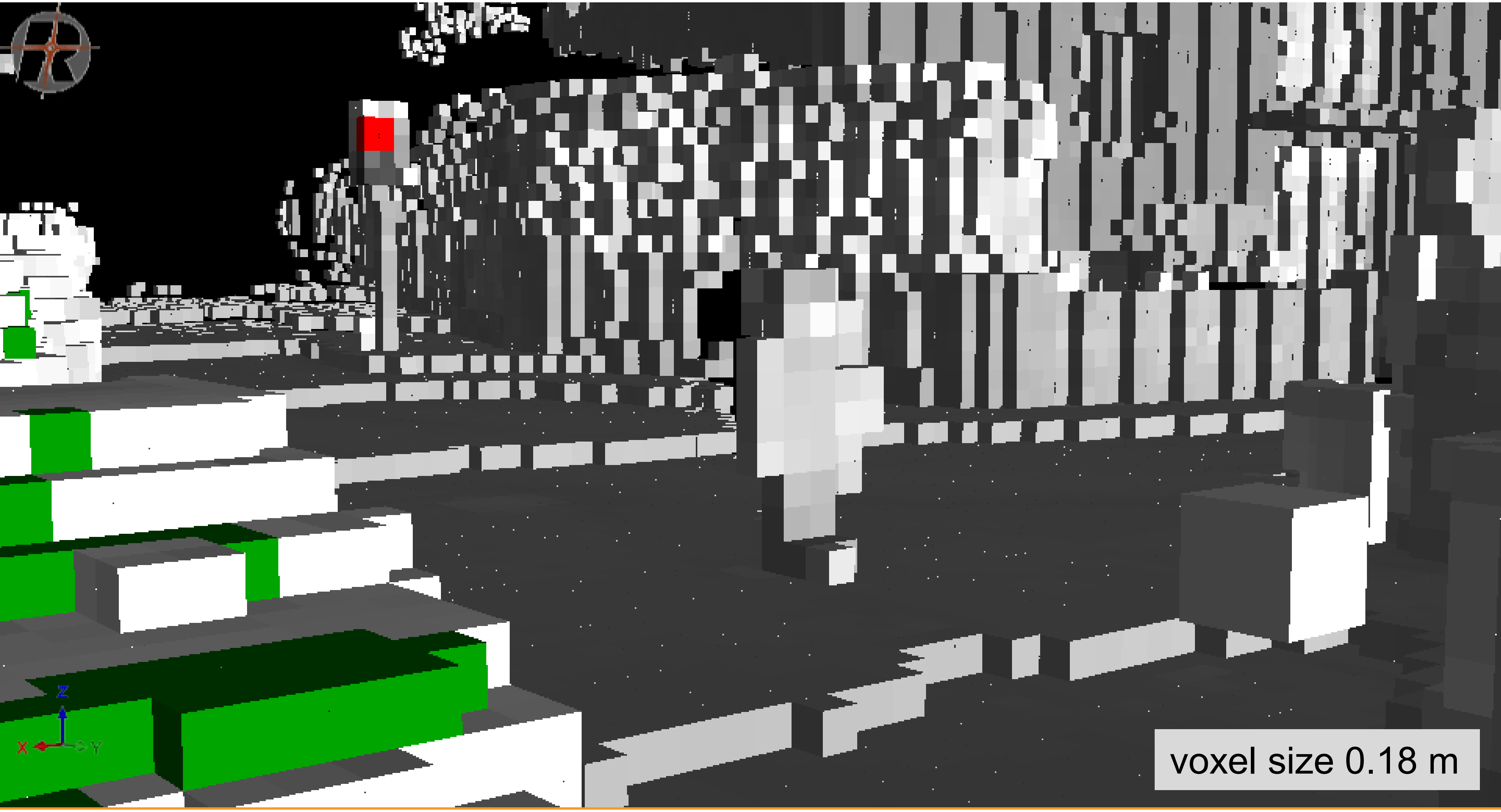
- resampling of irregular point cloud on 3D grid yields "voxelized" 3D data: $v(\mathbf{x})$
- Fourier transform of $v(\mathbf{x})$: $V(\mathbf{k})$
- same signal but rotated and shifted: $w(\mathbf{x})=v(R\mathbf{x}+\mathbf{t})$
- Fourier transform of $w(\mathbf{x})$: $W(\mathbf{k})$
- ***Fourier Rotation Theorem*** **and** ***Fourier Shift Theorem***
  $W(\mathbf{k}) = V(R\mathbf{k})\, exp(i2\pi\, \mathbf{k}^T R^{-1}\mathbf{t})$
- magnitudes only
  $|W(\mathbf{k})| = |V(R\mathbf{k})|$ → **rotation matrix *R***
- for R equal to identity matrix (no rotation)
  $W'(\mathbf{k}) = V(\mathbf{k})\, exp(i2\pi\, \mathbf{k}^T \mathbf{t})$ → **translation vector *t***

voxelization of scans

- voxel attributes
  - average reflectance
  - number of points per voxel
  - shape attributes (linear, planar, volumetric)
- critical parameters for automated registration
  - voxel size (0.01 m – 1 m)
  - voxel count (256 – 1024)
  - to be adapted to project (automatically)

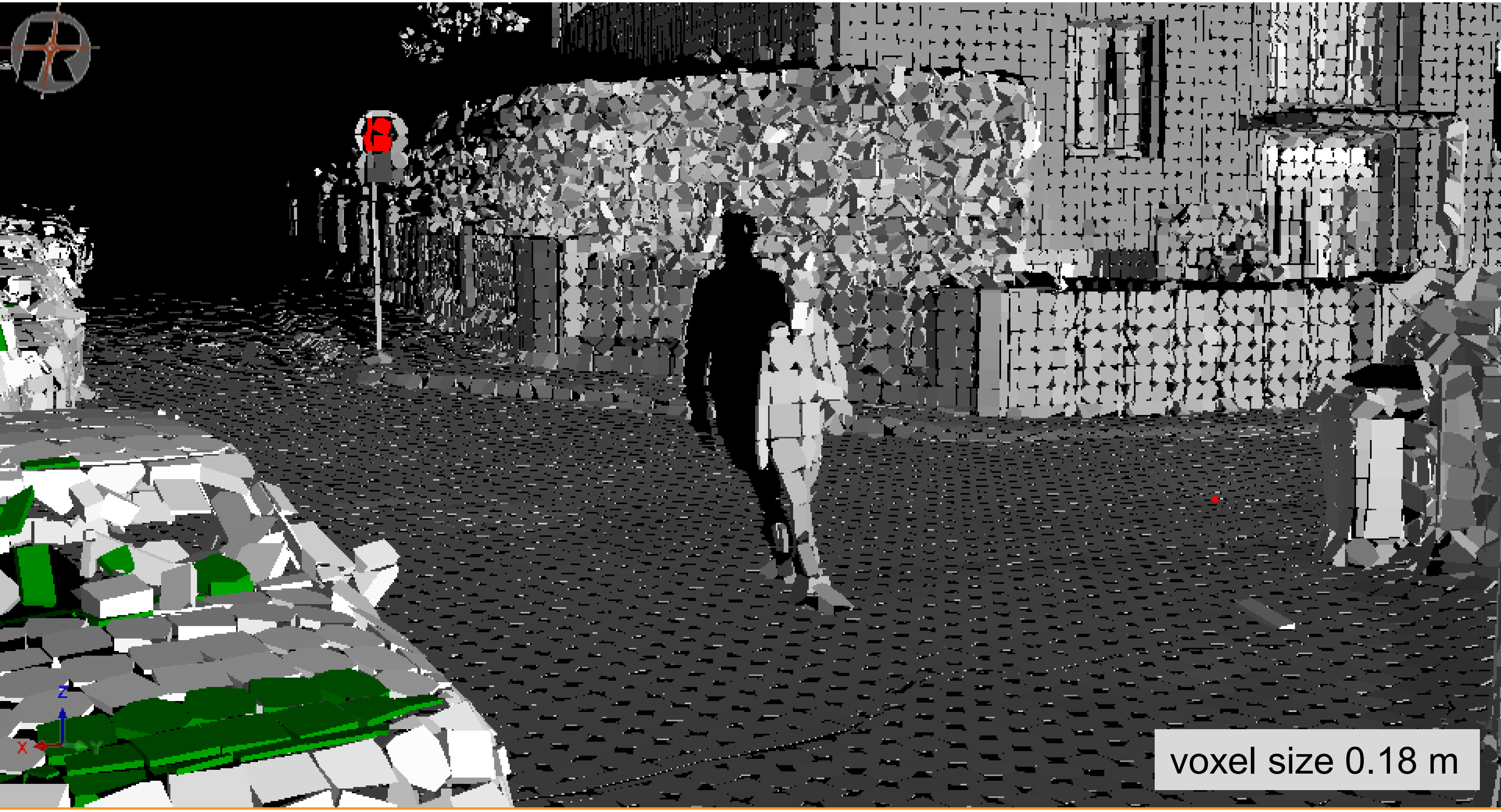
point cloud with reflectance encoding

voxels with reflectance encoding

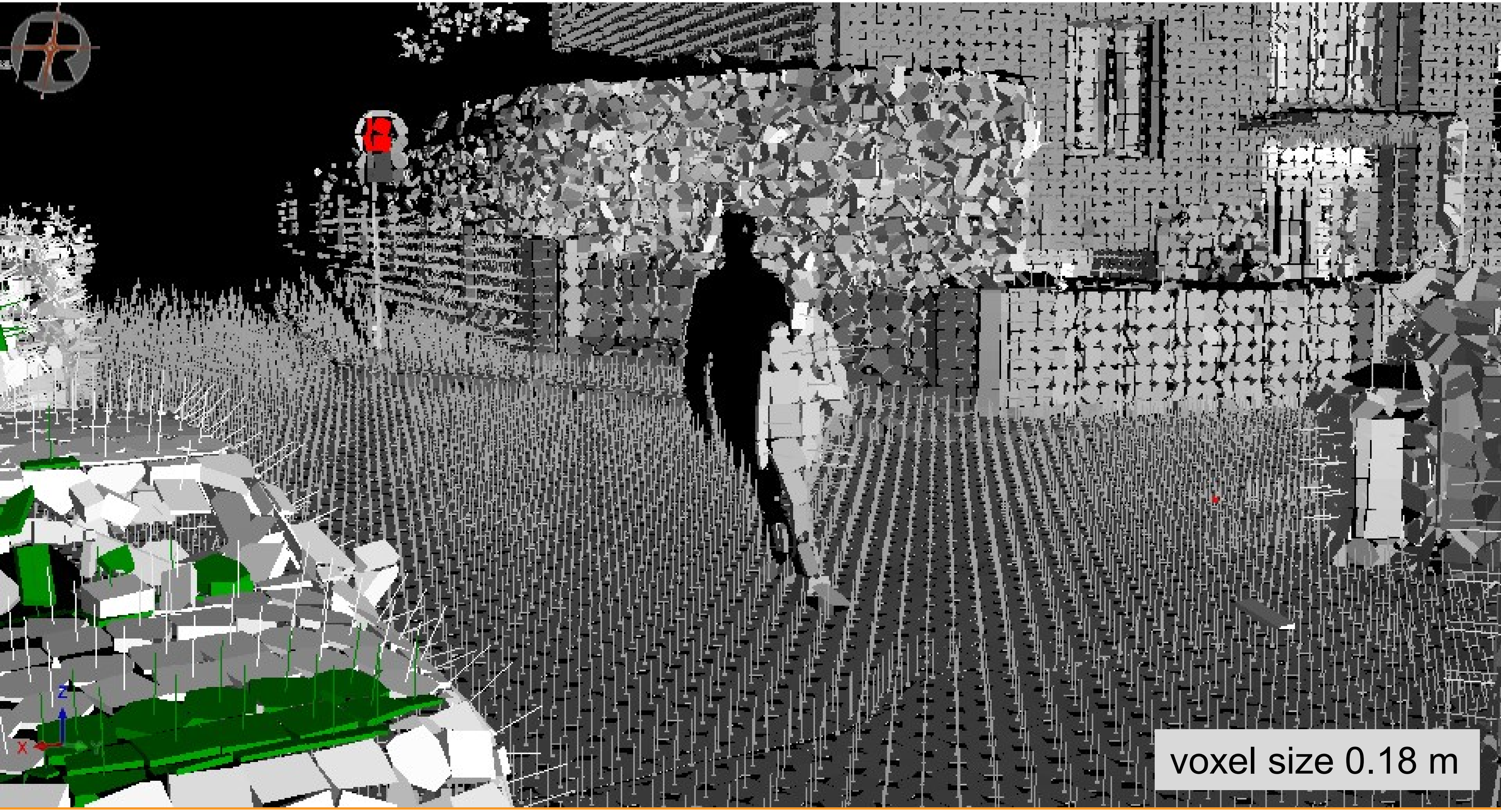


voxel size 0.18 m

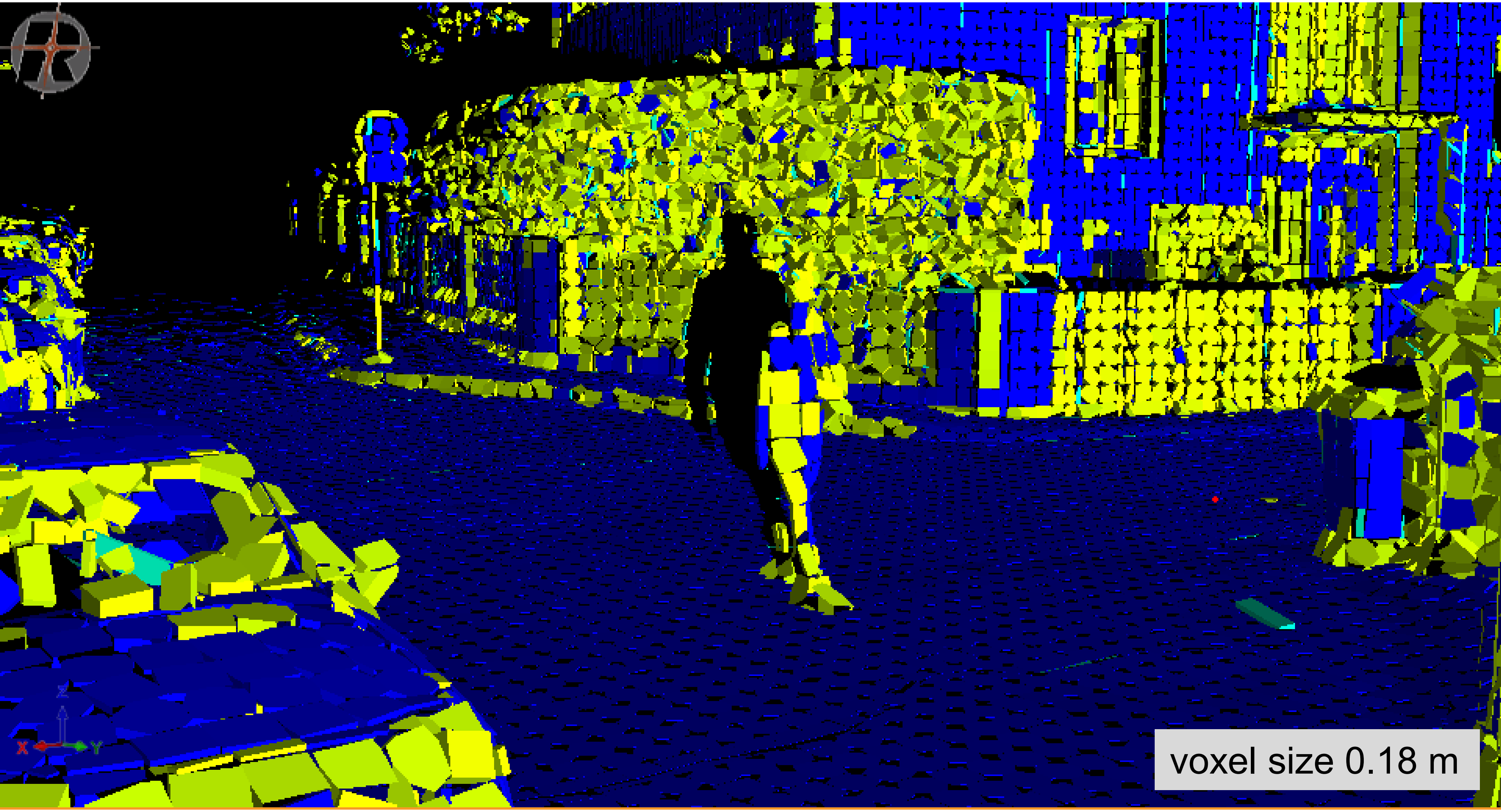
voxel objects (bounding boxes)



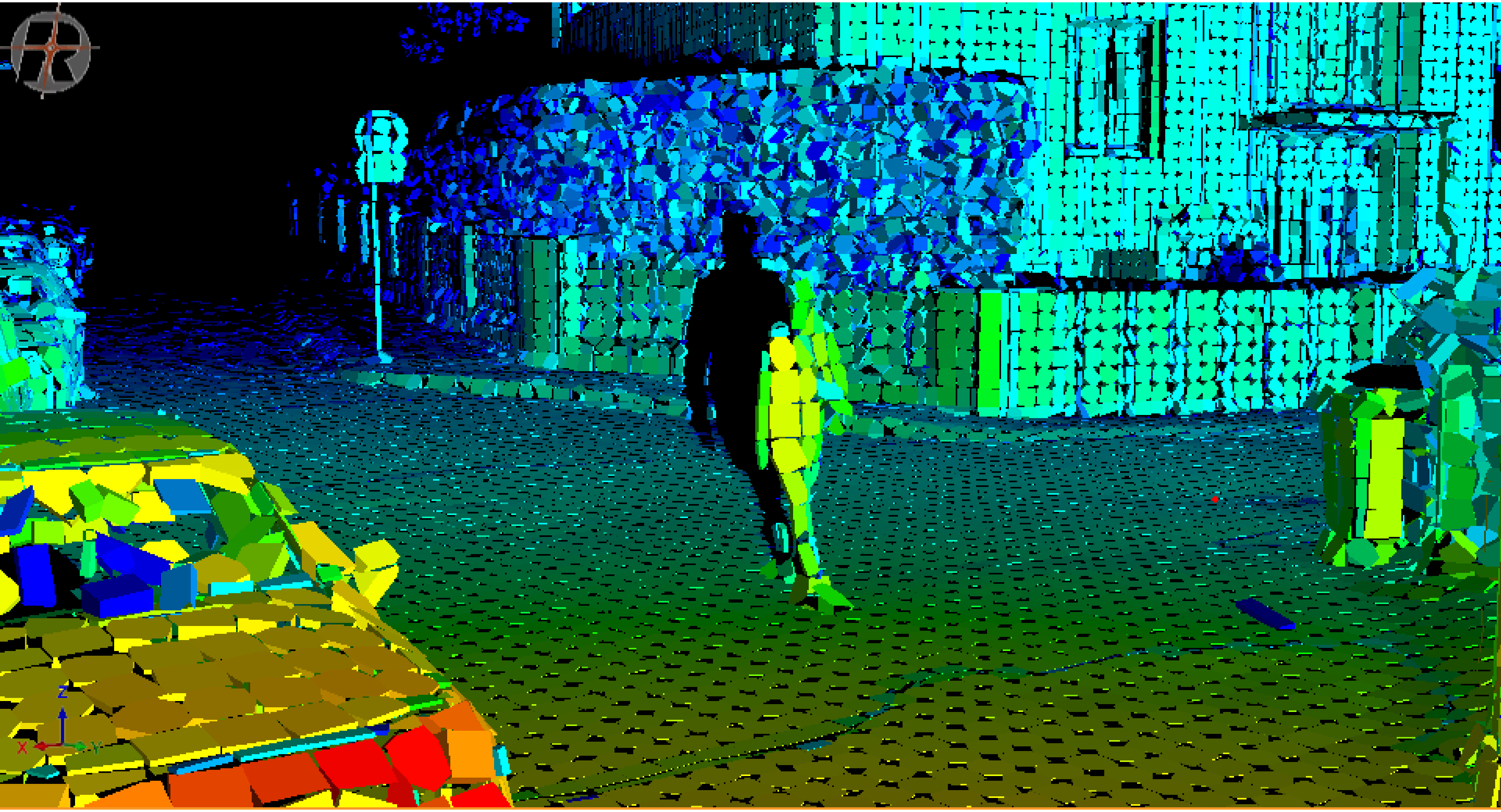
voxel objects with normals



voxel type



voxel point count



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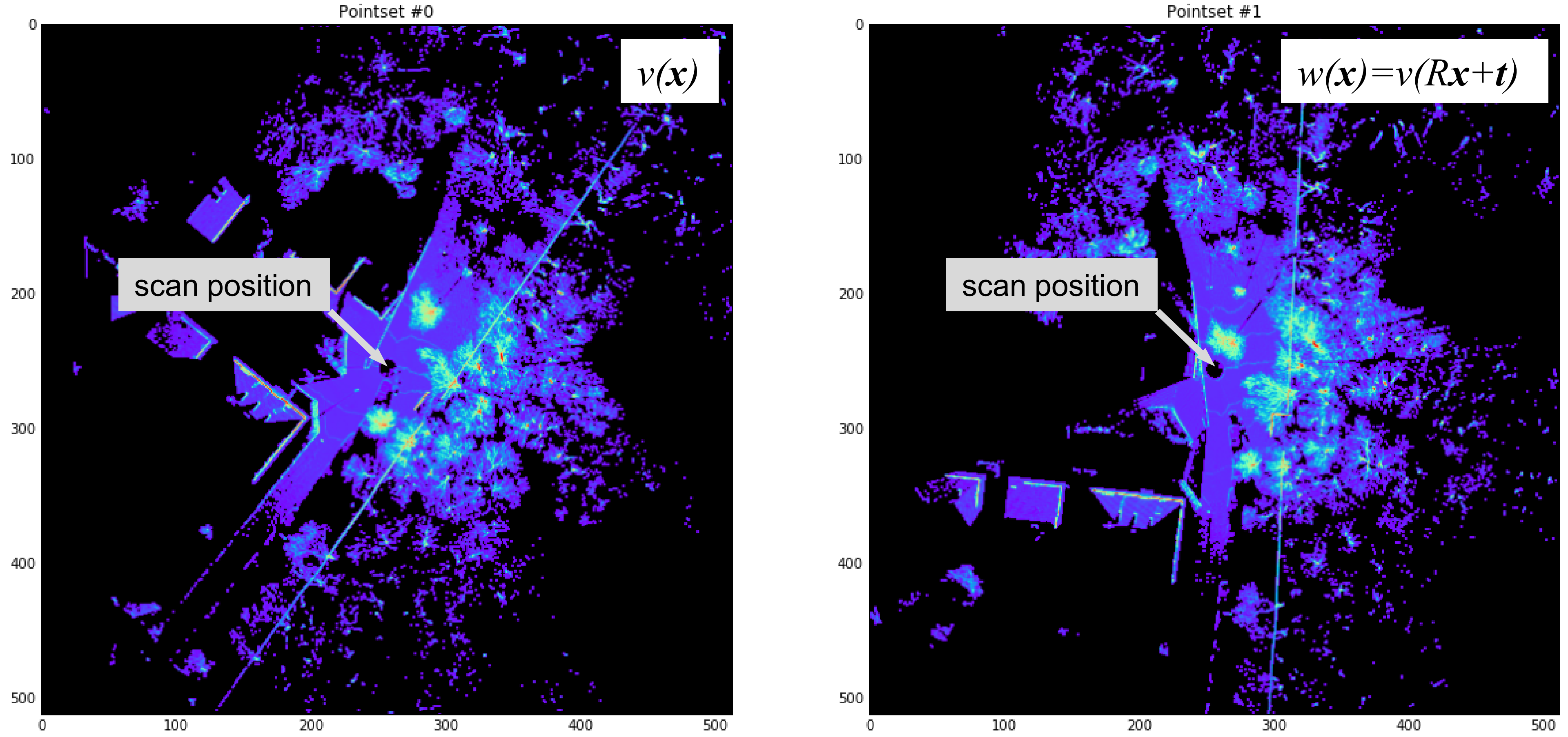
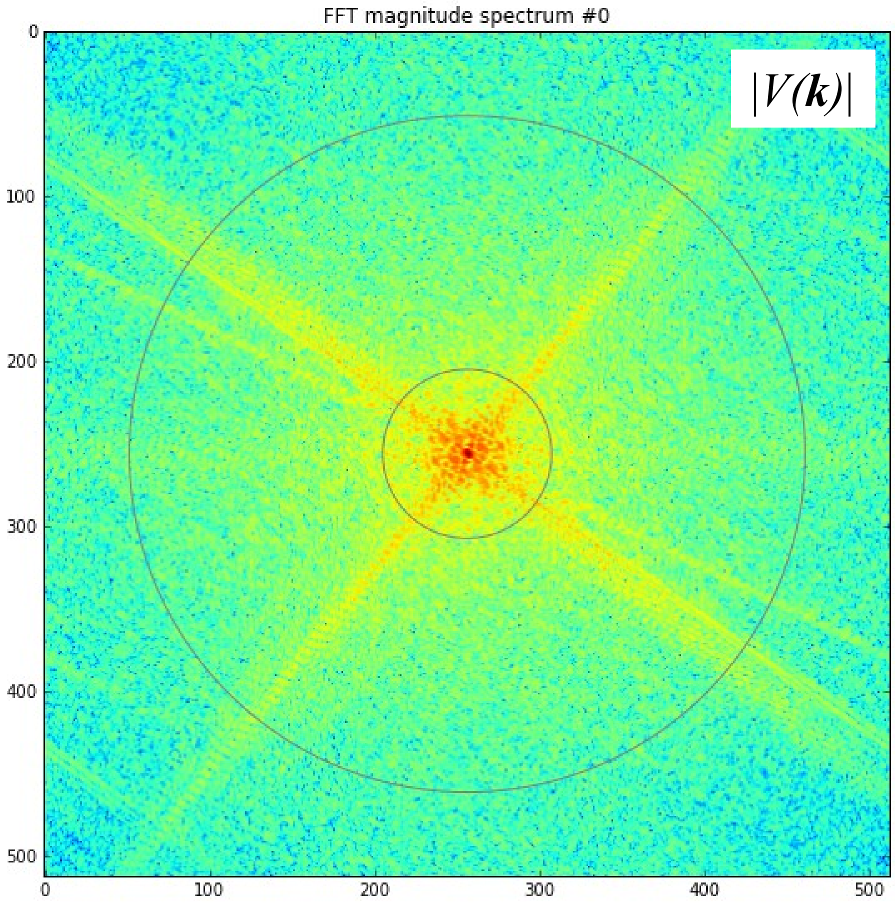
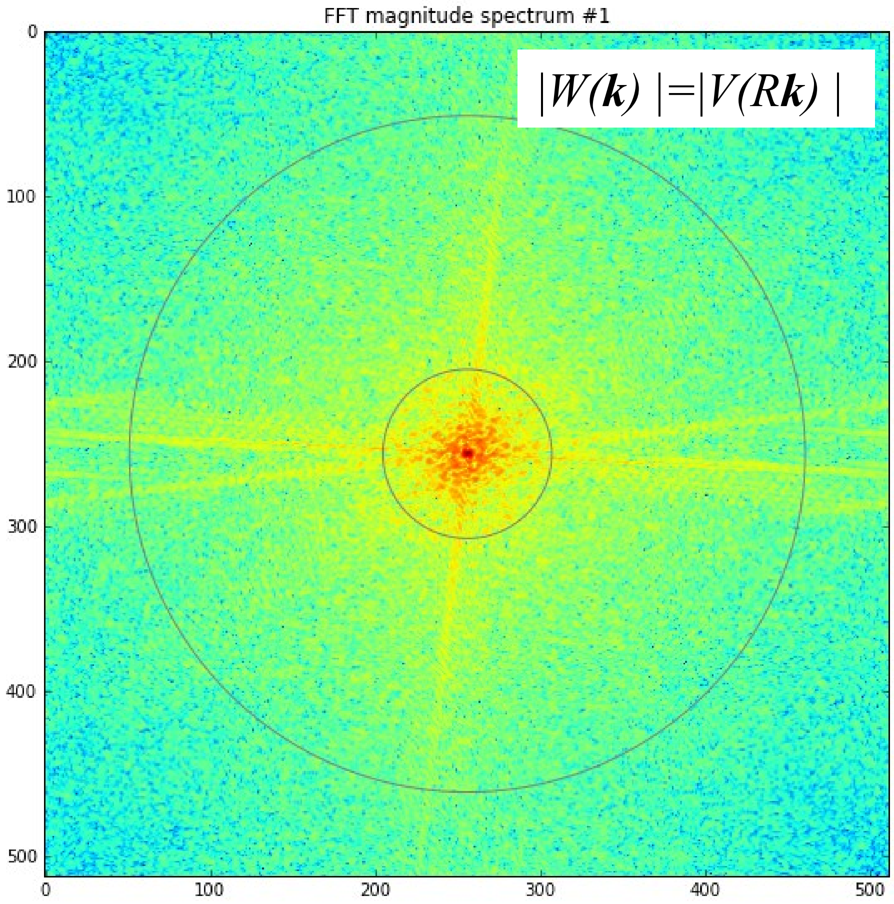
voxel data of two scan positions

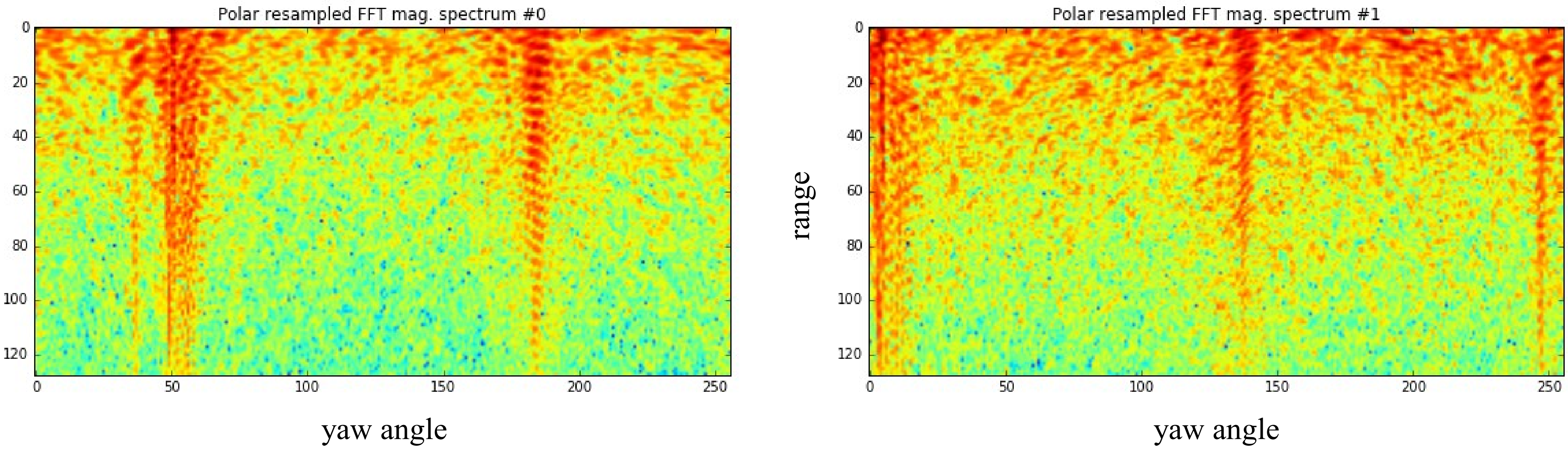


magnitude of spectra

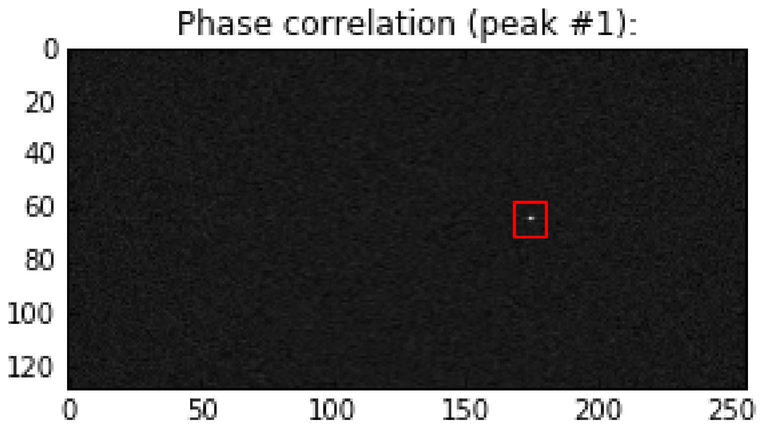




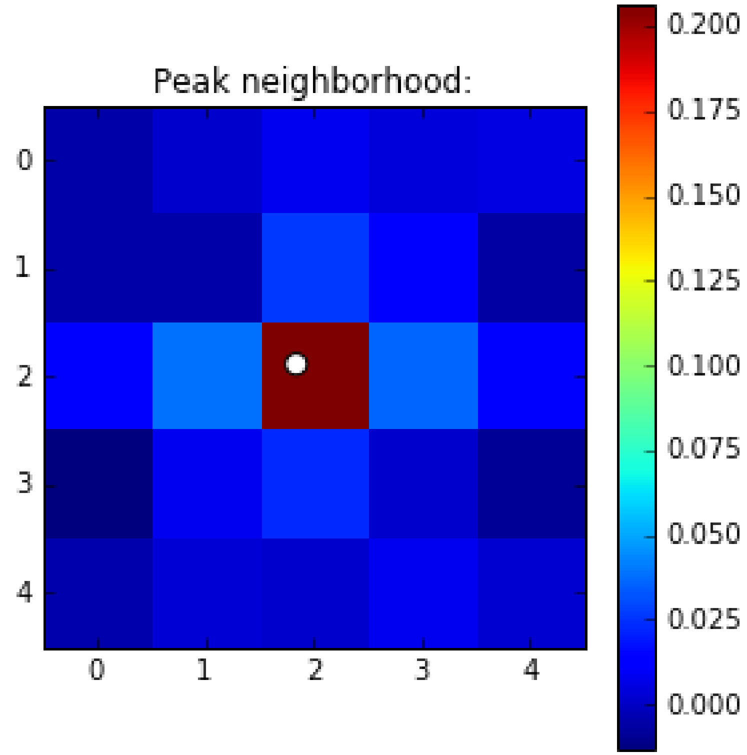
magnitude spectra resampled



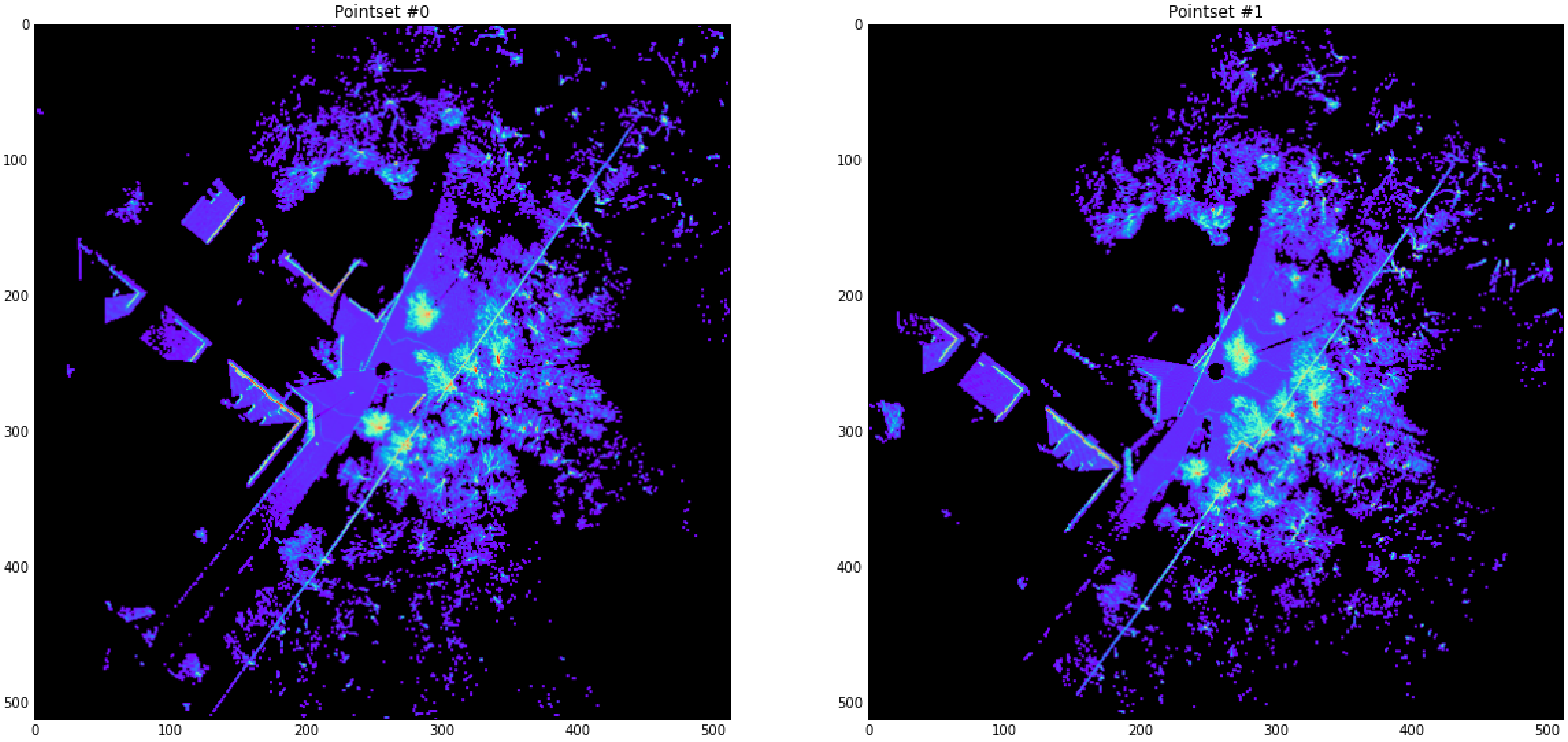
phase correlation by POMF for yaw



yaw angle

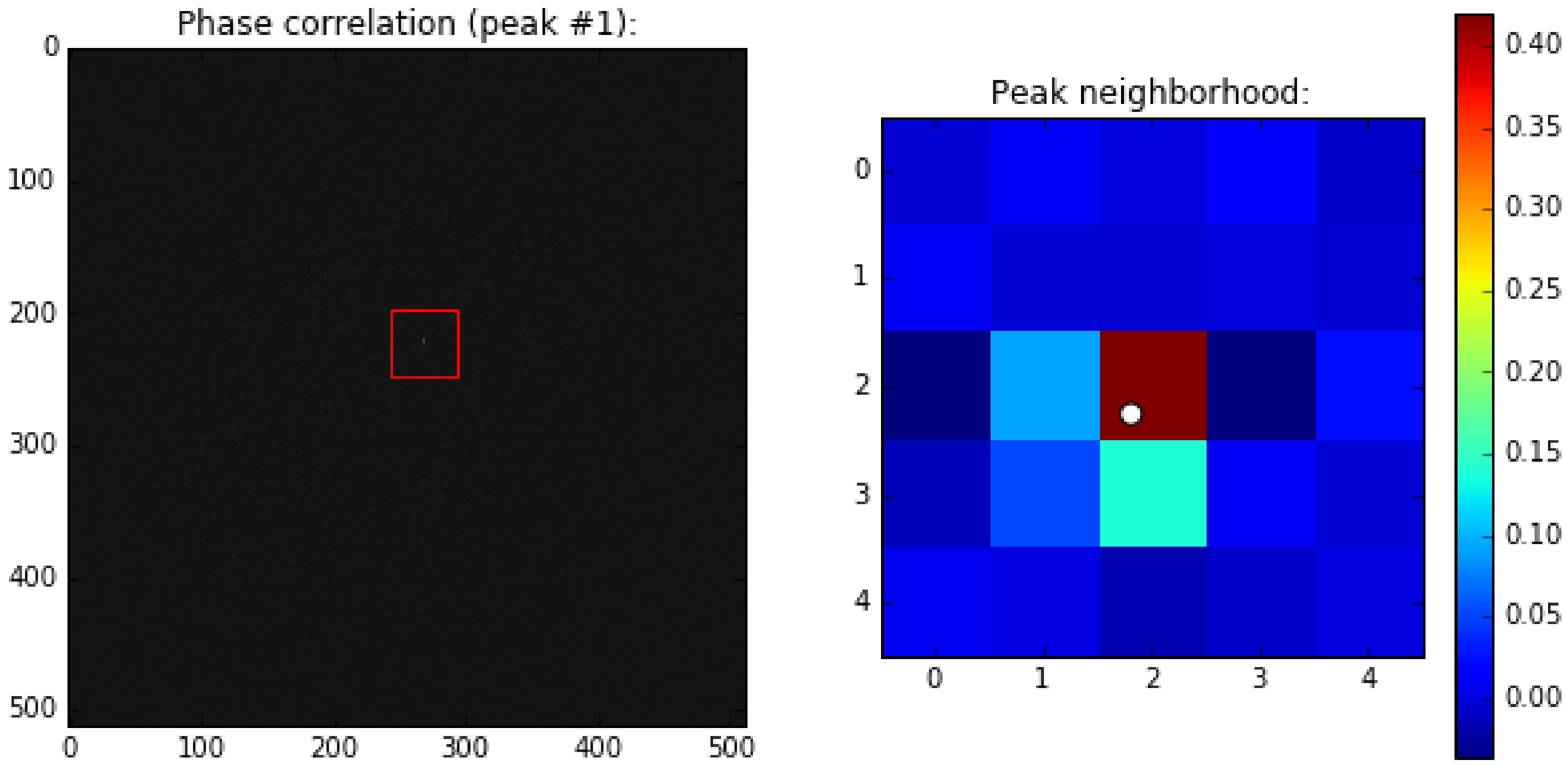


spatial domain, yaw applied

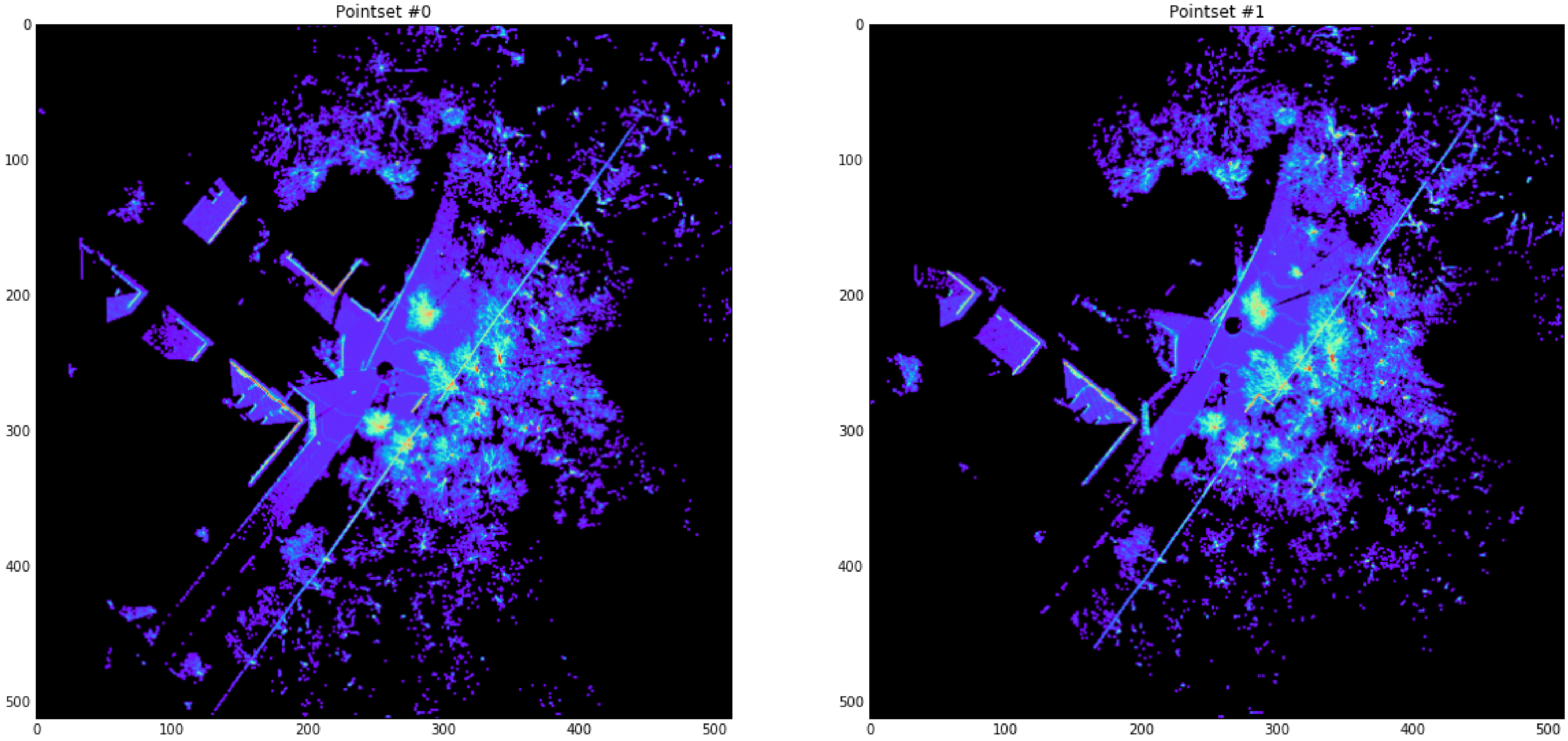


POMF for estimating translation

$$W(\boldsymbol{k}) = V(\boldsymbol{k})\, exp(i2\pi\, k^T \boldsymbol{t})$$



spatial domain, yaw and translation applied



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workflow per scan position

1. voxelization of scan data
2. spectral-based registration
   (utilizing a priori information when applicable)

a-priori information for registration

2. spectral-based registration
   (utilizing a priori information when applicable)

data of scan position to be registered

- GNSS position (not always)
- orientation from accelerometers and magnetic field sensor (reliable roll and pitch, unreliable yaw)
- position and orientation from IMU data relative to previous scan position

reference data (already registered data)

- voxelized representation

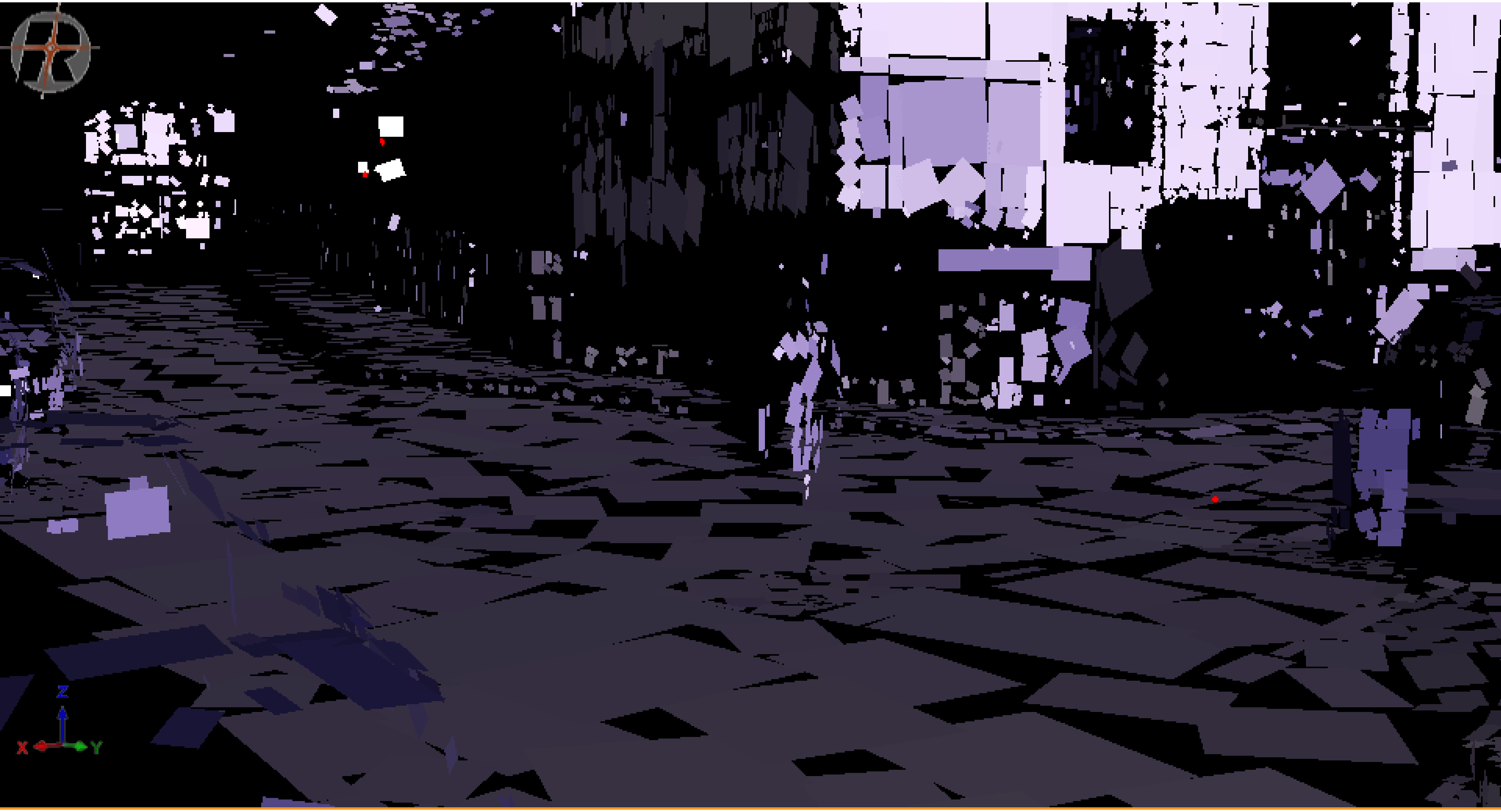
workflow per scan position

1. voxelization of scan data
2. spectral-based registration
   (utilizing a priori information when applicable)
3. least squares based fitting of corresponding plane patches

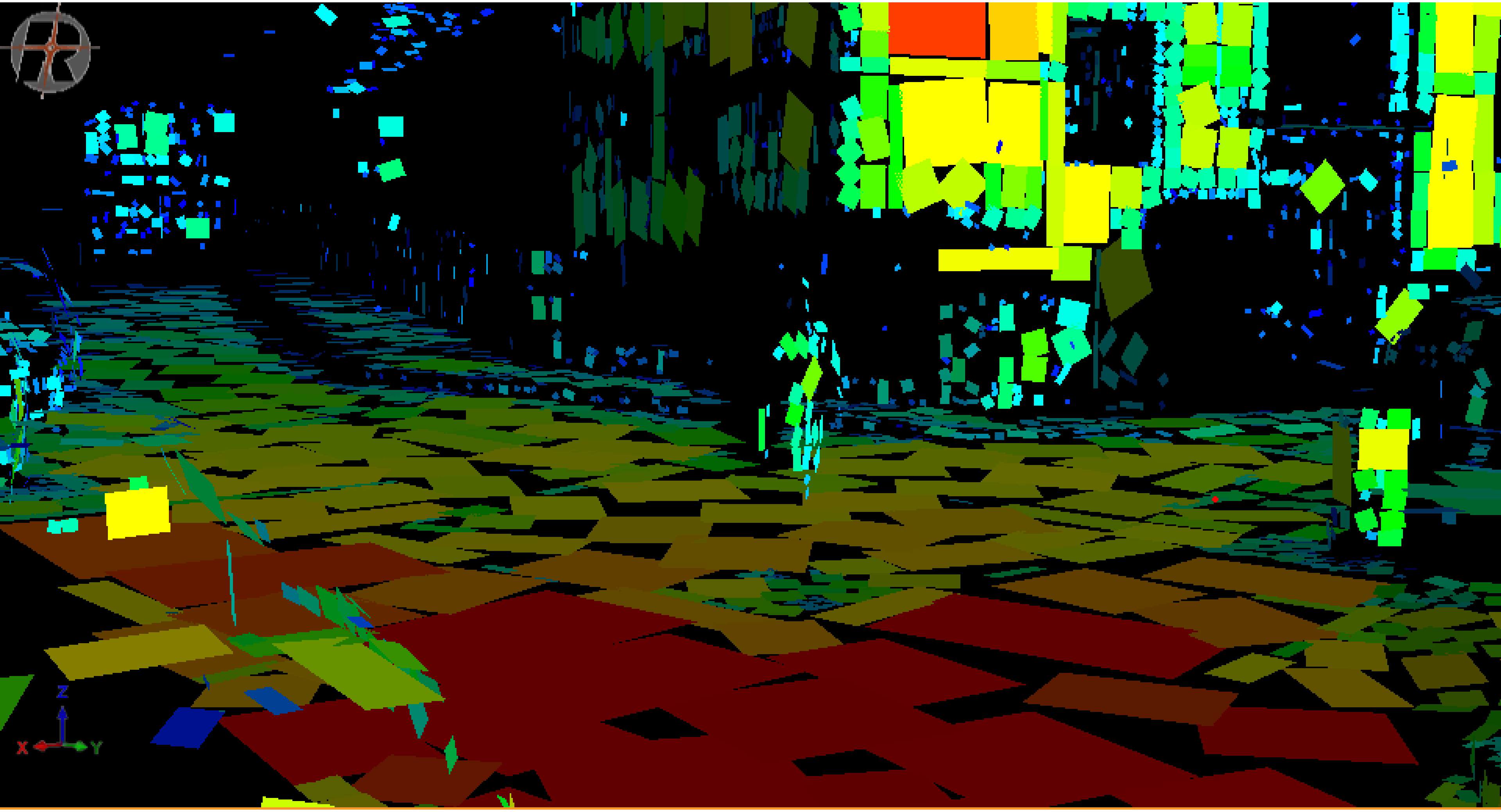
plane patches from scan

3. least squares based fitting of corresponding plane patches
   - plane patch attributes
     - center of gravity, normal vector
     - number of points
     - reflectance
     - confidence estimates
   - critical parameters
     - threshold for standard deviation of residuals
     - threshold for planarity

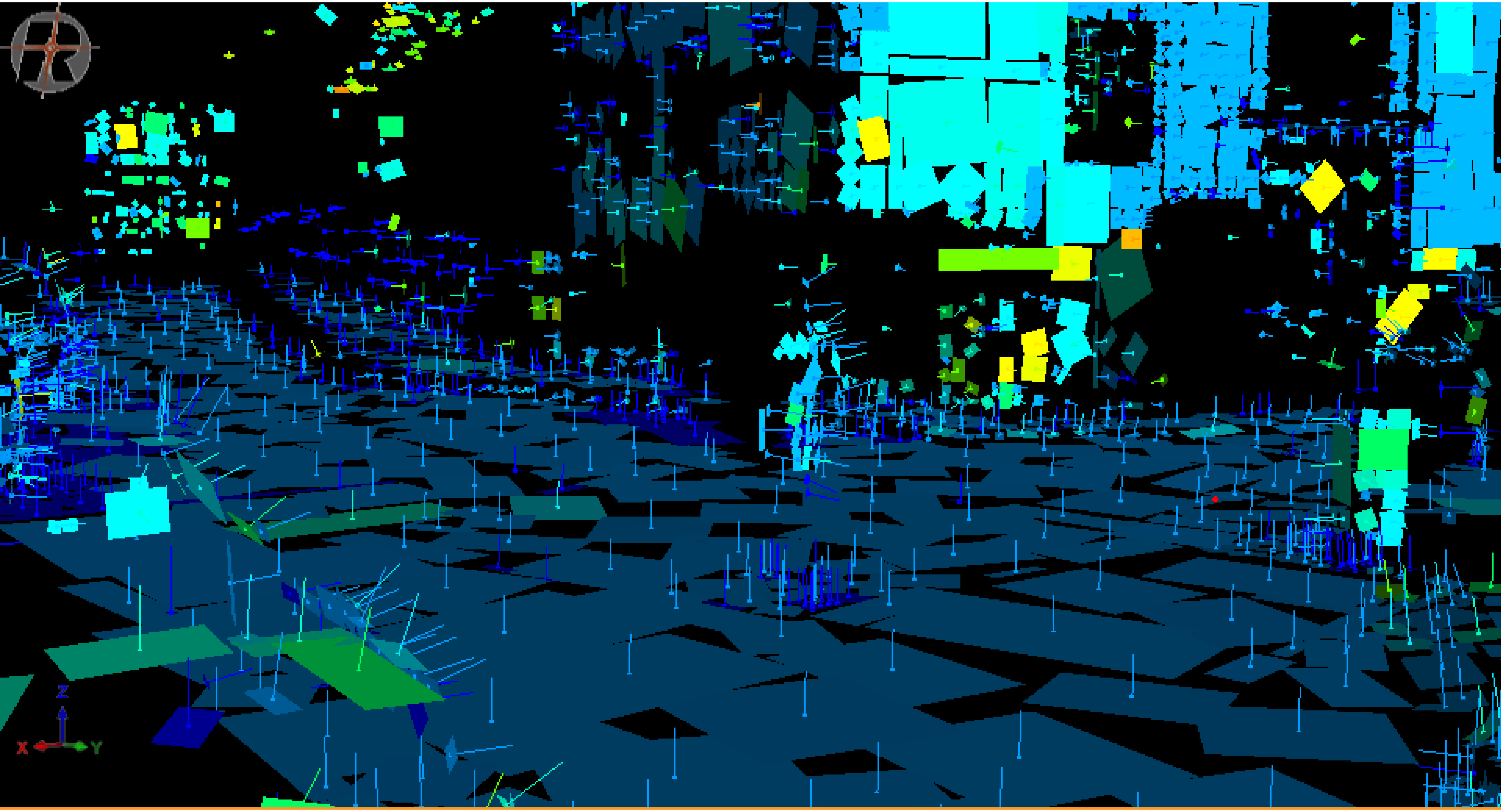
plane patches with reflectance



plane patches point count



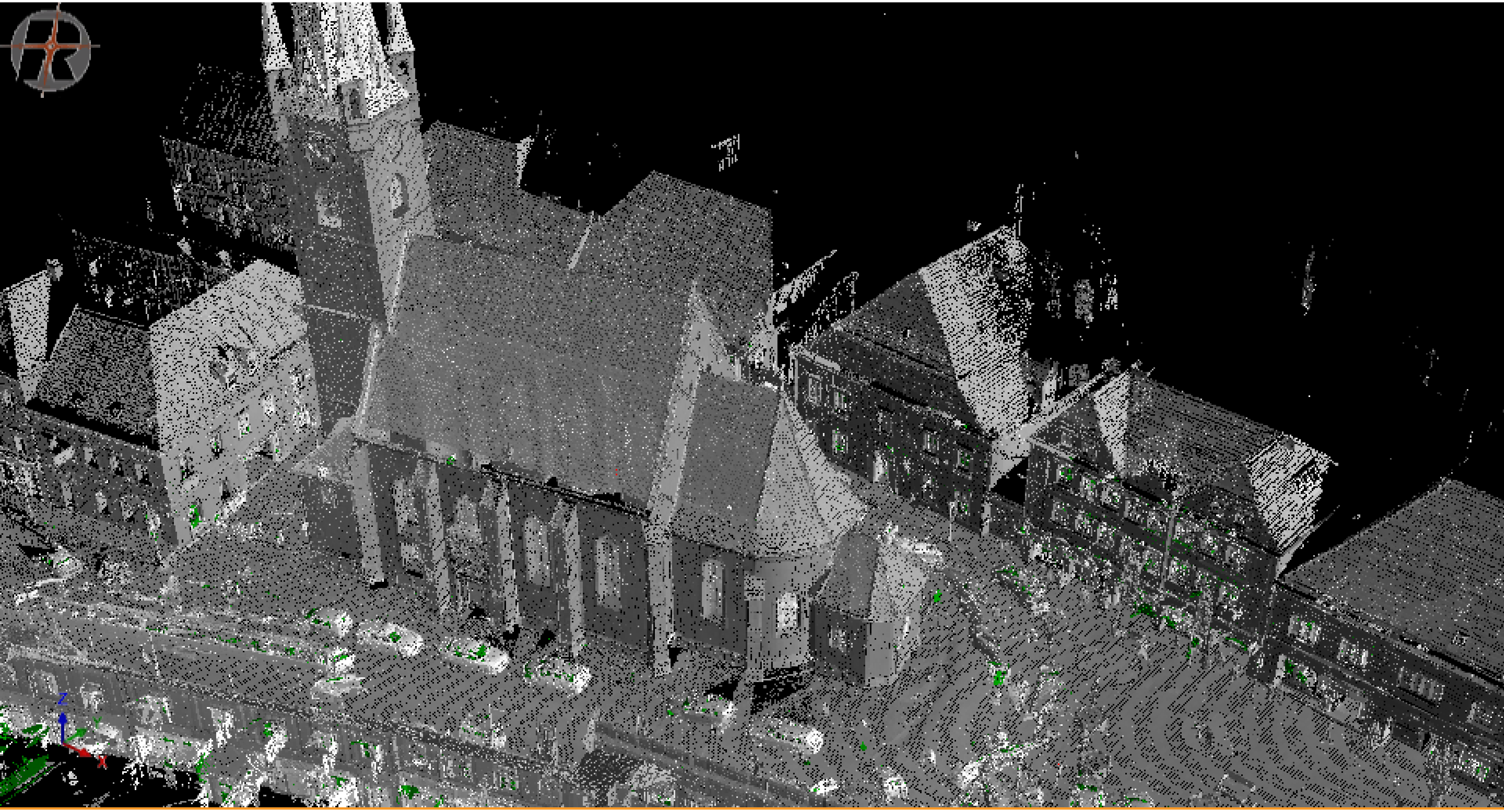
plane patches std residuals



workflow per scan position

1. voxelization of scan data
2. spectral-based registration
   (utilizing a priori information when applicable)
3. least squares based fitting of corresponding plane patches
4. updating voxel data base of project

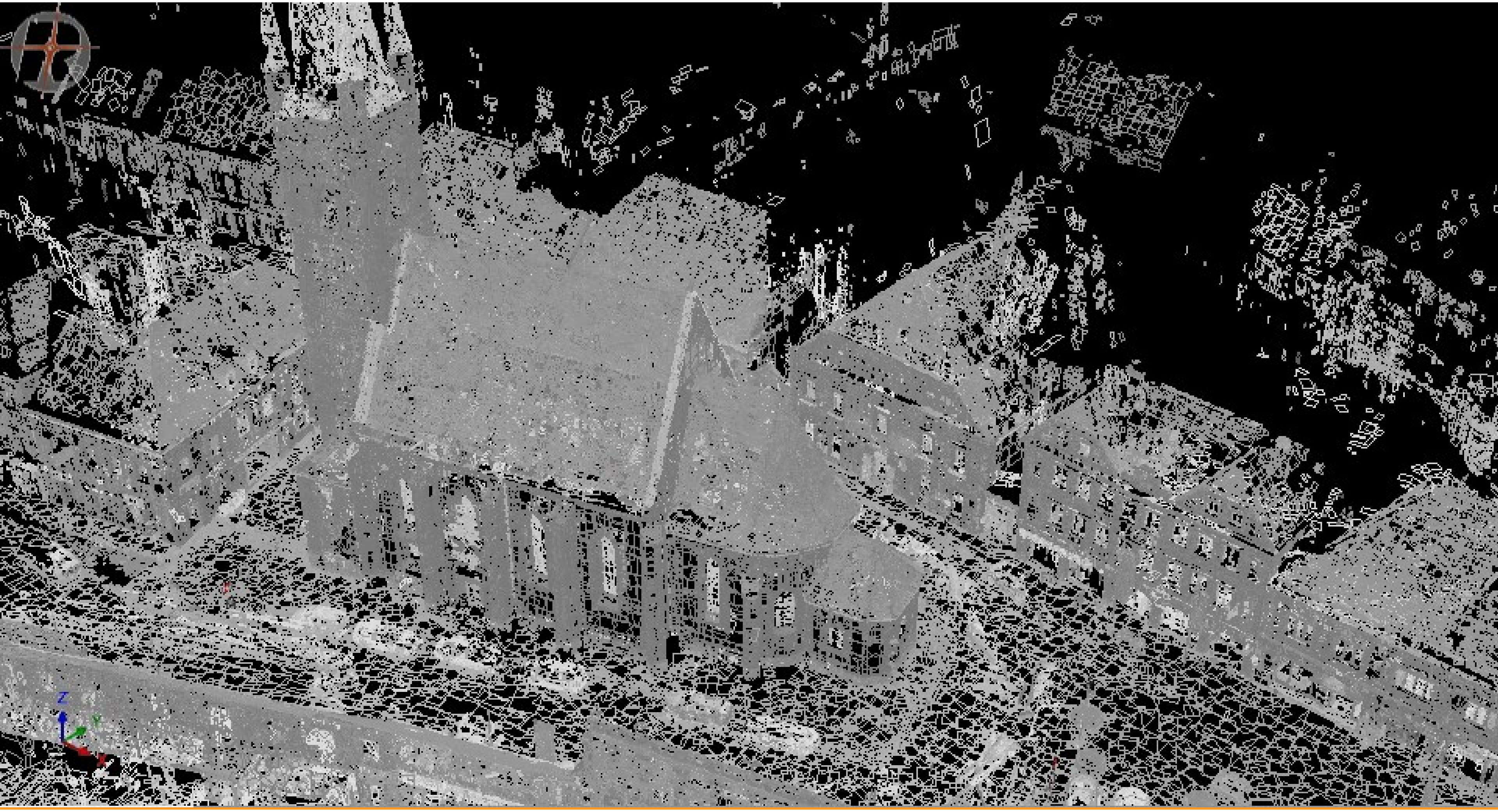
merged voxel data set



workflow per scan position

1. voxelization of scan data
2. spectral-based registration (utilizing a priori information when applicable)
3. least squares based fitting of corresponding plane patches
4. updating voxel data base of project
5. updating plane patch data base of project

merged plane patch data set



workflow per scan position

1. voxelization of scan data
2. spectral-based registration (utilizing a priori information when applicable)
3. least squares based fitting of corresponding plane patches
4. updating voxel data base of project
5. updating plane patch data base of project
6. updating overall pose of project in CRS

updating overall pose in CRS

6. updating overall pose of project in CRS
   - updating position and orientation of merged data set in CRS
   - utilizing all prior external orientation measurements (GNSS, tilt, magnetic yaw, …)
   - optimization in LSQ sense

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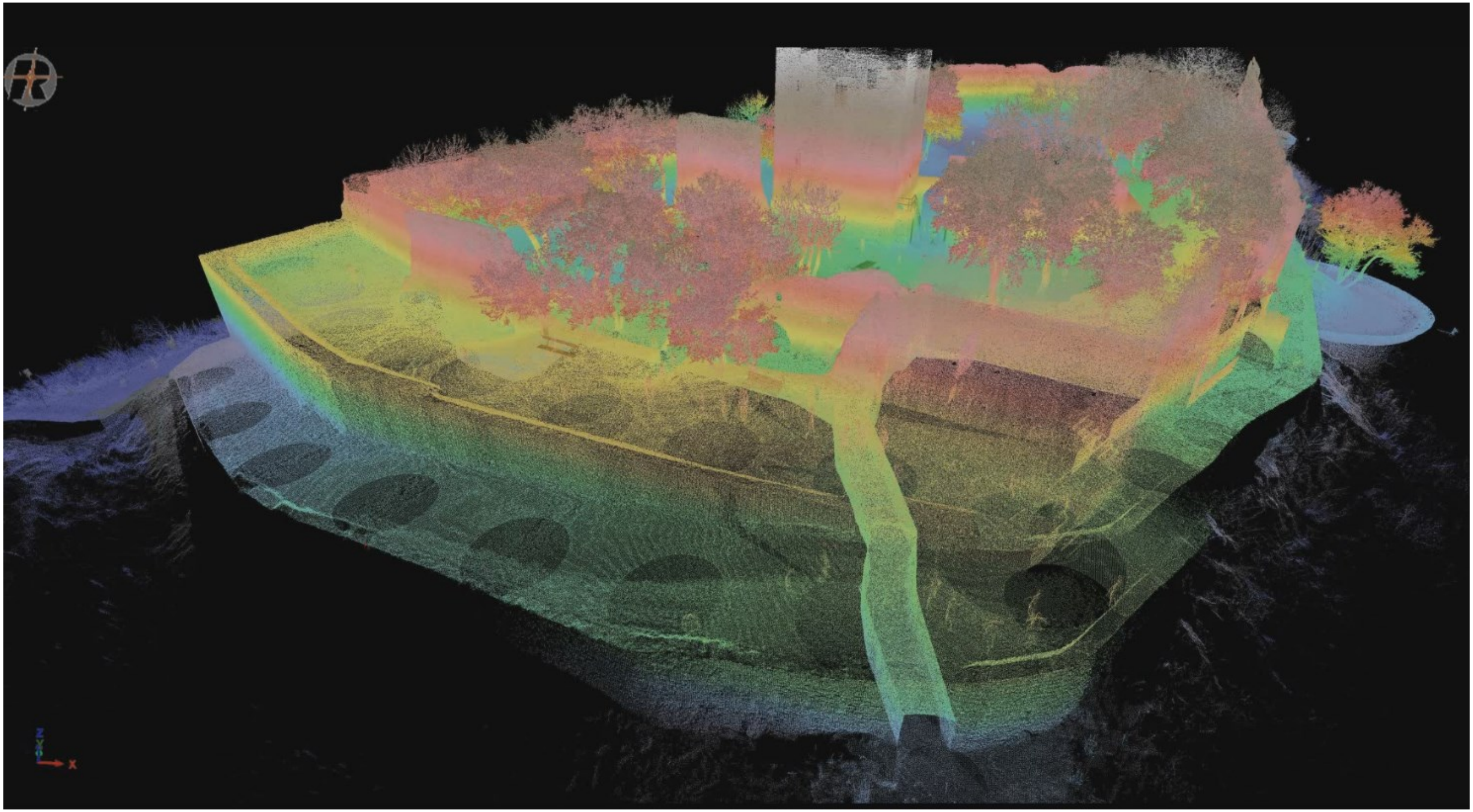
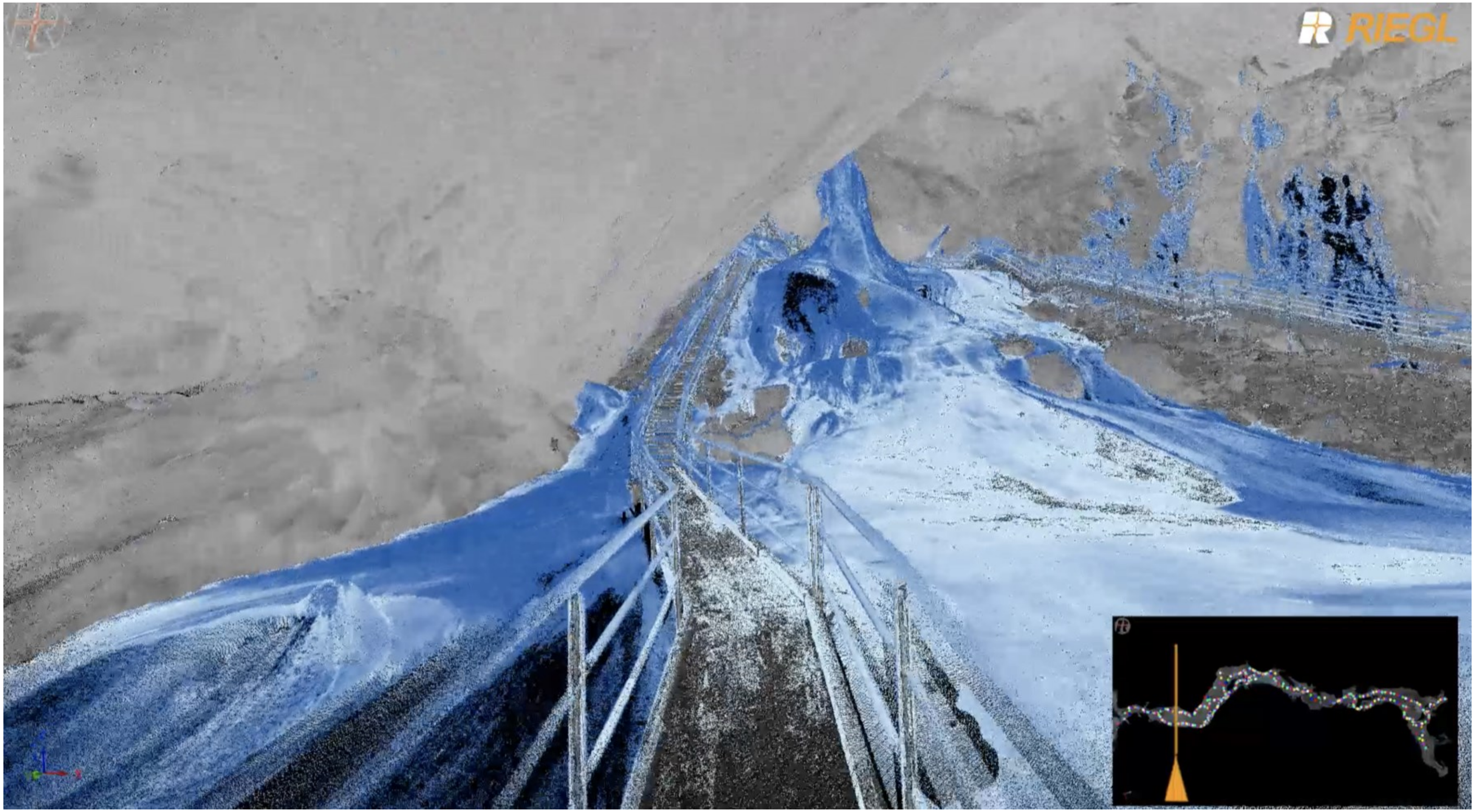
example outdoors - Hainburg

Hainburg – Austria, castle hill, at Danube between Vienna and Bratislava, a.d. 1050



example ice cave

Eisenriesenwelt Werfen – Austria, largest accessible ice cave worldwide



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Thank You