PDRG Meeting JRPUG2022

Application of Dual-tree Complex Wavelet to Three-dimensional Point Clouds of Pavement Surfaces

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Agenda

1. Background
2. Theory of DTCWT Analysis
3. Validation in a Yard
4. Case Study at In-service Walkway
5. Summary

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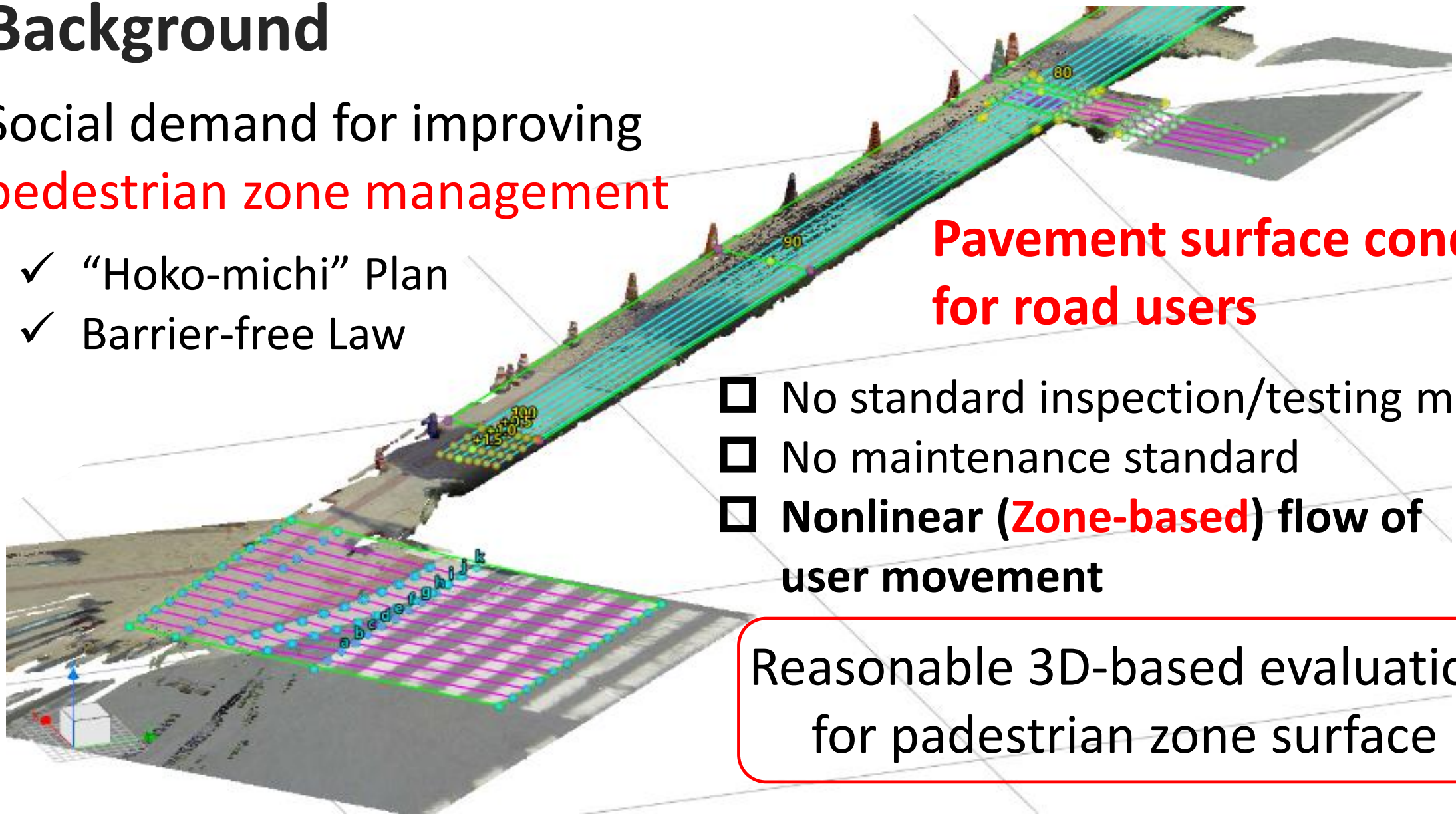
Background

Social demand for improving
pedestrian zone management

- ✓ “Hoko-michi” Plan
- ✓ Barrier-free Law



Pavement surface condition for road users

- ☐ No standard inspection/testing method
- ☐ No maintenance standard
- ☐ **Nonlinear (Zone-based) flow of user movement**

Reasonable 3D-based evaluation for padestrian zone surface

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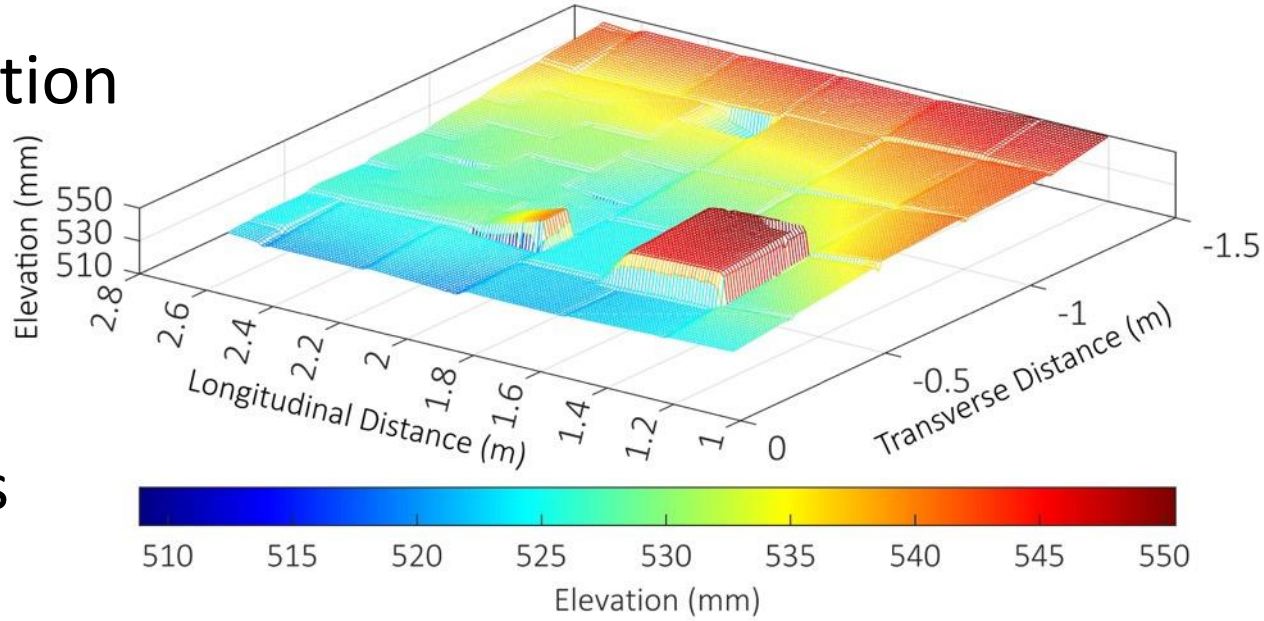
Bacground

■ Features of 3D-dased surface evaluation

- ○ include much information
- ○ detect localized irregularities
- △ identity the information required
- △ associate physical surface properties



Mathematical analysis of 3D point clouds based on

Dual-Tree Complex Wavelet Taransform (DTCWT)

- ☐ Effective and efficient data processing for 3D measurements (nonlinear)
- ☐ Diagnostic identification of wavelength, location, and direction (functional)
- ☐ Clear and theoretical evidence for the analysis (theoretical)

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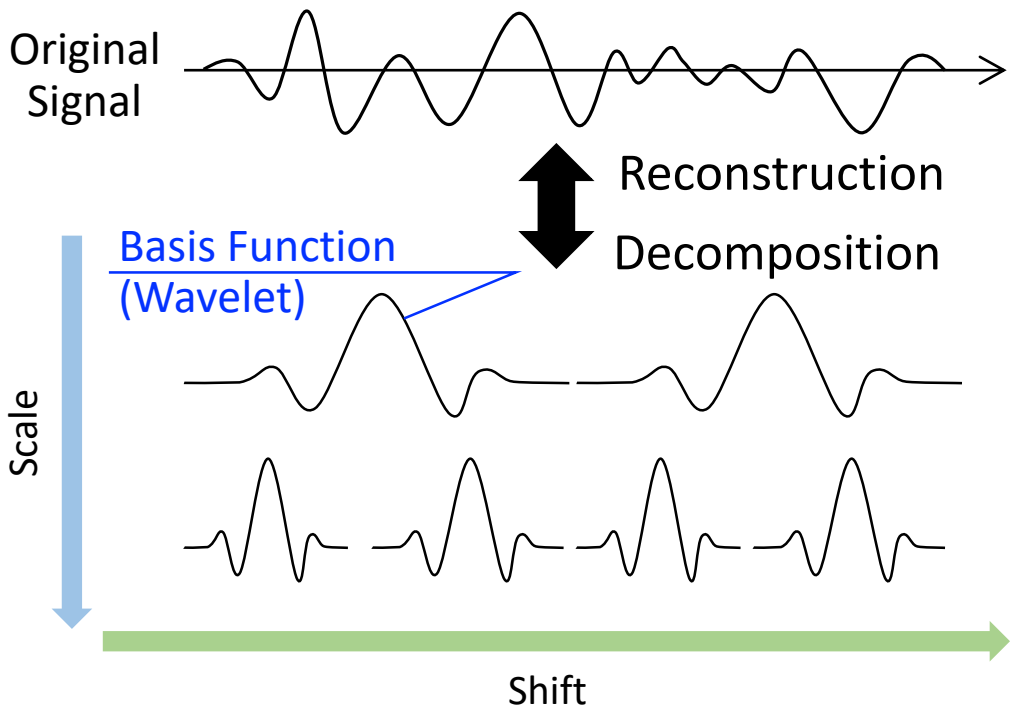
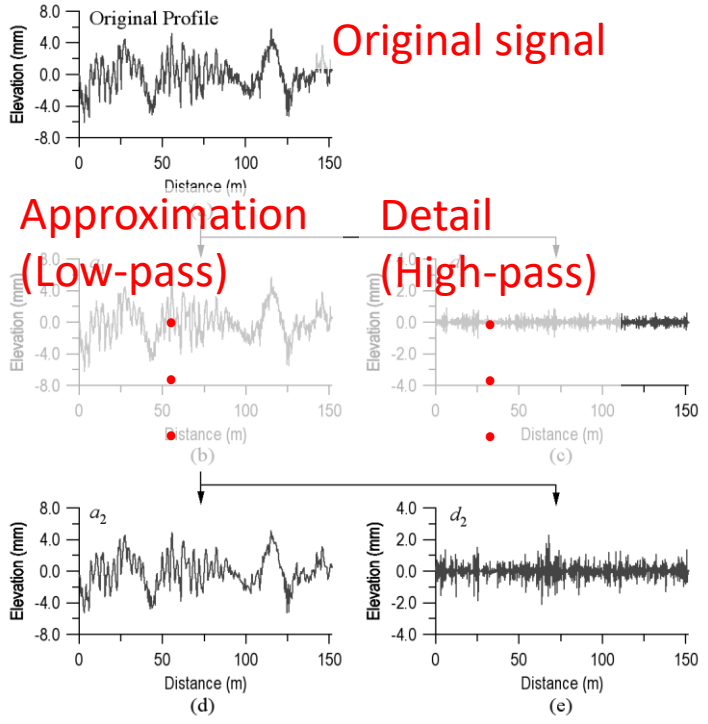
Theory of DTCWT Analysis

■ Idea of “Wavelet”



■ Multiresolution Analysis



Application to 3D Data (image/finger print)

- ✓ Denoising
- ✓ Data Compression
- ✓ Feature detection

- ✓ Analyze non-stationary wave by correlating with a small localized wave (wavelet)
- ✓ Implement spatial-spatial frequency analysis

Potential application to 3D point cloud analysis

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Theory of DTCWT Analysis

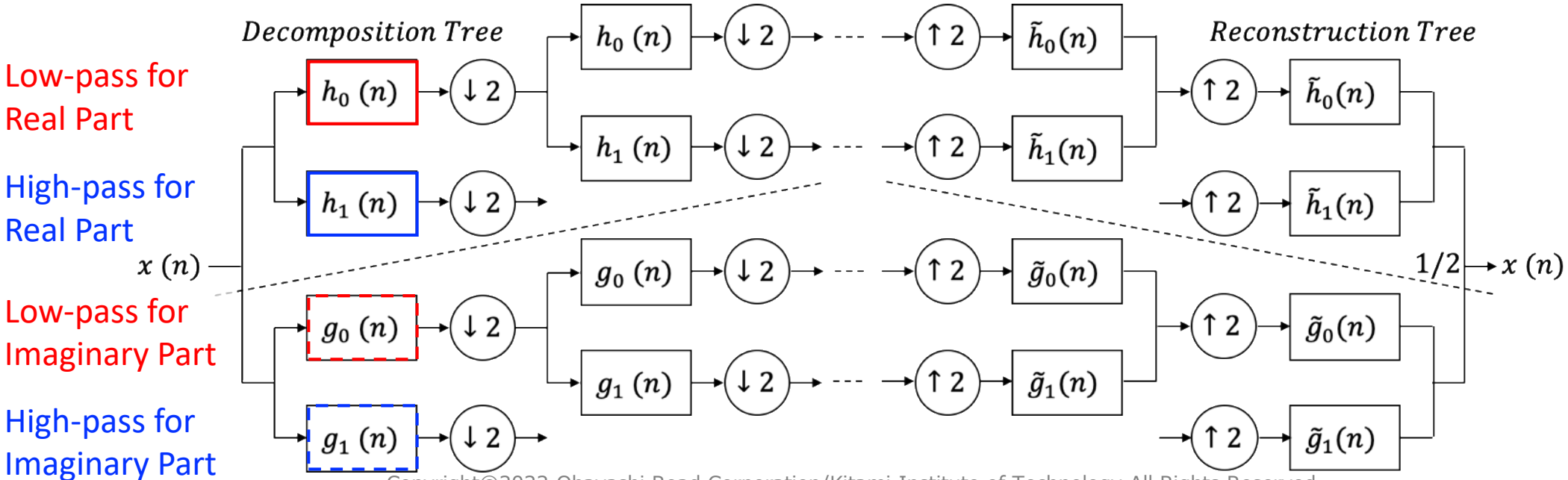
■ Decomposition and Reconstruction Tree

- ✓ Introduce complex numbers for the scaling function as same as Fourier Transform
- ✓ Realize approximately shift invariant analysis by a pair of decomposition trees

Wavelet function: $\psi_c(t) = \psi_{\mathrm{r}}(t) + \mathbf{i}\psi_{\mathrm{i}}(t)$

Scaling function: $\varphi_c(t) = \varphi_{\mathrm{r}}(t) + \mathbf{i}\varphi_{\mathrm{i}}(t)$

($\mathbf{i}$: imaginary unit)



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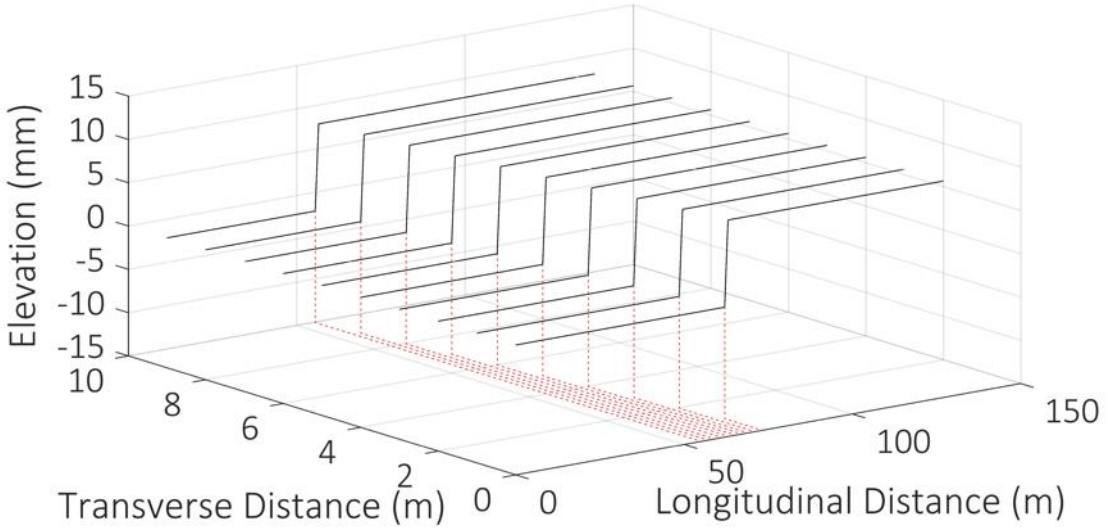
Theory of DTCWT Analysis

■ Approximately Shift Invariant Transform

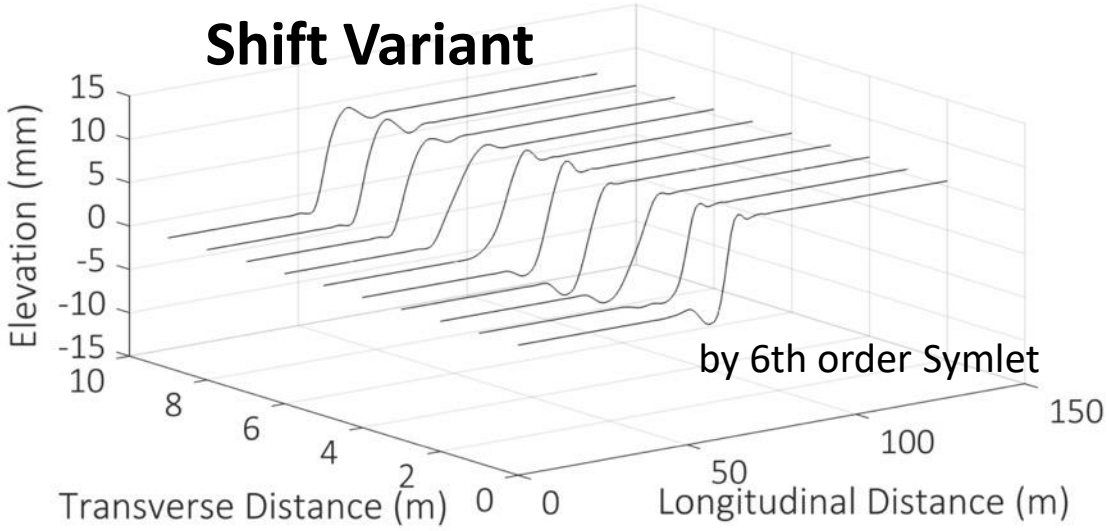
Step locations offset longitudinally
at an interval of 2 m



DWT

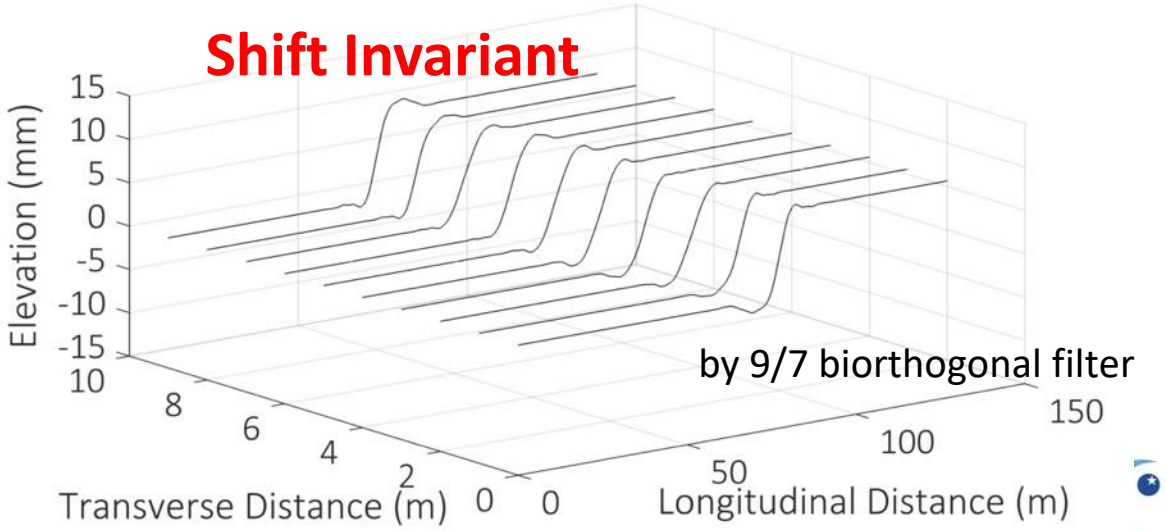
DTCWT

Shift Variant



by 6th order Symlet

Shift Invariant



by 9/7 biorthogonal filter

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Theory of DTCWT Analysis

■ Decomposition Level and Directionality

Diagnostic Points

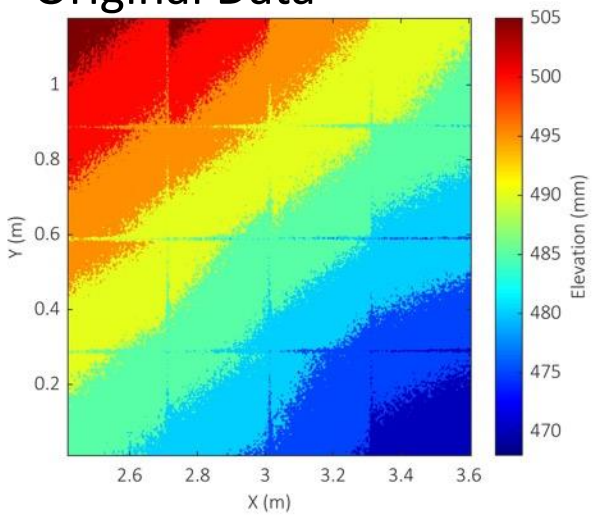
- ☐ Level 4 -> Edge fault
- ☐ Level 5 to 6 -> Joint fault
- ☐ Level 7 to 9 -> Unevenness

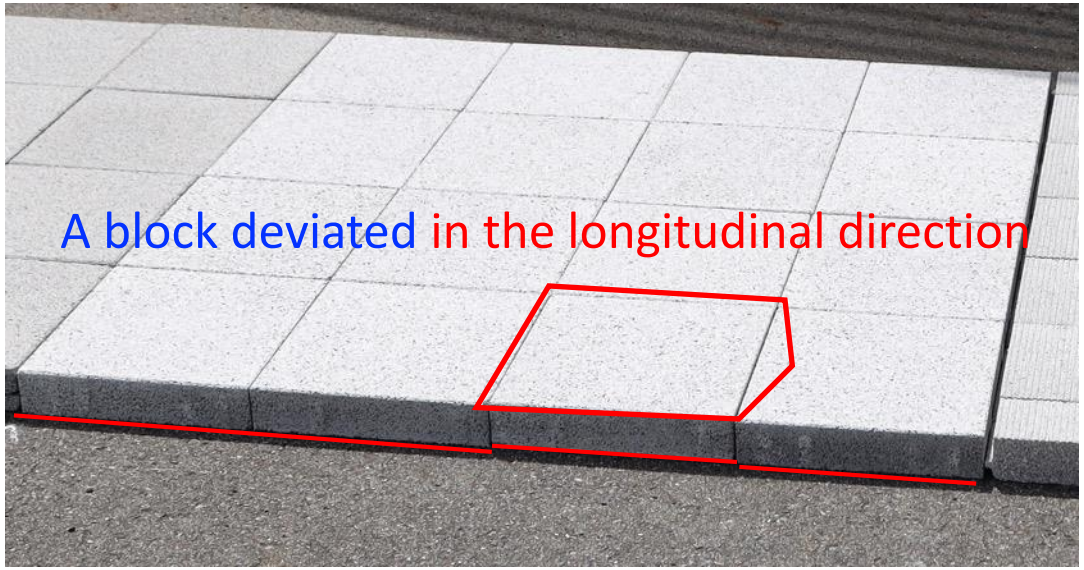
Integration of Level 4 and Level 7 to 9

⇩

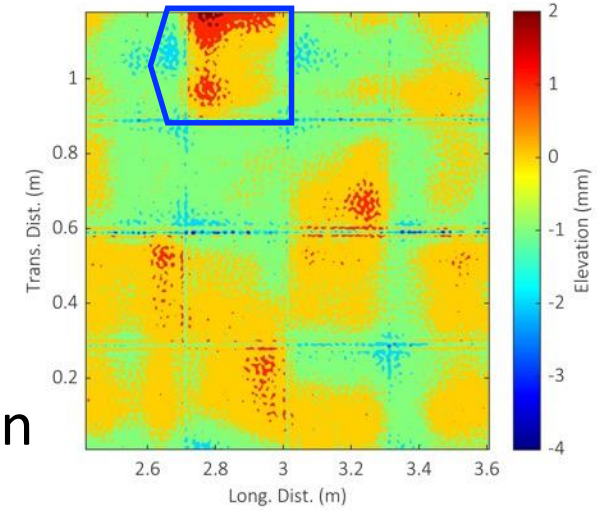
Functional Evaluation

Original Data

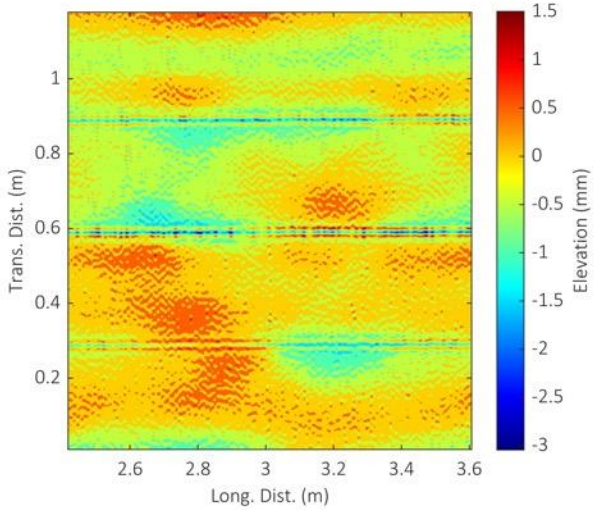




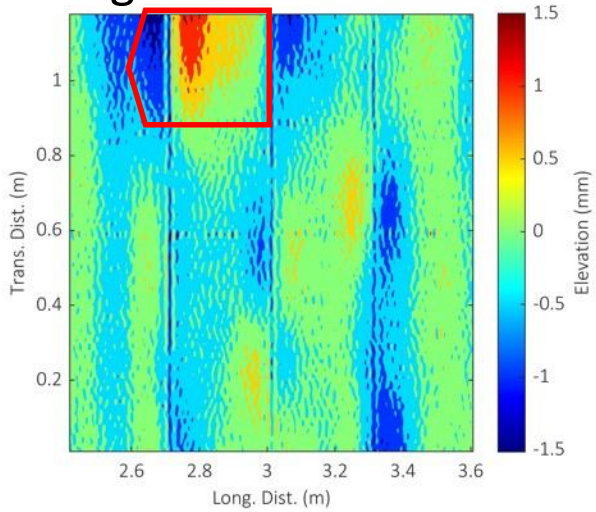
Omnidirectional



Transverse direction



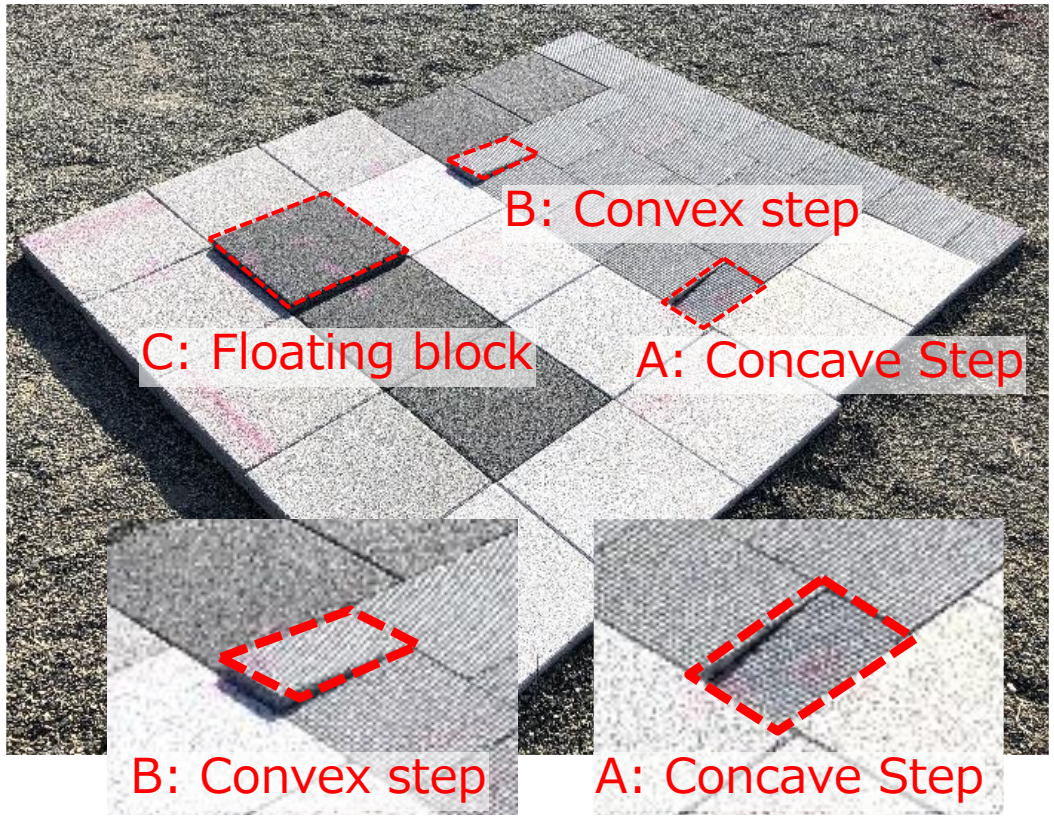
Longitudinal direction

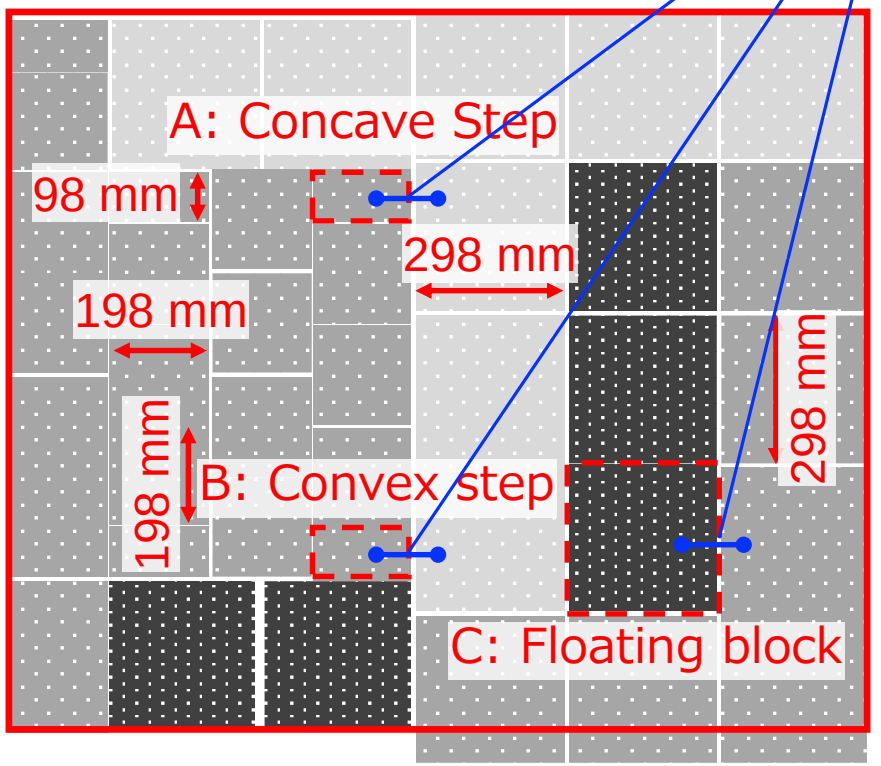


Validation in a Yard

■ Object for the Experiment

- Precast block pavement used in pedestrian zone
- Block height intentionally changing at the location A to C





Assumed displacement：5/10/20 mm

Processing area

Faulted block

Measurement line

Measured from 4 m away
(Instrument height: 1.2 m)

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Validation in a Yard

■ Employed Devices

- 3D Laser Scanner (TLS)
- Calipers (Resolution of 0.05 mm)
- Rod & Level (Resolution of 0.1 mm)

- Scan Density:
  3 mm @ 10 m
- Coordinate Accuracy:
  1.9 mm @ 10m
- Num of Scan Points:
  600K points

TLS (LeicaRTC360)

Step Measurement by Calipers

Leveling Survey

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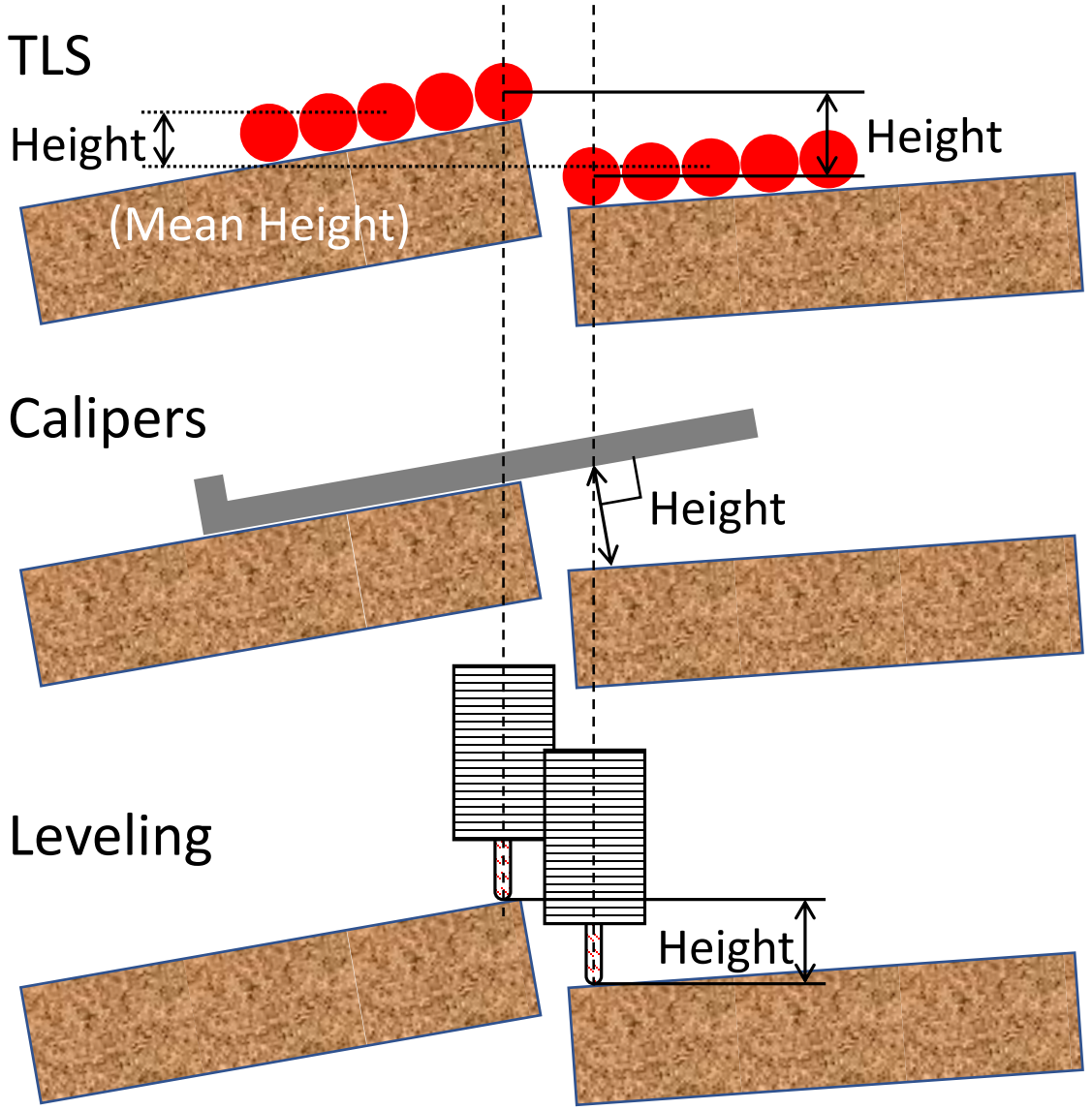
■ TLSの計測精度：平均1mm以内

Validation in a Yard

■ Accuracy: less than 1 mm in average

Measurement Results of Step Height

Position	Step Height (mm)			
	Nominal	TLS	Calipers	Leveling
A: Concave Step	5	6.00	5.90	6.1
	10	12.00	12.00	12.7
	20	20.00	20.40	20.2
B: Convex step	5	6.00	6.10	5.8
	10	13.00	12.90	12.2
	20	17.00	18.30	16.5
C: Floating block	5	3.00	3.50	2.7
	10	9.00	9.15	8.7
	20	19.00	19.10	18.8



Difference of Height Measurement

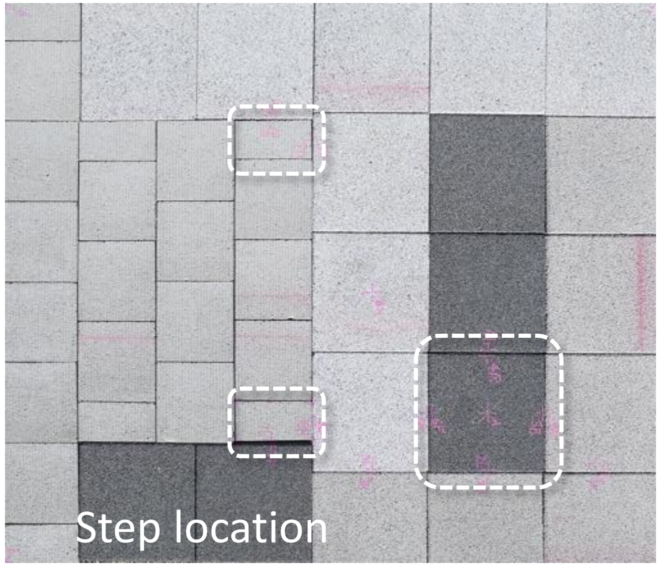
Validation Result

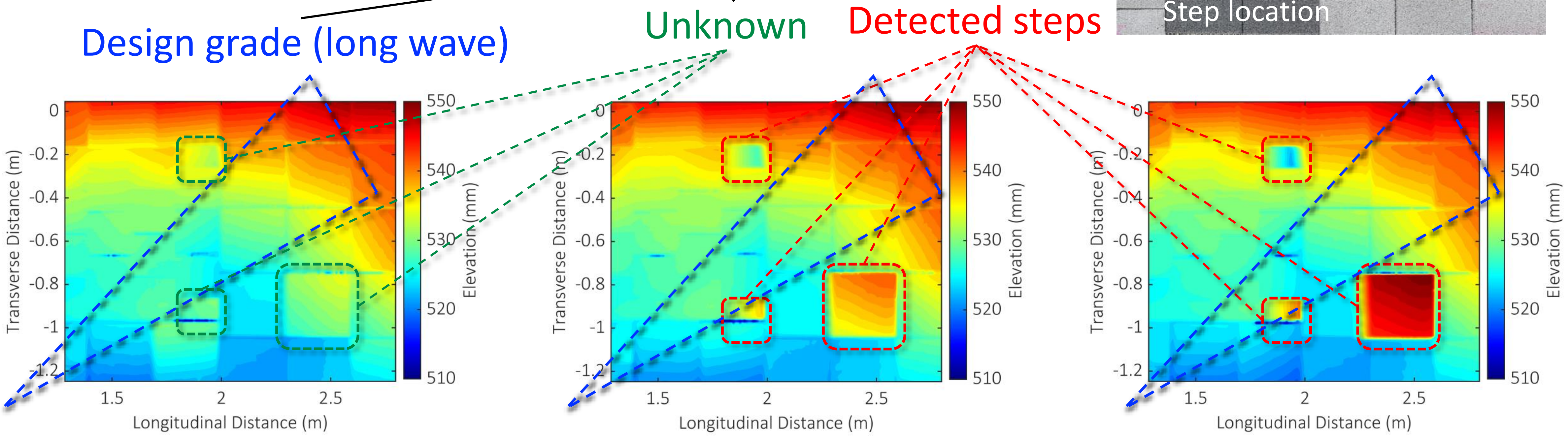
■ Pre-processing

- Convert to local coordinate
- Up/down sampling (constant interval of 0.01 m)

- Long wavelength -> High amp.
- Short wavelength -> Small amp.

=> Detecting wanted information





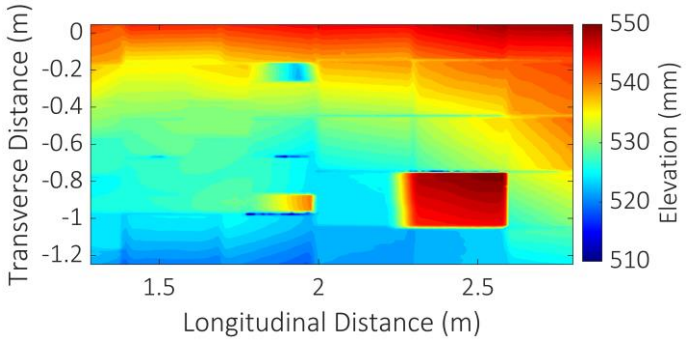
Step height: 5 mm

Step height: 10 mm

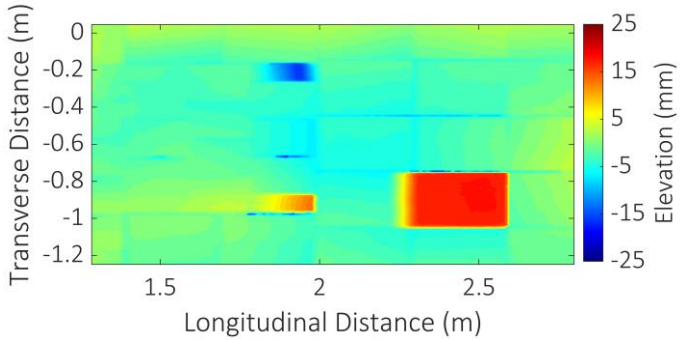
Step height: 20 mm

Validation Result

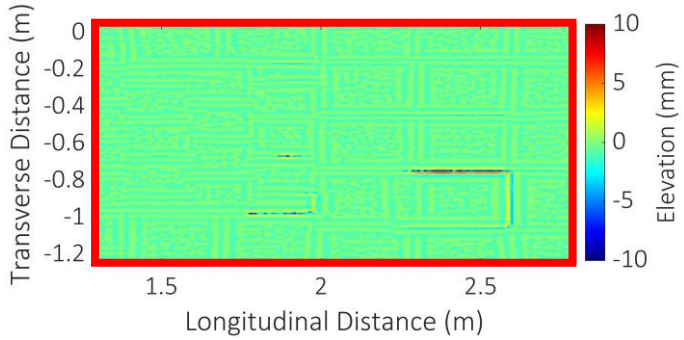
■ Multiresolution Analysis (Height 20 mm)



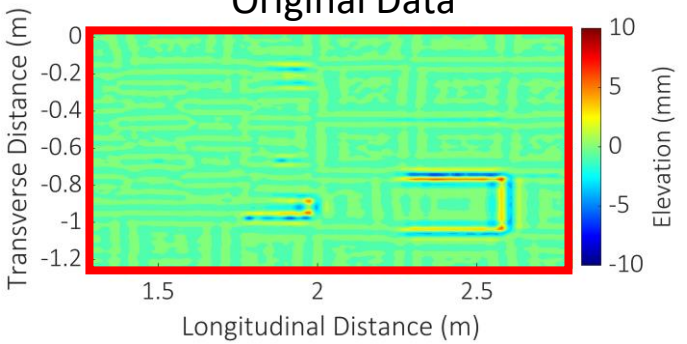
Original Data



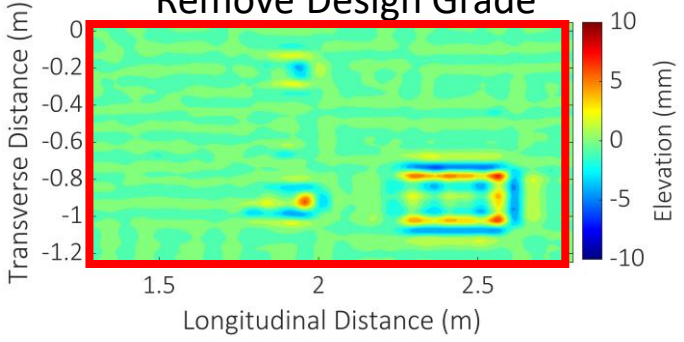
Remove Design Grade



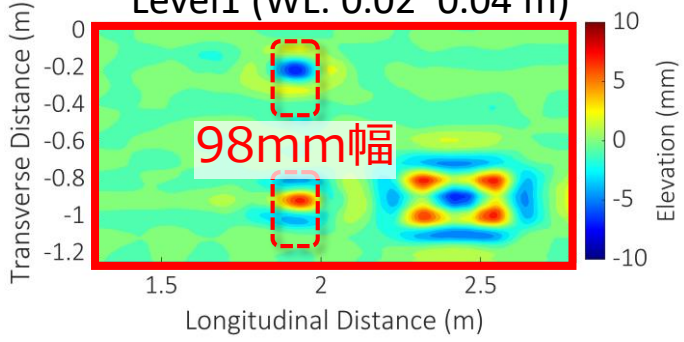
Level1 (WL: 0.02~0.04 m)



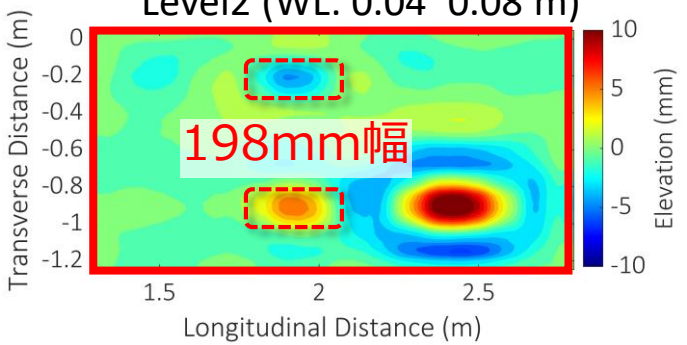
Level2 (WL: 0.04~0.08 m)



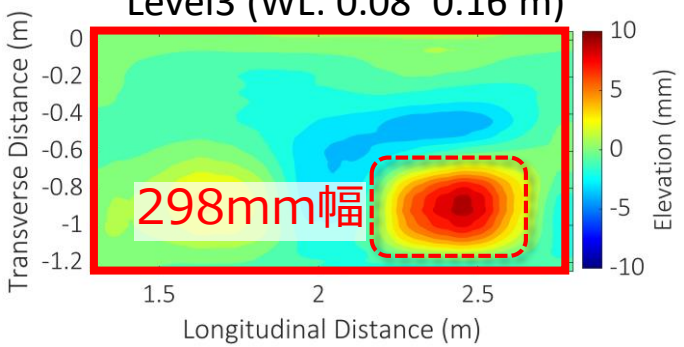
Level3 (WL: 0.08~0.16 m)



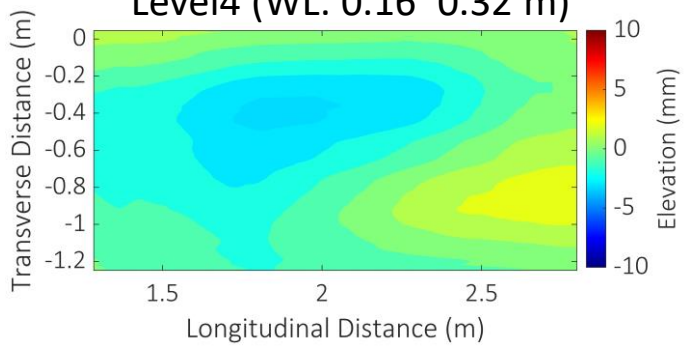
Level4 (WL: 0.16~0.32 m)



Level5 (WL: 0.32~0.64 m)



Level6 (WL: 0.64~1.28m)



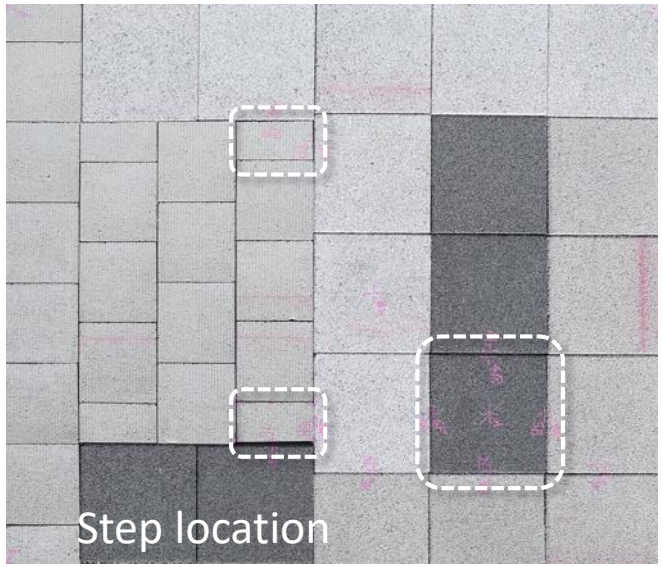
Level7 (WL: 1.28~2.56m)

Validation Result

■ Theoretical Step Identification

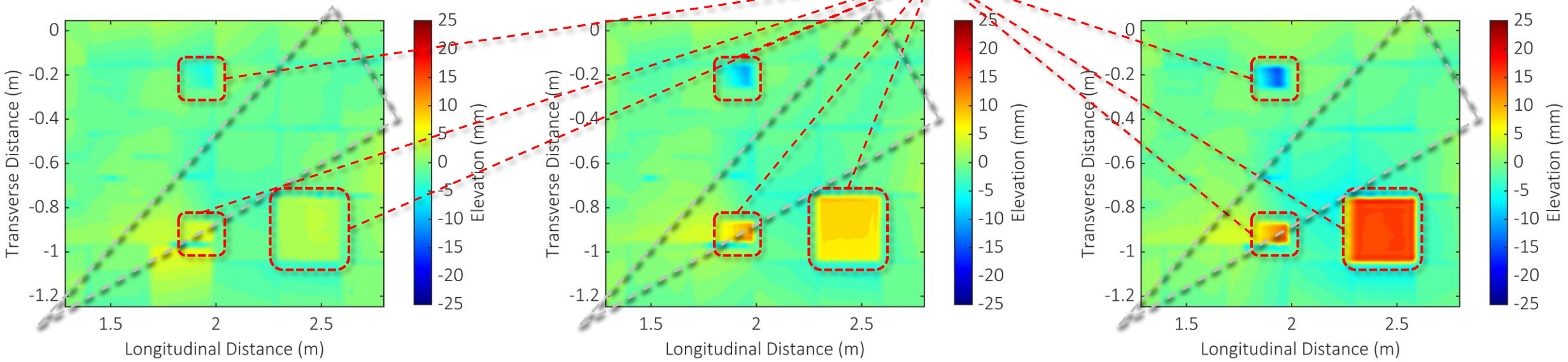
- Remove design grade
- Reconstruct Lev. 1~6

Theoretical Detection and Visualization



Detected steps

Design grade (long wave)



Step height: 5 mm

Step height: 10 mm

Step height: 20 mm

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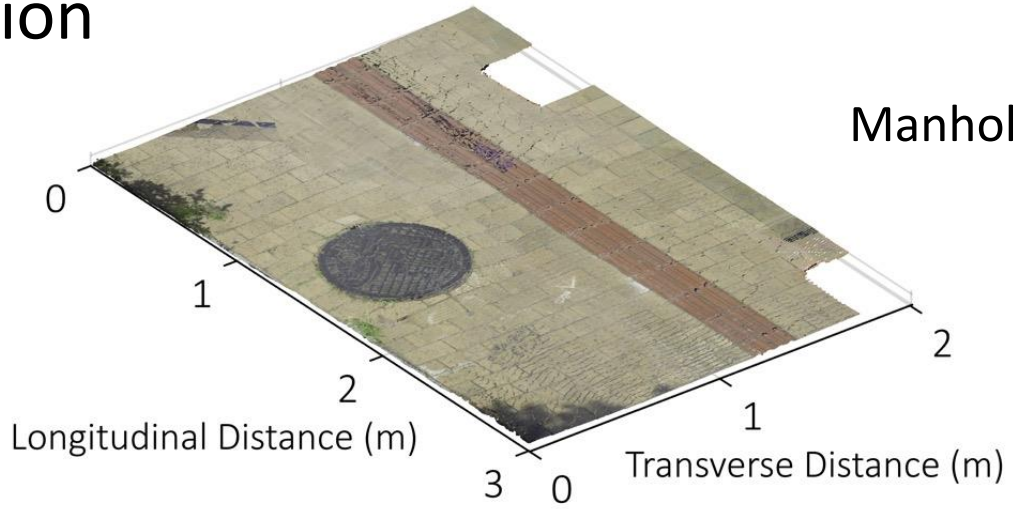
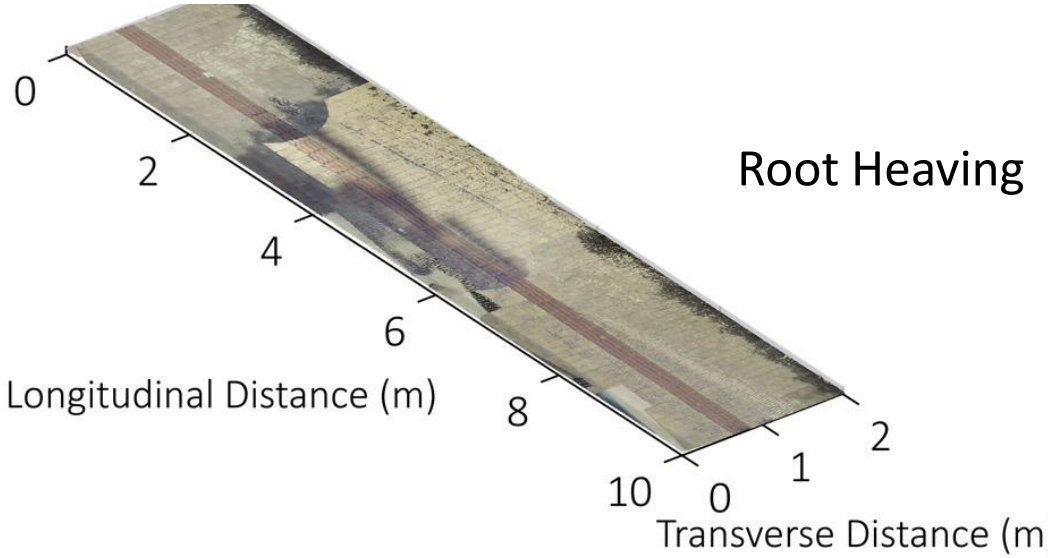
Case Study at In-service Walkway

■ Manhole and root heaving identification

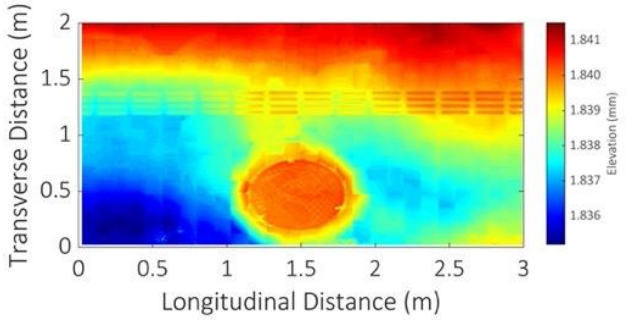
- In-service pedestrian zone
- Measured by mobility-mounted TLS



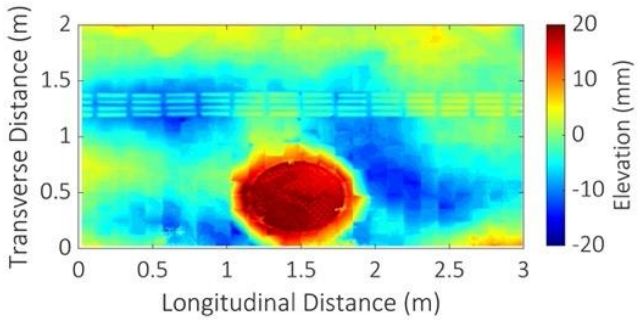


Result of Case Study

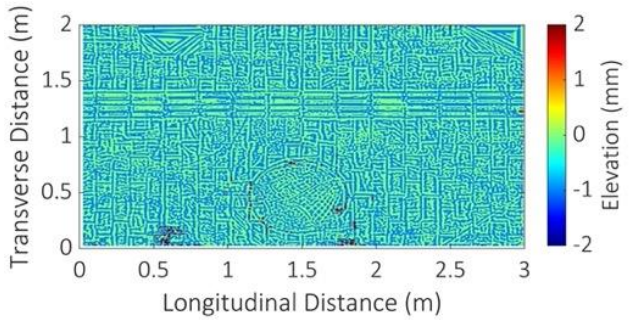
■ MRA of Manhole Measurement



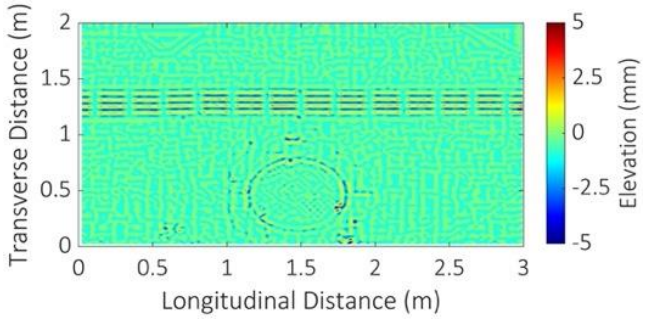
Original Data



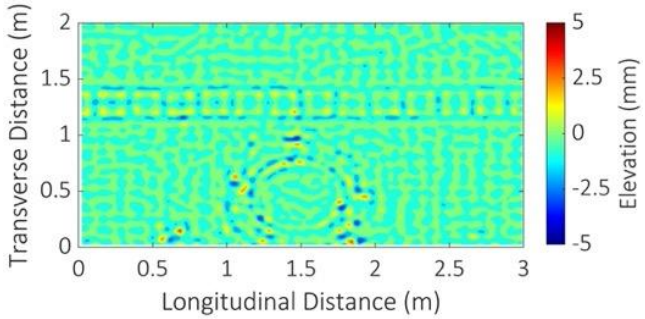
Remove Design Grade



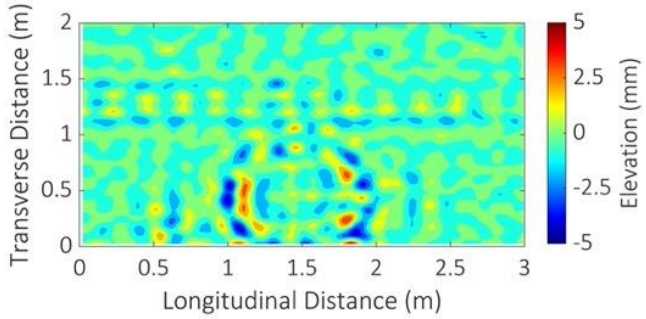
Level1 (WL: 0.02~0.04 m)



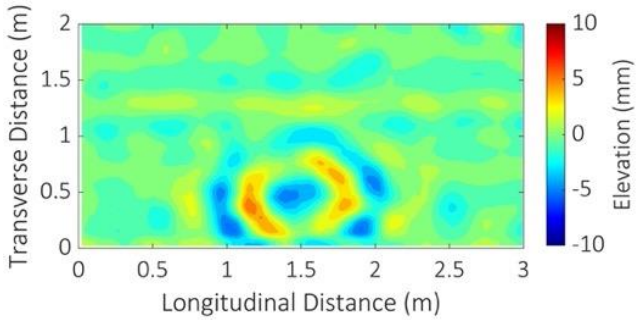
Level2 (WL: 0.04~0.08 m)



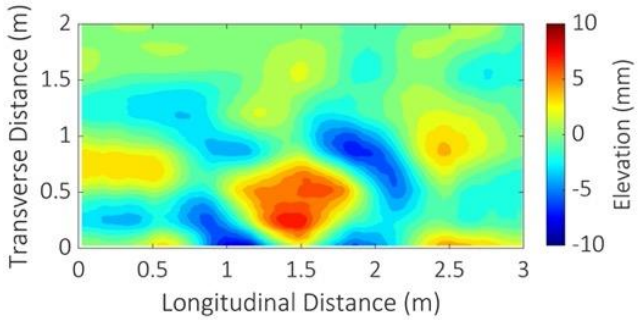
Level3 (WL: 0.08~0.16 m)



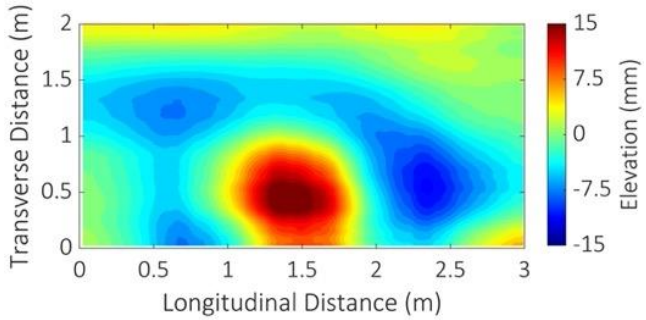
Level4 (WL: 0.16~0.32 m)



Level5 (WL: 0.32~0.64 m)



Level6 (WL: 0.64~1.28m)



Level7 (WL: 1.28~2.56m)

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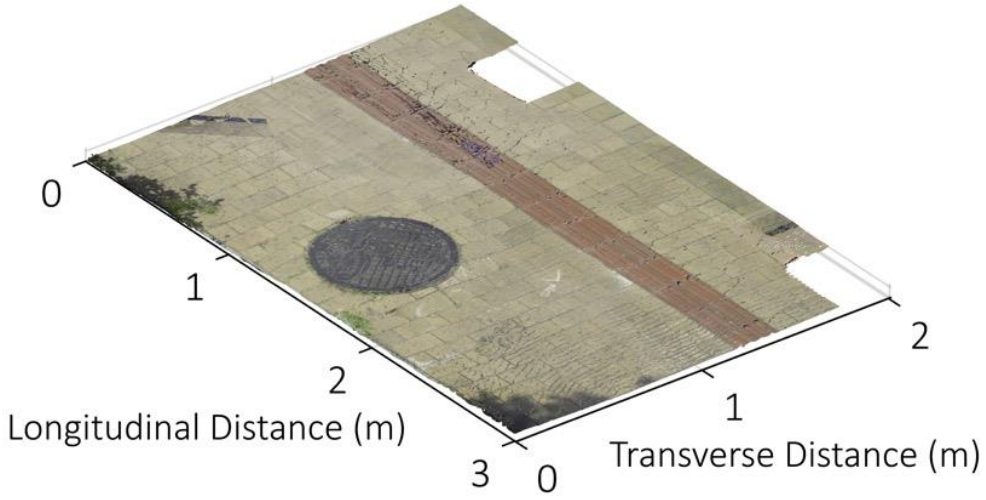
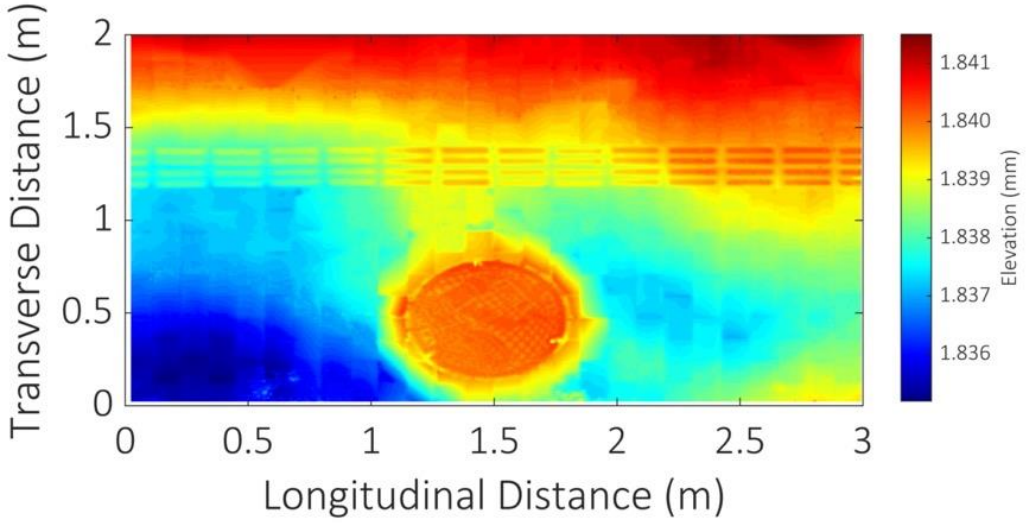
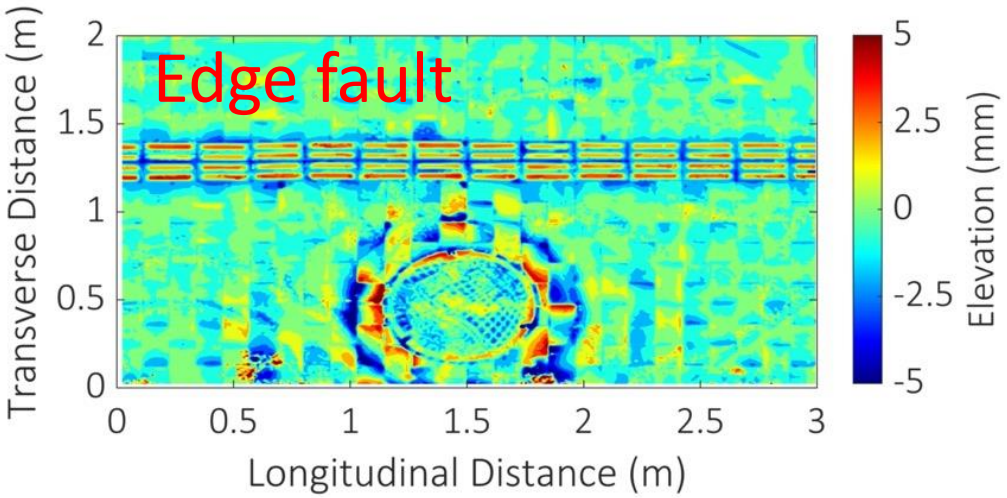
Result of Case Study

■ MRA of Manhole Measurement

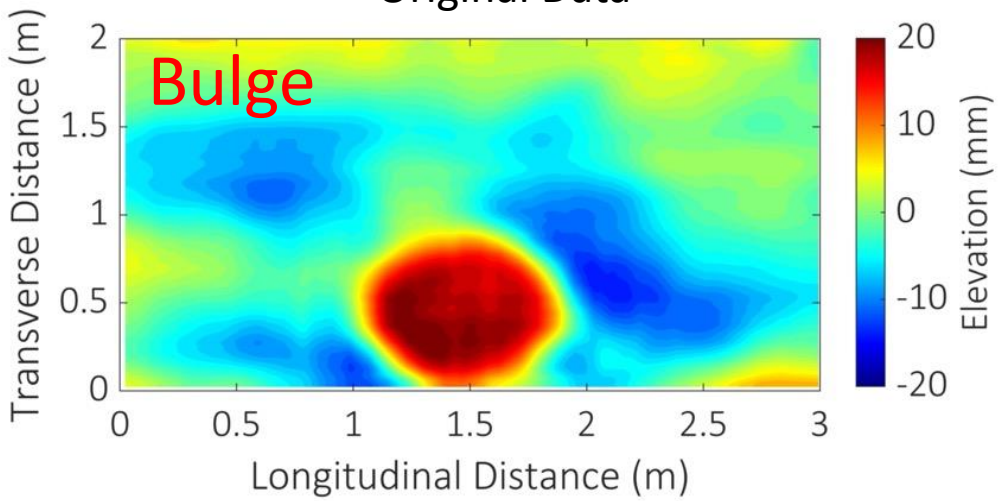




Original Data



Reconstruction of Details (Lev. 1~4)



Reconstruction of Approximations (Lev. 5~7)

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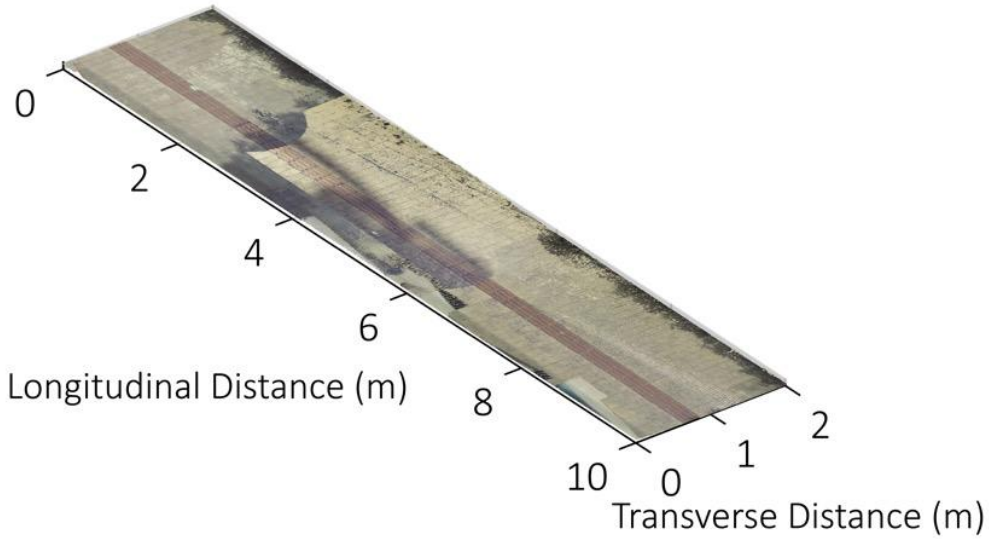
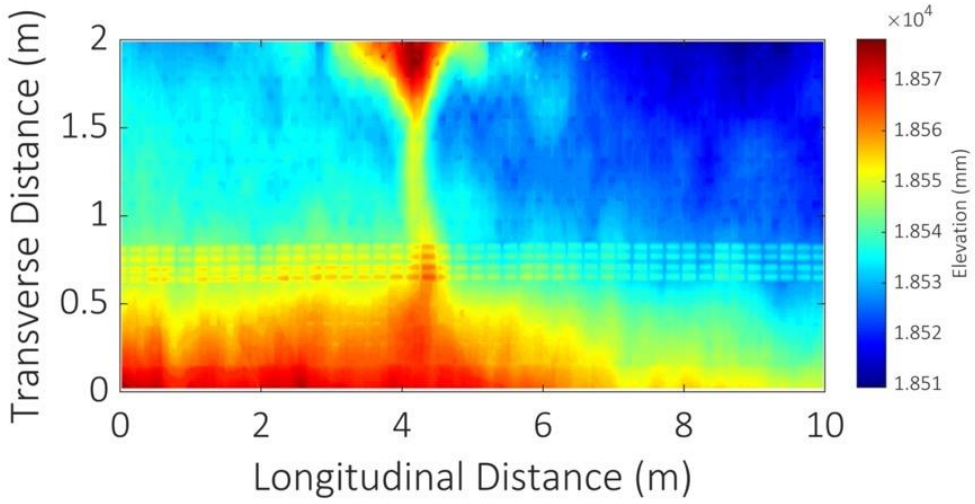
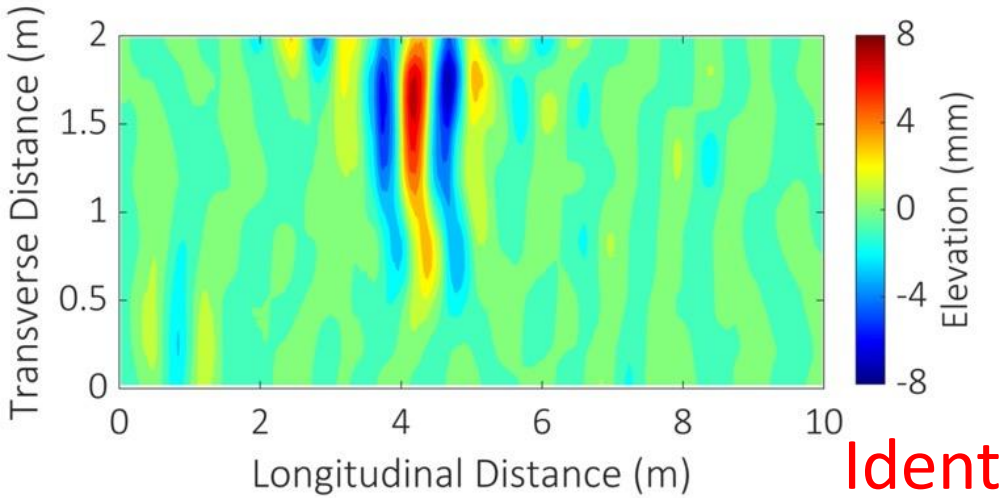
Result of Case Study

■ Directional MRA for Root Heaving



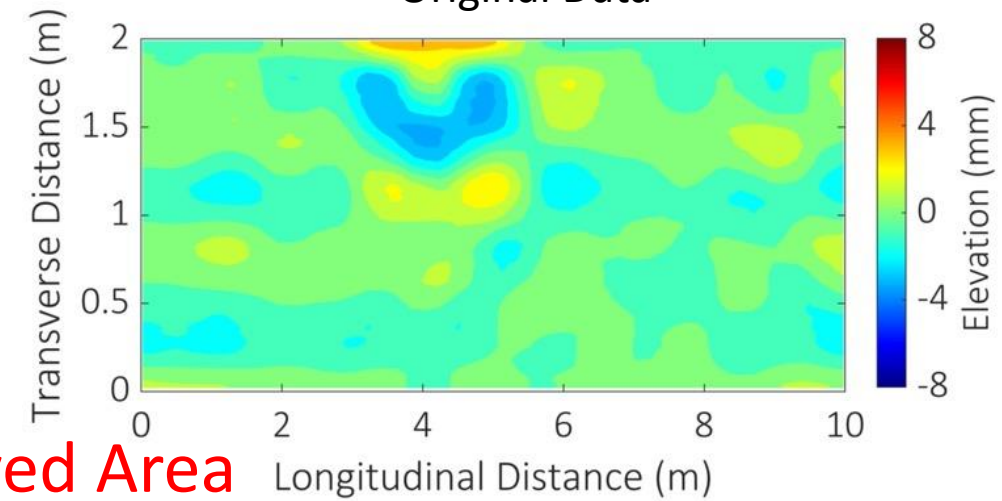


Original Data



For Longitudinal Direction (Lev. 6)

Identify Heaved Area



For Transverse Direction (Lev. 6)

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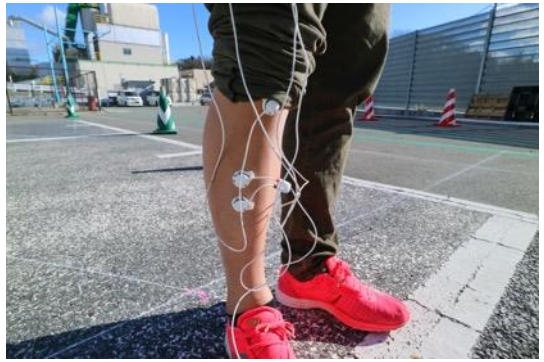
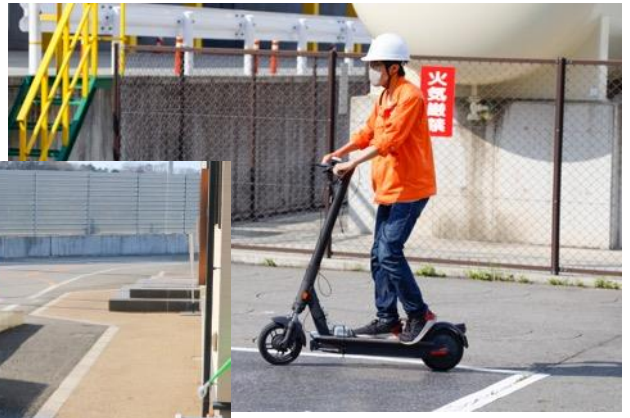
Summary

Safe and comfortable zone for pedestrian and mobility users



Myoelectric Potential



E-scooter

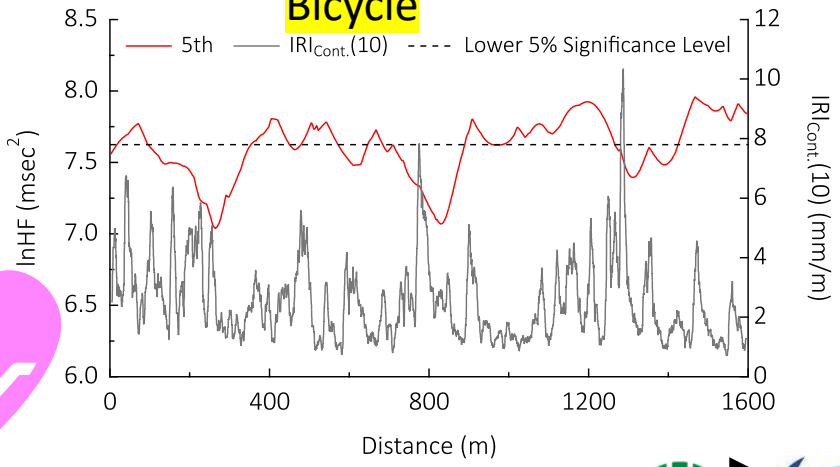
Bicycle

Four wheel mobility

Wheelchair

Pedestrian

Physiological Info



Fast/Long

Moving Speed/Distance

Slow/Short

Linear

Moving Direction

Non-Linear

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Summary

- High demand for the development of human-centered pedestrian zones
  - Improvement of safety and comfort for road users
  - Establishment of testing method and maintenance criteria dedicated to the surface of pedestrian zones
- Zone-based evaluation by DTCWT with 3D surface point clouds
  - Efficient processing and effective analysis of 3D data
  - Waveband-based theoretical detection and visualization of surface irregularities
- Challenges in the future
  - Development of a functional index based on viewpoints of safety and comfort for road users and state-of-the-art devices

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PDRG Meeting JRPUG2022

Thank you for your kind attention!!

Questions?