"Technical Research and Development for Road Policy Quality Improvement" Study Summary

No.	Title	Principal Researcher
No.31 - 6	High-precision and high-speed detection of floating and spalling damage on tunnel surfaces using analytical signal processing	Univ. of Tokyo Prof. Tetsuya ISHIDA

The objective of this research is to develop a technology to detect concrete floating and spalling on tunnel surface and other structures using point cloud data. The research results will be implemented in society as a technology that will lead to more efficient and productive tunnel inspections by conducting inspection and diagnosis with high speed, realize repairment in a quasi-real-time, not only with high accuracy, but also by detecting floating and spalling at high speed through automated processing.

1. Backgrounds and Objects

With the aging of infrastructure structures and the decline in the productive population due to the low birthrate and aging population in Japan, there is a need for further efficiency in maintenance and management. In particular, the inspection of tunnels has become an urgent need to improve the efficiency of inspection work, as close visual inspection has become mandatory for periodic inspections.

The objective of this research is to develop a new technology that enables detection of concrete floating and spalling in tunnels and other facilities from point cloud data.

- Measurement technology: Development of measurement technology utilizing a laser ranging device that captures damage of 1,2 mm or more in thickness.
- Analysis technology: Development of analysis technology to detect floating and spalling from point cloud data with a detection rate of about 80%.
- Analysis technology: Development of technology that completes analysis in about 2 days after measurement.
- Technical Verification: Confirmation of applicability under different conditions such as region, construction method, etc.

2. Activities in Research Period

(1) Measurement technology (hardware)

A high-precision laser ranging device with sub-millimeter thickness detection capability was selected, and a vehicle-mounted laser measurement system based on this device has been developed. The system has already been installed in several demonstration field measurements, and has successfully captured floating of 1 mm or more and spalling of 2 mm or more.

(2) Analysis technology (software)

The algorithm has been improved based on the road surface deformation evaluation algorithm developed by this research team in previous studies. The improved analysis algorithm was applied to several demonstration fields, and a detection rate of more than 80% (number of damages detected/number of damages confirmed by hammering tests) was confirmed in all fields. In addition, the high-speed signal processing made it possible to detect damage at a maximum speed of 10 seconds per meter.

(3) Technology Verification

We have conducted hammering tests in actual fields with multiple construction methods and surface conditions, and compared and verified the results with the analytical results. The applicability of the technology was verified in a field with a smooth surface, which was originally planned, and in a field with severely deformed surface of non-damage origin, which was requested after the start of the research, and it was confirmed that the technology is capable of highly accurate detection under various conditions.

3. Study Results

(1) Selection of laser ranging device and development of measurement vehicle system

The detection of floating and spalling by a laser ranging system is highly dependent on the accuracy of laser ranging (accuracy of irradiation direction), and a laser ranging system with sub-millimeter ranging accuracy is necessary to detect damage of 1 or 2 mm in thickness by moving measurement. Figure 1 shows the results of mobile body measurement of a specimen by thickness using a phase-shift laser scanner with a ranging accuracy of 0.4 mm*1, confirming a detection capability of 1 mm in thickness. In addition, a vehicle system equipped with this sensor was built, and laser measurements were conducted at each verification field.

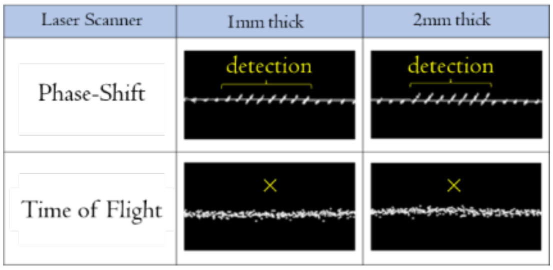

Figure 1. Measurement results of the specimen

(2) Development of an algorithm to detect floating and spalling by analytical signal processing

Therefore, in order to detect sections with large amplitude waveforms, we first calculated the "absolute value of the analysis signal obtained by the Hilbert transform (waveform envelope)" along longitudinal and transverse lines respectively, which enables estimation of amplitude modulation characteristics. By determining that the envelope value above a certain threshold value is damage and below that threshold value is non-damage, candidate damage sections were estimated robustly and efficiently. These processes were performed continuously in the longitudinal and transverse directions of the tunnel to estimate the reference plane, and the three-dimensional shape of the local irregularities on the tunnel surface was extracted by subtracting the reference plane from the original data. Furthermore, it is now possible to distinguish damage from attached structures based on the characteristics of the 3D shape, and to extract only the damage.

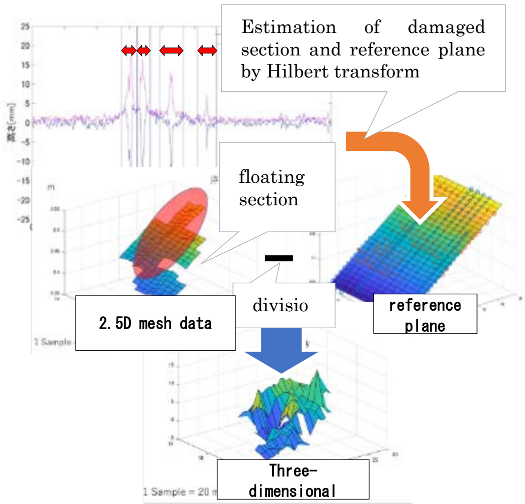

Figure 2. 3D shape extraction of damage

(3) Verification of practicability

The practicability of this analysis algorithm were verified by comparing the analysis results with hammering test results in tunnels with different construction methods and surface conditions. It was confirmed that the detection rate of more than 80% was obtained. We were also able to demonstrate the high practicability of the algorithm, which can control the analysis accuracy and processing time by changing the measurement pitch (point density) of the 3D point cloud data.

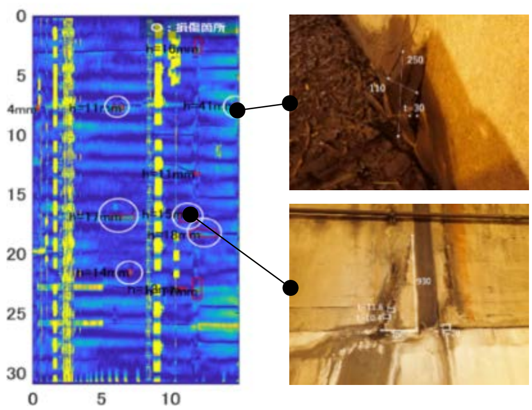

Figure 3. Verification in the demonstration field

4. Papers for Presentation

- T. Mizutani, T. Yamaguchi, T. Kudo, K. Yamamoto, **T. Ishida**, Y. Nagata, H. Kawamura, T. Tokuno, K. Suzuki, and Y. Yamaguchi, "Quantitative Evaluation of Peeling and Delamination on Infrastructure Surfaces by Signal and Image Processing of 3D Point Cloud Data," Automation in Construction (Elsevier), pp. 1-10, 2021. (DOI:

10.1016/j.autcon.2021.104023) (Impact Factor: 7.700, Cite Score:12.0)

- Tomoaki Tokuno, Yoshifumi Nagata, Hinari Kawamura, **Tetsuya Ishida**, Tsukasa Mizutani, Junko Yamashita, 2-Dimensional Innovative Pavement Evaluation via Mobile Mapping System, 16th REAAA Road Conference, June 15-17, 2021, Manila
- Tsukasa Mizutani, Toratsugu Kudo, Kazuho Yamamoto, Takahiro Yamaguchi, **Tetsuya Ishida**, Yoshifumi Nagata, Hinari Kawamura, Tomoaki Tokunoh, Hiroya Yamaguchi, Kiyoshi Suzuki, Detection of Floating and Spalling on Infrastructure Surface by Analytical Signal Processing of MMS Point Cloud Data, 34th Road Conference, Inspection Session 709, No.6035, 2021. (in Japanese)

5. Study Development and Future Issues

In order to deploy this technology in other countries, it is necessary to accumulate data from various regions and improve the algorithm to make it more robust. For example, developing countries are thought to have more shape changes in infrastructure surfaces than Japan, and there is a great potential for this technology to be used in other countries by repeatedly improving data measurement, analysis, and verification.

6. Contribution to Road Policy Quality Improvement

By switching the measurement conditions according to the required speed and accuracy, we believe that the system can be used for both screening and main inspection.

7. References, Websites, etc.

https://mizutanilab.iis.u-tokyo.ac.jp/archives/602