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

No.	Title	Principal Researcher
No.2010 - 10	Development on the identification of cavity and rebar corrosion using complex permittivity quantitative imaging by the fusion of microwave radar and tomography.	Univ. of Electro-Communications, Professor, Shouhei Kidera

In order to realize non-destructive quantitative inspection of road interiors by microwave, we have developed an image analysis method that can identify anomalies such as cavities and leaks in road interiors and estimate target complex permittivity, position and shape information with high accuracy, for the purpose of constructing an integrated method of radar, tomography and deep learning, and verified it by experiments on road specimens and real roads. Research and development to validate the method with experimental data on a road sample and actual road.

1. Backgrounds and Objects

Microwave nondestructive road evaluation is promising as a rapid and large-scale screening technique with non-contact measurement. On the other hand, the conventional microwave radar method for roads and bridges can predict only the location and shape of cavities and rebar, but it is extremely difficult to identify electric properties of buried anomaly object, because the radar cannot extract complex permittivity. Thus, the identification performance of this technique can be dramatically improved by reconstructing the complex permittivity profile with high accuracy. In order to solve the above problem, this project aims to develop a technology platform that integrates radar and tomography methods to achieve both highly accurate shape estimation (within 10 mm) and complex permittivity estimation (within 20% relative error). We will also develop an anomaly identification method by deep learning of radar data, and establish an innovative microwave-based road inspection technology.

2. Activities in Research Period

In order to achieve the above objectives, two tasks were carried out in parallel in this project: (1) Imaging complex permittivity profile by integrating radar and tomography, and (2) Development of anomaly detection method using deep learning. In (1), the region of interest is first narrowed down using radar images, and the tomography method is applied within the same region to improve the accuracy of dielectric constant estimation by alleviating ill-posed condition that the number of data is much less than that of unknowns. Furthermore, the accuracy of the radar image is improved by using the initial estimate for post-tomography optimization method. In task (2), to identify cavities and leaks between the floor plate and pavement directly from radar data, an effective rebar response suppression method is used as a preprocessing, and data compression and nonlinear clustering methods based on time-frequency data and deep learning are used to quantitatively evaluate anomalies inside the roadway.

3. Study Results

In the first task, the accuracy of complex permittivity estimation was greatly improved by applying the CSI (tomogpraphy) method with the RPM (radar) method (Fig. 1). Furthermore, the evaluation of the actual specimen shows that the initial dielectric constant evaluation based on the CSI cost function can eliminate the local optimization problem caused by the ill-posed condition (Figure 2). The results show that the dielectric constant of water area between the pavement and the floor board can be estimated with an error of about 10 %, and its localization error is within 20 mm. This accuracy is hardly achieved by the conventional tomography, and is sufficient for quantitative diagnosis. In the second task, we investigated the anomaly detection scheme for the roadway of the Shin-Tonegawa Bridge in

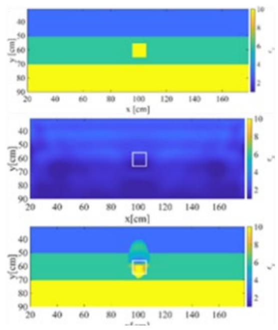

Fig. 1: Permittivity reconstruction results by the traditiona (mid) proposed method (bottom)

Ibaraki Prefecture (with a free lime area in the lower part), and confirmed that the method can quantitatively evaluate abnormal locations caused by water leakage and cracks in the roadway by using data acquired with existing hardware, and are expected to be quickly deployed in real-world applications.

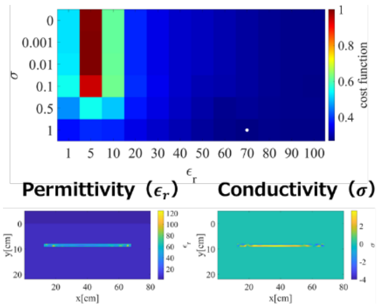

Fig. 2 : Initial estimate (upper). Final reconstruction (lower)

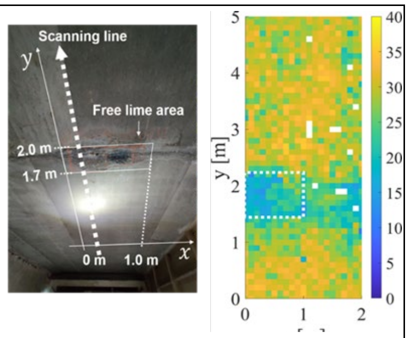

Fig.3 : Free lime area (left). Anomally detection results (right)

4. Papers for Presentation

[1] Yoshihiro Yamauchi and **Shouhei Kidera**, "Contrast Source Inversion for Objects Buried into Multi-layered Media for Subsurface Imaging Applications", IEICE Trans. Electron., Vol. E106.C, 2023.

[2] Shuto Takahashi, Katsuyuki Suzuki, Takahiro Hanabusa and **Shouhei Kidera** "Microwave Subsurface Imaging Method by Incorporating Radar and Tomographic Approaches", IEEE Trans. on Antennas and Propagation, vol. 70, no. 11, pp. 11009-11023, Nov. 2022

[3] Takahiro Hanabusa, Takahide Morooka and **Shouhei Kidera**. "Deep Learning Based Calibration in Contrast Source Inversion Based Microwave Subsurface Imaging", IEEE Geoscience and Remote Sensing Letters, vol. 19, pp. 1-5, 2022.

5. Study Development and Future Issues

Based on the results of Problem 1), it can be put to practical use as a technology that can quickly and quantitatively (complex permittivity value) estimate the condition of the road interior in large areas using microwaves, rather than qualitatively. This will enable us to establish a more efficient and reliable monitoring technology for long-term maintenance of road quality by presenting the spatial distribution of internal water retention and cavity cracks that cause road delamination and free lime. The method developed in Problem 2) can be used in the field immediately because it identifies anomalies directly from radar data, which reduces processing time and does not require hardware modification. In addition, it is possible to construct an anomaly identification method for rebar using the rebar response that is incidentally obtained during rebar response suppression. Therefore, since the method can be applied immediately to the radar data already acquired for (2). In addition, the complex permittivity estimation method proposed in (1) may be applied to the anomaly location for more accurate and quantitative anomaly identification in the future.

6. Contribution to Road Policy Quality Improvement

As described in Section 5, Issue (2) can be applied immediately to already acquired radar data and can be handled by existing hardware, so the research results can be expected to be reflected in practice promptly. For issue (1), it is necessary to narrow down the area and increase the speed for analysis of larger areas as described in issue (2) in order to reach a practical level. As a simpler and more practical method for estimating complex permittivity, a method focusing on the characteristics of rebar response is proposed in Problem (1), and we believe that it can capture an overview of the anomaly area by estimating the permittivity of the area, where the rebar exists. This additional technique (dielectric estimation using radar images) can be applied to large areas, and the processing time can be reduced to a few seconds because it is based on radar image processing. By applying these methods, it is possible to quantitatively evaluate the average dielectric constant of the interior, which cannot be obtained from current radar images, and use it to determine the presence or absence of cavities or leaks. In the future, it will be necessary to verify the effectiveness of this method by applying it to actual radar data.

7. References, Websites, etc.

http://www.ems.cei.uec.ac.jp/