公益財団法人 セコム科学技術振興財団
研究成果報告書

研究課題名

弾性波動論と AI の融合による完全非接触レーザー超音波非破壊検査システムの開発

Development of non-contacting laser ultrasonic nondestructive testing by the integration of elastodynamic theory and AI

研究期間

令和２年　10 月　～　令和６年　９月

報告年月

令和６年　12 月

研究代表者

群馬大学大学院理工学府　環境創生部門　准教授
斎藤　隆泰

Department of Civil and Environmental Engineering, Gunma University, Associate Professor
Takahiro SAITOH

Abstract

Non-destructive testing is widely used for assessing the health of various structures and materials, ranging from social infrastructure such as bridges to nuclear equipment and aircraft. In particular, ultrasonic non-destructive testing (UT) has been widely used in the field of the non-destructive testing due to its convenience and the absence of adverse effects on human health compared to radiographic testing. However, UT has some disadvantages. For example, a coupling medium must be applied between the ultrasonic transducer and the test materials, and the ultrasonic transducer must be firmly pressed against the test materials to ensure proper propagation of the ultrasonic waves. Additionally, on-site ultrasonic testing for large-scale infrastructure requires rapid inspection over a wide area. Furthermore, understanding the complex ultrasonic waveforms to identify defects demands significant expertise from inspectors, raising concerns about a potential shortage of skilled personnel in the future. Thus, it is necessary to develop new ultrasonic non-destructive testing methods that address these limitations.

In this study, we aim to develop and apply a novel ultrasonic non-destructive testing method that overcomes the challenges of conventional UT methods. Specifically, we investigate the automation of Laser Ultrasonic Visualization Testing (LUVT), which is a technique that visualizes ultrasonic waves propagating along the surface of test materials, using machine learning and deep learning techniques. This study comprises following four main research contents.

Development of ultrasonic simulators: To visualize ultrasonic wave propagation in various materials, we develop ultrasonic simulators. Ultrasonic waves exhibit elastic wave properties in solid materials. Therefore, we have to numerically solve the elastic wave equation for visualizing ultrasonic wave propagation in isotropic, anisotropic, and heterogeneous materials. The simulators are based on time-domain methods such as the finite difference method (FDM), finite element method (FEM), and boundary element method (BEM). The choice of method depends on the material properties and the characteristics of the analysis domain.

Laser ultrasonic visualization testing: LUVT experiments are conducted for various materials, including aluminum and concrete, to understand their characteristics and to collect training data required for subsequent machine learning and deep learning processes. Additionally, numerical simulations for LUVT are performed using the developed ultrasonic simulators to verify their accuracy and effectiveness.

Application of machine learning and deep learning to LUVT: Machine learning and deep learning, which are basic technologies for AI, are applied to LUVT to automatically detect a defect in ultrasonic propagation images obtained by LUVT. When sufficient training data is unavailable, we try to

generate synthetic images equivalent to actual LUVT images using the developed ultrasonic simulator and image generation techniques such as style transfer.

Defect shape reconstruction methods: Techniques for reconstructing defect in isotropic, anisotropic and heterogeneous materials from received waveforms are developed. In particular, this study revisits tomographic theories traditionally used for assessing the integrity of concrete materials and proposes a new tomographic theory based on quantum algorithms.

Finally, the four main research contents are synthesized to present the conclusions and future challenges of this study. By integrating various deep learning techniques into LUVT, this research aims to establish a wide-ranging automated non-destructive inspection method. This study contributes to the advancement of NDE 4.0, the new non-destructive evaluation paradigm incorporating data science, currently under discussion in Europe and the United States. It also lays the foundation for the next-generation NDE 5.0.