学　位　論　文　内　容　の　要　旨

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学　位　論　文　題　名

A study on deep learning-based automatic defect detection for social infrastructure maintenance
（社会インフラの維持管理支援のための深層学習に基づく自動変状検出に 関する研究）

In recent years, developed countries, including Japan, have been grappling with the challenge of rapidly aging social infrastructure, which was built during periods of swift economic growth. It is projected that, over the next 20 years, there will be a significant increase in the proportion of infrastructure in Japan that is over 50 years old. Furthermore, the aging population has led to labor shortages and cost issues, which have subsequently resulted in a decrease in the number of inspectors. The process of training inspectors is time-consuming, and conducting non-destructive testing presents further challenges. Additionally, in specific scenarios such as plateau regions or environments requiring high-altitude operations and drilling platforms, technical expertise is required to automate the inspection process. Consequently, it is essential to develop methods that can alleviate the burden on engineers, reduce the overall cost of maintenance and management, and ensure the safety of existing facilities.

To address these challenges, Japan is actively promoting the use of IoT (Internet of Things), big data, artificial intelligence, and robots to support more efficient and advanced infrastructure maintenance and management. These initiatives are aligned with the government's strategy, with active research, development, and implementation projects underway for next-generation infrastructure. In the field of infrastructure maintenance and management, numerous methods have been proposed for automatic inspection using conventional defect detection and robots. However, despite the implementation of these methods, the final decisions regarding the necessary countermeasures for inspected locations still heavily rely on human judgment. As a result, there is a need for technologies that directly assist engineers in this decision-making process.

This thesis aims to develop a highly accurate defect detection method for infrastructure images by addressing three main challenges specific to infrastructure structures: support for high-resolution images, management of diverse defects, and practical robustness. Regarding the first challenge, defects in infrastructures often exist within small portions of a large image region, necessitating the development of a defect detection model capable of processing high-resolution images. Addressing the second challenge, it is crucial to understand that infrastructures have a wide range of defects varying in size, type, and their consequent impacts on repair policies. Therefore, it is essential to detect these diverse defects simultaneously. Lastly, given the significant variation in the appearance of infrastructures based on their construction methods and age, the third challenge is to build a model that can find defects based on high versatility.

Specifically, I construct a defect detection method using subway tunnel images. First, I adopt a novel approach to detect defects in real-world infrastructure image datasets. The subway tunnel shield structure dataset presents challenges due to its high resolution. Hence, conventional deep learning tech-

niques, by themselves, could not be applied to the entire image. To address this challenge, I develop a method that enables the collaborative use of different deep-learning models. I combine fully convolutional networks (FCNs) and convolutional neural networks (CNNs) that allow us to leverage the strengths of each network in capturing defects of different scales. In particular, FCNs are designed to be independent of input resolution, thereby enabling them to process high-resolution image inputs effectively. Furthermore, I develop a defect detection method based on U-Net, which combines the benefits of both FCNs and CNNs, and I have validated its effectiveness. Next, I enhance the network structure to handle a diverse range of defects. I present a novel defect detection method, utilizing a U-Net architecture that effectively addresses challenges such as background-foreground imbalance, multi-scale targets, and feature similarity. By incorporating an atrous spatial pyramid pooling module and an inception module, the proposed method outperforms traditional CNN-based approaches. Lastly, by incorporating a spatial attention module based on HRNet, which inherits the features of U-Net, I have enhanced the versatility of the defect detection process. As described above, I have successfully implemented a highly accurate and versatile defect detection method by tackling the distinct challenges associated with defect images, which substantially deviate from natural images.

The structure of this paper is shown below. Chapter 1 introduces the research background and objectives. Chapter 2 provides the related works of my thesis. Chapter 3 presents an overview of the dataset used in this study, highlighting its key characteristics and information. In Chapter 4, the CNN-based defect detection method is presented. Chapter 5 focuses on the combination of FCN and CNN methods for high-resolution subway tunnel images. In Chapter 6, I discuss the limitations of CNN and FCN in defect detection using tunnel images and propose a new U-Net-based defect detection method. In Chapter 7, I compare the constructed U-Net-based defect detection method with various semantic segmentation methods and confirm the effectiveness of our approach in identifying issues such as long-tail problems and inadequate accuracy in detecting sub-pixel objects during the application process. In Chapter 8, I propose an improved version of U-Net to enhance the capability of the defect detection method. In Chapter 9, I propose a new HRNet-based network architecture to enhance the robustness of the defect detection method. Through these modifications, I confirm the efficacy of the proposed enhancement approach in improving detection accuracy. Finally, in Chapter 10, I provide a summary of the study's findings, highlighting the contributions, limitations, and potential directions for future research.

In summary, the thesis aims to evaluate and improve the deep-learning methods throughout the application to the infrastructure maintenance domain. The image datasets in the infrastructure maintenance area always have multi-scale, unbalanced, and long-tail problems. This thesis aims to showcase the effectiveness of the enhanced deep learning network in practical applications by addressing specific issues that may arise in the field of infrastructure. Through targeted improvements, the study demonstrates how these enhancements contribute to improved performance in real-world scenarios.