Advanced Techniques for Continuous and Big Seismic Data Analysis: Empowered by AI and Unconventional Seismic Sources

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論 文 名　：Advanced Techniques for Continuous and Big Seismic Data Analysis: Empowered by AI and Unconventional Seismic Sources
（連続的なモニタリングデータと巨大な地震探査データの解析に向けた機械学習と小型震源装置を用いた新規手法の開発）

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論　文　内　容　の　要　旨

This thesis aims to enhance seismic exploration for environmental monitoring through cutting-edge neural network applications and innovative seismic acquisition techniques. It explores the utilization of a portable, active seismic system designed to address acquisition challenges and generate continuous seismic data. The dissertation introduces pioneering techniques for managing and analyzing this substantial data using advanced artificial intelligence (AI) tools. By comparing AI analysis results with traditional methods, the study highlights the efficiency and accuracy of AI in handling complex seismic datasets, contributing valuable insights to advance environmental monitoring methodologies such as CCS projects. The thesis consists of 6 chapters laid out as follows:

Chapter 1 serves as the foundational backdrop for the rest of the thesis. The initial section delves into the evolution of seismic acquisition and seismic data volume, tracing the trajectory that led to the seismic big data era. The focus then shifts to the future outlook of Carbon Capture and Storage (CCS) in Japan, dissecting both the geopolitical and environmental aspects. The chapter also describes the foundation of a continuous monitoring system known as The Accurately Controlled Routinely Operated Signal System (ACROSS). It dscribes the overarching objective and approach employed in the thesis. Lastly, the chapter outlines the structure of the thesis, providing a glimpse into the organization and interconnections of the upcoming sections.

Chapter 2 presents a thorough exploration of seismic methodologies. It initiates with an explanation of seismic acquisition, encompassing advanced techniques, environmental impact, mitigation strategies, and a detailed process overview. Subsequently, the focus shifts to passive seismic sources, shedding light on their significance in exploration. The chapter concludes by delving into the integration of artificial intelligence in seismic exploration, offering insights into current applications and potential advancements in the future. Meanwhile, the first two chapters describe a detailed explanation of cutting-edge neural network application approaches for environmental monitoring.

Chapter 3 explores advancements in Portable Active Seismic Sources (PASS), featuring a small continuous source system for both above-ground and borehole applications. The chapter details two specific PASS designs: Borehole-PASS (B-PASS) and High Energy-PASS (HE-PASS) optimized for reflection and refraction seismic surveys. The chapter also covers methods for improving signal-to-noise ratio (SNR) with spiking deconvolution and weighted stacking. HE-PASS signal could propagate up to a 1 km offset distance using a dense geophone system, while distributed acoustic sensing (DAS) allows the imaging of the reflected wave at a depth (travel time) of 1.2 seconds using 295 stacked sweeps or ~2 hours of stacking. The link between the required number of stacked sweeps and vertical depth using a heat map is also covered in this chapter. It states that in a 300-meter open borehole, the HE-PASS can accomplish clear signal propagation with as low as 60 rounds. The B-PASS signals propagated 450 m away from the source using 900 sweeps.

In Chapter 4, Convolutional Neural Networks (CNN) are evaluated for their effectiveness in interpreting offshore 3D seismic data and covering slumps, fault systems, and gas chimneys. Proving to be a robust and efficient method, CNN outperforms conventional techniques with faster and more precise findings. The chapter qualitatively compares CNN results with traditional fault detection methods, showcasing its potential for a realistic explanation of fault systems. CNN accurately interprets large 3D seismic volumes, identifying slump units in the Kumano forearc basin off the Kii Peninsula, Japan, including the discovery of previously unknown slump units. The network's versatility is demonstrated through training on 2D seismic data from the Nankai Trough, achieving an impressive 95% accuracy in classifying slumping units. CNN extends its proficiency to interpreting seismic data from Sanriku-Oki in northeast Japan and mapping gas chimneys in the West Delta Deep Marine in Egypt with high accuracy.

In Chapter 5, an AI-based traffic monitoring system using car seismometer data is introduced, conducting a comparative analysis of three neural network architectures and machine-learning techniques (logistic regression, support vector machines, and Naïve Bayes) for classifying vehicles into three size categories. Rigorous assessments using metrics like F1-score, recall, precision, and classification accuracy reveal CNN as the standout performer, achieving a remarkable 96% accuracy in classifying vehicle size. Notably, CNN exhibits rapid processing, analyzing a month-long record in just 70 minutes. Additionally, a method using synthetic random noise is proposed to expand the training dataset by 500%.

Chapter 6 concludes with a thorough summary, distilling key findings from the exploration of neural network applications, seismic processing techniques, and the Portable Active Seismic Source system. Emphasizing a forward-looking perspective, the chapter outlines avenues for future research, particularly focusing on refining methods for continuous seismic data processing.