論 文 の 内 容 の 要 旨

論文題目　Study on Automated Occupational Hazards Identification in Construction and Decommissioning Sites of Nuclear Facilities based on Scene Graph Representation
（シーングラフ表現に基づく原子力施設の建築および廃止措置現場における労働災害識別自動化の研究）

氏　　名　　陳　実

Construction sites are one of the most perilous environments where many potential hazards may occur. Decommissioning of nuclear facilities is an invasive process that presents industrial and chemical hazards as well as radiological ones, and indeed the non-radiological hazards generally represent the higher overall risk to workers. Besides, decommissioning the Fukushima Daiichi Nuclear Power Station (NPS) is a type of work that has never been done before. The entire site was contaminated with radioactive materials from the accident, and radiation dose levels were not low. At present, a multitude of Tokyo Electric Power Company (TEPCO) workers, manufacturers of nuclear reactors, construction companies, and their contractors are engaged in the decommissioning project of Fukushima Daiichi NPS and are consequently exposed to various health risks. However, compliance of regulatory rules is not strictly enforced among workers due to all kinds of reasons. Traditional on-site occupational safety monitoring, which relies heavily on on-site/off-site observers, is not sufficient to ensure the safety of workers due to human factors and human errors. Consequently, an automated on-site occupational hazards identification system is urgently needed.

Therefore, the objective of this work is to propose an image-sentence inference model, which enjoys both perceptual and reasoning capabilities, to process images and regulatory rules sentence for on-site occupational hazards identification, and develop a robust and efficient real-time automated system to help to facilitate the safety monitoring work of workers to ensure the compliance of regulatory rules.

In chapter 1, the essential requirements and difficulties regarding automated on-site occupational hazards identification are stated. Additionally, the state-of-the-art works made

attempts to on-site occupational hazards identification are reviewed. Both merits and limitations of these works are discussed which have figured out four problems to be addressed: (a) the needs of automated regulatory information extraction and representation, (b) the model to perform multi-hazard identification task, (c) the solution to avoid impacts from viewpoint changes of the on-site surveillance cameras and different individual postures, and (d) the requirements of real-time processing and reliability for industrial applications.

As a point of departure, chapter 2 reviews four candidate structures to represent information extracted from regulatory rules and on-site images. Taking advantage of scene graph structure, the framework of an image-sentence inference model is proposed to drive the development of this work, which is constrained by (a) regulatory information representation module, (b) image information representation module, and (c) automated reasoning module for on-site hazards identification.

Chapter 3 describes the proposed regulatory information representation approach. Existing regulatory rules in Architecture, Engineering and Construction (AEC) domains are mostly documented with natural language sentences that need further processing for information understanding. However, given a large number of regulatory documents, the variability of their provisions in terms of formatting and semantics, and the large amount and complexity of the information they describe, the manual process of regulatory compliance checking is time-consuming, costly, and error-prone. To address this gap, a regulatory information extraction approach is proposed based on NLP techniques and ontology modeling. Subsequently, to address the limitation of the traditional scene graph in representing complex relationships of types of requirements, an original hierarchical scene graph structure is proposed for regulatory information representation. Based on the proposed approach, a novel automated regulatory rules processing system has been developed.

Chapter 4 presents the proposed image information representation approach in response to the limitations of the traditional object detection-based approaches in multi-hazard identification and with viewpoint changes and different individual postures of on-site workers. It adopts YOLOv3 and OpenPose for detecting objects and individuals, respectively. Meanwhile, geometric relationship analysis is originally implemented to combine deep learning-based object detection and individual detection model to construct a scene graph for image information representation. To provide prior knowledge and reduce computational complexity, a method based on minimum weighted matching in bipartite graphs is proposed to associate detected objects with individuals. Present work in this thesis is able to cover four types of individual-object relationship processing: (a) individual-head protection PPE, (b) individual-grinder, (c) individual-glove, and (d) individual-body harness. (a), (b), and (d) is identified based on key length analysis of associated objects and individuals. (c) is realized

based on a color-based skin detection algorithm.

In chapter 5, an automated reasoning approach is proposed. It integrates the proposed regulatory and image information and deploys graph structure analysis for hazards identification. Based on the on-site image scene graph, the relevant regulatory rules are first extracted from the regulatory hierarchical scene graph to construct a relevant rules scene graph which contains all regulatory rules for the situation of the on-site image. Subsequently, pruning is performed on the relevant rules scene graph to extract the prohibition regulatory rules scene graph and obligation regulatory rules scene graph. Furthermore, automated reasoning for hazard identification is performed based on the extracted scene graphs analysis. Additionally, a novel system is developed based on the proposed approach for real-time occupational hazards identification.

Chapter 6 describes the experiments to validate the robustness and efficiency of the proposed approach. The validity of the developed automated regulatory rules processing system was demonstrated in the experiments of processing ten selected construction/decommissioning regulatory rules. Subsequently, 13,893 images of hard hats, dust masks, full-face masks, safety masks, body harness, and grinder were collected to train the object detection model. Furthermore, a validating dataset was created considering the impacts of illumination, viewpoint changes of cameras, and different individual postures under various distances (3m, 5m, 7m). The performance of the developed on-site occupational hazards identification system was experimentally evaluated on the validating dataset. The validating results indicate that the developed system was capable of identifying the hazards with high precision (94.22%) and recall rate (85.45%) while ensuring real-time performance (7.95 FPS on average).

The final chapter is the principal conclusions and perspectives of this work. In conclusion it is discussed the outcome of this work and how the objectives were achieved. It also discussed the originalities and achievements of this work. Finally, it contains the prospect of this work, considering the improvements for regulatory and image information representation.

In particular, the following originalities and achievements are thought to be the contribution of the present work.

(1) The regulatory information extraction approach originally deploys NLP-based grammatical structure analysis with the ontology concept to extract key information from regulatory rules in AEC domains.

(2) The hierarchical scene graph presents a novel structure extending the regular scene graph to represent conditional and prohibition relationships in regulatory information.

(3) The image information representation approach originally deploys geometric relationship analysis to perform the combination of object detection and individual detection model with interpretable explanations and outputs. Specifically, it provides a

solution for multi-hazard identification regarding viewpoint changes of on-site cameras and different individual postures of on-site workers.

(4) As the framework of this work, the image-sentence inference model drives the pipeline of this work from regulatory rules/on-site image processing to on-site hazards identification. To the author's best knowledge, it is the first model to address both regulatory and image information in AEC domains.

(5) Robustness and efficiency of the developed on-site occupational hazards identification system were experimentally evaluated for real-time on-site processing.