DNN AI Model to Detect Defection for SFR's Invisible Environment of Internal Structure

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1. Introduction

Nuclear power has long been acknowledged as a potent and reliable energy source, essential for meeting the escalating demands of a dynamic world. Among various nuclear reactor technologies, Sodium Fast Reactor (SFR) has emerged as frontrunners, offering substantial energy output and efficient fuel utilization, thereby playing a pivotal role in sustainable and carbon-neutral energy production. However, SFRs present unique challenges in terms of fuel handling and structural integrity monitoring, particularly due to the utilization of liquid sodium coolant and the opaque reactor environment [1].

Despite the stringent evaluation of structural soundness following regulatory standards, conventional optical inspection methods commonly used in light water reactors are rendered ineffective in SFRs. Consequently, there is a pressing need for innovative approaches to monitor and detect structural defects in real-time. This paper presents the development of an Artificial Intelligence (AI) based automatic control system integrated with waveguide ultrasonic sensors, specifically designed for SFR environments. By leveraging location information from these sensors, combined with deep learning algorithms, the system aims to promptly identify deformations and detect anomalies in images captured through ultrasonic visualization systems. The study investigates the efficacy of this AI model in enhancing defect detection, emphasizing the importance of real-time monitoring for ensuring the safety and reliability of SFRs [2]. Through the super resolution model and filtering algorithms during data pre-processing, the paper aims to improve the performance of defect detection in SFRs, thus contributing to advancements in reactor safety and maintenance practices.

2. Methodology

To ensure the structural integrity and safety of SFR, regular inspections during operation are imperative. Among the components crucial for safety, the reactor containment stands out, necessitating the establishment of a monitoring and diagnostic system for defect detection. In this research endeavor, we have engineered a multi-wave guide ultrasonic sensor and reactor system capable of real-time measurement of diverse defect simulation samples to validate structural integrity. Subsequently, the ultrasonic sensor data underwent imaging to discern defect characteristics, such as shape and size, facilitating the learning process of YOLOv7 AI model [2].

Subsequently, multiple steps were undertaken to assess the capacity of the selected YOLOv7 Deep Neural Network (DNN) AI model in discriminating defects within image data acquired from the SFR environment. As previously noted, ensuring the durability and quality of image data amidst the harsh conditions of the SFR environment necessitated the development of an ultrasonic sensor protection tube capable of withstanding prolonged exposure to high-temperature liquid sodium. This protective measure was instrumental in establishing an ultrasonic C-Scan sensor system, leveraging ultrasound scanning techniques renowned for their efficacy in inspecting obscured or difficult-to-access metallic structures. The utilization of C-Scan technology facilitated real-time acquisition of high-resolution images, thereby enhancing the efficiency and accuracy of the inspection process [3, 4].

The existence of diverse noise types presents a significant hurdle in preserving image fidelity during the conversion of ultrasound signal data. The persistent degradation in image resolution attributed to this noise complicates the extraction of meaningful information from the dataset. Furthermore, this noise represents a critical factor in the decline of performance, especially when employing AI models for object detection tasks. Hence, we employed two strategies, which are ESR-GAN deep learning super-resolution and Sobel filtering algorithm on image data, to enhance the object detection capabilities of the AI model by effectively enhancing data quality [2].

Finally, we tested the defect image data acquired in the underwater environment was converted to the image data by applying an image preprocessing method that combines the ESR-GAN model for super-resolution and the Sobel algorithm for noise filtering as shown in Fig. 1.

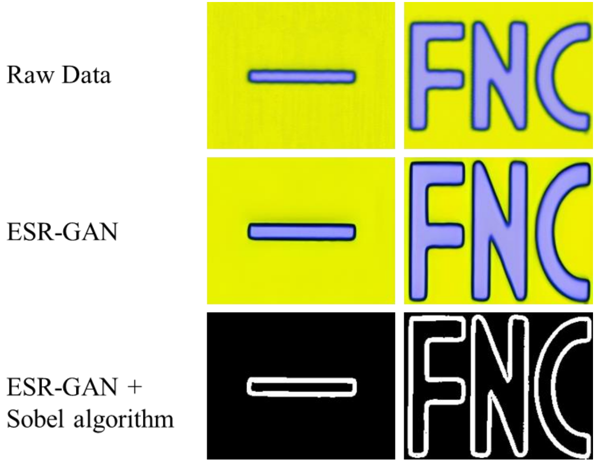

Fig. 1. Preprocessed image data using ESR-GAN and Sobel algorithm.

3. AI model test case

Regarding C-Scan image data, in pursuit of improving both the AI model's performance and the acquisition of C-Scan image data from the ultrasonic system, a probe protector was incorporated. However, it became evident that the image resolution suffered due to the attenuation of sound waves passing through the guide block. To mitigate this challenge, enhancements were made to the final radiating surface of the guide block within the probe protector, transforming it into a concave lens shape to optimize sound wave focusing. The utilization of this modified guide block yielded a significant enhancement in the quality of C-Scan image data acquisition.

The C-Scan image data underwent super resolution processing utilizing the ESR-GAN model, subsequently followed by noise filtering through the Sobel algorithm. Subsequently, the preprocessed image data was employed for object detection utilizing the YOLOv7 AI model.

4. Results

In the object detection assessment, the efficacy of the YOLOv7 AI model was gauged through the calculation of confidence scores, pivotal in determining object detection accuracy. A comparative analysis was conducted, contrasting the model's performance before and after the enhancement of C-Scan image data through super-resolution and noise filtering methods. The resulting performance metrics, delineated in Table I, provide a comprehensive portrayal of the model's proficiency across different shape of defect data.

Table I: Comparison of average defect detection performance whether or not applied ESR-GAN and Sobel algorithm

Type of defect shape	AI model confidence score	
	Without ESR-GAN and Sobel algorithm	With ESR-GAN and Sobel algorithm
Line	0.55	0.73
Character	0.61	0.82

To compare the object detection results of YOLOv7 with and without ESR-GAN and Sobel algorithm, we show the defect detection accuracy as a confidence score. The results showed that the accuracy of defect detection increased with super-resolution and noise filtering compared to before they were applied, and that further research is needed to improve accuracy.

5. Conclusion

We studied DNN AI Model to detect defection for SFR's invisible environment of internal structure utilizing an AI model. Our objective was to detect structural defects in objects within SFR reactors, particularly focusing on nuclear fuel cladding, crucial for reactor safety and performance. By applying various methodologies to enhance the AI model's performance, we established a robust system capable of effectively analyzing image data and locating structural defects in SFR fuel cladding.

In this study, we address the challenge of accurately detecting structural defects in objects measured in underwater environments using image data. And we implemented the ESR-GAN super-resolution model and the Sobel filtering algorithm for noise removal, enhancing image data quality.

We then comprehensively evaluated the object detection performance of our AI model in detecting structural defects. C-Scan data was inputted for each process, and defect detection accuracy was quantified through confidence scores. Our findings demonstrate a significant enhancement in defect detection accuracy when employing ESR-GAN and the Sobel algorithm with YOLOv7 on C-Scan data. These results highlight the effectiveness of our approach in enhancing defect detection capabilities, with promising implications for structural integrity assessment.

In the future, we plan to study optimization methodologies for object detection by introducing the YOLOv8 model to improve the performance of the object detection model, and we plan to use roboflow to improve the efficiency of augmentation and labeling of C-Scan data.

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