Commun. Comput. Phys. Vol. **35**, No. 5, pp. 1287-1308
doi: 10.4208/cicp.OA-2023-0252 May 2024

A Noise and Vibration Tolerant ResNet for Fiel d Reconstruction with Sparse Sensors

Han Li[1], Jialiang Lu[1], Hongjun Ji[1], Lizhan Hong[1] and Helin Gong[1,*]

[1] *Paris Elite Institute of Technology, Shanghai Jiao Tong University, Shanghai 200240, China.*

Received 27 September 2023; Accepted (in revised version) 24 December 2023

Abstract. The aging of nuclear reactors presents a substantial challenge within the field of nuclear energy. Consequently, there is a critical demand for field reconstruction techniques capable of obtaining comprehensive spatial data about the condition of nuclear reactors, even when provided with limited observer data. It is worth noting that prior research has often neglected to account for the impact of noise and changes in sensor states that can occur during actual production scenarios. In this paper, the so called Noise and Vibration Tolerant ResNet (NVT-ResNet) is proposed to tackle these challenges. By introducing noise and vibrations into the training data, NVT-ResNet is able to learn the tolerance thus exhibits robustness for the field reconstruction. The influence of sensor numbers on the model's performance is also investigated. Numerical results convincingly demonstrate that even with limited sparse sensors exposed to a noise with magnitude of 5% and vibrations, NVT-ResNet consistently achieves a reconstruction field of relative L_2 error within 1% and relative L_∞ error of less than 5% in average sense. Additionally, NVT-ResNet exhibits remarkable computational efficiency, with field reconstruction taking only microseconds. This makes it a viable candidate for integration into online monitoring systems, thereby enhancing the safety performance of nuclear reactors.

AMS subject classifications: 68T07, 93B51, 94A08

Key words: Field reconstruction, NVT-ResNet, observation noise, nuclear reactors, sensor vibrations.

1 Introduction

Nuclear energy holds a crucial role in contemporary society, contributing significantly to both industrial production and daily life. Nevertheless, the nuclear reactors responsible

*Corresponding author. *Email addresses:* gonghelin@sjtu.edu.cn (H. Gong), chill_yann@sjtu.edu.cn (H. Li), jialiang.lu@sjtu.edu.cn (J. Lu), hongjun.ji@sjtu.edu.cn (H. Ji), lzhong2048@sjtu.edu.cn (L. Hong)

for generating nuclear energy encounter a range of challenges, including issues related to aging components, such as control rods, core instrumentation, and particularly fuel assemblies [1]. Additionally, these components may experience vibrations arising from factors such as flow blockages and disturbances in coolant inlet conditions, among other operational concerns [2, 3].

To address these challenges, it becomes imperative to monitor nuclear reactors closely. However, the number of observers available, both within the core and in the surrounding areas (ex-core), is often limited, providing restricted access to the entire reactor system. Hence, the utilization of field reconstruction techniques becomes essential [4–6]. The core principle of these techniques is to recover comprehensive spatial data using a limited number of observers, which belongs to data assimilation techniques [7–13].

Typical approaches to field reconstruction encompass the application of optimization-solving methods [14–17], machine learning techniques [5, 18], and neural networks [4, 6, 19]. In a specific context, [20] employed Voronoi tessellation to create a structured-grid representation based on sensor positions. Subsequently, they utilized Convolutional Neural Networks (CNNs) to establish a mapping from mobile sensors to the physical field. On the other hand, [21,22] adopted a different approach, using CNNs for spatial dimension mapping while introducing Long Short-Term Memory (LSTM) networks [23] to predict the temporal evolution of latent vectors obtained through the CNN-AE (Autoencoder) or Variational Autoencoders (VAEs) [24]. Additionally, [25] presents a framework based on super-resolution generative adversarial networks for estimating field quantities from randomly sparse sensors. This algorithm employs random sampling to provide an incomplete view of the high-resolution underlying distribution and is referred to as the Random Seeded Super-Resolution Generative Adversarial Network (RaSeedGAN).

Indeed, prior research has primarily relied on simulated data and has not fully addressed the complexities of real-world industrial scenarios. In actual industrial settings, detector observations are frequently afflicted by noise [26], and the positions of detectors in nuclear reactors may be influenced by vibrations [27]. These real-world challenges can significantly impact the robustness and reliability of field reconstruction models, necessitating further investigation and development to account for such factors [28].

In summary, the field reconstruction of nuclear reactor faces several critical challenges:

(i) Sensor Position Vibration: An important area of study involves examining whether the model's reconstruction performance remains reliable as sensor positions experience vibrations due to the aging of nuclear reactors.

(ii) Robustness to Noisy Data: Ensuring the robustness of the model when dealing with noisy input data in real production scenarios is a significant concern. Developing techniques to handle noisy sensor data is vital.

(iii) Effect of The Number of Sensors: Investigating the impact of the number of sensors on model performance is essential for minimizing detector costs while maintain-