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不确定性感知卷积自编码器在核电厂异常检测中的应用

摘要

作为预测与健康管理的关键组成部分，异常检测对于确保核电厂的稳定运行和安全至关重要。随着人工智能技术的快速发展，深度学习在异常检测方面取得了重大进展。然而，关于核电厂深度学习中不确定性量化的研究仍然有限。本文提出了一种不确定性感知卷积自编码器（UAC-AE），用于核电厂时间序列数据的无监督异常检测。该方法结合了卷积神经网络在特征提取方面的优势以及贝叶斯神经网络提供的不确定性估计。核心思想是在自编码器中引入基于蒙特卡洛丢弃的变分推理，这允许在有效重建输入数据的同时，在重建过程中评估认知不确定性和偶然不确定性。实验结果表明，UAC-AE 在异常检测方面优于传统的自编码器方法，特别是在有噪声的背景条件下。该模型不仅提高了异常检测的准确性，还提供了有价值的不确定性信息。这项研究强调了在异常检测中考虑不确定性的重要性和优势，为提高实际核电厂的可靠性和安全性提供了一种有效的解决方案。

关键词

核电厂，异常检测，卷积自编码器，不确定性感知

Abstract

As a critical component of Prognostics and Health Management, anomaly detection (AD) is crucial for ensuring the stable operation and safety of nuclear power plants (NPPs). With the rapid development of artificial intelligence technologies, deep learning has made significant strides in AD. However, research on uncertainty quantification in deep learning for NPPs remains limited. This paper proposes an Uncertainty-Aware Convolutional Autoencoder (UAC-AE) for unsupervised AD in time-series data from nuclear power plants. This approach combines the strengths of Convolutional Neural Networks in feature extraction with the uncertainty estimation offered by Bayesian Neural Networks. The core idea is to introduce the Monte Carlo Dropout-based variational inference in the autoencoder, which allows for effective reconstruction of the input data while evaluating both epistemic and aleatoric uncertainty in the reconstruction process. Experimental results demonstrate that UAC-AE outperforms traditional autoencoder methods in AD, particularly in noisy background conditions. The model not only improves the accuracy of AD but also provides valuable uncertainty information. This study highlights the importance and advantages of considering uncertainty in AD, offering an effective solution to enhance the reliability and safety of actual NPPs.

Keywords

Nuclear Power Plants, Anomaly Detection, Convolutional Autoencoder, Uncertainty Aware.

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