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Unsupervised anomaly detection of industrial building energy consumption

摘要

检测建筑能耗中的异常数据，可以有效减少能源浪费并提升用能效率。这一技术在工业建筑领域具有特殊应用价值，此类建筑不仅具有高能耗特征，其异常能耗事件还可能引发安全隐患。虽然智能电表采集的海量数据印证了数据挖掘技术在异常检测中的优势，但实际应用场景中往往面临标注数据缺失的瓶颈。为此，本研究构建了集成学习框架，融合局部离群因子（LOF）、深度孤立森林（DIF）和异常变换器（Anomaly Transformer）三种无监督算法，重点针对能耗子序列异常进行精准识别。本研究还基于 Transformer 模型实现了数据缺失值的精确填补，从而提升检测系统的鲁棒性。两栋工业建筑逐时能耗数据的案例分析表明，该集成方法在无监督场景下可以有效检测出异常的用电行为。为深入解析异常成因，本研究采用 XGBoost 算法构建特征解释模型，揭示了工作日状态与露点温度等关键因素对异常用电模式的显著影响。在分类性能评估中，ROC 曲线下的面积（AUC）的平均值达到 0.96 以上，充分验证了方法的可靠性。本研究通过构建" 检测-解释" 一体化方法，为智能建筑能源管理提供了新的提升方法，其成果对实现能耗异常趋势的实时预警和能源系统的优化调度具有重要实践价值。

关键词

工业建筑；深度异常检测；能源管理；无监督学习；缺失值填补

Abstract

Detecting anomalies in building energy consumption can reduce unnecessary energy waste and improve energy efficiency. The role of anomaly detection has become particularly pivotal in industrial buildings because of their high energy consumption and the potential risks associated with abnormal events. Although extensive data collected through smart meters has indicated the advantages for anomaly detection using data mining techniques, labeled data are often unavailable in practical situations. Therefore, this study develops an ensemble framework that combines three unsupervised learning algorithms, including Local Outlier Factor, Deep Isolation Forest, and Anomaly Transformer, to identify anomalous power consumption with a focus on subsequence anomaly. The transformer-based network is established to precisely impute missing values and enhance the reliability of anomaly detection. The experimental results based on hourly cooling energy consumption in the two industrial buildings confirmed the effectiveness of the proposed method. To better interpret the anomaly detection results, the Extreme Gradient Boosting is applied to construct the relationship between influencing factors and anomalous consumption. The area under the Receiver Operating Characteristic curve is used as a metric for the classification task, and an average of over 0.96 indicates robust performance. Weekday and dew point temperature are found to have significant impacts on the electricity usage pattern. The research findings provide valuable insights for developing effective solutions to identify unexpected trends in building energy consumption and support efficient energy management.

Keywords

Industrial building; deep abnormality detection; energy management; unsupervised learning; missing value imputation

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