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Mining Gradual Patterns in Big Building Operational Data for Building Energy Efficiency Enhancement

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Abstract

The advance in information technology has enabled the real-time monitoring and controls over building operations. Massive amounts of building operational data are being collected and available for knowledge discovery. Advanced data analytics are urgently needed to fully realize the potential of big building operational data in enhancing building energy efficiency. Data mining (DM) technology, which is renowned for its excellence in discovering hidden knowledge from massive datasets, has attracted increasing attention from the building industry. The rapid development in DM has provided powerful mining methods for extracting insights in various knowledge representations. Gradual pattern mining is a promising technique for identifying interesting patterns in big data. The knowledge discovered is represented as gradual rules, i.e., '*the more/less A, the more/less B*'. It can bring special interests to building energy management by highlighting co-variations among building variables. This paper investigates the usefulness of gradual pattern mining in analysing massive building operational data. Together with the use of decision trees, motif discovery and association rule mining, a comprehensive mining method is developed to ensure the quality and applicability of the knowledge discovered. The method is validated through a case study, using the real-world data retrieved from an educational building in Hong Kong. It shows that novel and valuable insights on building operation characteristics can be obtained, based on which fault detection and optimal control strategies can be developed to enhance building operational performance.

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1. Introduction

Adopting the Building Automation System (BAS) for the real-time monitoring and controls of the building services systems has become a top trend in the building sector. As reported by Waide et al. (2013), approximately 22% of the energy consumed during building operations can be saved through the use of advanced building automation technologies. Considering that building operations account for 80-90% of the total building energy consumption, reliable and robust BAS-based building energy management methods are urgently needed to achieve building sustainability.

One promising approach is to perform knowledge discovery from the massive amounts of building operational data collected by BAS. Building operational data typically record the indoor and outdoor environment, power consumptions and operating parameters of different building services systems or components. The knowledge hidden can be very helpful for improving the building energy efficiency. As reviewed by Ma and Wang (2009), previous studies mainly adopted traditional data analysis methods, such as statistics and physical principles, to analyze building operational data for predictive modeling, fault detection and diagnosis, and control optimization. Despite of the encouraging research results, such data analysis methods are neither efficient nor effective when analyzing massive amounts of data. Advanced data analytics for analyzing building operational data are urgently needed to fully realize the potential of big building operational data.

Data mining (DM) is a powerful technology in discovering potentially useful knowledge from large and noisy data. It has been successfully applied in various industries, such as retails, financial services and health care [Liao et al. 2012]. DM techniques can be generally classified into supervised and unsupervised techniques. Supervised techniques are capable of revealing the complex relationships between input and output variables. In the building field, existing studies mainly applied supervised DM to facilitate the predictive modeling of building energy consumptions, system performance indices, and indoor environment [Molina-Solana et al. 2017]. Unsupervised DM is useful for identifying the intrinsic data structures, correlations and associations. It has been applied to identify typical building operation conditions, operating behaviors, and interactions among building variables [Yu et al. 2016]. Association rule mining (ARM) is one of the most powerful unsupervised DM techniques. The knowledge discovered is highly interpretable and typically represented as a rule, i.e., $A \rightarrow B$, stating that if event A happens, B will also happens. Conventional ARM algorithms, such as Apriori and FP-growth, are suitable for mining associations between categorical variables. Such algorithms have been applied to extract associations among building operational data [Xiao and Fan 2014]. Considering that building operational data are mostly numerical data, some studies have adopted quantitative association rule mining (QARM) as the mining technique [Fan et al. 2015]. QARM adopts a data-driven approach to automatically identify the intervals for data discretization. Another research direction is to explore the temporal associations in building operational data [Fan et al. 2015].

Despite of the usefulness of the abovementioned ARM techniques, the knowledge discovered can only describe the co-occurrence of different events or conditions. There lacks methodologies to examine the co-variations between building variables. Gradual pattern mining, which is a special branch of ARM, can be utilized to discover gradual patterns (or co-variations). This study investigates the power of gradual pattern mining in analyzing massive building operational data. Together with the use of decision trees and motif discovery, a comprehensive methodology is proposed to enable the discovery of applicable knowledge for building energy management.

2. Research Methodology

2.1. Research outline

Fig. 1 depicts the research outline. The left side illustrates the overall knowledge discovery process and the right side shows the techniques or methods used at each mining phase. Data cleaning is performed to handle missing values and outliers. Data partitioning is performed based on decision trees. The insights obtained are used to partition the whole building operational data into different groups for separate mining. The aim is to enhance the reliability and

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