Computers & Graphics 38 (2014) 27–37

Contents lists available at ScienceDirect

Computers & Graphics

journal homepage: www.elsevier.com/locate/cag

Special Section on Visual Analytics

Anomaly detection for visual analytics of power consumption data

Halldór Janetzko *, Florian Stoffel, Sebastian Mittelstädt, Daniel A. Keim

University of Konstanz, Germany

ARTICLE INFO

Article history:
Received 21 June 2013
Received in revised form
4 October 2013
Accepted 8 October 2013
Available online 17 October 2013

Keywords:
Importance-driven
Pixel-based visualization
Anomaly detection
Visual analytics

ABSTRACT

Commercial buildings are significant consumers of electrical power. Also, energy expenses are an increasing cost factor. Many companies therefore want to save money and reduce their power usage. Building administrators have to first understand the power consumption behavior, before they can devise strategies to save energy. Second, sudden unexpected changes in power consumption may hint at device failures of critical technical infrastructure. The goal of our research is to enable the analyst to understand the power consumption behavior and to be aware of unexpected power consumption values. In this paper, we introduce a novel unsupervised anomaly detection algorithm and visualize the resulting anomaly scores to guide the analyst to important time points. Different possibilities for visualizing the power usage time series are presented, combined with a discussion of the design choices to encode the anomaly values. Our methods are applied to real-world time series of power consumption, logged in a hierarchical sensor network.

© 2013 Elsevier Ltd. All rights reserved.

1. Introduction

Commercial buildings consume a significant amount of electricity. According to the Energy Information Administration's 2010 statistics [1], the United States alone consumed an estimated 1.3 trillion kW. It is about 37% of the total electricity generated. How power is used in a commercial building has a large effect on energy efficiency strategies. The most important energy usage is lighting. Then heating and cooling are next in importance [2]. Current approaches for reducing the power consumption for example integrate motion detection sensors for each lamp switching them on and off.

There is a growing interest in understanding how energy is spent in the commercial buildings. Furthermore, building administrators want to know how to reduce the failure rate and detect anomalies. In addition, they want to know how to visualize large volumes of energy consumption data collected by power meters (sensors) in a building to find patterns, trends, and anomalies. In the end, our goal is to find how to automatically discover the anomaly, like unusual power consumption measurements highly differing from old observed patterns, and to reduce the energy cost of a building. For this task, anomalies are of special interest, because they can be caused either by faulty equipment or potentially misconfigured devices consuming significantly more or less energy than required for proper operation.

In this paper, we present an analytical and visual approach to support the building administrators in detecting anomalies and examining energy consumption data as shown in Fig. 1. Our input data consists of a tree of time series reflecting the hierarchical nature of the power meters, e.g., 1 m for the whole building and one for each power outlet. The analytical part is the automatic anomaly detection and is based on a time-dependent energy consumption model. We have explored two different anomaly discovery methods. In the beginning, we estimate the error rate using prediction. Then, we use clustering-based anomaly detection. Both methods have benefits and drawbacks and are complementing each other.

The last step in our pipeline is the visualization being capable of effectively displaying large amounts of data and, at the same time, allowing quick recognition of anomalous regions in the data. We integrated the three most common time series visualization techniques (line charts, spiral visualizations, and Recursive Patterns) presented in Aigner et al.'s book about time series [3]. Besides giving an appropriate overview of the data, the visualization is also able to support the administrator in a more detailed examination of the data, for example areas with unusual power consumptions by interaction facilities. In addition, the visualization is capable of showing the hierarchical nature of the data set. This is necessary, because commonly the energy consumption of different floors or buildings is independently monitored resulting in an inherent hierarchy in the recorded data.

Our methods rely purely on the recorded power consumption data, which we were not cleaning in any way as the data was in very good shape. There are many external influences to the power consumption, like the environmental conditions or the number of

* Corresponding author. Tel.: +49 7531884793.
E-mail address: janetzko@dbvis.inf.uni-konstanz.de (H. Janetzko).

0097-8493/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.cag.2013.10.006

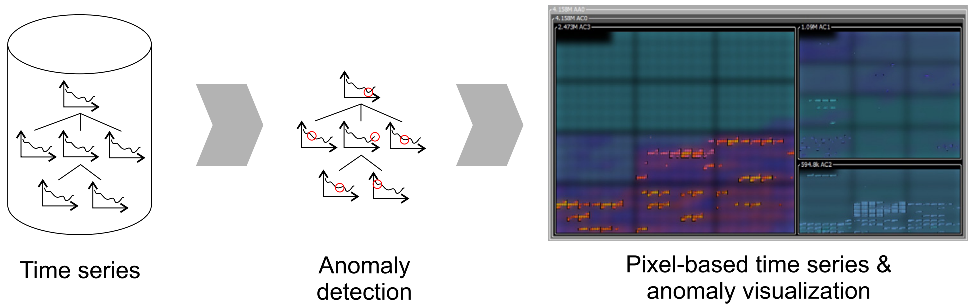

Fig. 1. The input set of hierarchical time series is processed by anomaly detection methods. The resulting anomaly values are visualized together with the time series values by pixel-based techniques. The visualization combines the raw time series with boosting techniques like highlighting and blurring for the anomaly scores.

people working in an office building. The large number and high complexity of external factors prohibit the fully automatic diagnosis of anomalies. Hence, a human subject matter expert is needed to validate found anomalies and investigate the interesting ones. Even though it is possible to think of extensions for an automatic analysis of anomalies like incorporating external factors as weather data and holidays.

It is important to note that our methods are applicable not only to power consumption time series data sets, although they have been developed with a particular application in mind. This is caused by the general nature of time series data and the generality of both, the analytical and the visual methods presented in this paper. The most application-dependent part of this work is the anomaly detection being designed for daily patterns.

2. Related work

Reading energy consumption statistics shows that commercial buildings have a high energy usage, which motivates many research projects developed to improve power efficiency. Within the context of our work two main categories can be distinguished: analysis of power consumption data (detecting whether the energy consumption performs normally or abnormally over different locations and time) and visual analysis (visualizing similarities and anomalies with appropriate interaction techniques).

2.1. Analysis of power consumption data

Applying data mining techniques for power consumption data is a known approach for identifying abnormal usage behavior. Agarwal et al. [4] examined 6 months of data from the UCSD campus, including aggregate power consumption of four buildings. Agarwal et al. focus more on the setup of power meters and provide only simple visualization methods like line charts. Catterson et al. [5] used an approach to monitor old power transformers. Their goal is to proactively search for abnormal behavior that may indicate the transformer is about to fail. Similarly, McArthur et al. [6] searched for anomalies to detect problems with power generation equipment. Jakkula and Cook [7] compared several outlier detection methods to find which is better at identifying abnormal power consumption. Seem [8] used outlier detection to determine if the energy consumption for a day is significantly different from previous days' energy consumption. This is a known approach for identifying abnormal system behavior.

The work conducted at Lawrence Berkeley National Laboratory [9] focuses on demand response. Mathieu et al. used a time-of-week and piecewise-linear modeling approach to analyze commercial and industrial electric load data. To our knowledge, the unsupervised anomaly detection algorithms from prediction and clustering described in this paper differ from the Mathieu et al. method in two aspects: finer granularity and weighted by time distance (recent data weights more than old data).

The review of several prediction methods for power data performed by Zhao et al. in [10] investigates the effectivity and efficiency. Neural networks and Support Vector Machines were performing better than statistical approaches. We though decided to use the prediction technique developed in [11] as peak-preservation is one of the main strengths of this technique.

2.2. Visual analysis

Visualization of building energy consumption has not yet been a major focus of research thus far. Most of the energy consumption visualizations have been time series line charts, scatter plots, and maps [12–15]. Recently, Many Eyes [16] allows analysts to choose a visualization type for analyzing public building electricity consumption. The Google PowerMeter [17] recently provides a free energy monitoring tool for people to view home energy usage.

In addition to these existing tools, improving visualization techniques for time series data is ongoing research work. In SAVE [18], Shi et al. presented a sensor anomaly visualization engine that guides the user to diagnose sensor network failures and faults using multiple coordinated views. In this paper, we map multiple sensors' calendar time series in a single view to enable users to visually analyze energy usage and identify anomalies. In SAGA Dashboard [19], Buevich et al. provided a visual interface for interaction with the sensor network. They require the user to use a device that tracks and visualizes home energy usages. We extend the home energy consumption visual analysis to large commercial buildings with dozens of sensors. We therefore restricted ourself to space-efficient visualizations like pixel-based Recursive Patterns. Furthermore, no pre-defined devices and sensor types in our methods are required. Another related work being capable of visualizing hierarchical time series data is the TimeEdgeTrees introduced by Burch and Weiskopf in [20]. The technique shows the time series as one-dimensional, color-coded timelines instead of drawing the graph edges. The hierarchy is preserved better by this approach while the space-efficiency is worse compared to the pixel-based approaches we use. We chose the pixel-based techniques as periodic patterns are easier perceivable. Additional discussions on related work concerning anomalies detection and boosting methods can be found in Sections 3 and 4.

2.3. Our contribution

To leverage the prior work and to support analysts in understanding power consumption data, we combine automated anomaly detection algorithms with interactive time series visualizations. The resulting anomaly score is used to highlight unusual power

Download English Version:

https://daneshyari.com/en/article/441921

Download Persian Version:

https://daneshyari.com/article/441921

Daneshyari.com