A Visualization Tool for Building Energy Management System

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***Abstract*—Many public offices and companies manage their energy consumption by Building Energy Management System (BEMS). It is not an easy task to determine whether the past energy consumption was really necessary or just wasted. Visualization for energy consumption is useful to understand the situations of energy consumption to determine their necessity. This paper presents a visualization tool for energy consumption with BEMS. The tool firstly divides the daily variation of the energy usage and environmental measurements (e.g. temperature and humidity) into the meaningful number of patterns. It displays "long-term polyline chart" to represent the frequency of the daily pattern so that users can easily focus on particular dates at particular places. It also displays " one-day polyline chart" to represent the daily variation of the recorded values of the particular dates and places specified by users' click operations. The paper introduces the examples of visualization to demonstrate the effectiveness of the presented tool, with a real dataset of business office building.**

***Keywords*-Building management, time-varying data visualization, support vector machine.**

I. Introduction

Energy management is a very serious social problem. For example, electric energy saving has been an important problem in Japan after a big earthquake and an accident of a power plant in 2011. All public offices and companies in Japan has been required to save the electric energy, because supply of the electric power has decreased after the earthquake. Management, monitoring, and analysis of electric energy usage has been therefore important, to understand whether the past electric energy usage was really required.

Many buildings of public offices or companies record their electric energy consumption by BEMS (Building Energy Management System). BEMS is a generic term of specifications and implementations for management of resources including water, gas, and electric energy, and environmental measurements such as temperature and humidity. Usually BEMS records such information block-by-block, where a *block* is a subregion of a floor. In other words, BEMS usually does not record fine information of energy consumption for each air conditioner, light, door, and so on. Commercial systems of BEMS feature simple representations which just display the time-varying information of energy consumption and environmental measurements as bar charts or polyline charts. It is often difficult to carefully analyze the frequent patterns and abnormity using only such simple representations.

This paper presents a visualization tool of energy consumption datasets recorded by BEMS. Figure 1 shows a snapshot of the tool. It displays "long-term (e.g. one month) polyline chart", "one-day polyline chart", and "floor map" as the linked view in a single window. The two polyline charts display variation of recorded values including energy consumption and environmental measurements of each block of the building. The tool also divides the recorded daily values into the meaningful number of patterns by applying supervised learning and clustering algorithms. Users can easily observe how often, and where each of the patterns appear in the building.

II. Presented Visualization Tool

A. Data Definition

This study supposes the following information is recorded by BEMS. Here, we assume floors of the target building are divided into blocks. We also suppose all the values including energy consumption and environmental measurements are recorded at the same time.

The study supposes that the whole dataset D consists of:

$$D = \{b_1, b_2, ..., b_{n_B}\},$$

where b_i is the whole values of the i-th block, and n_B is the number of blocks in the building.

The values b_i at the i-th block consists of:

$$b_i = \{d_{i1}, ..., d_{in_D}\},$$

where d_{ij} is the whole values of the building on the j-th day, and n_D is the number of days recorded in the dataset.

The values d_{ij} at the i-th block on the j-th day consists of:

$$d_{ij} = \{v_{ij1}, ..., v_{ijn_V}\},$$

where v_{ijk} is the k-th type of the values at the i-th block on the j-th day, and n_V is the number of types of recorded values.

The k-th type of values v_{ijk} at the i-th block on the j-th day consists of:

$$v_{ijk} = \{a_{ijk1}, ..., a_{ijkn_T}\},$$

where a_{ijkl} is the l-th value of the k-th type at the i-th block on the j-th day, and n_T is the number of timesteps in a day.

In our experiment, recorded values include measurement of temperature and humidity, and electric power consumption for air conditioning and lighting. In the near future, we would like to add the values of amount of working persons into the datasets.

B. Visualization and Interaction Design

Figure 1 shows the snapshot of the visualization tool we developed in this study. Figure 2(Left) shows the processing flow of the presented tool. This section describes the components realizing the linked view of the visualization of energy consumption data.

Long-term polyline chart featured at the upper part in the window displays long-term (e.g. one month) variation of the recorded values. In this example, it features four polyline charts to display the average values of the days recorded at each of the four blocks. In other words, this part displays n_B polyline charts to represent each of the values b_i, while the horizontal axes of the polyline charts are divided into n_D. This chart is clickable to specify d_{ij}, the daily value corresponding to the particular block on the particular day.

One-day polyline chart featured at the lower-left part in the window displays the daily variation of the recorded values finely (e.g. hour-by-hour). It displays the recorded values d_{ij} at the particular block on the particular day, specified by the click operation on long-term polyline chart. Colors of polylines depict v_{ijk} in one-day polyline chart, while the horizontal axis is divided into n_T.

Floor map featured at the lower-right part in the window displays the floor map of the building which BEMS is equipped. The floor is divided into four blocks in this example, where electric energy usage and environmental measurements are recorded block-by-block. When a user clicks the long-term polyline chart to specify a block, the floor map highlights the corresponding block.

Pattern selection panel featured at the right part in the window provides buttons and a small drawing area to assist the selection of particular patterns. The presented tool divides the daily variation of the recorded values into the meaningful number of patterns, as described in the next section. When a user presses a button corresponding to the particular pattern, the small drawing area displays the average values of the specified pattern. Also, particular portions in the long-term polyline chart corresponding to the specified pattern are painted in gray, to assist understanding how often, where the pattern appears.

C. Supervised Learning of Noticeable Patterns

It is important to determine whether the energy was wasted in the past record. The user interface to select the particular patterns, described in the previous section, is useful to discover unusual energy consumption patterns.

On the other hand, necessity of energy consumption strongly depends on the building-specific situation and policy, and therefore it may be difficult to define the unified criteria to determine the energy waste. Therefore, the presented tool provides a user interface for supervised learning. It features the button which is supposed to be pressed if users feel the daily value d_{ij} seems unusual. The tool learns the numeric patterns specified by the users by applying Support Vector Machine (SVM), and divides the learned patterns from other patterns by applying a clustering algorithm.

Given the training dataset D_0 containing sufficient long-term (e.g. one month) values, the tool firstly divides the daily values d_{ij} into the meaningful number of patterns without any supervisory signals, as shown in Figure 2(Right)(1). Our implementation simply applies the k-means clustering method to divide the values of the blocks with various number of clusters, and evaluates the clustering results applying the Davis-Bouldin Index (DB Index) to determine the optimum number of clusters. Users can focus on particular patterns, since long-term polyline chart paints particular portions corresponding to the patterns selected by pressing the buttons.

The tool features a button to press if the users feel the daily patterns are unusual. It records the daily patterns when they press the button, and divides them into several groups according to their similarity by applying a hierarchical clustering algorithm. The tool then learns the each of divided patterns by applying a supervised learning algorithm, where our implementation applies SVM.

Given a practical use dataset D_1, the tool firstly extracts the daily value d_{ij} similar to the learned patterns. The dots painted in red in Figure 2(Right)(2) illustrate the unusual daily values specified by a user. The dots painted in pink in Figure 2(Right)(3) illustrate the daily values similar to the learned patterns. The tool then divides the rest of values by applying the k-means algorithm into the meaningful number of patterns, as shown in Figure 2(Right)(4). Finally, the tool displays the set of buttons corresponding to the patterns. The button to specify the unusual patterns is still active at this moment, and therefore users can supervise new unusual patterns while visualizing the practical use datasets.

III. Example

This section introduces our experiments with the presented technique. We implemented the technique using Java Development Kit (JDK) 1.7.0, and executed on Lenovo ThinkPad T430 (2.60MHz Dual Core, RAM 8GB) with Windows 7 (64 bit).

We applied a BEMS dataset storing the various energy usage and environmental measurements in one month. The building is located at Tokyo, Japan, and the dataset was recorded in August, 2013. Amount of electric energy consumption is usually maximum in the year in this building, because August is the hottest month in Japan. This dataset contained the recorded values of a floor divided into four blocks; the first block consisted of meeting rooms, the second and third blocks consisted of office desks for regular employees, and the fourth block consisted of computer system spaces. Long-term polyline chart displays the energy consumption of these four blocks in this order.

This section introduces the examples visualizing the following three values:

- E_a: Electric energy consumption for air conditioning. Drawn in orange.
- E_l: Electric energy consumption for lighting. Drawn in pink.
- T: Temperature. Drawn in green.

In order, we knew an outlier pattern that energy consumption for air conditioning once got zero in the evening, and then turned higher again in the late night. Temperature suddenly got higher just when the energy consumption got zero, and then it got lower when the air conditioning turned on. We specified such daily patterns shown in Figure 3(Upper) as supervisory signals, and then processed the aforementioned BEMS dataset. As a result, we could gather similar unusual daily patterns shown in Figure 3(Lower).

Figure 4(Left) shows the examples of three patterns observed mainly at the office desk spaces. Figure 4(Upper-left) and 4(Center-left) show typical patterns frequently observed in this floor. We found they are major patterns of office desk spaces because the second and third rows of long-term polyline charts were mainly painted when we selected these patterns. Figure 4(Upper-left) illustrates the pattern of the days which temperature was relatively low, and therefore energy consumption for air conditioning was also relatively small. Figure 4(Center-left) illustrates another typical pattern of the weekdays that energy consumption for air conditioning got zero in the evening, and therefore temperature got higher in the evening. We may need to investigate if there were remaining employees in the evening, and how they felt the increase of the temperature. On the other hand, Figure 4(Lower-left) shows the outlier pattern collected by the aforementioned supervised learning. We found the pattern just appeared once or twice in a month at each of the blocks.

Figure 4(Right) shows the examples of three patterns observed mainly at the meeting rooms and computer system spaces. Long-term polyline chart clearly illustrates the intermittent variation of energy consumption; it decreases weekends or holidays at these places. Figure 4(Upper-right) illustrates the pattern is frequently observed in the meeting rooms on weekdays, where energy consumption for air conditioning was large until the night and then suddenly decreased. This suggests that the meeting rooms were usually used until approximately 8PM. Figure 4(Center-right) illustrates the pattern is observed only at computer system spaces on weekdays, where energy consumption for air conditioning got large in the morning and then constant until late night. This suggests that temperature in the computer system spaces is high in the early morning in the normal use. On the other hand, Figure 4(Lower-right) illustrates an outlier pattern sometimes observed at the computer system spaces, where energy consumption for air conditioning was large all the day even though temperature was low all the day. It might be caused by system or human errors because this pattern is extremely different from Figure 4(Center-right), and therefore it may be worth to record as supervisory signals.

IV. Related Work

Monitoring and analysis of energy consumption are important tasks and therefore many systems and tools have been recently presented. The tasks got more important and critical since situation of energy consumption became more complicated due to spread of smart grid [8] and heterogeneous sensors [5]. Detailed use cases, including context-aware services [1], demand-based management [7], and decision-making control [9], have been taken into account to develop new techniques for energy management. Visualization has been applied to monitor the electric power consumption in many systems [6], [10], [2]. Recent works on visualization of electric power consumption applied visual analytics mechanism [3] and artistic representation [4]; however, there are few works on visualization of electric power consumption for building management.

V. Conclusions and Future Work

The paper presented a visualization tool for monitoring and understanding of electric energy consumption. Long-term polyline chart displays long-term variation of energy consumption while painting the user-specified daily patterns. One-day polyline chart displays finer variation of energy consumption corresponding to the day and place which users clicked in the long-term polyline chart. All the daily variations of energy consumption are divided to the meaningful number of patterns in order, so that users can easily select interested patterns. This paper introduced typical and unusual patterns of energy usage observed in a real office building.

Our potential future issues include the following.

Currently we are measuring the time-varying amount of working persons in each block. This information is very useful to determine whether the electric energy consumption was really necessary or just wasted. The measurement of amount of persons is outside the mechanisms of BEMS. Therefore, we would like to integrate the data between this measurement and the dataset recorded by BEMS, and have visualization experiments with the integrated datasets.

Extended implementation of floor map is another issue. Our current implementation just indicates corresponding portions when users click long-term polyline charts. It also supposes that BEMS records all types of energy consumption and environmental measurement values completely at the same places. However, it is possible that temperature or amount of working persons are measured at multiple and different positions in a single block. Supposing such cases, we would like to extend the implementation of floor map so that we can represent the detail.

We also would like to test the tool with larger datasets. The real dataset introduced in this paper is not very practical. Many of practical BEMS datasets contain tens of blocks and multiple floors, and therefore we need to extend the design to visualize more blocks. After testing with larger datasets, we would like to conduct user experiences and evaluate the effectiveness of the presented tool.

We suppose the presented tool will be used by the employees directly managing the building energy. On the other hand, it is also important to broadcast energy consumption information to ordinary employees to motivate the understanding of energy saving. Therefore, we would like to develop additional implementation to send necessary information to mobile devices of the ordinary employees and display on the devices.

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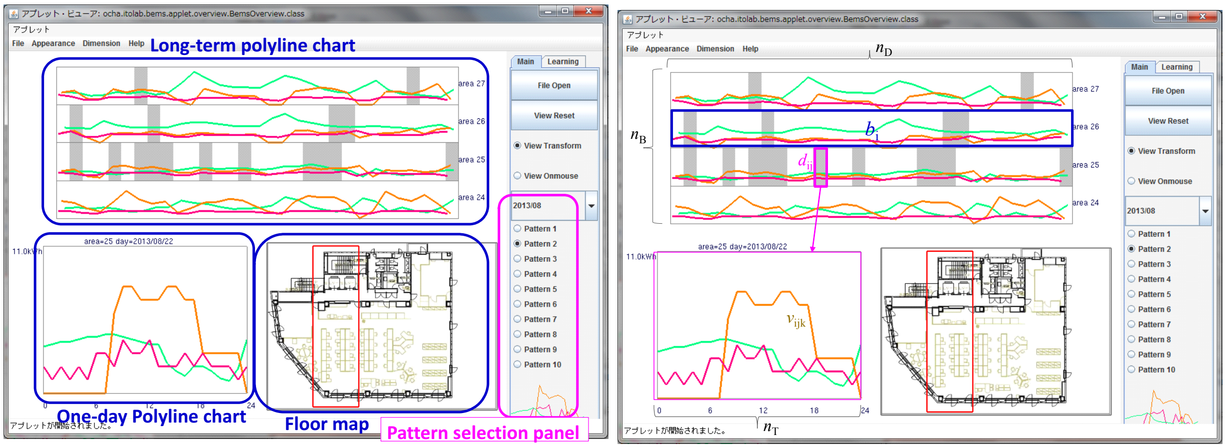

Figure 1. Snapshots of the presented visualization tool for building energy management. Long-term polyline chart is clickable so that users can specify blocks of the building on the particular day. The energy consumption and other values corresponding to the clicked position are displayed in one-day polyline chart. The values of each block, each day are divided into the meaningful number of patterns so that users can interactively focus on specific patterns.

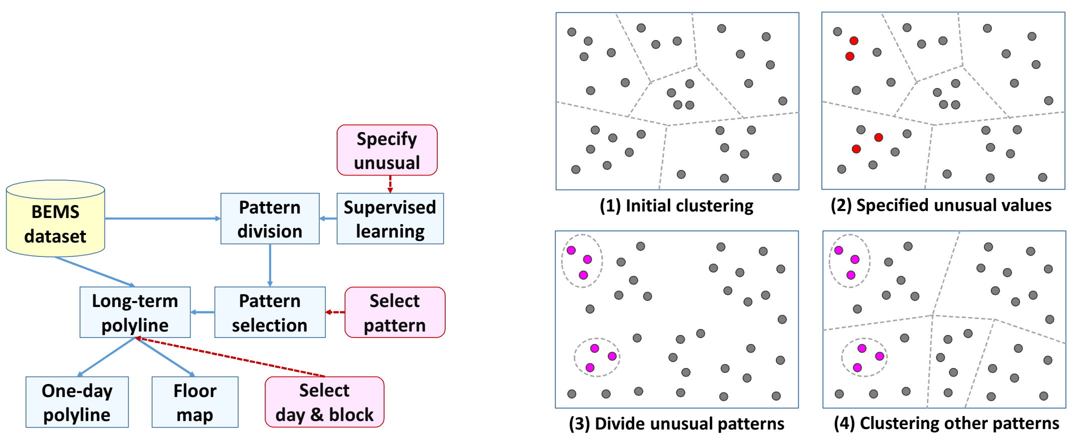

Figure 2. (Left) Processing flow of the presented tool including three kinds of interactions. (Right) Dividing the daily values into the meaningful number of patterns.

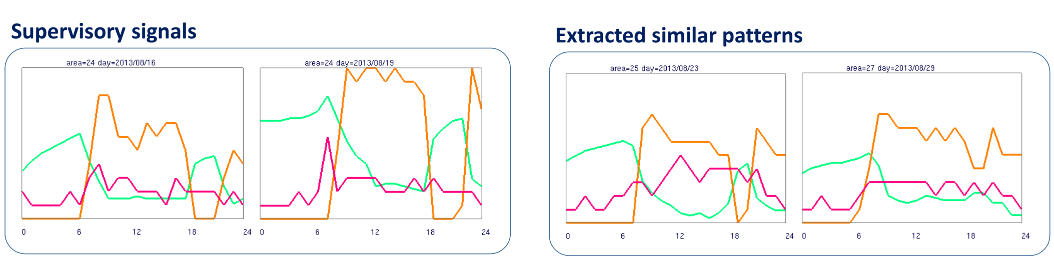

Figure 3. Example of daily pattern which we applied the supervised learning. (Left) Daily patterns selected as supervisory signals. (Right) Daily patterns determined as similar to the user-selected patterns.

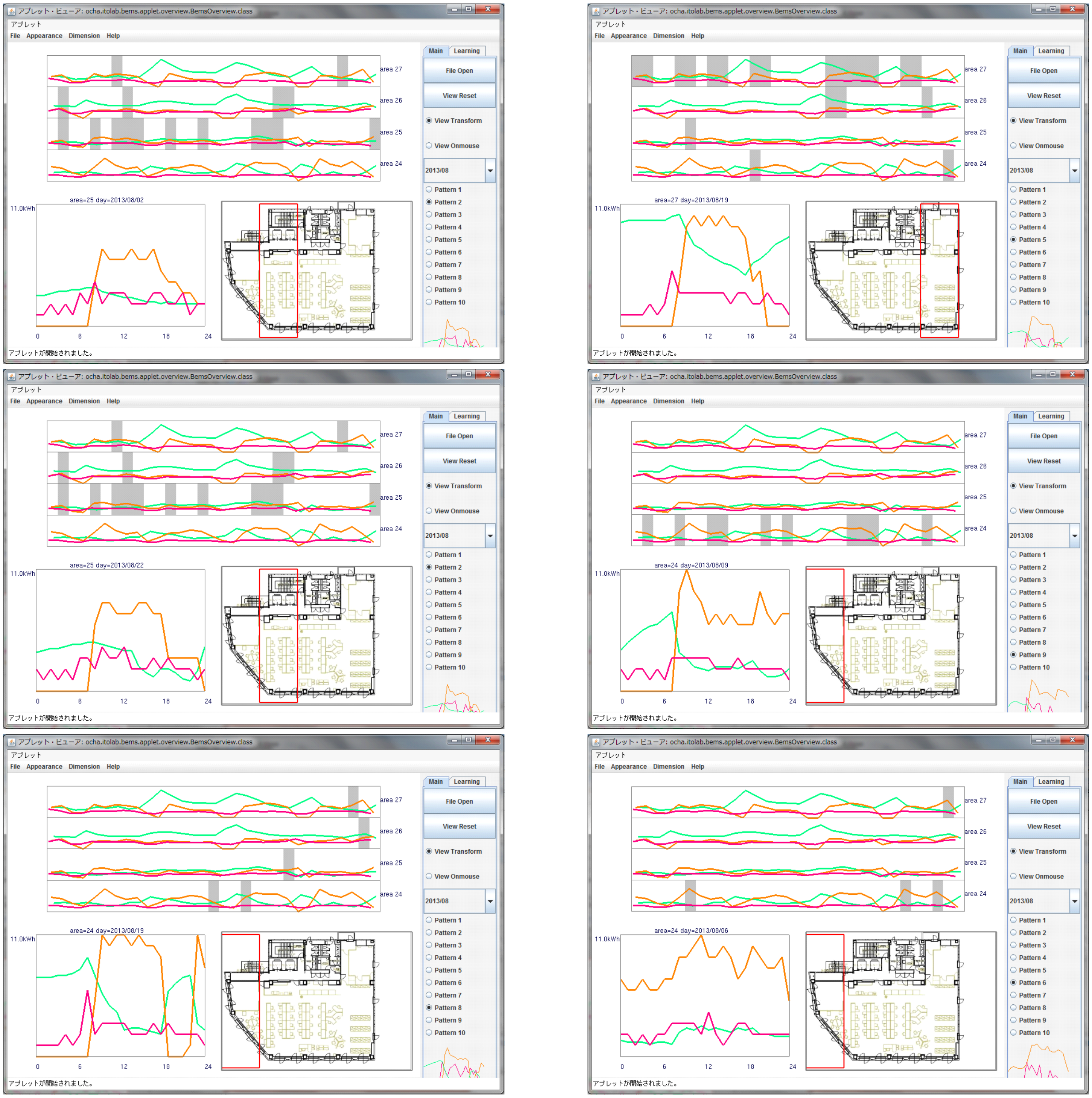

Figure 4. (Left) Examples observed mainly at the office desk spaces. (Upper-left) Energy for air conditioning was relatively small because temperature was also relatively low. (Center-left) Energy for air conditioning was high in the daytime while it turned zero in the evening. (Lower-left) Energy for air conditioning got zero once in the evening, but then it turned higher again because temperature was high. (Right) Examples observed mainly at the meeting rooms and computer system spaces. (Upper-right) Energy consumption for air conditioning got zero at late night. This pattern is often observed at the meeting rooms on weekdays. (Center-right) Energy consumption for air conditioning got higher in the morning, and then constant in the afternoon. This pattern is observed only at the computer system spaces on weekdays. (Lower-right) Energy consumption for air conditioning was large all the day, while temperature was low all the day.