SMART CAMPUS ELECTRICITY DATA VISUAL ANALYSIS SYSTEM

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ABSTRACT:

Smart grid is the basic support of smart city development. The application of visual analytics to electricity system helps monitor and analyse the characteristic information in electricity data, which provides a strong guarantee for mastering the operation status of electricity system and achieving effective energy planning. However, as the complexity and size of electricity data continues to grow, it increases the burden on electricity workers to understand and analyse the electricity consumption situation. In response to these problems, a new type of electricity data visualisation and analysis system has been proposed, which enables interactive analysis of large amounts of electricity data. The system has the following advantages. First, A novel visualisation graphic has been designed and implemented to enable electricity workers to visualise a comprehensive picture of electricity consumption at different granularities. Second, designing appropriate visualisations to highlight the characteristics of the data itself, depending on the specific needs and type of data. Finally, the system provides a set of coupled visual views and interactions to support system users to freely explore the campus electricity situation from multiple scales.

1. INTRODUCTION

With the development of smart cities, the number and size of urban electricity supply networks have increased dramatically. In order to effectively grasp the operation of the electricity system, we put higher requirements on the intelligence and flexibility of the system. Numerous data sources are generated in the process of the development of digitalization, informatization and intelligence of the electricity system. Under the new situation of explosive growth of electricity system data, it is particularly important to achieve rapid acquisition of massive electricity data information with the help of big data visualization technology (Netek, Brus et al. 2019). Commonly used methods for visualizing electricity data are line graphs, pie charts, line tide charts, and scatter plots (Gegner, Overbye et al. 2016, Fang, Wang et al. 2019, Zhao, Zhang et al. 2020). Other scholars use superposition visualization, where multiple data are displayed in one space by overlaying (Lu, Xu et al. 2020, Jing, Guo et al. 2022). These visualization forms have specific advantages in characterizing different data. The key to data visualization is to choose the appropriate visualization method based on the data type and analysis needs (Jing, Du. et al. 2019).

The smart electricity visualization system is an effective tool to assist electricity management departments to master electricity data and rationalize electricity planning by using various visual analysis technologies. The smart electricity visualization system is particularly suitable for areas with relatively concentrated electricity consumption, such as communities, parks and different levels of electricity management. Smart electricity visualization system as an effective means of electrical energy management, the application is more commonly used in some developed countries, and China is also in the process of accelerating the construction of smart grid (Dileep 2020, Lu, Xu et al. 2020).

We found some shortcomings in the process of investigating existing smart electricity visualization system. First, existing studies mostly use the traditional visualization method of presenting one type of data or the analysis results of multiple data in one chart. Second, the system needs to be improved in terms of human-computer interaction to facilitate system users to freely explore electricity data from multiple levels and perspectives.

To address the above challenges, we studied the actual daily electricity consumption of the campus over a 24-month period from 2018-2019. An interactive system was designed using multiple visualization methods. The system focuses on helping electricians to effectively grasp the electricity consumption of the campus and freeing them from the complex data. The main contributions of our research are as follows.

1) Design a reasonable list of tasks through discussions with electricity experts. Select the appropriate visualisation for the different task requirements and the characteristics of the dataset representation.

2) A novel visualisation of the graphics was designed and implemented. A visualisation-driven data mining model is proposed that integrates multiple data features in a single graphical notation through a customised data indexing mechanism, which helps electricity workers to grasp comprehensive information on electricity consumption.

3) Development of a set of coupled visualisations and an interactive framework to give electricity workers the freedom to explore campus electricity consumption from different perspectives and multiple scales.

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2. RELATED WORK

2.1 The Development of Smart Grids

With the explosive growth of electricity loads and the increasing pressure on the electricity supply of the grid, the traditional grid is no longer able to meet the growing demand for electricity. In the bottleneck period of electricity grid development, there is an urgent need for a more secure, reliable, efficient, energy efficiency and environmental protection of the intelligent system(Osama Majeed Butt, Muhammad Zulqarnain et al. 2021). Under this demand, smart grid emerges.

Compared to developed countries such as the United States and Japan, China started late with smart grid technology. However, it has developed rapidly in recent years. A series of national policies have been introduced to promote the development of smart grids in China. In July 2012, the Ministry of Finance issued a subsidy policy for cities that implement demand-side management (Ministry of Finance of the People's Republic of China 2012). In August 2015, a policy was issued to solve the problem of weak distribution network and improve the acceptance capacity of new energy (National Development and Reform Commission 2015). In 2018, intelligent terminal security policies such as new energy, distribution network and load management will be issued (Administration 2018). This series of policies has promoted the construction of smart grid related projects.

Some scholars have studied related technologies of smart grid. For example, Hasan (Hasan, Toma et al. 2019) proposes CNN-LSTM electricity theft detection system to identify ordinary users and electricity theft users separately. Ghulam (Ghulam Hafeez, Khurram Saleem Alimgeer et al. 2020) proposes a hybrid electricity load prediction model to predict the future electricity load. Yao (D. Yao, M. Wen et al. 2019) uses an improved CNN model to detect abnormal behaviors of metering data and reduce the risk of users' energy data being leaked during transmission. With the improvement of global energy awareness, demand side management (DSM) is one of the key developments of smart grid. Literature (Puttamadappa C. and Parameshachari B.D. 2019) applied firefly swarm optimization (GSO) and support vector machine (SVM) to the decision-making process of battery storage to reduce the cost of end users.

However, there are still some challenges in the development of smart grid. First, the combination and operation of China's electricity grid and Internet is still not perfect. Secondly, smart electricity meters that can display all kinds of electricity consumption information in real time have not been popularized in China, which is also a problem to be solved in the development of smart grid in the future.

2.2 Application of Visualization Technology in the Field of Electricity

In the last decade, visualization technology has developed by leaps and bounds. As an effective means of presenting information, data visualization generally takes three forms: Juxtaposition, displaying multiple data side-by-side in a single display space. Superposition, overlaying multiple results in a single display. Explicit encoding, display different data using colour, symbol size, and other coding differences (Michael Gleicher, Danielle Albers et al. 2011, Fang, Wang et al. 2019). The traditional visualization methods are mainly statistical charts, cluster analysis charts and thematic charts (Xiao, Fei et al. 2019) However, these are mostly static visualization techniques. As society develops and science advances, higher demands are placed on mining and analysis technologies as well as dynamic presentation and interactive operation technologies.

Electricity data in the city mainly comes from smart meters, pylon, generators and transformers (Tom Wilcox, Nanlin Jin et al. 2019, D. Syed, A. Zainab et al. 2021). Types of data include the electricity data, the customer data, the equipment data and the line data (Lu, Xu et al. 2020). With the advantages of visualization techniques in expressing spatiotemporal data, more and more scholars are applying visualization techniques in the field of electricity. According to the data type and analysis requirements, selecting the appropriate visualization method can help to characterize the data (Zhao, Wang et al. 2014, Xiao, Fei et al. 2019). In this literature customers' electricity consumption behaviour is analysed and visualised (Hou, Xiao et al. 2018). In this literature electrical tide data is visualised and analysed in the form of topological diagrams (Zhao, Zhang et al. 2020). In this document, the entire wide area network electricity data is displayed by using animated loops and scaled text-sized line graphs (Gegner, Overbye et al. 2016). Li based on the idea of superposition visualization, superimposed line diagrams, sector maps and hotspot maps show the operation of the electricity system and the distribution of electricity users (Li, Cheng et al. 2019). Lu display of electricity distribution and supply conditions based on superposition visualization ideas and color coding (Lu, Xu et al. 2020).

In summary, visualization techniques have been have been commonly used in electricity system. A number of functions have been implemented such as real-time display of electricity data, data analysis and fault detection. However, there are fewer applications of electricity system within the campus.

3. STUDY AREA AND DATASET

3.1 Study Area

In this study, a university in Beijing was selected as the study area. As independent communities in the city, campuses are characterized by carrying multiple functional areas within a limited spatial scope. Based on the heterogeneity of functions within the campus, the study area was divided into Teaching Community, Dormitory Community, Research Community, Recreation Community, Logistics Community and Master and Doctoral Apartment Community (Communities where teachers live). The study area is shown in Figure 1.

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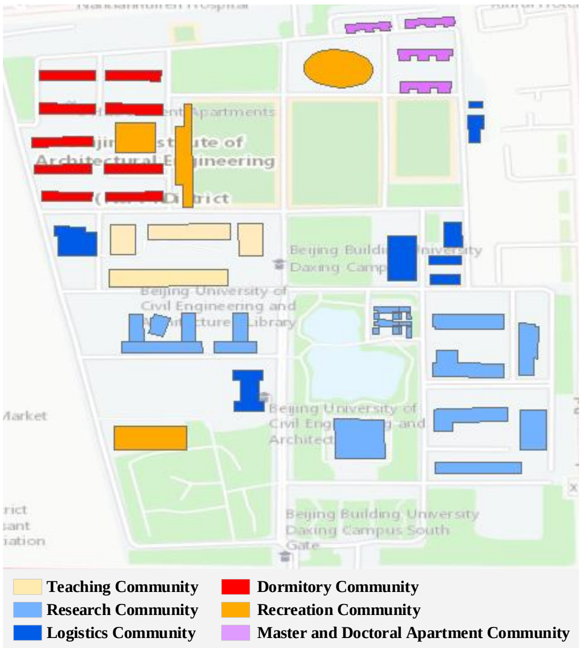

Figure 1. Study area is a university in Beijing.

3.2 Dataset

The dataset used in this study includes vector data for the study area, actual electricity consumption data for a total of 24 months from 2018-2019 and meteorological data for equal time intervals. The electricity data specifically contains: building id, building name, electricity consumption, and time. The study area vector data contains spatial location information and attribute data. The attribute data contains the building name, the functional area category to which it belongs and the electricity consumption. In addition, we use crawling techniques to obtain meteorological data for the study area at equal time intervals, which contain time, maximum and minimum temperatures, days of the week, and weather conditions. The data processing including data pre-processing, data and map association, and data indexing in database.

4. TASK AND SYSTEM DESIGN

4.1 Task Description

After communicating with experts and the head of the electricity department, we confirmed the requirements for the smart campus electricity data visualization and analysis system and compiled a task list.

1) Campus electricity system have large data sizes and complex non-linear relationships. In order to facilitate electricity workers to grasp the information related of electricity consumption, the electricity consumption of each area needs to be displayed in real time. Therefore, the electricity system needs to provide time-series-based analysis of electricity consumption dynamics and customers' electricity consumption behaviour.
2) The smart campus electricity system needs to present data from multiple perspectives, and this data needs to be as easy to understand and observe as possible. Therefore, the system needs to select the appropriate graphical presentation according to different electricity data characteristics.
3) Campus electricity system need to provide different levels of electricity data visualization and interaction to meet the needs of electricity workers to explore the data freely.

4.2 System Framework Design

In this study, a framework for visual analysis of electricity data was designed to help the electricity department keep track of electricity consumption on campus in real time. The framework of the visual analytics system is shown in Figure 2. The system adopted a three-layer architecture of data layer, analysis layer and presentation layer. The data layer utilizes a MySQL database to manage geographic and non-geographic spatiotemporal data. The analysis layer contains the analysis functions, models and components for each metric. The representation layer provides the user with multiple view modules for displaying the analysis results for each metric.

The functions of each view module of the presentation layer are as follows.
1) Electricity consumption situation. This module is to explore how campus electricity consumption evolves over time and to master the peak and low periods of electricity consumption.
2) Differential analysis of electricity consumption. By analysing electricity consumption in different regions, we explore the correlation and differences in electricity consumption patterns of different customer groups.
3) Correlation analysis. This module explores the correlation between electricity consumption and temperature and workday.
4) Anomaly detection. This module mainly detects fluctuations in electricity consumption and abnormal electricity consumption, and displays the differences in the distribution of electricity consumption in different communities.
5) Comprehensive information display. This module integrates several important data features into a novel graphic symbol, providing users with a comprehensive information display view that allows them to visualize the status of electricity consumption.

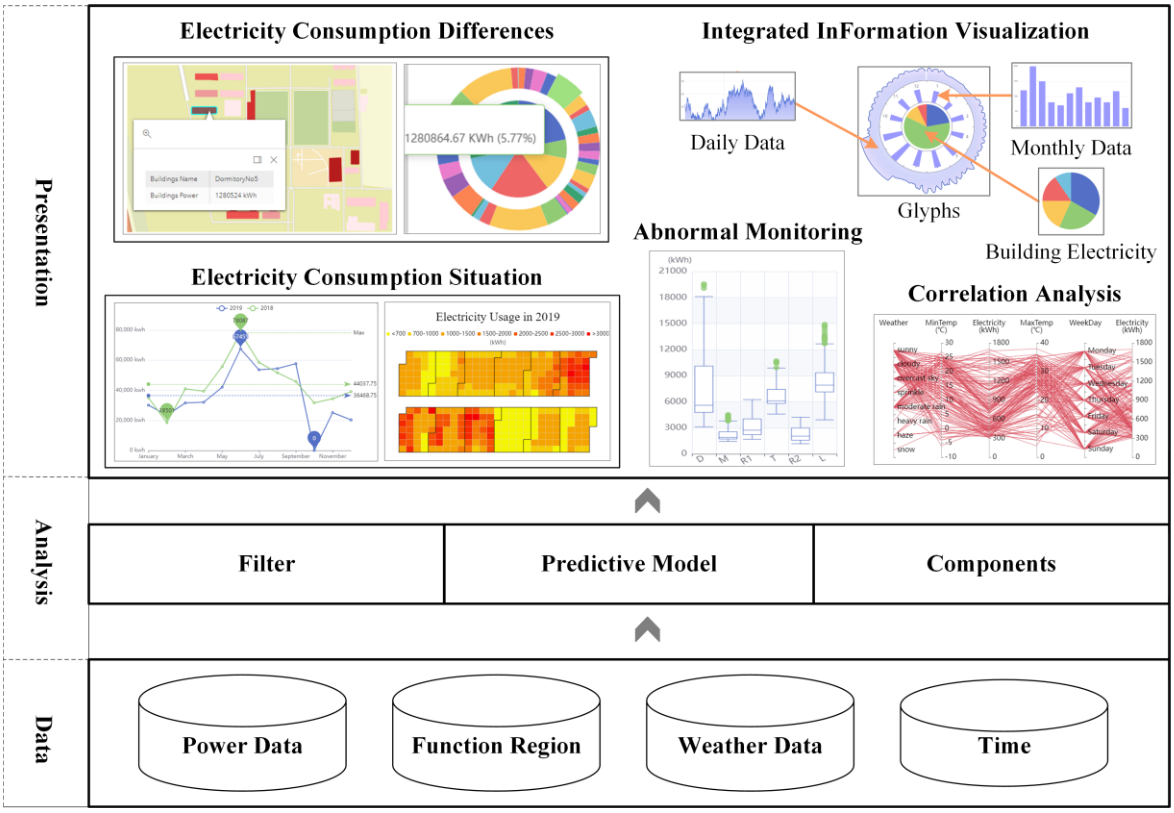

Figure 2. System Architecture

5. SYSTEM IMPLEMENTATION

Based on the task description in Section 4.1 and the visualization analysis framework in Section 4.2, an intelligent campus electricity data visualization analysis system is implemented in this study. The system interface is shown in Figure 3. A denotes the selection filter. B denotes the electricity consumption related factors view. C denotes the anomaly monitoring view. D denotes the electricity consumption percentage view. E denotes the heat map view. F denotes the electricity consumption trend view. G denotes the integrated view of electricity consumption information. H denotes the electricity consumption calendar view.

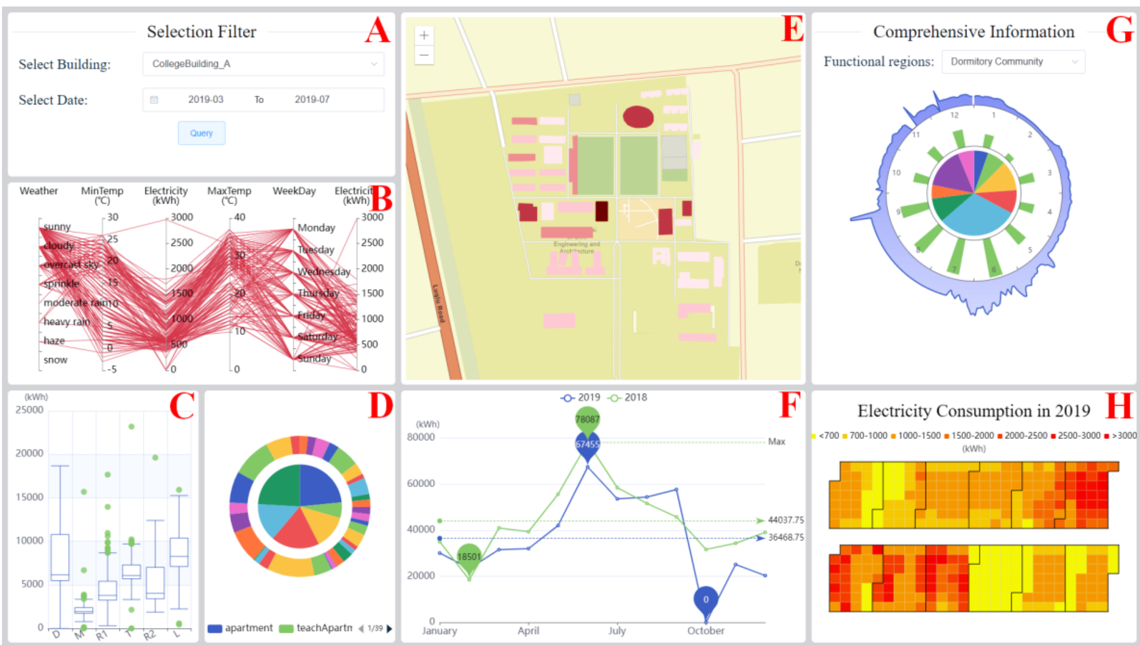

Figure 3. System Implementation. In (C), D denotes Dormitory Community, M denotes Master and Doctoral Apartment Community, R1 denotes Research Community, T denotes Teaching Community, R2 denotes Recreation Community, and L denotes Logistics Community.

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5.1 Selection Filter View

Figure 3A is the selection filter for the built-in dataset filter. This view is used by the user to filter the area and time period of interest. In the selection panel, target area filtering and custom time range filtering are displayed from top to bottom. The area filter is based on building units, and the time filter is based on month units.

In addition, electricity workers tend to pay attention to multiple electricity data attributes at the same time, and there may be some relationship between these data. This is a linkage effect where a change in one data point causes a change in another data point. In order to explore the internal relationship between different data from multiple analysis perspectives, visual objects in multiple views are monitored, and dynamic association of multiple views is realized during user interaction. When the system users interact with visual objects in any view, they are dynamically linked to visual objects in other views. The multi-view linkage technology used in this study breaks through the limitation of displaying data from a single perspective.

5.2 Electricity Consumption Situation View

The electricity system accumulates a large amount of electricity data based on time series. Understand how electricity consumption evolves over time, master the peak and trough periods of electricity consumption was provided scientific basis for the macroscopic planning of electricity system load. The electricity situation view shows the evolution of electricity consumption over time in the form of line charts and calendar thermal maps.

As shown in Figure 3F, the broken line chart shows the monthly electricity consumption of specific areas from 2018 to 2019, which is convenient for electricity workers to master the macroscopic electricity consumption situation of the campus. Each broken line automatically marks the maximum and minimum electricity consumption of the region it represents in the form of bubbles, and a dotted line shows the average electricity consumption. At the same time, it also uses the form of calendar chart to display fine-grained electricity consumption. As shown in Figure 3H, the calendar thermogram is composed of the thermogram and the calendar graph, which represents the relationship between electricity consumption and time variables. Each colour block in the calendar map represents one day's electricity consumption. The unit of daily electricity consumption is rendered through a designed colour mapping table, with the darker the colour rendering the higher the daily consumption. This visualization provides a visual representation of the distribution of electricity consumption over a period, facilitating comparative analysis of electricity consumption over a time span and providing a clear understanding of peak and trough periods of electricity consumption for electricity workers.

5.3 Electricity Consumption Differential Analysis View

The heterogeneous nature of campuses results in differences in electricity demand and consumption patterns among user groups. This study uses a combination of maps and graphs to show the differences in electricity consumption by user group.

Maps can provide visual insight into geographical locations. As shown in Figure 3E, the view consists of an ArcGIS online map and a vector layer containing information about the building. In addition, the view offers two functional layers, the heat map and the marker layer. The heat map utilises colour coding techniques where a colour mapping table is designed to represent the differences in electricity consumption between groups by rendering different areas. The method provides a visual representation of the differences in electricity consumption between regions. To facilitate the analysis of differences in electricity consumption between time periods by system users, the heat map layer supports the definition of target time periods. Clicking on a target building allows the system user to explore the map in one step, focusing the whole campus on the building of interest and activating the marker layer at the same time. An information box pops up at the corresponding location on the map, showing building information and detailed electricity consumption information.

The charts are a quantitative way of perceiving the differences in electricity consumption by user groups. As shown in Figure 3D, the view adapts to the dynamics of the data by designing a nested ring chart that calculates in real time the share of electricity consumption in each area in the different tiers. Set the six categories of functional regions delineated in Figure 1 as the first level areas, indicated by the inner circles. The buildings in the functional regions are set up as second level areas and are represented by an outer ring. This visualization method visualizes the differences in electricity consumption between areas in a quantitative way.

5.4 Electricity Correlation Analysis View

Electricity data is a large data set with complex spatiotemporal properties, and electricity consumption is influenced by several factors. The electricity consumption correlation analysis module explores the correlation between electricity consumption and these factors were affected. These factors are combined with electricity data to produce a data set with multiple dimensions. Traditional graphical visualizations are limited in their ability to represent multi-dimensional data. Parallel coordinate system consists of N parallel lines spanning multiple vertically equidistant axes, and the line density maps the relationships between multiple dimensional variables, which is advantageous when expressing correlations between multidimensional data. Therefore, we use a parallel coordinate system to show the relationship between electricity consumption and temperature, weather and working days, as shown in Figure 3B. Considering that it is more intuitive to observe the relationship between adjacent variables, the axis ordering of the parallel coordinate system in this paper is set to: weather - maximum temperature - electricity consumption - minimum temperature - weekday - electricity consumption. In addition, users of the system can filter redundant data by selecting the region and time period of interest.

5.5 Anomaly Detection View

The operation of campus electricity system is subject to uncontrollable contingencies such as signal interruptions, equipment failures and abnormal electricity consumption situations subject to human influence. Accurate knowledge of these anomalies helps electricity workers to respond to safety incidents in a timely manner. Box line plots describe the discrete distribution of data in a relatively stable way. It also has significant advantages in determining the skew and tail weight of data and visualizing outliers in the data set. Therefore, Box line diagrams were drawn to view the distribution of electricity consumption and to monitor abnormal electricity consumption, as shown in Figure 3C.

An illustration of a box diagram is shown in Figure 4, which consists of the main box, the median, the stem and the whiskers.

From bottom to top, the five statistics for a set of data are indicated: minimum, first quartile, median and third quartile and maximum, with the values on the outside of the box being abnormal electricity consumption.

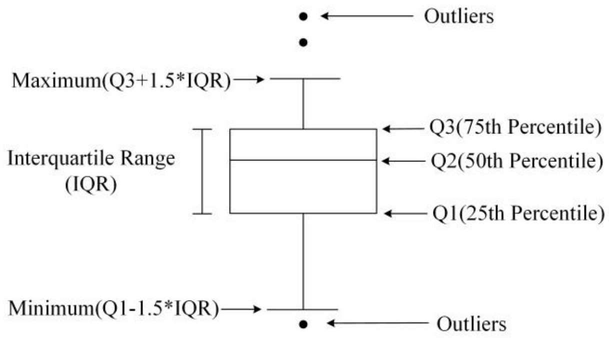

Figure 4. Illustration of Box line diagram

5.6 Comprehensive Information Display View

As in Figure 3G, a view of the integrated electricity consumption information display for different functional regions is shown. The view is designed to provide electricity workers with a visualization of the important features of electricity data, allowing them to quickly grasp the electricity consumption on campus. Inspired by the technique of overlapping visualization, it considers the advantages of a flexible overlay of multiple layers of information in a torus. A novel visual metaphor for representing integrated electricity consumption information is achieved using a circular chart framework with nested line, bar and pie charts. After discussions with electricity experts, key information for the visual coding was identified, e.g., the daily and monthly electricity consumption of each functional regions and the percentage of electricity used by buildings in each functional region. The folded line has a clear advantage in representing time-series characteristics, so the daily electricity data is presented using a folded area chart. The single bar in the middle represents the monthly electricity consumption. The internal pie chart shows the percentage of electricity consumption in each building within the functional regions. Table 1 shows the key pseudocode for the glyph symbol. On the one hand, this visualization method helps electricity workers to quickly grasp the overall situation of campus electricity consumption. And on the other hand, helps to intuitively compare the differences between different data sets. This view allows the system user to view comprehensive electricity consumption information for a specific functional area by selecting a drop-down box.

```
barData = barData.map ((e, index) => [e, index + 1]);
this.chart = echarts.init(this.$refs.chart);
Option:
    Line:
        polarIndex: 0
        type: "line",
        radius: ["60%", "90%"]
        data: lineData,
    Bar:
        polarIndex: 1
        type: "bar",
        radius: ["32%", "60%"]
        data: barData,
    Pie:
        type: "pie",
        radius: "29%",
        data: pieData,
this.chart.setOption(option, true);
```

Table 1. Key pseudocode for glyph symbols.

6. DISCUSSION

To detect the spatiotemporal patterns of campus electricity consumption, a series of visualizations was designed to present the data. For example, considering the advantage of parallel coordinate system in expressing multidimensional data, it was used to establish the correlation between electricity consumption and influencing factors. Box line plots can visually represent the distribution of a set of data and detect outliers. These visualization tools facilitate our effective understanding of different types of data. In the integrated visualization view, an index of multiple data features was created that are integrated in a single graph to show the electricity consumption of a specific functional regions. This visualization method allows integrated graphics to better present more information in a limited visual space than traditional visualization methods that can present only a single piece of data. Reduces the visual burden on the system user to observe and compare multiple data in a large spatial area.

7. CONCLUSIONS

In this paper, a series of visualisation mining methods was designed for different requirements. Various interactive visualisation techniques were used to explore the campus' electricity consumption patterns and a collaborative, interactive visualisation system with multi-view links was developed. The system designs appropriate visualisations for different data characteristics and needs. Also to effectively reduce the cognitive burden on system users, a novel glyph symbol was designed to show the integrated electricity consumption of each functional regions of the campus. Finally, the view modules are integrated in the visual framework in a tightly coupled manner.

Although the study was conducted using a university campus as a case study, it has good applicability and can be easily applied to other similar scenarios. Examples include the mining and analysis of communities and parks electricity consumption patterns. In addition, the system is scalable and can incorporate additional types of data, such as grid distribution and equipment information. Adding a fine-grained exploration of the campus electricity model on a room-by-room basis is the next step in our work plan.

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