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Optimization Sampling for Building Energy Consumption Monitoring System

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***Abstract*:** *Building energy consumption data has important research value and realistic meaning, because it is the only method to evaluate the performance of building energy saving. This paper analyzes the advantages and disadvantages of common sampling methods, which include equivalent period sampling frequency variable sampling, and Lebesgue sampling. On that basis, puts forward the optimization sampling method for different types of energy data, which could enhance the data transmission efficiency of building energy consumption monitoring system, and save the storage of database. This paper offers important theory and technical support for further application of building energy monitoring system in future.*

Keywords: *building energy consumption data, sampling theory, sampling method optimization*

1. Introduction

The meaning of building energy saving is to increase the energy usage efficiency, and the ultimate goal of this is reducing the energy consumption during the actual operation of equipment in buildings. Energy data plays an important role in this process, because it is the sole criterion to evaluate the performance of building energy saving [1]. The building energy consumption monitoring platforms have been established to obtain the real-time energy data all over the world in recent years [2-5]. T. Nagata developed an electric power energy monitoring system in a campus, which could collect energy consumption in every minute, hour, day and month [2].

However, there is a problem existed in these systems that they all acquire data, such as electrical energy quantity, real-time voltage, current, heat energy quantity etc., at the same time period, with the defect of this method is that the quantity of energy data is too large. Besides that, it increases the pressure of data transfer and the requirement of large storage capacity in server.

This paper puts forward two optimization sampling methods according to the sampling theory based on the characteristics of different kinds of energy data, frequency variable sampling method and Lebesgue method to enhance the data transmission efficiency of building energy consumption monitoring system, and save the storage of database. The energy data characteristics and sampling methods are introduced in Section II and Section III, respectively. In addition, the optimization sampling methods for energy data are given in Section IV. Finally, we make the conclusion in Section V.

2. Data Characteristics

The monitoring energy consumption information in building is consisted of three main types, electric, water and heat, of which electric is the primary energy consumption compared to others. The parameters included by them are as below.

(1) Electrical information: A phase voltage, B phase voltage, C phase voltage, A phase current, B phase current, C phase current, A phase power, B phase power, C phase power, power factor and quantity of electrical energy consumption.

(2) Water information: quantity of water flow.

(3) Heat information: quantity of heat flow, inlet water temperature and outlet water temperature.

3. Sampling Method

The continuous time signal changes on the timeline as a regular manner, the process that obtaining discrete data from continuous time signal is called “sampling”, on the other hand, “reconstruct” describes the process of turning the discrete data into original signal in the receiver. Nyquist–Shannon sampling theorem is a powerful mathematical tool to explain these two processes, which is presented by Harry Nyquist [6] and Claude Elwood Shannon[7]. The sampling frequency decides the quality and quantity of data, the higher quality of collected data with higher sampling frequency, meanwhile, generating huge amount of data, absolutely.

3.1. Normal Sampling

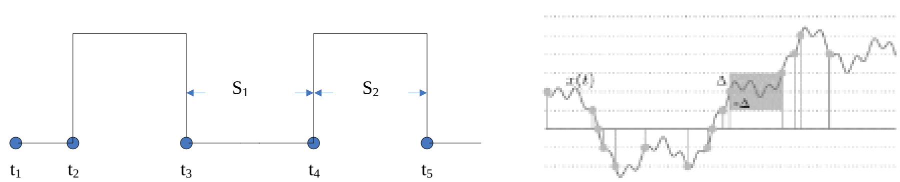
The most common method for sampling is equal interval sampling, which is also called Riemann Sampling. This method samples a point at the same time interval T_s, which is sampling period, such as 1 minute, 5 minute et al. The advantage of this method is good compatibility and can be used in almost every kinds of signal sampling.

Assume the maximum frequency of original signal is fc, sampling frequency is f_s, and then fs should satisfy the equation (1).

$$f_s = K \cdot f_c \quad (K > 2) \tag{1}$$

Where K is the ratio of f_s and f_c, the value should be more than 2. Setting the space required for once sampling is Q, and the relevant storage capacity for a sampling time period ‘t’ is shown as in equation (2).

$$S = \frac{t}{T_s} \cdot Q = t \cdot f_s \cdot Q = t \cdot K \cdot f_c \cdot Q \tag{2}$$



(a) Frequency variable sampling (b) Lebesgue sampling

Fig.1. Sampling method

3.2. Frequency Variable Sampling

If the change trend of signal is apparent, the sampling period could be changed with the trend of signal in order to save storage capacity. When the fluctuating range of is relatively great, the sampling frequency should be higher, otherwise, the sampling frequency may be lower. The name of this method is called frequency variable sampling as the feature of it. Fig.1 (a) shows this process, in the time period of t3~t4, the sampling period is T_{s1}, and in the time of t4~t5, the sampling period is T_{s2}, and then the relevant storage capacity for a sampling time period ‘t’ is shown as in equation (3), where t = t_1+t_2.

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$$S = \frac{t_1}{T_{s1}} \cdot Q + \frac{t_2}{T_{s2}} \cdot Q \tag{3}$$

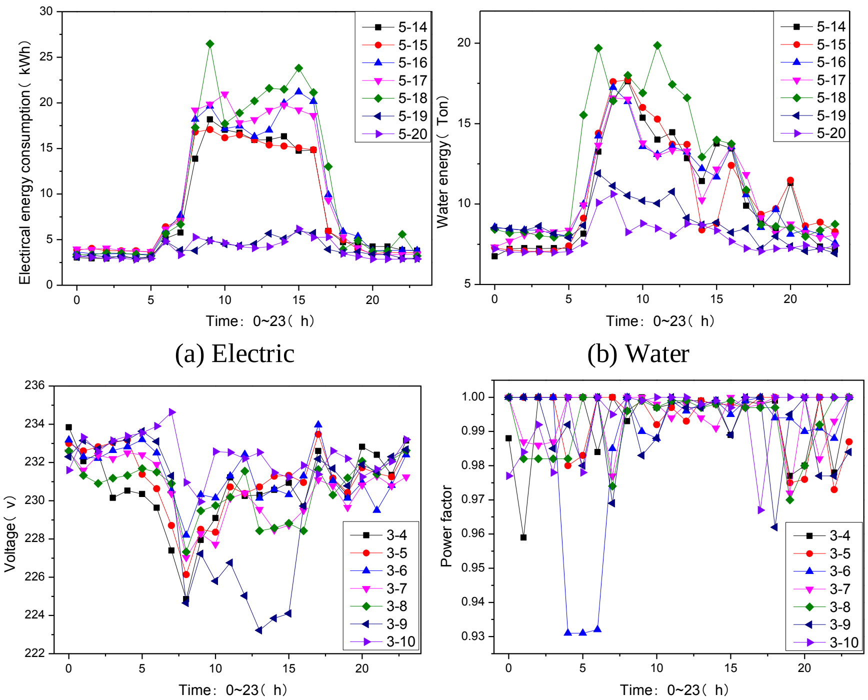
3.3. Lebesgue Sampling

Different from Riemann Sampling and frequency variable sampling, which are triggered at a fixed time point, Lebesgue sampling is known as level-triggered [8]. Fig.1 (b) presents a canonical Lebesgue sampling scheme, the sampling point looks like random in the timeline, but at the same interval prevision along the vertical scale. According to this sampling strategy, the signal is sampled every time it crosses one of the pre-assigned levels. For a continuous time signal x(t), Lebesgue sampling accuracy is Δx, and then the samples sequence can be expressed as in equation (4).

$$x^*(t) = \sum_{i=1}^{\infty} x(t_i)\delta(t - t_i) \tag{4}$$

The storage capacity for a sampling time period 't' is shown as in equation (5). There's an inverse relationship between capacity and sampling precision.

$$S = \frac{t}{\Delta x} \cdot Q \tag{5}$$



(a) Electric (b) Water

(c) Voltage (d) Power factor

Fig.2. Original data from building energy consumption monitoring system:

*The period in figure (a~d) is 60M in order to grasp the change trend.

4. Optimization Sampling

4.1. Statistics Data

Fig.2 (a) and Fig.2 (b) show the energy consumption quantity changing curves of electric and water in a week, May 2012, respectively. It is can be clearly observed that, the value of sampling is small and fluctuation trend is gently before 6 o'clock and after 18 o'clock when there are a few or nearly no office workers in the building. On the other hand, during 6 o'clock and 18 o'clock, the energy data fluctuated widely at a relative high level compare to the value outer of this time period. The variation tendency of statistics data looks like square wave in the Fig.1 (a), which is suitable for FVS method to optimize.

Before optimization: sampling with equivalent time period, 5 minutes, and then the entire storage capacity needed is as shown in equation (6).

$$\text{sampling points}=\frac{24*60M}{5M(T_s)}=288 \tag{6}$$

After optimization: sampling with frequency variable method, 5 minutes sampling period during 6 o’clock to 18 o’clock on the same day, and 30 minutes sampling period after 18 o’clock on the same day and before 6 o’clock on the next day. In addition, the total storage capacity needed by this method is as shown in equation (7).

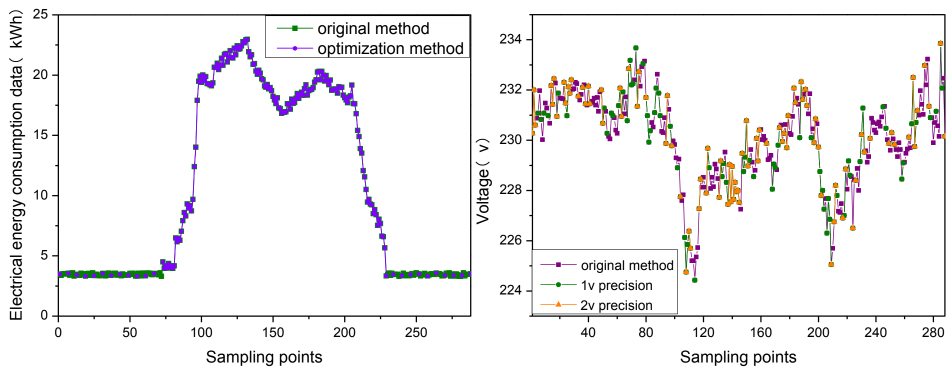
$$\text{sampling points}=\frac{12*60M}{5M(T_{s1})}+\frac{12*60M}{30M(T_{s2})}=168 \tag{7}$$

4.2. Monitoring Data

Fig.2 (c) and Fig.2 (d) show the real-time change curves of monitoring voltage and power factor. The voltage varies between 223v and 235v, while, on the other hand, the maximum value of power factor is 1, and the lowest value is 0.93 on March 6. In this case, the Lebesgue sampling is more appropriate method to acquire three phase voltages and power factor.

Before optimization: the entire sampling points needed to be transfer for voltage and power factor are 288, as shown in equation (6).

After optimization: Here, take voltage as an example, setting the precision is 1v, and the sampling points are dropped to 155 by using Lebesgue method. Furthermore, the sampling points can be reduced to 90 if the precision is 2v.



(a) Electrical energy (b) Voltage

Fig. 3: Comparison between original signal and optimize sampling

5. Results And Discussions

The quantity of statistics data such as electrical energy consumption data, heat energy consumption data can be reduced to 41.7% when optimized by frequency variable sampling method. On the other hand, the monitoring information such as real-time voltage or power factor is suitable for Lebesgue sampling method, and the quantity can be decreased to 50% if the precision is selected appropriately. In addition, Fig.3 (a) and Fig.3 (b) show the performance of optimization method compared to the original sampling and the changing trend is reserved. Table 1 shows the suitable optimization sampling method for the building energy consumption data and the corresponding optimal performance. While the three phase currents and three phase power are belong to real-time monitoring information and the fluctuating range is relatively great, so there is no optimization method chose for them in order to keep the characteristics of changing trend.

TABLE I: Selection and Performance Analysis of Optimization Sampling Method

Classification	Optimization method	Optimal performance
electrical energy quantity	Frequency variable method	41.7%
heat energy quantity	Frequency variable method	41.7%
water energy quantity	Frequency variable method	41.7%
three phase voltage	Lebesgue method	50%
three phase current	Normal sampling	-
three phase power	Normal sampling	-
power factor	Lebesgue method	50%
temperature	Lebesgue method	50%

6. Conclusion

This paper presents two optimization methods for data sampling in building energy consumption monitoring system. The new sampling methods could enhance the data transmission efficiency of building energy consumption monitoring system, and save the storage of database. Analysis and results show the applicability and efficiency of the two sampling methods, which offer important theory and technical support for further application of building energy monitoring system in future.

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