

Optimization of Public Building Monitoring System Based on Human Behavior

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Abstract. In recent years, with the rapid development of the economy, China's building energy consumption has increased year by year, and energy conservation has become an inevitable requirement for development. Among them, the impact of human settlements on building energy consumption is obvious, and the study of building energy consumption by human settlements has certain social significance. At present, the research on the model of human behavior is obtained under certain assumptions, resulting in inaccurate results. Therefore, a set of energy consumption monitoring system platform based on personnel behavior was developed, and the number acquisition device was developed. The cumulative error estimation algorithm was used to optimize it, which provided a data foundation for solving the problem of energy-saving optimization of intelligent buildings based on human settlements.

Introduction

Our large-scale public construction area of less than 4% of the total area of the town, but the total energy consumption accounts for 22% of total electricity consumption in cities and towns.

Domestic and foreign companies and scholars have conducted a lot of research on energy of building consumption monitoring^[1]. The Pacific Northwest National Laboratory has developed a software (WBD) that can be used to diagnose building energy savings, which provides a statistical analysis of the overall energy use in the building. The above results have been researched and applied in terms of building energy conservation, but few of them consider building energy conservation from the perspective of human behavior. So we independently developed a monitoring system based on the Habitat building behavior. The focus has been on improving the number of people collecting devices. The high-precision camera is used on the hardware. The algorithm uses the cumulative error estimation algorithm to improve the accuracy of the number-collecting device, and provides a data foundation for building energy-saving optimization for the subsequent settlement of human behavior.

Human Behavior Monitoring System

The system^[2] consists of slave nodes, master nodes, and a host computer. The node group part are different carrier matters for data acquisition and status monitoring; the concentrator is responsible for communicating with the node group and the host computer, acquiring the downlink node group data in real time and timing and storing, and uploading the data timing to the upper computer, and capable of receive the host computer command to control the indoor electrical equipments^[3-7]. The LabVIEW software used by the host computer software implements functions such as receiving, displaying, storing, and controlling power devices. Figure 1 shows the structure of the building automation monitoring system.

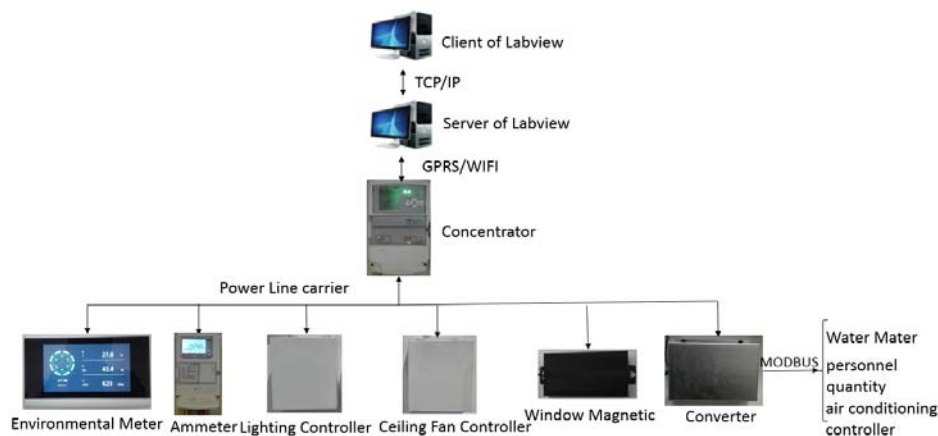


Figure 1. Shows the structure of the building automation monitoring system

Hardware Design

Data acquisition equipment includes electricity meter, environmental meter, water meter, personnel quantity statistics equipment and window magnetic monitoring. The environmental devices are used to collect environmental parameters of the office, including temperature, humidity, CO₂ and PM2.5. Water meters collect water consumption. Personnel quantity monitoring devices get the number of personnel. Window magnetic monitoring to obtain the switch status of the window. The lighting control devices receive the command of the upper computer and controls the switching condition of the illumination. The air conditioning control device receives the upper computer command and controls the running state of the air conditioner. Ceiling fan control device control gear position.

The Upper Computer

The upper computer implements the following functions: (1) concentrator configuration and query of node group parameters; (2) calibration time; (3) sending read data command and receiving data; (4) querying lighting status; (5) When the consumption is too high, the alarm is given on the host computer interface. The function interface of the upper computer is shown in Figure 2.



Figure 2. The function interface of the upper computer

Hardware Design of Personnel Quantity Collection Device

The personnel counting device is composed of a video analysis system and a number acquisition system. The video analysis system uses a camera to acquire character characteristics in real time and analyze human flow information to obtain information about people entering and leaving the room.

The number acquisition system is self-developed hardware. It consists of power module, power line carrier module, RS485 communication module and so on. The power source mainly supplies power to all components, the power line carrier module is used for external communication, and the RS485 communication module is used to communicate with the video analysis device.



Figure 3. Video analysis system



Figure 4. Personnel counter device

Software Design of Personnel Quantity Collection Device

The video camera analyzes the picture of the corresponding area of the door in real time, gets the character of the character, and obtains the information of the person entering and leaving the room. Then, the number of people entering and leaving the house is obtained in real time through the RS-485 communication interface, and then the number of indoors at this moment is calculated and stored in the controller; finally, the data is reported to the concentrator by using low-voltage power line carrier communication to realize data transmission.

Optimization of the Number of People Based on Cumulative Error Estimates

After a large amount of data testing, the measurement accuracy based on the improved number of personnel counters has been significantly improved, but since the video count is an accumulating counter, it will cause cumulative errors after long-term operation, so it is necessary to find a cumulative error estimation method. Make corrections to improve counting accuracy.

Algorithm

In response to this problem, this paper finds a method for estimating the cumulative error of discrete time^[8]. First, according to the actual number of people counter installation environment, the indoor and outdoor are divided into two separate spaces, and the two spaces are connected. In the algorithm design, the indoor and outdoor areas are defined as the i area and the j area, respectively. At the border of the area, we installed a staff counter to detect the entry and exit of people indoors and outdoors. Assuming that people are moving indoors randomly, according to the Markov chain, we can estimate the random movement of people in the building, that is, there must be events in the entire time period when people leave the area. So it can be expressed as:

$$\sum_{k=1}^K p_{i,j} = 1 \quad (1)$$

$n_i(k)$ represents a real number of area i at time k , $m_{i,j}(k) \geq 0$ represents the time region k from i to j number of regions, the total number $k+1$ of the time domain may be expressed as:

$$n_i(k+1) = n_i(k) - m_{i,j}(k) + m_{j,i}(k) \quad (2)$$

If $\bar{n}_i(k)$ is the number of measured i -area counters at time k , then the actual number of people in area i at time k can be expressed as:

$$\bar{n}_i(k) = \hat{n}_i(k) - \bar{m}_{i,j}(k) + \bar{m}_{j,i}(k) \quad (3)$$

$\hat{n}_i(k)$ is the estimated number of people in the i -zone at time k , and $\Delta n_i(k)$ is the correction amount of the estimated number of people in region i at time k . Then the estimated number of people in the $k+1$ time zone i can be expressed as:

$$\hat{n}_i(k+1) = \bar{n}_i(k) + \Delta n_i(k) \quad (4)$$

Analysis of Algorithms

Hypothesis 1: In actual office hours, within a certain time, there is a person entering or leaving;

Hypothesis 2: The total number of people in the indoor area i is relatively fixed.

For these two hypotheses, we propose a method based on the residence time in a certain area to estimate the number of people in the area^[9]. The time at which the person leaving the area i is d_j ($j=1,2,3\cdots$), and the time at which the entry or exit event exists before the j departure is t_j ($j=1,2,3\cdots$). So in the interval of $d_j - t_j$, the indoor area i . The number of i can be expressed as $n_i(t_j)$. As shown in Figure 5.

Assuming that the number of people in the i -zone at time k is n , then the probability that no person will leave in time t after k time is:

$$P_1 = (p_{i,j}^t)^n \quad (5)$$

So, the probability that at least one person will leave the area is:

$$P_2 = 1 - (p_{i,j}^t)^n \quad (6)$$

Assume that the shortest time that a person leaves the room is T_{\min} , and the longest time is T_{\max} . Then you can get the relationship shown in Figure 6.

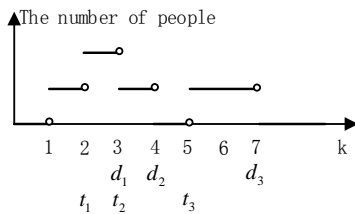


Figure 5. The number of People

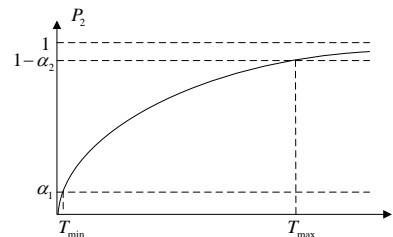


Figure 6. The relationship shown

Among them, in order to eliminate the randomness in the algorithm design, the parameter $\alpha_1, \alpha_2 \in [0,1]$ is introduced. If there are n people in the indoor i area, then in the case where the person n is likely to leave the indoor the area at time $[T_{\min}, T_{\max}]$ ^[4]:

$$I_{\min}(t, n) = \begin{cases} 1, & d_j - t_j \leq T_{\min} \\ 0, & \text{else} \end{cases} \quad (7)$$

$$I_{\max}(t, n) = \begin{cases} 1, & d_j - t_j \geq T_{\max} \\ 0, & \text{else} \end{cases} \quad (8)$$

Assuming that J represents the number of times a person leaves the event during the entire time period, you can conclude that:

$$\hat{\sigma}_{\min} = \frac{\sum_{j=1}^J I_{\min}(t_j, \hat{n}_i(k_j))}{J} \quad (9)$$

$$\hat{\sigma}_{\max} = \frac{\sum_{j=1}^J I_{\max}(t_j, \hat{n}_i(k_j))}{J} \quad (10)$$

If $\hat{\sigma}_{\min} \geq \lambda_1 \alpha_1$, $\Delta n_i(k) = 1$. It can be concluded that the actual departure frequency of the indoor staff is more than the estimated departure frequency, and the actual number of people can be obtained more than the estimated number of people; If $\hat{\sigma}_{\max} \leq \alpha_2 / \lambda_2$, $\Delta n_i(k) = -1$, Indicate that the actual number is less than the estimated number. In the actual application process $\lambda_1, \lambda_2 > 1$.

Algorithm Design

Through these above algorithms modeling and analysis, in order to verify the accuracy of algorithms, two algorithms were developed to compare with each other.

Algorithm 1: According to the counter, the entry and exit situation of the personnel is collected in real time, including data such as time, number of people entering, number of people leaving, and number of people in the room.

Algorithm 2: Estimate the number of people in the room using the error estimation method of the person leaving the time interval. These steps are as follows:

- (1): Initialize $\hat{n}_i(0)$, and $k = 0$.
- (2): The video system acquires $\bar{m}_{i,j}(k)$ and $\bar{m}_{j,i}(k)$, $j \in V$, $\Delta n_i(k) = 0$.
- (3): Calculate the update $\bar{n}_i(k)$, $\bar{n}_i(k) = \hat{n}_i(k) - \bar{m}_{i,j}(k) + \bar{m}_{j,i}(k)$.
- (4): Calculate the update leaving event sequence $[\hat{n}_i(k_j, t_j)]$, $j = 1, 2, \dots, J$.
- (5): Calculate the update $\hat{\sigma}_{\min}$ and $\hat{\sigma}_{\max}$, as follows: $\hat{\sigma}_{\min} = \frac{\sum_{j=1}^J I_{\min}(t_j, \hat{n}_i(k_j))}{J}$.
- (6): $\Delta n_i(k) = 1$, if $\hat{\sigma}_{\min} \geq \lambda_1 \alpha_1$. $\Delta n_i(k) = -1$, if $\hat{\sigma}_{\max} \leq \alpha_2 / \lambda_2$.
- (7): Calculate the update, $\bar{n}_i(k)$, $\bar{n}_i(k) = \hat{n}_i(k) - \bar{m}_{i,j}(k) + \bar{m}_{j,i}(k)$.
- (8): $\Delta n_i(k) = 1$, if $\bar{n}_i(k)$, and $\bar{n}_i(k) = \bar{n}_i(k) + \Delta n_i(k)$, then loop through step (8); otherwise, perform step (9).
- (9) $\hat{n}_i(k+1) = \bar{n}_i(k)$, $k = k + 1$, return to step (2).

Experimental Result

Data with complete data and no sampling errors (data from April 1, 2018 – April 30, 2018). Take valid data from 9:00 am to 11:30 pm, and Table 1 shows the data April 9th.

Table 1. Data collection

Time	Real-time data	K time to leave the number of people	K time to enter the number of people
9:00	15	/	/
9:15	22	4	11
9:30	24	10	13
9:45	24	7	6
10:00	19	1	2
10:15	19	10	9
10:30	19	7	5
10:45	17	3	6
11:00	21	6	6
11:15	19	11	7
11:30	16	13	9

Through a large amount of data analysis, it is possible to obtain a departure event for a maximum of about 15 minutes, and an entry event occurs when it stays for about 3 minutes outdoors, and consider that the camera itself has a counting period of 1 minute, we let $T_{\max}=15\text{min}$, $T_{\min}=3\text{min}$, $\alpha_1=\alpha_2=0.001$.

Table 2 below shows the statistics of the actual number of people, the number of people collected, and the estimated number of people working on the morning of April 9; Figure 7 is the corresponding graph.

Table 2. Comparison of the number of people collected, the actual number of people and the estimated number of people on April 9

Time	the number of people collected	the actual number of people	the estimated number of people
9:00	15	17	15
9:15	22	24	23
9:30	24	27	25
9:45	24	26	25
10:00	26	27	26
10:15	23	26	27
10:30	22	24	24
10:45	24	27	26
11:00	23	27	25
11:15	20	23	23
11:30	16	19	19

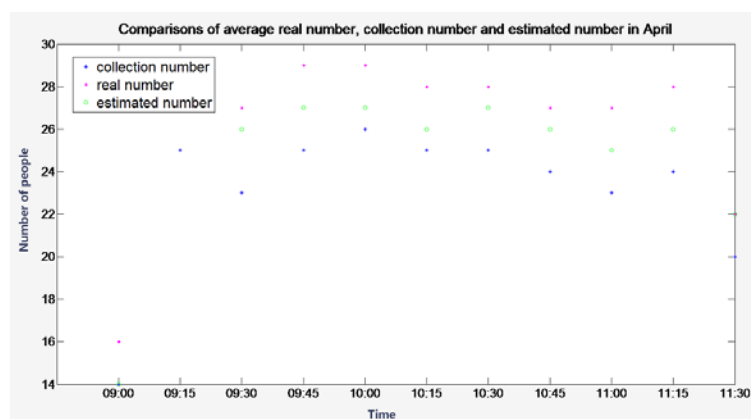


Figure 7. Comparison of personnel quantity

Table 3 shows the statistics of the actual number of people, the number of people collected, and the estimated number of people in the morning of April. Figure 8 shows the corresponding graph. Since there is a small number in the calculation of the average number of people, in the subsequent optimization algorithm, the actual number of indoor personnel is an integer, so it should be processed accordingly and rounded to an integer.

Table 3. Comparison of the average number of people collected, the actual number of people and the estimated number of people in April

Time	the number of people collected	the actual number of people	the estimated number of people
9:00	14	16	14
9:15	25	29	27
9:30	23	27	26
9:45	25	29	27
10:00	26	29	27
10:15	25	28	26
10:30	25	28	27
10:45	24	27	26
11:00	23	27	25
11:15	24	28	26
11:30	20	22	22

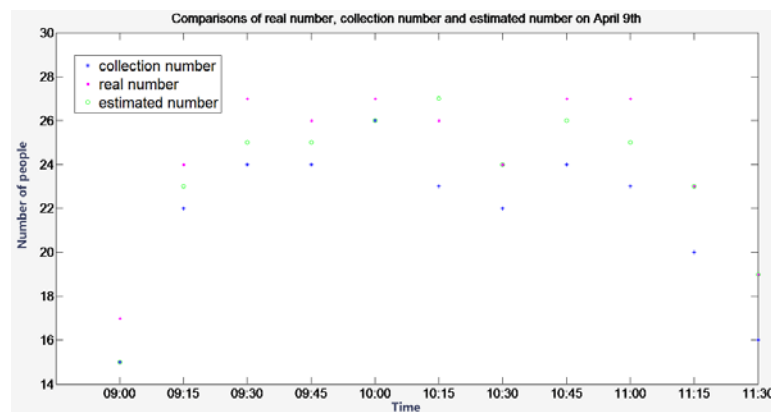


Figure 8. Comparison of personnel quantity

It can be seen from Figure 7 and Figure 8 that during this time period, the estimated number of people is more accurate than the number of people collected, and the maximum error is reduced from 4 to 2, which shows the effectiveness of the algorithm. After further averaging the data for one month, after calculation, the counting accuracy rate is improved from 87.4% to 94.9%, and the accuracy of the optimization algorithm is higher than the acquisition accuracy of the camera. Therefore, the result plays a good role in the optimization of the human flow counter, and is of great significance to the design of the subsequent energy optimization algorithm.

Summary

This paper introduces the personnel quantity monitoring device in detail from two aspects of hardware and software. The number of people using the video method is counted on the hardware, and the accumulated error estimation method based on the departure time is used in the software. Through the above two ways to improve the monitoring accuracy, it has laid a good foundation for the subsequent power consumption optimization.

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