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An IoT-Based Smart Controlling System of Air Conditioner for High Energy Efficiency

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***Abstract*— In current electric energy statistics, the largest power is consumed by heating and cooling air conditioners, which are widely used in residential and commercial buildings. Hence, reducing energy consumption of air conditioners is vitally important for improving power utilization efficiency in global energy perspective. To save electricity consumption of air conditioners, this paper proposes an Internet of Things (IoT)-based smart controlling system including smart meter, smart gateway, and cloud computing modules. We manufacture a smart meter to control the compressor operation of air conditioners based on the specified temperature. Meanwhile, it is able to monitor the real-time power consumption datasets, which are delivered to a cloud server via a wireless gateway. Using Zigbee communication protocol, our developed gateway enables automatic detection of smart meter by a broadcasting method. After gathering the IP addresses of connected smart meters, the gateway dispatches controlling signals to relevant meters. We developed a general programming interface to control the operation of this smart gateway so as to support flexible and extensible IoT development. The collected electricity consumption datasets are transmitted to a cloud server in real time via Internet. Meanwhile, the remote operation signals of smart meters are transmitted to the cloud. An extreme learning machine is implemented to analyze the energy distribution for energy consumption prediction. Based on the analysis results and operation signals, the cloud generates an energy-saving decision to control the distributed air conditioners by the smart meters, which are linked to the Internet through the gateways. This way, an individual smart meter controls cooling and heating operations of its corresponding compressor to realize local energy management. Besides, the energy saving strategy eases power grid burden and decrease load of power station. Thus, our proposed system has positive influence on greenhouse gas reduction.**

Keywords—energy conservation; smart meter; IoT; cloud computing

I. Introduction

With the implement of tiered electricity pricing policy, individuals pay more attention on saving energy consumption to reduce electricity bill [1]. Meanwhile, a large proportion of electricity consumption is produced by air conditioners in residential homes and business quarter [2]. For increasing energy efficiency, the optimization of electricity utilization behaviors is a feasible approach in air conditioners operation [3]. If the preset temperature is controlled in a mild method, a large amount of electricity consumption can be reduced [4].

Traditionally, the relation between preset temperature and electricity consumption needs to be balanced manually for saving energy. For avoiding the electricity waste caused by the manual controlling method, several automatic management systems are developed in smart house so as to improve the power utilization efficiency [5]. The remote controlling provides a means of communication via the Internet to reduce electricity of air conditioners, which consume the largest power among common household appliances [6].

In smart house, multiple-sensor based smart controlling of air conditioners is an effective method to realize autonomous management for responding fluctuate environment situations. The environmental information, such as illumination, humidity, and temperature, provides behavior planning basis of an adaptive operation selection [7]. Meanwhile, the real-time electricity datasets generated by the air conditioners are transmitted to a cloud server for energy consumption analysis [8]. The consumption characteristics gathered from distributed appliances enable the demand side management of electricity usage.

For increasing energy utilization efficiency of air conditioners, this paper proposes an Internet of Things (IoT)-based smart controlling system, including smart meter, smart gateway and cloud server modules. The smart meter with the embedded multiple sensors submits the sensed environmental information and electricity consumption datasets to the gateway using the Zigbee protocol. The gateway sends the datasets received from the smart meter to a cloud server using a HyperText Transfer Protocol (HTTP) for the characteristics analysis for the demand side management. Besides, the gateway delivers real-time controlling signals generated from cloud server to the corresponding smart meters for reducing energy waste. The smart meter implements several controlling functions following basic behavior regulations to automatically release the compression overload caused by excessive preset temperature. All the linked smart meters are divided into different regions corresponding to their geographic position mapping from the static IP address. In the managed area of a power station, the total energy consumption is essential information to judge whether extra electricity needed to be produced.

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Using the cloud platform, the proposed smart controlling system of air conditioner realizes the remote management functions, such as data collection and intelligent operation. Using an online sequential extreme learning machine (ELM) implemented in the collected datasets, the power load is accurately predicted. This way, the proposed IoT-based smart controlling system enables the balance of supply and demand so as to avoid redundant electricity manufacturing. Therefore, electricity consumption is reduced for both individual air conditioners and the demand side management.

The remainder of this paper is organized as follows. Section 2 provides an overview of related work. Section 3 introduces the proposed IoT-based smart controlling system. Section 4 evaluates the performance of the proposed system. Section 5 concludes the paper.

II. RELATED WORK

Smart houses enable remote operation and automatic power management with low electricity consumption. Zhou et al. [9] described a home energy management system with rechargeable renewable resources, such as solar energy and wind energy. In this system, the monitoring module contained measuring and displaying energy consumption gathered by the smart meters. By analyzing the electricity consumption and high/low price periods, various automatic controlling methods were implemented to reduce electricity cost of domestic appliances. Without sensors acquiring environmental information, such systems had limited intelligence to autonomously adapt dynamic varied situation. Marinakis et al. [6] proposed a building automation system with remote monitoring and smart controlling functions. The integration of meters and sensors monitored both energy consumption and environmental information for the behavior decision process in the intelligent management. Although these systems enabled high efficient energy utilization, the management servers were extra device besides household appliances that cost additional high power consumption.

To eliminate the extra consumption, Shang et al. [10] developed a smart IoT gateway for signal transmission so as to replace the center management server in smart home. In the wireless networks, all the smart meters in a smart house were linked with a gateway to deliver the signals conveniently without the extra computers. Meanwhile, the remote signals received by the gateway were transmitted to the corresponding meters for controlling appliances operation.

Using the communication module between the smart meters and the gateways with the wireless local area network (WLAN), the low energy consumption is required as an essential characteristic. Fig.1 illustrates the capabilities of the common wireless communication protocols, such as Zigbee and Bluetooth. Among them, Zigbee has an advantage of transmission rate for a certain transmission distance so as to satisfy the real-time data transmission in smart home.

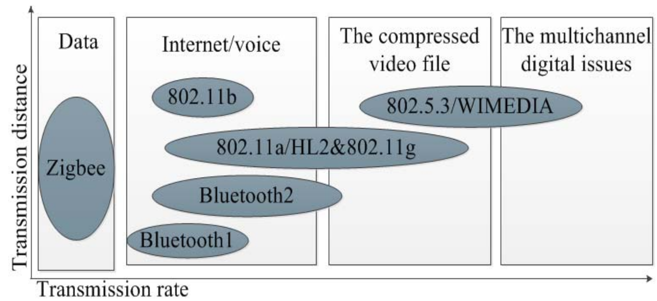


Fig. 1. The characteristics of the common wireless communication protocols.

To increase electricity efficiency, Liu [11] proposed a Zigbee protocol using such module for realizing high speed data exchange in a real-time controlling and monitoring system. With the Zigbee protocol, Han et al. [12] developed an energy-saving system to remote control the distributed electricity appliances in a low-cost approach. The reducing energy consumption generated by a manual remote controlling method based on the current environment information and energy consumption datasets. The voluntary behaviors of household users were unmanaged and imprecise to achieve energy-saving effect. Yanga et al. [13] proposed a statistical table solution by collecting information from environment sensors, domestic appliances and user behavior. After analyzing these information characteristics, a behavior planning model was structured for formulating automatic energy-saving decision in smart home. However, in an individual smart home system, the reduction of energy consumption was limited even though using the automatic management models.

In consideration of the demand side management of electricity usage in an area, the total power consumption was vital for both power station and customers in current period. A power station was able to judge whether extra energy was needed to be generated by analyzing the energy consumption and production. The householders adjusted appliances working periods to avoid the electricity peak load for reducing energy expenses under the Time-of-Use price policy. Mitala et al. [14] described an IoT solution with a community service for collecting and analyzing local electricity consumption datasets in a city. Based on the IoT technology, smart meters delivered the power consumption datasets to a community center for analyzing datasets via wireless network. From the analysis results, power station generated electricity based on the real-time demand so as to avoid unnecessary source waste. The remote controlling interface was necessary to be integrated into this solution so that the users were able to submit the signals through smart mobile devices for operating common appliances. To solve these problems, we propose an IoT-based smart controlling system of air conditioners using cloud computing and IoT technologies.

III. IOT-BASED SMART CONTROLLING SYSTEM

A. System Framework

The proposed IoT-based smart controlling system is shown in Fig.2, which includes smart meters, smart gateways, and a cloud platform. In the system, the smart meters based on multiple sensors submit environmental information and power consumption datasets to the smart gateway via Zigbee wireless network. Meanwhile, infrared signals generated by the meters are delivered to air conditioners for real-time smart controlling. The smart gateways connecting the smart meters and the remote console are developed based on a Zigbee wireless communication protocol.

The cloud server receives environment temperature and power consumption datasets from the smart gateways. Meanwhile, it transmits the remote controlling signals from the client application via Internet. For increasing energy efficiency, the cloud server balances the preset temperature and the in- /out- door temperature with a mild decision. After analyzing the energy consumption characteristics in temporal and spatial domains, a management strategy of power utilization is formulated to avoid electricity waste.

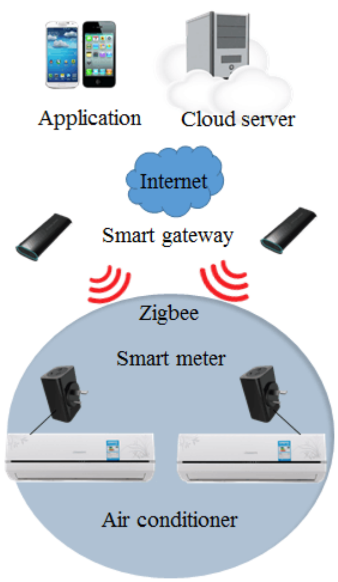
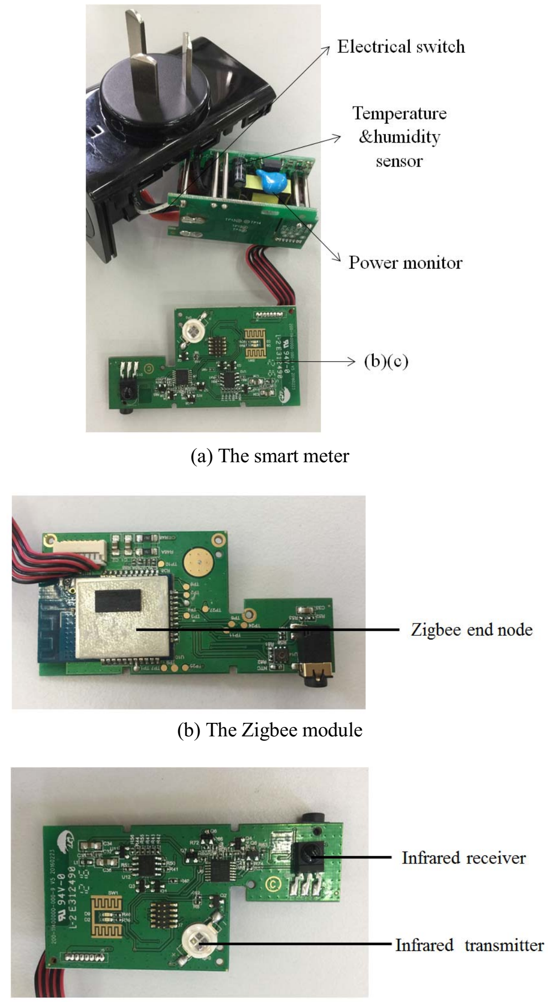


Fig. 2. The framework of the proposed IoT-based smart controlling system.

B. Smart Meter

Real-time monitoring and controlling of air conditioners are the two main functions of the smart meter. As shown in Fig.3, the smart meter is composed of five modules, which are the temperature and humidity sensor, the integrated infrared controller, the electrical switch, the power monitor, and the Zigbee end node. The temperature and humidity sensor detects indoor environment situation. The power monitor senses power consumption of air-conditioning in real time. All the collected datasets are converted into electrical signals, including electric mark and the on-off state, which are transmitted to the smart gateway via the Zigbee module, as shown in Fig.3 (b).



(a) The smart meter

(b) The Zigbee module

(c) The integrated infrared controller

Fig. 3. The Architecture of the developed smart meter.

The meter processor and wireless communication module are the core components of the whole system. Through smart gateway, the command signals are received from both the cloud server and the remote client. The on-off status of electrical power is controlled based on the received signal. When the meter receives an instruction of temperature adjustment, the Zigbee end node sends a signal to the integrated infrared controller as shown in Fig.3 (c). The meter supports several basic operation interfaces, such as temperature and wind speed adjustment.

In smart home, controlling and monitoring signals are transmitted within a low rate. Thus, Zigbee protocol is applied to construct a wireless network, based on IEEE 802.15.4., which has several advanced characteristics including low cost, low complexity, low power consumption, and high reliability. Meanwhile, the number of maximal nodes in the protocol is much higher than other wireless communication networks. The smart gateway with the embedded Zigbee coordinator realizes a wireless network autonomously. With an initialization phase, the coordinator is able to judge whether the requests received from the local end nodes are permitted to join the network. In the working phase, the controlled end nodes response to the requests from the remote control devices using the coordinators.

C. Smart Gateway

Fig. 4 shows the architecture of the developed smart gateway, which contains a Zigbee coordinator and a Zigbee/Internet conversion. As the core of the smart system, the gateway implements several functions including data uploading, protocol conversion, and sensors network controlling. In our proposed system, data uploading between cloud server and terminal devices is a basic function of the smart gateway, which sends the remote control commands to the node terminal devices using Zigbee serial port. With a Zigbee coordinator, the smart gateway manages and controls the Zigbee network, including starting and maintaining a wireless network automatically, and sending commands to the end node of the smart meter. In the broadcasting process, the network state of the coordinator is reactive when a new network is established. To join the established network, a new terminal device is initialized and sends request data to the coordinator. Then, the coordinator replies a confirming message to the terminal device whose network state is updated corresponding to the joining coordinator. Finally, the unicast process between the gateway and the connected smart meters is executed as their communication. For the extendibility, the gateway supports different programming language interface using a HTTP to deliver the controlling commends to the smart meters based on developer's intentions.

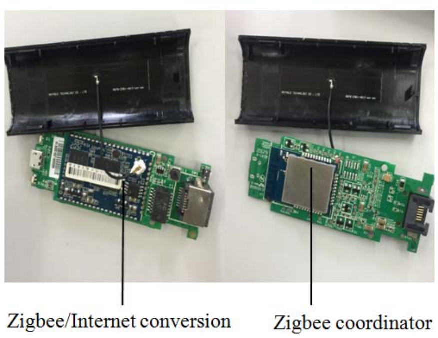


Fig. 4. The architecture of the developed smart gateway.

Moreover, the monitoring datasets containing the power consumption and environmental temperature are transmitted to the cloud server from the smart gateway through the Internet. Routing and address allocating module supports the static and dynamic Routing Information Protocol and Dynamic Host Configuration Protocol. Through Internet, the Web Services module displays the dataset in the application server to realize the remote access and query of the cloud platform. When access the smart gateway, the cloud platform submits a Simple Object Access Protocol (SOAP) message to request processor. Then, the Web Services inform processor to generate the corresponding SOAP response, which is sent to the cloud platform by a HTTP. The communication, such as receiving the command and sending the message, is implemented between the smart gateways and the smart meters to response the user's requirement. Under normal circumstances, the smart gateway monitors the connection requests generated from the smart interactive terminal. When a connection request is submitted from terminal, the gateway allows the request and establishes a connection. The smart meters receive command messages through the connection.

D. Cloud Computing

Fig.5 illustrates the cloud computing platform of smart electricity utilization for real-time analysis of large-scale power consumption datasets in multiple domains. This platform provides administrator and users with remote monitoring and data visualization interfaces on computers or mobile devices. The environmental information and power consumption datasets are transmitted to a cloud server, which is utilized to collect and analyze the environment information and monitoring datasets received from the smart meter. The server also delivers the remote controlling signals to the relevant devices. Meanwhile, a government cloud platform gathers the necessary information in a local area for the real-time electricity product management corresponding to the current power demand side. Based on the power consumption statistics in temporal and spatial domain, intelligent controlling commands and power consumption prediction are generated automatically for increasing energy efficiency.

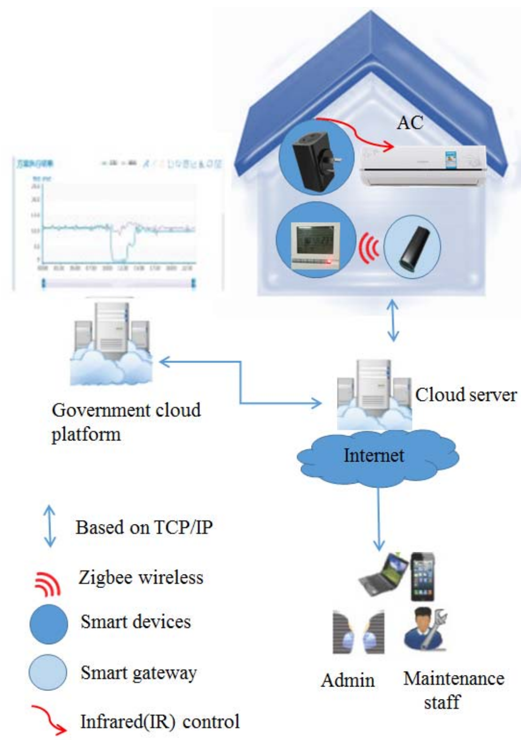


Fig. 5. The cloud computing platform of smart electricity utilization.

The bad usage habits cause energy waste. For example, the room temperature hardly reaches a low preset value in a hot weather because of the exorbitant outdoor temperature. According to the temperature specification, the air conditioners keep continuously operating so as that not only lead to unnecessary electricity waste but also shorten the electrical life. The cloud server balances the refrigeration operation and electricity consumption. If the environment temperature achieves a certain degree, the compressor suspends for a period. This way, 10% to 20% power consumption can be decreased. The temperature and airflow settings of the air conditioners have a great impact on the energy consumption. In this case, every more 1 beyond the outdoor temperature will cost extra 10% to 25% energy consumption.

Conventionally, the smart temperature controlling by the smart meters increase or decrease preset temperature only based on several simple behavior planning methods. To provide comfortable experience with low power consumption, the operation of air conditioners compressor should be implemented by analyzing outdoor temperature, room temperature, preset temperature and current usage habit of the guests. For example, during sleeping period, the user complains that he/she always feels cold at night when the air conditioner is specified at a low temperature. In our system, the cloud server is able to increase the target temperature by a little based on the integrated datasets analysis results.

The air conditioners are regarded as high-power electrical appliances in household. After gathering the power consumption, the cloud server analyzes the power peak in temporal and spatial domains so as to estimate the user's electricity using habit. The load of power consumption is analyzed to provide a behavior planning basis for both supply side and demand side responses. Therefore, the electricity factories have a reference for supply side to avoid power waste. From the demand side, a timely adjustment of consumption habits enable stagger the power peak and relieve the pressure of power utilization.

In our prediction process, an ELM is utilized for single hidden layer feed forward neural networks (SLFNs). With the characteristics of self-learning and optimization calculating, the ELM processes the imprecise and massive unstructured datasets. After specifying a suitable node number of latent layer, we randomly choose the input and the output weights of SLFNs for data training. The most optimal solution is generated without requiring the iteration. When new datasets are registered into the ELM, the retraining process is required. To solve this problem, a distributed online sequential ELM prediction decision model is proposed in Fig.6 to avoid extra retraining computation for new data registration. In our implementation, *n* datasets are trained in the initial phase of online sequential ELM to generate the outputs of the initial hidden layer, including the matrix and vector of target value. The new registered dataset is consider as the n+1 th sample, which is used to calculate the new hidden layer output matrix and weight vector.

Meanwhile, the cloud computing technology based on Map Reduce is utilized to optimize and improve the ELM for processing the massive and high latitude datasets. This technology is able to deal with the high dimensional data and improve the accuracy of power load forecasting.

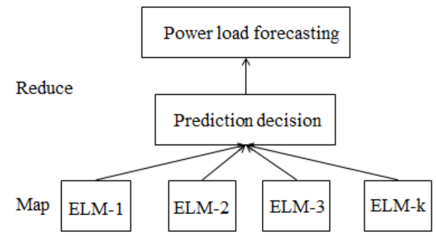


Fig. 6. A distributed online sequential ELM prediction decision model based on Map Reduce

The online sequential ELM based on Map-Reduce is implemented as the following steps.

Step 1: After the training datasets are registered into the distributed file system in the cloud-computing platform, the dataset is segmented into *k* different training subsets by using the floor mechanism in Map Reduce programming framework. Here, *k* is the number of the cloud computing clustering.

Step 2: According to the online sequential ELM, the *k* subsets are trained using *k* learning machines.

Step 3: *k* different predictors generated from the learning machines are transmitted to the reduce phase in the Map Reduce programming framework. Hence, an ultimate predictor is received from weighted averages of *k* predictors.

Step 4: In consideration of the requirements from the sequential learning mechanism and the medium-/long- term load forecasting, the electricity consumption of the next day is predicted based on the current datasets.

IV. EXPERIMENTS AND ANALYSIS

In this section, we analyze the performance of the proposed IoT-based smart controlling system for air conditioners with the cooling functions. We tested this system on the air conditioners installed in 16 rooms located in the first and second floors of a hotel. The power consumption datasets were collected for 13 days.

The smart meters were installed in the first and second floors, which commonly had a high occupancy rate. The smart gateways were installed on the wells of the first and the second floors respectively without changing any architecture and human intervention. The cloud server managed the air conditioner by delivering the decision message to the smart meter through the smart gateways. The smart meters connected with the air conditioners were also remote controlled by the mobile client application that provided the several operation interfaces, such as equipment installation, power monitoring and storage. The Graphics User Interface (GUI) and the power monitoring results are shown in Fig.7.

To indicate the performance, the power consumption was analyzed with and without the smart meter. In the second floor, the air conditioners of the 8 rooms were controlled manually without the smart meters. Our proposed system was only installed in the 8 air conditioners located in the first floor for saving energy following the energy-saving strategies implemented by the cloud platform. By comparing the power consumption between the first and the second floor, we analyzed the performance of our proposed system.

Fig. 7. The GUI of the remote controlling.

In Table 1 and 2, show the environmental datasets reported from the smart meters, including the maximum outdoor and indoor temperature, energy consumption, power, and working period. Before our proposed system tested, both first and second floors did not implement the energy saving strategies in order to prove that the environment interferences were similar in the two floors. Table 1 and 2 show the environmental datasets reported from the smart meters, including the maximum outdoor and indoor temperature, energy consumption, power, and working period.

TABLE I. THE COLLECTED ENERGY CONSUMPTION DATASETS OF FLOOR 1

Data	The max outdoor temp.	Indoor temp.	Energy consumption	Working period	Power
7-Jun	27	25.86	11080	5.49	224.14
8-Jun	26	25.42	10241	4.53	251
9-Jun	27	24.66	11640	5.84	221.43
10-Jun	30	24.84	22399	5.34	466.48
11-Jun	30	25.51	24060	3.26	821.16
12-Jun	27	26.47	14198	2.16	822.28
13-Jun	30	26.45	28160	7.87	397.46
14-Jun	33	26.52	27792	7.07	561.27
15-Jun	31	27.17	21737	6.06	448.49
16-Jun	29	27.07	16942	5.93	357.43
17-Jun	32	26.26	34138	8.76	487.22
18-Jun	32	26.96	41120	9.79	526.39
19-Jun	30	26.55	36545	11.55	395.51
total	29.54	26.11	300052	6.37	432.23

Without the smart controlling method, the air conditioner keeps on a long-term working status, even for low temperature situation. The average working time of air conditioner was around 6.37 hours on the first floor and 6.46 hours on the second floor. The average maximum temperature outdoor was 29.54 ℃. The average temperatures of the first and second floors were 26.11 ℃ and 26.15 ℃ respectively. The average power consumption was around 432.23 and 438.47 watts respectively. The energy consumption of the second floor was higher than that of the first floor slightly. Thus, we installed the smart meter in the first floor to examine the performance of our proposed system.

TABLE II. THE COLLECTED ENERGY CONSUMPTION DATASETS OF FLOOR 2

Data	The max outdoor temp.	Indoor temp.	Energy consumption	Working period	Power
7-Jun	27	25.38	7628	7.07	215.79
8-Jun	26	25.32	8416	6.91	203.12
9-Jun	27	25.47	14371	3.58	573.69
10-Jun	30	25.76	20074	5.16	647.9
11-Jun	30	26.15	21765	4.65	668.32
12-Jun	27	26.02	17644	4.96	593.41
13-Jun	30	25.48	26193	8.39	445.96
14-Jun	33	26.56	24526	7.3	480.12
15-Jun	31	26.46	21458	8	383.29
16-Jun	29	26.45	15515	6	269.4
17-Jun	32	26.73	17473	4.78	522.1
18-Jun	32	27.3	19386	7.08	391.24
19-Jun	30	26.87	29276	9.99	418.73
total	29.54	26.15	243725	6.46	438.47

The experiment results without the smart controlling are shown in Fig.8. The energy consumption of the air conditioners changed obviously with outdoor temperature. The average power consumption was about 517.67 watts per room when the air temperature was higher than 30 ℃. The average power consumption was only 373.17 watts per room when the air temperature was less than 30 ℃. The energy consumption was more affected by environmental conditions. The difference of average power consumption between the first and second floors was insignificant.

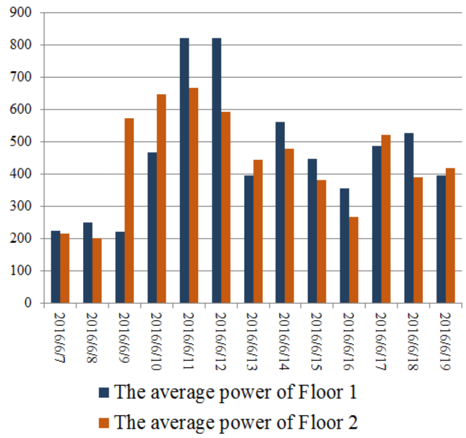


Fig. 8. The power consumption without our system.

The experiment results using the smart controlling system are shown in Fig.9. There was significant difference of power consumption between the first floor with the smart meters and the second floor without smart meters. On the first floor where the smart meters installed for saving energy, the average working period per day per room were 8.2 hours and the average power consumption were 258.5 watts. On the second floor, the average working period and consumption were 8.01 hours and 449.2 watts respectively. The average maximum temperature is 28.9 ℃ during 13 days. The result shows that 35.7% power consumption reduced with using the smart meter.

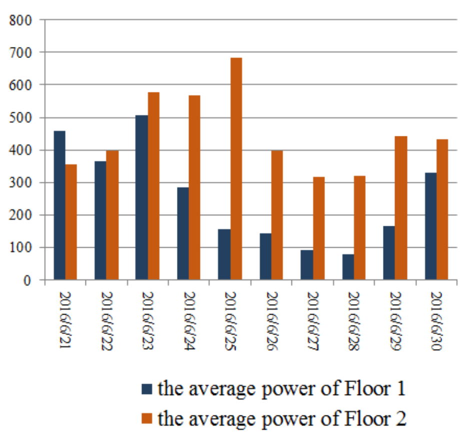


Fig. 9. The power consumption with our system.

The proposed online sequential ELM algorithm was executed to analyze the prediction accuracy. Fig.10 illustrates the comparison between prediction results and actual power consumption. Although a small amount of error existed in a few peaks, the power consumption forecasting results were similar as the actual detection datasets. Thus, the cloud platform was able to report the available prediction results to demand side management of electricity usage.

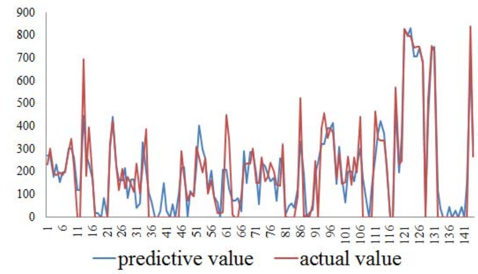


Fig. 10. The prediction results using the proposed online sequential ELM.

CONCLUSION

This paper proposed an IoT-based smart controlling system for air conditioner to save electricity consumption. The smart meter was developed to monitor environmental information and power consumption in real time, which was reported to the cloud computing server. The remote controlling signals were delivered to the smart gateway through the cloud server by a protocol conversion between Zigbee and Internet. The cloud server remote controlled the air conditioners intelligently and predicted the power peak in temporal domains with the reported datasets from the distributed smart meters. The proposed smart controlling method was tested in 16 air conditioners located in the hotel rooms. The experimental results indicated around 35.7% power consumption was reduced. Thus, the proposed system has positive influence on greenhouse gas reduction. Meanwhile, this paper proposed an online sequential ELM algorithm to predict power load of the air conditioners. In future, we will study a cloud-based data stream mining algorithm to analyze the power utilization features in spatial and temporal domains.

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