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GreenTech: A Case Study for Using the Web of Things in Household Energy Conservation

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Abstract—**Energy conservation has become a hot worldwide topic for a number of years. Based on our research, the Web of Things can be used to conserve people's domestic energy consumption in a smart way. In this paper, we have proposed a model based on the Web of Things for the purpose of not only measuring power consumption of household appliances, but also providing web services for householders to scan and control their indoor electricity usage. In addition, we have designed and implemented a prototyping system, which comprised a smart outlet used to detect appliances' power consumption and control them, some sensors used to sense indoor circumstances including temperature, humidity and light intensity, a household gateway for data transmission, a service platform for data publishing and a mobile application. Finally, in order to verify the model's feasibility and efficiency, we have tested our system's performance by real-time and accuracy experiments.**

Keywords-Household Energy Conservation; Web of Things; Smart Outlet; Intelligent Inference

I. INTRODUCTION

Energy conservation has become a hot worldwide topic for a number of years. A convenient and efficient way for ordinary people to make contribution to energy conservation is to manage their domestic energy consumption in an intelligent way. Household energy conservation has been a widely discussed issue on which not a few researchers worked during recent decade. The research in [1] reported that households in the United States were responsible for 1214.8 million metric tons (21%) of the whole US energy-related CO2-emissions in 2003. Besides, emissions related to electricity use have risen by 2.4% annually, and those related to gas use have increase by 0.9% every year since 1990. Another similar research in Western European countries figured that the households' energy use had contributed 15% and 20% to total energy use during the last several years of 20 century [2, #492]. A detailed study on in-home energy use [3, #492] has shown that the most electricity were consumed by appliances (33%) followed by air conditioning, heating and ventilation systems (31%) and water heating (9%).

Household energy conservation is useful but not easy to accomplish. There are at least two issues need researchers and developers to confront. The first one is how to obtain every appliance's power consumption. Traditional ammeters can detect the whole situation of indoor electricity usage, but power consumption of the specific appliance cannot be measured. This demands a per-appliance level power measurement. The second issue is the lack of management mechanism to control the appliances to conserve energy. This needs a toolkit to assist people in managing their domestic energy consumption. For these two requirements, the Web of Things (WoT) can be used to build a web architectural home system to provide householders with scan and management of electricity usage. The WoT came from the conception named Internet of Things. Unlike the latter, the WoT is about re-using the web standards to connect the quickly expanding eco-system of embedded devices built into everyday smart objects. Well-accepted and understood standards and blueprints such as URI, HTTP, and REST are used to access the functionality of the smart objects. In sum, using the WoT in household energy conservation is feasible and convenient.

Applying the WoT in domestic energy-saving is confronted with three implementation challenges: (1) to real-time and accurately measure energy consumption of every appliance, (2) the contradiction between collecting range and real-time of power consumption data, and (3) to complete intelligent management of household power consumption. To solve the problems above, this paper has proposed a model and implemented a prototyping system based on the WoT for the purpose of not only measuring power consumption of household appliances, but also providing web services for householders to scan and control their indoor electricity usage. There are three contributions of this paper: (1) designed and manufactured a smart outlet to detect power consumption of one appliance and control it, (2) proposed a layered system architecture in which a gateway was deployed in people's home while a service platform was deployed at a remote place so as to resolve the contradiction mentioned previously, and (3) advanced an intelligent inference framework to help people manage their household energy consumption.

The remainder of this paper is organized as follows. Section 2 talks about related works in the field of using network technology in household energy conservation. Section 3 lists four key technologies of this paper. Section 4 describes our system's architecture and specifies every parts of the system. Section 5 shows the result of real-time and accuracy experiments of the system. Section 6 gives a conclusion and lists some future works.

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II. RELATED WORKS

Household energy conservation is a meaningful topic that has been studied by some researchers. The work [5] focused on energy-saving home and discussed that current green home systems could not satisfy the real-time demand of household appliances' power consumption for users. They also announced that energy-saving home should take economic condition into account and make the cost can be accepted by most families.

How to exactly measure appliance's power consumption is the foundation of indoor energy-saving. This is not a simple thing because real-time and accuracy of the power data must be guaranteed. For this purpose, the work [6] proposed a power detecting system to measure when and where the power be consumed and show these information to users. They said that their system could estimate the end-point power consumption within 10% error.

The central issue of using the Web of Things to conserve household resources is to build a system which can not only integrate power consumption data but also provider web services to publish them for users' scan and feedback. Most of the current systems under this field use Representational State Transfer (REST) [8] architecture to build themselves. For instance, the work [7] implemented a smart system on a mobile phone connected with a single sensor in user's home to test power consumption and handle user's feedback based on REST. For bridging energy-aware smart home and smart grid, the work [4] used web technique to build a smart home system within which the paper's authors used JavaScript and Google Web Toolkit to develop a client application to control appliances to save energy. They also used REST architecture and believed that by means of the web, smart homes could be fully synchronized with city grids.

III. KEY TECHNOLOGIES

Realization of household energy conversation based on the Web of Things requires a completed circuit of data collection, data publishing and feedback between physical environment and end users. It has four key technologies – per-appliance level measurement and control, data integration and publishing, intelligent management and web sharing mechanism. The following will specify the details of these technologies.

A. Per-appliance Level Measurement and Control

Measurement and control of every indoor appliance is the foundation of household energy conservation. In our system, we designed a smart outlet which can be used to measure one appliance's power consumption and control it. The outlet has two functions – to sense current and to communicate with the gateway. It can send power consumption data to the Sink Node plugging in the gateway, at the same time, it can receive control commands sent by people, and then it will let itself turn on or turn off, in this indirect way, the appliance plugging in the outlet will be turned on or turn off. The smart outlet senses the current of an appliance. Power consumption value of the appliance can be obtained through multiplying the current value by the stable voltage value (220V) and time. The range of current can be measured is from -19.2A to 19.2A, so common appliances' power consumption can be calculated by our system.

B. Data Integration and Publishing

There is great heterogeneity in our system because it includes various types of data carriers such as appliances, sensors, the outlet, the gateway, the service platform and the mobile application with their own data processing and transmission mechanism. Therefore, data integration and publishing demands a uniform web interface to scan and control household energy usage. For this purpose, we selected Representational State Transfer (REST) architecture to build our system because of its convenient-integrating feature. REST is first proposed by Roy Fielding in his PHD thesis [8]. By using REST architecture, it is easy for developers to create a large number of applications. REST regards providing uniform operation on resources as its principle by which would not only solve heterogeneity problem, but also lessen the enter-barrier for developers.

C. Intelligent Management

Due to inefficiency and inconvenience of manual operation, an intelligent inference framework has been proposed to complete the automatic control of the household appliances. By the framework, people can set a comfort standard described the environmental parameters including temperature, humidity and light intensity. The standard is a range for which we supported a recommendatory range described in TABLE I based on general knowledge. When indoor environmental value is within the range that set by people, it means that the current environment is confortable for the householder, so the automatic control program will keep the correlative appliances be closed unless people manually open them. Choosing indoor temperature system as an example, people can set the confortable temperature range to be from 15 to 25 centigrade, and then our system will turn of the temperature control appliances such as an air conditioner or a heater when the currently indoor temperature is within the range. The temperature value is obtained by some temperature sensors deployed in home as well as humidity and light intensity value. Because currently we cannot control the electric current of appliances but only turn on or turn off them, we could not decrease the appliances' real power when the indoor environmental value is within the comfortable range which we think is a better control model.

TABLE I. RECOMMENDATORY VALUE FOR COMFORT STANDARD

Environment Elements	Recommended Setting Range
Temperature	20℃ – 25℃
Humidity	30% - 70%
Light Intensity	100lx – 500lx

In addition, for making the system more practical, we designed and implemented a damage reminder for users. It allows people to set a Normal Range recommended by us to 20% - 120%. When the cumulative time that the ratio of an appliance's real power to its power rating exceeding the range is equal to 24 hours, then we will notify the householder that the appliance may have something wrong. After receiving the notice, the householder can select either to continue to monitor the appliance or to ignore it.

D. Web Sharing Mechanism

We have used the concept of mash up into our system to allow users creating various applications based on our service platform. We have supported RESTful APIs that can be used to measure appliances' power consumption and control them. In this way, users can use the APIs to create new applications to manage their household energy consumption. For instance, we have developed a web sharing function on our mobile application. People can use it to share household information on Sina Micro-blog which is currently very popular in China.

IV. SYSTEM DESIGN AND IMPLEMENTATION

A. System Architecture

Our system aims at helping people to get and control their houses' power consumption which is just an experimental system. We built our system using a layered architecture to simplify the system's implementation as described in Fig. 1.

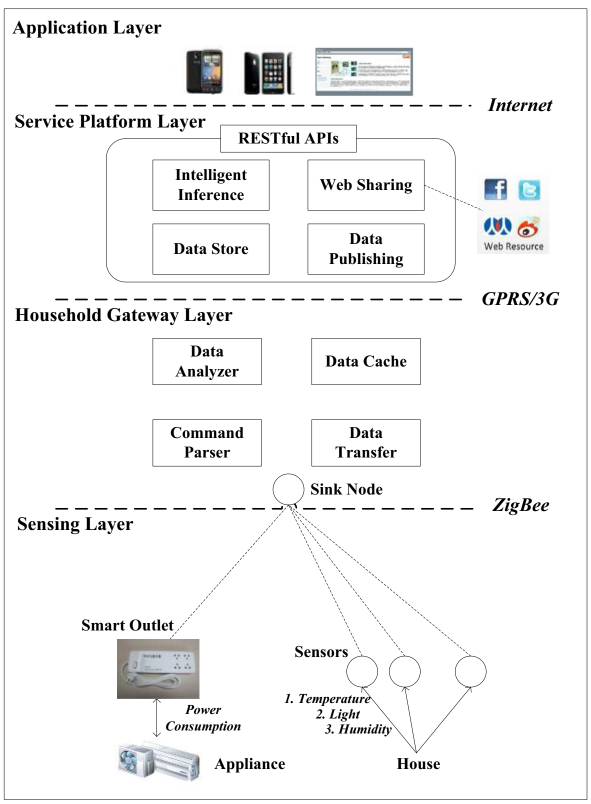


Figure 1. System Layered Architecture

We have designed the workflow of our system as following. Firstly, deploy a smart outlet linking with the appliance to be measured to sense power consumption, and deploy several sensors at home to sense household temperature, humidity and light intensity. Next, integrate these data from the sensors to a gateway by a kind of wireless networks such as ZigBee and then transfer these data to a remote service platform through GPRS/3G. The gateway is always deployed in people's home while the service platform is often put in a remote place such as a research center, a school's laboratory or a WoT service supporting company which will be common in the future. Finally, publish these power consumption data through some web services and provide various terminal user supports. With these supports, people can use a browser on PC or an application on mobile phone to scan the energy information as well as control their indoor appliances.

B. Sensing Layer

As shown in Fig. 1, sensing layer contains one smart outlet and several sensors. These sensors are equipped with a 250kbps, 2.4GHz, IEEE802.15.4-compliant Chip CC2420 Radio. IEEE802.15.4 is an IEEE standard that defines a MAC and PHY layer targeted to Wireless Sensor Networks (WSN). The operating system on the sensors is Telosb.

The smart outlet's internal implementation view is shown in Fig. 2. It has five function modules - power relay module, Hall sensor module, Analog to Digital Converter (ADC) module, Single Chip Micyoco (SCM) module and wireless communication module. The wireless communication module use ZigBee protocol to connect physical environment and gateway. Via this indirect way, we can get appliances' power consumption and turn on or turn off them. In sum, the smart outlet plays a middle role between gateway and appliances.

Figure 2. Sensing and Communication Module of the Smart Outlet

The outlet has two functions – to measure power consumption and to control the appliance linking with it. The following is the detail information of the two functions.

1) For the measurement function, the smart outlet will complete serval steps as follows.

a) Sampling: Electric current flows into the Hall sensor through the power relay, and then, the Hall sensor transforms the electric current into analogy voltage to be output.

b) Converting: The analogy voltage that has been output comes into the ADC module. ADC module changes the analogy voltage to digital signal and stores this digital signal into the SCM's memory. Though the processes above, the electric current information of household appliances has become digital signal data which can be send to computer.

c) Communication: The wireless communication module sends these data to a computer via ZigBee protocol.

d) Restoring: Our system on the computer can restore the digital signal data to electric current value bases on the corresponding relation between them.

e) Calculation: Mutiplied the eclctric current value by the voltage value which usually equals 220V makes real-time power for one time. Our outlet can do samplying serval hunders of times per seconds, so it can calculate average power value, and then, mutiplied by the time that we recorded will obtain power consumption value that we want.

2) For the control function, the smart outlet will complete these steps as follows.

a) Receiving: Our system sends controlling commands, and then, the wireless communication module receives these commands and store them.

b) Transmission: The wireless communication module transmits the commands to the SCM module.

c) Control: The SCM module control the power relay's open or close to indirectly control the appliance.

C. Household Gateway Layer

As shown in Fig. 1, the gateway plays a middle role between the sensing layer and the service platform. It is used to transfer appliances' power consumption data and household temperature, humidity and light data to the service platform, meanwhile, transfer service platform's control command to the smart outlet. These things are completed by the data transfer module which contains two data input and output programs. One is a GPRS send & receive program for transmitting data between the service platform and the gateway, the other one is a serial port read & write program used for transferring data between the gateway and the sink node plugging in the gateway by a USB serial port. In consideration of the possibility of data blocking, we designed a small-sized data cache to guarantee data transfer speed.

Because the data between service platform and the gateway differs from the data between the gateway and sink node, data analyzer module and command parser module are developed to unify them. The command parser module parses the command URL predefined by the RESTful APIs in service platform to a sensors-readable command, and then notifies data transfer module to send it to sink node. The data analyzer module converts power consumption data and household environmental data to people-readable data, and then, as well as the command parser module, notifies data transfer module to send the data to service platform.

Since the fact that smart outlet and sensors do not offer TCP/IP protocol by default, we use ZigBee protocol to transfer data between sink node and the sensors as well as the smart outlet. The protocol's standard is IEEE802.15.4 which is same to the standard of the sensors. The gateway we have chosen is based on ARM9 32-bit RISC processor architecture, and has S3C2440 400MHz CPU processor and 64M Flash memory. Its actual picture is shown in Fig. 3.

Figure 3. External Appearance of the Household Gateway

D. Service Platform Layer

Compared with the gateway deployed in people's home, service platform will be deployed in a remote place such as a WoT technology company. In our design, it is deployed on a PC which has enough computing capability and memory space to gather data, store data, publish data and maybe do data mining to find people's preference. The platform's main responsibility is to publish power consumption data as web resources based on REST architecture. In this way, people can use a terminal application to connect with the service platform firstly, and then they can check appliances' power consumption and send command to control them.

As shown in Fig. 1, service platform unifies various data and operations to web resources with the same format which can be accessed by user. The platform implemented the RESTful APIs using http protocol and accessed the sensors used four basic HTTP operations including GET, POST, PUT and DELETE. The detail information of RESTful APIs in our system is specified as following.

TABLE II. THE RESTFUL APIS

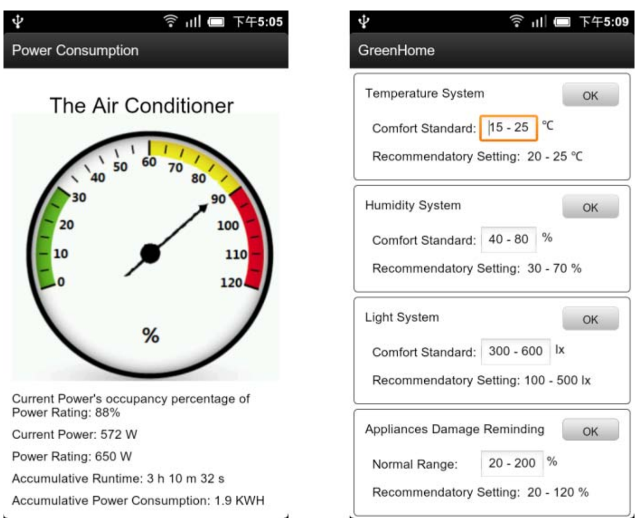
Resource	REST Verb	MIME Type	URI
SenCurrentRes	GET	XML/JSON	sensors/{sensorid}/{dataType}.{mediaType}
SenHistoryRes	GET	XML/JSON	sensors/history/{sensorid}/{dataType}/{fromTime}/{toTime}.{mediaType}
SenActiveRes	GET	XML/JSON	sensors/activeNode/all.{mediaType}
SenCmdRes	POST	XML/JSON	sensors/{sensorid}/command/{dataType}/interval

As shown in Table II, we defined four types of URI as the identifications of sensors: SenCurrentRes is the root identification of current resources; SenHistoryRes is the identification that predicates data stored in the cache or database of the gateway; SenActiveRes is the identification that indicates the activity sensor nodes; SenCmdRes is the identification that indicates commands altering the state of physical devices. All the resource URIs has two types' presentations. XML [9] is the default standard for structured information on the Web. Application scenarios can define their own schemas for XML, and in many cases standards or standards exist and can be reused. The JavaScript Object Notation (JSON) [10] provides a better solution for JavaScript environments. This representation may be more limited than XML, but can be a good way to make resource data available for Web 2.0 applications.

E. Application Layer

We have designed two access methods for end users – through a mobile application or via a web site. Householders can use the two ways to scan and manage their domestic power consumption in a remote place which has network insertion. We have implemented the mobile application on an Android phone to experiment our system. In the Android application, we used Restlet [11] framework to connect Java classes and REST. Restlet has been transplanted on Android with both the client-side and server-side HTTP connectors. By using it, we can simply call the RESTful APIs in the service platform to accomplishment the connection between the mobile application and household appliances. So householders can scan power consumption of every appliance and control it which has been connected with our system through their mobile phone. Obviously, it is practical and convenient for householders to manage their domestic energy use.

As shown in Fig. 4 (a), we used a percentage that current power occupying in the power rating to present the real-time power use. The appliances' accumulative runtime and accumulative power consumption are also calculated and showed to user. In addition, user can also manage household appliances in a smart way by setting a series of inference and reminding rules as shown in Fig. 4 (b).



(a) (b)

Figure 4. User Interfaces of the Mobile Application

V. Experiments and Evaluation

A. Experiment Environment

Our experiment environment contains a smart outlet, several temperature, humidity and light sensors, a RESTful gateway has data store module, a GPRS gateway doesn't have data store module, a service platform, an Android phone and an air conditioner. All of these besides the last two items have been described in the earlier content of this paper. The Android phone is Motorola Milestone which has 600MHz CPU, 512MB ROM and 256MB RAM. The software environment we used to build our application is Android 2.3.3, API 10. The air conditioner is Haier KFRd-26GW / 02D (HF)-S1 whose power source is 1PH.220V ~ .50Hz, power rating is 650W for refrigeration and rated current is 3.0A for refrigeration.

B. Performance Evaluation

The key issues of our system is the real-time and accuracy of the power consumption data. In this section, we will present the experiments' result of the two features using our experiment system described earlier.

In the real-time experiment, Fig. 5 presents the results of the experiment executions delay time. There are four test experiments: real-time data with XML presentation, real-time data with JSON presentation, history data with XML presentation, and history data with JSON presentation. Since the history data back response has more than 1000 items of data compared with the current data back response, it has longer delay time in the experiment. When the amount of data is small (real-time data response is small amount), JSON and XML presentations have more or less time delay. If the data amount is large, using JSON as resource presentation has less time delay than XML.

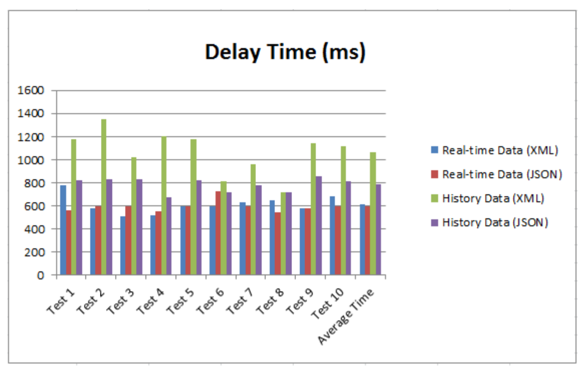


Figure 5. Delay Time Comparison Between XML and JSON Data

Further, we have designed an experiment to test the data store module should set in the service platform or in the gateway. Total Time is the total time consuming in the gateway has data store module, T1 is the time that read data by the serial port and data interpret; T2 is the time storing the data into database or cache, T3 is the time that encapsulated data to resource presentation. We performed ten times test and gain their average time in the experiment. Fig. 6 presents the results of the experiment executions. Since the Gateway 1 has additional database operation, which cost most time, it had longer delay time cost than the Gateway 2 which doesn't have data store module. This experiment verified that implementing data store function in service platform is better than in household gateway.

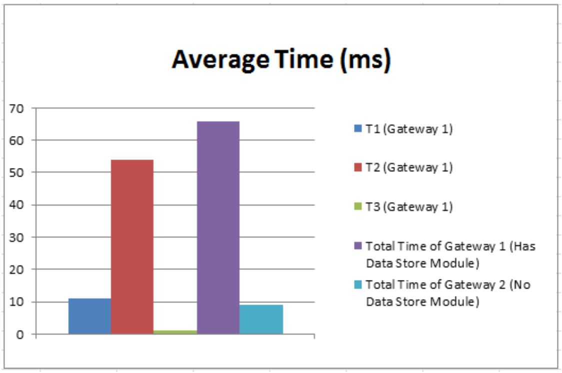


Figure 6. Time Use Comparison Between the Gateway Has Data Store Module and the Gateway Doesn't Have Data Store Module

In the accuracy experiment, as shown in Fig. 7, we have taken ten times of experiments on the same air conditioner described in Part A. Each experiment continued one hour and we calculated the average current value in the hour as one result. From the figure we can see that the current measurement's average error is within 10%, so the accuracy is acceptable.

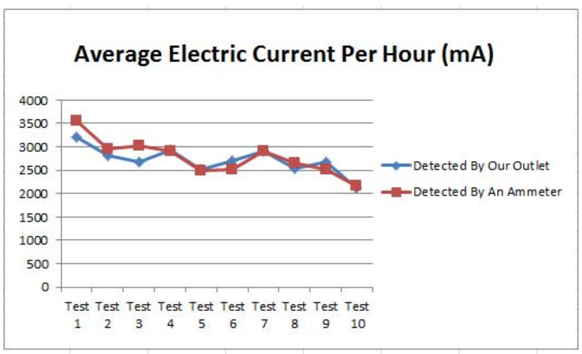


Figure 7. Current Measurement Accuracy Comparison Between Our Outlet and A Commercial Ammeter

VI. Conclusion and Future Works

This paper did some research in the field of household energy conservation. We have proposed a household energy-conserving model based on the WoT and implemented a prototyping system to collect indoor appliances' power consumption and intelligently control them. After this, we have evaluated the system's performance by real-time and accuracy experiments to verify the model's feasibility and efficiency. According to the experiments' results, we can see that the real-time and accuracy of our system is acceptable. There is a little error between our experiment data and the real data, but it is not serious. So our system have proved that applying the WoT in green energy conservation is workable， especially in home. Once it can enter the period of practicability, everyone can make contribution to energy conservation in his or her own home, and it will not only save energy resource, but also lead a green life style.

We believe that there are three further works have to be completed so that the system can be deployed into ordinary people's home. The first work is to strengthen the protection of personal privacy so that after our system publishing a user's domestic household appliances' information on web, others will not see the information without the user's permission. The second work is to cut down the cost of deploying our system in user's home. It is directly related to whether the WoT can be enter everyone's home, but until now, it is not cheap to deploy the smart outlets because every household appliance linked in our system needs a smart outlet which is not easy to be manufactured. The last work is to lower the power consumption of our system itself. This is also another common problem in the WoT field.

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