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An intelligent power distribution service architecture using cloud computing and deep learning techniques

Weishan Zhang[a,*], Gaowa Wulan[a], Jia Zhai[b], Liang Xu[a], Dehai Zhao[a], Xin Liu[a], Su Yang[c], Jiehan Zhou[d]

[a] Department of Software Engineering, China University of Petroleum, No. 66 Changjiang West Road, Qingdao266580, China
[b] Science and Technology on Optical Radiation Laboratory, Beijing 100854, China
[c] College of Computer Science and Technology, Fudan University, Shanghai 200433, China
[d] University of Oulu, Finland

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ABSTRACT

Smart management of power consumption for green living is important for sustainable development. Existing approaches could not provide a complete solution for both smart monitoring of electricity consumption, and also intelligent processing of the collected data effectively. This paper presents a cloud-based intelligent power distribution service architecture, where an intelligent electricity box (IEB) is designed using Zigbee and Raspberry Pi, and a standard MQTT (Message Queuing Telemetry Transport) protocol is used to transfer monitored data to the backend Cloud computing infrastructure using open source software packages. The IEB provides cloud services of real-time electricity information checking, power consumption monitoring, and remote control of switches. The current and historical data are stored in HBase and analyzed using Long Short Term Memory (LSTM). Evaluations and practical usage show that our proposed solution is very efficient in terms of availability, performance, and the deep learning based approach has better prediction accuracy than that of both classical SVR based approach and the latest XGBoost approach.

1. Introduction

Smart building aims to improve quality of life, and working quality by providing convenient and comfortable smart environment (Al-Fuqaha et al., 2015). Traditionally, smart building concentrates on using smart devices and equipment to build and to provide smart services. With the emerging requirements of green life and energy saving, more efforts should be put on managing power distribution and consumption in a smart building, in order to know in advance potential problems such as unusual power usage, power leakage, and so on.

In order to effectively manage electric power systems, the first thing is to collect power usage status, which is achieved with smart metering in an intelligent electricity box (IEB) (Bahmanyar et al., 2016; Depuru et al., 2011). But these IEBs are not fully making use of existing Internet of Things protocols in order to provide effective control and management services, in different network environment. After the collection of the corresponding data, there raises the issue of how to effectively manage, store, process these data. Cloud Computing begins to be used as an effective solution for resolving this issue, as discussed in Grozev et al. (2016). A Smart Home Electricity Management System (SHEMS) using Cloud Computing was proposed in Garcia et al. (2013) to manage power usage data. However, these two didn't provide details on how cloud computing was used to realize scalable data collection, storage, and processing. We are looking for an effective solution scalable to handle large amount of real time collected data. At the same time, the solution should be affordable using open source software packages.

On the other hand, dedicated data mining framework is emerging for electricity power consumption analysis using meter data (Silva et al., 2011). And some begin to use Cloud services to identify outage sources and fault localization, capturing peaks and repeat “offenders” of circuits and transformers, and so on as in Lang et al. (2016). However, the existing data analysis can not accurately predict power usage trend, the existing solutions can be improved by the latest deep learning techniques, as shown in our previous work on analyzing resource requests in a data center (Zhang et al., 2017).

Considering all the above mentioned issues, this paper presents a comprehensive solution and architecture on intelligent power distribution management services using existing network protocols, where a smart power distribution box is designed to take place of conventional

* Corresponding author
E-mail address: zhangws@upc.edu.cn (W. Zhang).

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power distribution boxes, which is used to collect electricity information, power consumption data, and remote control of switching. In addition, power usage data can be transferred via both local area networks and/or Internet, and these data are stored on cloud servers and are used to conduct power consumption behavior analysis. Deep learning (Lecun et al., 2015) based approach (LSTM (Gers et al., 2000) in our current work) is used to conduct accurate analysis of power usage trends.

The contribution of this paper includes:

- We propose a cloud-based architecture supported by a cloud-based computing and storage infrastructure, an IEB to handle power usage, and a data mining engine. This approach can work in various network environment.
- We propose a comprehensive communication solution that combines MQTT (Message Queuing Telemetry Transport) (Thangavel et al., 2014), Zigbee (Farahani, 2008), Wifi, and socket communication, which ensures a unified access to the power usage data across NAT (Network Address Translation), LAN (Local Area Network) and WAN (Wide Area Network).
- LSTM is used for mining power usage data, which can provide very accurate power usage prediction in different situations. We also compared the capabilities of LSTM with that of XGBoost (Chen and Guestrin, 2016), and SVR (Castro-Neto et al., 2009).
- We have extensively evaluated the proposed solution in terms of performance, reliability, extensibility, and accuracy of data prediction, which can be used as a reference solution for similar domains like smart factories.

The rest of the paper is organized as follows. Section 2 presents the architectural design of our solution, including both hardware and software components. Section 3 evaluates our work in terms of performance, reliability, extensibility, and so on. We then review the related work in Section 4. Conclusion and future work end the paper.

2. Architecture design of the proposed solution

Before the design of the cloud-based intelligent power distribution service architecture, we need to make some design decisions (Bass, 2007). These include that:

- Wherever possible, existing Internet of things protocols should be used in order to make the integration of smart devices easier.
- Open source software packages should be used if possible in order to save costs.
- To make the power distribution service available to different platforms, it should support clients on different platforms including IOS, Android, and normal Web clients.
- The power distribution service should be scalable to make it usable in a big building where there may be hundreds of IEBs.
- The power distribution service should be available across different network environment, including networks behind firewall, local area network, and wide area network.

Considering these requirements, we design the overall power distribution service architecture as shown in Fig. 1. It uses MQTT as a protocol for communications between IEB modules, data processing server, and clients, if there is an Internet connection. The IEB consists of a tiny computer (Raspberry Pi[1]), and an expansion board. At the same time, the IEB has switch components which can retrieve electricity parameters including voltage, current, leakage current, power and power factor. These parameters are transfered to the Raspberry Pi, and are then sent to the backend cloud servers via

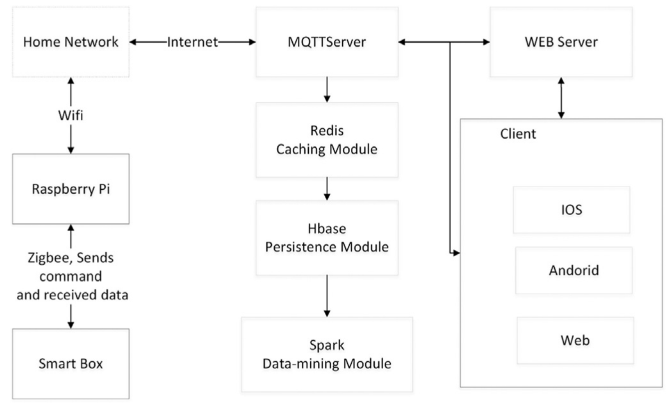

Fig. 1. Schematic diagram of the proposed solution.

Internet using MQTT. The reason to choose MQTT is that the MQTT-based communication can solve Network Address Translator (NAT) penetration effectively. The cloud servers provide data caching, data storage, data analysis and data query services to users.

Users can use three kinds of platforms to access the power distribution services, including Android, IOS and Web clients, to access and control the IEB and retrieve real-time electricity usage information. The architecture is a layered style, including data collection, communication, storage and analysis module, as shown in Fig. 2.

2.1. Electric unit

An electric unit is the basic element of an Intelligent Electric Box, which mainly contains three parts, namely switch control, data collection and communication. Each electric unit is equipped with an electric metering chip to count and calculate the electric information such as voltage, current, energy and power. Then the electric information is converted into hexadecimal and transfered to Micro Controller Unit (MCU). Similarly, The switch control chip on each electric unit can receive commands from MCU and return switch status to MCU in the form of hexadecimal, and turn the switch on or off according to the commands. The Zigbee chip on each electric unit is an end, which is in charge of exchanging electric information and commands with MCU by wireless communication. There are also sensors like temperature sensor, humidity sensor and leakage sensor in each electric unit, which can detect the environment and guarantee the security of the system.

Raspberry Pi is an ARM based micro computer with Linux operating system running on it, which was chosen as the computing kernel in our system because of its high computing capability and low power consumption. The MCU was customized by adding a real-time clock (RTC), a watching dog and a Zigbee chip to the Raspberry Pi in order to meet our requirements. For example, if MCU can not synchronize time with an Internet time server, it will read the time from the RTC. And the watching dog can monitor the real-time status of the Raspberry Pi and reboot it when there are some serious errors occurred. Different from the Zigbee chip in the electric unit, the Zigbee chip in the MCU is a coordinator, which builds up a network of connected switches and manages this network, and it also receives data from each electric unit and transfers the data to the Raspberry Pi through a serial port. In addition, MySQL database is installed in the Raspberry Pi to store data from one recent week, and it could synchronize data with cloud servers every day.

Generally, there are several electric units and one MCU in an IEB. That is to say, from the network point of view, several terminals and one coordinator establish a self-organizing network, in which each terminal can be recognized by an unique identification, and these identifications are stored on the coordinator, which means that only the registered terminal can join the self-organizing network. As the control center and data transfer station, MCU sends inspection commands to

[1] https://www.raspberrypi.org/.