Towards a PowerPedia – A collaborative energy encyclopedia

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Abstract
When it comes to conserving electricity, it is crucial for users to understand how much electricity is used by single appliances. However, the rather technical feedback in pure numbers and intangible units of existing energy feedback systems is not appropriate for most users. To improve this situation, we present PowerPedia, a system that aims at providing action guiding feedback beyond pure consumption values. PowerPedia enables users to identify and compare the consumption of their residential appliances to those of others. It thus helps users to better assess their electricity consumption and draw effective measures to save electricity.

Keywords
Energy use, visualization, smart meter, mobile computing, feedback systems.

ACM Classification Keywords
H5.2. Information interfaces and presentation: User interfaces.

General Terms
Measurement, Design, Human Factors.

Introduction
Residential electricity consumption accounts for one third of the total electrical energy produced [1]. Despite considerable efficiency gains with respect to the large and omni-present household appliances (e.g., refrigerators, freezers, washing machines), electricity use for household appliances in the IEA19[1] grew by 57% from 1990 to 2005 [2]. Moreover, electricity consumption in residential buildings is highly dependent on the behavior of the habitants. Virtually identical households (same buildings with same number of inhabitants, identical age groups, same location, and a similar set of appliances) can easily vary by a factor larger than two

[1] 19 of 22 countries covered by the International Energy Agency (IEA) provide detailed insights on household energy use.

with respect to energy usage [3]. A major burden for people who are willing to save energy at home is the lack of information about their energy consumption. Although, there exist helpful off-the-shelf products that depict the energy consumption in near real time, they do not fully meet the user needs, since their representation is often rather technical and they lack the ability to put the intangible consumption in a picture that allows users to draw conclusions and effective measures.

In this work, we present a system that tries to overcome this drawback by providing users with action-guiding feedback rather than pure numbers. PowerPedia enables users to identify and compare the consumption of their residential devices to those of others. At the same time, an efficiency ranking shows users how their appliances perform compared to appliances of the same category. In addition, general and device-specific measures to conserve energy can be obtained from the community and consumer web sites.

Portable energy feedback systems

With the rise of ubiquitous computing technologies, information provisioning at an increasingly detailed level becomes possible. In terms of energy feedback, this has led to systems that provide feedback on the consumption on household and on device level.

Household-level systems visualize the total residential electricity consumption with a sensor that is either installed in the fuse box or at the electric mains. There exist several commercially available solutions, e.g., Wattson [4] or Onzo [5] to just name two. In addition to displaying the current overall consumption, most of them also provide other features, such as a presentation of the historical consumption, accumulated consumption over time, and consumption equivalents (e.g., CO_2). However, with such systems users cannot determine the consumption of single appliances. Another downside is the complex installation due to the required modification around the electric wiring. Other work from Peterson et al. [6] builds upon a circuit breaker box that is to be attached to the fuse box in order to acquire consumption information per circuit and propose a user interface on a mobile phone.

Device-level electricity feedback systems can provide more detailed information about the consumption of single devices. They are mostly realized as smart power outlets that are plugged between the power outlet and the power cord of the appliance that is to be monitored. In order to visualize the consumption data, systems such as Kill-a-Watt [7] and Click [8] feature an attached display that often depicts rather limited information. Other smart power outlets [9, 10] provide remote access to the measured data through wireless communication means and thus enable users to access the data with their mobile phone for example. However, feedback is limited to the devices directly attached to the outlet. To overcome this drawback other research focuses on the development of systems that integrate multiple sensors [11]. A gateway is responsible for the discovery of the smart sockets within communication distance. The approach facilitates functions such as remote switching, supports different user interfaces, and offers local aggregates of device-level services (e.g., the accumulated consumption of all sockets). While the concept is interesting, the application of a large number of current sensors and communication modules is often too cumbersome and expensive [12].

In contrast to the systems sketched above, our work tries to put the energy consumption in a picture that allows users to better assess and classify the consumption of their residential appliances. In order to conserve energy, users need action guiding feedback rather than technical feedback in intangible numbers [13]. For that, we propose PowerPedia that is based on a smart metering infrastructure and provides users with appliance-specific information on the efficiency and energy saving measures that can be applied to conserve energy.

PowerPedia

PowerPedia aims at providing users a tool that allows them to determine more about the electricity consumption of their appliances. Most people do not have an understanding about how much energy is consumed in their households. In particular, they often do not know how much electricity is used by a single appliance or how their appliance performs energy-wise compared to other appliances of the same device category. In the following, we first describe the general concept of PowerPedia before we present the architecture and finally the developed user interface.

General Concept

The goal of PowerPedia is to make users aware how much energy their residential appliances use. It allows them to better assess the electricity consumption and the energy efficiency of their appliances. For that, users are provided with a possibility to determine the electricity consumption of single devices with simple means (that is an electricity measurement functionality provided on a mobile phone user interface). By connecting a mobile phone directly with a smart electricity meter, users can determine the current electricity consumption of single switchable appliances. However, since many users have no comprehension of intangible units such as watt or watt-hour, and thus are not able to judge whether that corresponds to a particularly high or low consumption, further support is required. Besides measuring the consumption, users can use PowerPedia to derive further information on the efficiency and specific energy saving possibilities of devices. By publishing the measured device to PowerPedia, users can compare the consumption of the measured device against the consumption of other devices that reside in the same device category and have been previously published by others. In addition, device and category specific energy saving measures can be uploaded. In that way, users become aware of the efficiency of their devices as well as of measures conducted by other users or recommended by consumer organizations. In order to keep track of the most energy-efficient devices of each category, PowerPedia embeds a harvester module that automatically updates the data by incorporating the top performing devices gathered from consumer organizations. The harvester also initializes PowerPedia with a first set of energy-efficiency measures.

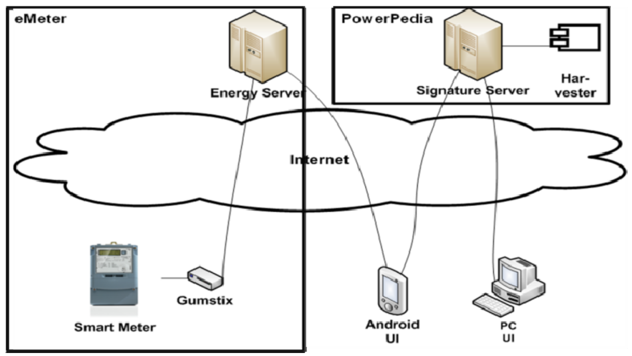

Figure 1. Architecture of PowerPedia realized as an extension to the eMeter system.

Table 1. Example URIs of the PowerPedia

URI	Method	Action
/recognition	POST	Create new recognition
/device	POST	Create new device
/category/$id/rate/$watt	GET	Gather the efficiency rating of a specific device
/tipsCategory	GET	Get a list of all tips categories


```
{
    "device":{
            "id":"96",
            "name":"Osram - Mini Globe",
            "description":"Leistung (Watt)",
            "picture":"www.topten.ch/[...]/mglobe-e27.jpg",
            "manufacturer":"Osram",
            "type":"Mini Globe",
            "categoryId":"19",
            "createdOn":1272312189,
            "avgWatts":"7.0000",
            "efficiencyrating":{
                    "count":4,
                    "position":1,
                    "best":7W,
                    "worst":9W,
            },
            "userId":"5"
    },
    "user":{
            "id":"5",
            "username":"m",
            "password":"x",
            "createdOn":1273790766
    }
}
```


Figure 2. Json represention of a device stored in PowerPedia.

Architecture

The overall architecture of PowerPedia is depicted in figure 1. PowerPedia is realized as an additional component to the eMeter system, which is described in more detail in [15]. It consists of two components: the SignatureServer that stores the information about residential appliances and a harvester that is used to automatically update the PowerPedia. In order to access the provided functionality a stationary and a mobile user interface have been implemented.

The first component, the SignatureServer, is written in PHP using the Recess[2] framework. One of the advantages of Recess is the built-in support for REST [14]. This enables users to access resources using URLs. For that, every resource is bound to a unique resource identifier (URI) that can be accessed and modified with corresponding http verbs (GET, PUT, POST, DELETE). The final data format of the resource is not defined by REST, which leads to high flexibility as data can be represented differently just by adding the corresponding ending, e.g., .html for HTML or .json for JSON. Table 1 provides an overview of selected functionalities that are provided by the RESTful PowerPedia API. It details the URI that can be called together with the corresponding http verb to perform the indicated action. Figure 2 shows an example of the JSON representation of device number 96 that is stored in the Signature. It can be obtained as response by simply calling the following URL:
*http://[serverAddress]/powerPedia/*device/96.json

[2] www.recessframework.org

The SignatureServer follows the Model-View-Controller paradigm that is the basis of the Recess framework. The following models are implemented:

- User: The user model is used to store user authentication information. This includes a username, a password as well as the first and last name.
- Category: The categories are used to group appliances of the same category (e.g. lights). Categories are structured hierarchically, which means that a category can have multiple sub-categories.
- Devices: The device model is used to represent a signature of each device. It contains fields (figure 2) for the name, a description of the device, a picture, the manufacturer, the type, the consumption, time information, and an efficiency rating. Every device is linked to exactly one category.
- Recognition: The recognition model is used to store the data that is collected when users measure the electricity consumption and subsequently upload it to PowerPedia. A recognition is linked to a device and to the model of the user who uploaded the recognition.
- Devicepersonals: To compute the cumulative energy and the costs of a device, the user can specify the usage for every measured device. The model is linked to the user and the device. Furthermore, the user can specify the location of the device (e.g. office, home).

The second component, the harvester, is used to initialize the Powerpedia with a first set of devices and energy saving measures as well as to monthly update the database with the most energy efficient appliances of each category. For that, the SignatureServer starts the update by issuing a GET request to the corresponding URI of the harvester (figure 3). The harvester then scans dedicated external consumer organization web

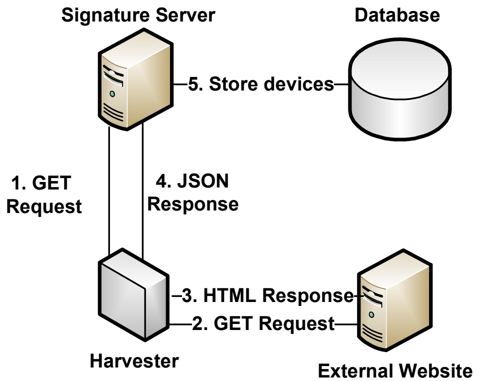

Figure 3. The harvester ensures that the SignatureServer holds a list of the most energy-efficient devices per category.

sites to acquire and extract the data before translating it into JSON. After that, the result of the scan is passed on to the SignatureServer, which updates its list of devices in the database.

The mobile user interface exploits the functionality provided by PowerPedia. It is implemented in Java and runs on the Android operating system. To visualize the consumption data acquired by the smart meter, the client sends a GET request to the Energy Server utilizing the REST-API. The server responds with a JSON string, which facilitates the parsing of the data in the application on the mobile device. The same principle is used to publish new devices to PowerPedia as well as to acquire facts, such as efficiency or energy saving measures, of a particular device from PowerPedia.

User Interface

In order to overcome the drawbacks of existing energy monitoring systems, the Android user interface aims at making users aware of how much energy their residential appliances use. Thus, besides basic feedback features (e.g., current consumption, historic consumption, and standby consumption), the interface provides a measurement functionality that allows users to identify how much single appliances consume. To put the consumption in a bigger, more tangible picture, additional action guiding information, such as appliance efficiency and user-based energy saving measures are provided. For that, users can publish their devices to PowerPedia and compare the consumption against the consumption of devices previously published by others.

The measure view (figure 4 left) allows users to interactively measure the electricity consumption of single switchable appliances. To perform a measurement, users have to initialize the measurement by pressing the start button. Thereafter, users are asked to turn on or off the device that should be measured. Within two to ten seconds, the system will then compute the result based on the measurement algorithm. That is, besides regarding the increase or drop in real power, the algorithm also takes the different electric circuits and additional physical variables, such as apparent power and power factor, into account. This allows determining on which line the switching event has occurred as well as failure detection in the case where two appliances are switched on at the time. In the latter case, users are notified to repeat the measurement, and by comparing the jump after normalization to the previous measurement, the consumption can be identified.

Thereafter, users can personalize the measurement (figure 4 middle). The user interface offers the possibility to take pictures of the measured appliance, assign a location, specify a device category and manufacturer, and adjust its utilization to calculate the incurred yearly costs. By publishing the device to PowerPedia, users can compare their measured consumption to the consumption entered by other users as well as to the consumption of the most energy-efficient appliances of the category harvested from consumer organization web sites. An efficiency ranking puts the consumption in a more tangible picture. It shows users the efficiency rank of their device, information on the best and worst performing device as well as the number of uploaded devices in the category.

The tips view (figure 4 right) displays energy saving measures loaded from PowerPedia. It consists of tips that can be applied in general as well as specific tips that relate to the device category of published devices. The user interface also offers the possibility to upload one's own energy saving measures. Tips can be checked to indicate that they have been applied. This allows indicating the percentage of users that already have applied the measure.

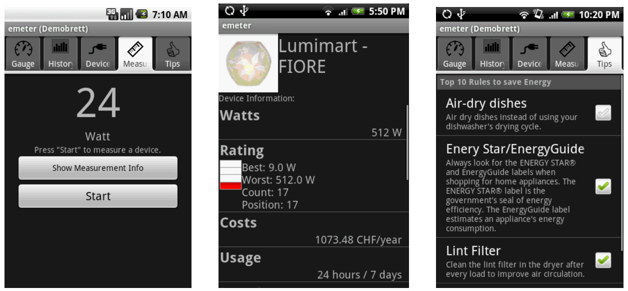

Figure 4. Android user interface. Measure view (left), device details (middle), energy saving measures (right).

Conclusions and Future Work

In this work, we presented a system that allows users to interactively explore their energy consumption. The possibility to upload the measured data to PowerPedia which serves as a community platform introduces a social networking aspect to energy feedback systems. It puts the energy consumption in a broader picture beyond pure numbers and encourages users to compare the consumption of their devices to those of others. As the system continuously updates the database with the most efficient device types from external sites, it succeeds to provide user with top rated devices. Besides real power, our system also measures additional variables, such as apparent power, distortion power, and power factor. Thus, besides evaluating the prototype, future work targets the possibility to gather a broad collection of appliance signatures that can be used to automatically recognize switching events of devices in the load curve.

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