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A system for collecting activity annotations for home energy management☆

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ABSTRACT

Home energy management is becoming increasingly important and, though there are a plethora of tools for accessing energy consumption data, few provide concrete insights that can directly help users manage demand. Mechanisms that enable a user to draw connections between activities and energy consumption by attaching contextual labels to energy events are a promising step; however solutions for collecting annotations from users can be error prone or intrusive. This work presents a system for collecting in situ annotations using a smartphone application coupled with an off-the-shelf home energy measurement infrastructure. We use a novel power profiling approach to identify important energy consumption events and solicit contextual annotations from the user via a push notification sent to a smartphone. Using a five-week study performed in five homes, we show that our power profiling approach can identify a significant percentage of important energy consumption events using a very small number of monitored devices. We were able to collect an average of over 2 annotations per day and while users provided a wide range of annotations, the motivation to provide annotations varied across subjects.

1. Introduction

A key component of creating a sustainable world is managing energy in the home [1]. Recent years have seen a marked increase in the number of tools that end users can employ to monitor their energy consumption, but most tools simply provide access to raw numbers. Users can, for example, install energy meters that provide readouts of the watt hours consumed by a particular appliance, or even provide estimated operating cost. Prior research has demonstrated, however, that users seek solutions that can provide greater insight into energy usage and its impact [2–4].

Tools that allow users to connect their activities to their energy consumption habits have been shown to be a promising means of offering desired insights into a home or appliance energy profile [5]. These tools help a user to understand *why* a given quantity of energy is consumed, for example because the user watched an on-demand movie that required the cable box in addition to the television. Costanza, Ramchurn, and Jennings discovered that even the annotation process itself can raise a user's awareness. Their annotation mechanism, FigureEnergy, allows a user to annotate an energy consumption timeline after the fact using a visualization tool; however this assumes that the user will accurately recall what he or she

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was doing at a particular point in the past. Other approaches attempt to automatically derive a user's activity [6,7], though require pervasive sensing systems and deployments that can be costly, intrusive, and difficult to manage. This work presents a minimally intrusive, in situ approach for annotation of home energy data. Using only the information collected from a set of off-the-shelf energy meters, the system determines, in real time, whether the energy profile of a device suggests that the user is performing an important energy consumption activity. If so, it sends a push notification to a user's smartphone requesting that he/she provide an annotation of his/her current context. This approach both obviates the need for sensors such as cameras and motion detectors, as well as captures a user's activity while it is in progress and fresh in the user's mind. We make two primary research contributions in this work.

Our first contribution is a novel power profiling algorithm that uses appliance power signatures collected by our energy monitoring system to determine when a power consumption change is sufficient to suggest that the user may be performing a different or new activity. Many appliances do not have a clear on/off state and determining when the raw power draw indicates that the device has transitioned into a more active state is not straightforward. Our approach uses the DBSCAN clustering algorithm to identify a unique power profile for each individual device. Using this approach, we were able to generate usable profiles for 31 of 39 devices across 5 homes participating in a five-week deployment. Of the remaining devices, two were never used during the experiment period and three were always on and remained in the same power state.

Our second contribution outlines the results of a five-week deployment in 5 homes. Using the profiles generated by our algorithm, we notified the user anytime any device in the home transitioned into a higher power state, and we also asked users to annotate any time they thought they were performing a relevant activity. We were able to collect an average of over 2 annotations per day, and in one day we saw 13 annotations from one of our subjects. Users provided a wide range of annotations across different times of day and representing different types of activities; however the overall response rate was lower than expected leading to a sparse data set. The data set can, however, be used for understanding ties between energy consumption of appliances and activities and can augment a visualization interface like FigureEnergy to help the user better understand energy consumption patterns.

2. System design

Accurate annotations of energy data are useful for enabling automation of energy management as well as for encouraging improved manual management of energy demand by providing users with a better understanding of how energy usage corresponds to their daily activities. This work presents a novel component for collecting *in situ* annotations integrated into an existing home energy measurement system—Green Homes [8,9]. Data already collected by the Green Homes energy meters is provided as input to a power profiling algorithm that identifies fine-grained changes in the user's context. The algorithm aggressively prompts the user to annotate his/her context by sending a notification to a smartphone application. In this section, we first provide a brief overview of the Green Homes system, then present the power profiling algorithm and describe the implementation of the notification component. While our system uses individual appliance level energy consumption traces to generate power profiles, it can also work on disaggregated data collected using a non-intrusive load monitoring technique [10,11].

2.1. The Green Homes system

The Green Homes project [8,9] is an ongoing effort to understand energy usage in homes, particularly those powered by renewable sources, and to encourage sustainability by developing automated mechanisms for matching energy demand with available supply. At present, 9 homes are participating in our study, including one grid-tied home with solar panels and one off-grid home entirely powered by solar panels. In each home, we have installed between 5 and 10 off-the-shelf energy meters [12] that collect energy usage of appliances include televisions, lamps, microwaves, and computing equipment. The appliances monitored are illustrated in Table 2. We chose these appliances since they are commonly used when performing the activities that we were interested in—cooking, entertainment, chores, and work. For instance, Ovens and Microwaves are common cooking appliances while Laptop and PCs are used for work. Where possible, we also collect energy usage of the entire home.

Fig. 1 illustrates the architecture of the Green Homes system. The off-the-shelf energy meters communicate with a dual-radio gateway [13] in each home. Also in each home is a client component that polls the energy meters every 30 s and reports readings to a centralized server. We chose a 30 s interval since our *z*-wave based energy monitoring system uses sequential polling of all the energy meters. In a house with at least 10 m, once every 30 s is the fastest rate at which we can collect data. This interval, therefore, allows us to collect data at the finest granularity possible. Data on the server, including graphs of past usage and current device status, can be accessed by a web or smartphone application (both Android and iPhone are supported). Additionally, every one minute, the notification component on the server side executes the power profiling algorithm described below and, if appropriate, pushes a notification to the user's phone. We use a one-minute interval as it provides at least two energy value readings that can be used as an input to our power profiling algorithm. The short time interval also allows us to capture the change in energy consumption when a device is switched on, or when a device changes its power state—longer intervals might average out these energy spikes. Annotations entered by the user are then stored on the server for postprocessing.