Pervasive and Mobile Computing 12 (2014) 58–78

Contents lists available at ScienceDirect

Pervasive and Mobile Computing

journal homepage: www.elsevier.com/locate/pmc

An efficient and inexpensive method for activity recognition within a smart home based on load signatures of appliances

Corinne Belley, Sebastien Gaboury, Bruno Bouchard *, Abdenour Bouzouane

LIARA Laboratory, Universite du Quebec a Chicoutimi (UQAC), 555 Boul. de l'Universite, Chicoutimi (Quebec), G7H 2B1, Canada

ARTICLE INFO

Article history:
Received 1 October 2012
Received in revised form 25 January 2013
Accepted 8 February 2013
Available online 14 March 2013

Keywords:
Activity recognition
Smart home
Load signature
Non-intrusive appliance load monitoring (NIALM)
Appliance identification

ABSTRACT

With the increasing demand in terms of non-intrusive appliance load monitoring (NIALM), more and more smart meters and smart analyzers were released on the market to extract well-defined load signatures and/or for performing autonomously the various monitoring operations as needed. Nevertheless, this hardware proves to be very expensive and not necessarily accessible to all. Moreover, most applications resulting from the use of these smart devices simply refer to energy saving and costs reducing of energy consumption. Thus, this paper proposes a new algorithmic method for an application field that is still very lightly exploited, i.e. the activity recognition of reduced-autonomy residents living in a smart habitat through load signatures. This one is based on steady-state operations and signatures and its extraction process of load signatures of appliances is carried out in a three-dimensional space through a single power analyzer which is non-intrusive (NIALM). This approach has been tested and verified rigorously through daily scenarios reproduced in the smart home prototype in a laboratory. Hence, we can affirm that, with an exceptionally minimal investment and the exploitation of especially limited data, our method can recognize the use of appliances with high precision and low-cost allowing us to compete with other approaches which are much more expensive and require supplementary equipment.

1. Introduction

In the last few years, the research done on appliance load monitoring has been more specifically observed in the interest of customers of the utilities. In fact, as each appliance has a load signature specific to its operation, which varies with the time and its mode of function, it helps to determine the energy consumption, the frequency, the time and the exact moment of use of an appliance. The impacts of these scientific studies about the appliance load monitoring are that the latter is used to determine the average power consumption of each household device to then establish the energy balance of a residence for safety [1–4], economical [1,2,5,6] and ecological purposes [1,5,7,8]. Briefly, they consisted in associating a device with the proper load signature extracted from smart meters and analyzers. Consequently, the real challenge, with respect to the appliance load monitoring, is the identification of the load signatures according to the operation mode of the appliances, because these must be accurate and distinct as much as possible so that overlap and, subsequently, misidentifications are avoided.

Initially, the methods used to accomplish this task were intrusive, but now, most researchers in this area proceed by means of non-intrusive methods [1–6,8–25]. Several of them suggested monitoring methods for extracting the characteristics of devices so as to obtain load signatures in two-dimensional spaces [2,3,6,15], in three-dimensional spaces [11,17,21] or with more than three features [4,9]. Moreover, there exist three types of approaches to describe the load

* Corresponding author.
E-mail address: Bruno.Bouchard@uqac.ca (B. Bouchard).

1574-1192/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.pmcj.2013.02.002

signatures: the technique with steady-state operations [2,15], the process with transient operations[1] [11] or a mixture of both [4,9,18,24,25]. The systems that are reserved for these previous methods are provided with analyzers with diverse sampling rates, which introduce a gap between the accuracy of each approach. Most of them involve major costs and sometimes require additional sensors or equipments to get greater precision for feature extraction of appliances, which generally introduces a certain degree of intrusiveness [2,3,11] and important inconveniences [6,15] that the suggested method takes care of avoiding while delivering a particularly high precision.

Currently, some methods, to recognize the activities of a person in a smart home, exist. These methods rely on RFID technology, sensors, etc. [20,26]. The main issues with these approaches are the intrusiveness for the resident and the important quantity of hardware for maintenance it requires. Consequently, in this paper, to provide a solution to these problems, a cheap NIALM system for identifying load signatures of appliances with the aim to ensure the recognition of activities is proposed. Our conceptual contribution consists in developing a NIALM system for activity recognition of patients with Alzheimer's disease living in a smart home. This is achieved through the extraction of the load signatures represented by three features of the appliances and based on power analysis at the steady-state. Secondly, our practical contribution is a complete implementation of this system within a real smart home environment provided with a power analyzer which is centralized in a single point, either the main electric panel, and the monitored household appliances used daily. Finally, we rigorously tested our load appliance monitoring system with some real scenarios of activities with some household devices among the 16 monitored appliances in order to demonstrate its efficiency in this specific use context. Our procedure then enables analysis of the power consumption of appliances to make the recognition of activities within a smart home for Elders and cognitively-impaired people. Indeed, our method was developed in order to recognize the lifestyle of the smart home's resident and to detect unusual situations or simply ongoing activities. Therefore, the focus will aim on the temporal and spatial aspects of detected events to address the recognition of activities. Regrettably, this scope is still disregarded, since, for the time being, very few researchers are dedicated to this issue [22,23]. Nevertheless, this remains of paramount importance given the aging population and the need for autonomy that is felt among cognitively-impaired people in our society. Thus, considering our method, which involves low investments and demonstrates accuracy comparable to the quality approaches, it appears to be a very interesting technological advance with an incredible potential to be developed.

The sections of this document are structured as follow. The Section 2 defines terminology and concepts. The third explains the features used for our method. Then, the fourth part presents both phases of our new contribution based on steady-state signatures in a two-dimensional space. Subsequently, the Section 5 describes the implementation of our system and the experimental methodology used in this case. In Section 6, the analysis and comparison of the test results are discussed. Subsequently, Section 7 presents the limitations of our approach. Next, Section 8 elaborates and provides details on the related works concerning the various methods used to describe and monitor load signatures of appliances. Finally in the last section, the potential development opportunities in the near future through our contribution are presented.

2. Concept and definitions

2.1. Load signature

The load signature corresponds to the specific electrical behavior of an individual appliance/piece of equipment when it is in operation [9]. Typically, the variables considered are the voltage, the electric current and the power. In this way, each appliance is represented by its own waveform of power consumption versus the time.

2.2. Smart home

In fact, a smart home is a house or an apartment equipped with sensors (e.g.: motion detectors, RFID tags, pressure detectors, etc.) [15] installed to track the person residing there and to detect atypical situations through monitoring and then be able to intervene and assist the person visually or auditorily if the need arises. Additionally, this habitat is fitted with tablet computers (iPad) to take control of various devices remotely. Moreover, some household items are equally endowed of RFID tags that permit their location and identification within the apartment. Thus, the intelligent home is a house designed so as to introduce various forms of artificial intelligence that ensure the monitoring and care of its inhabitants independently.

2.3. Activity recognition

The activity recognition is currently an area of growing research, particularly in regard to smart home [15,20,22,23] because we seek to provide a form of autonomy for individuals who require increased daily monitoring. This is actually a method for determining the routine of a person which is based on a sequence of observed events by means of multiple sensors such as motion detectors, pressure detectors, RFID tags, electrical power analyzer, etc. In summary, data and elements of daily living of the inhabitant must be collected to be able to establish what activities are normally carries out by this inhabitant in a day. Additionally, in some cases, when the activity recognition is considered with time and space, it can detect the strangeness of a situation according to the reading of data returned by the sensors and/or analyzers.

[1] Sometimes the transient operations appeal to turn-on transient energy (PQU_T).