An Experimental Study on Electrical Signature Identification of Non-Intrusive Load Monitoring (NILM) Systems

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Abstract. Electrical load disambiguation for end-use recognition in the residential sector has become an area of study of its own right. Several works have shown that individual loads can be detected (and separated) from sampling of the power at a single point (e.g. the electrical service entrance for the house) using a non-intrusive load monitoring (NILM) approach. This work presents the development of an algorithm for electrical feature extraction and pattern recognition, capable of determining the individual consumption of each device from the aggregate electric signal of the home. Namely, the idea consists of analyzing the electrical signal and identifying the unique patterns that occur whenever a device is turned on or off by applying signal processing techniques. We further describe our technique for distinguishing loads by matching different signal parameters (step-changes in active and reactive powers and power factor) to known patterns. Computational experiments show the effectiveness of the proposed approach.

Keywords: feature extraction and classification, k-nearest neighbors, non-intrusive load monitoring, steady-state signatures, support vector machines.

1 Introduction

"Your TV set has just been switched on." This may very well be a sms or email message received on your mobile phone in the near future. For energy monitoring, health care or home automation, concepts like Smart Grids or in-Home Activity Tracking are a recent and important trend. In that context, an accurate and inconspicuous identification and monitoring of electrical appliances consumptions are required. Moreover, such monitoring system should be inconspicuous.

Currently, the available solutions for load consumption monitoring are smart meters and individual meters. The first ones supply aggregated consumption information without identifying which devices are on. To overcome this limitation, to use an individual meter for each appliance in the house would be sufficient. However, this would turn out to be an expensive solution for a household.

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A non-intrusive load monitoring system (NILM) fulfills all the requirements imposed by the Smart Grids and in-Home Activity Tracking challenges at virtually no cost. NILM is a viable solution for monitoring individual electrical loads: a single device is used to monitor the electrical system and to identify the electric load related to each appliance, without increasing the marginal cost of electricity or needing extra sub-measurements. Nevertheless, only with the present low-cost sensing devices, its full potential could be achieved.

The central dominant goal of a NILM system is to identify which are the appliances switched on at a certain moment in time. The signals from the aggregate consumption of an electrical network are acquired and electrical features are extracted, in order to identify which devices are switched on. Each appliance has a particular electrical signature which must be recognized in order to perform an accurate identification. This paper presents a study for its electrical distinctive characterization. The proposed signature is based on the analysis and recognition of steady-states occurring in the active and reactive power signals and the power factor measurements. To evaluate this approach, data from a set of appliances were collected and classified using a Support Vector Machine (SVM) method and the K-Nearest Neighbors (K-NN) technique. The results of the computational experiments indicate that an accurate identification of the devices can be, in fact, accomplished.

This paper is organized as follows: the next section presents a brief overview of the related literature. Section 3 describes the concepts behind the NILM system and the electrical signature problem. It proceeds describing the developments associated to the step-changes analysis in an electrical signal and the features that can be used as distinctive marks, introducing a result that enables an algorithm for steady-state recognition. Finally, Section 4 describes the experimental setup, where the new algorithm for feature extraction was used followed by SVM and K-NN classification algorithms and the classification results. Conclusions and future work are addressed in Section 5.

2 Related Literature

To identify the devices switched on at a certain moment in time, a non-intrusive load monitoring system uses only the voltage and current signals of the aggregated electrical consumption using sampling of power at a single point. The concept was independently introduced by Hart [1] (then working at the Electric Power Research Institute) and by Sultamen (Electricité de France) [2]. Over the last decades, due to the pressing environmental and economic issues, the interest in this area has increased, being the focus of PhD theses as [3]. In 1996, the first NILM system was commercialized by the company Enetics, Inc..

The main steps in a non-intrusive load monitoring system are: a) the acquisition of electrical signals, b) extraction of the important events and/or characteristics and c) production of a classifier of electrical events (see Figure 1). To perform the identification, the definition of an electrical device ID is needed. Therefore, the electrical signatures are the basis of any NILM system [1]. These are defined as a set of parameters that can be measured from the total load. For