Master Thesis

Sniffer: monitoring and signature analysis of mains-operated electrical equipment

Keywords: electrical disaggregation, signature analysis, machine learning, Non-Intrusive Load Monitoring, smart buildings

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Context

Developing smarter and greener buildings has been an expanding field of research over the last decades. One of the essential requirements for energy utilities is the knowledge of power consumption patterns at the single-appliance level. To estimate these patterns without using an individual power meter for each appliance, Non-Intrusive Load Monitoring (NILM) consists in disaggregating electrical loads by examining the appliance specific power consumption signature within the aggregated load single measurement. Therefore, the method is considered non-intrusive since the data are collected from a single electrical panel outside of the monitored building. Thus, NILM has been a very active field of research with renewed interest over the last years [7]. Knowing the plug-level power consumption of each appliance in a building can lead to drastic savings in energy consumption and NILM can thus play an important role in energy management and reduction in buildings and homes.

Another application to electrical appliance monitoring is related to security. In certain contexts, it is important to recognize the electrical signature of authorized IT equipment, and to be able to detect if unauthorized ones, especially computers, are connected to the mains. Based on the SmartSense platform and on traces of the power consumption of individual electrical appliances and building-level power monitoring, the aim of the Sniffer project and of this Master thesis work is the detection and surveillance of equipment connected to the mains supply using advanced machine learning techniques.

Sensor-Aided Non-Intrusive Load Monitoring

Various approaches to solve the problem of device determination in NILM have been considered with interesting results. The features applied in low-frequency based approach essentially include the step-change (or edge) and the steady state [7]. In [8], the author uses a probabilistic approach to tackle this challenge. Recently, machine learning methods, especially deep neural networks, have shown significant improvements in classification problems over the last few years and was applied to improve NILM [6].

Environmental sensing and additional heterogeneous information can be exploited to address some of the prevailing challenges faced by the current NILM techniques. We proposed several methods to improve NILM algorithm performance with the use of data extracted from sensors networks and introduced the concept of Sensor-Aided Non-Intrusive Load Monitoring [1-2]. Using these environmental sensors, and testing several algorithms, we show that monitoring a few appliances could drastically improve NILM performance. Detecting the state of an appliance with the adequate sensors can be a low-complexity task. For example, the operation of a workplace printer may be readily recognized with an audio sensor. Lights can be easily monitored by sensors as well. Assuming the state of an appliance is known, an interesting task is then to estimate the characteristics of steady-state power of an appliance, on a length-significant power trace. In their work around ViridiScope [9], the authors implemented a power monitoring system by indirect sensing with self-learning automatic calibration of each sensor.

In [1] we introduce three algorithms to solve the l1-norm minimization problem in NILM and show results on power measurements obtained from a real appliance deployment. With a small number of devices, the obtained precision varies from 75% to 99%, depending on the tolerance criterion to determine the steady state of a given device. In [2], we address the issue of NILM inaccuracy in the context of industrial or commercial buildings, by combining data from a low-cost, general-purpose, wireless sensor network. We have proposed a novel approach based on a simplex solver to estimate the power load values of the steady states on sliding windows of data with varying size. We have shown the principle of the approach and demonstrated its interest, limited complexity, and ease of use.

SmartSense: a sensor network platform for smart building research

With 150 nodes deployed at INRIA (Lannion and Rennes), the SmartSense platform collects many different data related to energy consumed and uses in buildings. These data pave the way for a large number of applications, in particular in data mining, electrical load disaggregation or in sensor processing. Each node comprises approximately 20 sensors: camera, infra-red, audio, radio spectrum sensing, 9-axis inertial, humidity, atmospheric pressure, temperature, light (red, green, blue, white, UVA, UVB), centimeter precision distance ranging, C02+VOC.

Objectives

In the context of electrical network compromise analysis, the first step consists in identifying equipment connected to the sector of an installation (e.g., building, factory) relying on machine learning techniques. The identification extracts equipment characteristics (such as PC, monitor, charging mobile phones) when they are connected to the mains. Then, these electrical signatures are processed to perform in-depth learning and detect the presence or absence of specific equipment on that network. Our aim is to combine the electrical signals with data obtained from sensors and from electromagnetic radiation which are closely related to the current and power consumed by an electrical device. We also want to evaluate if a specific software running on a PC and launched as a daemon (a background process) can generate some unique signatures on the electrical network.

Our approach is based on formulating the disaggregation as an optimization problem, which consists in minimizing the difference between the main power meter output and the sum of disaggregated reconstructed appliances and by solving this optimization problem to detect if an equipment is connected or not on the mains. For validation, we will mainly rely on the SmartSense platform that provides real-time (but low-frequency) electrical power traces of our Laboratory, together with many sensor information.

Therefore, this Master thesis will focus on solving this optimization problem by choosing the right algorithm for signature analysis in this context and by conducting experiments on real power traces, both for training the optimizer and to evaluate its performance. Machine learning algorithms like Bayesian optimization, deep learning or time-frequency analysis will be particularly investigated.

Note on the bibliography: for the bibliography part of this Master thesis, a small set of techniques for electrical disaggregation and signature analysis will be studied from the literature. The project will consist in developing some code to evaluate some techniques that can detect if a given equipment is connected or not to the electrical network. For this part we will use data from the SmartSense platform.

References

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