Electrical Power and Energy Systems 90 (2017) 168–180

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

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

Development of a real-time non-intrusive appliance load monitoring system: An application level model

Trung Kien Nguyen [a,b,*], Eric Dekneuvel [b], Gilles Jacquemod [b], Benjamin Nicolle [c], Olivier Zammit [c], Van Cuong Nguyen [a]

[a] University of Science and Technology – The University of Danang, Viet Nam
[b] University of Nice-Sophia Antipolis, EPOC-UNS, Sophia Antipolis, France
[c] Qualisteo Company Nice, France

ARTICLE INFO

Article history:
Received 9 June 2016
Accepted 21 January 2017

Keywords:
NIALM
CUSUM
Genetic algorithm
K-mean
FPGA
System modeling
Hardware software co-development
Synchronous DataFlow

ABSTRACT

The research "Behavior Change and Energy Use" (US Department of Energy and Climate Change, 2011) [1] shows that with better information in the monthly electricity bill, the Energy Performance Certificate (EPC) can encourage people to reduce their energy usage. That is why smart meters - the emerging technology to help people to know their monthly energy consumption, are gradually replacing mechanical power meters. In this paper, we investigate a special energy monitoring process named Non-Intrusive Appliance Load Monitoring (NIALM), which is potentially the best method to give consumers pertinent information with respect to power consumption. However, real-time feedback feature in a low cost NIALM system is still a big challenge in such technology because of the complication in NIALM's algorithms. System on Chip (SoC) technology can solve this challenge. Besides including high-speed interconnection and multi-processors, integrating Field-Programmable Gate Array (FPGA) into SoCs may be the most important evolution, which provides developers a powerful tool to develop a low cost but high performance system. Therefore, in this paper we proposed a development of a real-time NIALM system based on the SoC with FPGA acceleration.

1. Introduction

1.1. NIALM technology

The NIALM technology, first introduced by Hart in 1992 [2], aims to provide an approach using only one sensor to monitor all appliances in an electric network. In comparison to the conventional method, as illustrated in Fig. 1, NIALM system is more economical because the system installation and maintenance is faster, safer and more flexible. Such technology has been applied in many areas of daily life: home or building energy monitoring [2,3], water and gas monitoring [4], fault detection in system maintenance [5]. A standard NIALM system has five basic processes:

- Data acquisition: to collect data from sensors at a predefined sampling rate.
- Pre-processing: to filter the noise and to extract some electrical signatures such as total real power, re-active power, apparent power, harmonics data, power factor, etc.
- Event Detection: to detect the ON/OFF activities of appliances in an electrical network and to extract the change of electrical signatures after that event.
- Classification: to find ON-events and OFF-events groups, which are parts of appliances and to recognize them based on the known information in a supporting database.
- Estimation: to summarize the percentage of power consumption in each appliance.

NIALM technology has been become a hot research area from 2000. Most of researches in NIALM have focused on improving the accuracy of the technology by exploring more complicated disaggregation algorithms and using supervised database [6–10]. However, these algorithms required powerful hardware platforms that are expensive. Patel et al. [7] used a power-line interface hardware, a USB oscilloscope interface (EBest 2000), and a computer to develop his complex 100 MHz sampling rate NIALM system. His

* Corresponding author at: University of Nice-Sophia Antipolis, EPOC-UNS, Sophia Antipolis, France.

E-mail addresses: ntkien@dut.udn.vn (T.K. Nguyen), dekneuv@polytech.unice.fr (E. Dekneuvel), Gilles.Jacquemod@polytech.unice.fr (G. Jacquemod), benjamin.nicolle@qualisteo.com (B. Nicolle), olivier.zammit@qualisteo.com (O. Zammit), ngvancuong2000@gmail.com (V.C. Nguyen).

http://dx.doi.org/10.1016/j.ijepes.2017.01.012
0142-0615/

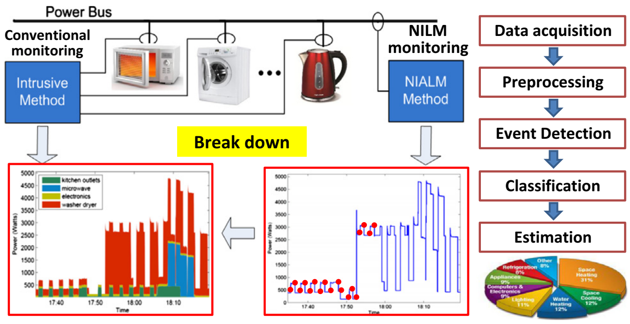

Fig. 1. Conventional and NIALM method in power monitoring application [26].

system run the sliding window FFT algorithm to extract harmonic information and the Support Vector Machine (SVM) algorithm for classification. Cox et al. in 2006 [11] even proposed using a complex pre-processor to compute a set of spectral coefficients of distortion voltage in the electric network to identify home appliances. Baranski et al. in 2004 [6] used a standard computer to detect transients from time series power data using a sliding window algorithm. They used a cluster algorithm to group these transients to many cluster. Finally, the Genetic Algorithm (GA) algorithm was used to discover both ON_OFF and multi-state appliances. Suzuki et al. in 2008 [8] used the waveform of a cycle of current to disaggregate appliances based on Integer Programming. His algorithm also works with multi-states appliances, however, it needs a database of waveform of each appliance but such waveforms are too sensitive to noises. Some other NIALM researches [2,9,12] used a complex statistical algorithm such as Hidden Markov Model (HMM) to classify appliances based on a data of power sampled at a low sampling rate. However, low sampling rate can sometimes lead to the loss of the "peak" states, which may be an important signature to distinguish appliances. Moreover, training phases can encounter problems if there are new appliances that did not exist in the pre-trained database.

Therefore, researchers still have to find the ways to reduce the cost but still improve the effectiveness of algorithms for NIALM smart meters. System on Programmable Chip (SoPC) technology, which will be presented in the next section, can solve this challenge.

1.2. SoPC technology

SoCs so far contain most of essential elements to be able to develop a complete system in a single chip: one or many programmable processors, many levels of memory (cache, RAM, Flash, DMA), a complex bus structure (processor bus, peripheral buses, communication bus) and real world interfaces (temperature sensor, ADC blocks, DAC blocks). Some SoCs may have special functional units optimized for specific applications such as video/audio decoding/encoding unit, graphic acceleration unit, and power management unit. However, integrating new hardware functions into SoC for specific applications is still very expensive.

SoPCs are special SoCs with an integrated reprogrammable hardware FPGA that can be reprogrammed a custom Digital Signal Processing (DSP) hardware to accelerate a complex computation. As illustrated in Fig. 2, algorithm accelerated by FPGA is faster 18 times than running in a standard DSP processor. The hardware reprogrammable feature makes SoPC to be a powerful tool to quickly explore a system in different architectures (one core, dual core with FPGA acceleration) to find the best one for the final product. Therefore, such SoCs can reduce the iteration cycles in system development, increase the productivity and reduce product cost. We will present in more detail about using SoPC to develop an innovative real-time NIALM system, which is able to overcome many NIALM challenges.

1.3. Contributions of the research

In coming sections, this paper will present two important contributions of the research. First contribution is proposing an effective disaggregation algorithm for NIALM technology presented in Section 2. With this algorithm, the Pre-processing and the Event Detection process can extract more electrical signatures and improve the appliance classification. The Event Detection process can even detect slow transients and simultaneous transients, which are still challenges of NIALM. The disaggregation algorithm based on Genetic Algorithm can detect multi-state load appliances.

Section 3 will present the second contribution: a proposal of a Hardware/Software (HW/SW) co-development methodology to develop the NIALM system. This approach allows modeling an executable system specification, static scheduling, memory resources allocating and prototyping the real-time NIALM system based on SoC quickly using LabVIEW FPGA [14]. This methodology may be applied to develop a low-cost powerful NIALM system which is able to process all NIALM's algorithm in real-time. In order to demonstrate this advantage, we can set the constraints of the system as bellow: 5 s maximum delay between a real event and its display in the Graphical User Interface (GUI), less than $150 cost, low power consumption and able to disaggregate 80% total power consumption in an electrical network.

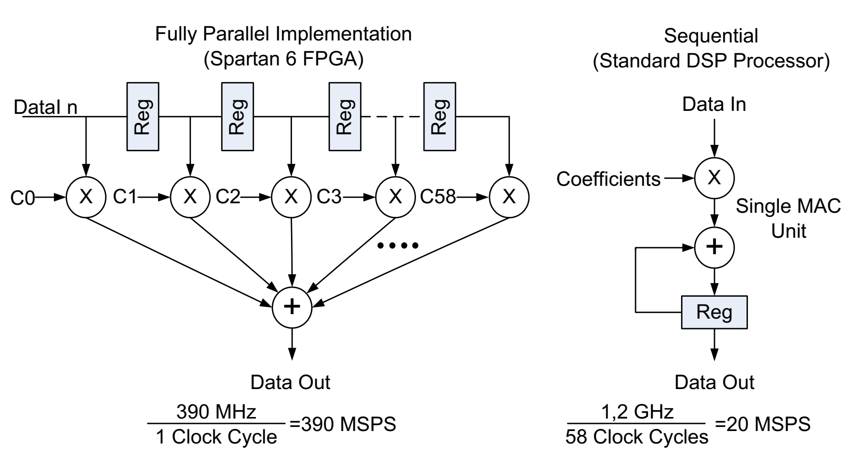

Fig. 2. DSP algorithm accelerated using FPGA [13].