iHomeLab experience with NIALM for Smart Buildings

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ABSTRACT

This iHomeLab work description discusses the usage of Non-Intrusive Appliance Load Monitoring (NIALM) for Smart Buildings. NIALM is the enabling technology used for load disaggregation and the energy consumption information about single appliances with minor to no alterations of the infrastructure. NIALM has been used in our project LoReMA, which had the goal to identify most of the electrical appliances installed in a building. The description gives an overview about our system architecture and concept how NIALM was implemented and used in the project. The project results are discussed and we close with the conclusion and the opportunities for future work of NIALM.

Keywords

NIALM, NILM, load disaggregation, Smart Metering, Smart Grid, User-driven energy efficiency, in-home networks, Smart Energy Profile

1. INTRODUCTION

Most of the private household and industrial building users have only a small or no understanding about their own energy consumption and have limited instruments to assess and optimize it. Consumers need to see and understand the electricity being used by different appliances. They're keen to see whether a new appliance, or a change in habits, affects the amount of electricity used. The hourly metering values for entire electricity use in offices and households cannot distinguish the effects or patterns of individual appliances, or register the effects of small brief changes [1]. Consumers have a clear wish to be able to understand the amount of energy used by different appliances and during different time periods. This information could give the best results in increasing the energy efficiency through user interaction.

Studies have shown that the real time and detailed visualization of energy consumption curves offers an average potential of 5 to15% energy savings in modern homes and offices. The information provided to the end-users must include categorization of appliance groups, like HVAC, lightening, white goods, computers, infrastructure and others. Building these appliance categories will help the user to understand his energy consumption and to develop own energy efficiency strategy.

Non - Intrusive Appliance Load Monitoring (abbreviated as NIALM) is the enabling technology used to get the energy consumption information. Furthermore, NIALM is an enabler for feedback systems to provide real time, summarized and categorized data to the end-users. Soft degradation of appliances, the aging and out dated appliances will be identified. After appliances have been identified and assessed, supporting proposals to the end user can be made to help him in his self-developed energy efficiency strategy even more.

2. NIALM experience at the iHomeLab

The iHomeLab of the Lucerne University of Applied Sciences has its main research area in building intelligence and smart homes with the focus on energy efficiency of systems and components.

In 2009 we began to investigate the methods for load disaggregation [2,3,4,5] to provide end user feedback for energy consumption. Further, the iHomeLab has initiated the project LoReMA with the focus on Load Recognition Monitoring and Acting.

2.1 LoReMA Project

LoReMA follows the objective to identify all installed loads in a building without altering the infrastructure. The LoReMA System consists of three main parts: measurement nodes (sockets), a coordinator and a control unit.

The concept of LoReMA consists of multiple measurement nodes placed where ever needed in the building. The miniaturization allows placing the nodes direct into power outlets. With the decentralized approach the measurement is very close to the appliance and makes the identification of small loads possible. The nodes are connected with a control unit over wireless network, using ZigBee stack. Each node transmits its measurements in form of energy footprints to the control unit for further processing.

The control unit has an internal database with all the measured energy footprints. Upon receiving a new measurement it searches the database for the identification of the appliance. Further, the control unit is capable to turn off/on the power outlets. Using the last feature, the standby loss in homes and offices can be brought to a minimum.

The last part of the project was dealing with the miniaturization of the measurement nodes. We were able to bring the whole functionality: measurement unit, switching unit and the communication unit, of the nodes to the size of a power outlet socket. The complete node has a power consumption of 280 mW.

2.2 Data Acquisition

Each load consumes a different amount of power and while doing this it generates its own load curve. A set of measurement values is always forwarded from the measuring node to the coordinator upon detecting the load changes,,

The coordinator sends the measurement values for further processing to the control unit.

For the energy measurement, an energy measurement chip from Analog Devices is used. The voltage and current signal are sampled with a sampling rate of 3.2 kHz at the ADC inputs of the energy measurement chip. Hence, having the energy network frequency of 50 Hz, 64 measurement samples are generated for each period. The chip offers the access to other values like: active power, the reactive power, the individual waveform samples and the RMS value of the current.

With a FFT analysis, the current harmonics of the current waveform samples are calculated on the chip as well.

2.3 Data Analysis

The load identification of the LoReMA System uses following energy measurement values: the active power, the reactive power and the current harmonics (only the odd form the 1^{st} to the 11^{th}). All parameters together form the energy footprint. The energy footprints are stored in a data base on the central unit. A detected load change is sent from the measurement node to the control unit, the algorithm of the control unit consults the database and seeks for the corresponding load, which matches the energy increase or loss best.

In order to process the device identification fast, the algorithm tries to distinguish between a state change of the appliance and start of new appliance first. The probability of a state change of an active appliance is higher. The database has the states of the appliance stored as well. This approach makes matching of the load change faster and more reliable.

2.4 Data transfer and control unit

Using ZigBee as wireless communication standard gives the opportunity of setting up a mesh network with the multiple nodes. Various decentralized measurement nodes get very easily connected by the mesh network capability of ZigBee.

The measurement nodes send their values from detected event changes to the network coordinator. The coordinator sends the values through wireless network to the control unit.

ZigBee Smart Energy Profile (SEP) is used in the RF-Frontend to communicate securely and reliably.

In our prototype the control unit has a simple user interface to show the current active appliances on a screen or on a smart phone.

The communication between the nodes and the control unit is bidirectional and the control unit actuate the power outlets. Using this feature, the standby loss in homes and offices can be brought to a minimum. With a corresponding building intelligence the behavior of the office users or habitants can be learnt and switching commands during night times can be sent automatically form the control unit. Not used infrastructure will be switched off and energy will be saved.

2.5 Preliminary Results

For the test environment the LoReMA System consists of a database of 15 different loads. This includes appliances of a typical household.

On our test bench hit rate of 95% with single appliances could be achieved (100 load changes). The system made incorrect assignments if load changes were unknown to the system or different appliances had very similar footprints. Multiple load tests are still in progress.

Variable loads are not possible to get identified but this fact is valid for the most of the NIALM methods and algorithms.

The used ZigBee Smart Energy Profile for the wireless communication does not support NIALM energy footprints. The SEP devices had to be misused for the NIALM purpose.

There is no public available energy footprint database. A database model must be defined.

3. Conclusion and future work

Various NIALM algorithms have their strength and weaknesses depending on the usage and goal to be met.

During our research activities it became clear that missing standards will make it hard to bring commercial success into NIALM products.

The closer measurement unit placed to the appliance, the better is the identification hit rate.

IEA 4E ordered a scoping study about NIALM at the iHomeLab research centre. The goal is to investigate in more details on NIALM when public and globally used. The following four questions need to be answered:

1) Investigate on international research activities about NIALM. Who are the leading universities and are there communities established?
2) What kind of standards and norming for the energy footprints are required to roll out NIALM for wide use?
3) What kind of communication standards is required and which standardization bodies can pick up NIALM?
4) What would be the best data model for a global database storing energy footprints? Who can host and maintain a global database?

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5. REFERENCES

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About the iHomeLab:

iHomeLab (www.ihomelab.ch) of the Lucerne University of Applied Sciences (HSLU) is the leading research centre for building intelligence in Switzerland. Connected within a broad network of experts, it also engages in international initiatives, contributes to scientific conferences and trade fairs and actively takes part in shaping new standards being a member of several organisations (e.g. ZigBee Alliance, KNX Scientific, and others). Together with its partners, the iHomeLab team of around 17 electrical engineers and computer scientists conducts funded applied research to increase the energy efficiency, security and comfort in residential as well as commercial buildings. The research strategy focuses on the three research areas energy efficiency (EE), ambient assisted living (AAL) and human building interaction (HBI) under the roof of the meta-research topic "The Building as a System". Applied research projects are conducted together with industrial partners and technologically focused on building automation network infrastructures based on low power wireless mesh networking technologies, indoor-localisation systems, plug'n'play / zero-engineering protocols. Further, the team has hands-on experience in the analysis, adoption, integration, deployment and test of building automation infrastructures. The **iHomeLab – Research Center** (www.ihomelab.ch) is supported by over 80 industrial and commercial partners, which range from device manufactures over infrastructure providers to health insurance companies. Main goal of the initiative is to promote the idea of the networked home, bringing together stakeholders of different disciplines, and underlying basic network infrastructure needed. In over 170 events conducted in the iHomeLab yearly the latest research results and new solutions of our partners are presented.

About the authors:

Stephan Tomek is a research group leader and senior researcher at the Lucerne University of Applied Sciences where he has received his degree of Informatics Engineer earlier. He has received his bachelor degree in economics at the FH Zürich. The last 20 years he spent in various industries like semiconductors, power networks, facility management and industrial automation with the focus on project management. The recent 8 years he worked for Schindler Elevators R&D, leading the hardware and software development team for high rise elevators. Currently, he is performing research and coaching projects in the field of building intelligence and smart homes with focus on energy efficiency, smart metering and demand side management at the iHomeLab Research Center (www.iHomeLab.ch).

Aliaksei Andrushevich is a software and IT technology coordinator and researcher at the Lucerne University of Applied Sciences. He has received his Master of Science in Embedded Systems Design from the University of Lugano in continuation to research in Radio-Frequency Identification. Previously he completed the 5-year program at the Faculty of Applied Mathematics and Computer Science, Belarusian State University, with focus on Optimization Algorithms. Currently he is working on his PhD in adaptive building management systems and performing research on algorithmic and optimization aspects of Embedded Systems, Wireless Technologies and semantic web technologies at the iHomeLab Research Center (www.iHomeLab.ch).

Pascal Walther is R&D Engineer at the Lucerne University of Applied Sciences. He has received his Master of Science in ICT and Buildings Intelligence from the Lucerne University of Applied Sciences in continuation to research on a load recognizing meter and actor project. Previously he completed the Bachelor of Science in electrical engineering. Currently he is working on a research project in the field of building intelligence and smart homes with focus on energy efficiency, smart metering and demand side management the iHomeLab Research Center (www.iHomeLab.ch).

Alexander Klapproth is a professor at the Lucerne University of Applied Sciences. He has a strong industry background, having been among others a systems engineer and head of firmware development group at Landis+Gyr, Switzerland. He is head of the CEESAR Research Center (www.ceesar.ch) and initiator of the iHomeLab Research Center – The Swiss Think Tank and Research & Open Innovation Laboratory for Intelligent Living (www.iHomeLab.ch). Partnerships with leading industry companies are grown on his profound experience in introducing emerging technologies into industrial devices. His research is centered around the topics Energy Efficient Building Automation, Ambient Assisted Living (AAL) and Human Building Interaction (HBI).