Doctoral School on Engineering Sciences
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Extended summary

New technologies for smart environments:

from Wireless Sensors Networks to Domotics

Curriculum: Ingegneria Informatica, Gestionale e dell'Automazione

Author

Massimo Grisostomi

Tutor(s)

Prof. Sauro Longhi

Dott. Ing. Gianluca Ippoliti

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Doctoral School on Engineering Sciences
Università Politecnica delle Marche

Abstract. The topic of smart environments, also called ambient intelligence, has been gaining more and more interest in recent years. The term ambient intelligence refers to the embedding of sensors and actuators within a room or an environment able to automatically react to users and other devices. The availability of small and inexpensive sensors, the growing diffusion of networking technologies worldwide, the availability of small computing devices available in homes such as smartphones, tablets and netbooks, make easier the development and installation of smart environments infrastructures. The thesis aim is to provide technological solutions to the ambient intelligence problem in order to make smart such ambient. The considered environments have been divided into two main categories: industrial and domestic ones. The focus of the first part of this thesis is on the integration of wireless sensor network (WSN) technologies in industrial applications. In particular the intelligent on line monitoring of a factory is presented to find real time performance indexes. The second case study presented concerns the automatic information harvesting in a resource recovery system. In addition it is also described the design of a novel prototype of a modular node which aims to overcome the problem of the standardization of communication in high customization level WSNs. The focus of the second part of the thesis concerns the use of different domotic technologies to equip home parts for a more intelligent and automatic monitoring and remote control. In particular, due to the large number of home automation devices and protocols and the differences between house to house, it has been developed a framework to integrate different devices with a Web based protocol. Furthermore it has been realized and validated a fuzzy logic home consumption model to test energy management and home automation control techniques.

Keywords. Ambient Intelligence, Domotics, Interoperability, WSNs.

1 Problem statement and objectives

Sensor networks have been widely used for many important social and scientific applications and their protocol design has received considerable research interest. In this context, the topic of smart environments, also called ambient intelligence, has been gaining more and more interest recently. The term ambient intelligence refers to the embedding of sensors and actuators within a room or environment that react automatically to the users or the machines within that environment [1-3]. The sensors are hidden from the user to become part of the environment and should not require the user to explicitly interact with the devices. These sensors could be in the form of thermometers, microphones, cameras, motion sensors, or any device that can provide information to an automated control system, a human or automated supervisor regarding the state of the environment. The control system can then use actuators to alter the conditions in the environment. These actuators could be a furnace or air conditioner to control the temperature, the lights or curtains within a room to control the lighting, etc. The ability of the environment to perceive and react to changes gives the home or office a sort of ambient intelligence.
The recent interest in smart environments can be attributed to several factors.

1. The availability of small and inexpensive network-aware sensors and devices that can be easily embedded in the environment.
2. The growing availability of networking technologies worldwide, such as Wi-Fi, Bluetooth, and power line Ethernet that allow these devices to communicate.
3. The availability of small computing devices available in homes such as smartphones, tablets and netbooks.

This availability of processors and network communication makes it easy to develop and install the infrastructure needed for smart environments. The present work aims to provide technological solutions to the ambient intelligence problem in order to make such ambient smart ones. The considered environments have been divided into two main categories: industrial and domestic ones. The focus of the first part of the work is on the integration of wireless sensor network (WSN) technologies in industrial applications, in particular a factory and a resource recovery system. In addition, due to the differences of the industrial applications, in this part it is presented the prototype of a novel modular node to overcome the node customization problem. The focus of the second part concerns the use of different domotic technologies to equip home parts for a more intelligent and automatic monitoring and remote control. In particular, due to the large number of home automation devices and protocols and the differences between house to house, it is often impossible to integrate all the desired features in a domotic system. It has been developed a framework to make possible the integration of different devices and an easy test of energy management and control techniques.

2 Research planning and activities

2.1 Industrial scenario

In industrial scenarios, wired solutions adopted to supply power and acquire information from sensors suffer of various problems, such as the need of complex, expensive, and often very difficult installation and the lack of flexibility in placing sensors, making harder the deployment of a sensor network. For these reasons the Wireless Sensors Networks (WSN) technology, widely studied in many universities and research centers in the last years [4-8], made significant progress and WSN-based commercial products have already appeared on the market.

WSN are complex system consisting of spatially distributed autonomous devices (the so called Sensor Nodes) collaborating to monitor environmental conditions. Design, implementation, and deployment of a WSN involves a wide range of disciplines and considerations for various application-specific constraints.

2.1.1 Modular WS node design

Nodes of a WSN establish wireless links and collaborate with each other to execute application tasks. Most of the existing commercial node architectures provide little flexibility and configurability (for example the TelosB, used for many research studies [9]). Daughter boards may provide sensing capabilities, but the processing and communication modules are fixed and cannot be extended. This limitation constrains the usability of the same node across various applications. In this stage a novel architecture for the design of a modular wireless sensor node is proposed, dividing the connection and sensing functions in two separate boards.

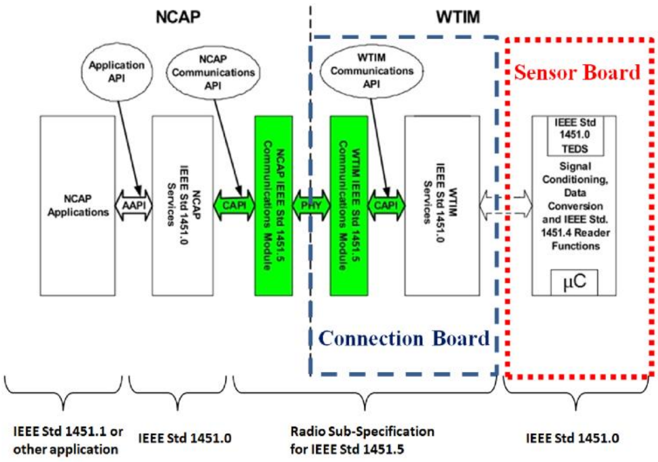

Figure 1. New network architecture and IEEE 1451 standard division.

The main design novelty presented is the division of the WTIM in two independent boards to perform in a separate way the connection and sensor interfacing function of the WTIM always respecting IEEE 1451 standards, as shown in Fig. 1. The connection board performs only actions involved in the wireless connection process with the NCAP node: it maintains in memory only the wireless related PHY TEDS and communication module commands. For what regards transducers related commands it acts as a gateway for the sensor board. The sensor board is equipped with another microcontroller to perform the remaining functions: transducers interfacing, signal acquisition and conditioning.

2.1.2 WSN based on line monitoring of a factory

Wireless sensor networks (WSNs) in factory automation bring an array of advantages over wired systems in terms of ease of deployment of the sensor network, elimination of complex and expensive installation, flexibility in placing sensors, and so on. This network system effectively solves the problem of the on-line monitoring of the plant and is useful for the evaluation of industrial performance indexes, such as manufacturing lead time, work-in-process, throughput and so on. In order to improve the effectiveness of a cell, it is important to recognize, measure and reduce losses. The most effective method is to analyze the overall equipment effectiveness (OEE) and the total effective equipment productivity (TEEP) of the cell. These indexes represent a measure of the value added to production through equipment, which is a function of machine availability, performance efficiency and the rate of quality. Those parameters are drastically reduced by losses, often caused by operator actions and equipment faults. In this application, a wireless sensors network has been designed and installed, based on IEEE1451 standard, to monitor a packing manufacturing cell, extract and analyze information about the single machines (fault rate, working time, and so on) and the overall production, as shown in Fig. 2. The goal of the work is to analyze equipment effectiveness with a low cost monitoring system, in order to inform company operators on its real value. A Web2Py framework is then used to gather data from sensors, store them and make them available to operators.

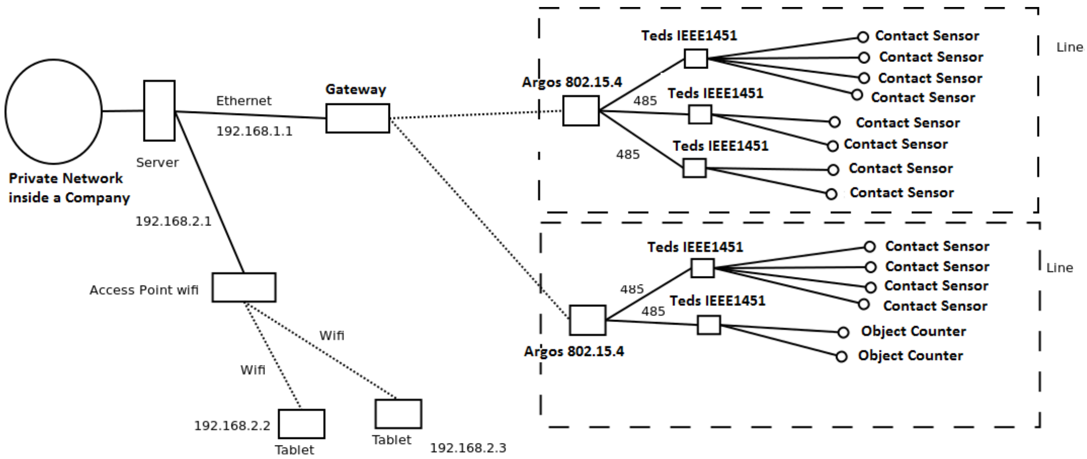

Figure 2. Architecture of the installed WSN

2.1.3 *WSN based Solid Waste Management Architecture*

In this section a solution has been proposed for the best path searching problem in terms of garbage bins filling prediction in a solid waste management scenario. An innovative solution based on Wireless Sensor Network has been developed to improve the garbage bins monitoring process. It represents the main results of Smart Ecologic Area (SEA) project, where several efforts have been done in order to create a system architecture easily adaptable to the different scenarios of the solid waste management (e.g. cities, small town, mountain resorts, isolated areas, etc.). The whole system has been designed to have physical architecture based on three layers, as shown in Fig. 3. The first layer is composed by sensor nodes, which need for the filling monitoring and provide short-range transmissions through RF technology. The second layer is composed by communication modules, which provide long-range transmission through GSM/GPRS. The third layer is composed by servers, which provide data storage and supervisor modules.

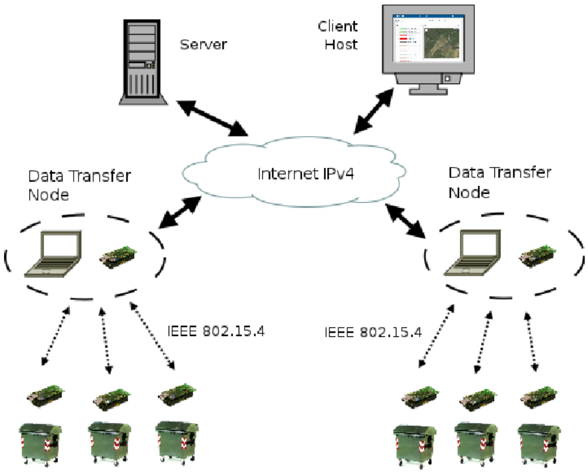

Figure 3. Proposed system Architecture

Taking into account the different scenarios, the components of the first layer provides several benefits within urban contexts by the use of the Industrial Scientific and Medical (ISM) bands, which allow low power transmissions without requiring a telephone operator subscription. For this solution a cost reduction of 50% has been estimated. The second layer acts as a bridge between sensor nodes and servers. It consists of GSM/GPRS nodes which provide long-range data transfers, ensuring the remote system monitoring and faults detection. Differently from the components of the first layer, the components of the second one provide benefits within remote and harsh geographical areas. Finally, the third layer consists of servers that provide data storage and data-mining solutions, ensuring the development of a Decision Support System (DSS). The DSS should be adaptable to the different operative contexts and should be able to extract consistent data from the database, in order to optimize the solid waste management process.

2.2 Residential scenario

In 1984, the National Association of Home Builders (NAHB) introduced the "smart house" concept. According to [10], smart means having the capability to autonomously collect and apply knowledge. In this scenario, a smart house needs information about its surroundings as well as about its internal workings. Those information have to come from multiple sensors in distributed locations, forcing researchers of all over the world to face this problem, see e.g. [11-12]. The automation of a building can be extremely expensive through the installation of a WSN, that's the reason why researchers focused their attention on domotic and home automation to bring intelligence inside a household.

2.2.1 Web based approach for domotic interoperability

In the actual worldwide scenario several constraints move the dream of a "smart house" far away from reality: the high cost of many systems, capacity problems, lack of standardization, etc. Among them the most worrying one is the absence of interoperability between commercial systems. Nowadays in all the hottest markets the compatibility between systems plays a crucial role for their success and for the development of the involved technologies. The concept of interoperability can be defined as the transparent compatible connection between equipment from different manufacturers. In this work an interoperability framework for home automation system has been developed following the IP-based approach and exploiting the capabilities of OpenWebNet protocol. One of the novelties proposed in this approach is the combination of the web of things concept (with an IP-based strategy), an open solution (with the use of an open protocol) and a commercial view of the problem (the protocol is already on the market and allows communication with home automation devices provided by bTicino). The framework consists of a real and a virtual environment: the real setup includes commercial devices connected to a central gateway whereas the virtual environment has been developed as a LabVIEW toolkit.

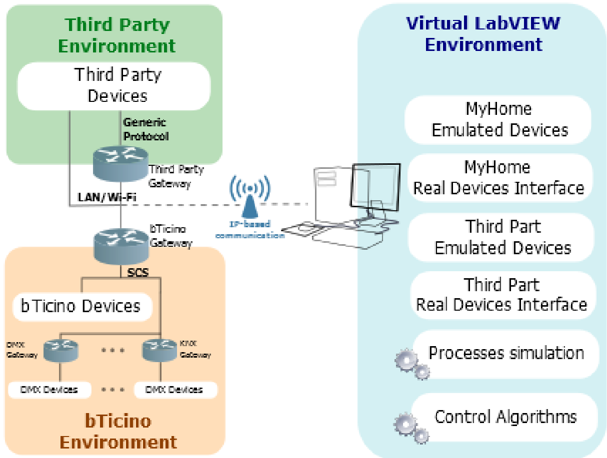

Figure 4. Interoperability framework structure

The interconnection of the environment is IP-based, exploiting the capabilities of the selected gateway. The aim of the work is the development of an hybrid environment coming from the extension of a real and completely working real home automation setup with a transparent emulated environment. The purpose of this environment is to provide a functional tool to speed up the design of an interoperable home automation system, allowing the test of different control algorithms for both emulated and real devices in the same smart house.

2.2.2 Household consumption modeling through wireless sensors

The importance of energy management in households is widely recognized all over the world. There are increasing numbers of studies on smart homes, on the benefits of demand-side management and identification of energy consumption pattern [13-15]. Most of the existing models and analysis found in literature focus on data from a specific region under investigation, and try to explain the results in a local perspective [16-17]. Based on the typical appliance's patterns for each household, it is possible to simulate future energy demands, planning Energy Management actions in domotics environments and designing proper Demand Response techniques. Since the total load profile shape will vary from day to day and house to house, there's a real need for a simulator that can easy represent the household consumption. The approach proposed in this section to model and simulate electrical consumptions for each different household is based on wireless sensors measures taken from appliances (see Fig. 5) and a Fuzzy Inference System algorithm (see Fig. 6).

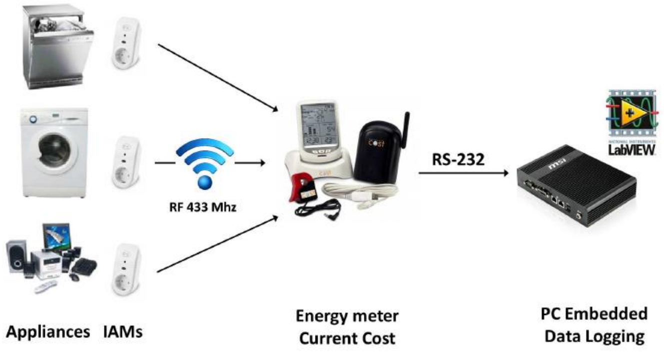

Figure 5. Measurement acquisition architecture

The main differences with respect the other models proposed in literature by [18-20] is the possibility to easily customize this model and adapt it to every household without acquiring a large amount of data. In fact it is possible to add in the model every kind of appliance and customize the use of the existing ones changing only the fuzzy rule set.In this work we developed a model using a "bottom-up" approach, according to those proposed by [18]. The basic building block is the appliance, i.e. any individual domestic electric load, such as a television, a washing machine, a dishwasher. The modeling of the appliance's usage has been performed with a linguistic fuzzy inference system to determine if whether or not it is going to be started. The usage pattern, depending on the appliance's category, can be related to many variables, such as the number of active people in the house, the typical frequency of the appliance, the time of the day, the temperature.

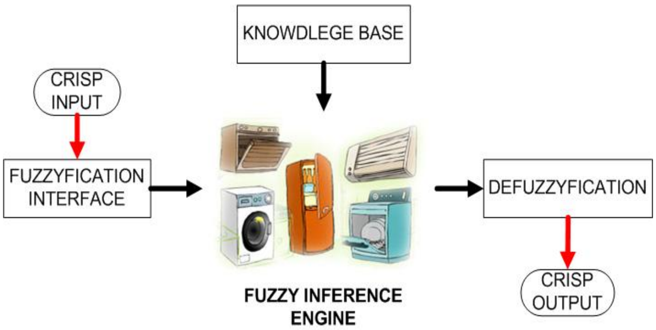

Figure 6. Fuzzy system architecture

3 Analysis and discussion of main results

3.1 Industrial WSN applications

A possible solution for solid waste management has been proposed through the use of a wireless sensor network [21]. Long-range communication modules collected data concerning the bin's filling and sent them to a remote server where operator controls the state of the system. Several efforts were done for the whole system optimization: the increasing of sensor node's battery life-time, in order to reduce maintenance, the improvement of electromagnetic shielding interfaces, in order to reduce interferences, the improvement of remote querying efficiency and robustness, the improvement of the GUI adaptation to the local administrations needs.

A WSN has been also introduced in a manufacturing cell to provide an on-line monitoring [22].
The cell was monitored over a period of 4 weeks between June and July 2013. During this period 4 different product lines were made and all the activities such as stoppage, speed reduction, set-up/adjustments, quality impaired and reworks were recorded for all the machines in the cell. A direct communication with the server is used to collect data from all the sensors installed. The true performance of the equipment productivity is measured by total effective equipment productivity (TEEP), and is a combined measure of equipment utilization (which includes planned downtime) and OEE to reflect the true quality and effectiveness of the equipment when running as reported in Table 1.

Table 1. Effectiveness indexes computed for the different production lines.

Data Type	Line A	Line B	Line C	Line D
Actual Availability	74, 4%	43, 6%	70, 1%	65,5%
Utilization	93, 0%	65, 6%	94, 0%	89,7%
Performance Efficiency	99, 8%	99, 4%	99, 8%	99,6%
Rate Of Quality	99, 9%	99, 4%	99, 9%	99,7%
TEEP	74, 2%	43, 1%	69, 9%	65,1%
OEE	69, 0%	28, 3%	65, 7%	58,4%

Since the low index for the B line could be explained with the working time spent to set-up machines and change tools due to customization required by the customer, managers decided to limit customizations offered to customers.
A novel modular prototype of a wireless sensor node has been designed following IEEE 1451 standard. The node is composed by two main boards, related to the connection and the sensor interface respectively (as shown in Fig. 7).

Figure 7. Prototype of the novel wireless sensor node

The main purpose of this design is to standardize the communication for the entire sensor network (thus reducing industrial cost of this part) giving on the same time the chance to use a wide variety of sensors.

3.2 Home Automation

The interoperable home automation framework made up by virtually emulated and real commercial devices has been developed to enable vertical solutions in different and multifunctional (energy, security, comfort) applications. The framework has been realized using an open web based protocol (OpenWebNet). The opportunities provided by the virtual framework addition have been presented in terms of design, testing, processes simulation and control algorithms development.

Figure 8. Experimental setup and software implementation of the framework

Second a novel Fuzzy approach to model household electrical consumption has been presented [23]. The model has been validated with electricity demand data recorded over the period of 12 months within 12 dwellings in Ripatransone (AP), in the central east coast of Italy (a sample is shown in Fig. 9).

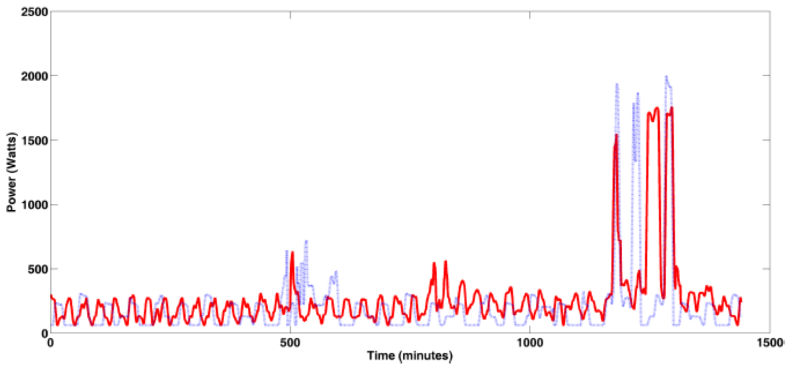

Figure 9. One day simulated (red line) and measured (blue line) consumptions for a household

The model shows a good performance simulating the energy behavior of the households (less than 18% RMSE hourly error), moreover for what regards daytime period (9%) making possible its use for Demand Response planning, PV plant's sizing and Energy Management actions.

4 Conclusions

In the first part of the work wireless sensor networks have been used to add intelligence in industrial systems, in particular a solid waste management system and a line production.
In the second part different domotic technologies to equip home parts for a more intelligent and automatic monitoring and remote control have been presented, in particular an in-

teroperable framework to integrate different home automation products and a household electrical energy model.

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