An Intelligence-Based Tool for Energy Management by Device Interoperability in Smart Houses

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***Abstract* — The recent developments in Information and Communication Technologies (ICT) and Internet of Things (IoT) make several house devices cooperate to each other to achieve higher energy performances and offer new services. However, the increasing embedded intelligence of smart devices is also generating a huge quantity of data, which must be properly managed. In fact, it is difficult to easily manage data to make certain functions available and to define a strategy for results maximization. This paper defines a methodology to improve smart home information management based on the selection, aggregation and classification of the sensible data and the correlation with the device typology, nature, and destination of use. Furthermore, a case study focused on washing machine is presented to demonstrate how this methodology can be implemented to realize a supporting tool encouraging service ideation to benefit the different subjects involved. The proposed model represents a first step towards the creation of a standard for smart house information management and device interoperability.**

Keywords - Smart houses; Smart information processing; Smart energy and optimal consumption; Intelligence-based service design; Device Interoperability.

I. INTRODUCTION

The actual growing world energy demand and the high attention to environmental impact reduction are generating a strong convergence of scientific, industrialists and politicians interests towards the use of Information and Communication Technologies (ICT) tools to support a more efficient use of the energy resources. In this regard, the concepts of "Smart Grid" and "Internet of Things" push a radical technological change where objects cooperate to achieve high-level objectives. They create a continuous flow of information that can be used to support real-time decisions, optimize the use of resources and increase safety and quality of life. Their application is particularly significant if considering that actually the residential sector is responsible for about 20% of total consumption and system usually operates without any users' cooperation.

Nowadays, the rising intelligence of smart devices can make a large amount of information available every day about personal actions as well as events taking place at home or outside. However, bad information management and difficulties in capturing and effectively transmitting essential data as well as interpreting such useful information for end-users, may drastically reduce the potential benefits and not encourage the diffusion of smart homes [1]. Therefore, a dedicated supporting tool must be designed and developed aiming to efficiently manage information on the basis of the users' purposes and ensure all the connected devices to be really interoperable. This scope is still an open issue in smart home system design [2].

The paper proposes a methodology to generate an innovative tool able to intelligently manage smart devices information in order to make them interoperable and provide tailored services to final users. It has been conceived for domestic environments, but it could be translated also in similar contexts. It provides to properly catalogue home devices and all the generated information, and it suggests how to realize an interoperable system able to implement home devices interoperability based on the correlation between system information categories and device classes. Furthermore, the paper adopts the proposed methodology to support a real use case focusing on washing machines: it allows identifying how to properly manage information for energy efficiency and how to provide a set of additional services according to the specific user needs.

The remainder of the paper is organized in four sections. Section II provides a quick overview on the state of the art of information management in smart houses. Section III describes the methodology steps and presents the information devices classification. Section IV illustrates the use case supporting the tool rationale definition for washing machine smart energy management.

II. BACKGROUND ON INFORMATION MANAGEMENT IN SMART HOUSES

Over the years many definitions of smart home, also called smart houses, have been proposed [3]. The basic definition defines the smart home as a special home where all the sub-systems (lighting, security, household appliance, sensors, etc.) are interconnected allowing the homeowner to save energy, to reduce operating costs and to improve safety, comfort and multimedia services. In recent years, the technological research has focused on sub-systems integration, leading to the rapid growth of residential gateways [4]. Thanks to a gateway, domotic solutions have the ability to manage all the devices connected to the home area network.

A considerable amount of new solutions for the smart home automation have been recently developed, i.e., several systems with different communication protocols and architectures. Existing systems can be classified into two groups: open systems and proprietary systems. The former, defined as "standard", are systems whose operating specifications are public to give companies the possibility to develop compatible devices. Well-known examples are: Konnex [5], Lonworks [6], Zigbee [7]. Proprietary systems are produced by software houses, which usually keep technical information as reserved and make them not available to third parties. Some examples are electrical and home automation systems: SCS by Bticino [8], Vimar By-Me [9], C-BUS of Schneider Electric [10].

The availability of common rules is fundamental to make devices interoperable when they are produced by different manufacturers [11]. It is expected that in the future home automation systems will be based on a single standard facilitating smart home management. However the issue of interoperability is particular challenging due to the huge amount of data to manage and the level of complexity of the devices' integration in the home area network. The introduction of smart appliances within a home network is not a new idea. However, it requires a more deepen investigation in respect with the actual strategies to achieve an efficient energy management. In particular, it entails understanding which functions a certain device is able to perform when connected to the network, what information can be sent and what for, and which commands must be received. In this context, the project CHAIN by the European Committee of Domestic Equipment Manufacturers (CECED) faced device interoperability issues and established a preliminary application profile for home connected, promoting the standard European Committee for Electrotechnical Standardization (CENELEC) in 2007 [12] [13]. However, the issue of interoperability between different home appliances is still open. Although numerous researches recently proposed different system architectures to obtain an integrated interoperable system, the existing system do not define an overall and unique standard data management tool, that is still missing. Actually, the majority of projects are focusing on the energy issue [14]. The most significant are: Smart Energy 2.0 (USA) [15], Energy@home (Italy) [16], EEBus/E-Energy (Germany) [17] [18]. All of them focus on network energy management via data exchange with smart grids and do not care about data elaboration and mining addressing high-level services. Indeed, the existing systems are finalized to provide a specific benefit or service such as monitoring, analyzing and estimating the energy consumption [19], even if they have great potentiality to be exploited for several purposes. Therefore, they have the advantage of introducing standard rules for the information exchange between the users and the utilities.

In addition to energy information management, many other services could be integrated thanks to the existing technological infrastructures. However, there is a lack of an overall vision and a strategic roadmap for future developments. Services related to devices remote control have been proposed but there are some open issues regarding their implementation on the white goods [20]. Also appliances remote maintenance concept is studied to provide benefits for both users and companies, but it has been considered as a concept independently of any architecture and available tools capabilities [21].

For this reason, the paper aims to identify and classify the involved information and defines the tool rationale to support service ideation satisfying the needs of the different subjects involved and achieving bigger advantages. The classification proposed aims to provide an overall vision of the smart house as a whole, able to consider all information necessary to include different services cited and encourage their continuous improvement. The idea to create a smart management tool supporting an integrated system also paves the way for companies to carry out market analysis and service tailoring, which are still ignored in this context. Furthermore, a possible innovation is represented by the use of the information generated by white goods for the elder people assistance, which is currently not exploited for such scope.

III. Research approach and system architecture

By definition a smart home has a lot of smart devices connected to the Home Area Network (HAN), which collect and/or exchange information about some specific aspects. The research approach aims to guarantee the classification, aggregation and selection of all the information according to the device typology, and identify a strategy to manage all the involved information by an intelligence-based information management tool. The proposed approach consists of five main steps:

1) Classification of smart home devices into a set of homogenous classes (for typology, treated data, home interaction modalities, etc.);

2) Definition of a possible system architecture able to effectively realize the desired information management and device interoperability;

3) Identification of a general information management model characterized by information categories that are significant for the smart home;

4) Correlation between device classes and information categories to match their specific funtioning with the general information management model;

5) Definition of a set of application rule, to be impemenented intelligence-based information management, to design services on the basis of the users' needs.

A. Smart home devices classification

The most popular devices in smart home have been analyzed and classified into a set of homogeneous classes as follows.

Meters: this class includes electricity, gas and water meters, whose data are communicated through the home network and the smart grid. Control and safety systems (e.g. electrical safety, gas leaks, water leaks) are included in this category. Indeed, it is possible to detect gas or water leak in

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real time and, consequently, shut off the corresponding meter remotely.

Consumer electronics: it includes entertainment systems (e.g., tv, game console, audio equipment and players) and small household appliances (e.g., coffee makers, electronic cutters or graters, toasters). They typically have low and constant energy consumption and can be easily switched off/on by a remote control without any preventative measures. For this category the power consumption can be simply monitored as well as its usage (e.g., when and how long they are used; state of devices to allow a remote control).

Household appliances: it includes the major household appliances grouped as cooling (refrigerator and freezer), cooking (oven, hob, and hood) and laundry (washer, dryer, and dishwasher), enhanced by some items: to be interoperable, they require a microcontroller [13] that manages the processes during the automatic operation mode as well as the remote control mode; to be connected to a home network, they need a communication node that it can be installed on board or located outside (e.g., a cheaper solution has been developed by Indesit Company, called "Ultra-Low cost Power-line" (ULP) [22]). The communication node can also contain the energy control technology (e.g., Dynamic Demand Control (DDC) [23]).

Lighting, doors/windows, and security: it comprehends common classes of components such as lighting, doors, windows, window curtains and shutters. All of them can be controlled by similar functions (e.g. turn on/off, intensity regulation, opening/closing control, opening regulation). This category also includes the intrusion detection sensors for doors and windows of a generic alarm system. Information characterizing these devices is typically used for remote control and interaction analysis. In particular, thanks to motion sensors for automatic light switching, it also allows users to be localized and abnormal behaviors to be detected by recording the user's movements. It may be useful for Ambient Assisted Living (AAL) scopes to improve safety and human health.

DHW and HVAC: it includes Domestic Hot Water devices (DHW), Heating, Ventilation and Air Conditioning devices (HVAC), and all the devices and sensors related to their functioning, even when located in different areas or on other devices (e.g., sensors of indoor/outdoor temperature, humidity sensors, etc.).

B. *Smart home interoperable architecture*

The creation of an interoperable system able to mutually control all the devices and properly manage all the necessary data requires: a) the physical device connection to an HAN and b) the communication infrastructure. These items guarantee to deliver all the collected data to a central management tool and make data available for other systems or services (e.g., data analysis and data mining applications, user monitoring, remote control).

The existing physical connections have different capabilities in terms of distance, speed and volume data transfer. The list below shows the physical media that can be actually used in the smart home for interoperability purposes.

Power line: it can be realized by exploiting the existing house wiring that supplies all the electrical devices and the Power Line Communication (PLC) technology. Since every home already has it, power line is convenient and does not require any additional wiring. The most common communication standards for power line are X10 [24], HomePlug [25], and LonWorks [6]. However interference and noise issues inherently occur [26].

Phone line and other wiring: it includes all the other wirings of the smart home, such as twisted pair, coaxial cable, fiber optic and others. They allow managing high bandwidth and huge quantity of data, as required by entertainment systems. Wired communication through these connections is more stable than the wireless one, as it is less subject to external interference; however it entails higher costs. Some wired communication standards are Ethernet, USB, and HomePNA.

Wireless network: it uses electromagnetic waves to connect devices and send/receive information. It is practical because it allows connecting numerous devices in an easy way, also including devices not connectable by a physical cable. However, there may cause some problems due to the signal propagation (i.e., distance, presence of physical barriers and interferences). Well-known wireless communication standards are ZigBee, Wi-Fi, and Bluetooth.

As far as the creation of a unique communication infrastructure is concerned, it is worth to consider that each device has different requirements in terms of connections and communication protocols and a residential gateway is required. The gateway concentrates all data and serves as a bridge between the HAN and the Internet to exploits other systems or web services [27]. The user interface can be local (e.g., system display) or remote (e.g., web application or smartphone app). The user will monitor home conditions, control the devices and be informed about specific. Furthermore also utilities and companies can access some data transmitted from the smart home, according to the privacy policy, for specific services (e.g., remote assistance).

The described architecture represents a valid structure to implement the methodology and tool proposed in this paper.

C. *The system information management model*

Such a complex architecture requires managing a large amount of data derived from home devices, understanding their explicit and tacit relationships, and identifying a set of algorithms to realize functions and services. For these purposes all relevant information has been classified and algorithms investigated. In this context, several classification criteria have been already proposed [28] [29]. However the proposed model merges theoretical studies and industrial experience and has been validated by practical cases to satisfy the research goals. The model is based on four information categories and their correlation with the devices classes as presented in Table I. The selected categories are described below.

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TABLE I. CORRELATION MATRIX BETWEEN SYSTEM INFORMATION CATEGORIES AND DEVICE CLASSES

			DEVICE CLASSES						
			Meters	**Consumer electronics**	**Household appliances**	**Lighting**	**Doors and windows**	**Security**	**DHW and HVAC**
INFORMATION CATEGORIES	**Continuous monitoring**	Ambient light level				x	x		
		Gas consumption	x		x				x
		Outdoor temperature					x		x
		Power consumption	x	x	x	x			x
		Rooms humidity							x
		Rooms temperature					x		x
		Video surveillance						x	
		Water consumption	x		x				x
	User interaction	Interaction time		x	x	x	x	x	x
		Scheduled on/off time		x	x	x			x
		Scheduled open/close					x		
		Set extra function			x				x
		Set light brightness				x			
		Set program			x				x
		Set speed			x				x
		Set temperature			x				x
		Shutting on/off time	x						
		User presence				x	x	x	x
	Control parameters	Air quality			x				x
		Air temperature			x				x
		Burnt out bulb			x	x			
		Component parameters			x				x
		Cycle time			x				
		Door lock			x				
		Electrical overload	x						
		Flow rate	x		x				x
		Intrusion detected						x	
		Noise level		x	x				x
		Pressure	x		x				x
		Short circuit	x						
		Water temperature			x				x
	State parameters	Cycle in progress			x				
		Light Brightness				x			
		Load presence			x				
		On/Off	x	x	x	x		x	x
		Open/Close			x		x		
		Opening rate					x		
		Standby		x	x				x

Continuous monitoring category: it includes all the information that is continuously monitored when the appliances are turned on. They mainly consist of resources consumption data (e.g., energy, water, etc.). They are used to provide a direct feedback to final users, who are encouraged to make a more efficient use of energy as demonstrated by recent studies [30].

User interaction category: it refers to all the information regarding the user-product interaction and characterizing the users behaviors (e.g., selected options, duration of use, time of use, frequency, etc.). Generally, data are aggregated for statistic analysis to define significant user profiles or frequently events as well as for marketing analysis. Data are usually sent when required.

Control parameters category: it comprises all data referring to the functional device parameters, which serve for supervising the device function or the user security. They are continuously analyzed and compare with a set of target parameters to predict a problem or detect dangerous conditions. Generally, they are forwarded to companies or service providers when a specific threshold is exceed.

State parameters category: it refers to all information regarding the device state in a particular scenario and carrying out the remote control.

The classification can also include two extra categories, which are not directly linked to the devices but they are from other entities. They are:

External data: they are generated by external entities but provide useful information about the scenario (e.g., building typology, occupants' characteristics, economic indicators, fees of utilities, climatic conditions). Also reference information (e.g., datasheets, standard consumptions, etc.) about the smart appliances provided by the manufactures can be included.

Derived data: they are obtained by other data elaboration such as statistics analysis and post-processing for realizing specific service functionalities (e.g., average time of use, average expenditure over the time, use frequency of a particular function).

IV. USE CASE: WASHING MACHINE SMART ENERGY MANAGEMENT

This section presents how the proposed approach can be implemented and how an energy management tool can be used for supporting washing machine use. The case study focuses on household appliances that represent one of the most challenging class since they combine mechanical, electrical and IT parts and having a strong interaction with the final user. As a consequence, the use case allows testing the approach in a complex scenario by using the proposed tool to manage a huge quantity of information and to delivery some related services. Among all white goods, the use case focuses on washing machines that are probably the most common appliance.

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The first step was classifying all the information provided by the *washing machine* item. The second step was defining how to manage each specific data for each information category. The model application to the use case is shown in Figure 1.

Continuous monitoring data are monitored in real time and their management is mainly finalized to improve the use of energy resources and save money. Final users can compare real consumptions with the target ones, view and analyze historical trends, see how they evolve over time, and receive useful advices by exploiting also *External data* (e.g., how to use the washing machine to save energy or when to use it to save money according to the energy fee policy or providing interesting commercial offers on the basis of the user's needs). Furthermore, grid frequency information is useful to implement the DDC technology [23] and utilities could encourage this solution by rewarding users with cost reduction.

User interaction data monitoring allow companies analyzing how their customers act, which programs or functions are more frequently selected, and whether a specific product feature is successful as expected. The analysis of the users' habits can also support the definition of new functions and product options. Indeed, household appliances are generally optimized according to the standards and the customer habits, but real data can confirm or rebut such preliminary statements. Standard market analyses do not always provide truthful and accurate data because they depend on sample users' collaboration and personal subjectivity. In the use case, statistics will be based on the observation and direct analysis of user-product interaction. Such information are used by manufacturing companies and service providers: the former can identify a set of user profiles and optimize their products for each of them, and the latter can conceive and propose services according to their effective needs. Combining this information with *External data* (e.g., number of people, location, profession) allows characterizing users according to different parameters to improve the company strategies by low cost investments. Data concerning user interaction can be also analyzed to extract relevant information useful for elderly assistance to evaluate their quality of life and ensure their independence. For example, changes in user behavior or loss of abilities (memory problems, oblivions, etc.) can be detected by monitoring wrong actions and/or forgetfulness. Furthermore, users may be guided to choose the best washing program according to the clothes typology.

Control parameters allow directly interacting with devices at work for different purposes. For instance, corrective maintenance can be replaced by more accurate preventive or predictive actions. Manufacturers and users can agree to obtain mutual benefits: the company staff monitors some specific parameters to prevent failures and observe the appliance behavior to improve the product itself; contemporarily users have a continuous assistance and benefit from the reduction of product failure rate and downtime, and from a lower product consumption. It can support observing a malfunctioning, which is usually not detected also for a long time while product consumptions increase. In the use case, monitoring the selected parameters allows analyzing cycle execution and verifying if performances are good as desired. When real data exceed the defined thresholds, the manufacturer (or the technical assistance company) is noticed, predictive maintenance actions are scheduled, and the user is informed.

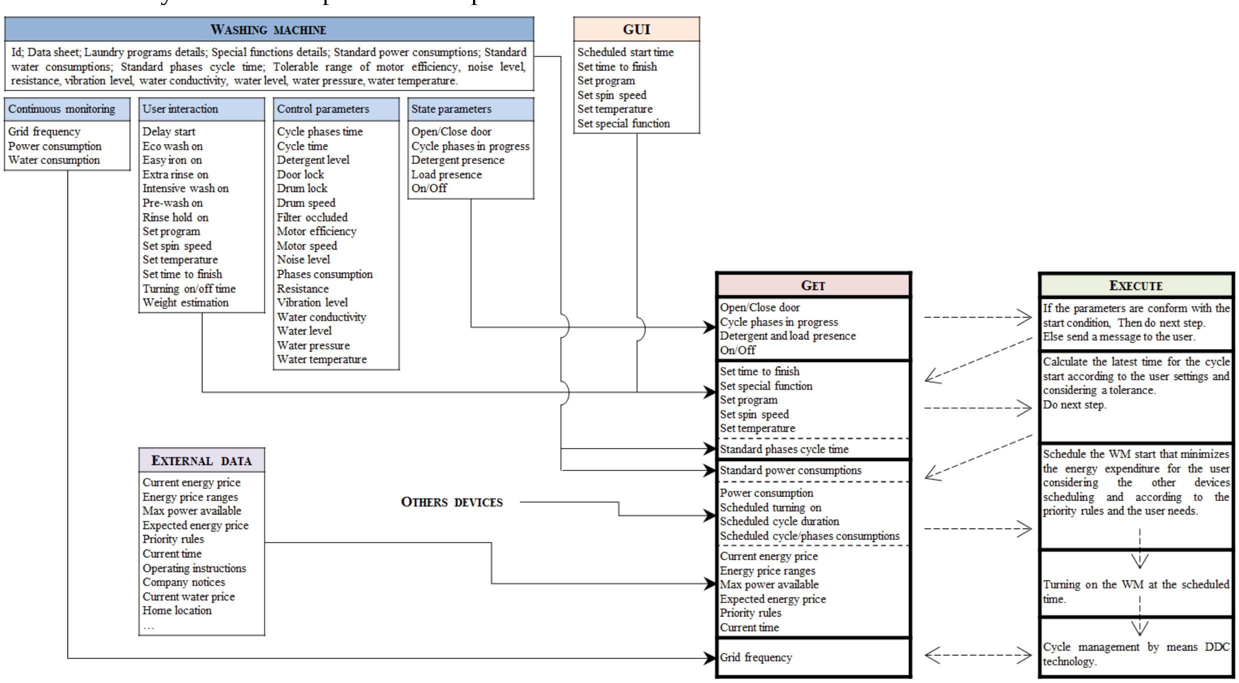

Figure 1. Tool rationale to schedule the washing machine start.

The proposed tool also facilitates the implementation of device remote control, which is a crucial aspect to guarantee people safety and comfort. The customer can visualize whether and how the machine is working at home, and remotely start, stop or change the washing program. The *state parameters* information is the basis to realize such a service. In fact, to do the remote control, the washing machine door has to be closed and system has to know if there is a cycle in progress. Furthermore, it is favorable to know if the load or detergent is not present in the machine in order to the remote control is not activated unnecessarily. Figure 1 presents the tool rationale and shows how the proposed model has been implemented for the use case. Identification of the user needs and system goals represents the first step for the development of the rationale behind the tool. For the proposed use case, the goal is scheduling the machine start to minimize the cycle energy cost according to the user's preferences. The user can select the *set time to finish* and the laundry cycle settings directly on the washing machine control panel or through the GUI. According to the information received and read, grouped in the GET table, the tool performs the actions described in the EXECUTE table to achieve the expected purpose.

V. CONCLUSIONS AND FUTURE WORKS

This paper presented a methodology to improve smart home information management promoting device interoperability. It allows classifying data originated by different smart appliances and matching them with an information management model to propose intelligence-based services. The research represents the first step to create a standard for information management and system interoperability, which can be applied also for other applications. The use case focused on washing machines and shown how to intelligently control data to save energy and provide energy-based services. Future works will consider a more detailed information asset, a wider devices' classification and will assess the achieved benefits by Life Cycle Assessment (LCA) and Life Cycle Costing (LCC). In this way, a more reliable methodology will be defined and a more robust aggregation of data will be managed. The proposed tool paves the way to the creation of standard systems the future smart home.

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