User and home appliances pervasive interaction in a sensor driven Smart Home environment: the SandS approach

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***Abstract*—EU FIRE research project "Social and Smart" aims to formalize and build a complete ecosystem of users, context sensors and smart home appliances that interact following the ubiquitous computing paradigm in order to adapt and enhance the everyday user-appliance interaction. In this framework a user is modeled through the use of Personas stereotypes. Contextual information is collected via wireless ambient sensors, such as temperature and humidity ones, but can also include Smart City sensors and services. This contextual information is further related to each user's model through the enforcement of home rules, expressed in a high level language. Knowledge representation is supported through Semantic Web technologies that also ensure the interoperability between all the actors of the ecosystem. Preliminary experimental results have been carried in a small scale Smart Home setting, but also in a larger scale using the FIWARE[1] framework provided by the SmartSandander testbed.**

Keywords*—*Pervasive Computing, Smart Homes, Sensors, Context Awareness, Semantic Interoperability, Smart Cities.

I. Introduction

Filling a home with sensors and controlling devices by a computer is nowadays not only possible, but it is commonly found in homes [1]. Sensors are available off-the-shelf that localize movement in the home, provide readings for light and temperature levels, and monitor usage of doors, phones and appliances. Small, inexpensive sensors are attached to objects not to only register their presence but also record histories of recent social interactions. At the same time, in order to incorporate social contextual real-life interactions via sensors, the Human-Computer Interaction (HCI) area has widen its scope considerably, placing the human-user in the center of a continuous interaction with smart objects and appliances [2]. The latter are identified as Internet resources and are utilized as such, within the pervasive environment of Smart Homes.

So far, the scope of most applications or services w.r.t. smart homes have focused on the concept of small regions, such as hospitals [3], where according to the level and type of contexts along with the goal of context-aware systems, the context modeling process, the inference algorithm and interaction method of personas [2] are modified. Although interaction between personas and cooperation among components of the same architecture have been investigated, to date, a standard interaction, cooperation and operation in the different context-aware system has not been studied.

At the same time, in the areas of ubiquitous or pervasive computing, collected contextual information may be considered as information used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including location, time, activities, and the preferences of each entity. A user model is context-aware if it can express aspects of the user's contextual information and subsequently help the system adapt its functionality to the context of use. Nevertheless, to provide personalized services to user models according to user preferences, task and emotional state of user, the cognitive domains such as situational monitoring are needed; so far few authors have addressed utilizing the cognitive elements of a user's context and the semantics of the relations between the user and the system's entities [4]. Still, several researchers have proposed models to capture the internal elements of context. Different from previous works, our objective is to specifically target to formalize and build a common context-aware architecture system in which the user ("eahouker" in SandS) will be able to control his household appliances in a collective way via the SNS (Social Network Service) and in an intelligent way via the adaptive social network intelligence.

[1]http://www.fiware.org/

[2]Humans known as personas for computational representation purposes.

As our system is human-centered the UM (User Modeling) is related to the user's activity inside the ESN (Eahoukers Social Network), while the context aware environment refers to the contextual information that characterize the situation and conditions of the system's entities. Finally, the modeling of the contextual information is completed through the capture of the semantics of the relationships between the user and the various entities of the ecosystem (other users, appliances, recipes) to further improve the overall user experience. The semantic description framework of our proposed approach, is based on a number of home rules that are defined for a specific household and eahouker. Since the SandS architecture consists of two layers, high and low, respectively, we have on the one hand recipes for common household tasks produced and exchanged in the SandS Social Network that are described in near natural language.

Additionally, on the other hand we have every user's context which consists of the actual appliances that the user has in house with their particular characteristics (type, model, brand, etc.). To ensure executability and compatibility of a recipe and to deal with any uncertainly and vagueness in the process of modeling the contextual information, a number of axioms are imposed, so as to enforce constraints on all objects ("things" in the IoT paradigm) of the ecosystem; the latter were introduced within the proposed Web Ontology Language (OWL) representation adopted. Experimental results for the above framework are presented herein that have been conducted inside the "SandS"[5] system, which aims to highlight the potential of IoT technologies in a concrete user-centric domestic pervasive environment. Large scale experiments are planned at SmartSantander [6], a city-scale experimental research facility in support of typical applications and services for a smart city, comprising a very large number of online ambient sensors inside a real-life human environment.

The remainder of this paper is structured as follows: we discuss corresponding user modeling in section II and further introduce context-awareness in HCI along with the collection of ubiquitous data in section III. The semantic representation and the experimental results will be analyzed in sections IV and V, respectively, with related conclusions derived and presented within section VI.

II. User Modeling

User modeling is the process through which systems gather information and knowledge about users and their individual characteristics. Therefore, a user model is considered a source of information about the user of the system, which contains several assumptions about several relevant behavior or adaptation data. Approaching user modeling from the HCI perspective, there is the potential that user modeling techniques will improve the collaborative nature of human-computer systems. During the last 20 years, there has been a lot of work done in this area. Authors attempted to cover all possible scenarios through the development of different definition for users and user modeling approaches respectively.

Reviewing how "user models" term has been approached, within HCI literature, it is indicated that users are part of an enlarged communication group in which users change through time and according to the environmental conditions and the experience they gain. Thus, in the end, there are three types of users: "novel", "intermediate" and "expert". Another more oriented work, is that of [7], as it focuses on the specific group of elderly people with none, one, or more than one disabilities respectively, whose needs and capabilities change as they grow older underlying the need for having more diverse and dynamic computing systems for modeling users. A few years later, in terms of having rich adaptive output information, ontology-based approaches have been used for the design of the "Ec(h)o" audio reality system for museums to further support experience design and functionality related to museum visits.

Based on ontology approaches to characterize users capabilities within adaptive environments, in 2007, the GUMO ontology has been proposed [8]. The latter takes into account the emotional state, the personality, the physiological state of the user and particularly stress. Five years later, Evers and his colleagues [9] implemented an automatic and self-sufficient adaptation interface to measure the user's stress levels. The "Persona" concept has then been introduced to distinguish between different user groups within an adaptive user interface domain. These "Persona" concepts have been proved really useful as a wide range of potential users could be covered by assigning random values to characteristics, such as: age, education, profession, family conditions, etc.. From a computational perspective, using "personas" is a quite common approach in UM due to its correlation with the actors and roles used in software engineering systems, its flexibility, extensibility, reusability and applicability [10]. It is thus observed, that from product design to multimedia and user interfaces adaptation, the approaches described above, even though they differ a lot with respect to the collected personal data characteristics which use to improve the system and user's satisfaction, still share the same goal. For a more extended review the reader is directed to [11].

III. Context

As social interaction is an aspect of our daily life, social signals have long been recognized as important for establishing relationships, but only with the introduction of sensed environments where researchers have become able to monitor these signals. Hence, it is possible to look at socialization within the smart home and cities and examine the correlation between the socialization parameters and productivity, behavioural patterns or even health. These results will help researchers not just to understand social interactions but also to design products and behavioral interventions that will promote more socially real-life interactions.

A. *Context aware in HCI*

In everyday social contextual situations, humans are able to, in real-time, perceive, combine, process, respond and evaluate to a multitude of information including semantics meaning of the content of a interaction, non-verbal information such as facial and body gestures, subtle vocal cues, and context, i.e., events happening in the environment. Multimodal cues unfold, sometimes asynchronously and continuously express the interlocutors' underlying affective and cognitive states, which evolve through time and are often influenced by environmental and social contextual parameters that entail ambiguities.

These ambiguities with respect to contextual aspect range from the multimodal nature of emotional expressions in different situational interactional patterns [12], the ongoing task, the natural expressiveness of the individual, to the intra- and interpersonal relational context [13]. According to the first work which introduced the term context-awareness in CS, [14] the important aspects of context are: Who you are with, When, Where you are, What resources are nearby. Thus, context-aware applications look at the Who, Where, When and What (the user is doing) entities and use this information to determine Why the situation is occurring. Other approaches such as Ryan et al. [15] include context as the user's location, environment, identity and time while others have simply provided synonyms for context. However, to characterize a situation, the categories provided by [14] have been extended to include activity and timing of the HCI.

Based on context's broader approach [16], context can be formalized as a combination of four contextual types: Identity (e.g., gender, age, children, social and marital status), Time, Location (e.g., geo-localization, proximity to other homes) and Activity (e.g., what is occurring in the situation) which are the primary context types for characterizing the situation of a particular entity and also act as indices to other sources of contextual information. As far as real-world, context-aware HCI computing frameworks, context is defined as any information that can be used to characterize the situation that is relevant to the interaction between the users and the system [14]. Thus, this definition approaches better the understanding of human affect signals. An even more suitable definition is the one that summarizes the key aspects of context with respect to the human interaction behavior (who is involved (e.g., dyadic/triadic interactions among persons), what is communicated (e.g., "recipes" to perform a specific task), how the information is communicated (the person's cues), why, i.e., in which context the information is passed on, where the proactive user is, what his current task is and which (re)action should be taken to participate actively in content creation [17]).

All these context-aware systems that model the relevant context parameters of the environment depend on the application domain and hence face difficulties in modeling context in an independent way and also lack of models to be compared. Setting aside the fact that sometimes the domains such as context-aware computing, pervasive environments and ubiquitous computing entail similarities with respect to the necessity of managing context knowledge, the concrete applications and approaches domains are different. In the area of pervasive computing, the work of [18] refers to context in environments taking into account the user's activity, the devices being used, the available resources, the relationships between people and the available communication channels. To allow developers to consider richer information as activities and abstract knowledge about the current global context and to model specific knowledge of the current sub-domain, an ontology based approach has been proposed [19] in which context information is modeled into two separate layers (high and low-level respectively). Modeling high level information allows to perform deeper computations taking into account behavioral characteristics, trends information etc. While, on the other hand, modeling low-level information such as location, time, environmental conditions, is used to achieve the system's final goal which is the adaptation to the user interface.

B. *Ubiquitous contextual information*

Proliferation of sensors in the home results in large amounts of raw data that must be analyzed to extract relevant social contextual information. In this view, researchers have started to record smart-homes or work situations to further achieve even higher levels of social naturalistic data. Representative examples are the collection of natural telephonic data that have been gathered by recording large numbers of real phone conversations, as in the Switchboard corpus or audio corpora of non-telephonic spoken interaction or even collections of everyday interactions by having subjects wear a microphone during their daily lives for extended periods. Once data is gathered from wearable sensors and smart appliances, the amount of data may get too large to handle. This reason justifies the need for more advancements w.r.t. such a situation: the diffusion of mobile devices equipped with multiple sensors and the advent of Big-Data.

There is no doubt, that mobile devices can nowadays collect a large amount of contextual information (geographic position, proximity to other people, audio environment, etc.) for extended periods of time. Big-Data analytics can make sense of that data and provide information about context and its effect on behavior. Thus, it is possible to overcome limitations ranging from collecting affect-related data in a large population or having involved participants in the experiment for too long, to being able to design algorithms that will enable HCI in a private, personal and continuous way and allow our sensors to both know us better and be able to communicate more effectively on our behalf with the world around us. Consequently, "designing" smart-homes is a hard task. The friendly design of an intelligent and responsive to our needs ecosystem that can make users feel more comfortable for affective feedback collection and may change user's social behavior is very promising to boost the affect detection performance and explore the possibility of further HCI techniques.

IV. Semantic Representation

In this Section, Semantic technologies are used in order to represent the knowledge of an ecosystem. This ecosystem consists of cities, comprising a number of houses. Additionally, in every city and in every house is located a number of sensors which give data for the environmental context e.g. humidity, temperature and so on. They are also able to give more specific information such as noise and pollution levels or information about the human presence inside the house. All these data are received from the sensors and are stored in a database.

In this ecosystem we can define a number of rules, which we will call home rules, for example defining under which conditions house appliances should be switched on or off. Another more concrete example would be "do not operate the air-condition when the outside temperature is high".

The OWL 2 Web Ontology Language (OWL 2) [20], an ontology language for the Semantic Web with formally defined meaning was adopted for the Semantic Representation of our ecosystem. OWL 2 ontologies provide classes, properties, individuals, and data values and they are stored as Semantic Web entities. The following sections explain in more detail on how the ecosystem is represented by our ontology. The ontology was created using the open source Protégé 4.2 platform [21].

A. Ontology Hierarchy

Figure 1a illustrates the ontology's hierarchy. The ontology's classes describe different aspects of the ecosystem which may be:

1) The Appliances which contain all the different types of the ecosystem's appliances, such as, a) the refrigerator, b) the washing machine, c) the air-condition and d) the television,
2) The Location, which contains both the house and city,
3) The Sensor, which is a class that contains the individuals of all the existing sensors,
4) The Person, which contains all the individuals,
5) The Gender, the House Role and the Social Status which for the different types of gender, house roles, and social status implement the user model.

B. Properties

The ontology also comprises a series of properties. These properties are both object properties and data properties. Object properties provide ways to relate two Objects (also called predicates). Object properties relate two objects (classes), of which the one is the domain and the other is the range. The object properties of the ontology of this ecosystem are mainly used to relate the sensors with a specific location and the inhabitants of the house and the appliances. Some of the ontology's object properties are described below:

1) hasGender, which relates classes person and gender,
2) hasSensor, which relates a sensor class with a location,
3) hasHouseRole, relating a Person class and a house role,
4) isLocatedIn, which relates a house with a city,
5) livesIn, which relates a person with a house,
6) builtIn, which relates a house with a city.

On the other hand, data properties are similar to object properties with the sole difference that their domains are typed words. In our ontology, they relate the actual sensor values with a sensor, power on or off status of the appliances, and the user properties with numerical features. Some of them are described below:

1) hasNoise, which relates a sensor with the actual captured noise value, e.g. 40dB,
2) hasTemperature, which relates a sensor with the actual captured temperature value, e.g. 25°C,
3) isOn, which has a true value if the appliance is turned on and is false otherwise,
4) numberOfChildren, which relates a person with the number of his children, which must be a non-negative integer.

The object's and the data's properties of the ontology appear in Figure 1.

C. Individuals

The ecosystem contains a large number of appliances, sensors and people. Every single appliance, sensor and person is represented in the ontology as an individual of the Appliance, Sensor or Person class respectively. Figure 1d illustrates a small set of Individuals contained in the ontology.

(a) Ontology hierarchy (b) Ontology Properties (c) Data Properties (d) Ontology Individuals

Fig. 1: Example of Object Properties, Classes and Individuals of an ontology representing an ecosystem

D. Rules and Consistency Check

In the current section we provide a novel semantic representation of the home rules of the ecosystem. These home rules are expressed using the Semantic Web Rule Language (SWRL) [22]. SWRL has the full power of OWL DL, only at the price of decidability and practical implementations. However, decidability can be regained by restricting the form of admissible rules, typically by imposing a suitable safety condition. Rules have the form of an implication between an antecedent (body) and a consequent (head). This meaning can be read as: 'whenever the conditions that are specified in the antecedent may hold, the conditions that are specified in the consequent must also hold'. A critical property of our ontology is that the ontology should always be consistent, a condition that is verified with the use of a Pellet reasoner [23]. Thereat, whenever a home rule is violated, a corresponding inconsistency must be detected. Taking it into account and whenever the conditions that are specified in the antecedent's hold, the conditions specified in the consequent must also hold, hence the home rule's violation is transformed to the respective antecedent of the SWRL.

For this reason, a data restriction has to be created in the Appliance class. A data property, called 'restriction' is created. Its domain is an appliance and its range is a boolean, but it is also restricted to exist an appliance with the restriction property. Then, every home rule is transformed to a SWRL, and if the left side of the rule is satisfied, it leads to the creation of the 'restriction' property for an appliance. This makes our ontology inconsistency restricting the appliance to start working. So every time a database record changes, or a new one is added, the ontology individuals are populated with the new values querying the database. Then, using the Pellet reasoner, the system checks for a possible existence of any inconsistency. Finally the inconsistency is being handled by forcing the appliance to switch off or on. Figure 2 illustrate some examples of transformed home rules to the respective SWRLs in Protégé. For example, the first one means that any washing machine, existing in a house of the ecosystem, must not be operating if a person is in this house and there exist noise more than 40dB, while the third one means that it should not operate any washing machine when the temperature of the city is greater than 26°C in an ecosystem this home rule holds.

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House(?house), Person(?per), Sensor(?sens), WashingMachine(?wm), hasSensor(?house, ?sens), isLocatedIn(?wm, ?house), personFound(?sens, ?per), hasNoise(?sens, ?noise), isOn(?wm, true), greaterThan(?noise, 40) -> restriction(?wm, true)
House(?house), Sensor(?sens), Television(?tv), hasSensor(?house, ?sens), isLocatedIn(?tv, ?house), hasHour(?sens, ?hour), isOn(?tv, true), lessThan(?hour, 8) -> restriction(?tv, true)
City(?city), House(?house), Sensor(?sens), WashingMachine(?wm), builtIn(?house, ?city), hasSensor(?city, ?sens), isLocatedIn(?wm, ?house), hasTemperature(?sens, ?temp), isOn(?wm, true), greaterThan(?temp, 26) -> restriction(?wm, true)
House(?house), Sensor(?sens), Television(?tv), hasSensor(?house, ?sens), isLocatedIn(?tv, ?house), hasHour(?sens, ?hour), isOn(?tv, true), greaterThan(?hour, 22) -> restriction(?tv, true)
Appliance(?ap), House(?house), Person(?per), Sensor(?sens), hasHouseRole(?per, Junior), hasSensor(?house, ?sens), isLocatedIn(?ap, ?house), personFound(?sens, ?per), hasPolution(?sens, ?pol), isOn(?ap, true), greaterThan(?pol, 300.0) -> restriction(?ap, true)
AirCondition(?ac), House(?house), Sensor(?sens), hasSensor(?house, ?sens), isLocatedIn(?ac, ?house), hasTemperature(?sens, ?temp), isOn(?ac, true), greaterThan(?temp, 26) -> restriction(?ac, true)
```

Fig. 2: Examples of transformed Home Rules to the respective SWRLs in Protégé

Fig. 3: SmartSantander sensors locations

V. Experiments

A. Smart city sensors

Large-scale tests of the unified user in a smart home in a smart city, SandS will use context sensor data gathered at SmartSantander. SmartSantander [6], born as an European Project is turning into a living experimental laboratory as part of the EU's Future Internet initiative. Major companies involved in the project include Telefonica Digital, the company's R&D wing, along with other smaller suppliers as well as utility and service companies. In terms of application areas five main areas have initially been targeted in the trials so far: traffic management and parking, street lighting, waste disposal management, pollution monitoring and parks and garden management. The sensors are divided into several categories based on the data they should collect. The sensors may be, mobility sensors which are sensors giving information about every vehicle, their speed, altitute, etc, traffic and parking sensors giving information about the traffic volumes and the road occupancy, environmental sensors, that are collecting data concerning, such as temperature, humidity and noise, and finally park and garden irrigation sensors which mostly they get information from certain parks and gardens in order to efficiently control their irrigation and their water consumption. To this aim the city of Santander, in Spain, has been equipped with a large number of sensors used to collect a huge amount of information. The type and the exact location of these sensors is illustrated in Figure 3.

At the moment the data collected by these sensors are stored in the USN/IDAS SmartSantander cloud storage platform. This platform stores in its databases all the observations and measurements gathered by the sensors. It contains live and historical data. These database are migrating on the Fi-lab platform as an instance of the FIWARE ecosystem.

In very minimal terms our experiments will manage the integration of the two systems only in one direction: by exploiting SmartSantander data in favor of SandS with special regards to the empowerment of the home rules used by the DI. Hence the contact between the two systems will happen via the home rules which may be feed by the SmartCity sensor data either in their current version or in an enlarged one to be capable of profiting from the data. Available sensor data, related to the SandS domain include: temperature, noise, light, humidity and quantity of rain. Other data, for instance those concerning traffic, could be considered in a more long-term planning and scheduling approach. Our goal is to feed the existing home rules with the signals provided by the SmartCity system in order to see how the home rules are triggered when an inconsistency is detected.

B. Sensor Integration

In the ecosystem, there are sensors both in every house and for the whole city. These sensors send periodically information about environment, such as the temperature and the noise and the position they are installed (e.g. the city center, for the city sensors, and the kitchen, or the bathroom for the in-house sensors), and their timeStamp. All the sensors send their values periodically to the ecosystem. These values are stored to a specific table of a database overwriting the previous record that was stored. In order to collect the city sensor values tools such as FIWARE Ops tools [24] are used. Adding all these information of the sensors to a database, it is every time feasible for the system to identify the exact condition inside and outside the house, just doing a simple query in the database. Then, due to the structure of the home rules it is possible in a very short time for the ecosystem to know if any home rule is triggered and if an appliance in a house should be switched on or off.

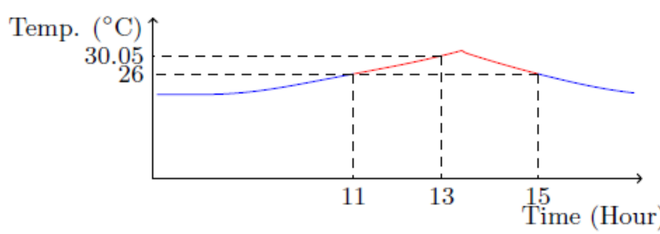

Fig. 4: SmartSantander Sensor values of the temperature for a specific period in a day

Next, an indicative example is presented of how a home rule is triggered based on the temperature a city sensor, such as the SmartSantander sensors, is receiving every moment. If in the ecosystem, the home rules presented in Section IV-D, hold and the temperature of the city every moment in a day is the one presented in Figure 4, an inconsistency is detected between 11:00 and 15:00, because of the third home rule, leading the forcing a house's washing machine to switch off at this period of time. For extended justifications through tests on a wider set of SWRL rules, the reader is referred to [25], where it is shown that our proposed framework is able to cope with more complex actions based on user preferences.

VI. Conclusions and Future Work

In this paper we tried to build a new knowledge representation framework where we first place the human user in the center of this interaction. Further, we discussed the ubiquity of context information in relation to the user and the difficulty to propose a universal formalization framework for the open world. We showed that by restricting user related context to the Smart Home environment, we can reliably define simple rule structures that correlate specific sensor input data and user actions that can be used to trigger arbitrary smart home events. This rationale is then evolved to a higher level semantic representation of the domotic ecosystem in which complex home rules can be defined using Semantic Web technologies. Preliminary experimental results confirmed exciting utilities of our proposed FIWARE framework.

Future directions include further incorporation of user, usage and context information, through a unified semantic representation, driving an adaptation mechanism aiming to provide a personalized service and optimizing the user experience. Finally, an additional potential extension of that method would be a larger scale validation at SmartSantander to provide us with useful insights about the latter. We are also going to compare our modeling proposal with other related work, such as [26] and [27].

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