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Smart Homes to Improve the Quality of Life for All

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***Abstract*— A home is smart when, being aware of its own state and that of its users, is capable of controlling itself in order to support the user wishes and thus improving their quality of life. This holds both for users with special needs and for those with ordinary domestic needs. In this paper, we overview the Smart Homes for All project which represents the current state of the art with respect to software control and user interfaces in the smart homes arena.**

I. Introduction

Due to the ever increasing availability of cheap sensors and actuators, homes are becoming more technological [2]. This goes well beyond the 'gadgetification' of the house of the early adopters and wealthy, as domotic solutions are becoming massively accessible for creating more secure and comfortable living spaces. Such trend is welcomed by the general public in as much as by the people who have special needs such as limited mobility. The current shift does not simply provide for homes with hundreds of sensors and actuators, but also for a different way of interacting and controlling the home. If in the past one had direct command-effect interactions or, at most, simple feedback loops, now we are going towards smart pro-active homes [1]. The idea is that quality of life will improve when not only we have means to mechanize domestic activities, but when we also are immersed in an environment that is aware of us inhabitants, of our activity and adapts itself to best support us.

This can be done by resorting to software solutions and embedded systems specifically tailored for home deployment. The software is mostly responsible of coordinating devices and actuators that are dynamically available in the home, while coupling the coordination with sensing activities. Let's consider a smart home scenario first.

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A. A smart home scenario

A person is at home and decides to take a bath. S/he would like to simply express this to the house and have the available services collaborate in order to move the house to a new state which represents the desired one. The temperature in the bathroom is raised through the heating service, the wardrobe in the sleeping room is opened in order to offer the bathrobe, the bath is filled in with 37^{o}C water, etc. If we suppose the person is disabled, some services cannot be directly automated, e.g., the one of helping the person to move into the bath. In this case, a service still exists, but it is offered by a human, e.g., the nurse, which is doing her job in another room, and that at the right moment is notified – through her PDA or any other device – to go into the bath and help the patient. Maybe this service is offered also by the son of the patient (or any other person) living in a nearby house, which is notified at the right moment, and if the nurse is not present at home, to help the patient. The scenario shows the idea of a system of services, some offered in a completely automated way through sensors/appliances/actuators, other realized through the collaboration of other persons, which moves continuously from a desired state to a new one, in order to satisfy user goals. Clearly, as in all complex systems, there are trade-offs to be considered (the goal of the person willing to take a relaxing bath contrasts with the availability of the nurse/son offering the "help" service).

B. Objective

In this paper, we provide a general overview of the European Project Smart Homes for All as an state of the art example of techniques to create smart homes. We provide a general introduction to the project in Section II, an overview of the technical architecture of the system (Section III) and information on evaluation of a prototype with end-users, Section IV. We conclude the paper with a short discussion over related work and some concluding remarks in Sections V and VI, respectively.

II. The Smart Homes for All Project

The Smart Homes for All project (SM4All) is an European Union Small and Targeted Research Project funded in the context of the seventh framework, objective ICT-2007.3.7: Network embedded and control systems objective. It was kicked off on the first of September of 2008 with a duration of three years. SM4All objectives are the study and development of an innovative middleware platform for the inter-working of smart embedded services in immersive and person-centric environments, through the use of composability and semantic techniques, in order to guarantee dynamicity, dependability and scalability, while preserving the privacy and security of the platform and its users. The study is instantiated on residential homes considering both abled and physically disabled users in their daily activities with different user interfaces.

The project partners range from academic research institutions to industrial organizations and end-users. La Sapienza University of Rome, University of Groningen, Technical University of Vienna and the Royal University of Stockholm are part of the research team, together with the Swedish defense agency, the large companies Telefonica and Elsag Datamat, the SME g.tec, the end-users Fondazione Santa Lucia (a hospital in Rome specialized in rehabilitation) and Thuiszorg Het Friese Land (a home care organization with more than 10.000 clients) complete the consortium. More information about SM4All is available on its website: `http://www.sm4all-project.eu`.

III. SM4All Technical Architecture

Two are the key technical ideas behind the SM4All architecture. First, the software infrastructure is entirely based on the abstraction of a service providing for an open, dynamic and flexible sensing and control infrastructure. Second, the possibility to have many interfaces for the same

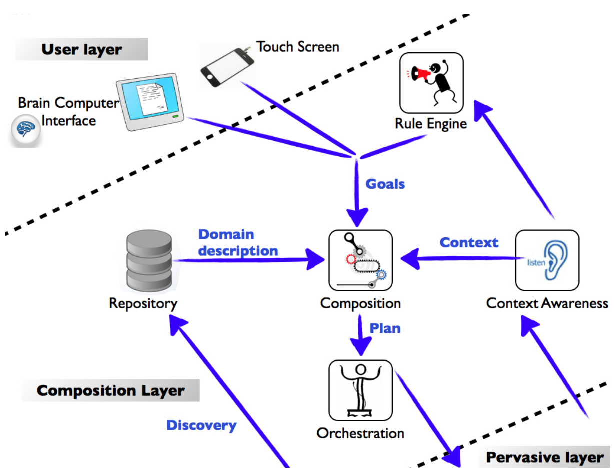

Fig. 1. Architectural overview.

system including state of the art Brain Computer Interfaces (BCI). Additionally, as it is now current practice, it must be possible to integrate heterogenous devices independently of the interconnectivity protocol they implement. These key features come back as part of the organization of the overall architecture. In fact, one can distinguish three layers: user, service-composition, and pervasive layer. In Figure 1, we provide a schematization of the architecture highlighting the three layers and the major components of these and discuss each in the next sections.

A. The User Layer

The user layer abstracts from the implementation of the devices and it provides a distributed access to the home. The commands that can be given may be direct instructions to a single device and, more interestingly, can be also general commands that involve the sequential and parallel interaction with a number of devices. The main novelty of the interface lays in the ability to manage many different user interface models with a unique adaptable algorithm, able to change itself on the basis of the interaction device characteristics (speech/auditory, visual/touch, handheld, brain-controlled. . .) and on the basis of the user preferences, automatically gathered, analyzed and synthesized on top of the previous interactions with the system. Let us consider the two interfaces actually implemented in SM4All.

1) Touch interface: Through a message screen the user can see notifications coming from the system. The room actions' screen shows the list of actions that can be invoked, gathered by groups which are built according to the rooms where the services offering the actions are actually located. The number of available services in the home can be very high, and a service can offer many actions; on the other hand, the icons that can be shown on a screen is limited. A pagination of the information, though useful and indeed exploited in many prototypes, is not sufficient to provide an effective interaction, since it would introduce a huge effort for the user to find the desired element among the big amount of items, navigating back and forth. Hence, in SM4All, the Abstract Adaptive Interface (AAI) integrates a mechanism for grouping and smartly ordering the icons in order to improve the ease of interaction [5]. An icon may represent either a service or an action. Sometimes, only a few actions, among the ones offered by a given service, are available, e.g., a "bedroom light" service offers a "turn off" and a "turn on" action, but only the first (or the second, conversely) is available when the lamp is switched on (off). In such a case, there is no need to show the service icon, as the available action is enough. When the user can fire more than one action, related to a single service, a clustering is needed. It is realized by initially showing the service icon; once activated, all of the other items are hidden and only the available related actions are displayed.

Beyond grouping, the AAI exploits the possibility to order the items according to their importance, with respect to the preferences of each user. In this way, the actions which are known to be more relevant for the user will be displayed on the first screen, in order to appear at a first glimpse, while the others are going to be shown next. Two algorithms are offered: a *static* and a *dynamic* one. The user can select which one s/he prefers through an administration menu. The static algorithm makes use of explicitly defined user settings to identify her/his preferences. Each preference is constituted by (i) a set of conditions, representing the state of the environment which enables the action, (ii) a time frame in which the preference has to be considered (Always, Morning, Afternoon, Evening, Night), and (iii) a usage expectation degree (certain, highly probable, very probable, probable). The dynamic algorithm orders the actions according to the probability that each one is going to be executed, on the basis of the current environment status and previous invocations:

the higher the probability, the higher the priority of the associated icon in the list (*partial order*).

2) The P300 Brain Computer Interface: For people with the ability to concentrate, but not to operate a touch or traditional point and click interface due to severe deficits in voluntary contraction of the muscles, we consider the use of a Brain Computer Interface (BCI) [6]. Non-invasive BCIs are able to translate the users' voluntary electroencephalographic (EEG) modulations into a control signal for an external device. The EEG based BCIs are portable and less expensive with respect to other brain imaging techniques. These features make EEG based BCI suitable and appealing for use outside of research labs. One of the EEG components used to control BCI systems is the P300 potential. P300 is a positive deflection (around $10\mu V$) in the central-parietal region of the scalp that occurs 250-400 ms after the subject recognizes a rare or relevant stimulus (Target, e.g., the flashing of an icon corresponding to the intended command) within a train of frequent stimuli (NoTarget, e.g, the flashing of any other icon).

Fig. 2. BCI testing with active EEG electrodes g.GAMMAsys on the SM4All simulation environment.

Figure 2, shows a patient of Thuiszorg Het Friesland wearing the BCI cap, looking at a visualization of a home she can control and having a screen showing the available commands for controlling the home. We refer to [3] for more details on the actual functioning of the BCI system.

B. The Composition layer

The central composition layer is further abstracted into five major components [10]. The *context awareness* module is responsible for the collection of the sensed information from the home, and the maintenance of a representation of the user context in the home, by reading information directly from the pervasive layer [4]. The *repository* keeps a number of key data bases which include a registry of description of abstract devices, a registry of currently active devices, semantic descriptions of service invocations, and the layout of the house (e.g., the rooms that comprise it, and how they are arranged). A *rule engine* is constantly informed about any changes in the context and identifies whether certain conditions hold. If the conditions entail that some action has to be taken, the rule engine directly invokes the composition module. The *composition* module is the central one of the composition layer. It is responsible for finding the right combination of service operations that can satisfy the high level complex goals issued either by the rule engine (e.g., an emergency goal for combating some dangerous gas that has been identified) or by the user layer (e.g., a request for a beer). The composition module has to be aware of the home description stored in the repository, as well as of the current state of the environment, as seamlessly provided by the context awareness component. The working of the module is based on AI planning [11]. Once a composition of services is computed, it needs to be executed. The execution is controlled by the *orchestration* module, which retrieves and invokes the physical services. Since the current state of the environment constantly changes, and these changes may interfere with the process in execution, the orchestrator should be able to receive feedback about the status of the system to drive the execution of each invocation accordingly.

C. Pervasive Layer

The pervasive layer is a dynamic and open environment where devices join and leave while offering and consuming services. A number of requirements have to be satisfied. Firstly, new services should be automatically detected, and the interested parties should be notified accordingly. Secondly, the services should be described in a standardized programmatic manner, and it should be possible to control them in accordance with this description. Thirdly, interested parties should be notified about changes of services' states in a event-driven manner, and communication between services should be enabled regardless of the platform each service runs on. Moreover, the pervasive layer should be able to perform well with varying loads.

To realize the layer and satisfy the above requirements, we use *Universal Plug and Play (UPnP)* as the protocol for the direct access to hardware services, WSDL and SOAP protocols [2] to expose high-level services, and the *OSGi framework* as the intermediate between the physical UPnP and the WSDL-level service invocations.

IV. User Experience

To test the usability and acceptability, among other parameters, of the SM4All concept, we have implemented a proof of concept SM4All system. In its current version it is a full implementation of the architecture just described which can be coupled either with a real home, or with a 3D visualization of a home. In Figure 3, we see a snapshot of the visualization of a home wich exists at the premises of the Fondazione Santa Lucia, also being equipped with the SM4All system for testing and demonstration purposes.

In the months of October-November 2010, we have then tested the system with 31 clients (ages between 47 and 91, average 71) of the Thuiszorg Het Friesland in the North of The Netherlands. In relation to their physical conditions, 8

Fig. 3. A screen-shot of the home simulation output.

users used the BCI interface (the photo in Figure 2 was taken during the testing), while the rest a point and click one. In March 2011, we have run the exact same test with 27 students of the University of Groningen (ages between 21 and 30, average 23). The test consisted in presenting the user with a set of scenarios, like the one of Section I-A, which was then‘run’ by them in the home using the SM4All interface. After the use of the prototype, their their impressions regarding usability and acceptability of the solution relating it to their own home were recorded. For the BCI extra sessions for system tuning and getting acquainted with the BCI were necessary. The detailes of the results beyond the scope of the present treatment, here we emphasize that the overall response to the test has been extremely positive with the elder users more willing to give up some privacy in order to get better support at home. The BCI users were particularly keen on regaining control over a number of activities for which they otherwise needed help from a nurse or relative, though remarked that the continuous use of the BCI can become tiring.

V. Related Work

A full overview of projects and techniques to realize smart homes is beyond the scope and purpose of this article. We review a few prominent examples in order to put SM4All into a wider perspective. At Georgia Tech a domotic home has been built for the elder adult with the goals of compensating physical decline, memory loss and supporting communication with relatives [12]. This work also considers issues of acceptability of domotics identifying key issues for the adoption of the technology by the end-user. Acceptability, dangers and opportunities are also surveyed in [13]. Having a reliable system is a primary concern for all users. At Carnegie Mellon people’s behavior is studied by automatic analysis of video images [7]. This is fundamental in detecting anomalies and pathologies in a nursing home where many patients live. Pervading the environment with active landmarks, called Cyber Crumbs, aims at guiding the blind by equipping him/her with a smart badge [14]. A number of projects to give virtual companion’s to people, to monitor people’s health and behavioral patterns, to help Alzheimer patients are presented in [9]. The Gator Tech Smart House [8] is a programmable approach to smart homes targeting the elder citizen. The idea is to have a service layer based on OSGi [15] in order to enable service discovery and composition.

VI. Concluding Remarks

Smart homes will become a reality when able to improve the quality of life of their inhabitants without forcing the users to change their behavior or give up their control of the home. To reach this goal research spanning from engineering to the medical arena going through sociology and the theory of computation is necessary. Here, we overviewed the Smart Homes for All project which is at the state of the art when it comes to coordination middleware and user interfaces.

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