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Proposal of an Adaptive Service Providing System for a Multi-User Smart Home

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Abstract

This paper presents a new system which provides services to elderly and persons suffering from motor or cognitive impairments in a smart home (SH). SH are alternative solutions in order to keep elderly and impaired persons as long as possible at their homes to allow them to live with more comfort. SH are dynamically evolving environments, thus the provided services by this system are context aware and customizable for every user. These services can be accessed by users through an application installed on a mobile device. The system uses a multi agent system (MAS) to have a dynamic and adaptive response to environmental change. Experiments are carried out in order to validate the chosen solutions.

Introduction

The population in developed countries as France or Canada is ageing.

The French national institute of statistics and economic studies foresees (INSEE) that 31.9% of the French population will be aged 60 or more by the year 2050. Likewise the Institute of Statistics in Quebec (ISQ) predicts an increase of the population over 70 years old. Cognitive and motor impairments with elderly have huge human, social and economic costs. Since the number of impaired people increases constantly and caregiver's resources are scarce, an alternative solution must be found to keep people with disabilities independent as long as possible. A way to reduce these costs is to keep these people in their home as long as possible before going to specialized institutions. These homes must be adapted in order to host such a person. Automated homes, also called smart homes (SH), are an alternative solution for this problem and have to assist people in their activities of daily living (ADL). For example, preparing dinner or take a bath could present a challenge for disabled people or elderly. These daily tasks are represented by services. This work aims to assist people with cognitive impairments such as Alzheimer illness and persons with paraplegia. Since cognitive and motor impairments are different, the assistance given to these persons is distinct. This paper will present a system which will dynamically adapt itself to the user's preferences, his medical profile and context. Section 2 will explain the different scientific and technological choices made. Section 3 will show the implementation of the different parts of the system. The following section will show the different experimentations in order to validate the choices. The last section will conclude and show perspectives of this work.

Background

A SH is a home containing a certain number of interacting electronic devices such as computers, televisions and mobile devices like smartphones and touchpads. SH also contain less visible devices such as sensors and actuators and form a pervasive and dynamic environment (Waldner, 2013).

Smart homes as pervasive environments

The advantage of a pervasive infrastructure is that the inhabitants aren't conscious of the technology surrounding them. The usage of the pervasive environment becomes an interaction at a subconscious level if the user expectations are always met (Satyanarayanan, 2001). Using a pervasive environment is essential for inhabitants to feel comfortable at home. Especially for people with cognitive impairments who can be easily distracted from their daily tasks. According to Dujardin (Dujardin & Rouillard, 2011), pervasive computing can be apprehended with 4 concepts:

(i) Ubiquity: the people can interact with the system from any location and with a multitude of different devices, for example smartphones, televisions or a simple press button.

(ii) Attentiveness: the system has to be attentive to the environment which is constantly evolving to adapt its interfaces at best.

(iii) Natural interaction: the inhabitants can interact with the system with the most natural ways without learning, using the natural senses of humans.

(iv) System intelligence: the capacity of the system to analyze context and adapt itself dynamically to changes. Today more and more sophisticated mobile devices have appeared and are integrated into SH. All these devices use one or more networks (wired or wireless) to communicate between them. A drawback of a pervasive environment is the bandwidth capacity of the network (Weiser, 1993). A way to reduce bandwidth usage in a SH is to only consider information collected physically close to the user. For example, if a person is in the living room of his SH, the system doesn't need to collect the information from other rooms.

Context and personalization

Impaired people often suffer from multiple disabilities; their medical profile is thus unique.

Our system provides customized services to adapt itself at best to users. The services have three levels of customization (Musa, Mokhtari, Ali, Rasid, & Ghorbel, 2010):

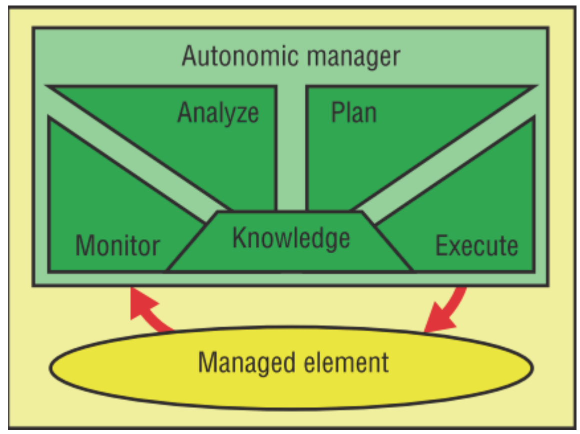
(i) A medical record elaborated by doctors and nurses will indicate the level of assistance needed for the SH to help the person achieve his ADL. The medical record will also contain the information about services that can represent a danger for him and the environment. For instance if we consider a service that uses the gas cooker used to prepare dinner, this service can represent a danger if the user suffers from Alzheimer. He can forget that the service is in use, which can represent a risk of fire. This service can also be forbidden at particular times of a day – especially at night.

(ii) Services can be customized according to user preferences. For example a temperature or light intensity can be tuned by a person to best fit his needs.

(iii) Context can customize services as well. For example, a television service can automatically lower the volume after a certain hour in the evening not to disturb the neighborhood.

A user is mobile and can move around in a smart home, locating a person in a non-intrusive way can be challenging. Harter (Harter, Hopper, Steggles, Ward, & Webster, 2002) uses a small sensor tag carried by the user for locating. Thus it represents an easy and accurate solution, it's not adapted for cognitive impaired people who can easily forget to carry the sensor tag. Addlesee (Addlesee, Jones, Livesey, & Samaria, 1997) uses an active floor detecting weight variation. Although it is possible to recognize people through foot signatures, it can become costly to cover the entire floor of a SH. When a person changes room the services must evolve in consequence, as if the services "follow" the person (Musa et al., 2010). This aspect is quite interesting because it's directly related with the concepts of pervasive computing: If a person moves from the living room and that the light automatically turns on when he arrives in the kitchen, the adaptation of the system is almost transparent. A challenge in service customization lies when there are multiple people in the same location.

As shown, context is an important factor and the system has to adapt itself continually. Context is unpredictable, so it's impossible to create a system which will work correctly in every situation without adaptation. The use of more and more mobile devices makes the environment change more often. A context aware system works with a MAPE-K loop (Kephart & Chess, 2003; Piechnick et al., 2014) as shown.



The monitor, Analyse, Plan, Execute – Knowledge (MAPE-K) loop

This loop monitors the environment using the sensors in the smart home. It analyzes the gathered data and instantiates a related context-model. The loop plans next the different reconfigurations needed to meet the new plan and finally executes the plan using the different actuators in the smart home. The knowledge logs the different configurations that have been executed. The MAPE-K loop is used to check if a service has been executed correctly. For example, if a user in the living room asks for the television service, it will monitor the request and analyze the environment – including the services in use by other users. It will then plan and execute the reconfiguration needed. It will eventually monitor the execution of the plan to check if the service is correctly executed.

Services and autonomous systems

Since the environment is continually evolving and the smart homes becoming more and more complex, it becomes very hard to configure and optimize the services.

Autonomic computing is a vision of a computer system that is completely autonomous. Its objective is to manage itself by configuring and optimizing parts of itself to improve performance (Kephart & Chess, 2003). The self-Managing is made from 4 concepts:

(i) Self-Configuration: Parts of the system will automatically configure itself in order to integrate the system so that other parts can adapt themselves to its presence. This is very useful to when new devices appear and new services are available. Those new services will configure themselves in order to be able to communicate with the system automatically. Khan (Khan, Awais, & Shamail, 2008) uses an self-configuring system to prevent forest fires.
(ii) Self-Optimization: the system is capable of optimizing every parameter for optimal performance. Since the context is evolving continually, it is impossible for a computer scientist to optimize every service dynamically. Every service will have to make sure that the quality of service provided is at its best, by using the most adapted sensors and actuators. Using the most adapted devices to fulfill a service is often equal to using the most relevant or closest devices to the user, which is useful for optimizing bandwidth (Weiser, 1993). The most relevant or closest device can be a wireless device, in which case also battery lifetime issues can occur (Byun, Jeon, Noh, Kim, & Park, 2012). A classic application of an autonomous self-optimizing is the traveling salesman problem (TSP) (Liu, Chen, Yang, & Lu, 2011).
(iii) Self-Healing: detecting the source of a failure can be a very difficult task for a computer scientist. In autonomous systems, when a failure occurs, the source can be determined by isolating parts of the system and test them individually. Self-healing in autonomous system has two objectives: Maintenance of health and survivability (Psaier & Dustdar, 2011). Self-healing has to detect suspicious information, diagnose and calculate a recovery plan and finally recovering by applying those plans. Rebooting the complete system is expensive in time and should only be done if it is strictly necessary. This will cause services to be unavailable, inhabitants would notice the disruption and would yet be against the principles of pervasive computing. To avoid rebooting the system at a whole, a heartbeat mechanism (Liao, Jong, & Fu, 2008) can be put in place for every service. In the worst case, only a single service would reboot.
(iv) Self-Protection: autonomous systems protect themselves from external malware. In SH it is difficult to put self-protection in place because new devices appear and have to integrate the system dynamically. Those devices, especially mobile devices using wireless networks represent potential dangers (Arabo, Brown, & El-Moussa, 2012).

Implementation

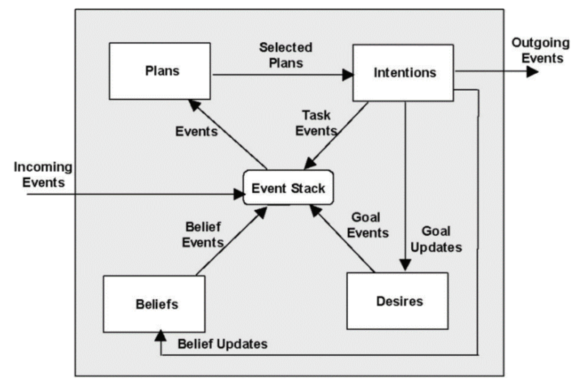
We see services as autonomous systems.

They dynamically detect new devices and follow the users in a smart home. Their goal is to satisfy the user requests. We propose to use a multi agent system (MAS) to represent those services. Each MAS element, called an agent, is an egocentric entity who decides alone how to reach its goals (Wooldridge, 2009). Agents have the same characteristics as services. PADIS (Personal Assistant for Domotic Intelligent Services) is our system based on a mobile and server application which proposes to the user a number of services in a SH. A MAS will be used to represent services in PADIS.

Beliefs, desires and intentions

In order to obtain self-optimizing services in our system, we use a Beliefs, Desires and Intentions (BDI) model to represent our agents (Buford, Jakobson, & Lewis, 2006).

An agent has beliefs; it is how the agent "sees" his environment via sensors. An agent also has desires, the objectives and goals it has to accomplish, his intentions are the actions it carries out on the environment. The BDI model is similar to the MAPE-K, both analyze environment's state in order to plan and execute a new, better fitting configuration.



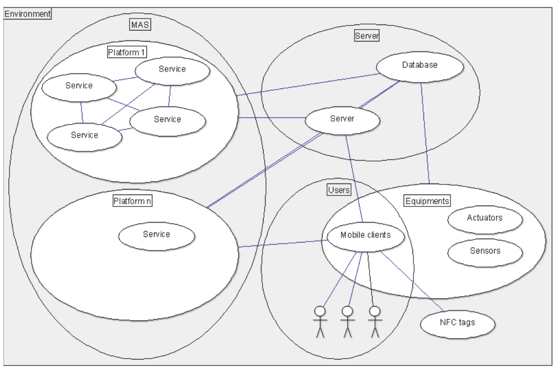
The Beliefs, Desires and Intentions (BDI) model

Agent communication, organization and mobility

Agents can interact using high level communication protocols such as FIPA-ACL (Foundation for Intelligent Physical Agents – Agent Communication Language) (Poslad, 2007) that are similar to human conversations.

Agents can cooperate, coordinate and negotiate actions together (Wooldridge, 2009). Negotiations can be very useful when a conflict appears between two user requests: for example, resource sharing between several services. In order to manage these high level communications between a large number of services and to address more complex goals that simple agents are unable to solve, MAS can be arranged in high level organizations. This is very interesting when developing scenarios or high level services which need several lower level services to work together. Horling and Lesser (Horling & Lesser, 2005) list a set of different organizations with benefits and drawbacks for each organization. Since agents appear and disappear dynamically in our system and that services have a long lifetime, the best organization for our work is a congregation. Congregations are groups of agents who are bound together in a flat organization, sharing information. They are not designed to have only one goal, since different agents and thus services, in a congregation can have different goals. The members can move freely from one congregation group to another, which will be analogous to a service which will move from one room to another in a smart home in order to follow users. We use a MAS made of agents in congregation groups (one per room) representing user services. Some agents are used to check the proper working of the system such as self-protection and self-healing for autonomous systems. We use the JADE (Java Agent Development framework) platform to program our agents which allows agent migration on different platforms. Agents of the MAS represent the services in the smart home. They are interconnected with other elements in our system.

The architecture of PADIS is made of a MAS, a server, a database and a mobile application:



Architecture of PADIS

Our agents are interconnected with the database. The database is used to represent a context image; it is thus connected with the different devices that are spread throughout the environment. When mobile devices connect to the system, for example when a person uses the mobile application, the system recovers the embedded sensor data of the mobile device and updates the database for using them as available sensors for services. The database also contains the medical profile and preferences of users.

The server is seen as a particular agent, programmed in JavaScript with Node.JS. We use this server for mobile devices to connect to our system.

The mobile application is used by the people in smart homes to acquire services. In order to obtain custom services, the mobile device should know the user's identity. We use the user's email address, which is almost mandatory to have on Android to use it properly, in order to identify the user. Since among the aimed users we can find cognitive impaired persons, the graphical user interface (GUI) is thought to be very easy to use.

Obtaining the device's location is done using NFC (Near Field Communication) tags spread out throughout the smart home. This means that only mobile devices embedding NFC technology could be used to use PADIS. We have chosen to use NFC technology to locate devices because it is a widespread and low-cost solution. The mobile application will ask the user to place the device near a NFC tag to have tracking information. Since the user can use several mobile devices - and also for privacy and security reasons - the medical profile of the user is not stored in the mobile devices, but rather in the database.

The mobile device connects and sends user information to the server, which will return the available services for that person and location. A user can then select one of the offered services and will be put in touch with the corresponding service agent. Agents will autonomously check if they have enough resources to perform the service. If not, they will not be available and the corresponding service will not be proposed to the user. If only partial resources are available for a certain service, for example a service that manages the lighting in the living room only has actuator resources and no light sensors, the service will be able to run but not optimally because it will not have any feedback on the service quality, the user will be notified that this service is in a degraded state.

Experiments

PADIS will be tested in two complementary living labs for validation and acceptance by the users:

(i) The DOMUS (DOmotic and Mobile computing in the University of Sherbrooke) laboratory located in Sherbrooke, Canada, is a living lab specialized in cognitive impairments such as Alzheimer or TBI. The living lab is a smart home composed of an entrance, a living room, a kitchen, a bathroom and a bedroom. The DOMUS living lab regularly hosts TBI and Alzheimer patients and is used to perfect systems before deploying in real life environments.

(ii) The rehabilitation center in Kerpape, France, is a center that hosts motor impaired persons. They have a studio made of a kitchen/bed/living room and a bathroom, and an apartment with a kitchen/living room, a separate bedroom and a bathroom. They use these SH to measure autonomy of their patients. Typical patients suffer from motor disabilities.

The two testing labs host patients suffering from different disabilities, which interact differently with the smart home, so two different scenarios are elaborated. The scenarios are elaborated to test the different aspects of PADIS, such as a multi-user usage with its challenges: service customization, incompatibilities and negotiations, services following the user movement. Self-optimization, self-healing and self-configuration of autonomous computing is tested by raising a failure in the system. The scenarios present two main personas, a male who will be known as René and represents an elderly person suffering from impairments. The second persona, called Jeanne, is René's wife and is in good health. The two personas live in the same smart home and can benefit from the services offered by PADIS. A third persona, George, is a professional caregiver that follows the medical situation of René (Castebrunet, 2011).

Scenario in the DOMUS living lab

In the DOMUS living lab, René will be played by an elderly suffering from Alzheimer disease of moderate stage, equivalent to level 4 and 5 of Reisberg's scale (Reisberg, Ferris, De Leon, & Crook, 1982).

The moderate stage of Alzheimer disease is when the person has loss of his cognitive and functional faculties. At this stage, the person needs an increase in health care and moving to a specialized center is contemplated (Alzheimer Society Canada, 2014). The smart home is an alternative solution for this stage of illness.

During the scenario the two personas, René and Jeanne, are in the living room sitting on the sofa and want to watch television. It is 9:00AM and the light is on. René uses his tablet to access the PADIS mobile application and places the tablet on the nearest NFC tag. Among other services, the television service appears and René selects it. The television will turn on. The ambient light intensity will drop because the television is a source of light and will raise the intensity of the ambient light, so the light service will lower the intensity to keep light at the desired set point. Since the user preferences of René indicate that René desires a certain level of light intensity in order to watch correctly television, the television service communicates the new desired set point to the light service, which is represented by an agent in the same congregation.

After an hour, Jeanne wants to read a book and accesses the light service on the tablet from her account. This event will produce a conflict between the requests of Jeanne and René, because Jeanne will need higher light intensity in order to correctly read her book. The services will have to satisfy both requests: a negotiation will take place between the two instances of light service (one for each user) in the living room. The best solution is to raise the light intensity to allow Jeanne to read her book correctly. René can continue to watch television even if the light intensity is higher. This decision will satisfy at best both users.

After some time, a message will appear on the television to tell René that he has to take his medication. He brings with him the tablet to the kitchen where the medication is stored. Once he arrives and places the tablet on the NFC tag on the kitchen worktop, the services follow René. All the services René used before and are available in the kitchen, will automatically turn on in the new location. Since René suffers from Alzheimer disease, he forgot where he stored his medication. Thus he selects the medication service which will indicate René where his medication is stored. The doors of the kitchen cabinet are equipped with small lights to indicate when the closet has to be accessed. The light of the closet door where the medication is stored is broken and cannot be used to help René. The medication service will have to find an alternative way to assist. It will look for other services in the congregation able to guide René. The kitchen is also equipped with speakers to send audio messages. This support will be used to notify René and assist him in taking his medication.

Once René has taken his medication he returns to the sofa in the living room. George, the professional caregiver knocks on the door. George brought with him a smartphone with the PADIS mobile application installed on it. Since George is not an inhabitant of the SH, he is not a known user for PADIS. He will be able to use the offered services by PADIS but will not have any preferences and a lower priority then the inhabitants. George comes to talk with René about his health and to check if his medical profile is up to date.

Scenario in the Kerpape apartments

The rehabilitation center in Kerpape is specialized in people suffering from motor impairments.

A scenario takes place in their apartments. René will be played by a person suffering from paraplegia. Paraplegia is an impairment in motor or sensory function of the lower extremities of the body. People suffering from paraplegia often move using a wheelchair. PADIS is compatible with other motor impairments as long as the persons are able to use the mobile application. The scenario proceeds as follow:

It is 12:00PM and Jeanne is watching television, using the television service on her mobile device. René enters the smart home and wants to prepare lunch. In order to do that, he launches the PADIS mobile application on his mobile device and places it on a NFC tag on the kitchen worktop. He chooses the adapted service which will assist René locating the kitchenware he needs to prepare lunch. The kitchen is equipped with motorized cupboards which can be automatically closed and opened. The kitchen will configure itself to suit René's preferences (worktop height, adapted lighting etc.). Since the kitchen and the living room are physically the same location, the light and noise generated by René's ADL reduces the quality of service for Jeanne. The amount of noise generated cannot be adapted, the television service serving Jeanne has no other choice than raising the televisions' volume.

While René is preparing dinner, a failure will occur on the hood in the kitchen. Since there is no other device able to perform the same task, the service has to find an alternative. The service will look for other services in the congregation to be able to evacuate smoke. Context gives information about the time of the day and the temperature. The system decides to open a window in order to evacuate steam from the kitchen. When dinner is ready, they both sit at table and eat.

Validation of our system

These scenarios show the ability of PADIS to adapt itself to different types of impairments and healthy people through user preferences and their medical profile.

Conflicts occur when multiple users are located in the same room and will highlight negotiations between services. The self-configuration and self-optimization of autonomic computing in services are highlighted by the use of these services by users who move from room to room and by context information. Failure of devices in the scenarios test the ability of the system to manage such events (self-healing) and find alternative solutions, solutions that aren't necessary in the scope of the service which detects the failure. The arrival of an unknown person represents the use of PADIS for everybody with a default profile. This raises security issues, since everybody could access services in the smart home, but that person would need a connection with the domestic wireless network, and dispose of valid NFC tags. These scenarios also bring feedback on the acceptance of the mobile interface and allow us to check if it is easy to use for cognitive impaired persons.

Conclusion and perspectives

Elderly or impaired people may have difficulties in performing daily tasks on their own.

Smart homes allow them to stay at home longer and improve their life conditions. Doctors and nurses are able to easily follow the patients' medical profile. PADIS is a system aimed to help these people to accomplish their ADL in the best conditions possible and in the same time giving extra comfort for healthy people. An experimental model has been developed to demonstrate that the system works correctly. The scenarios are currently carried out for experimental results and for validation in a real life situation.

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