Providing home care using context-aware agents

Dante I. Tapia*, Francisco De Paz, Sara Rodríguez, Javier Bajo and Juan M. Corchado

Departamento de Informática y Automática,
Universidad de Salamanca,
Plaza de la Merced s/n, 37008, Salamanca, Spain
E-mail: dantetapia@usal.es
E-mail: fcofds@usal.es
E-mail: srg@usal.es
E-mail: jbajope@usal.es
E-mail: corchado@usal.es
*Corresponding author

Abstract: This paper presents an ambient intelligence based architecture model that defines intelligent hybrid agents. These agents have the ability to obtain automatic and real-time information about the context using a set of technologies, such as radio frequency identification, wireless networks and wireless control devices. The architecture can be implemented on a wide diversity of dynamic environments, especially for providing home care to elderly and dependent people.

Keywords: home care; ambient intelligence; AmI; context-aware; multi-agent systems; hybrid systems; case-based reasoning; CBR; wireless technologies.

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Biographical notes: Dante I. Tapia is a Researcher at the BISITE Research Group of the University of Salamanca, Spain. His research interests include ubiquitous computing, wireless technologies, distributed architectures and middleware systems. He received his PhD in Computer Science from the University of Salamanca (Spain) in 2009.

Juan F. De Paz is a Researcher at the BISITE Research Group of the University of Salamanca, Spain. His research interests include bioinformatics, biomedicine and artificial neural networks. He received his PhD in Computer Science from the University of Salamanca (Spain) in 2010.

Sara Rodríguez is an Associate Professor at the University of Salamanca, Spain. Her research interests include virtual organisations and patterns analysis. She received her PhD in Computer Science from the University of Salamanca (Spain) in 2010.

Javier Bajo is a Researcher at the BISITE Research Group of the University of Salamanca, Spain. His research interests include case-based reasoning and AOSE tools. He received his PhD in Computer Science from the University of Salamanca (Spain) in 2008.

Juan M. Corchado is the Dean of the Faculty of Sciences and Leader of the BISITE Research Group of the University of Salamanca, Spain. His research interests include hybrid AI and distributed systems. He received his PhD in Computer Science from the University of Salamanca (Spain) in 1998 and his PhD in Artificial Intelligence (AI) from the University of Paisley, Glasgow (UK) in 2000.

1 Introduction

Agents and multi-agent systems (MAS) have become increasingly relevant for developing distributed and dynamic open systems, as well as the use of context aware technologies that allow those systems to obtain information about the environment. This paper is focused on describing the main characteristics of an ambient intelligence (AmI) based architecture which integrates deliberative Believe, Desire, Intention (BDI) agents (Jennings and Wooldridge, 1995; Georgeff and Lansky, 1987; Bratman et al., 1988; Pokahr et al., 2003) that employ radiofrequency identification, wireless networks, and automation devices to provide automatic and real-time information about the environment, and allow the users to interact with their surroundings, controlling and managing physical services (i.e., heating, lights, switches, etc.). These context aware agents collaborate with hybrid agents that use case-based reasoning (CBR) and case-based planning (CBP) (Hammond, 1989) as reasoning mechanisms as a way to implement adaptive systems on automated dynamic environments.

A hybrid CBR-BDI agent (Corchado and Laza, 2003) uses CBR as a reasoning mechanism, which allows it to learn from initial knowledge, to interact autonomously with the environment as well as with users and other agents within the system, and to have a large capacity for adaptation to the needs of its surroundings. We shall refer to the hybrid CBR-BDI agents specialised in generating plans as hybrid CBP-BDI agents. Deliberative BDI agents can be implemented by using different tools, such as Jadex (Pokahr et al., 2003). Jadex agents deal with the concepts of beliefs, goals and plans; they are java objects that can be created and handled within the agent at execution time.

The architecture presented in this paper is founded on AmI environments, characterised by their ubiquity, transparency and intelligence. AmI proposes a new way to interact between people and technology, where this last one is adapted to individuals and their context. It also shows a vision where people are surrounded by intelligent interfaces merged in daily life objects (Emiliani and Stephanidis, 2005), creating a computing-capable environment with intelligent communication and processing to the service of people by means of a simple, natural, and effortless human-system interaction for users (Richter and Hellenschmidt, 2004). For this reason, there is a need for developing intelligent and intuitive systems and interfaces, capable to recognise and respond to the users necessities in a ubiquitous way (Ducatel et al., 2001). These developments must consider people in the centre of the development (Schmidt, 2005) when creating technologically complex environments in medical, domestic, academic, etc. fields (Susperregi et al., 2004). Agents in this context must be able to respond to events, take the initiative according to their goals, communicate with other agents, interact with users, and make use of past experiences to find the best plans to achieve goals.

There is an ever growing need to supply constant care and support to elderly and dependent people (Nealon and Moreno, 2003) and the drive to find more effective ways to provide such care has become a major challenge for the scientific community. The World Health Organization has determined that in the year 2025 will be 1 billion people over 60 years in the world and twice by 2050, with near 80% concentrated in developed countries (WHO, 2005). In particular, Spain will be the third 'oldest country' in the world, just behind Japan and Korea, with 35% citizens over 65 years (OCDE, 2007). In fact, people over 60 years old represent more than 25% of the European population (Camarinha-Matos and Afsarmanesh, 2002), and people over 65 years old are the fastest growing segment of the population in the USA (Angulo and Tellez, 2004). Furthermore, over 20% of people over 85 years old have a limited capacity for independent living, requiring continuous monitoring and daily assistance (Angulo and Tellez, 2004). The importance of developing new and more reliable ways to provide care and support to the elderly is underlined by this trend (Camarinha-Matos and Afsarmanesh, 2002), and the creation of secure, unobtrusive and adaptable environments for monitoring and optimising healthcare will become vital. Some authors (Nealon and Moreno, 2003) consider that tomorrow's healthcare institutions will be equipped with intelligent systems capable of interacting with humans. MAS and architectures based on intelligent devices have recently been explored as supervision systems for medical care for dependent people (Foster et al., 2006). These intelligent systems aim to support them in all aspects of daily life, predicting potential hazardous situations and delivering physical and cognitive support.

Next, the specific problem description that essentially motivated this development is presented. Section 3 describes the main characteristics of the mechanisms integrated to the agents' structure. Section 4 describes the technology implemented to provide information about the context to the agents. Section 5 presents the architecture model that provides the main functionalities, where similar developments can be developed over it. Finally, Section 6 presents the results and conclusions obtained.

2 Problem description

AmI based systems aim to improve the people's quality of life, offering a more efficient and easy use of services and communication tools to interact with other people, systems and environments. One of the most benefited segments of population with the development of these systems is elderly and dependent people (Carretero and Bermejo, 2005). Dependence is the permanent situation where people need important assistance from other people to perform their basic daily life activities, such as essential mobility, objects and people recognition, and domestic tasks (IMSERSO, 2005). Dependent people can suffer degenerative diseases, dementia, or loss of cognitive ability (IMSERSO, 2005). Overall, these systems contribute to enhance important aspects of their daily life, mainly healthcare (Emiliani and Stephanidis, 2005). In Spain, dependency is classified in three levels (IMSERSO, 2005): Level 1 (moderated dependence) covers all people that need help to perform one or several basic daily life activities, at least once a day; Level 2 (severe dependence) wrap all people that need help to perform several daily life activities two or three times a day, but does not require the support of a permanent caregiver; and finally, Level 3 (great dependence) covers all people that need support to perform several daily life activities numerous times a day and because of their total loss of mental or physical autonomy, need the continuous and permanent presence of a caregiver.

Agents and MAS in dependency environments are becoming a reality, especially on healthcare (Foster et al., 2006). Most agents-based applications are related to the use of this technology in patients monitoring, treatment supervision and data mining. Lanzola et al. (1999) present a methodology that facilitates the development of interoperable intelligent software agents for medical applications and proposes a generic computational model for implementing them. The model may be specialised in order to support all the different information and knowledge related requirements of a hospital information system. Meunier (1999) proposes the use of virtual machines supporting mobile software agents using the functional programming paradigm. This virtual machine provides the application developer with a rich and robust platform upon which to develop distributed mobile agent applications, specifically when targeting distributed medical information and distributed image processing. This interesting proposal is not viable due to the security reasons that affect mobile agents, and they do not have defined an alternative for locating patients or generating planning strategies. There are also agents-based systems that help patients to get the best possible treatment and remind the patient about follow-up tests (Miksch et al., 1997). They assist the patient in managing continuing ambulatory conditions (chronic problems). They also provide health-related information by allowing the patient to interact with the online healthcare information network. Decker and Li (1998) propose a system to increase hospital efficiency using global planning and scheduling techniques. They propose a multi-agent solution using the generalised partial global planning approach that preserves the existing human organisation and authority structures, while providing better system-level performance (increased hospital unit throughput and decreased patient stay time). To do this, they extend the proposed planning method with a coordination mechanism to handle mutually exclusive resource relationships, using resource constraint scheduling. Other developments focus on home scenarios to provide assistance to elderly and dependent people. RoboCare presents a multi-agent approach that covers several research areas, such as intelligent agents, visualisation tools, robotics, and data analysis techniques to support people on their daily life activities (Pecora and Cesta, 2007). TeleCARE is another development that makes use of mobile agents and a generic platform to provide remote services and automate an entire home scenario for elderly people (Camarinha-Matos et al., 2004). Though these developments expand the possibilities and stimulate the research efforts enhancing assistance and healthcare to elderly and dependent people, none of them consider the integration of intelligent agents, reasoning and planning mechanisms, and context-aware technologies together at their model. Next, the hybrid reasoning and planning agents implemented in the architecture presented are described.

3 Hybrid reasoning and planning agents

The architecture presented in this paper integrates CBR and CBP mechanisms, which allow the agents to make use of past experiences to create better plans and achieve their goals. All agents in this development are based on the BDI deliberative architecture model (Bratman, 1987), where the internal structure and capabilities of the agents are based on mental aptitudes, using beliefs, desires and intentions. We have implemented hybrid agents which integrate CBR (Allen, 1984) as a deliberative mechanism within BDI agents, facilitating learning and adaptation and providing a greater degree of autonomy than pure BDI architecture.

CBR is a type of reasoning based on the use of past experiences (Kolodner, 1993) to solve new problems by adapting solutions that have been used to solve similar problems in the past, and learn from each new experience. To introduce a CBR motor into a deliberative BDI agent it is necessary to represent the cases used in a CBR system by means of beliefs, desires and intentions, and then implement a CBR cycle to process them. The primary concept when working with CBR systems is the concept of case, which is described as a past experience composed of three elements: an initial state or problem description that is represented as a belief; a solution, that provides the sequence of actions carried out in order to solve the problem; and a final state that is represented as a set of goals. CBR manages cases (past experiences) to solve new problems. The way cases are managed is known as the CBR cycle, and consists of four sequential phases: retrieve, reuse, revise and retain. The retrieve phase starts when a new problem description is received. Similarity algorithms are applied in order to retrieve from the cases memory the cases with a problem description more similar to the current one. Once the most similar cases have been retrieved, the reuse phase begins, adapting the solutions for the retrieved cases to obtain the best solution for the current case. The revise phase consists of an expert revision of the solution proposed. Finally, the retain phase allows the system to learn from the experiences obtained in the three previous phases and consequently updates the cases memory. The retrieve and reuse phases are implemented through FYDPS (Leung et al., 2004) neural networks which allow the agent to recover similar cases from the cases memory and to adapt their solutions using supervised learning, in order to obtain a new optimal solution. The incorporation of these neural networks in the reasoning/planning mechanism reinforces the hybrid characteristics of the agent.

CBP derivates from CBR, but are designed specially to generate plans (sequence of actions) (Corchado et al., 2008). In CBP, the solution proposed to solve a given problem is a plan (i.e., sequence of actions), so this solution is generated taking into account the plans applied to solve similar problems in the past. The problems and their corresponding plans are stored in a plans memory. The reasoning mechanism generates plans using past experiences and planning strategies, thus the concept of CBP is obtained (Glez-Bedia and Corchado, 2002). CBP consists of four sequential stages: retrieve stage to recover the most similar past experiences to the current one; reuse stage to combine the retrieved solutions in order to obtain a new optimal solution; revise stage to evaluate the obtained solution; and retain stage to learn from the new experience. In practice, what is stored is not only a specific problem with a specific solution, but also additional information about how the plans have been derived. As well as in CBR, the case representation, the plans memory organisation and the algorithms used in every stage of the CBP cycle are essential to define an efficient planner.

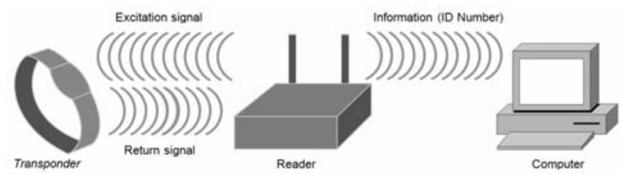
Hybrid CBR-BDI and CBP-BDI agents are supported by BDI agents that manage a set of technologies to obtain all the context information required by the reasoning and planning mechanisms implemented, creating AmI-based systems that automatically adapt themselves to the changes in the environment. Next, these technologies are described.

4 Technologies for context awareness

The essential aspect in this work is the development of an AmI-based architecture as the core of MAS over automated and dynamic environments. Thus, the use of technologies that provide the agents automatic and real-time information of the context, and allow them to react upon it, is also important. AmI provides an effective way to create systems with the ability to adapt themselves to the context and users necessities. The vision of AmI assumes seamless, unobtrusive, and often invisible but also controllable interactions between humans and technology. AmI provides new possibilities for resolving a wide range of problems. It also proposes a new way to interact between people and technology, where this last one is adapted to individuals and their context. AmI shows a vision where people are surrounded by intelligent interfaces merged in daily life objects (Emiliani and Stephanidis, 2005), creating a computing-capable environment with intelligent communication and processing to the service of people by means of a simple, natural, and effortless human-system interaction for users (Richter and Hellenschmidt, 2004). One of the most benefited segments of population with the appearance of AmI-based systems will be the elderly and people with disabilities, improving important aspects of their life, especially healthcare (Emiliani and Stephanidis, 2005).

Radio Frequency Identification (RFID) technology is a wireless communications technology used to identify and receive information about humans, animals and objects on the move. An RFID system contains basically four components: tags, readers, antennas and software. Tags with no power system (i.e., batteries) integrated are called passive tags or 'transponders', these are much smaller and cheaper than active tags (power system included), but have shorter read range. Figure 1 shows how these four elements combined enable the translation of information to a user-friendly format. The transponder is placed on the object itself (i.e., bracelet). As this object moves into the reader's capture area, the reader is activated and begins signalling via electromagnetic waves (radio frequency). The transponder subsequently transmits its unique ID information number to the reader, which transmit it to a device or a central computer where the information is processed and showed. This information is not restricted to the location of the object, and can include specific detailed information concerning the object itself. It is used in various sectors including healthcare (Sokymat, 2006). The configuration presented in this paper consists of a transponder mounted on a bracelet worn on the users' wrist or ankle, and several sensors installed over protected zones, with an adjustable capture range up to 2 metres, and a central computer where all the information is processed and stored.

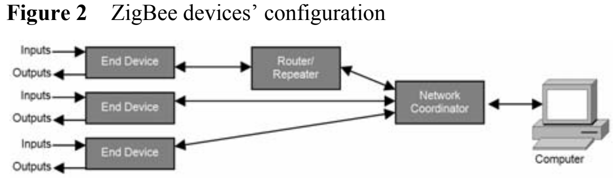
Figure 1 Functioning of RFID technology



Wireless LAN's (Local Area Network) also known as Wi-Fi (Wireless Fidelity) networks, increase the mobility, flexibility and efficiency of the users, allowing programs, data and resources to be available no matter the physical location (Sun Microsystems, 2000). These networks can be used to replace or as an extension of wired LANs. They provide reduced infrastructure and low installation cost, and also give more mobility and flexibility by allowing people to stay connected to the network as they roam among covered areas, increasing efficiency by allowing data to be entered and accessed on site. New handheld devices facilitate the use of new interaction techniques, for instance, some systems focus on facilitating users with guidance or location systems (Poslad et al., 2001) by means of their wireless devices.

Automation devices are successfully applied on schools, hospitals, homes, etc. (Mainardi et al., 2005). There is a wide diversity of technologies that provide automation services, one of them is ZigBee, a low cost, low power consumption, two-way, wireless communication standard, developed by the ZigBee Alliance (ZigBee Standards Organization, 2006). It is based on IEEE 802.15.4 protocol, and operates at 868/915 MHz and 2.4 GHz spectrum. ZigBee is designed to be embedded in consumer electronics, PC peripherals, medical sensor applications, toys and games, and is intended for home, building and industrial automation purposes, addressing the needs of monitoring, control and sensory network applications (ZigBee Standards Organization, 2006). ZigBee allows star, tree or mesh topologies, and devices can be configured to act as (Figure 2): network coordinator (control all devices); router/repeater (send/receive/resend data to/from coordinator or end devices); and end device (send/receive data to/from coordinator).

Figure 2 ZigBee devices' configuration



The architecture presented in this paper incorporates 'lightweight' agents that can reside in mobile devices, such as cellular phones, PDA's, etc. (Bohnenberger et al., 2005), and therefore support wireless communication, which facilitates the portability to a wide range of devices. These agents are very simple and have limited processing capabilities. However, they can remotely invoke complex mechanisms, such as CBR or CBP for providing users with a full set of functionalities.

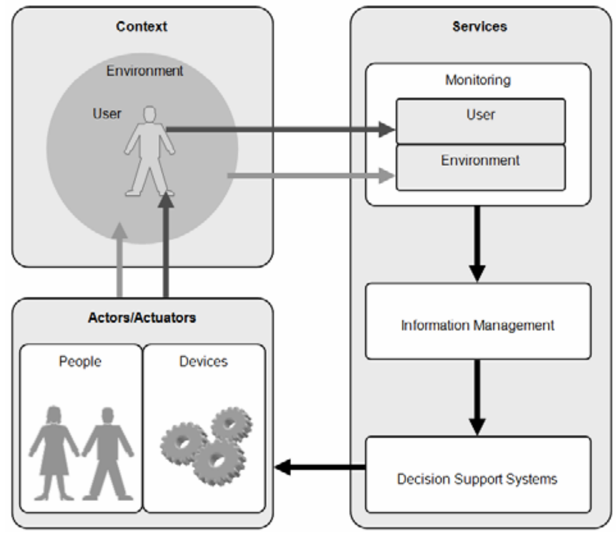
5 Architecture model

Among the general population, those most likely to benefit from the development of AmI based systems are the elderly and dependent persons, whose daily lives, with particular regard to healthcare, will be most enhanced (Corchado et al., 2008; van Woerden, 2006). Dependent persons can suffer from degenerative diseases, dementia, or loss of cognitive ability (Costa-Font and Patxot, 2005). In Spain, dependency is classified into three levels (Costa-Font and Patxot, 2005): Level 1 (moderated dependence) refers to all people that need help to perform one or several basic daily life activities, at least once a day; Level 2 (severe dependence) consists of people who need help to perform several daily life activities two or three times a day, but who do not require the support of a permanent caregiver; and finally, Level 3 (great dependence) refers to all people who need support to perform several daily life activities numerous times a day and, because of their total loss of mental or physical autonomy, need the continuous and permanent presence of a caregiver. Agents and MAS in dependency environments are becoming a reality, especially in healthcare.

Agents and MAS can help to distribute resources and reduce the central unit tasks (Ardissono et al., 2004; Chavez et al., 1997; Voos, 2006). A distributed architecture provides more flexible ways to move functions where actions are needed, obtaining better responses on execution time, autonomy, services continuity, and superior levels of flexibility and scalability than centralised architectures (Camarinha-Matos et al., 2004). Besides, the programming effort is reduced because it is just necessary to specify global objectives to get the agents cooperate to solve problems and reach specific goals, this gives the systems the ability to generate knowledge and experience (Angulo and Tellez, 2004). The development of agents is an essential piece to analyse data from distributed sensors (Mengual et al., 2004) and give those sensors abilities to work together and analyse complex situations, achieving high levels of interaction with humans (Pecora and Cesta, 2007).

Reasoning and planning mechanisms and the technology described on Section 4 are integrated into a multi-agent system prototype. This prototype can be implemented on different scenarios for monitoring and improving assistance and healthcare for dependent people with basic structural changes according the users and project necessities.

Figure 3 Main entities and their relationship in the architecture



The process for designing and modelling the architecture starts when defining all the entities involved, from actors to devices and processes. Once defined these entities, it is possible to represent the basic life cycle of the system. As shown in Figure 3, the cycle begins to obtain information from the context (i.e., the users and their environment) through a monitoring service by means of sensors or people. The information is analysed and processed by an information manager which gives consistency to the data and stores it. Once the information is processed, a decision support system personalises the activities and assigns them for being executed. Decisions are sent to the actors and actuators (e.g., individuals or devices) to stimulate either the user or its environment. The users can switch their roles during the process and thus trigger events which affect the context. This cycle is repeated with each new interaction with the context.

Most of the system functionalities, including monitoring, information management, and decision support are performed by a group of intelligent agents. The system has five different deliberative agents based on the BDI model (BDI Agents), each one with specific roles and capabilities:

- User agent. This agent manages the users' personal data and behaviour (monitoring, location, daily tasks, and anomalies). The beliefs and goals used for every user depend on the plan or plans defined by the super-users. User agent maintains continuous communication with the rest of the system agents, especially with the ScheduleUser agent (through which the scheduled-users can communicate the result of their assigned tasks) and with the SuperUser agent. The user agent must ensure that all the actions indicated by the SuperUser are taken out, sending a copy of its memory base (goals and plans) to the manager agent in order to maintain backups. There is one agent for each patient registered in the system.

- SuperUser agent. It also runs on mobile devices (PDA) and inserts new tasks into the manager agent to be processed by a CBR mechanism. It also needs to interact with the user agents to impose new tasks and receive periodic reports, and with the ScheduleUser agents to ascertain plans' evolution. There is one agent for each doctor connected to the system.
- ScheduleUser agent. It is a BDI agent with a CBP mechanism embedded in its structure. It schedules the users' daily activities obtaining dynamic plans depending on the tasks needed for each user. It manages scheduled-users profiles (preferences, habits, holidays, etc.), tasks, available time and resources. Every agent generates personalised plans depending on the scheduled-user profile. There are as many ScheduleUser agents as nurses connected to the system.
- Manager agent. It runs on a workstation and plays two roles: the security role that monitors the users' location and physical building status (temperature, lights, alarms, etc.) through a continuous communication with the devices agent; and the manager role that handle the databases and the tasks assignment. It must provide security for the users and ensure the tasks assignments are efficient. This assignment is carried out through a CBR mechanism, which is incorporated within the manager agent. When a new assignation of tasks needs to be carried out, both past experiences and the needs of the current situation are recalled, allocating the respective and adequate task. There is just one manager agent running in the system.
- Devices agent. This agent controls all the hardware devices. It monitors the users' location (continuously obtaining/updating data from sensors), interacts with sensors and actuators to receive information and control physical services (lights, door locks, etc.), and also checks the status of the wireless devices connected to the system (e.g., PDA's). The information obtained is sent to the manager agent to be processed. This agent runs on a workstation. There is just one devices agent running in the system.

The essential hardware used is Sokymat's Q5 chip 125 KHz RFID wrist bands and computer interface readers for people identification and location monitoring; Silicon Laboratories' C8051 chip-based 2.4 GHz development boards for physical services automation (heating, lights, door locks, alarms, etc.); mobile devices (PDA's) for interfaces and users' interaction; a workstation where all the high demanding CPU tasks (planning and reasoning) are processed; and a basic Wi-Fi network for wireless communication between agents (in PDA's and workstation). All hardware is some way integrated to agents, providing them automatic and real-time information about the environment that is processed by the reasoning and planning mechanisms to automate tasks and manage physical services.

The technological infrastructure is installed in a ubiquitous way all over the user's home to automatically get information from the environment. The agents process the information received and adapt their behaviour according each situation. The functionalities of the system can change depending on the user's location. For example, if the user is in a determined room, PDA interfaces chance to show different menus to control the devices inside each room.

6 Conclusions and future work

Deliberative BDI agents with reasoning and planning mechanisms and the use of technology to perceive the context, provide a robust, intelligent and flexible architecture that can be implemented into homes or any dynamic environment where is a need to manage tasks and automate services.

A prototype system based on the architecture presented in this paper has been successfully implemented into a geriatric residence (Corchado et al., 2008), improving the security and the healthcare efficiency through monitoring and automating medical staff's work and patients' activities, facilitating the assignation of working shifts and reducing time spent on routine tasks. We are currently working on adapting this prototype to meet most of the needs defined for a home care scenario. We expect to release a fully functional system by Q4 2008.

The experience obtained from previous developments (Bajo et al., 2006; Tapia et al., 2007; Corchado and Lees, 2001; Corchado et al., 2008) demonstrates that the use of CBR systems helps the agents to solve problems, adapt to changes in the context, and identify new possible solutions. These new hybrid agent models supply better learning and adaptation than pure BDI model. In addition, RFID, Wi-Fi and ZigBee devices supply the agents with valuable information about the environment, processed trough reasoning and planning mechanisms, to create a ubiquitous, non-invasive, high level interaction among users and the system.

The architecture presented facilitates the development of AmI based MAS. It also makes easy the inclusion of context-aware technologies that allow systems automatically obtain information from users and the environment in a distributed way, focusing on ubiquity, awareness, intelligence, mobility, etc., all concepts defined by AmI. The architecture exploits the agents' characteristics to provide a robust, flexible, modular and adaptable solution that can cover most requirements of a wide diversity of AmI projects. The system, by means of the agents, can modify its behaviour and functionalities in execution time.

However, it is necessary to continue developing and improving the AmI-based architecture presented, adding new capabilities and integrating more technologies to build more efficient and robust systems to automate services and daily tasks. One of these improvements consist on implementing the system into a real home care scenario and deploy a large-scale ZigBee-based sensors network all over the home for obtaining more information about the context. Another enhancement is regarding performance, so we must optimise the overall performance both the architecture and the system by including automatic errors detection and recovery mechanisms.

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