Ambient Intelligence Based Architecture for Automated Dynamic Environments

Dante I. Tapia, Yanira de Paz and Javier Bajo

Departamento Informática y Automática, Universidad de Salamanca
Plaza de la Merced s/n, 37008, Salamanca, Spain
{dantetapia, yanira, jbajope}@usal.es

Abstract. This paper presents an Ambient Intelligence based architecture that uses intelligent agents with reasoning and planning mechanisms. The 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. A case study is presented, describing the main characteristics of the planning mechanism supported by the architecture, implemented in a geriatric residence, giving the agents a high level of autonomy and flexibility for solving problems.

1. Introduction

Agents and multi-agent systems (MAS) have become increasingly relevant for developing distributed and dynamic open systems [8], as well as the use of context aware technologies that allow those systems to obtain information about the environment [6][20][22].

This paper is focused on describing the main characteristics of an Ambient Intelligence based architecture which integrates deliberative BDI (Believe, Desire, Intention) [4] agents with Case-Based Reasoning (CBR) [1] and Case-Based Planning (CBP) [12] as a way to implement adaptive systems on automated dynamic environments. These agents collaborate with context aware agents that employ Radio Frequency Identification [21], wireless networks [14], and automation devices [23] 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.). All the information provided is processed by the reasoning mechanisms.

A CBR-BDI agent [7] uses Case-Based Reasoning 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. CBP-BDI agents are CBR-BDI agents specialized in generating plans [12]. BDI agents can be implemented by using different tools, such as Jadex [17]. Jadex agents deal with the concepts of beliefs, goals and plans; these are java objects that can be created and handled within the agent at execution time.

The architecture is founded on Ambient Intelligence (AmI) environments, characterized by their ubiquity, transparency and intelligence [9][19][20]. Ambient Intelligence proposes a new way to interact between people and technology, where this last one is adapted to individuals and their context, showing a vision where people are surrounded by intelligent interfaces merged in daily life objects [10], 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 [19], reason why to develop intelligent and intuitive systems and interfaces, capable to recognize and respond to users necessities in a ubiquous way [9], considering people in the centre of the development [20], and creating technologically complex environments in medical, domestic, academic, etc. fields [22]. Agents on this perspective 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 best plans to achieve goals.

The architecture developed proposes a new approach for Ambient Intelligence based systems, through the use of context aware agents that handle a set of technologies and the incorporation of reasoning and planning mechanisms that provide the agents the flexibility and adaptation to survive on dynamic environments and accomplish the AmI vision [10]. Next, the main characteristics of the architecture are explained, focusing on the most important capabilities of the agents and technologies integrated.

2. Technologies for Context Awareness

The essential aspect in this work is the development of an Ambient Intelligence based architecture as the core of multi-agent systems over automated and dynamic scenarios. Thus, the use of technologies that provide the agents automatic and real time information of the environment, and allow them to react upon it, is also important. Ambient Intelligence (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 and proposes a new way to interact between people and technology, where this last one is adapted to individuals and their context, showing a vision where people are surrounded by intelligent interfaces merged in daily life objects [10], 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 [19]. 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 health care [10].

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 (e.g. 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 (e.g. 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. The most use is in industrial/manufacturing, transportation, distribution, etc., but there are other growth sectors including health care [21]. 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 meters, and a central computer where all the information is processed and stored.

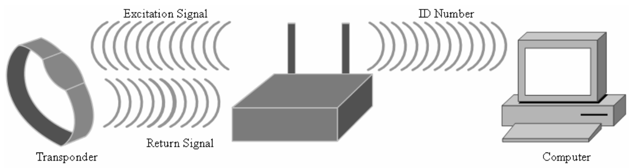

Fig. 1. Functioning of RFID technology

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. 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 [14]. New handheld devices facilitate the use of new interaction techniques, for instance, some systems focus on facilitating users with guidance or location systems [8][18] by means of their wireless devices. The architecture presented in this paper incorporates “lightweight” agents that can reside in mobile devices, such as cellular phones, PDA’s, etc., and therefore support wireless communication, which facilitates the portability to a wide range of devices.

Automation devices are successfully applied on schools, hospitals, homes, etc. 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 [23]. It is based on IEEE 802.15.4 protocol, and operates at 868/915MHz & 2.4GHz spectrum. ZigBee is designed to be embedded in consumer electronics, home and building automation, industrial controls, 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 [23]. ZigBee allows star, tree or mesh topologies. As shown on Figure 2, devices can be configured to act as: 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).

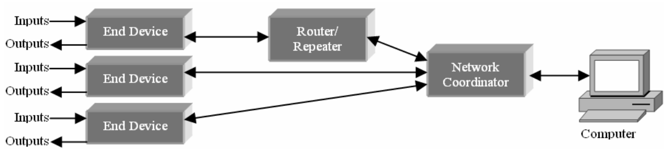

Fig. 2. ZigBee devices' configuration

3. Architecture Model

This paper presents a robust, intelligent and flexible architecture that can be implemented in a wide diversity of scenarios, such as hospitals, geriatric residences [6], schools, homes or any dynamic environment where is a need to manage tasks and automate services. Figure 3 illustrates a basic structure of the architecture, integrating reasoning and planning mechanisms and technology described before into a generic multiagent system prototype, with some changes according the users and project necessities.

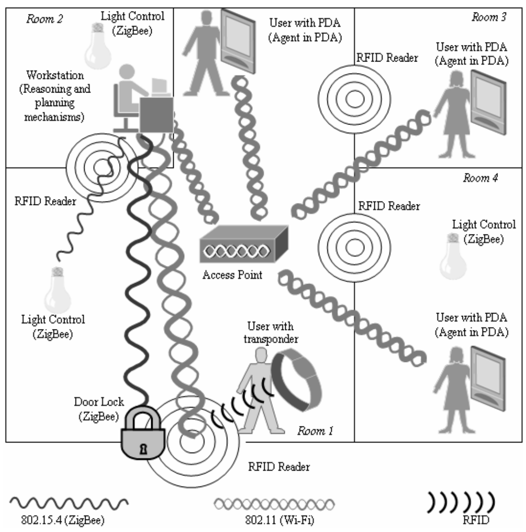

Fig. 3. Basic structure of the architecture presented

The essential hardware used is: Sokymat's Q5 chip 125KHz RFID wrist bands and computer interface readers for people identification and location monitoring; Silicon

Laboratories' C8051 chip-based 2.4GHz 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 automatic and real time information about the environment that is processed by the reasoning and planning mechanisms to automate tasks and manage physical services.

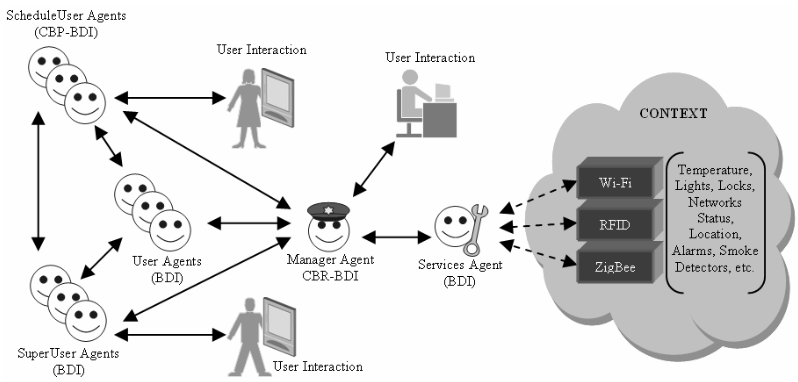

Fig. 4. Agents and technology in the architecture

Figure 4 shows the technology, the five different agents in the system, and the communication between them and the users. Each agent has specific roles and capabilities:

- User Agent is a BDI agent that runs on mobile devices (PDA). It 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.
- SuperUser Agent is a BDI agent that runs on mobile devices (PDA). It inserts new tasks into the Manager Agent to be processed by the 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.
- ScheduleUser Agent is a CBP-BDI planner agent that runs on mobile devices (PDA). 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 personalized plans depending on the scheduled-user profile.
- Manager Agent is a CBR-BDI Agent that runs on a Workstation. It plays two roles: the security role that monitors the users' location and physical building status (temperature, lights, alarms, etc.) trough 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 reasoning engine, 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.

Devices Agent is a BDI agent that that runs on a Workstation. This agent controls all the hardware devices. It monitors the users' location (continuously obtaining/updating data from the RFID readers), interacts with the ZigBee devices to receive information and control physical services (lights, door locks, etc.), and also checks the status of the wireless devices connected to the system (PDA's). The information obtained is sent to the Manager Agent to be processed.

4. Autonomous Reasoning Mechanism for Solving Problems

All agents in this development are based on the BDI (Belief, Desire, Intention) deliberative architecture model [4], where the internal structure and capabilities of the agents are based on mental aptitudes, using beliefs, desires and intentions. The implementation of CBR systems [1] as a deliberative mechanism within BDI agents facilitates learning and adaptation, and provides a greater degree of autonomy than pure BDI architecture. CBR is a type of reasoning based on the use of past experiences to solve new problems [15] 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, creating a deliberative CBR-BDI agent.

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.

In a planning agent, the reasoning mechanism generates plans using past experiences and planning strategies, thus the concept of Case-Based Planning is obtained [12]. 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. Case-Based Planning (CBP) is the idea of planning as remembering [13]. CBP is a specialization of Case-Based Reasoning (CBR) which is a problem solving methodology based on using a library of solutions for similar problems [13]. In CBP, the solution proposed to solve a given problem is a plan, 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. Problem description (initial state) and solution (situation when final state is achieved) are represented as beliefs, the final state as a goal (or set of goals), and the sequences of actions as plans. The CBP cycle is implemented through goals and plans. When the goal corresponding to one of the stages is triggered, different plans (algorithms) can be executed concurrently to achieve the goal or objective. Each plan can trigger new sub-goals and, consequently, cause the execution of new plans.

CBR-BDI and CBP-BDI agents in this paper work in conjunction with other BDI agents that manage a set of technologies to obtain all the environment information required by the reasoning and planning mechanisms implemented, creating AmI-based systems that automatically adapt themselves to the changes in the environment.

5. Developing an Intelligent Environment for Geriatric Residences

It is important to develop new and more reliable ways to provide care and support to the elderly [5], and the creation of secure, unobtrusive and adaptable environments for monitoring and optimizing health care will become vital. Some authors [16] consider that tomorrow's health care institutions will be equipped with intelligent systems capable of interacting with humans. Multi-agent systems and architectures based on intelligent devices have recently been explored as supervision systems for medical care for the elderly or Alzheimer patients [11], these intelligent systems aim to support them in all aspects of daily life, predicting potential hazardous situations and delivering physical and cognitive support.

Most of the architecture presented in this paper has been used to develop a multi-agent system prototype to monitor Alzheimer patients and manage medical tasks in geriatric residences [6][7]. The prototype has been improved with the incorporation of the context aware agents presented in this work. Next, the planning mechanism is briefly described, showing how Case-Based Reasoning provides the agents the flexibility to adapt themselves to the context and supply efficient solutions in execution time to improve medical assistance and the quality of health care and supervision of patients in geriatric residences.

In this case, ScheduleUser Agents (CBP-BDI) are assigned to a nurse or a doctor in the residence, managing the working shifts and providing information about patients, historical data, alarms, tasks, etc. The internal structure and capabilities of ScheduleUser agents are based on the mental aptitudes of beliefs, desires, and intentions. This high level structure facilitates the incorporation of CBR systems [1][7] as a deliberative mechanism within BDI agents, facilitating learning and adaptation and providing a greater degree of autonomy than pure BDI architecture [7].

Each ScheduleUser Agent implements the reasoning cycle of the CBP system by means of three capabilities: Update, KBase and VCBP (Variational CBP). The Update capability implements the retrieve and retain stages, while the KBase capability implements the reuse stage and the VCBP capability the revise stage, where the nurse opinion is evaluated. The VCBP capability is also in charge of dynamic re-planning task. By means of its Give Care capacity, the agents supervise each care task and generate the corresponding report. A task is a java object that contains a set of parameters, as can be seen in Table 1. The Consult Nurse Data capability allows the agents to execute different queries on stored data.

Table 1. Tasks description

Task	Data
TaskId	36
TaskType	32
TaskDescript	Description
TaskPriority	3
TaskObjective	0
TaskIncidents	0
UserId	7
UserNecessities	2
MinTime	10 min
MaxTime	60 min
TaskResources	2,4,8

The CBP mechanism constructs plans as a sequence of tasks that need to be carried out by a nurse. A description of the problem is formed by the tasks that the nurse needs to execute, the resources available, and the times assigned for her/his shift. In the Update stage, the descriptions of similar problems are recovered. In order to do this, ScheduleUser Agents allow the application of various similar algorithms (cosine, clustering etc.). In this step, those problem descriptions found within a range of similarity close to the original problem description are recovered from the beliefs base. In our case, a tolerance of 20% has been permitted. Once the most similar problem descriptions have been recovered, the K-Base capability recovers the solutions associated with them and proposes a new geodesic plan [7]. One solution contains all the plans (sequences of tasks) that are carried out in order to achieve the agent objectives for a problem description (assuming that re-planning is possible) in the past, as well as the efficiency of the solution being supplied. The KBase capability combines the recovered solutions to construct a plan. At this time ScheduleUser Agents take control of the processing of the plan (scheduling) by means of its VCBP capability. The VCBP capability is centred on the objectives and resources needed by each task, as well as on the objectives that the nurse needs to perform and the resources available in order to carry out the global plan. The objectives or global plans that each nurse has are to attend to the patients and not to work for over eight hours. The time available is a problem restriction. This available time will influence the hyper plan of restrictions [7] for the geodesic plan. If the plan varies and the restrictions are exceeded, then it will be necessary to re-plan. The resources necessary for some of the tasks are food, equipment and rooms. Finally, the VCBP capability takes care of incidents and interruptions that may occur during re-planning.

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 in a wide diversity of scenarios, such as hospitals, geriatric residences, schools, homes or any dynamic environment where is a need to manage tasks and automate services.

The use of CBR systems reasoning cycle helps the agents to solve problems, adapt to changes in the context, and identify new possible solutions, supplying better learning and adaptation than pure BDI model. CBP-BDI agents improve their learning as the CBP system comes into play and the context information is more precise, noticeable deducing the number of interruptions for re-planning. In order to evaluate the learning capacity of the agents, the quality of the plans has been measured. The number of interruptions indicates the number of re-plannings carried out up to the completion of a plan. The agents execute CBP cycles in order to learn. After 100 plans execution, the agents reduce the number of interruptions by 30% average.

The main characteristic of the architecture presented, and which makes a step ahead compared to similar architectures [3][11], is the use of CBR and CBP mechanisms merged into deliberative BDI agents that help them to solve problems, adapt to the context changes and identify new solutions, supplying 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, contributing to a ubiquous, non-invasive, high level interaction among users, system and environment.

The implementation of a system prototype, based on this architecture, into a geriatric residence, has shown some of the capabilities of this development, specially planning and reasoning capabilities [6] improving security and health care efficiency through monitoring and automating medical staff's work and patients' activities, facilitating working shifts organization and reducing time spent on routine tasks. Some preliminary experimental results can be observed in [6].

However, it is necessary to continue developing and improving the architecture presented, adding new capabilities and integrating more technologies to build more efficient and robust systems to automate services and tasks.

Acknowledgements. This work has been partially supported by the MCYT TIC2003-07369-C02-02 and the JCYL-2002-05 project SA104A05. Special thanks to Sokymat by the RFID technology provided and to Telefónica Móviles (Movistar) for the wireless devices donated.

References

1. A. Aamodt and E. Plaza, Case-Based Reasoning: Foundational Issues, Methodological Variations, and System Approaches, AI Communications 7 (1994) 39-59.
2. Allen, J.F.: Towards a general theory of action and time. Artificial Intelligence Vol. 23 pp. 123-154. (1984)
3. Amigo Project. http://www.amigo-project.org/. (2006)

4. Bratman, M.E.: Intentions, Plans and Practical Reason. Harvard University Press, Cambridge, M.A. (1987)
5. Camarinha-Matos, L, Afsarmanesh, H.: Design of a Virtual Community Infrastructure for Elderly Care, in: L.M. Camarinha-Matos, Ed., Proceedings of PRO-VE'02, Sesimbra, Portugal. (2002).
6. Corchado, J.M., Bajo, J., De Paz, Y. y Tapia, D.: Intelligent Environment for Monitoring Alzheimer Patients. Decision Support Systems. In Press. ISSN 0167-9236. (2007)
7. Corchado, J.M., Laza, R.: Constructing Deliberative Agents with Case-based Reasoning Technology. International Journal of Intelligent Systems. Vol. 18 No.12 1227-1241 (2003)
8. Corchado, J.M., Pavón, J., Corchado, E., Castillo, L.F.: Development of CBR-BDI Agents: A Tourist Guide Application. 7th European Conference on Case-based Reasoning 2004. LNAI 3155, Springer Verlag. pp. 547-559. (2005)
9. Ducatel, K., Bogdanowicz, M., Scapolo, F., Leijten, J., Burgelman, J.C.: That's what friends are for. Ambient Intelligence (AmI) and the IS in 2010. Innovations for an e-Society. Congress Pre-prints, "Innovations for an e-Society. Challenges for Technology Assessment". Berlin, Germany. (2001)
10. Emiliani P.L., Stephanidis, C.: Universal access to ambient intelligence environments: opportunities and challenges for people with disabilities. IBM Systems Journal. (2005)
11. Foster, D., McGregor, C., El-Masri, S.: 2006.A Survey of Agent-Based Intelligent Decision Support Systems to Support Clinical Management and Research, in: G. Armano, E. Merelli, J. Denzinger, A. Martin, S. Miles, H. Tianfield, and R. Unland, Eds., Proceedings of MAS*BIOMED'05, Utretch, Netherlands. (2005).
12. Glez-Bedia, M., Corchado, J.M.: A planning strategy based on variational calculus for deliberative agents. Computing and Information Systems Journal. Vol.10(1) 2-14. (2002)
13. Hammond, K.: Case-Base Planning: Viewing Planning as a Memory Task. Academic Press, New York. (1989)
14. Hewlett-Packard.: Understanding Wi-Fi. http://www.hp.com/rnd/library/pdf/. (2002)
15. Kolodner J.: Case-based reasoning. Morgan Kaufmann (1993).
16. Nealon, J., Moreno, A.: Applications of Software Agent Technology in the Health Care domain. Birkhauser, Whitestein series in Software Agent Technologies. (2003).
17. Pokahr, A., Braubach L., Lamersdorf, W.: Jadex: Implementing a BDI-Infrastructure for JADE Agents, in: EXP - In Search of Innovation (Special Issue on JADE), Vol. 3, 76-85. Telecom Italia Lab, Turin, Italy, September (2003)
18. Poslad, S., Laamanen, H., Malaka, R., Nick, A., Buckle, P., Zipf, A.: Crumpet: Creation of user- friendly mobile services personalised for tourism. In Proceedings of 3G. (2001)
19. Richter, K., Hellenschmidt, M.: Interacting with the Ambience: Multimodal Interaction and Ambient Intelligence. Position Paper to the W3C Workshop on Multimodal Interaction, 19-20 July. (2004)
20. Schmidt, A.: Interactive Context-Aware Systems Interacting with Ambient Intelligence. In G. Riva, F. Vatalaro, F. Davide & M. Alcañiz, Ambient Intelligence, IOS Press pp. 159-178. (2005)
21. Sokymat.: Sokymat. http://www.sokymat.com. (2006)
22. Susperregi, L., Maurtua, I., Tubío, C., Pérez M.A., Segovia, I., Sierra, B.: Una arquitectura multiagente para un Laboratorio de Inteligencia Ambiental en Fabricación. 1er. Taller de Desarrollo de Sistemas Multiagente (DESMA). Málaga, España. (2004)
23. ZigBee Standards Organization.: ZigBee Specification Document 053474r13. ZigBee Alliance. (2006)