Home Care Expert Systems for Ambient Assisted Living: A Multi-Agent Approach

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Abstract. The ageing process of population of the First World countries is increasing the interest towards solutions to improve the quality of life of elderly or disabled people and their families, providing an economically sustainable healthcare. Thus Ambient Assisted Living (AAL) and Ambient Intelligence (AmI) are moving towards the Artificial Intelligence field to develop modular, adaptable and intelligent systems to cope with changing needs that characterize the life of people with chronic diseases. These systems should find smart and simple ways to improve the patient quality of life, enhancing at the same time the communication between the system, the assisted person, his family and the medical staff, acting also as a filter of information that provides useful and significant data.
This paper introduces the basic architecture of an expert system for AAL: the Virtual Carer (VC). It has to be understood as an IT system modelling a distributed, reliable and modular sensor network composed by biometric and ambient sensors, being able to communicate with an assisted person, to monitor his health conditions and to control the environment around him. The main goal of the system is to help an elderly patient with his daily activities ensuring his security. The proposed system is based on a multi-agent architecture to ensure its flexibility and interoperability: new devices or sensors can be added simply adding new agents, thanks to the standardization of agent communication. The system includes also a reasoning part based on Belief-Desire-Intention (BDI) paradigm, trying to model the behaviours of a human caregiver.

1 Introduction

It is a well-known fact that a shift in the distribution of a country's population towards older ages is ongoing in almost every country in the world, to the point that the world has never seen as aged a population as currently exists globally. Due to their higher dependency ratio (i.e. the ratio between the number of people over 65 years old and those of working age), this is becoming a major problem in Europe, USA and Japan [1, 2].

The increasing median age of the population has significant social and economic implications. For example, it results in a rise in the number of chronic diseases causing the increasing of health-related emergencies and the growing of the healthcare spending [3]. Ambient Assisted Living (AAL) focuses on these themes and aims at extending the time older people can live in their home environment, assisting them with the activities of daily living, promoting the use of intelligent products and Information Technology (IT) tools to provide remote care services [4].

Through the AAL Joint Programme, the European Union aims to foster the emergence of AAL services and systems for ageing well at home, in the community, and at work [5]. The AAL Joint Programme defines these key objectives for AAL:

- to extend the time people can live in their preferred environment by increasing their autonomy, self-confidence and mobility;
- to support maintaining health and functional capability of the elderly individuals;
- to promote a better and healthier lifestyle for individuals at risk;
- to enhance the security, to prevent social isolation and to support maintaining the multifunctional network around the individual;
- to support carers, families and care organizations;
- to increase the efficiency and productivity of used resources in the ageing societies.

Every AAL system is based on pervasive devices typically used in Home Automation systems, and on Ambient Intelligence (AmI) technologies to integrate devices and build a safe environment for the assisted person [4]. The main goal of AmI is to help people in their daily activities, building around them an unobtrusive, interconnected, adaptable, dynamic, embedded, and intelligent environment [6]. Humans can interact with AmI-based systems using natural user interfaces like speech and gestures. One of the goals of AmI is to allow the user to interact with an AmI system as he would do with any other human [3]; anyway, assistive technologies can supplement human caregiving and cannot substitute it, having the potential to improve the quality of life for both older adults and their caregivers [7].

AAL and AmI systems have to adapt themselves over time to cope with the changing needs and health conditions of the assisted person. They need to perceive variation in habits that can signal health-related problems or stressful situations. Thus, applying Artificial Intelligence techniques on this domain seems to be a promising direction for research [8, 9]. Moreover the need of a smart interaction between AmI systems and the elderly is guiding the research community towards the exploration of Human-Computer Interaction (HCI) and Human-Robot Interaction (HRI) solutions. In such a context elderly people should be considered the most prominent stakeholders for IT developments [10].

1.1 Our Contribution

In this paper we propose a Multi-Agent System (MAS) for Ambient Assisted Living: The Virtual Carer. It should be understood as a system to manage a distributed sensor network composed by ambient and biometric sensors, being at the same time an interface layer between the network, the assisted person, his relatives and the medical staff. Furthermore it includes a goal-oriented reasoning module, i.e. the Virtual Carer Agent (VCA), based on Belief-Desire-Intention (BDI) paradigm.

The adoption of the MAS architecture derives from the natural features of these kinds of systems. As stated in [11] the main advantages are:

- distribution;
- modularity;
- robustness.

The MAS architecture allows to distribute software agents and the platforms that manage them over one or more networks; thus each sensor can be associated with an agent, making the system resilient to sensor failures and disconnections. The adoption of the FIPA standards as the Agent Communication Language (ACL) allows to add and remove sensors and devices in a transparent way, simply wrapping them with an agent.

In addition to the listed features, we took into account also pro-activeness, imagining a system that can autonomously take the initiative, guided by goals. Thus the reasoning module of the system, i.e. the VCA, is based on BDI paradigm. The VCA's main goal is to model logical structures, reasoning and behaviours similar to those of a human caregiver, transforming data from sensor agents in logical predicates representing its knowledge base. To perform actions on the monitored ambient and interact with the assisted person, VCA can collaborate with agents controlling actuators. Thus the system can monitor the health conditions of the assisted person and facilitate his daily activities.

1.2 Paper Structure

The rest of the paper is organized as follows. The next section deals with some related works on MAS, AAL, HCI and HRI; then the core of the proposed system is described. Section 4 deals with the description of the whole agency, describing the implementation of a simple simulation scenario and highlighting some features of the Virtual Carer. In the end conclusions are drawn and future work suggested.

2 Related Works

As stated in [12], an agent is an entity that can perceive the environment through sensors and act on the environment through actuators. In [13] the main properties of an agent are outlined: autonomy, social ability, reactivity and pro-activeness indicate that agents operate without external intervention, interact with other agents using some kind of Agent Communication Language (ACL), perceive the environment answering to changes and are able to autonomously exhibit goal-directed behaviours.

BDI agents act on the basis of practical reasoning [14]: their intentions, i.e. the goals agents are committed to achieve, originate from the intersection between beliefs, i.e. the agent knowledge about the environment, and desires, i.e. the set of states representing the environment as desired by agents. MAS and BDI agents with an appropriate knowledge base can meet the guidelines of AAL and AmI, indicating the need of unobtrusive, adaptable and dynamic intelligent environments [6] and requiring technical solutions that are flexible and adaptable to individual and changing needs [15]. MAS applications in the AAL domain are proposed in several scientific contributions. In the system described in [16] BDI agents carry out specific tasks, as controlling air condition and monitoring patient's heartbeat, in patient monitoring scenario. In [17] authors present a system to monitor patients suffering from dementia, in which a Risk Assessment Agent, using its knowledge base and information provided by agents responsible for various ambient sensors, applies a method based on fuzzy logic to predict risk situations and to trigger proper alarms. The work in [18] is based on Home Automation and describes a small society of BDI agents able to cope with energy efficiency issues when different devices are available. In [19] a Smart Home Environment is based on a MAS: a Butler Agent infers the user's goals to provide him suitable services, gathering information from the other agents.

A different research area is focused on Internet of Things scenarios for AAL and remote healthcare [20]. Here, the main problem is interoperability between different devices and sensors. The multi-agent paradigm offers a way to integrate such information sources in a manageable knowledge base, thus allowing for a better use of resources.

Also sensor networks, HCI, HRI and robotics applications are gaining an increasing attention, finding in AAL a natural field of application. In [21] data provided by a hierarchy of wireless sensor networks, in a home environment, are processed with machine learning techniques to monitor the posture and the health conditions of an elderly. The work in [22] highlights how the movements of the assisted person can be analysed. Voice interaction seems a natural way to communicate with the elderly, especially in smart homes ([23]): in [24] a set of patterns for spoken output are analysed; the acceptance degree of speech synthesis and audio interaction is evaluated in [25], where different English accents are considered. More in general the evaluation of the adoption of robotic technologies in healthcare and AAL has been object of several researches: for example in [26] the gender is recognised as more relevant than the age to asses the acceptance of a robot to measure the blood pressure of a patient; the work in [27] defines metrics to evaluate the interaction between robots piloted from remote and the inhabitants of the environment. In addition, the research on robotics is providing ever more powerful technologies as Attentive Systems ([28]).

3 System Architecture

The Virtual Carer is a MAS modelling a distributed, reliable and modular sensor network composed by biometric and ambient sensors, and integrating a BDI core agent (Virtual Carer Agent, VCA). The Virtual Carer is an IT system able to communicate with an assisted person, to monitor his health conditions and to control the environment around him. To cope with a highly variable environment the VCA models reasoning mechanisms and behaviours similar to those of a human being following the BDI paradigm. The large amount of information used by VCA is represented by logical predicates, forming its Knowledge Base (KB). VCA chooses the right actions to perform on the environment with an inference engine applied on its KB. The VCA works as follows:

- it analyses data provided by sensors and devices forming the system (i.e. by agents controlling them) and updates its KB;
- when its KB is updated, VCA generates new knowledge using its inference engine;
- with backward reasoning rules applied on its KB, VCA selects the main goal and chooses (through backtracking) the plan to satisfy it;
- VCA carries out the actions of chosen plan, collaborating with agents responsible for actuators, in order to directly act on the environment.

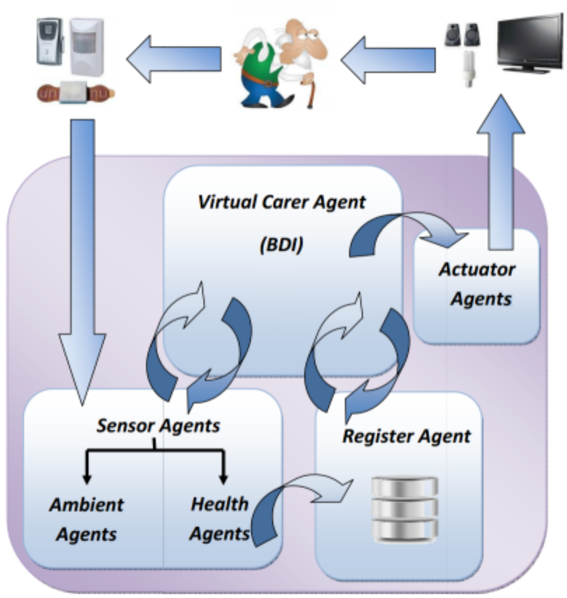

Fig. 1. Virtual Carer basic architecture

Figure 1 shows the basic architecture of the system. The system is composed by the BDI Virtual Carer Agent, a Register Agent and a number Actuator Agents and Sensor Agents.

3.1 Virtual Carer Agent

The main goal of this agent is to provide assistance to the elderly, through the execution of its plans on the basis of the context (its belief base), according to the BDI paradigm. Figure 2 shows the Actor Model in the i* language [29].

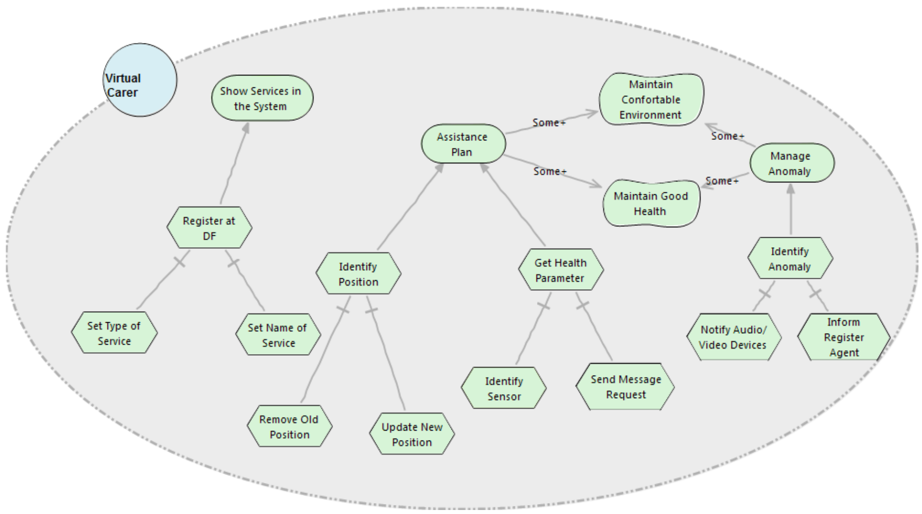

Fig. 2. Virtual Carer Actor Model

Goals can be satisfied thanks to several tasks: the VCA has to identify the position of the elderly, his health conditions and to detect anomalies using available sensors. All the detected anomalies are registered through the Register Agent. In order to complete these tasks the VCA has to register with the Directory Facilitator (DF) of the whole agency, to get its services available for other agents.

3.2 Sensor Agents

Sensor Agents can be distinguished in two types: Ambient Agents and Health Agents. Ambient Agents are responsible for reading the value of ambient sensors as, for instance, the temperature of a specific room. They check if the recorded values are in a predetermined range: if the value is outside of the range, the Ambient Agent communicates the anomaly to the VCA (figure 3). Presence sensors are managed by Ambient Agents, too. For example, we can consider a Passive Infrared (PIR) sensor: the Ambient Agent controlling it merely informs the VCA about the presence of someone in the monitored room. Health Agents, instead, manage sensors measuring values related to the health conditions of the assisted person.

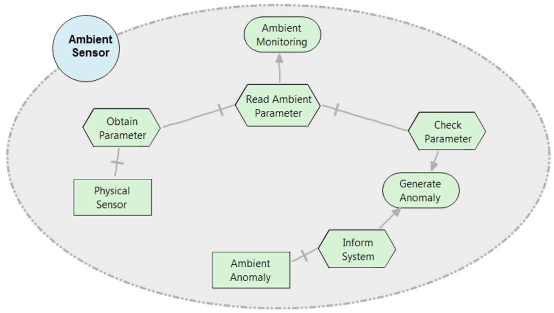

Fig. 3. Ambient Sensor Actor Model

3.3 Actuator Agents

These agents are responsible for the activation and deactivation of the devices composing the system, such as speakers, lights, monitors and so on. As highlighted in figure 4, they must be able to receive request messages (typically from the VCA) in order to execute on/off commands on the devices. Hence, their main goal is the switching of the state of the controlled device, after a request is received.

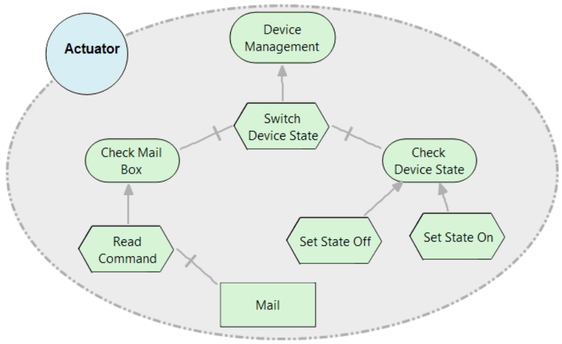

Fig. 4. Actuator Actor Model

3.4 Register Agent

The Register Agent is responsible for the database storage of all the information provided by sensors and of the anomalies detected by the VCA. Figure 5 contains the Actor Model for the Register Agent. Its goal is to register anomalies in the database.

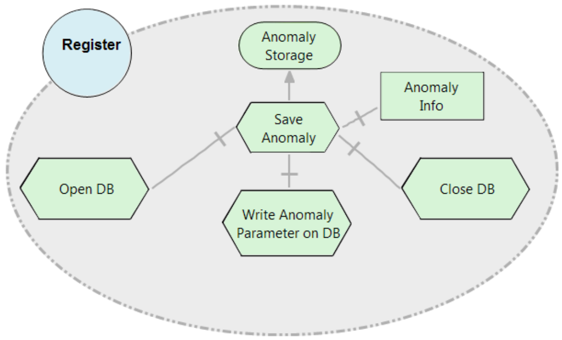

Fig. 5. Register Actor Model

4 Implementation

4.1 Agency

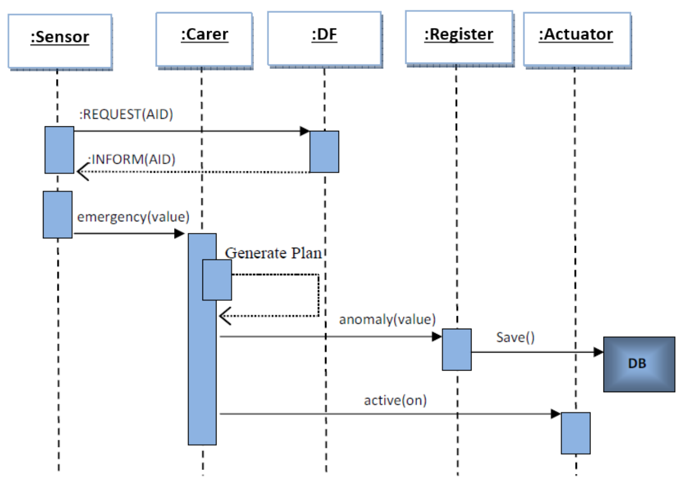

Fig. 6. Sequence diagram representing the interactions between the agents composing the Virtual Carer System

The typical interactions between the VCA, Sensor Agents, Register Agent and Actuator Agents are shown in figure 6. The VCA receives alarms from Sensor Agents when a value is out of the predetermined range; in addition, the VCA can directly require to read a value because the chosen plan requires data to satisfy the goal. The Register Agent receives and stores in a database values from Sensor Agents and anomaly reports from the VCA. The VCA can require values from the database to the Register Agent. The VCA sends request to the Actuator Agents in order to execute actions corresponding to the adopted plan.

Sensor and Actuator Agents are implemented using the JADE framework [30] whilst the BDI agent representing the VCA and the Register Agent are implemented using JASON and the AgentSpeak language [31]. It is important to notice that the use of JADE framework allows the communication between agents with FIPA-ACL messages, ensuring the modularity of the system: different devices can be added any time simply integrating more agents. JASON is used for the VCA, in order to apply the BDI paradigm, and for the Register Agent, allowing to store beliefs directly in the database.

4.2 Simulation scenario

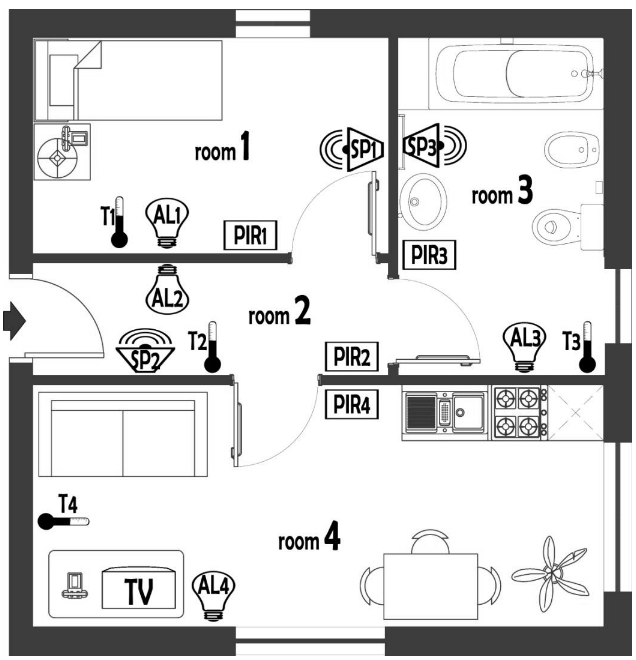

Fig. 7. Home map representing the implemented simulation scenario

Figure 7 shows the fictional home map we used in the simulation scenario, highlighting the arrangement of the available devices in the environment. In order to test the proposed architecture, preliminary simulations in a that scenario were carried out.

There are 4 rooms: the bedroom (room 1), the hallway (room 2), the bathroom (room 3) and the living room (room 4). For each one, a temperature sensor (T1, T2, T3, T4), a PIR sensor (PIR1, PIR2, PIR3, PIR4) and a device to turn the light on/off (AL1, AL2, AL3, AL4) are provided. In addition there is a speaker (SP1, SP2, SP3) for each one of the first three rooms, and a monitor to visually communicate with the assisted person in room 4. Pressure sensors are supposed to be in each place where the person can sit or lie down (e.g. couch, bed, seats), and contact sensors are supposed to be placed on every door and window, to monitor their open/close state. Body sensors are used to monitor the vital parameters (e.g. heartbeat, body temperature) of the assisted person. For each sensor and device in the described scenario the proper Ambient, Health and Actuator Agents are created.

4.3 Virtual Carer Agent

At the beginning of the simulation the VCA's belief base includes facts representing the environment structure and pointing out the available sensors and devices. Figure 8 shows an example of facts describing how the home environment for the simulation scenario is divided in rooms.

```
partOf(couch,hallway).
partOf(bed,bedroom).
partOf(livingRoom,home).
partOf(bedroom,home).
partOf(hallway,home).
partOf(bathroom,home).
```

Fig. 8. Belief base: composition of the simulation scenario

Another extract of the belief base is shown in figure 9. The listed facts indicate the areas covered by the available devices. For example the video device is significant for the couch; the speaker 2, instead, covers a whole room.

```
covers(tv,couch).
covers(speaker1,bed).
covers(speaker2,hallway).
covers(speaker3,bathroom).
```

Fig. 9. Belief base: room covered by video and audio devices.

In addition to the facts in the belief base, the VCA knowledge base is composed also by rules to infer new knowledge and thus to activate plans. The rules allow the VCA to localize the elderly in a specific room, to establish which actuator covers the room and to decide if it has to be activated for an emergency plan. Some examples of these rules are shown in figure 10.

In this simulation, the VCA has several emergency plans: the one shown in figure 11 is executed when an Ambient Agent, responsible for a temperature

```
admissible(D):- inside(A) & videoDevice(D) & covers(D,A).
admissible(D):- inside(A) & audioDevice(D) & covers(D,A).

covers(D,R1):- partOf(R1,R2) & covers(D,R2).

inside(R1):- partOf(R1,R2) & inside(R2).
```

Fig. 10. An example of the rules in the VCA knowledge base

sensor, reads a value out of the predetermined range. In this case the VCA communicates the anomaly to the Register Agent and activates the plan "notify" in order to evaluate if the monitored person has to be notified with some alarms. A similar plan is activated when the body temperature of the assisted person is out of a security range.

```
+emergency1(V)[source(A)] : true <-
        .print("Room temperature out of range");
        .print("from sensor ", A);
        .print("value ", V);
        .time(H,M,S);
        .send(register,tell,anomaly(A,V,H,M,S));
        .print("Information sent to Register Agent");
        ?em1(N);
        New = N + 1;
        -+em1(New);
        !notify;
        !canc.
```

Fig. 11. Emergency plan for room temperature

The system was complemented by a BDI agent, the Elderly Agent, modelling behaviours and activities of the person assisted by the Virtual Carer System. For simulation reasons the Elderly Agent is able to send messages to other agents of the system: for example, it informs the PIR agent when it moves in the controlled room, and sends requests to the Health Sensors to know the value of specific health parameters. To simulate the different behaviours of the assisted person, the Elderly Agent was provided with different plans. Figure 12 shows a plan including the transition from the hallway to the bedroom, and the request of the body temperature value.

In a first simulation scenario, we modelled the situation in which the assisted person goes to bed and measures its body temperature. The simulation works as follows. At first, the Elderly Agent initializes the VCA, providing it the information about its initial position; then, after 10 seconds (i.e. the time necessary to get to bedroom), it informs the PIR Agent of its presence in the final position (this simulates the detection of the elderly by the PIR sensor). The PIR Agent controlling the bedroom notifies the VCA about the presence of a person in the

```
+-scenario5 : true <-
        .send(carer,tell,init(hallway));
        .wait(10000);
        .send(pir1,tell,at);
        .send(carer,achieve,queryP(tempB)).
```

Fig. 12. Elderly agent's plan example

bedroom; thus VCA has a new belief (i.e. the presence of the assisted person in room 1), and activates the plan (figure 13) to turn the light on in the bedroom and to turn it off in the hallway. Finally, the Elderly Agent sends a message to the VCA to know its body temperature value. VCA activates a plan that includes all the actions necessary to require the data from the proper Health Agent and to communicate it to the Elderly Agent.

```
@ent[atomic]
+enter[source(A)] : true <-
        ?inside(M);
        ?spir(A,R);
        M \== R;
        -+inside(R);
        !powerOn(R,M);
        .print("light on in ");
        .print(R);
        .print("light off in ");
        .print(M);
        -enter[source(A)].
```

Fig. 13. When the VCA has a new belief "enter" sent by a PIR sensor, it updates its belief base with the new position of the elderly and activates the plan "powerOn"

Beside plans similar to the one just described, we simulated plans without an explicit request by the Elderly Agent, in which the Virtual Carer had to infer the right actions. For example, when a window remains open in the bedroom and the assisted person is sleeping, the decreasing of room and body temperature should activate the plan to wake up the person and ask him to close the window. In this scenario, the Ambient Agent associated to the bedroom window informs the VCA that the window state is "open". At a later stage the Ambient Agent responsible for T1 sensor communicates to the VCA that the detected value is out of the predetermined range; a similar message is sent by Health Agent. VCA updates its KB with these new beliefs and activates a plan ending with a message to the Elderly Agent, asking it to close the window.

4.4 Evaluation

The evaluation of an AAL system that aims at the interaction with the assisted individual to help him and ensure its security should include several perspectives, as described in [32]: at least the points of view of end users (elderly people and their relatives), physicians, medical caregivers and developers (software and systems engineers) are essential to assess the quality and the effectiveness of such a system.

At this stage of the work only the developers' point of view can be considered: the simulations we carried out are adequate to underline that MAS and BDI paradigm are useful when applied to AAL contexts. Agents, by their own nature, can be easily distributed over a network. The MAS approach and the adoption of communication standards as FIPA-ACL guarantee modularity to the system, in order to cope with the addition or removal of devices. Several agent-based frameworks, as JADE and JASON (both adopted for our simulations), provide techniques to respond to fault-tolerance requirements: the Main Container Replication Service (MCRS) ensures the execution of the agent platform, the Directory Facilitator (DF) Persistence supports the traceability of agent services. The BDI paradigm allows to quickly respond to changes in a dynamic environment: new data from sensors result in the updating of the belief base allowing the VCA to infer new beliefs and new desires. Thus goals are established and plans to achieve them scheduled, using the knowledge base rules and backtracking mechanisms to select the best plan for the current state resulting from the belief base.

Of course, the ideal test to fully validate the proposed approach should include an AAL scenario with sensors and devices deployed in a real home environment. In such a scenario the analysis of the effectiveness of the system could be carried out using participatory evaluations, as in [33].

5 Conclusions

We described a multi-agent architecture to model an expert system for AAL. The system, named Virtual Carer, has to deal with a dynamic environment, monitoring the health conditions of an elderly person. To achieve these tasks the system should model a distributed, reliable and modular sensor network including also those devices typical of home automation. The core of the proposed system is a BDI Agent, the Virtual Carer Agent (VCA) and it represents the reasoning module of the Virtual Carer.

The agents modelling various sensors and devices collaborate to simplify the daily activities of the assisted person and to trigger alarms when something is wrong with parameters regarding his health conditions. The multi-agent approach allows to distribute the agents and the platform over a network. The adoption of frameworks such as JADE guarantees:

– the communication through FIPA-ACL messages, ensuring the flexibility of the system. New devices can be added simply integrating agents in the proposed platform.

– Recovery techniques (such as the DF Persistence or the MCRS) to achieve fault tolerance goals.

We tested the proposed architecture considering several simulation scenarios and representing the assisted person using another BDI agent. Several plans were taken into account, modelling different actions performed by the Elderly Agent (e.g. movements, direct requests, changing of health parameters). These simulations confirm that MAS and BDI paradigm improve modularity and adaptability of AAL and AmI systems. The multi-agent approach guarantees the modularity of the system, whilst the BDI paradigm permits to respond to changes in the environment and in the needs of the assisted person. Thus this work confirm the crucial role of Artificial Intelligence to ensure a better quality of life in the modern society.

As future work more insightful tests have to be conducted: a real AAL scenario, i.e. a daily-used home environment equipped with devices and sensors, where an assisted person can live, is beyond our possibilities at this stage of the work, but is the only way to fully validate the proposed approach. Several technologies could be integrated in the Virtual Carer system: for example those for video surveillance described in [34] could be useful with the purpose of monitoring the conditions of the assisted person, ensuring its security. Moreover intelligent Cyber-Physical Systems, combining artificial intelligence and physical subsystems with computing and networking [35], are ideal for the proposed system.

However the direction that this work seems to undertake is that one of an interface between the medical personnel and the patient, being a Virtual Nurse, i.e. a virtual hospital ward at the patient's home environment. Such a system should act as a filter of information for the medical staff, monitoring the health parameters of the person on the basis of his disease and providing only that information considered significant. The result could be an earlier dehospitalization for the patient, following the need of having hospital wards available for emergencies and trying to provide an economically sustainable healthcare.

References

1. United Nations: World population ageing, 1950-2050. United Nations, New York (2002)
2. Christensen, K., Doblhammer, G., Rau, R., Vaupel, J.W.: Ageing populations: the challenges ahead. The Lancet **374**(9696) (2009) 1196–1208
3. Kleinberger, T., Becker, M., Ras, E., Holzinger, A., Müller, P.: Ambient intelligence in assisted living: enable elderly people to handle future interfaces. In: Universal access in human-computer interaction. Ambient interaction. Springer (2007) 103–112
4. Sun, H., De Florio, V., Gui, N., Blondia, C.: Promises and challenges of ambient assisted living systems. In: Information Technology: New Generations, 2009. ITNG '09. Sixth International Conference on. (2009) 1201–1207
5. AAL EUROPE: Ambient assisted living joint programme. Retrieved April 3, 2013, from http://www.aal-europe.eu/ (2007)

6. Sadri, F.: Ambient intelligence: A survey. ACM Computing Surveys **43**(4) (2011) 1–66
7. Pollack, M.E.: Intelligent technology for an aging population: The use of ai to assist elders with cognitive impairment. AI magazine **26**(2) (2005) 9
8. Cook, D.J., Augusto, J.C., Jakkula, V.R.: Ambient intelligence: Technologies, applications, and opportunities. Pervasive and Mobile Computing **5**(4) (2009) 277–298
9. O'Grady, M.J., Muldoon, C., Dragone, M., Tynan, R., O'Hare, G.M.: Towards evolutionary ambient assisted living systems. Journal of Ambient Intelligence and Humanized Computing **1**(1) (2010) 15–29
10. Holzinger, A., Searle, G., Auinger, A., Ziefle, M.: Informatics as semiotics engineering: lessons learned from design, development and evaluation of ambient assisted living applications for elderly people. Universal Access in Human-Computer Interaction. Context Diversity (2011) 183–192
11. Palazzo, L., Rossi, M., Dragoni, A.F., Claudi, A., Dolcini, G., Sernani, P.: A multi-agent architecture for health information systems. In: Advanced Methods and Technologies for Agent and Multi-Agent Systems. Volume 252 of Frontiers in Artificial Intelligence and Applications. IOSPress (2013) 375–384
12. Russell, S., Norvig, P.: Artificial Intelligence: A Modern Approach. 3 edn. Prentice Hall series in artificial intelligence. Prentice Hall (2009)
13. Wooldridge, M., Jennings, N.R.: Intelligent agents: Theory and practice. Knowledge engineering review **10**(2) (1995) 115–152
14. Bratman, M.: Intentions, Plans, and Practical Reason. Harvard University Press, Cambridge, MA (1987)
15. Wolf, P., Schmidt, A., Otte, J.P., Klein, M., Rollwage, S., König-Ries, B., Dettborn, T., Gabdulkhakova, A.: Openaal - the open source middleware for ambient-assisted living (aal). In: AALIANCE conference, Malaga, Spain. (2010) 1–5
16. Borowczyk, A., Gawinecki, M., Paprzycki, M.: Bdi agents in a patient monitoring scenario. In: Pervasive Computing Technologies for Healthcare, 2008. PervasiveHealth 2008. Second International Conference on. (2008) 82–85
17. Nefti, S., Manzoor, U., Manzoor, S.: Cognitive agent based intelligent warning system to monitor patients suffering from dementia using ambient assisted living. In: Information Society (i-Society), 2010 International Conference on. (2010) 92–97
18. Reinisch, C., Kastner, W.: Agent based control in the smart home. In: IECON 2011 - 37th Annual Conference on IEEE Industrial Electronics Society. (2011) 334–339
19. Cavone, D., De Carolis, B., Ferilli, S., Novielli, N.: An agent-based approach for adapting the behavior of a smart home environment. In: 12th Workshop on Objects and Agents, WOA-2011. Volume 741 of CEUR Workshop Proceedings. (2011) 105–111
20. Dohr, A., Modre-Opsrian, R., Drobics, M., Hayn, D., Schreier, G.: The internet of things for ambient assisted living. In: Information Technology: New Generations (ITNG), 2010 Seventh International Conference on. (2010) 804–809
21. Mileo, A., Merico, D., Pinardi, S., Bisiani, R.: A logical approach to home healthcare with intelligent sensor-network support. The Computer Journal **53**(8) (2010) 1257–1276
22. Pinardi, S., Bisiani, R.: Movement recognition, a lexical approach. In: AITAMI10. (2010) 170–177
23. Vacher, M., Portet, F., Fleury, A., Noury, N.: Development of audio sensing technology for ambient assisted living: Applications and challenges. International Journal of E-Health and Medical Communications (IJEHMC) **2**(1) (2011) 35–54

24. Schnelle-Walka, D.: I tell you something. In: Proceedings of the 16th European Conference on Pattern Languages of Programs. (2011)
25. Tamagawa, R., Watson, C.I., Kuo, I.H., MacDonald, B.a., Broadbent, E.: The effects of synthesized voice accents on user perceptions of robots. International Journal of Social Robotics **3**(3) (2011) 253–262
26. Zealand, N., Kuo, I.H., Rabindran, J.M., Broadbent, E., Lee, Y.I., Kerse, N., Stafford, R.M.Q., Macdonald, B.A.: Age and gender factors in user acceptance of healthcare robots. In: The 18th IEEE International Symposium on Robot and Human Interactive Communication. (2009) 214–219
27. Kristoffersson, A., Severinson Eklundh, K., Loutfi, A.: Measuring the quality of interaction in mobile robotic telepresence: A pilots perspective. International Journal of Social Robotics **5**(1) (2012) 89–101
28. Ognibene, D., Demiris, Y.: Towards active event recognition. In: Proceedings of the 23rd International Joint Conference on Artificial Intelligence. (2013) 2495–2501
29. Yu, E.S.: Social modeling and i*. In: Conceptual Modeling: Foundations and Applications. Springer (2009) 99–121
30. Bellifemine, F.L., Caire, G., Greenwood, D.: Developing multi-agent systems with JADE. Volume 7. Wiley (2007)
31. Bordini, R.H., Hübner, J.F., Wooldridge, M.: Programming multi-agent systems in AgentSpeak using Jason. Volume 8. Wiley-Interscience (2007)
32. Kleinberger, T., Jedlitschka, A., Storf, H., Steinbach-Nordmann, S., Prueckner, S.: An approach to and evaluations of assisted living systems using ambient intelligence for emergency monitoring and prevention. In: Universal Access in Human-Computer Interaction. Intelligent and Ubiquitous Interaction Environments. Springer (2009) 199–208
33. Demiris, G., Oliver, D.P., Dickey, G., Skubic, M., Rantz, M.: Findings from a participatory evaluation of a smart home application for older adults. Technology and Health Care **16**(2) (2008) 111–118
34. Claudi, A., Di Benedetto, F., Dolcini, G., Palazzo, L., Dragoni, A.F.: Marvin: mobile autonomous robot for video surveillance networks. In: Computer Modeling and Simulation (EMS), 2012 Sixth UKSim/AMSS European Symposium on. (2012) 21–26
35. Claudi, A., Sernani, P., Dolcini, G., Palazzo, L., Dragoni, A.F.: A hierarchical hybrid model for intelligent cyber-physical systems. In: Intelligent Solutions in Embedded Systems (WISES 2013), Proceedings of the 11th Workshop on. (2013) 1–6