Virtual Carer: A BDI Agent System for Ambient Assisted Living

Paolo Sernani, Luca Palazzo, Andrea Claudi, Gianluca Dolcini, Gianluigi Biancucci, Guglielmo Trentalange, Aldo Franco Dragoni

Dipartimento di Ingegneria dell’Informazione (DII)
Università Politecnica delle Marche
Via Brecce Bianche, 60131 Ancona, Italy
{p.sernani, l.palazzo, a.claudi, g.dolcini, g.biancucci,a.f.dragoni}@univpm.it

Abstract

Population ageing is a phenomenon occurring, with different degrees and paces, in almost every country in the world, and it is becoming a major problem in Europe, Japan and USA, due to the high dependency ratio of these countries. Research in the fields of Ambient Assisted Living (AAL) and Ambient Intelligence (AmI) is thus gaining great attention. To cope with the changing needs that characterize the life of people with chronic diseases, it seems necessary to combine AAL and AmI with Artificial Intelligence and develop intelligent systems that can adapt to the changing conditions of the patient. This paper presents the Virtual Carer (VC), a Multi-Agent System (MAS) based on the Belief-Desire-Intention (BDI) paradigm. The main goal of the system is to help an elderly patient in his daily activities, while his health conditions are monitored in order to ensure his security.

Keywords

Virtual Carer, Multi-Agent Systems, BDI, AAL, Ambient Intelligence.

Introduction

Population ageing is a shift in the distribution of a country’s population towards older ages. This demographic shift 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 (United Nations, 2002; Christensen, Doblhammer, Rau, & Vaupel, 2009).
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 which in turn cause the increasing of health-related emergencies and an increase in the health care spending (Kleinberger, Becker, Ras, Holzinger, & Müller, 2007). 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 (Sun, De Florio, Gui, & Blondia, 2009).

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 (AAL EUROPE). 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 (Sun et al., 2009). 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 (Sadri, 2011). 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 like it would do with any other human (Kleinberger et al., 2007).

AAL and AmI systems have to adapt themselves over time to cope with the changing needs and health conditions of the assisted person. Moreover, they need to perceive variation in habits that can signal health-related problems or stressful situations. Applying Artificial Intelligence techniques on this domain seems to be a promising direction for research (Pollack, 2005; Cook, Augusto, & Jakkula, 2009; O’Grady, Muldoon, Dragone, Tynan, & O’Hare, 2010).

In this paper we present Virtual Carer, a Multi-Agent System (MAS) based on the Belief-Desire-Intention (BDI) paradigm, which models, integrates and manages the typical services of an AAL system.
The Virtual Carer manages a distributed sensor network formed by ambient and biometric sensors. To increase modularity and reliability of the system, each sensor is associated with an agent; thus the system is resilient to sensor failures and disconnections. Depending on the complexity of the system to be managed, one or more BDI agents are used to form the Virtual Carer Agency (VCA). The main goal of VCA 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.

The rest of the paper is organized as follows. The next section deals with some related works on MAS and AAL; then the core of the proposed system is described. A simple simulation scenario highlights some features of the Virtual Carer. In the end some conclusions are drawn and future work suggested.

**Related Works**

As stated in (Russell & Norvig, 2009), an agent is an entity that can perceive the environment through sensors and act on the environment through actuators. In (Wooldridge & Jennings, 1995) 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.

MAS are capable to autonomously adapt to context changes resulting from user activity, device failures, and the addition or removal of devices and services. Hence, they meet the requirements on modularity and adaptability of AAL systems (Ayala, Amor, & Fuentes, 2012). BDI agents act on the basis of practical reasoning (Bratman, 1987): their intentions, i.e. the set of actions that an agent can perform, 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 the agent. 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 (Sadri, 2011) and requiring technical solutions that are flexible and adaptable to individual and changing needs (Wolf et al., 2010).

MAS applications in the AAL domain are proposed in several scientific contribution. (Nefti, Manzoor, & Manzoor, 2010) presents 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. In the system described in (Borowczyk, Gawinecki, & Paprzycki, 2008), instead, each agent cooperates with other
agents to carry out specific tasks, uses its own knowledge base to trigger an alarm if needed, and can alert the medical staff in dangerous situations. In (McNaull, Augusto, Mulvenna, & McCullagh, 2011) the focus is on the interaction with the user rather than on monitoring. The work in (Reinisch & Kastner, 2011) 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.

A different research area is focused on Internet of Things scenarios for AAL and remote healthcare (Dohr, Modre-Opsrian, Drobics, Hayn, & Schreier, 2010). 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.

The Virtual Carer 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 Agency, 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, and following the BDI paradigm, VCA models reasoning mechanisms and behaviours similar to those of a human being. 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 analyzes 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.

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. The Actuator Agents are responsible for the activation and deactivation of the devices composing the system, like speakers, lights, monitors and so on. They must be able to receive requests from other agents and to execute on/off commands on the devices. The Register Agent is responsible for the database storage of all the information provided by sensors and of the anomalies detected by the VCA.
Sensor Agents can be distinguished in two types: Ambient Agents and Health Agents. Ambient Agents are responsible for reading the value of ambient sensors, for example 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. 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. For example, a Health Agent can control a heartbeat sensor. The arrows in Figure 1 highlight the information flow characterizing the system. 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, for example because the chosen plan requires data to satisfy the goal. The Register Agent receives and store in a database values from Sensor Agents and warning and anomalies report 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. For example the VCA can send a request to turn on the light in the living room because the PIR agent detects the presence of the assisted person.

Sensor and Actuator Agents are implemented using the JADE framework (Bellifemine, Caire, & Greenwood, 2007) whilst the BDI agent representing the VCA and the Register Agent are implemented using JASON and the AgentSpeak language (Bordini, Hübner, & Wooldridge, 2007). 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 anytime simply integrating more agents. JASON
is used for the BDI agents composing the VCA, in order to apply the BDI paradigm, and for the Register Agent, allowing to store beliefs directly in the database.

![Home map for the implemented simulation scenario](image)

**Figure 2: Home map for the implemented simulation scenario**

### Simulation Scenario

In order to test the proposed architecture, a preliminary simulation was carried out. 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.

Figure 2 shows the fictional home map we used in the simulation scenario, highlighting the arrangement of the available devices in the environment.

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 on/off the light (AL1, AL2, AL3, AL4) are provided. In addition there are 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.
In this simulation, the VCA agent has two emergency plans: the first, shown in figure 3, is executed when an Ambient Agent, responsible for a temperature sensor, read 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.

```
/* Piano Emergenza Temperatura stanza*/
+emergency1(V)[source(A)] : true <-
    .print("Ricevuto Parametro Temperatura fuori norma");
    .print("dal sensore ", A);
    .print("con valore ", V);
    .time(H,M,S);
    .send(register,tell,anomaly(A,V,H,M,S));
    .print("Info inviata a Agent Register");
    ?em1(N);
    New = N + 1;
    +em1(New);
    !notify;
    !canc.
```

*Figure 3: Emergency plan for room temperature*

The plan in figure 4 is activated when the body temperature of the assisted person is out of a security range. This plan is similar to the previous one.

```
/* Piano Emergenza Temperatura Corporea*/
+emergency2(V)[source(A)] : true <-
    .print("Ricevuto Parametro Temperatura corporea fuori norma");
    .print("dal sensore ", A);
    .print("con valore ", V);
    .time(H,M,S);
    .send(register,tell,anomaly(A,V,H,M,S));
    .print("Info inviata a Agent Register");
    ?em2(N);
    New = N + 1;
    +em2(New);
    !notify;
    !canc2.
```

*Figure 4: Emergency plan for body temperature*

To simulate the different behaviours of the assisted person, the Elderly Agent was provided with different plans. Figure 5 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 Agent, providing it the information about its initial position; then, after 5 seconds (i.e. the time necessary to get to bedroom), it informs the PIR Agent of its presence in the final position. The PIR Agent controlling the bedroom notifies
the VCA about the presence of a person in the bedroom; thus VCA has a new belief (i.e. the presence of the assisted person in room 1), and activates the plan to turn on the light in the bedroom and to turn it off in the hallway. Finally, the Elderly Agent send 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.

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 VC Agent that the detected value is out of the predetermined range; a similar message is sent by the 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.

Of course, the ideal test for the proposed approach should include an AAL scenario with sensors and devices deployed in a real home environment. However, the simulations we carried out are adequate to underline that MAS and BDI paradigm are useful when applied to AAL contexts: the MAS approach guarantees modularity to the system, in order to cope with the addition or removal of devices, while the BDI paradigm allows to quickly respond to changes in a dynamic environment.

Conclusions

We described a MAS approach to AAL to deal with a dynamic environment, monitoring the health conditions of an elderly or disable person. The core of the system is a BDI agent representing a Virtual Carer. The Virtual Carer collaborates with other agents modelling various sensors and devices to simplify the daily activities of the assisted person and to trigger alarms when something is wrong with parameters regarding his health conditions. The JADE framework 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. We tested the system considering several simulation scenarios.
and representing the assisted person using another BDI agent. Several plans was taken into account, modelling different actions performed by the Elderly Agents (e.g., movements, direct requests, changing of health parameters). Tests confirm that MAS and BDI paradigm improves 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.

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. The next step could be towards the integration of more technologies in the Virtual Carer system: for example those for video surveillance described in (Claudi, Di Benedetto, Dolcini, Palazzo, & Dragoni, 2012) could be useful with the purpose of monitoring the conditions of the assisted person, ensuring its security. Furthermore the interface with the Virtual Carer could be improved, considering Automatic Speech Recognition (ASR) and Text-To-Speech (TTS) technologies.

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**References**


