Ambient Intelligence Agent for Health Care

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Abstract. This paper presents an autonomous intelligent agent developed for ambient intelligence health care in geriatric residences. The paper focuses on Ambient Intelligence (AmI) Technologies since the vision of AmI assumes seamless, unobtrusive, and often invisible but also controllable interactions between humans and technology. Monitoring within the care process is a vital function requiring AmI solutions. An autonomous deliberative case-based planner agent, AGALZ (Autonomous aGent for monitoring ALZheimer patients), is designed to facilitate the nurses' integration into a multi-agent intelligent environment, named ALZ-MAS (ALZheimer Multi-Agent System), capable of obtaining information about the environment through RFID technology. The agent operates in wireless devices and is integrated with complementary agents.

1. Introduction

Ambient intelligent environments are characterised by their ubiquity, transparency and intelligence [2]. The Agents and multi-agent systems (MAS) have become increasingly relevant for developing distributed and dynamic intelligent environments. This paper presents AGALZ (Autonomous aGent for monitoring ALZheimer patients), and explain how this deliberative planning agent have been designed and implemented. A case study is then presented, with AGALZ working in conjunction with complementary agents into a prototype multi-agent system (ALZ-MAS: ALZheimer Multi-Agent System). The residential health care problem is studied in terms of ambient intelligence and a multi-agent based solution is proposed in order to improve the efficiency of health care in geriatric residences. We also examine the residential health care problem and the possibilities of Radio Frequency Identification (RFID)[10] as a technology for constructing an intelligent environment and ascertaining patient location to generate plans and maximize safety.

We are mainly interested in the development of deliberative agents using case-based reasoning (CBR) [1] architecture, as a way to implement adaptive systems to improve assistance and health care support for elderly and people with disabilities, in particular with Alzheimer’s. 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, so we propose the development of a deliberative agent that incorporates a Case-Base Planning (CBP) reasoning mechanism, derivative from case-based reasoning (CBR) systems [6], specially designed for planning construction. CBP-BDI facilitates learning and adaptation, and therefore a greater degree of autonomy than that found in pure BDI (Believe, Desire, Intention) architecture [4]. BDI agents can be implemented by using different tools, such as Jadex [9]. 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.

During the last three decades the number of Europeans over 60 years old has risen by about 50%. Today they represent more than 25% of the population and it is estimated that in 20 years this percentage will rise to one third of the population, meaning 100 millions of citizens [5]. This situation is not exclusive to Europe, since studies in other parts of the world show similar tendencies. The importance of developing new and more reliable ways to provide care and support to the elderly is underlined by this trend [5], and the creation of secure, unobtrusive and adaptable environments for monitoring and optimizing health care will become vital. Some authors [8] 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, these intelligent systems aim to support them in all aspects of daily life, predicting potential hazardous situations and delivering physical and cognitive support.

2. RFID

The RFID (Radio Frequency IDentification) technology is a wireless communications technology used in applications to identify and receive information about humans, animals and objects on the move. An RFID system contains basically three components as can be seen in Figure 1: transponder, reader and software.

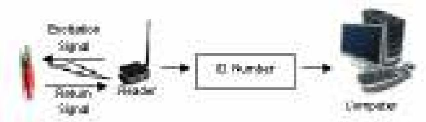

Fig. 1. Functioning of RFID technology

Figure 1 shows how these three elements combined enable the translation of information to a user-friendly format. The transponder, or tag, is placed on the object itself. As this object moves into the reader´s area of interrogation, the reader is activated and begins signaling via electromagnetic waves (radio frequency waves). The transponder subsequently transmits its unique ID information to the reader, which in turn converts it, through the software technology, into useful information. 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, and warehousing industries, but there are other growth sectors including health care [10]. The system used in the work presented in this paper consists of a transponder mounted on a bracelet worn on the patient's wrist or ankle, and several sensors installed over protected zones, with an adjustable capture range up to 2 meters. Radio Frequency devices deeply interact with the multi-agent system, including AGALZ, so propagation characteristics and interference must be considered. The transponders use a 125 kHz signal while Wi-Fi devices, PDA's (Personal Digital Assistant) and Bluetooth phones use 2.4 GHz signals. As such, one of the major problems for using wireless devices, electromagnetic interference, can be easily resolved.

3. Autonomous Health Care Agent

We have developed AGALZ, an autonomous deliberative cased-based planner (CBP-BDI) agent that integrates with other agents into a multi-agent system named ALZ-MAS as a proposal to improve the efficiency of health care and supervision of patients in geriatric residences. AGALZ presents a deliberative architecture, based on the BDI (Belief, Desire, Intention) model [4]. In this model, the internal structure and capabilities of the agents are based on mental aptitudes, using beliefs, desires, and intentions. This method facilitates the incorporation of CBR systems [1] as a deliberative mechanism within BDI agents, facilitating learning and adaptation and providing a greater degree of autonomy than pure BDI architecture. A deliberative CBP-BDI agent is specialized in generating plans and incorporates a case-based planning (CBP) reasoning mechanism. The purpose of a CBR agents is to solve new problems by adapting solutions that have been used to solve similar problems in the past [1], and the CBP agents are a variation of the CBR agents, based on the plans generated from each case. Next, the CBP planner used for the AGALZ agent to find a plan to give daily nursing care in the residence is presented. It is very important maintaining a map with the location of the different elements that take part in the system at the moment of planning or replanning. So use of RFID technology facilitates enormously the dynamic planning. Let $E = \{e_0,...,e_n\}$ the set of tasks that the nurse is assigned to.

$$a_j : \begin{array}{ccc} E & \to & E \\ e_i & \to & a_j(e_i)=e_j \end{array} \tag{1}$$

An Agent plan is the name given to a sequence of actions (1) that, from a current state e_0, defines the path of states through which the agent passes in order to offer to the client the better path according to each client's characteristics. Below, in (2), the dynamic relationship between the behaviour of the agent and the changes in the environment is modelled. The behaviour of agent A can be represented by its action function $a_A(t)\ \forall t$, defined as a correspondence between one moment in time t and the action selected by the agent. From the definition of the action function $a_A(t)$ a new relationship that collects the idea of an agent's action plan (3) can be defined.

$$Agent\ A = \{a_A(t)\}_{t \in T \subseteq N} \tag{2}$$

$$p_A(t_n) = \int_{t_0}^{t_n} a_A(t)dt \tag{3}$$

The variation of the agent plan $p_A(t)$ will be provoked essentially by: the changes that occur in the environment and that force the initial plan to be modified, and the knowledge from the success and failure of the plans that were used in the past, and which are favoured or punished via learning. *O* indicates the objectives of the agent and *O'* are the results achieved by the plan. *R* represents the total resources and *R'* are the resources consumed by the agent. The efficiency of the plan (4) is the relationship between the objectives attained and the resources consumed

$$E_{ff} = \frac{\#(O' \cap O)}{\#R'} \tag{4}$$

Where # means cardinal of a set. The objective is to introduce an architecture for a planning agent that behaves – and selects its actions – by considering the possibility that the changes in the environment block the plans in progress. This agent is called MRPI (most re-plan-able Intention agent) because it continually searches for the plan that can most easily be re-planned in the event of interruption. Given an initial point e_0, the term planning problem is used to describe the search for a way of reaching a final point $e_i \equiv e^* \in E$ that meets a series of requirements. Given a problem *E* and a plan *p(t)* the functions *Ob* and *Rc* accumulated are constructed from the objectives and costs of the plan (5). For all time points t_i two variables are associated:

$$Ob(t_i) = \int_a^{t_i} O(t)dt \qquad\qquad Rc(t_i) = \int_a^{t_i} R(t)dt \tag{5}$$

This allows us to construct a space representing the environment for planning problems as a vectorial hyper dimensional space where each axis represents the accumulative variable associated with each objective and resource. In the planning space, defined in this way, conform to the following properties:

1. Property 1: The representations of the plans within the planning space are always monotonously growing functions. Given that *Ob(t)* and *Rc(t)* are functions defined as positive, function *p(t)* expressed at these coordinates is constant or growing.
2. Property 2: In the planning space, the straight lines represent plans of constant efficiency. If the representations of the plans are straight lines, the slope of the function is constant, and coincides with the definition of the efficiency of the plan. $\frac{d}{dt}p(t) = cte \Leftrightarrow \lim_{\Delta \to 0} \frac{\Delta O(t)}{\Delta R(t)} = cte$

In an n-dimensional space, the extension of the straight concept line is called a geodesic curve. In this sense, the notion of geodesic plans can be introduced, defined as those that maintain efficiency at a constant throughout their development. This way, only the plans of constant efficiency (geodesic plans) are considered, due to the fact that they are the ones of minimum risk. In an environment that changes unpredictably, to consider any plan that is different from the geodesic plan means to accept a certain risk. The agent must search for the plan that determines a solution with a series of restrictions $F(O;R)=0$. In the plans base the plans sought are those that are initially compatible with the problem faced by the agent, with the requirements imposed on the solution according to the desires, and in the current state [1]. If all the possible plans $\{p_1,\dots,p_n\}$ are represented within the planning space, a subset of states that the agent has already attained in the past will be obtained in order to resolve similar problems. With the mesh of points obtained (generally irregular) within the planning space and using interpolation techniques, we can obtain the working hyperplan $h(x)$ (that encapsulates the information on the set of restrictions from restored experiences, by definition leading to a hyperplan since it verifies $h(x_j)=p_j$ $j=1,\dots,n$ and the planning space is the dimension n). From this, geodesic plans can be calculated and and the variation calculation is applied. Suppose, for simplicity's sake, a planning space of dimension 3 with coordinates $\{O,R_1,R_2\}$. Between point e_0 and objective points f_s $f=\{e_1,\dots, e_m\}$ and over the interpolation surface $h(x)$, the Euler Theorem [7] guarantees that the expression of the geodesic plans will be obtained by resolving the system of equations in (6), where R_i is the function accumulated R, O is the function of accumulated O and L is the distance function on the hyperplan $h(x)$, $L=\int_h dl$.

In order to obtain all the geodesic plans that, on the surface $h(x)$ and beginning at e_0, allows us to reach any of the points $e^* \in f_s f$, a condition of the surrounding must be imposed: the initial point will be $e_0=(O_0,R_0)$. Once an efficient plan is developed, the plan around it (along its trajectory) are used to create a denser distribution of geodesic plans. The tool that allows us to determine this is called the minimum Jacobi field associated with the solution set [1]. $g_0:[0,1]\rightarrow S$ be a geodesic over a surface S. Let $h:[0,1]\ x[-\varepsilon,\varepsilon]\rightarrow S$ be a variation of g_0 so that for each $t \in (-\varepsilon,\varepsilon)$, the set $\{h_t(s)\}_{t\in(-\varepsilon,\varepsilon)}$: $h_t(s)$ for all $t\in(-\varepsilon,\varepsilon)$ are geodesic in S and they begin at $g_0(0)$, in other words, they conform to $h_t(0)=g_0(0)$ for all $t\in(-\varepsilon,\varepsilon)$. In these conditions, taking the variations to a differential limit (7).

$$\begin{cases} \dfrac{\partial L}{\partial R_1} - \dfrac{d}{dO}\dfrac{\partial L}{\partial R_1^{'}} = 0 \\ \dfrac{\partial L}{\partial R_2} - \dfrac{d}{dO}\dfrac{\partial L}{\partial R_2^{'}} = 0 \end{cases} \tag{6}$$

$$\lim_{t\to 0}\{h_t(s) = g_0(s+t)\} = \lim_{t\to 0}\{h(s,t)\} = \frac{\partial g_0}{\partial t}\Big|_{(s,0)} = \frac{dg_0}{ds} \equiv J_{g_0}(s) \tag{7}$$

The term $J_{g0}(s)$ is given to the Jacobi Field of the geodesic g_0 for the set $\{g_n(x)\}_{n\in N}$, and in the same way that the definition has been constructed, it is possible to give a measurement for the distribution of the other geodesics of $\{g_n(x)\}_{n\in N}$ around g_0 throughout the trajectory. Given a set of geodesics, some of them are always g* that, in their environment, have a greater distribution than other geodesics in a neighbouring environment. This is equivalent to saying that it presents a variation in the distribution of geodesics lower than the others and therefore the Jacobi Field associated with $\{g_n(x)\}_{n\in N}$ reaches its lowest value at J_{g^*}. Let's return to the MRPI agent problem that, following the recuperation and variation calculation phase, contains a set of geodesic plans $\{p_1,\dots,p_n\}$. If the p^* is selected with a minimum Jacobi Field value, it can be guaranteed that in the event of interruption it will have around it a greater number of geodesic plans in order to continue. This suggests that given a problem with certain restrictions $F(O;R)=0$, the geodesic plan p^* with minimum associated Jacobi field associated with the set $\{g_n(x)\}_{n \in N}$ is called the most re-planable solution. The behaviour model G for the MRPI agent is (8).

$$G(e_0, p_1, \cdots, p_n) = p^* \Leftrightarrow \exists n \in N / J_{g_n} \equiv J_{g^*} = \underset{n \in N}{Min} \, J_{g_n} \tag{8}$$

If the plan p^* is not interrupted, the agent will reach a desired state $e_j \equiv e^* \in f_s f$, $j \in \{1,\ldots,m\}$. In the learning phase, a weighting $w_f(p)$ is stored. With the updating of weighting $w_f(p^*)$, the planning cycle of the CBP motor is completed. In Figure 2, it is possible to see what happens if p^* is interrupted. Let's suppose that the agent has initiated a plan p^* but at a moment $t>t_0$, the plan is interrupted due to a change in the environment. The geodesic planning meets the conditions of the Bellman Principle of Optimality [3], in other words, each one of the plan's parts is partially geodesic between the selected points. This guarantees that if g_0 is geodesic for interrupted e_0 in t_1, because e_0 changes to e_1, and g_1 is geodesic to e_1 that is begun in the state where g_0 has been interrupted, it follows that: $g = g_0 + g_1$ is geodesic to $e = e_0 (t_1 - t_0) + e_1 (t_2 - t_1)$.

Fig. 2. Model for behaviour G(t)

The dynamic process follows the CBP cycle recurrently: each time a plan finds itself interrupted, it generates from the state reached so far, the surroundings of the plans from the case base and adjusts them to the new problem. With this it calculates the geodesic plans and selects the one which meets the minimum conditions of the associated Jacobi field. In this way the dynamic planning model of the agent G(t) is characterised as it is shown in the Figure 2. A minimum global Jacobi field J(t) also meets Bellman's conditions of optimality [3], in other words, a minimum global Jacobi field, must select minimum Jacobi fields "in pieces" (9).

$$J_{\min}(t) = \{J_{\min}(t_1 - t_0), J_{\min}(t_2 - t_1), \cdots, J_{\min}(t_n - t_{n-1})\} \tag{9}$$

If on the one hand, successive Jacobi fields generate one Jacobi field, and on the other hand, minimum Jacobi fields generate a minimum Jacobi field, the MRPI agent that follows a strategy of replanning $G(t)$ as indicated to survive a dynamic environment, generates a global plan $p^*(t)$ that, faced with all possible global plans $\{ p_n(t)\}_{n \in N}$, presents a minimum value in its Jacobi field $J_{g^*}(t) \equiv J_{p^*}(t)$. An agent has been formally defined that in a dynamic environment seeks plans that lend it greater capacity for replanning.

The CBP agent constructs plans in such a way that a plan is a sequence of tasks that need to be carried out by a nurse. A task is a java object that contains the date of the patient who requested the service, the description of the service and the time limits to carry them out, as can be seen in Table 1. For each task one or more goals are established, in such a way that that the whole task is eventually achieved.

Table 1. Time (minutes) spent on indirect tasks

Task	Data	
TaskId	36	
TaskType	32	
TaskDescript	Feeding (lunch)	
TaskPriority	3	
TaskObjective	0	
TaskIncidents	0	
PatientId	7	
PatientDependence	2	
MinTime	12:30	
MaxTime	15:00	
TaskResources	Food	1

4. Case Study

The Alzheimer ST Residence of Salamanca has been interested in improving the services offered to its patients and has collaborated in the development of the technology presented here, providing their know-how and experimenting with the prototype developed. This residence is intended for people over 65 years old, and has the following services and facilities among others: TV room, geriatric bathroom, hairdressing salon, medical service, religious attention, occupational therapy, technical assistance, terrace, garden, laundry service, clothes adjustment, infirmary, reading room, living room, room of visits, cafeteria, social worker, chapel, elevator, customized diet, and multipurpose room.

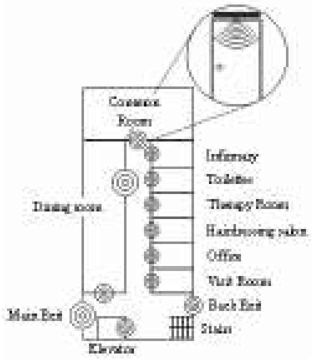

Fig. 3. Sensor positioning in the first floor of the ST Residence of Salamanca

Figure 3 shows a diagram of the first floor of the ST Residence of Salamanca containing the main facility rooms, while all the patients' rooms are located in the second floor. This residence has capacity for 60 patients, an average of 6 nurses, one social worker and 5 more employees with other responsibilities. We selected 30 patients to test the system, so the hardware implemented at the Residence basically consisted of 42 ID door readers, one on each door and elevator, 4 controllers, one at each exit, one in the first floor hall and another in the second floor hall, and 36 bracelets, one for each patient and the nurses. The ID door readers get the ID number from the bracelets and send the data to the controllers which send a notification to the Manager agent. To test the system 30 patient agents, 10 nurse agents, 2 doctor agents and 1 manager agent were instantiated.

4.1. ALZ-MAS

The characteristics of multi-agent systems make them appropriate for implementing into geriatric residences to improve health care of the patients. A multi-agent system is a distributed system based on the cooperation of autonomous agents.

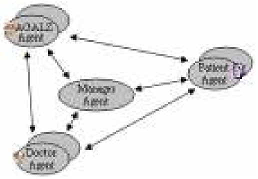

Fig. 4. ALZ-MAS architecture

The conclusions obtained after studying the requirements of the problem are that ALZ-MAS is composed of four different agent types as shown in Figure 4:

Patient agent manages the patient's personal data and behaviour (monitoring, location, daily tasks, and anomalies). Every hour validates the patient location, monitors the patient state and sends a copy of its memory base (patient state, goals and plans) to the manager agent in order to maintain backups. The patient state is instantiated at execution time as a set of beliefs and these beliefs are controlled through goals that must be achieved or maintained. The beliefs that were seen to define a general patient state at the ST Residence of Salamanca were: weight, temperature, blood pressure, feeding (diet characteristics and next time to eat), oral medication, parenteral medication, posture change, toileting, personal hygiene, and exercise. The beliefs and goals used for every patient depend on the plan (treatment) or plans that the doctors prescribe. The patient agent monitors the patient state by means of the goals. To know if a goal has been achieved or has failed, it is necessary to maintain continuous communication with the rest of the ALZ MAS agents, specially with the AGALZ agent (through which the nurse can communicate the result of her assigned tasks). At least once per day, depending on the corresponding treatment, the patient agent must contact the nurse agent. The patient agent must have periodic communication with the doctor agent. Finally the patient agent must ensure that all the actions indicated in the treatment are taken out. Patient agents run on a central computer

Manager agent plays two roles the security role that controls the patients' location and manages locks and alarms; and the Manager role that manages the medical record database and the doctor-patient and nurse-patient assignment. It must provide security for the patients and medical staff and the patients, doctors and nurse assignment must be efficient. This assignation is carried out through a CBR reasoning engine, that is incorporated within the Manager Agent. When a new assignation of tasks needs to be carried out to the nurses or from the patients to the doctors, both past experiences, such as the profile of the nurse or doctor, and the needs of the current situation are recalled. In this way tasks are allocated to a nurse. A nurse profile includes nurse's preferences such as hollidays, etc. Manager agent runs on a central computer.

Doctor agent treats patients. It needs to interact with Patient agents to order treatments and receive periodic reports, with the Manager agent to consult medical records and assigned patients, and with AGALZ agent to ascertain patients evolution.

AGALZ agent schedules the nurse's working day obtaining dynamic plans depending on the tasks needed for each assigned patient. AGALZ manages nurses' profiles, tasks, available time and resources. The generated plans must guarantee that all the patients assigned to the nurse are given care. The nurse can't exceed 8 working hours. Every agent generates personalized plans depending on the nurse's profile and working habits. AGALZ agents run on mobile devices, where each nurse can see her plans task by task. A plan can be interrupted for different reasons: a resource fails, a patient suffers some sort of crisis and requires unforeseen attention, a patient has an unexpected visit or visits to a patient gone on over the permitted time allowed.

5. Results and Conclusions

Figure 5 shows the average number of nurses working simultaneously (each of the 24 hours of the day) at the Residence before and after the implantation of the system prototype, with data collected from October 2005 to March 2006. The prototype was adopted on January 15th, 2006. The average number of patients was the same before and after the implementation. The tasks executed by nurses were divided in two categories, direct action tasks and indirect action tasks. AGALZ can act on the indirect action tasks. During the first period the problem was analysed, the residence was observed and data was retrieved. Finally averages of the time spent by nurses in the carrying out of the tasks for every patient were obtained, having into account that a task depends on the dependency level of a patient and the nurse skill. For the direct action tasks, the following times were obtained for each patient: 35' cleaning, 18' feeding, 8' oral medication, 30' parenteral medication, 25' posture change, 8' toileting, 60' exercise and 10' others. We are especially interested on time spent on indirect action tasks; daily average times obtained for every kind of task before and after the implementation for each task can be seen on table 2.

Table 2. Time (minutes) spent on indirect tasks

	Monitoring	Reports	Visits	Other	TOTAL
Before	167	48	73	82	370
After	105	40	45	60	250

The system facilitates the more flexible assignation of the working shifts at the residence; since the workers have reduced the time spent on routine tasks and can assign this time to extra activities. Their work is automatically monitored, as well as the patients' activities. The stored information may be analysed with knowledge discovery techniques and may help to improve the quality of life for the patients and the efficiency of the centre. The security of the centre has also been improved in two ways: the system monitors the patients and guarantees that each one of them is in the right place, and secondly, only authorised personnel can gain access to the residence protected areas. Nurses are easily integrated in the MAS by means of the ambient intelligence provided by AGALZ.

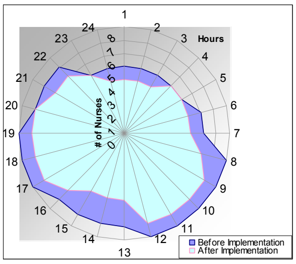

Fig. 5. Number of nurses working simultaneously

In the future, health care will require the use of new technologies that allow medical personnel to carry out their tasks more efficiently. We have shown some potential of deliberative CBP-BDI agents in a distributed multi-agent system focused on health care. In addition, the use of RFID technology on people provided a high level of interaction among users and patients through the system.

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