Assistive technologies for the disabled and for the new generation of senior citizens: The *e*-Tools architecture.

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In this paper we present our exploratory ideas about the integration of agent technology with other technologies to build specific *e*-tools for the disabled and for the new generation of senior citizens. '*e*-Tools' stands for *Embedded Tools*, as we aim to embed intelligent assistive devices in homes and other facilities, creating ambient intelligence environments to give support to patients and caregivers. In particular, we aim to explore the benefits of the concept of *situated intelligence* to build intelligent artefacts that will enhance the autonomy of the target group during their daily life.

Keywords: Assistive Technologies

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1. INTRODUCTION

The growing importance of the role that Artificial Intelligence (AI) – specially Knowledge-Based Systems (KBS) – is playing in medicine to support medical practitioners in making decisions under uncertainty (see [30]) by means of software solutions, is clear. Also, in medical scenarios in which many individuals are involved in a decision-making process or when their decisions and actions have to be coordinated, *Agent-Based Technology* (software systems composed of intelligent *Software Agents*) is getting an increasing role to a) model the processes (see [19]), and b) model the decision making processes (see [28]), but most of the current applications are centred in the information dimension of health care management (see §3.2.1).

Robotics is another field with growing applications. Robots are moving away from factories into environments such as private homes, in order to assist people in (very simple) daily routines. However, there are fewer projects investigating the use of autonomous robots technology for disabled and elderly people. Much of this work is devoted to the creation of electric wheelchairs that can autonomously navigate through an environment (just as a robot would do) [76]. Nevertheless, there are also some promising uses of technology stemming from in the robotics field (sensors, artificial vision) to create other services such as patient position tracking.

Ambient intelligence (AmI) builds on three key recent technologies (some of them barely a decade old): *Ubiquitous or Wearable Computing*, *Ubiquitous Communication* and *Intelligent User Interfaces*. *Ubiquitous Computing* means integration of microprocessors into everyday objects like furniture, clothing, white goods, toys, etc. *Ubiquitous Communication* enables these objects to communicate with each other and the user by means of *ad-hoc* and wireless networking. Finally an *Intelligent User Interface* enables the inhabitants of the AmI environment to control and interact with the environment in a natural (voice, gestures) and personalised (preferences, context) way [25].

The senior citizens represent a fast growing proportion of the population in Europe and other developed areas [13]. In an attempt to look for more appropriate solutions to meet the particular needs of this subset of the population, this paper is about envisioning the future use of all these technologies in which software agents, robotics technology, and information networks will be integrated into everyday environments, rendering access to a multitude of services and applications through easy-to-use interfaces, especially designed for the disabled and the senior citizens.

We are clearly thinking of applications that can be circumscribed to well-know, quasi-structured domains (i.e. places with predefined components such as a house, a hospital floor, etc) assuming that they are stable, that there exists enough information about them, and that the environment is somehow able to interact with a computational system (for instance, by providing information to the system). Recent advances in embedded computing and wireless communications make it possible to envision putting *intelligence* in every appliance, into the structure of hospitals, homes and, in the long term, even on every street corner (see [41]).

Future applications should be based on:

- Firstly, medical and social understanding. They are necessary to analyse in depth problems faced by disabled and senior citizens.
- Secondly, new assistive technology that help on facing those problems.

Assistive technology must aid disabled and senior citizens in their daily tasks. It can be enabled through:

- Innovative mechanisms by which physical and software agents coordinate sensing, cognition, reasoning, and actuation in well-known environments. Our target population require that this coordination be done effectively and securely.
- Flexible interfaces supporting the interaction between electrical and mechanical devices and people with a range of capabilities and needs.

The use and creation of new technologies for the disabled is crucial, as for this group of people assistance is not merely a matter of *doing* the same things more quickly or in a simpler way with the aid of an *e*-tool. For them it is a matter of *being able* to perform those tasks independently and, maybe, to learn how to perform new tasks in order to enhance their own autonomy.

The rest of this paper is organised as follows. In §2.1 we introduce the problem of disability and give some figures of its impact on society. Then in §2.2 we will discuss the interaction problem of senior and disabled people with technological devices. In §2.3 we address the issues of safety and soundness that are mandatory in systems integrating various technologies in a single platform. In §3 we address the possible uses of assistive technologies in building services for the senior citizens, review some of the current applications and give our own proposals for this field. Afterwards, in §4 and §5 we will introduce some futuristic but feasible (and very appealing) applications of assistive technologies, presented from the technical and the social and healthcare perspectives. Finally, in §6, we make some reflections about the future of this technology.

2. DISABILITY AND THE SENIOR CITIZENS

2.1. Ageing and disability

The ageing of the population today is without parallel in the history of humanity. Increases in the proportions of older persons (60 or older) are being accompanied by declines in the proportions of the young (under age 15). Nowadays (2002), the number of persons aged 60 years or older is estimated to be 629 million[1]. This number is expected to grow to almost 2 billion by 2050, when the population of older persons will be larger than the population of children (0-14 years) for the first time in human history. Fifty-four per cent, the largest share of the world's older persons, live in Asia. Europe has the next largest share, with 24 per cent. Around the world, the population of older persons is growing by 2 per cent each year, which is consid-

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[1] According to the Second World Assembly on Ageing Madrid, Spain 8 -12 April 2002

erably faster than the population as a whole. The older population is expected to continue growing more rapidly than other age groups for at least the next 25 years. The growth rate of those 60 or older will reach 2.8 per cent annually in 2025-2030.

The world has experienced dramatic improvements in longevity. Life expectancy at birth has climbed about 20 years since 1950, from 46 years to its current level of 66 years. Of those surviving to age 60, men can expect to live another 17 years and women an additional 20 years. 80 years or older people are currently increasing at 3.8 per cent per year and comprise 12 per cent of the total number of older persons. By the middle of the century, one fifth of older persons will be 80 years or older [52].

The increasing number of people affected by chronic diseases is a direct consequence of the ageing of the population. Chronic illnesses, such as heart disease, cancer and mental disorders, are fast becoming the world's leading causes of death and disability, including the developing world. In fact, according to the World Health Report 2001, noncommunicable diseases now account for 59 per cent of all deaths globally.

Two examples of highly invalidating diseases requiring medical assistance and/or institutional care are represented by *Alzheimer's disease* and *stroke*.

Alzheimer's disease (AD) is the principal cause of dementia in the elderly, affecting about 15 million people worldwide. The earliest symptom is usually an insidious impairment of memory. As the disease progresses, there is increasing impairment of language and other cognitive functions. Analytic and abstract reasoning abilities, judgment, and insight become affected. Behavioural changes may include delusions, hallucinations, irritability, agitation, verbal or physical aggression, wandering, and disinhibition. Ultimately, there is loss of self-hygiene, eating, dressing, and ambulatory abilities, and incontinence and motor dysfunction. Last stages of the disease use to lead to an institutionalisation in some kind of facility specialized to treat such cases. But this solution not only has a high cost (institutionalisation accounts for more than 66% of the costs associated to people with severe dementia), but also is harmful for the patient, that is placed in a unknown environment with unknown people.

Stroke is the most disabling chronic condition. It has this dubious honour due to the effects of stroke impact on virtually all functions: gross and fine motor ability, ambulation, capacity to carry out basic and instrumental activities of daily living, mood, speech, perception and cognition. Stroke represents a heterogeneous category of illness that describes brain injury, usually sudden (i.e. haemorrhages, vasospasms, thrombosis). Therefore, in each case the retraining and adaptation process to neurological handicaps depend on the nature of the underlying anatomic abnormality and not on the cause of such abnormality. About 200 people per 100.000 population will have a first ever stroke every year. Their mean age is about 72 years, and men and women are affected in roughly equal numbers. Stroke may have a devastating impact of patients' lives.

In both developed and developing countries, chronic diseases are significant and costly causes of disability and reduced quality of life. An older person's independence is threatened when physical or mental disabilities make it difficult to carry out the basic activities of daily living such as bathing, eating, using the toilet and walking across the room, as well as shopping and meal preparation. One or more diseases can be involved in causing disability; at the same time, a single illness can produce a high degree of disability. Therefore, disabled people are a very heterogeneous group, comprising a wide spectrum of function. This ranges from mild impairment and/or disability to moderate to severe limitations [10]. Moreover, the concept of disability itself is not always precise and quantifiable: this concept is not agreed upon by people who consider themselves to have a disability, professionals who study disability, or the general public. This lack of agreement is an obstacle to all studies of disability and to the equitable and the effective administration of programs and policies intended for people with disabilities. To facilitate agreement about the concept of disability, the World Health Organization (WHO) has developed the *International Classification of Impairment, Disabilities, and Handicaps (ICIDH-2)* and the *International Classification of Functioning, Disability and Health* (*ICF*).

The health environmental integration (HEI) concept has been expanded recently [64,65]. It was originally presented as a framework to study how humans and machines interact and complement each other along the ICIDH-2. Now-a-days, AT therapeutics are directed at both the person and the environment. The objective is to enhance HEI by using devices to neutralize impairments. By neutralizing impairment, there is an expansion of people's potential to enter into, to perform major activities within, and to fully participate according to the structure of the surrounding physical and social environments.

2.2. The interaction of disabled people with technology

According to the National Health Interview Survey (NHIS)[2] 1990 results, more than 13.1 millions American people (about 5.3% of total population) use AT devices to compensate their physical disabilities. Potential benefit of AT in improving functional self-dependency of disabled patients, well known in rehabilitation practice, has been reported in a number of legislative acts in different countries.

In the analysis, design and final creation of disabled-oriented devices, it is mandatory to keep in mind the interface problem, either because of a severe mental or mobility dysfunction or the usual complex relationship among elder people and new technologies [59]. The Rehabilitation Engineering Research Center on Technology Evaluation and Transfer (RERC-TET) (Buffalo, NY, USA) has focused on consumer-identified needs and preferences regarding several categories of assistive technology. According to the classification of Batavia and Hammer [8], 11 criteria have been identified that disabled patients consider important when selecting assistive devices: among others, *Effectiveness*, *Reliability* and, mainly, *Operability* – the extent to which the device is easy to use, is adaptable and flexible, and affords easy access to controls and displays. A listing of product categories which RERC-TET's consumers determined to be in high need of new or improved products comprises:

- Related to wheeled mobility: a) manual wheelchairs, b) wheelchair cushions, c) battery chargers, d) wheelchair tires, e) wheelchair tiedowns and f) van lifts and ramps.

- Other devices: a) voice input interfaces, b) voice output reading machines, c) portable ramps and d) workstations.

Fig. 1. An example of modern electric-powered wheelchairs.

The extreme difficulty with which persons with severe disabilities have been taught to manoeuvre a power wheelchair is an example of difficult interaction with AT: 9 to 10% of patients who receive power wheelchair training find it extremely difficult or impossible to use the wheelchair for activities of daily living; 40% of patients reported difficult or impossible steering and manoeuvring tasks; 85% of clinicians reported that a number of patients lack the required motor skills, strength, or visual acuity. Nearly half of patients unable to control a power wheelchair by conventional methods would benefit from an automated navigation system. These results indicate a need, not for more innovation in steering interfaces, but for entirely new technologies for supervised autonomous navigation [27].

Our main target is to address the needs of the future generation of senior citizens. It is of our belief that this new generation will be technologically savvy [3] and because of this fact will be more demanding. This represents in itself a challenge and an opportunity to further develop new AI technologies and tools and to integrate them assuming that the new future will bring a real Ambient Intelligence that will incorporate properties of dis-

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[2] This study was co-sponsored by National Center for Health Statistics (NCHS) and National Institute on Disability and Rehabilitation Research (NIDDR)

[3] A promising example that supports this claim is Japan, where nowadays even the elder people in the countryside areas have adapted to technologies such as the last wave of mobile phones, attracted by the appealing services that are provided by Japanese phone companies through their wireless network.

tributed interactivity (i.e., multiple interactive devices, remote interaction capabilities), ubiquitous computing, and nomadic or mobile computing (i.e. location awareness as explained in §5).

2.3. Safety and Soundness

Even though the domain of application is restricted to a quasi-structured, *situated environment* where *small* changes may appear but the most important landmarks will remain stable for long periods, this does not exclude that the domain remains dynamic and therefore *unexpected* changes may arise; therefore, the system needs to solve these unforeseen situations without entering in malfunctioning states. This implies that these systems need to exhibit an intelligent goal-oriented behaviour and yet still be responsive to changes in their circumstances.

However, as observed by Fox & Das [28], the use of heuristics or rules of thumb to solve problems seems unlikely to inspire confidence. In this domain the safety of users imposes bigger restrictions and the systems must be extensively tested – possibly off-line – to ensure effectiveness and performance of the devices. Therefore, *safety* should be one of the main concerns in the design of disabled-oriented devices. One possible option is to add a safety management layer in those systems. Likewise, the creation of safety plans is mandatory. That is a set of procedures and criteria that specify *what* the system is supossed to do when, but it deals specifically with hazardous circumstances and events [28].

This is an open issue that has to be further discussed and that should be included in the new technologies for the disabled and senior citizens, as well as in any agent-based application for healthcare tools.

3. ASSISTIVE TECHNOLOGIES

Assistive technology devices can be very useful to provide supportive services for individuals who require assistance with the tasks of daily living. Their use can be not only applied to people with cognitive impairment caused by aging factors but it can be extended to any disabled and handicapped people[4], in order to ensure an acceptable level of autonomy. By proposing *substitutes for* (or rather *extensions to*) nursing homes (i.e. Assisted Care Facilities), such assistive devices will help to reduce the patient's dependency (even from the psychological point of view) specially regarding the activity of daily life and improving his/her quality of life. Such supportive services are also helpful to the caregivers of those patients. In the patient's home environment, technology may aid non-professional carers (relatives, friends) in their efforts, contributing to lengthen the time spent by disabled and elderly individuals in their own home and to postpone the need for institutionalisation. In the hospital environment, such technologies may lead to a reduction of expenses, as increased autonomy of patients would lead to reduced nursing costs, and to a better use of the time and expertise of qualified nursing personnel.

There are some open and promising lines of research [5] in this field as:

- Assistive technology: devices that aid with mobility [46] [74], medication management, and household tasks.
- Cognitive Aids: technology that supports declining cognitive skills, including reminders, task instruction, and methods to reduce cognitive effort.
- Passive Monitoring: devices and reasoning systems that recognize the elder's activity and learn to detect abnormal situations (see §4).
- Decision-making: reasoning systems that respond to situations and the elder's needs by interacting with devices in his normal environment, interacting with the elder, or contacting caregivers.
- Human factors: interfaces that meet senior citizen's needs and capabilities – motor, sensory and cognitive (see §3.2.3).
- Adaptation: techniques to recognise the elder's changing capabilities.

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[4] From now on, we will use terms such as *patient* or *user* to refer not only to people with cognitive impairment caused by ageing factors but to the disabled and handicapped people.

[5] A good example is the AAAI2002 workshop on automation as Caregiver [1], which is focused in uses of AI in Elder Care

3.1. Issues to be solved

Services targeted to disabled people should be capable of solving the following problems:

- *Monitoring problems*: the creation of devices that can track several signals from sensors placed in the patient and autonomously decide, with a sound reasoning method, if the patient is in a safe condition or there is something abnormal that recommends to call for assistance (an alarm in the case of a Care Facility, an automatic phone call with an synthetic voice in the case of the patient's home).
- *Mobility problems*: The creation of devices (power wheelchairs) that are easily driven by people with mental and physical dysfunctions, and that are capable of autonomously taking decisions about *where* and *how* to go with the limited, even noisy inputs from the user and from the environment.
- *Cognitive problems*: the creation of devices that can assist the patient to recover from small memory loss. A good example is the (quite frustrating) situation where the patient is able to *Remember what but not where*[6] it is located. This is one of the most thrilling problems to be solved, as it requires a combination of technologies (e.g. a set of devices monitoring the user actions and linked with sensors and positioning systems installed in the room, all them interacting through wireless communications).

Solving or reducing the impact of these problems in the daily living may ease the healthcare and social interaction of a senior citizen person alone. Also it may delay their institutionalisation by prolonging the period of relative independence of individuals.

3.2. Integrating technologies to create intelligent assistive devices

There are several technologies that are useful to provide supportive services for physically or mentally disabled people.

3.2.1. Autonomous Agents

Autonomous intelligent agents are capable of understanding their environment and of independently determining and reasoning how to use their own resources in order to reach a desired goal [75]. Such agents can be either physical (robots) or software components.

Autonomous Robots are physical agents that perform tasks in the real world autonomously. They differ from classical and industrial robots in that they do not have a fixed sequence of actions previously programmed but a set of possible actions that are chosen to be performed depending on given goals or/and information about the environment. Therefore, autonomous robots present more adaptive behaviour and are capable of dealing with environments that cannot be completely controlled.

In the case of robots, *autonomy* is often related to *mobility* [35], and thus, the main task performed by autonomous mobile robots is considered to be navigation. Different techniques are applied to solve navigation problems depending on the different features of the environment such as:

- Its nature: it can be indoors [67], outdoors [38], planetary [36] or underwater [31]);
- The level of control over it: if it remains stable, if landmarks can be added [11], etc.
- The information available: if there is a map or if it is unknown [43], if changes can be monitored, etc.

A robot interacts with the environment through its actuators and sensors; therefore, navigation techniques also depend on the sensors a robot is equipped with. For example:

- Laser, ultrasonic (sonar) and infrared sensors are used to measure distances [26];
- Pressure switches and bumpers serve to detect collisions;
- Wheel encoders and Global Positioning Systems (GPS) help to compute location;
- Vision systems are used to recognize landmarks and targets [29].

Nevertheless, planning and positioning are two key aspects that must always be solved in any autonomous navigation problem. However, although many research efforts have been undertaken in this direction (see [42] for an overview), few of them have focused so far on disabled or elderly people [48].

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[6] A related neuropsychological study of the *Remember what but not where* problem has been carried out in [18]

Software intelligent agents are entities that interact with a *virtual* environment, obtaining information and exchanging it with other agents. Their reasoning capabilities allow them to do complex tasks such as allocating resources, coordinating the action of heterogeneous systems, or integrating information from different sources.

Most of the actual agent-based technologies in medicine could be classified, following [61], as:

- Patient centred information management [62]
- Cooperative patient management [2] [71]
- Patient monitoring and diagnosis [39]
- Remote care delivery [9]

However, all these applications are centred in the information dimension of the health care management. Until now, in the case of senior citizens or elderly people, applications of software agents have been directed towards the integration in society of this population subset via the use of virtual communities, trying to make Internet technology accessible to them (i.e. [9] [22]).

The use of this agent-based technology could be easily conceived to help solve other problems that at first look are very small and easy but that could help to enhance the quality of life of some people. An example is given by cognitive problems such as where the patient placed some item (the *Remember what but not where* issue). In restricted environments such as a house or a hospital, a software agent may help to trace the location of the desired object by keeping track of the *usual* places where this object should be or of the last time it was used and/or placed. This may require a shared memory between the intelligent agent and the environment, in a way that allows the agent to use some pointers in the environment to *remember* how things were the last time without having a complete memory of the whole scenario.

Another important area of application is safety management of technologies applied to health care. Software Agents' *proactiveness* could be used to perform an active safety management layer by the introduction of *guardian agents*, as in [28], that in a proactive way look for possible hazards and anticipate an answer or send an alert signal to the manager. For example, an intelligent wheelchair must never obey an order asking it to drive the user to the stairs nor to allow the composition of a plan to do that. However, it may override other conditions if the manager asks for it or in the case of an emergency – i.e. the agent should be able to recognise an emergency state – or to ask for help in the case of an impasse. To do this, it is necessary to build safety plans and to be able to reason about them.

3.2.2. Machine learning and other AI techniques

In addition to Artificial Intelligence (AI) techniques that are used in the Autonomous Agents area, assistive technologies may also take advantage of other AI techniques. These techniques can be applied to face both monitoring and mobility problems originated by elderly or disabled people. Think about the problem set out by the generation of a mobility plan to cross a very narrow door or navigate within a narrow and difficult corridor, or about the problem of recognising some impasse situations, or even emergency situations where disabled people are completely lost in their everyday environment. Other difficult states that are related to a certain degree of memory loss could also be faced, such as remembering where objects are located, or where objects were located last time they were detected. Moreover, there is the possibility to learn some new tasks or behaviours to enhance the autonomy and good performance of disabled people moving within a particular environment.

All these situations can be solved through some AI techniques such as planning, knowledge acquisition and machine learning tasks. All these tasks can be implemented following several AI approaches, but taking into account the highly advanced technological framework envisioned for the immediate future where ambient intelligence will provide the sensorial systems with large amounts of data and experiences in several forms, Case-Based Reasoning (CBR) seems to be a very promising approach.

The main idea of Case-Based Reasoning [33] is to solve new problems by using past successful experiences, rather than building new solutions from scratch. The key point in CBR is to remember similar past situations, known here as *cases*, and to reuse or adapt the old solutions to the current (new) problem. Also, there is the possibility to avoid some mistakes made in the past, and to learn from some new experiences as the system is running day after day.

Planning is a complex task. Good plans must be sequenced appropriately to ensure: (a) that late steps in a plan do not undo the intended results of earlier steps; (b) that preconditions of late steps in a plan are not violated by the results of earlier ones; and (c) that preconditions of later plan steps are fulfilled before the steps are scheduled [34]. As the number of plan steps increases, the computational complexity of projecting effects and comparing preconditions increases exponentially. In addition, a planner dealing with the real world [56] [20] must face the real world's complexity, including the fact that it is in many ways unpredictable, and that time is a limited resource – the time used for planning can reduce the time available for execution. In virtue of the features described above, CBR can address many of the issues raised in planning, affording the opportunity to anticipate problems [57], re-planning, adapting old plans to new situations, and recovering or repairing a plan that might fail at execution time [3].

3.2.3. Affective Computing

Emotions are an essential element of our daily lives and interactions with other people and objects around us. Traditionally, however, technology has been oriented towards supporting, improving or extending human capabilities in physical and "intellectual" (reasoning) tasks, disregarding the affective aspects of human cognition and interactions. This trend has started to change in recent years and a new field, generally known as *affective computing* [55], has emerged around the idea of bringing emotions into computing and artefacts. Given the richness of emotional phenomena, affective computing is concerned with building artefacts that can have (one or several) rather varied capabilities, such as recognising, expressing, responding to, facilitating, influencing, and in some sense "having" emotions. The models and techniques used to implement these capabilities are just as varied, bringing together concepts and technologies from fields such as (symbolic and behaviour-based) AI, human-computer interaction, signal processing, pattern analysis and recognition, animation, psychology, biology, etc. Research in this area has been very active in the last years, and numerous models and applications have been developed (see [55,15,16,54,6] for an overview and a selection of representative papers in various aspects of this field).

The potential benefits of integrating elements of affective computing into assistive technology for disabled and senior citizens are wide-ranging, and can be seen from two perspectives:

Improving the emotional state of the user These users are more prone to experience negative feelings such as loneliness, anxiety and frustration, and (mild or severe) affective disorders, given the increased difficulty they have to carry out daily activities, and the physical and social isolation they often suffer. Assistive technology that effectively *cares* for these users should also be able to recognize and monitor their affective states, respond appropriately to them, and try to elicit positive reactions and feelings from the users.

Using emotions as cognitive aids Recent findings in psychology and the neurosciences have evidenced the fundamental role that emotions play in other aspects of human cognition, even in tasks traditionally considered as being the sole product of reasoning, such as memory (see e.g. [58]) or decision-making [21]. Assistive technology should take into account not only the fact that some of the cognitive disorders suffered by these users can also carry affective impairments, but also that some aspects of emotions can be used to influence and facilitate other cognitive tasks.

Let us briefly illustrate with some examples how these general objectives fit within the research lines outlined at the beginning of §3.

- *Passive monitoring.* In addition to monitoring the vital parameters of patients, bio-sensors can be used to monitor their (coarse) affective states and detect negative affect such and anxiety and frustration resulting from inability to solve a task (e.g. [32]). This type of feedback could be used to indicate that the user is experiencing problems in performing an activity and might need assistance or emotional comfort.
- *Human factors and adaptation.* Affect-aware interfaces are a key element to achieve natural, user-centred and adapted human-machine interaction that promotes user acceptance. The use of affective computing and emotion modelling techniques permits to develop user-tailored interfaces that can detect and respond to the user's affective state in an appropriate way. They enhance interaction with users by allowing new tasks such as detection of user frustration or anxiety, development of a user's affective profile related to task achievement, or management of users' emotions through expressive elements – for exam-

ple soothing music played as a response to a state of anxiety, software or robotic agents that tailor their responses to the user's affective state (see e.g. [73] as an example of an affective pet robot used as therapeutic tool for the elderly), etc.

- *Cognitive aids.* Emotions often act as a memory biases that can reduce cognitive overload. Examples are phenomena such as mood-congruent retrieval – the fact that one tends to remember better contexts, situations and events experienced under a similar mood – and emotional memories – emotionally loaded memories are longer-lasting than emotionally neutral ones. These types of affective "markers" could be added to memory aid systems (for example, the CBR systems mentioned in the previous section) to make recall processes more efficient and better tailored to the autobiographical history of the user.
- *Decision-making.* Loss of memory is only one of the factors that can hamper efficient decision-making. Even if all the consequences that a decision will bring about can be remembered or foreseen, another major problem that can be present in disabled and senior patients is the lack of a good reason or motivation to decide between alternative courses of action. As pointed out by [21], emotions play a major role as value systems that make us prefer one alternative to the rest. In the context of assistive technology, emotions could help to support decision-making processes in two main ways. On the one hand, recalling or making the user aware of the emotional implications of different decisions (e.g. by the use of a reasoning or memory system) might help them select one option in a sensible manner. On the other hand, endowing assistive artefacts with internal motivational and emotional systems could allow them to make (simple) decisions autonomously (in cases when the safety of users is not compromised) in the same way they are used for decision making and action selection in autonomous agents and robots (e.g. [14,72,17]).

3.2.4. Wireless devices

Wireless technologies have created a revolution not only in technological achievement but also in social behaviours. Such technologies are daily used to control machines (remote controls), to bring communication to any place (mobile phones, beepers) or to provide services at any location (wireless network connections). The evolution in communication channels (to send and receive the maximum information with the minimum bandwidth use) has also come along with the increased availability of computational power inside small devices (PDA's, laptops, last-generation mobile phones).

Wireless links are usually based either on infrared or microwaves technologies. The main drawbacks of infrared based links is that direct visibility is required between the transmitter and the receiver. Also, resulting speeds are not very high. There are basically three different technologies for microwave based wireless communications:

- Wi-Fi (*Wireless Fidelity*): Wi-Fi is based on standard IEEE 802.11 for radio transmition in the ISM band (2,4 GHz aprox.). It was originally developed for unlicensed applications from 1 to 2Mbps, but the current specifications (IEEE 802.11b) allow as much as 11 Mbps [53]. It is presumed that future versions will allow up to 54 Mbps operating at 5 GHz. The coverage of this technology is equal to 100 meters in open space, but systems using directional antennae may cover several kilometers. This technology is widely spread and most laptops present a PCMCIA interface to support this technology. Other interfaces (PCI, USB or CompactFlash) are also available.
- GSM (*Global System for Mobile communications*) and GPRS (*General Radio Packet Service*): GSM and GPRS are operator controlled services. Avaliable *modems* are usually *dual band* (900-1800 MHz), but some models operate at 1900 MHz. GSM is basically oriented to voice communication, while GPRS provides a transition between GSM and third generation mobiles (3G) and supports data communication from 9.6 to 115 Kbps. It must be noted that GSM also support data communication but in a less efficient way (14.4 Kbps).
- *Bluetooth* and *ZigBee*: The *Bluetooth* and *ZigBee* technologies provide radio links of short and medium coverage to connect different devices without cables. They operate in the ISM band like Wi-Fi (standards 802.K.1 and 802.K.4 respectively). These technologies support point to point and point to multipoint connections by sharing bandwidth among several devices in a scheme known as *piconet*. In

these cases, bandwidth is controlled by a single unit configured as master. A *piconet* can yield up to 7 slave devices. If a larger coverage or a larger number of nodes is required, several *piconets* can be grouped into a *scatternet. Scatternets* typically present a hierarchical structure, where several slaves can be multiplexed in time and a master can be slave to a higher priority master.

In brief, currently *Wi-Fi* offers the best performance regarding coverage and speed. However, it presents a high power consumption. *GPRS* yields a low bandwidth and it is owned by mobile phone operators. *Bluetooth* is still under research, but it presents an adequate bandwidth and low power consumption.

All these technologies allow the creation of many applications and services accessible through small, portable devices, easily carried by people from one place to another, and are the basis of some of the solutions proposed in the following sections to connect patients and caregivers with their environment.

4. INTELLIGENT ASSISTIVE DEVICES FOR PATIENT MONITORING

One of the most promising uses of current technology is the creation of intelligent monitoring systems. Such systems would track several body signals and have reasoning capabilities to decide whether the patient is in a normal or acceptable state or whether s/he is entering into a *danger zone*, even proposing a diagnosis of the possible causes.

With such devices, residential care facilities for elderly and disabled people could be provided with intelligent beds equipped with embedded instruments for acquiring not only vital parameters (blood pressure, glycaemia, pO2) but even with sensors to evaluate pressure at the body-bed interface to prevent pressure-ulcers.

A mobile version of the same technology would consists in the creation of a portable device to do the tracking in people that can move within an area. Such systems could track body signals and trigger alarms when a danger situation has been detected, even sending an automatic call to the caregivers by the use of automatic phone diallers and voice synthesisers. Another use of such portable devices, wirelessly interacting with devices attached to the room walls, would be to monitor the movement of patients inside the room, and to identify behaviours like wandering as a symptom of dementia, or even to detect loss of equilibrium to prevent falls.

5. AN INTELLIGENT WHEELCHAIR

The scenario depicted in this section applies almost all the solutions presented in previous sections and it is based on a daily problem. Many disabled people[7] of all ages base their mobility in the use of a wheelchair and some times it is an power wheelchair. Usually those are driven using a mouse or joystick that allows the chair to navigate. However some disabled people experience considerable difficulties when driving a power wheel chair. Common manoeuvres are not at all easy (i.e. going out from a room). When the steering commands are not sufficiently accurate (due to spasticity, paresis or tremor in the upper limbs), a collision can result. And there is a group of target users that is unable to even use their hands.

For this sector of population, the solution is to provide them *Robotic Wheelchairs* with some reasoning capabilities that allow the Wheelchair to navigate in an area such as the patient's home or a hospital. The idea consists on the installation, on top of the hardware of a electric-powered chair, of a reasoning module that assists the user in the navigation. Most of the times the navigation is completely assumed by the reasoning module. The Tin Man series of robotic wheelchairs [46] are a good example of this kind of chairs. Similar ideas have been funded by the National Institute on Disability and Rehabilitation Research [51]. Yanco elaborated a complete survey of this kind of assistive robotic wheelchairs [76].

For people who still can walk there are other alternatives. One of them are the so-called *Assistive Robotic Walkers.* These devices can be seen as passive robots that can steer their joints, but require

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[7] In 1997, there were over 1.4 million wheelchair users of which 75% used manual versions. The remaining 25% used power wheelchairs. Power wheelchairs are used predominantly by people with both lower and upper extremity impairments resulting from cerebral palsy, high-level spinal cord injury, or muscular dystrophy.

a human to move them. Wasson *et al* [74] have been working in the development of these kind of personal mobility aids. Exactly which capabilities the walker exhibits at any time depend on the will and abilities of the user.

We will use as example the robotic wheelchair scenario, as the wheelchair has to show complete autonomy in tasks such as path planning, and be able to locate itself on an environment. Although we are thinking of a controlled situation in a quite well-known environment, structural elements like corridors, rooms, or halls may differ. Corridors in different places in the same building may have a various width, length and illumination sources. The number of rooms and their shapes depend not only on floor but also on the usage of those rooms, etc. Therefore some of the main problems to solve are: a) the interface with the user, and b) the navigation problem.

5.1. The interface with the user

Among the ideal features of the flexible interface we should include a) a voice interface, b) a touch pad interface, and c) a shared memory system. This interface should be able to adapt itself to the different user abilities to allow her to control the chair, navigating as smoothly and safely as possible (see §2.3). For example, the agent controller should be able to react to orders like *Stop!*, *Watch out!* or *No* when it is performing a given plan.

The main task of this interface is to interpret users' commands that could be noisy, imprecise and/or incomplete and transform them in *plausible* orders and plans (§5.2). Most of the times the user would be able only to say *what* is she willing to do, *where* is she willing to go (through a voice interpreter or a touchpad), leaving to the agent controller to figure out *how* to achieve it. These orders have to be integrated in the environment (by the creation of a shared memory as mentioned in previous sections) and follow the user's preferences. This implies that the agent supporting the interface should have knowledge about the current status of the world. In [48] different approaches to interfaces are presented.

Other existing approaches to create interfaces with an electric wheelchair are exploring the use of computing the face expression of a person to guide the chair and in this way take advantage of the user's non-verbal behaviours [50]. There are also some promising work in progress in the use of sensors or electrodes to use a) the *Electromyographic Signals* (EMG) generated by muscles in motion (jaw, elbow) [60] [47], b) the *Electrooculographic Signals* (EOG) generated by eyes and eyelids muscles [40], or even c) the *Electroencephalogram Signals* produced by the brain cortex [24,23], recognizing some distinctive neuron activation patterns (such as when the patient thinks in moving an arm) and use them as inputs.

5.2. The navigation problem

In the case of electric wheelchairs to be used with people with some mild/major physical and/or mental impairment, the chair should be the one that autonomously decides how to move through the environment.

Navigation is a key issue in robotics. It must be assumed that robots operate in unknown or dynamic environments, particularly since odometry is not precise due to slippage. Thus, robots cannot be pre-programmed to pursue a fixed course of action. Instead, they rely on on-board sensors to perceive the outer world and react to it. Sonar sensors are quite popular because, despite their obvious drawbacks, they are light, cheap, fast, easy to process and they yield a long detection range.

The navigation problem is briefed in the following questions: i) *where am I* (localization); ii) *where am I going?* (goal definition); and iii) *how do I get there?* (planning). Localization consists of determining the agent position in a global coordinate system and it is typically solved by measurement, correlation and triangulation. Localization is not easy. Most systems rely partially on odometry. However, slippage errors accumulate in an unbounded way. Furthermore, no odometric information might be available (global localization). Localization can be performed either using on-board or external active sensors (i.e. GPS). In dynamic environments, both a place learning and a place recognition technique must be combined for on-board sensor based localization. Place learning usually consists of storing the position of discriminating features of the environment (landmarks) [68]. Methods working with active landmarks to calculate the object position by triangulation are only feasible and efficient in controlled environments. However, if a mobile agent might not present on-board sensors, it is necessary to use external sensors to locate the mobile in a non-intrusive way (i.e. video surveillance). Several vision techniques can extract a mobile object from a background. If the camera moves, either optical flow calculation [7] or parametric estimation methods [63] are required. However, these methods tend to be computationally expensive. Real time implementations of these methods basically rely on decreasing the field of view or the resolution. It is possible to use non-uniform resolution image topologies in order to achieve high resolution only in the areas of interest of the image, where the mobile object is [70]. If the camera does not move and, hence, the field of view is mostly static, it is simpler and faster to rely on background substraction. The background can be either pre-recorded in absence of mobiles or extracted by averaging a sequence of several images so that moving objects are not included in such a background [45].

Navigation and planning are usually solved together. These schemes can be divided into two large groups [5]: reactive and deliberate schemes. Deliberative planning typically relies in a classical top-down hierarchical methodology where the world is represented and processed according to actions and events in a $sense - model - plan - act$ cycle. The main disadvantage of deliberative planning is its inability to react fast. Also, a reliable model of the environment is required. Reactive schemes directly couple sensors and actuators [12]. Global actions are the result of combining one or more reactive behaviours. Reactive schemes deal easily with several sensors and goals. They are also robust against errors and noise. However, they tend to be less efficient than deliberative ones and often fall in local traps. Hybrid systems combine deliberative and reactive schemes in order to achieve a better performance. Usually, low level control is performed in a reactive way whereas high level processing follows a deliberative pattern [5]. Most recent approaches to navigation rely on layered hybrid architectures: i) deliberative layers propose efficient paths to arrive to a goal; ii) these paths are tracked in a fast reactive way to handle unexpected situations.

Hybrid architectures typically need a representation of the environment for the deliberative layers. Representations are usually constructed according either to the metric or the topological paradigm. Metric representations reproduce explicitly the metrical structure of the environment [49]. Topological approaches [44] aim at representing the environment as a set of meaningful regions so that the map becomes a topological graph. Both approaches present complementary strengths and weaknesses, so recent research has been focused on achieving a hybrid representation. A topological-metric representation can be build either by annotating a topological representation with metrical information while it is constructed [37] or by extracting a topological map from a metric one [66]. When a representation is available, conventional path planning techniques like the A* algorithm can be used to obtain a path and reactive layers provide the low level control to track such a path in a reactive way.

5.3. A multi-level architecture

In order to provide the proper healthcare management (embedded monitoring and diagnosis functionalities) and to ease the relation of patients with other people and the environment we propose to build an integrated system where the environment (a home, a hospital) and the people inside it (patients, carers) are connected. This approach integrates Ambient Intelligence (sensors, automatic diallers, automatic cooling and heating system) with various technologies and AI paradigms such as Software Agent technologies, Situated intelligence, Machine Learning and Robotics.

Our proposal is to install on top of the hardware of a electric-powered chair a Multi-Agent System that controls the behaviour of the Wheelchair, monitors the patient's health and interacts with him through a flexible interface that gives to the patient, depending on their individual capabilities, more or less assistance in the navigation. Most of the times the navigation will be assumed by the agent controller.

In order to aid in navigation, the wheelchair will be wirelessly connected to the environment. The basic idea is to create active landmarks, that is, small wireless machines installed in some strategic places of an area to transmit local information to the mobile entity. Similar initiatives and ideas could be found in the design of intelligent buildings for the disabled and elderly people (see for example [4]) or the last generation of road traffic support systems.

In order to filter all the information received from the sensors and to send only relevant information to the patient's wheelchair, each room is monitored and controlled by a multi-agent system. This agent-based controller can proactively take decisions about the room conditioning or process the sensor signals in order to extract meaningful information (i.e. to track a given person in the room).

Figure 2 depicts an example of architecture. It is composed of three levels:

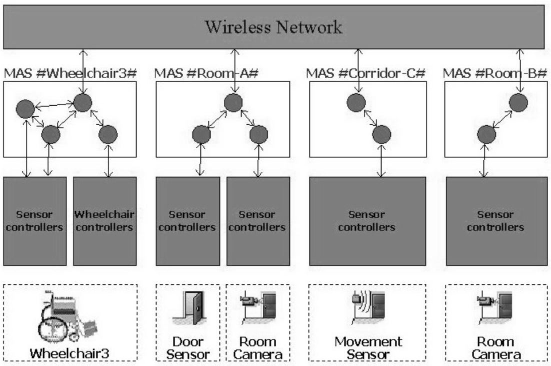

Fig. 2. The proposed multi-level architecture.

- In the lowest level there are all the devices that are connected to the environment. This level includes the cameras and sensors attached to the walls, patient monitoring systems, PDA's or other portable devices and intelligent wheelchairs.
- The next level is composed by the hardware controllers, that operate the devices and send the information to the next level. In the case of complex devices such as wheelchairs or cameras, this level also should perform tasks that need an immediate actuation of the device (in the case of the camera, a behaviour to follow a person that is being tracked, in the case of the wheelchair, an effective obstacle-detection and avoidance -*reactive navigation*- to ensure a high level of occupant safety).
- The third level is composed by agent-based controllers, which receive the information from the hardware controllers and are then able to reason about the knowledge they have about the state of the system, *what* information they need to improve their knowledge, *where* to get it, and *how* to get it. They can also reason about the *relevance* of the information they receive and distribute it to other agents or controllers that may need it.

There is also a wireless network that provides connection among layers. As not only the patients' wheelchairs but the environment and other people's portable devices have an agent-based controller connected to the network, the interaction and coordination issues can be solved by the software agents. This connection among the people and the environment may solve some of the daily problems patients and caregivers should cope with. One good example is the caregiver receiving information about the patients by means of a small wireless device such as a PDA connected to the environment by means of a wireless connection. The same system allows to route alarms: when a patient enters or will enter in a dangerous state, the multi-agent system detects this fact and broadcasts the message to some or every carer's PDA, depending on the state of the patient. This system may even send information to the patient's relatives, so they may receive on a periodical basis the state of the patient (filtering and adapting the information to the accurate level of detail).

The situation in this example can be easily managed by the proposed architecture as follows:

- Initially, either the caregiver generates a request for information on a given patient or the monitoring system detects a hazardous sensor reading and generates a request for a caregiver. This request is propagated to the third level of the architecture, where it can be handled by the software agents.
- The third level of the architecture interprets the request and asks for information from the lower levels of the architecture to decide a course of action.
- Despite the goal of the process, the location of either a caregiver or a patient is requested. In a small wireless network of active beacons, a given device is captured at most by two beacons so that its position can be inferred by triangulation. If no precise position information is required, this localization can even be performed by covering each room with a single receiver so that it provides information only on the presence of a given patient or caregiver in the room. The third level of the architec-

ture distributes a request for the position of a caregiver or patient to the first level architecture including the positioning devices of all rooms.

- If the caregiver has requested for information on a patient, a low level request for its monitoring sensors is directed to the located patient. These sensors transmit their readings to the closest node of the wireless network and the top level of the architecture redirects the information to the petitioner. If a danger situation has been detected, the third level of the architecture classifies the located caregivers according to their proximity to the patient in danger and a call is transmitted to the closest one.

Patients may also find the system very helpful. One good example is trying to go where another person (a relative or a caregiver) is. In the case where that person has the PDA connected to the wireless network, the environment may first locate in which room the patient and the person are[8]. Then, if both are in different rooms, the wheelchair multi-agent controller, with the help of the environment, builds a plan to go from one room to the other. The wheelchair then executes the plan, carrying the patient to the room where the target person is. If the target person moves from one room to another, the environment forwards this information to the wheelchair, which adapts the plan accordingly. The wheelchair may also report to a human supervisor and ask for help when encountering problems it cannot handle. This problem is analogue to the previously described one.

A more complex scenario happens when the target person has no connected device to the system, either because it is turned off or it runs out of batteries. In this case, the environment may use other devices such as movement sensors and cameras to locate the target. It is possible to use some knowledge about the target person (size, hair or even the places she uses to be or her patterns of behaviour) to localize that person in the environment, but recognition is classically a very complex problem unless the problem instance is heavily controlled, specially when the target may be moving in a non deterministic way. Hence, it is easier to keep a history of the position of every possible target in the environment when their devices are off. Basically, if a given device is turned off in a room, a video camera in the room starts to track all mobile objects inside. If a mobile leaves the room, the wireless network in the next room can detect whether it is the one with the device off. If such is the case, its position is updated. Thus, the system has the position of all unidentified mobiles available.

The key piece of the system is the patient's wheelchair. Apart of the connection that provides among the patient and the caregiver, the wheelchair enhances the patient's mobility. Naturally, one of the main advantages of working with a robotic wheelchair is that after the goal of a patient's request has been located in the environment, the wheelchair can move towards it in an unsupervised way. In order to increase the safety of the patient and to choose proper paths, the wheelchair also receives more information from the environment (such as trajectory between the goal and the departing point, provided by the agents in the higher level of the system).

As previously commented in §3.2.2, planning in the real world is usually complex because of unexpected situations or errors. We propose a hybrid architecture consisting of following a global plan provided by the agents in the third level but modulated by the reactive modules in the second level of the architecture (that is, the hardware controllers of the wheelchair). Basically, this approach (which extends the work presented in [69]) consists of two stages:

- Calculation of an efficient trajectory joining the current position of the wheelchair and its goal. To calculate this trajectory, a model of the environment is requested. This model is typically available in controlled indoor environments, but it is subjected to changes if obstacles are not bound to stay in the same position (i.e. a chair) or if there are other moving agents in the environment (i.e. caregivers). Hence, the robot modifies the available model of the environment according to its sensors readings. We propose to build and update a metric map of the environment because such maps are easily grounded. However, we extract a topological map from such a metric one to reduce the instance of the path-planning algorithm so that it can operate in a very fast way. We can use an A* algorithm to extract a

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[8] Wireless technologies such as Bluetooth support an inquire protocol to determine if a given node, identified by an unique physical address, is in its covered environment

path from the topological map. Following this approach, we can recalculate a path each time the goal changes its position or it is impossible to track the previous one further. A drawback of the approach is that the returning trajectory is not very precise but, nevertheless, it is extremely unlikely that the wheelchair would have followed any trajectory in a precise way in a non static environment so, as long as the trajectory joins the departure and arrival points in an efficient way, no optimal path is required.
- To track the calculated trajectory safely, a reactive approach like the well known potential fields can be used. In this approach, the goal acts as an attractor while all detected obstacles in the environment are repulsors. Since we already have a trajectory to follow, the points of such a trajectory also act as attractors. Hence, if the wheelchair has to move apart from such a trajectory because of an unexpected obstacle in the way, it will tend to return to the path as soon as it has avoided the aforementioned object. At the same time, the map of the environment is updated to show the position of this new obstacle. Hence, if the wheelchair falls in a local trap, we return to the previous stage using an updated map.

The system described is designed to be placed not only in a hospital (with professional caregivers) but also in the patient's home (where usually relatives play the role of caregivers). The advantages of the system are not limited to the controlled environment where the system runs, though. For instance, when the patient is in a hospital, relatives can be informed of the state of a patient. If the patient is at home, then a doctor may receive periodical reports. To do so, a timer can be set in the higher level to periodically transmit information about the state of the patient. Basically, this service is periodically triggered by an agent in the third level, which can be personalised to set how often the relatives or the doctors want to be updated, but when there's an important change in the state of the patient, the lowest level sends a petition to the third level to send an alert to the relatives. In both cases the agents in the high level filter the sensor information, adapt the information to the accurate level of detail and finally send it to the receiver by means of, i.e., a phone line, an e-mail or even a simple SMS[9] message.

6. CONCLUSION

Assistive Technologies can empower people with disabilities in ways that go far beyond medicine and surgery. The power of AT is still underrecognised by physicians; the potential of AT as an aid to patients is not fully exploited. AT could be seen as a therapy or as a commodity. There are limits on the extent to which rehabilitation professionals can help to improve someone's impairments and the broader environments in which he or she lives. AT is one of our most important rehabilitation therapeutics.

Although existing solutions that increase an independent living for senior citizens are currently available on the market, those are oriented to solve problems in a very poor manner and address a small subset of user's needs. As said in §1, most of them try to solve teleassistance problems, as in [22]. Other just offer specialised information services for the elderly.

We are putting forward this proposal to provide support for disabled and senior citizens. They may be applicable to a wide range of levels and needs, from use by intact healthy people and those with mild cognitive limitation, to providing support for caregivers of elders with moderate impairment and disability. Those agent-based systems are devised to provide aid in carrying out activities of daily life, and also performing tasks related to health care maintenance (including standardised behavioural assessments useful in medical monitoring). In addition, they will provide links to the outside world, including entertainment and information, and will facilitate communication with family and the environment. Physical environments that are age-friendly can make the difference between independence and dependence for some older people. Senior Citizens who can safely go outside and walk to a neighbour's house or to the park can increase fitness and mobility and are less likely to suffer from isolation and depression.

Among the most important obstacles that new technologies (such as software agents) find in real

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[9] Short Message Service, available in mobile phones with GSM technology.

applications in medical informatics we have: user expectations and acceptance, security and trust issues, lack of standards and integration with preexisting health-care systems. But acceptance of such systems will increase in the future, as senior citizens will be more and more used to interact and rely on advanced technological devices.

We propose here real integration of heterogeneous technologies to serve to disabled and senior citizen with problems as those described in §2 and §3.1 in a non-intrusive way and securing the personal information of the users. It is also important to notice that there are different efforts trying to solve small problems in this direction but an integral solution has not been approached yet.[10] A view of the future of this technology could be found in [25].

Within this perspective, the whole range of professionals involved in health care and disability can contribute to a more widespread awareness of the feasibility of newer ways and means of facing the problems connected to old age and disabilities. It is possible to study new ways through which scientific knowledge, the respect of autonomy, the experience of proximity with patients, the acceptance of citizenship rights, and the application of new technologies will allow the construction of a support network that can change the lives of people who are affected by such conditions.

It is clear that the use of this new technological devices will help to enhance the quality of life of disabled and senior citizens, their families and reduce institutional and societal costs.

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[10] The European Union has already funded some research (*Ambient Intelligence* key action I in the IST FP5, EU Telematics Initiative for Disabled and Elderly people TIDE) for creating such an environment with an specific focus on patient centred healthcare management, the disabled and the senior citizens. In the case of the FP6 program, it explicitly mentions *e*-care and embedded systems as being part of the priority areas of future research (priority thematic areas 1.1.2.i and 1.1.2.ii). Also, in the USA and Japan there is a strong research trend in this line.

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