MINES ParisTech

Centre de recherche en informatique

Adapted Virtual Agents to Improve Usability and Acceptance of Assistive Technologies for Older Adults Living with Dementias

First year thesis report

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1 Introduction

Assistive technologies for older adults, in particular those living with dementia, are often computer-based. The two main obstacles to the efficiency of these systems are their usability and acceptance. For a system to be actually useful to this user group, it has to be both user-friendly and likable. The user interface should thus be adapted to the user for the product's use to be both easy and enjoyable. This is particularly difficult when dealing with older adults living with dementia, cognitive impairment and psycho-behavioral symptoms such as apathy, anxiety or agitation. This is due to two main factors: firstly, age-related declines in cognitive and executive functions make the devices' ergonomics more critical to support user-friendliness. Secondly, cognitive impairment and dementia make it very difficult for the patients to learn how to use a new device and causes attentional and behavioral disorders. In addition, the attentional disorder caused by the disease makes the engagement with the device more and more difficult to obtain as the neurodegenerative process evolves. Thus, the possibility of a natural human-machine interaction is investigated, as it does not require any learning. Furthermore, multimodal stimulation by anthropomorphic characters is believed to catch the user's attention efficiently.

Some exploratory studies have shown promising results regarding the use of Embodied Conversational Agents (ECA) for Human-Computer Interaction (HCI) involving older adults with and without cognitive impairment, as well as with younger cognitively impaired adults. ECAs are virtual agent systems which feature a virtual character, usually displayed on a screen, able to produce human-like communication behaviors, by speaking and gesturing, and sensing capabilities to capture the user's input. These virtual agent systems depend on several technology domains including, but not limited to, speech recognition, speech synthesis, computer graphics, computer vision and artificial intelligence. In addition, imitation by a computer system of natural Human communication requires knowledge from several social sciences including psychology, linguistics and anthropology. In this quite recent and interdisciplinary field many open research questions are yet to address.

The main goal of this thesis work is to explore the possibilities and feasibility of ECA-based user interfaces adapted to the special needs of older adults living with dementia. To do that we adopt a user-centered design methodology. Then, we aim at testing the developed system and produce guidelines for assistive technology interface design based on our experience.

This report introduces the subject of the thesis in detail and discusses its challenges and pitfalls. Then, the intended work methodology and forecast planning are presented.

1.1 Motivation

Thanks to the progress of health care in the past century, life expectancy at birth has dramatically increased in developed countries. But this comes at a cost: demographic projections in France predict that by 2060, about a third of the population will be over 60 years old [Blanpain and Chardon, 2010]. This will greatly impact the financing of retirement pensions and healthcare. The aging of the world's population is accompanied with an increase of the number of elderly people affected by brain illnesses resulting in dementias, Alzheimer's disease being the most frequent one. The World Health Organization identified dementia in elderly people as a public health priority: 35.6 million people worldwide were living with dementia in 2010 and predictions suggest that this number will exceed 100 million by 2050 [World Health Organization and Alzheimer's Disease International, 2012].

Alzheimer's disease and other demential syndromes affecting older adults cause cognitive impairments as well as psycho-behavioral and communication disorders which make them dependent on caregivers. This situation often ends up with the institutionalization of the dementia sufferers until their passing [Luppa et al., 2010]. Taking care of dementia patients and, more broadly, of dependent older adults, with a decreasing working population and in a cost efficient manner is, undoubtedly, one of the main challenges of the next decades. In that sense, assistive technologies seem like a promising solution to support independent living of people living with dementia.

It is worth noting that these technologies not only aim at helping dementia patients perform activities of daily living but also at helping their helpers. That is to say, reducing the charge on both the informal caregivers, such as spouses or family members, and the formal caregivers, who are health professionals. In addition, assistive technologies featuring ECAs, however "intelligent" they may become, are not intended to replace human help but to complement it. Some studies have shown promising results that assistive technologies may positively impact the quality of life of dementia patients and their families as well as the costs of caregiving [Lapointe et al., 2013]. In this thesis work, we aim at improving the Human-machine interaction aspects of assistive technologies for them to be well adapted to the special needs of cognitively impaired older adults and support technology acceptance and widespread.

1.2 Context

This thesis work is conducted within a partnership between the MINES ParisTech computer science research center and LUSAGE laboratory at the Broca hospital in Paris. It is supervised by Pierre Jouvelot, PhD, senior researcher at MINES ParisTech, specialist of domain-specific languages. It is co-supervised by Samuel Benveniste, PhD, MINES ParisTech associate researcher and CTO of CEN STIMCO, the French national expertise center in cognitive stimulation. As for the Broca hospital, a thesis co-direction will be established in June with Anne-Sophie Rigaud, MD, psychiatrist, geriatrician, head of the hospital's geriatric service, head of the LUSAGE laboratory and president of CEN STIMCO. The thesis is also co-supervised by Maribel Pino, PhD, researcher in assistive technologies and ergonomics at LUSAGE. The LUSAGE laboratory is a "living lab" [Pino et al., 2012] specialized in healthcare and assistive technologies for older adults with cognitive impairment and their helpers. Its activities consist in applying co-conception methodologies to the design of assistive technologies by involving the target user group as well as other stakeholders (health professionals and engineers for instance) at every step of the technology design from specification to the final product. This methodology is intended to develop products that are actually adapted to the users' needs, that they will be able to use and may enjoy using. The living lab approach is covered in more details later in this report.

1.3 Research goals

This PhD thesis work aims at exploring the possibilities, feasibility and design issues of embodied conversational agents (ECAs) as user interfaces in assistive technologies for cognitively impaired older adults. This work consists in studying the contribution of an ECA-based interface to both usability and acceptance of assistive technologies. More specifically, we focus on three aspects:

1. **Interaction modalities and implementation issues:** The first aspect we investigate is how to design an ECA system which is able to autonomously communicate with cognitively impaired older adults to deliver a message effectively, guide them in the use of the assistive device and activate its functionalities on demand of the user. This implies determining what modalities of interaction should be sensed to properly understand the user's requests, needs and feedbacks with the limitations of sensor, computer vision and speech recognition technologies. It also involves studying how the ECA should behave to deliver prompts efficiently and manage the dialog through the interaction. This implies mobilizing efficiently the user's attention to create engagement with the system. Lastly, as ECAs feature sensing, decision and behavior production capabilities, we will look into description languages for behavior sensing, behavior synthesis and internal representation.

2. **Assessing the usability and acceptance of the embodied conversational agent system:** The second aspect of this thesis work is how to evaluate the system's usability and acceptance based on the users' responses. This, of course, requires running experiments with users from the target group. It also requires determining which metrics to use and finding a trade-off between collecting objective data, performing subjective observations and collecting feedbacks from the users. To assess the system's usability, task performance cues may be collected as well as data on user's engagement in the interaction with the system. Regarding acceptance assessment, questionnaires are usually used but it may get very difficult to collect feedbacks when dealing with cognitively impaired patients. Conversational engagement and other social-like attitudes toward the system may thus represent an interesting alternative. To do that, data representation and behavior description languages have to be investigated.

3. **Character features and personalization:** Last but not least, we would like to study the impact of character features and personalization on both usability and acceptance of the system. More specifically, what should the character look like and how realistic its animation, voice and behaviors should be to obtain optimal performances. We think it is important to figure out how to suggest natural verbal and non-verbal communication intents on the users' side while avoiding suggesting too high expectations regarding the virtual agents' capabilities to avoid counter-productive effects. This phenomenon is known as Mori's "uncanny valley" [Mori, 1970] for robots and may also occur with ECAs. Lastly, we would like to investigate how to adapt the character's features (gender, hair color, clothes, realism, personality, etc) and behaviors with respect to the preferences and cognitive capabilities of each user.

In addition to the intrinsic challenge of tackling the research questions discussed above, ethical matters (how intrusive and disruptive may the device be, how to run the tests in an acceptable manner, etc) as well as cost matters should be kept in mind. The low intrusion and disruptiveness are essential to the respect of human dignity and acceptance of technologies intended to be installed in people's homes. The costs should be kept as low as possible because many elderly people have low retirement pensions and this element is also critical to healthcare stakeholders. In this research work, costs are not part of the main considerations as this is more of an industrial development concern. On the contrary, ethical considerations are critical to the success of this work and mandatory in a care environment such as a hospital or a nursing home.

1.4 Progress of the thesis project, training and language skills

The first seven months of this PhD thesis work have mostly consisted in :

- Reviewing the literature on ECAs and related work. More specifically, I have collected, read and analyzed publications in several research fields, including ergonomics, human factors, medicine, psychology, human-machine interaction, social signal processing, social robotics and embodied conversational agents.

- Getting acquainted with the hospital environment, the multidisciplinary aspects of the subject and the living lab research methodologies. I have attended medical consultations with Professor Rigaud and had exchanges with other medical doctors about the conditions treated within the hospital.

- Helping to conduct experiments and focus groups. I have helped with an experiment on the recognition by older adults of emotions displayed by a robot. I have participated in a focus group about an assistive technology to help dementia patients find their personal belongings featuring engineers and designers. I have also participated in conducting another focus group involving elderly women to collect their opinions about robots at home, in which I have prepared and performed small demonstration scenarios with Aldebaran's Nao robot.

- Attending courses and training programs. The detail is given in the following table.

Course name	institution	type	hours
Neuropsychologie du vieillissement	Université Paris Descartes	scientific	14
Programmation multimédia interactive	Télécom SudParis	scientific	16
Point de départ	A.R.B.	professional	14

Table 1: Summary of the training hours completed

This 7-month period has also been dedicated to defining the research goals, and discussing partnerships with laboratories specialized in research on ECAs. Due to the complexity of these systems, it is necessary to rely on existing elements of ECA systems to reach the ambitious goals detailed in the previous section. This is especially critical regarding the animation and computer graphics aspects which are very time consuming and require both technical and artistic skills I do not possess. In addition, computer graphics is not the most relevant aspect of ECA design to focus on given the environment of this thesis. This is why it should be left aside to focus on the strengths of the living lab approach which hopefully will lead to a well adapted design for the specific needs of dementia patients and cognitively impaired older adults. In other words, we chose to leave some specific technical questions to researchers who are more capable than us to deal with them to focus on how to make an ECA-based interface truly adapted to the needs and personal tastes of our target group. Lastly, I have contributed to the following publication: J. Wrobel, M. Pino, P. Wargnier and A.-S. Rigaud, Robots et agents virtuels au service des personnes âgées : une revue de l'actualité en gérontologie. *NPG Neurologie - Psychiatrie - Gériatrie* 2014.

Regarding my English skills I am fluent in writing, listening, speaking and reading. I had the B2 level certified by the CLES (Certificat en Langues de l'Enseignement Supérieur) in 2011 and I achieved 100/120 at the internet-based TOEFL test in 2010, before studying abroad for a year in Canada.

2 Aging, dementias and assistive technologies

To begin this section, it is useful to define when people are classified as older adults. Although each person is different and age does not affect everyone the same way, scientific studies require a precise categorization. In most cases, people are categorized in the older adults group from age 60. In the literature the lower limit of this age category ranges from 50 to 65 years of age [Fisk et al., 2009]. With the increase of life expectancy, subcategories are sometimes used: the younger-old are individual from 60 to 75 years of age and the older-old which are people over 75 years of age.

In this section, age-related declines affecting the interaction with technological devices are described. Then the specific needs of cognitively impaired older adults are detailed. After that, the possibilities of assistive technologies to support independent living are discussed. Lastly, the results of studies involving older adults with or without cognitive impairment and cognitively impaired younger adults are presented before a conclusion is drawn.

2.1 Normal aging and effects on product use

Aging is usually accompanied with declines in cognitive and executive functions. In [Fisk et al., 2009], the authors identified what factors in aging may affect product use and show that ergonomics are more critical when designing for older adults than for younger people. A summary is given here.

2.1.1 Sensory functions

All sensory functions tend to decrease with growing age, though there may be important inter-individual variability. Though all five senses are affected, only vision and hearing, which are the most relevant, are detailed here:

- **Audition:** By age 65, 50% of men and 30% of women suffer hearing loss which makes social interaction more difficult. For most people over 70 year-old, frequencies above 4kHz become inaudible. Comparatively, the frequencies of the human voice are roughly between 100Hz and 3.5kHz. The standard telephone bandwidth is 4kHz. Hearing impairment is considered severe when an individual's hearing threshold is higher than 35dBA (acoustic decibels).
- **Vision:** Though vision impairments affect many people regardless of age, their prevalence increases with age. 70% of people over 45 need to wear glasses. With age, people tend to develop presbyopia, the inability to see close objects properly. In addition, the eyes' ability to adapt to darkness and the breadth of visual field decrease. Lastly, visual information processing slows with age.

Given these elements, it is necessary to make sure that the output sound is loud enough for most elderly people to hear. In addition, the low frequencies for voices and sounds should be privileged. Lastly, large display size should be used for people to see properly the ECA. That being said, in the context of cognitive impairment, visual acuity might not be the most limiting factor to select display size given the attention disorders affecting dementia patients.

2.1.2 Cognitive functions

In addition to sensory declines, cognitive functions also change when people age. Here, the terminology is introduced and some details are given, based on [Fisk et al., 2009].

The main cognitive processing components involved in interaction with products are working memory, semantic memory, prospective memory, procedural memory, attention, spatial cognition and language comprehension. As in a computer, *working memory* is an active memory. It contains information that has just been perceived or retrieved from long-term memory. To continue with the computer analogy, *semantic memory* is somehow equivalent to the hard drive. It is a long-term memory of acquired knowledge. *Prospective memory* corresponds to the ability to plan actions in the future. It allows remembering that an action should be performed at a certain time (meeting Mr. X at 2 p.m.) or what to do in response to an event (turning off the oven when the buzzer goes off, for instance). *Procedural memory* is knowledge about how to perform daily activities, for example, pushing the pedals harder to go faster and using the brakes to slow down when riding a bike. Some of these actions may even become somehow automatic. *Attention* can be defined as the process that controls awareness. It is limited and operates selectively on stimuli of the environment. It can be divided between sources of information and switched between tasks. *Spatial cognition* is the ability to manipulate images or patterns mentally, to project into a map for instance. Lastly, *language comprehension* is the ability to interpret written or spoken verbal information.

Only some of these cognitive functions show age-related declines. For memory, working memory declines the most and prospective memory is affected in a less visible manner. On the contrary, semantic memory shows minimal decline, though the access to the information it contains may be slower and less reliable. Procedural memory is also very well preserved for well-learned procedures, but older adults are slower and less successful at acquiring new procedures compared to younger adults.

Regarding attention, older adults may experience difficulties focusing on one particular stimulus when surrounded by other stimuli. This gets worse as the number of stimuli increases. In addition, they require more time than younger people when switching attention from a stimulus to another. As a result, elderly people may get distracted when too many stimuli are presented at the same time and perform poorly when a situation requires multitasking.

Eventually, spatial cognition declines with age whereas language understanding is not affected. Outside of cognitive and sensory functions, the other executive function that is affected by age is motor control: older adults move more slowly and less precisely than their younger counterparts.

2.2 Pathological aging: impact on independent living and product use

One of the consequences of living longer is the increase of pathologies and chronic diseases leading to disability. As mentioned in the previous section, not everybody age the same way. Some experience a healthy "normal" aging phenomenon, which is usually accompanied with the sensory and cognitive declines presented earlier. Others are less lucky and develop severe age-related pathologies (Alzheimer's disease is one of them) resulting in disability. According to [Pino, 2012] (pp. 14-15), three models of disability are frequently used in the related literature: A medical model, a social model and a bio-psychosocial model. From a medical point of view, disability can be defined as *"a direct consequence of a disease, trauma or other health condition, which requires medical care in the form of individual treatment provided by health professional"*. The social model *"considers disability as a socially created problem and not at all an attribute of an individual"*. Lastly, the bio-psychosocial model was proposed in the International Classification of Functionning, Disability and Health (ICF) [World Health Organization, 2002]. It takes both biological and social factors into account. Within this model, the term *disability* may refer to either an impairment in a body function or structure, a limitation to perform daily activities or a restriction to participate in everyday life situations.

In the context of this research work, the latest definition is probably the most suitable. Dementia and cognitive impairment in older adults comply fully with this definition: they are usually related to damaged structures in the brain (impairment of a body structure), this damages causing memory losses and other psychological and behavioral symptoms that affect performance of daily activities and social aspects of everyday life. In the next two subsections, the most frequent pathologies and their symptoms which affect the ability of an individual to perform activities and use technologies autonomously are detailed, based on [Pino, 2012], [Benveniste, 2010] and [Lapointe et al., 2013].

2.2.1 Mild Cognitive Impairement (MCI):

Mild Cognitive Impairment (MCI) affects 10 to 20% of people over 65 year-old. Its symptoms consist mostly in memory losses but it may cause other cognitive deficits. It may evolve in Alzheimer's disease after a few years. Two types of MCI can be distinguished: Amnestic MCI (a-MCI) and Non Amnestic MCI (na-MCI). In the first form, episodic memory, that is to say the memory of past events, is affected. This causes deficits in learning and recalling recently acquired information. In na-MCI, episodic memory is not affected but abnormal declines are observed in attention, spatial cognition or language comprehension. In addition, MCI patients can suffer from impairments in one or several of the cognitive functions listed above, regardless of the a-MCI/na-MCI classification. These patterns were established by Winblad *et al.* in [Winblad et al., 2004].

Regarding the ability to perform activities of daily living independently and to use technology products, older adults with MCI have it more difficult than cognitively healthy older adults. In the case of a-MCI, the learning process of how to use a new product may get very difficult. Though MCI patients maintain functional independence, pathological declines of their cognitive function cause them to be slow. They may experience difficulties in planning and completing complex tasks. In addition, MCI patients usually have poor judgement. All of this results in loss of effectiveness in everyday functioning.

2.2.2 Alzheimer's disease (AD)

Alzheimer's Disease (AD) is a neurodegenerative disorder. It is characterized by a progressive pathological decline in cognitive functions. It is the most frequent cause of dementia in older adults as it represents 60 to 80% of dementia patients [Pino, 2012]. However other types of dementia mostly differ by their causes but have more or less the same effects on the person's daily functioning. Here are listed the most common symptoms.

- Short-term memory loss. AD patients are unable to recall recent events, which is linked to working memory and episodic memory. This results in repetitive questioning and conversations, recurring loss of personal belongings, forgetting events and appointments, getting lost on a familiar route or not being able to pick up where they left when interrupted during a task.

- Executive disfunction. Demented patients experience great difficulties in planning and executing the sequential steps of a complex task. Even though they are able to execute each of the subtasks involved they have trouble finding the right order. For instance, they may go into the shower without taking their clothes off. This is linked to a deficit in prospective memory.

- Attention disorders. Demented patients get distracted very easily and often have trouble focusing on a long task. Visual attention impairment, in particular, makes it very difficult to follow fast-changing images.

- "Aphasia" is the inability to understand or to produce spoken or written language. This means that AD patients may be temporarily or permanently unable to recognize or produce written or spoken words they normally know. This may result in incoherent speech, misunderstanding, and other difficulties to communicate effectively with others.

- "Agnosia" is a deficit in recognition of visual or auditory stimuli not caused by a sensory deficit. People with AD may not be able to recognize the faces of their relative for instance. This can also cause difficulties to get dressed (putting clothes on back-to-front or inside-out), inability to find objects in direct view or to recognize signals such as warning signs.

- "Apraxia" designates a deficit in voluntary motor control that is not due to a paralysis or motor weakness.

- Psycho-behavioral disorders. People with dementia usually experience anxiety, agitation, emotional instability, apathy and depression. This results in wandering and socially unacceptable behaviors.

It is important to note that Alzheimer's disease and other dementias have high interpersonal variability. Though the same symptoms are usually observed in most patients, the levels may vary depending on the patient and the progression stage of the illness. The evolution of the disease can be very different in speed and intensity from a patient to another. Nevertheless, after about two years most patients become unable to live independently without the support of a caregiver on a daily basis. In addition, interpersonal variability is also observed: a given person with AD usually has good and bad days and may even experience changes within the same day.

However, some functions are well preserved in spite of the illness, even at advanced stages of the disease. Though demented patients experience great difficulties to consciously access the information stored in their memory, the information is not actually lost. Thus they are able to achieve learning through implicit and non-conscious memory processes. Procedural memory is one of the best-preserved capabilities and people with AD are still able to perform well-learned routines. This is why it is possible to condition new behaviors through repetition and exposure to recurring stimuli.

Another aspect of cognition that has received much attention in the research on AD is the ability to process and produce non-verbal behaviors. Though the verbal communication skills are very affected, the non-verbal communication capabilities are well preserved. This includes recognizing and expressing affects through facial expressions, prosody (variations in pitch and energy in the voice), gestures and body movements. Details on non-verbal communication modalities are given in Section 3.3. Lastly, though this is still subject to debate, personhood seems to remain well preserved in AD. As a result, people still have their personal tastes and interests as well as life-long habits.

This section should have given the reader a sense of the challenge of adapting a natural communication-based user interface to the special needs of older adults with AD or similar dementias. Based on the elements given above, the solution should be to adapt in a personalized way the user interface based on the remaining capabilities of each patients, as suggested by Lapointe *et al.* in [Lapointe et al., 2013] and by Alm *et al.* in [Alm et al., 2011], and according to their personal preferences.

2.3 How assistive technologies can help cognitively impaired older adults

To this day, the causes of dementia are still not clearly identified by researchers, thus few pharmacological treatment exist and their effects are, at best, to reduce slightly the progression of the symptoms. For this reason, non-pharmacological therapies are given more and more interest for dementia care because they can be both more efficient and less costly [Benveniste, 2010]. However, the aim of assistive technologies is not always therapeutic but can also be to support home staying instead of institutionalization and quality of life for dementia patients and their helpers, as well as reducing the cost of care. In this section, some details are given about the types of interventions allowed by assistive technologies and which aspect of daily living they support.

According to a recent survey on computer-based *"cognitive prosthesis"* [Alm et al., 2011], four categories of assistive technologies can be defined depending on what aspect of the patient's daily living are supported: daily activities (this includes washing hands or going to the bathroom for instance), social life, entertainment and creative activities. More broadly, assistive technologies aim to support:

- access to information, communication and social connexions;
- mobility, planning and daily tasks;
- needs for stimulation and entertainment;
- management of psycho-behavioral symptoms.

For the sake of briefness imposed for this report, few details are given here. The interested reader can also refer to a recent survey of ambient intelligence in healthcare [Acampora et al., 2013]. Finally, it can also be stressed that this classification is not the only one available. In an other review, Gillespie *et al.* propose to organize assistive technologies depending on which cognitive function is supported [Gillespie et al., 2012], according to the ICF classification of disabilities mentioned in section 2.2.

2.4 Embodied conversational agents, older adults and dementia

As stated in the introduction, some studies have shown promising results regarding the use of embodied conversational agents (ECA) in the context of older adults and cognitive impairment. Results in the literature on the accessibility and acceptability aspects are contradictory or not significant regarding some of the issues addressed in our case. Nevertheless, some results regarding older adults with or without cognitive impairment and younger adults with light to moderate cognitive impairment tend to show that:

- Cognitively impaired people perform rather better in a task when guided by a virtual agent than with a different interface such as text and speech (which is the most common control condition in the literature).
- Older adults without cognitive impairment perform at least as well when guided by a virtual agent as with another type of interface.
- Older adults do not necessarily prefer interacting with a virtual agent to interacting with an other kind of interface.

These results can be found in [Yaghoubzadeh et al., 2013, Ortiz et al., 2007, Morandell et al., 2009].

On other aspects, more reliable results can be found in the literature, but have not been verified for older people with strong cognitive impairment [Ortiz et al., 2007, Carrasco et al., 2008]:

- The use of a virtual agent enhances the user's attention and engagement.
- People interact with an anthropomorphic virtual agent in a natural way.
- Thanks to their human-like appearance, embodied conversational agents are perceived as trustworthy.
- Embodied synthetic speech is easier to understand than disembodied synthetic speech. A virtual agent conveys more information than a standard interface thanks to nonverbal behavior. The importance of lip articulation movements (sometimes called "visemes", or "visual phonemes") in speech understanding has been shown by McGurk and MacDonald in [McGurk and MacDonald, 1976].

Few studies were conducted in which ECAs were actually installed in people's homes. The most extensive study on an assistive technology for older adults featuring an ECA was conducted by Bickmore *et al.* in [Bickmore et al., 2013]. The article presents a randomized controlled trial (which is the norm to prove the effectiveness of medical interventions) of a virtual exercise coach for older adults. The study was conducted in Boston and included 263 participants each followed over a 12-months period. The aim of the system was to encourage sedentary older adults to walk more. Half of the participants (the intervention group) were given a touch-screen computer with the ECA and a pedometer. The other half of the participants (the control group) were only given a pedometer. The intervention group participants had the ECA system installed in their home for 2 months and were followed for 10 months after the intervention. The results show that participants in the intervention group walked significantly more on average than participants from the control group during the 2 months of the intervention. This effect persisted over the 10 following months, though the difference between the intervention group and the control group reduced. This clearly shows that ECAs have the potential to be actually used by older adults and that they can have a real impact on their habits. However, the results of this study suggest that the system should be installed durably in people's homes for the effects to be maximal.

Another study was conducted by Vardoulakis *et al.* in which a virtual companion for isolated older adults, intended to be installed permanently in people's homes, was proposed [Vardoulakis et al., 2012]. In this study, a "relational agent" was installed in the homes of twelve older adults for a week. The participants all lived alone but were not particularly lonely and their age ranged from 56 to 73 years old. The outcome was rather positive but the results are not very conclusive in terms of technology acceptance. In fact, the ECA system was remotely controlled by an operator in a Wizard of Oz-like setup but the participants were informed of it for obvious ethical reasons given that the system included a video camera. This is a source of bias because it caused some of the participants to be particularly concerned about their privacy. The Wizard of Oz methodology [Kelley, 1984] is normally intended to give the experiment participants the illusion that the system actually works on its own and is quite common in the literature on ECAs. In this case it could not be implemented properly. It is also important to note that the system is not intended to replace human contact. On the contrary one of its functionalities is promoting social integration by suggesting the participant to get a walking companion. A similar effort for the design of an ECA as a companion for older adults with memory impairment, was proposed in [Huang et al., 2012]. The main difference resides in the fact that the agent is claimed to be autonomous. In addition the authors propose a mobile system that can record information from the patient's life to enrich the conversation. However, no evaluation regarding the actual performances of the system and its acceptance was performed so far.

2.5 Conclusion

In this part of the report, information was given about the human factors of the target user group, the possibilities and encouraging results of the use of assistive technologies and the use of ECA systems by older adults with or without cognitive impairment. This gives a sense of the challenge we are facing and what factors should be considered to design a usable interface for elderly people with cognitive impairment.

The use of ECAs and assistive technologies for this public was shown to be promising. The pilot studies on ECAs give clues that acceptance and usability of such systems are achievable. However, a review of the literature shows a need for field studies and laboratory experiments featuring autonomous agents. This is interesting in the context of this thesis work as we are in a good position to conduct such studies in the laboratory or even install experimental systems in people's home. To support acceptance and usability of such technologies, personalization possibilities should be looked at carefully as several researchers agree on.

Finally, one could argue that ECAs are not able to provide a physical help and that the use of robots would be more appropriate but ECAs have other advantages. Firstly, they are potentially integrable in any computer-based technology, even on mobile devices. Secondly, they are very flexible and much easier to adapt to the needs and tastes of each user. Thirdly, robots moving around in a home may cause the beneficiaries of the intervention to fall whereas ECAs do not present that risk as they are confined to their virtual worlds. In addition, software is potentially much less costly than hardware. Lastly, several aspects of research on ECAs are common to social robots and thus transferable. For these reasons, we think that working on ECAs to assist older adults with dementia is relevant enough to justify the effort. In the following part, we go into the technical details of ECA systems design.

3 Giving machines social interaction capabilities

In this section we first discuss the existing modalities of interaction between man and machines. We then introduce the broad concepts of ECA design and go into some details about how to implement ECAs. Finally, we discuss what are the most promising and essential elements in the context of dementia care.

3.1 Social beings and unsocial machines

Around 328 B.C. Aristotle wrote *"Man is by nature a social animal"*. Since, scientists in various domains have identified biological structures that tend to confirm this statement [Vinciarelli et al., 2012]. In fact, a number of structures in the human body seem to be particularly adapted to interpersonal communication. Our ears are particularly sensitive to the frequencies of the human voice, our vocal tracts allow us to produce articulated sounds to form words and our brains are equipped with "mirror" neurons whose main function is to improve our awareness of other people [Vinciarelli et al., 2012]. This is why relying on people's natural verbal and non-verbal interpersonal communication capabilities seems like a good choice for interacting with cognitively impaired older adults.

Machines, on the contrary, though designed by humans and for humans, and as "intelligent" as they might be, are devoid of the most elementary communicative capabilities. As a result, people need to adapt to the machines' functioning and interaction modalities by learning how to use them through complicated interfaces. At the very beginning, computers were programed using punch cards. As computing technologies evolved, Human-computer interaction modalities have changed. Today, the most common Human-computer interface is the graphical user interface (GUI). It requires a display and can be controlled thanks to a keyboard and a mouse or by touching the screen. Touch display is today the preferred interface for mobile devices [Karlin, 2013]. As it is considered more user-friendly than classical GUIs (with a keyboard and a mouse), its use by older adults have been investigated and was proven to be as effective as for younger adults even with a small display size [Stößel et al., 2010].

However, age-related sensory and motor declines presented in Section 2.1 as well as low technology acquaintance of older adults do not necessarily make touch displays the ideal way of interaction for the elderly. The solution might come from an unexpected field of computer engineering: video games. Microsoft's Kinect sensor, initially introduced to play with the Xbox 360 gaming console, allows user skeleton and facial keypoints tracking almost out of the box thanks to the provided software development kit. This allows easy gesture and facial action recognition. This sensor has been used by many researchers in computer vision for human activity recognition and hand gesture recognition, amongst other things [Han et al., 2013]. As gestures are essential in natural interpersonal communication, this kind of sensor eases the work of social signal processing. The Kinect is particularly interesting as it also features microphones and can be used as the only sensor for multimodal interaction. In the next section, the design of embodied conversational agents is discussed.

3.2 Designing embodied conversational agents

Building embodied conversational agents (ECAs) is allowed by progresses in social computing and relies on several technologies, including speech recognition, speech processing, computer vision, computer graphics and artificial intelligence. All the elements are available, each having its own limitations, to somehow build socially interactive computer programs featuring virtual characters and called ECAs. To design an autonomous ECA, three elements are required:

1. **A sensing and analysis stage.** In this module, the user's input is sensed through external sensors (usually, a video camera and a microphone) and analyzed to extract information about user behavior.

2. **A decision stage.** This stage takes the information extracted in the sensing stage and decides what to do. That is to say, what behavior the ECA should produce in response to the user's input.

3. **A behavior production stage.** This stage produces the animation and sounds of the virtual character which compose the output sent to the user through a display and loudspeakers.

These three elements are put together as illustrated in Figure 3.2. Note that the process is sequential. However, there may be feedbacks from a module to the previous one. This figure was adapted from [Kopp et al., 2006, Scherer et al., 2012]. These papers present international efforts to harmonize ECA architectures as well as internal representation of sensed data, behavior planning and behavior realization. The first one ([Kopp et al., 2006]) presents the behavior markup language (BML) and the other one presents the perception markup language (PML). A third representation language, the function markup language (FML) is presented in [Heylen et al., 2008]. BML and FML are part of the SAIBA framework. This framework was adopted by most laboratories working on ECAs and even in some social robots (in [Le and Pelachaud, 2012], for instance). Though, in most cases, only BML is used. These languages are oriented towards behavior generation. They are presented in more details in Section 3.4. PML is quite new and has not spread as much so far. It is used to represent the sensed and analyzed input data.

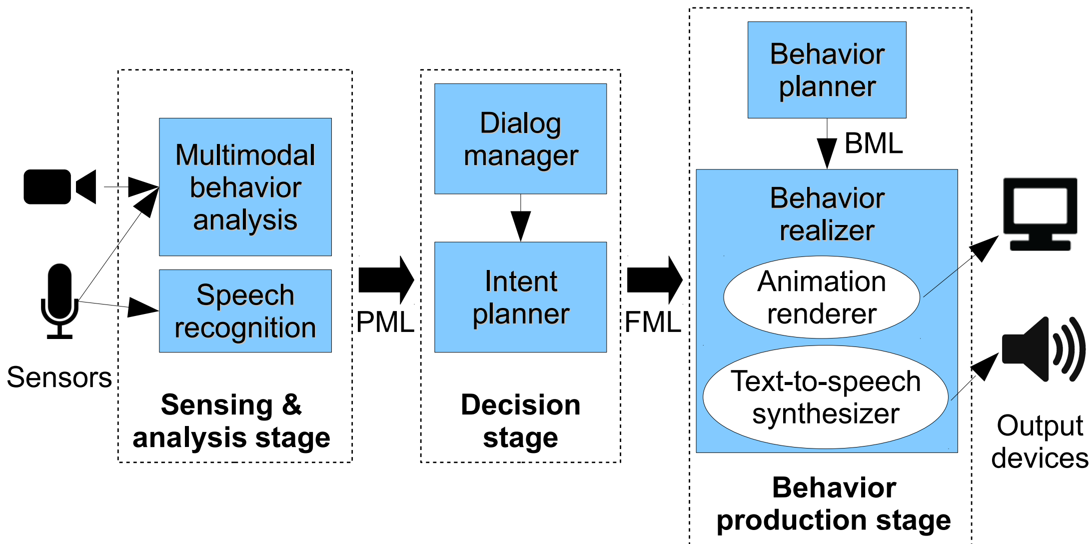

Figure 1: Typical architecture of an embodied conversational agent. Figure adapted from [Kopp et al., 2006] and [Scherer et al., 2012].

Though research efforts on animating ECAs and sensing social signals have been accomplished in the past few years, there is still a long way to go for computer programs to be able to interact in a fully natural way. Many research questions are yet to tackle: What should the ECA look like? More specifically, should it be anthropomorphic or animal-like? Should it be realistic or cartoon-like? Should it look like a male or a female? We could go on like that and this is just regarding the embodiment, that is to say, the virtual character's appearance. In the following sections, the sensing and interpretation of the user's input are discussed. Then, the existing behavior production systems are reviewed and more details about the internal representation are given.

3.3 Sensing and interpreting the user's communicative behavior

The last decade has seen the appearance of a new discipline of computer science and engineering called "social signal processing" (SSP) [Pentland, 2007]. This recent field aims at sensing, measuring, analyzing and modeling, in a computational and automated manner, the social behaviors of people for the machines to reach some kind of understanding of these "social signals" and to give them the ability to interact in a social-like way with humans. A recent review of the field can be found in [Vinciarelli et al., 2012].

Social signals are defined by Vinciarelli *et al.* as follows: *"Social signals and social behaviours are the expression of one's attitude towards social situation and interplay, and they are manifested through a multiplicity of non-verbal behavioural cues including facial expressions, body postures and gestures, and vocal outbursts like laughter."* [Vinciarelli et al., 2009]. In this section a short taxonomy is given based on [Vinciarelli et al., 2009], [Salah et al., 2011] and [Vinciarelli et al., 2012].

The first distinction to make when talking about social signals is between verbal and non-verbal. Verbal social signals are just spoken words. Non-verbal social signals are every other aspects of human social interaction conveying information but are not words. This includes physical appearance (height, somatotype), gestures, body postures (forward or backward), space (interpersonal distance), facial expressions, eye gaze and vocal behavior (which is not limited to prosody but also includes linguistic vocalizations, non-linguistic vocalizations, silences and turn-taking). It is worth noting that "verbal" and "semantic" are not synonyms as non-verbal also may contain semantic information. In fact, non-verbal messages may be more important than verbal messages as the latest only account for about 7% of social perception.

The types of messages conveyed by non-verbal behavior cues are the following:

- **Affective/attitudinal/cognitive state:** information about how one feels (joy, stress, etc.), what attitude that persons adopts in a given social context (disagreement, politeness, etc.) or how available to converse the person is (inattention, fatigue, etc.).
- **Emblems:** Culture-specific actions that convey semantic information such as a wink or a raised thumb.
- **Manipulators:** actions used to act on objects of the environment or self-manipulation such has head-scratching or lip-biting.
- **Illustrators:** actions accompanying speech such as pointing or gazing at an object to designate it or raising eyebrows.
- **Regulators:** conversational mediators such as head nods or smiles. They are mostly used to give feedback in a conversation.

The analysis by a computer of social signals is essentially composed of three steps: sensing the environment (through video and audio recording mainly), detecting people in the incoming signals and interpreting their behaviors. There are many aspects that were studied by social signals researchers but in the context of this thesis work we are mainly interested by four aspects: the verbal messages, the attention payed to the ECA or conversational engagement of the user, the attitude of the person towards the ECA and the affective state of the person. To address these issues, there are several modalities that are used in the state of the art and that can be combined to achieve better robustness. Verbal information can be retrieved through audio-based speech recognition, which might be combined with lip-reading [Lan et al., 2012] but machine lip-reading techniques are not very reliable so far. Attention can be estimated by looking at eye-gaze [Ishii et al., 2013], posture [Sanghvi et al., 2011] and back-channeling [Rich et al., 2010] (feedbacks given in a conversation to show conversational engagement). Some or all of the previously mentioned cues can even be combined with facial expressions [Peters, 2005]. The social attitude or *"interpersonal stance"* towards the agent can be estimated through body postures and vocal behavior [De Carolis et al., 2012]. Another interesting cue to characterize the attitude of the person towards the system is the "approach avoidance behavior" [Gómez Jáuregui et al., 2013]. Lastly, the affective or emotional state of the person can be estimated through all previously mentioned modalities and is investigated by many researchers. A state-of-the-art of affect recognition based on body movements can be found in [Karg et al.,] for instance.

3.4 Producing artificial social behavior

The issues of producing artificial social behaviors are not only linked to computer graphics but also to modeling facial expressions, body movements and speech according based on psychology, anthropology and linguistics. It has been investigated by researchers around the world for about a decade. As mentioned earlier in Section 3.2, efforts were made to unify behavior generation frameworks using description languages for internal representation: the Behavior Markup Language (BML) and the Function Markup Language (FML).

BML offers a description at the behavior level. That is to say facial actions, lip movements, speech output or basic gestures. It allows to describe a behavior by putting together its basic elements and synchronizing them thanks to dedicated tags. It is an XML language and can be generated on the fly to be fed to a behavior realizer which analyzes the instructions specified to produce a character animation accordingly. BML is the most widely used and at least two BML realizers are publicly available: SmartBody [Thiebaux et al., 2008] and MARC (Multimodal Affective and Reactive Character) [Courgeon and Clavel, 2013].

FML works at higher level of abstraction and allows defining communication intents directly. It is then interpreted by a behavior planner and translated into BML. The only platform that is fully compliant with the SAIBA framework that uses both FML and BML, and from which figure 3.2 was adapted, is Greta [Niewiadomski et al., 2009]. It is thus particularly interesting for our purpose and has the great advantage of being developed at Télécom ParisTech which makes it easily available for us. We met Catherine Pelachaud, the leader of the Greta team, in April, to discuss the possibilities of collaboration.

In addition to the behavior description and realization, producing artificial behaviors also requires text-to-speech synthesis. But to design ECAs as long-term assistants, some researchers argued that it is not sufficient to produce believable behaviors, and have proposed long-term relationship models. In addition, the "intelligence" aspects of ECAs are not supported in BLM, nor is it in FML, and dialog managers have also been proposed in the literature and are usually included in the frameworks.

3.5 Conclusion

To build an ECA system adapted to the special needs of demented or cognitively impaired older adults, the most promising approach seems to rely as much as possible on available technologies and code reuse. Due to the complexity of ECAs and of each of the underlying technologies, our best hope is to bring together simple existing tools and combine them smartly in an incremental way. This will allow us to determine what are the most relevant behavioral cues to interpret, how should the agent and to tackle the research questions mentioned in the first part of this report.

More specifically, Greta should be the best character animation platform available regarding our needs as it is controlled at high level of abstraction and includes lip-synchronization and speech synthesis in French. For the sensing and user detection aspects, the Kinect sensor and its software development kit, which together allow user tracking, facial keypoints detection, voice recognition and sound source localization out of the box is particularly interesting. The algorithms to interpret behaviors are not determined yet, but interesting options are cited in Section 3.3. Lastly, the decision and intelligence aspects can be very simple as the context of dementia and cognitive impairment imposes the interaction to be kept as simple as possible and built on binary choices. In that sense, the cognitive limitations of the patients can make things easier for us as the main limitations of the state-of-the-art concern verbal speech recognition and artificial intelligence.

4 Approach, methodology and forecast planning

To tackle the challenge of using natural interaction for patients to use assistive technologies, our approach mostly focuses on the problem of attention and engagement. More specifically, we will first study the algorithmic estimation of engagement which was identified as key to maintaining the user in the interaction. Then, we will study the attention-catching strategies through the agent's behavior to obtain a first engagement of the user and maintain it throughout the interaction with the device. It is useful to monitor the user's attention to develop strategies to recapture it when the person got distracted and it could also provide cues about usability and technology acceptance.

Regarding technology acceptance, the user's attitude towards the ECA, assessed computationally from behavioral data, is also a metric we could use to rely on objective data. This can also be taken into account in the interaction loop because it is a way of giving some kind of control to people who experience difficulties expressing themselves for the system not to be too disruptive.

Lastly, looking into the estimation of the emotional or affective state of the patient opens improvement possibilities. Getting this information as an input could allow to adapt the ECA's behavior depending of the emotional context of the user. For instance, determining when the patient is anxious could allow triggering a distraction strategy to calm him or her down, such as playing a soothing music that he or she likes.

To develop our system we apply the "living lab" methodology mentioned in section 1.2. It is an iterative design method which consists in involving the target user group at each step of the development cycle. It takes elements form user-centered design methods [Fisk et al., 2009] and action research [Benveniste, 2010] (pp. 40-42) combined with ethical analysis. It requires running many tests in a trial/error framework. This is illustrated in Figure 4.

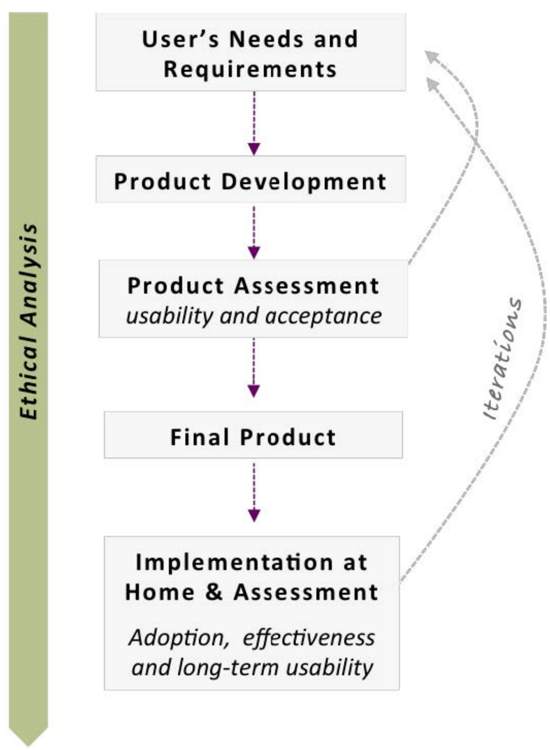

Figure 2: Assistive technology development cycle. Figure taken from [Pino, 2012].

To test some modules of the system without having to implement all parts of the complex ECA system, the Wizard-of-Oz [Kelley, 1984] testing methodology can be used. It consists in remotely controlling the system without letting the test participants know to give the illusion that it works on its own. This allows getting information on the impact of specific design choices on the interaction whitout having to worry about the performances of the ECA's automation. Regarding the implementation of the system, the experience in using description languages, such as BML or PML, gained through testing will allow us to evaluate their relevance to adapt ECAs for demented patients.

Lastly, regarding the time-frame, the first test system should be developed by the end of 2014. Then, we plan on testing a new iteration every 6 months. The last 6 months of the PhD project will fully be dedicated to writing the thesis. This is summed up in figure 4 in which the white "D" stands for deliverable.

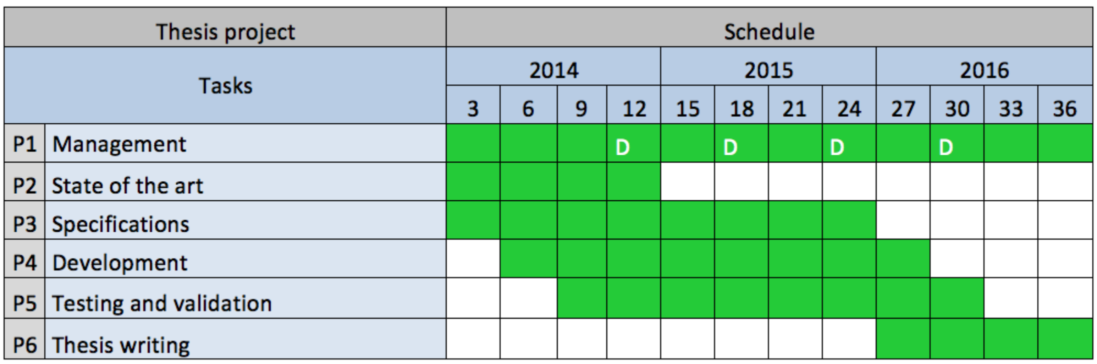

Figure 3: Work plan diagram

5 Conclusion

In this report, the motivations, goals and challenges of this PhD thesis research work have been presented, as well as the approach and methodology to tackle the goals we set ourselves. In summary, Alzheimer's disease and similar dementia are insidious degenerative illnesses which sadly affect more and more people around the world. Cognitive impairment and dementia cause disabilities to the patients which makes them unable to perform activities of daily living on their own. This becomes a heavy burden on their families and caregivers and cause apathy and depression to the patients. Assistive technologies are believed to be a sustainable solution to improve the patients' quality of life, lighten the burden on the care givers and even have therapeutic effects on the patients to slow down the progression of the disease while reducing healthcare costs. In this thesis work we aim to address the issues of usability and acceptance of assistive technologies by introducing adapted natural communication-based interfaces via the use of embodied conversational agents. These systems are highly complex and we aim at implementing them through a user-centered and ethically-driven iterative design process.

Our goal is to produce some useful knowledge and technology to improve the quality of life of many older adults suffering from dementia and their families. Based on the experience gained through iterative implementation and testing, we will attempt to produce guidelines for the integration of ECAs in assistive technologies. Amongst other things, the adequacy of behavior description languages in the context of dementia will be assessed and recommendations about the interaction modalities, the ECA's appearance and its behavior will be produced. Lastly, one could ask the question of the usefulness of our work compared to pharmaceutical research. But as long as no cure for Alzheimer's disease will be available in the foreseeable future, we try and do what seems achievable in the next two years.

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