Embodied Ambient Intelligent Systems

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Abstract. The information and communication technology (ICT) we interact with in daily life is more and more distributed in the environment (the so called intelligent space). Most of these devices have increasing calculation capacity and therefore the potential to contribute to an overall distributed calculation power and therefor a processing intelligence. These so called intelligent nodes can for example provide context information (sensors) or act as an interface through which we interact with the whole system. At the same time interaction with such ambient intelligent systems gets more and more complex. The interaction with the system is not any more human to single machine, like we were used in the interaction with the personal computer (PC) or personal device, it's an interaction with a system which is around us and ubiquitously distributed in our surroundings.Research projects are currently investigating the possibility of users interacting with avatars. The advantage of avatars is, that the systems gets an embodiment and a personality. The complexity of the underlying distributed system is hidden from the user. The user is interacting in a natural dialogue with a system which has a personality, cognitive and effective capabilities, human like memory structures as well as perception and awareness. The paper presents the concept of ambient intelligent systems and the challenges regarding user interaction. It shows how the interaction of such systems can be improved by the embodiment of an ambient distributed system. Based on three current research projects working with avatars this concept is explained and first results are presented.

Keywords. ambient intelligent systems, avatars, user interaction, Embodied Conversational Agents, cognitive systems

1. Introduction

The distributed intelligent systems we interact with will be self adaptable and can be extended or reduced in functionality by integrating or reducing the so called intelligent nodes. We will interact with these intelligent systems via a human-machine dialogue in a free manner. To give this system a personality, avatars can be used. It makes the conversation direct and addressed. Cognitive systems are defined as a category of technologies that uses natural language processing and machine learning to enable people and machines to interact more naturally and to extend and magnify human expertise and cognition [1].

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This paper describes the experiences and achievements towards these paradigms based on three different projects. It shows how the conversation with avatars can be applied in ambient intelligent systems and how it is accepted by users. It explains projects with the concept of the adaptable architecture and intelligent nodes which can be used for such ambient spaces. Robots can be special intelligent nodes in such future systems. Anyway also in this case the robot should serve as one part (node) in an intelligent space. The paper describes also this concept in more detail. Ramos at al. [30] mentioned already in 2008 that agents in ambient intelligence environment can be a good way to model, simulate, and represent meaningful entities such as rooms, cars, or even persons. Further research has shown that especially the conversation with avatars which represents a human like intelligence increase the interaction with system and technology.

Intelligent human computer interaction is becoming increasingly important as users face increasing system complexity and information overload when interacting with ambient intelligent (AmI) environments. Intelligent user interfaces promise to support more sophisticated and natural input and output (e.g., voice, gestures), to enable users of AmI environments to perform potentially complex tasks more quickly, with greater accuracy, and in a personalized way (e.g., considering preferences, context) [32]. With this new class of interfaces, rather than communicating with a single computer or device, users are able to communicate with their environment via intelligent embodied interfaces, such as avatars, which support multimodal dialogue-based interaction and have perceptual competences enabling them to interpret the state of the user and what is going on in the environment. The agent dynamically adapts to the current context and situation and gracefully handles information from multiple sources in the AmI environment. This facilitates users in communicating with the underlying system/devices which may be very complex. The overall aim of an embodied interface is both to increase the interaction frequency of the user with the intelligent environment and at the same time to increase interaction effectiveness by improving the quality of interaction.

2. Ambient Intelligence Systems and Smart Cognitive Spaces

The AmI concept refers to a digital environment that proactively, but sensibly, supports people in their daily lives [5] and [8]. It describes the vision of an ambient environment in which technology becomes ”invisible” and embedded in the natural environment, present where needed, activated by means of simple interactions, in line with our senses, adaptive to user and context needs.

The cognitive system research addresses smarter ways of human - system interaction as well as cognitive system architectures. In the concept of the Smart Spaces, the cognitive capabilities are distributed in the environment. This offers several advantages concerning sharing context information, sharing sensory information, sharing cognitive capabilities inside the system etc.

There is an emerging trend that recognizes that ambient intelligence will focus more and more in auto-adaptable and self-configuring systems in order to support smarter habitats. This concept envisages environments where the needs, moods and lifestyles of the inhabitants are taken into consideration to provide better services and life conditions, leading to the pursuit for symbiotic and user-centric environments focused on the peoples well-being [34].

Intelligent systems need to be capable of systematically interpreting and understanding the semantics of data patterns which have been acquired by different types of setups and situations. The advantage is that such systems can automatically adapt and evolve according to their users' needs [8]. This can enhance the confidence of users, allowing thus an easier integration of the system in their daily routines. The main requirement for reasoning is context-awareness. Context has been defined in literature as a any information that can be used to characterize the situation of an entity[33]. An entity is a person, place, or object that is considered relevant to the interaction between a user and a cognitive system, including the user and the system themselves. To refine reasoning and to integrate context about a person living within his/her home environment in the broadest sense possible, models must be developed that are capable *i)* of using a priori knowledge, either hard-coded or from experience, and *ii)* of evolving over time. This information will be used in the identification of activities of daily life (ADLs) in order to provide the correct services to attain end-user goals. This may be achieved through classical use of cognitive perception-action loops by simple surveillance. Alternatively, a way of short cutting the artificial cognitive systems access to the current context would be through the information gathered from engaging in a natural dialogue with the subject.

Due to the complexity it is clear that the handling of user interaction in ambient intelligence environment is manifold. AmI systems are highly distributed and need dynamic configuration in terms of the integrated devices and the installed applications. Context awareness, personalization, and multimodality are critical for supporting more natural interaction and optimizing the interaction in an adaptive way. Different efforts tried in the past to work on platforms with a high level of freedom in developing and deploying applications without needing to care about the available Input/Output (I/O) infrastructure. An independence of applications from the available I/O infrastructure can help to share mechanisms and manage such a complex scene more adequately. The key idea behind such a framework is the natural distribution of tasks according to the real scene using a middleware solution supporting seamless connectivity and goal-based interoperability [6].

The distributed system is composed of many so called "nodes". As with humans, two entities cannot cooperate and understand each other if they do not share the same language and the same semantics, the same "understanding of the world". Intelligent nodes that operate in a smart distributed environment need to share and learn the contextual information so they can consequently adapt their services to the user's needs and desires. In the same way, a smart environment with intelligent nodes presence and operation is no longer a static space, but a dynamic environment where the smart systems need to operate. This highlights the necessity of sharing a common framework that allows reciprocal contextual exchange between the intelligent nodes and the smart environment.

In relation with the ambient intelligent systems concept the following technologies for achieving it are mentioned: smart materials, microelectro-mechanical systems and sensor technologies, embedded systems, ubiquitous communications, I/O device technology, and adaptive software [7]. The same Information Society and Technology Advisory Group (ISTAG) report mentions also these components: natural interaction, computational intelligence, context awareness, and emotional computing. Especially, the last mentioned technologies can be realized through an embodiment of the complex system. The advantage for a successful implementation and usage of ambient intelligent system can be to highlight further the mentioned technologies of natural interaction. It seems that a natural interaction needs a concept of an embodied communication partner.

3. Embodied Conversational Agents

Human-like computer-animated characters, also known as Embodied Conversational Agents (ECAs), have attracted a lot of attention over the past years [10]. ECAs are screen-based entities designed to simulate human face-to face conversation with their users and are typically represented as humans and are specifically lifelike and believable in the way they behave.

Cassell [9] defines ECAs as those virtual characters that have the same properties as humans in face-to-face conversation, including:

- The ability to recognize and respond to verbal and non-verbal input.
- The ability to generate verbal and non-verbal output such as mouth movements, eye movements, head movements, hand gestures, facial expressions, and body posture.
- The ability to deal with conversational functions such as turn taking, feedback, and repair mechanisms.
- The ability to give signals that indicate the state of the conversation, as well as to contribute new propositions to the discourse.

Motivated by findings related to the important role that emotions play in our everyday social interactions, researchers are exploring how to equip ECAs with the ability to express synthetic human-like emotions through speech, body language, and facial expressions.

An increasing number of researchers are examining the potential of ECAs to enhance human-computer interaction (HCI) by either accompanying or replacing traditional computer interfaces. One of the primary goals, is to create agents capable of having natural and effective interactions with users that can produce some desirable or beneficial outcome [22]. Numerous experiments and empirical studies have been conducted in fields including health [21] and therapy [23]. More recently, ECAs have also been used to address the needs of older adults, ranging from companionship and assistance in health related domains [24] (i.e.physical exercise, medication adherence).

A study by Ortiz et al. [15] revealed that ECAs can improve the natural interaction with elderly users in ambient intelligent environments. Specifically, older adults both with and without cognitive impairment, are capable of recognizing emotions in the facial expressions of an agent and follow instructions much better when interacting with an agent. Similarly, Nijholt [16] concluded that embodied agents allow the development of affinitive relationships with their human partners and can therefore help to fulfil the need of affiliation in ambient assisted living environments. A meta-analysis conducted by Yee et al. [25] found that the use of an embodied agent in an interface produced more positive social interactions.

Researchers have explored the design of ”relational agents”, namely ECAs that interact with users over multiple conversations, ranging from a handful of interactions to hundreds of interactions spanning months or years [17], [18] and [19]. Studies [20], [21] explored how ”relational agents” form long term social-emotional relationships with their users for health education and health behaviour change interventions. Results of a two month trial that investigated exercise promotion showed increased physical activity for participants using a virtual exercise coach compared to those using a conventional pedometer. Nevertheless, this effect diminished when the coach was removed, suggesting that further research is needed to cause long-term behaviour change. In a similar study, Bickmore et al. developed a virtual laboratory to explore the longitudinal usage of a virtual exercise coach. Older adult participants interacted with an agent from their home once a day for up to 120 days. Results showed that users who interacted with an agent that used variable dialogue exercised significantly more than those interacting with an ECA with non-variable dialogue. Ring et al. developed a conversational agent-based system to provide longitudinal social support to isolated older adults by means of empathic feedback. An exploratory short-term pilot study demonstrated significant reductions in loneliness of older adults based on self-reported affective state. Vardoulakis et al. investigated the use of an agent to provide social support and wellness counselling to older adults. Qualitative analysis of interactions with a remote-controlled agent (i.e., Wizard-of-Oz) installed in homes of older adults, identified multiple topics that users liked discussing and showed high acceptance ratings and a positive attitude towards the agent.

A growing body of research demonstrates that ECAs move beyond the paradigm of computer as a tool and allow for multimodal interaction reflecting natural human-to-human communication. By exhibiting a certain level of intelligence and autonomy as well as social skills and emotions, ECAs have the potential to provide familiar and non-threatening interfaces, especially useful for building systems that are easy to use, engaging and gain the trust of their users.

4. Embodiment of Ambient Intelligent Systems

Ambient assisted living (AAL) is a new approach which promises to address the needs of older adults,namely, to construct safe environments,to increase their autonomy and assist them in carrying out activities of daily life extending the time they can live in their home environment. Many efforts towards building AAL systems are based on developing complex distributed systems including pervasive devices and use Ambient Intelligence to integrate these devices together into modular, adaptable and intelligent systems able to cope with the changing needs that characterize the life of older adults.

It is clear that user interaction with AAL systems or general distributed intelligent systems goes beyond the interaction to a single personal device. Nowadays we do not use just one single point of access to interact with digital media - we are surrounded by computing systems in the form of mobile devices like tablets, smart phones and wearables [28]. The conventional PC is only one of many nodes of the overall system we need to interact with. Different studies (see chapter 3) have shown that the embodiment of the systems helps the user to interact with the system. It seems that people are likely to use human-like communication strategies (e.g., greeting, farewell, small talk elements) and also cooperative in answering questions of an agent and try to fasten down the degree of the ECAs human-likeness and intelligence which indicates the attribution of the sociality of the ECA [29].

4.1. Architecture of an Embodied Ambient Intelligent System

Figure 1 shows the abstract architecture of an embodied ambient intelligent system, which in this case is applied in a home environment. The main goal of the system is to communicate with assisted persons, to monitor for example their health conditions, to control the environment around them and support them in the execution of daily activities. The system is composed of a modular distributed network of different intelligent nodes and an ECA with which the user is interacting. The intelligent nodes can be for example a PC, a tablet, a mobile device but also typical household appliances like a fridge or washing machine. According to the AmI concept, these devices are distributed in the environment and have a certain amount of calculation capacity. Following the Internet of Things (IoT) paradigm, the devices are also connected to the internet, mostly through a hub node in the network. The connection to the cloud provides the possibility to outsource certain intelligence and calculation effort. It is also possible that services can be accessed which are running externally from the smart environment itself [51]. The different nodes inside the distributed network in the house have to run a middleware component that allows them to communicate through virtual buses. A promising approach to realize the communication of such a distributed network of nodes has been achieved in the universAAL project [48]. The mentioned middleware components running on the nodes are the core part of the universAAL platform. The middleware establishes peer to peer communications, to ensure that all universAAL enabled nodes in a certain intelligent environment can cooperate with each other and share different kind of platform semantic information flows (e.g., context, service and user interaction etc.) following a shared ontological model.

An ECA allows a natural interaction between the user and the AmI system. In many research projects the dialogue is based on multimodal communication where the ECA can interpret gestures from the user based on visual information and imaging processing techniques (e.g., Kinect technology), emotion understanding based on face emotion recognition and emotion recognition from speech intonation as well as a voice recognition which allows a normal and natural speech conversation. An important part in natural conversation is also the natural dialogue, namely how an ECA is communicating and is structuring the dialogue with the user. In this way ECAs are capable of understanding the user's voice, gestures and emotions and plan based on this understanding multimodal utterances from propositional representations of meaning [29]. Further examples and benefits of ECA agents have been presented in section (see chapter 3).

An embodied agent is not necessarily fixed to a certain device. An advantage could be that the ECA is following the user through the different intelligent nodes and devices distributed in the environment,depending on where the user is present or where it is temporarily better to interact with him/her. The interaction requires basically two aspects: *i)* the context where the person is present as well as *ii)* the generation of user interfaces on different devices in real time. The context regarding the position of the user can be addressed by the AmI environment, by including presence sensors or other technology for indoor localization [50]. To cover different kinds of interaction devices at once, it is needed to model user interactions instead of modeling single user interfaces. The user interface developers need to generate interaction models, embed and connect these interaction models in a unified framework. The execution process during run-time needs to interpret these models [28].

Considering the proliferation of inexpensive portable devices with high powered processors and sensors, such as cameras and depth sensing technology (e.g., Kinect sensor) there are new potentials for realizing such novel embodied ambient intelligent systems simulating real-time natural human-to-human interaction between users and AmI environments. Nevertheless, for the development of such a solution a multitude of technological challenges still need to be addressed, such as: multimodal sensing and processing; immersive human-computer interfaces including 3D animated characters capable of capturing users attention and engaging users in active tasks; environmental context extraction and event interpretation as well as rich descriptions of human activities and emotional state and generation of behaviour models.

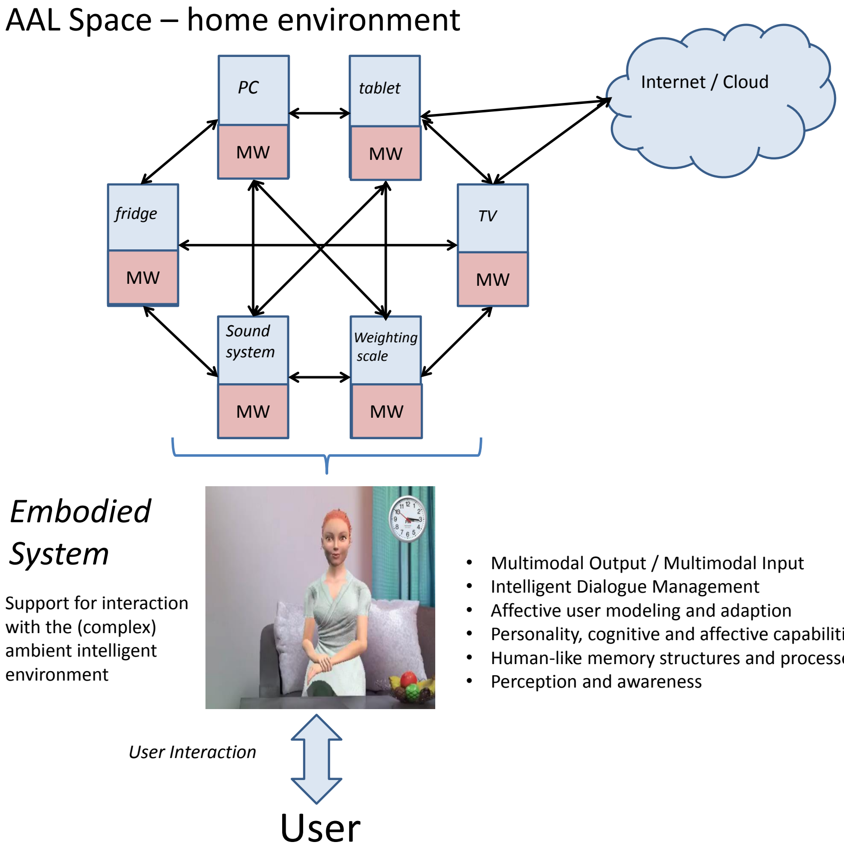

Figure 1. Simplifying the communication of a user with a complex distributed system through a embodiment of the system

4.2. Interaction with an Embodied Ambient Intelligent System

Intelligent interaction with an embodied real-time empathetic elder care system promises a richer range of interaction modalities based on natural input and output. This will enable users to perform potentially complex tasks more quickly, with greater accuracy, improving their confidence and satisfaction with the AmI environment. Based on the state of the art and the outcomes, implications and limitations of three empirical studies,discussed in section (see chapter 5), we discuss requirements and suggestions for the design of future embodied ambient intelligent systems aiming to introduce human-human communication characteristis in the interaction with ambient intelligent systems.

Multimodal input: The ability to recognize and respond to verbal (e.g., spoken language) and non-verbal input (e.g. gestures, gaze, etc). Ubiquitous devices give a lot of possibilities to input information that when combined in a correct way can lead to effective multimodal input interpretation. Speech recognition is one of the possibilities. This involves the ability to match voice patterns against a determined vocabulary. Typically, a limited carefully-spoken vocabulary is recognized, however, more sophisticated software has the ability to accept and recognize free natural speech. To date, ongoing research in the topic of multimodal data analysis is addressing various challenges such as the interpretation of imprecise, ambiguous, and partial multimodal data.

Multimodal output: The ability to generate verbal and non-verbal output delivered via an interactive, animated life-like agent. This requires automated generation of coordinated prosodic speech, natural language and animation generation such as mouth movements, eye movements, head movements, hand gestures, facial expressions, and body posture. Advances in tools and techniques for 3D virtual character animation (e.g. Open Agent Architecture [43] , SmartBody [42] and Behavioural Markup Languages (BML) [43] and [44] that transform behaviour descriptions into realtime animations pave the way for the creation of rich 3D multimodal output. Nevertheless, communicating the agents affective state to the user remains a challenge. Researchers investigate how well users understand the emotions expressed by an agent,typically expressed via facial and/or bodily expressions (e.g., expressing emotional displays via life-like facial expressions or gestures).

Intelligent dialogue management: The ability to interpret the current situation of the user and the environment, to decide how to react and produce the appropriate response for a certain communicative function. The dialogue management includes competences such as interpreting natural language, dealing with conversational functions such as giving feedback and signals that indicate the state of the conversation, turn taking, gracefully handling errors and interruptions etc. The agent should dynamically adapt to the current context and situation and contribute new propositions to the ongoing discourse with the user. Developing multimodal dialogue management systems is a complex task for a number of reasons; the users multimodal input may be misinterpreted or misunderstood, ill-formed or incomplete [35]. This remains an active research topic and different approaches (finite-state and frame-based, information-state based and probabilistic, plan-based, and collaborative agent-based approaches) are being examined, each with advantages and disadvantages [36].

Affective user modelling and adaptation: The ability to build up a dynamic profile of the user of and make use of this information to support immediate adaptation of system's behaviour to the user's state. Typical existing user modelling approaches focus on the user's past and present behaviour in terms of interactions with the system, preferences and interests (e.g. preferred services, topics of discussion, etc.) and the agent's static knowledge of the user (e.g., name, age) and the semantics of the environment. The agent relies on the internal representation of the user to communicate the "right" thing at the "right" time in the "right" way. As the demands for system effectiveness and agent believability increase, there is increasing demand for accurate user models. Future models need to support not only immediate recognition and adaptation, but also more extensive understanding of the user's affective profile, and the user's needs and behaviour over longer periods of time. This requires a mixture of unobtrusive learning by observing and interpreting the user's interactions with the system and asking for explicit feedback automatically adjust the user models.

Personality, cognitive and affective capabilities: Just as happens with humans, an agent should consider the user's affective state and express coherent behavioural responses that can be interpreted by a human observer as indicative of a personality. The capabilities an agent employs can have a strong impact on the perception of its intelligence, quality of interaction and more importantly, on user engagement. Recent years have seen a significant expansion in research on computational models of human cognitive and affective processes with emphasis on fidelity with respect to human emotion processes [37]. These models are complex systems that integrate a number of sub-component, based on theoretical principles from psychology (i.e. appraisal, dimensional, anatomical, rational theories). The long-term goal is to develop sophisticated computational models to enhance agents' ability to sustain realistic, effective, efficient and pleasant interaction with human users, achieving thus a better fit within an AmI environment.

Human-like memory structures and processes: Memory constitutes an essential aspect of cognition for an agent as in any human social being. Memory is broadly regarded as information gained from experiences that is available in the service of ongoing and future adaptive behaviour [38]. An agent with human-like memory should be able to store events that are relevant to itself or to the user and make use of this information in sensible and plausible ways to ensure coherent interaction during subsequent interactions the users of an AmI environment. Although research (e.g., [40], [41]) has shown that agents possessing human-like memory structures and processes are capable to establish more natural and engaging relationships with human users over extended periods, up to date, many important aspects of human memory have not been given much attention [39].

Perception and awareness: The ability to know at each moment the current status of the users and the different devices distributed in the AmI environment. For example the agent needs to know the location and social situation the user is in, his / her emotions (e.g., joy or stress) and activity (e.g., idle, working),etc. In terms of the environment, in addition to knowledge about the available interactive devices and network connectivity, parameters such as the temperature and humidity levels, can be of interest depending on the application domain. Various ubiquitous sensors (e.g., camera) can be distributed in the environment and biosensors can be attached to the users body to collect for example physiological signals (e.g., heart rate, galvanic skin response, temperature). The information is processed by one of the nodes of the AmI environment and the agent can benefit from the knowledge acquired to modify the current state of the system accordingly. Currently, complex computer vision techniques allow agents to perceive the situation of the user and the environment based on what the camera sees. Research is carried out to develop wearable sensors that are integrated in usual pieces such as clothes, pendants, earrings allowing even more unobtrusive tracking.

The key role of the embodied agent is to support the interaction with the complex ambient intelligent environment. The ”persona” of the agent is the visible presence of the system from the user's perspective. By acting as an intermediate link between the user and the AmI system, the agent presents an easy to use interface which hides the complexity of the underlying distributed nodes. This interface is consistent with the current state of the environment, the user's dynamic profile and state during the interaction with the system. Primarily, the agent assists the user in communicating requests to the underlying system via natural multimodal interaction. The agent has the ability to interpret and respond to verbal (e.g., spoken language) and non-verbal input (e.g. gestures, gaze, etc) by producing appropriate communicative responses. In adidtion, the agents the ability to express emotional behaviours that influence a users emotional and motivational state could potentially, guide a user towards more effective interactions with the AmI system. Dynamic information collected from the distributed nodes of the intelligent system is processed and the agent benefits from this knowledge to modify the current state of the system accordingly. The user's affective state can be recognized via various ways such as the measurement of physiological signals, the analysis of facial expressions using image processing techniques, voice intonation, etc. Additionally, the agent may infer the user's affective state based on knowledge of the user's past behaviours stored in an internal memory structure. Information is presented to the user in a timely appropriate and accessible manner by the agent who can offer further support such as automated task completion or task help tailored to a specific situation. As an example, an embodied agent that represents a home based system which perceives physical activity and related behaviour patterns can convey emotions and intentions with the goal of helping a user to change his/her behaviour in a way that is beneficial for his/her health.

5. Empirical Case Studies

In this section we discuss three case studies which empirically evaluate the concept of embodied ambient intelligent systems, within the scope of three Ambient Assisted Living (AAL) projects. In these projects, older adults interact with an intelligent ambient home environment embodied in the form of a 3D human-like conversational agent which has the ability to perform tasks in a context and user dependent way. The agents recognize verbal (i.e., natural language) and non-verbal input (i.e., emotional facial expressions, gestures)and engage in conversations simulating the way older adults normally interact, collaborate and dialogue with a real human to accomplish their daily tasks. Three empirical studies are conducted to investigate the effects of the embodied agent on the user's experience, behaviour and performance with respect to the particular goals of the project. By discussing the outcomes, implications and limitations of these studies, we identify requirements and suggestions for the design and evaluation of future embodied ambient intelligent systems.

5.1. The CaMeLi ("Care Me for Life") Project

The European project "CaMeLi" [26], investigates the use of a home-based system centred on an innovative human-like 3D agent, acting as long-term assistive companion to support older adults (aged 65 and above) to cope with the challenges of ageing, to live independently in their homes for longer periods and to benefit better from the care they receive in assisted living care facilities.

An ambient intelligent system consisting of a distributed network of tablet devices and cameras is seamlessly integrated into the living environment of older adults allowing the agent to follow the daily life patterns of the users, to identify and attend to their needs. The system offers a variety of services to support older adults primarily in the sense of organizing and accomplishing their routine activities and self-managing their care, it promotes social integration with others and provides assistance in critical safety situations (e.g., falls).

Interaction is handled by a human-like agent that simulates expressive face-to-face conversation based on natural language, providing older adults and users unfamiliar with technology with an intuitive and non-threatening interface to accomplish tasks with ease and confidence. An intelligent dialogue manager component is responsible for interpreting the user's speech commands and generating the appropriate verbal and non-verbal behaviour of the agent. Emotional expression and other human-like behaviours (e.g., facial expressions and gestures) are used to communicate the agents affective state to the user. In addition, the agent takes advantage of visual information from the distributed camera network to perceive the status of the user and the surrounding environment. Using image processing and artificial intelligent algorithms, it is possible to detect the presence of persons and track them over time, identify certain behaviours and patterns (i.e.sitting, sleeping, reading etc.), as well as identify if the user behaves in a non-conformant way (e.g., going from repeatedly from one place to another).This information influences the agents behaviour (e.g. seeing a person fall down causes an alert, seeing a person is sad prompts the agent to contact a friend etc.).

The project started with a qualitative user study investigating perceptions, attitudes and expectations towards the idea of embodied ambient intelligent systems to support older adults accomplish their routine daily activities and make more efficient use of human care services [27]. In order to identify "useful" functionality and to decide which "social skills" are required for a embodied agent, the study addressed topics such as the desired communication behaviours (i.e., friendly informal vs. professional formal stance) and character traits (i.e., empathetic, joyful etc.) of an agent and specific tasks it should perform to support older adults .Furthermore, the study investigated expectations of older adults and caregivers about the appearance of a virtual agent. High fidelity mock-ups, covering a range of different possible looks: different gender and age groups, realistic human-like look versus cartoon-like look and formal versus informal look, were presented and participants were asked to rate them on a 7-point Likert scale, ranging from not "attractive" to "very attractive". The results of the preliminary study revealed that older adults and their formal caregivers were in favour of a virtual embodied agent and highlighted the potential of an embodied ambient intelligent system to assist the accomplishment of daily activities. Older adults were willing to accept this solution in their daily living context ,particularly in the near future, as they expected their needs to increase as they grow older. No significant correlations were found between the acceptance level and gender, age or experience with technology of the participants.

Professional caregivers interacting with older adults on a daily basis expected that an agent that assists elderly to structure their daily routine would bring positive effects in terms of motivation and self-esteem. Additionally, a embodied agent could take care of some trivial tasks, potentially enabling the care personnel to make more efficient use of their time with older adults. All participants emphasized the importance of interacting with a friendly face and voice. The virtual agent should communicate in a human like manner, namely using natural language and synchronized non-verbal conversational behaviour (i.e., facial expressions). Finally, the results highlighted the importance of behaviour traits such as being non-intrusive, considerate, proactive and possessing smooth communicative skills in order to engage in successful long-term interaction with older adults.

Figure 2 shows the user interface and the prototype of the animated 3D agent developed based on the outcomes of the ”CaMeLi” [26] qualitative user study. A fully functional prototype is currently deployed in a six-month user trial, to examine empirically how older adults interact with and evolve long-term relationships with virtual agents in real ambient assisted living environments. The results of the study are expected to provide useful insight for about desired ”social skills”, appearance and ”useful” functionality of agents in order to maximize the beneficial outcomes of long-term interactions with embodied ambient intelligent systems.

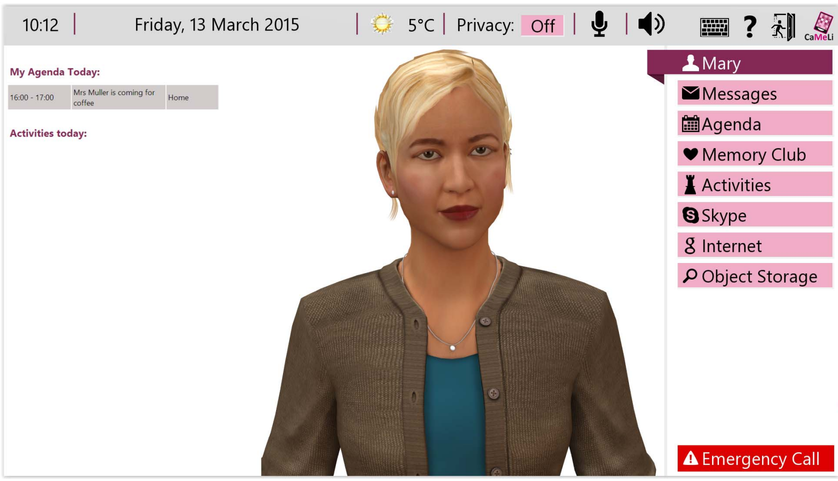

Figure 2. The CaMeLi user interface including the animated avatar [26]

5.2. The ibi (”ich bin informiert”) Project

The ”ibi” [49] project aims to reduce social isolation of older adults living alone by providing a lightweight, easy and accessible solution for communication and information exchange between older adults and their relatives and formal caregivers.

The system is focused on two main objectives. Firstly, on the inclusion of different information and communication channels and secondly on a variety of avatar based interaction possibilities. On the one hand, the system offers information to older adults for maintaining their independence and managing their daily activities in an easy way. On the other hand, informal caregivers and family members of people in need of care benefit from support and useful information about how to manage, sometimes novel, caregiver challenges. Formal caregivers are involved in the communication process and provide support by sending and retrieving concrete instruction messages to/from older adults, from the office, but also ”on the move”, during their working day.

The main focus of the ”ibi” project is the acceptance of the system by the user. Especially the intended user group of older people who are not so affine to use technology should be able to easily communicate with the system. The interface of the ”ibi” system can be displayed on the home TV as well as a tablet PC. The messages from the system (for example reminder to take medications) are transmitted by in interrupting home like avatar with human voice with a reluctant and positive attitude and appearance. Additional to the avatar the user can interact with the system through a touch display (tablet) or a remote control (TV).

The system is equipped with advanced logging functionality in order to be able to record the users’ behaviour during the interaction with the avatar. This advanced logging functionality allows to track which modality is selected by the system to present an action and which modality is used by the user to respond on this action.

Figure 3 shows the user interface and the animated avatar used in the ”ibi” project [49].

The”ibi” system was initially comprised of two functional mock-ups, implemented on a tablet and on a smart TV. Already this mock-ups have shown that a user interface with three areas (avatar on the top, textual representation of the spoken dialogue in the middle and the interaction area, with three buttons at most, on the bottom) is greatly appreciated by older adult users, as it provides better visibility of the textual representation of the ongoing interaction with the avatar. The speech recognition model we used in ”ibi” was very satisfying. The model, originally designed for elderly people from Styria in Austria, could easily be used by Viennese citizens. In general the speech interaction with the system has been experienced as natural. The advantage was that the elderly people could use the text to speech of the avatar without putting their glasses to read the messages from the relatives. Investigation on the avatar appearance showed that participants prefer a human like middle-aged female avatar which is dressed in everyday clothes and which interacts in a private surrounding, such as a living room [2] and [49].

Surprisingly, some of the users intuitively tried to respond verbally to questions asked by the avatar, although the speech recognition functionality was not implemented into the first prototype. A study conducted to compare the avatar interaction with the TV remote control interaction showed that people were more comfortable with using the avatar interaction. Even problems of some participants with the interaction of using a touch screen for typing or interaction could be potentially overcome through the avatar interaction. It could also be seen that using the TV remote control beyond the TV context has been considered unnatural by some users.

In general, users appreciated the possibility to interact with the system using multiple devices. Hence, many users combined these devices, e.g., by starting the dialogue on the tablet and continuing the interaction by using the avatar-based TV output and the speech recognition. Drawbacks of the avatar interaction have been that a few number of dialogues were automatically confirmed by the continuous activated speech recognition. Sources of noise, like the radio speech, triggered commands on the system without explicit intention from the users. This is of course related to the system design. In general the speech recognition has been rated as good.

5.3. The Miraculous-Life Project

The main aim of the ”Miraculous-Life” project is to design, develop and evaluate an innovative solution based on a Virtual Support Partner (VSP) that attends to the home

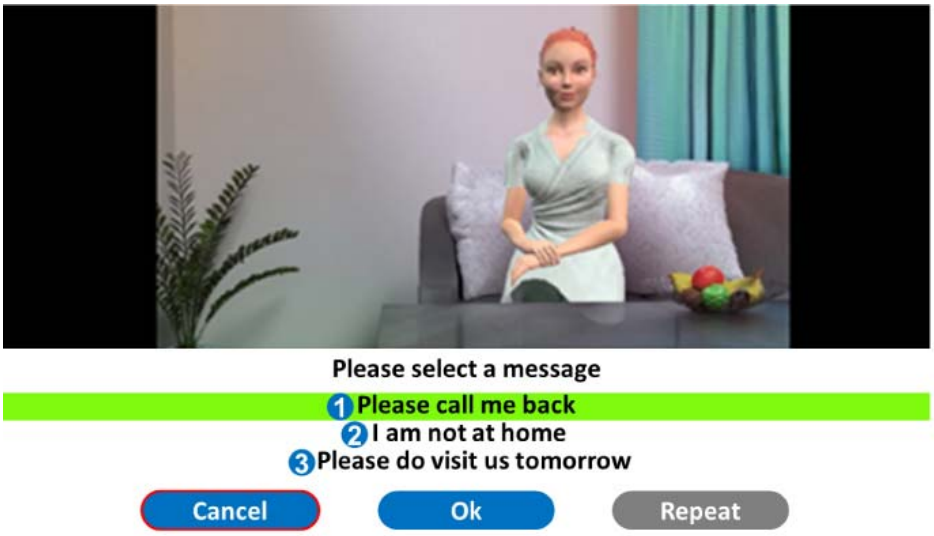

Figure 3. The ibi user interface including the animated avatar [49]

daily activity and safety needs of older adults. The VSP, is a embodied agent with a 3D avatar that aims to provide benefits on a practical, psychological and social level enabling and motivating the elderly to remain longer active in carrying out their daily life at home, prolonging thus their independence and improving their well-being.

The solution is delivered to the user in form of a stand-alone consumer product, operating on a scalable distributed network of interconnected devices (e.g., tablet, Kinect sensor, smart home sensor) seamlessly distributed in the user's environment. The VSP agent fuses together information collected by the devices, such as the user's facial expressions, voice intonation, gestures and other contextual information of the environment to provide emotionally enriched human-computer interaction and implicit support and safety through a number of ICT services that stimulate and motivate older adults to complete their daily activities.

The embodied agent simulates in essence the interaction with a real life partner, and plays the role of an advisor and assistant. It expresses appropriate empathetic feedback (i.e., emotional facial expressions and voice intonation) based on behaviour and dialogue patterns established between older adults and human caregivers over the lifetime.

Figure 4 shows the user interface and the animated avatar used in the Miraculous-Life project [47].

The validation of the system is realized in two well selected use cases in two different countries. Up to 100 elderly people and their caregivers are currently using the system over a six month period. Older adults as well as formal and informal caregivers assessed the basic functionality and avatar mock-ups early on in the project. Based on the evaluation results, a first prototype with reduced functionality was tested by experts on a tablet device. 3D agent mock-ups in conjunction with a questionnaire revealed that the avatar should act as a friendly personal assistant. Furthermore, most users preferred a human like avatar with a young woman's appearance. In terms of dialogue communication, the avatar should allow smooth turn-taking by different modes like waiting, listening and talking.

An expert group of professional caregivers analysed the embodied agents interaction patterns and the available ICT services to provide support and safety. In terms of interaction, the results indicated that the communication of older adults with the agent should be based on friendly and natural dialogues and it is critical that the agent has a clearly understandable speech output [2] and [31]. As some older adults experienced difficulties hearing and understanding the agent's speech, pronunciation and intonation had to be improved. An enhancement of the communication was achieved by disabling the speech recognition during the agent playback, in order to prevent the agent from activating actions through spoken commands. While the agents speed of speech was adjustable, a similar feature for adjusting the volume was requested by the end users. Many participants did not know when the system accepted the next command and wondered why the system would not react on their behalf. Additionally, the users found that the speech recognition was not always accurate, which lead to an unexpected system behaviour. The gestures expressed by the agent were perceived to be fluent and fit to the spoken words but the repertoire was too limited to simulate a natural interaction. Regarding the user interface, older adults stated that the buttons and labels were too small to be read. Additionally, the agent was considered to be too small in the service view and too big in the main view [31].

Since the "Miraculous-Life" project is currently under development, the following improvements have to be implemented in the final prototype. The user interface has to be redesigned by means of agent size, element contrast and colouring to meet the user requirements and suggestions. The usage of external speakers to better understand the agent rather than using the built-in ones needs to be assessed further. The current interaction mode of the agent must be clearly visible and perceivable. Furthermore, a possibility to skip an agent video is desired. The speech volume must be adjustable directly from the user interface and by spoken commands.

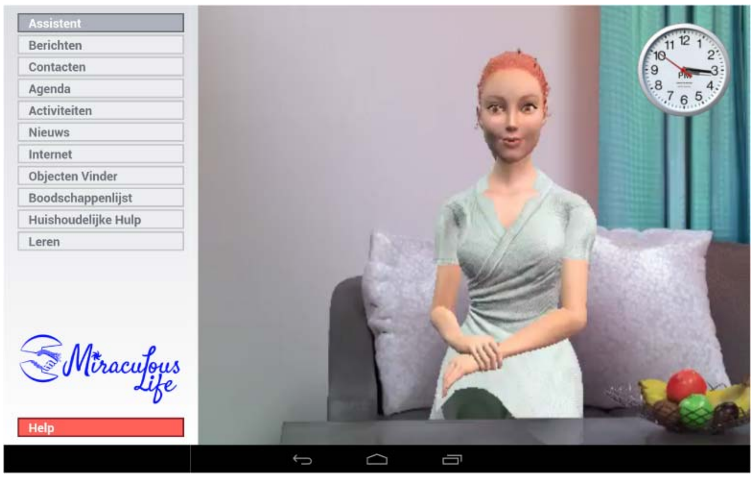

Figure 4. The Miraculous-Life user interface including the animated avatar [47]

5.4. Case Study Summary

We have presented three empirical case studies evaluating the concept of embodied ambient intelligent systems designed to support the needs of older adults. Although the main goal of the projects is different, all the three prototypes use a 3D avatar-based technology to facilitate the interaction with the underlying distributed system. The presented solutions also share various comparable aspects in terms of methodology, specification and technologies used.

Table 1 presents a summary of the key aspects of the three case studies. The table compares different parameters like the user groups and the methods used for requirment analysis. Based on the experience we consider it as important to have an automated logging functionality implemented in such systems. This functionality provides the possibility to log parameters like the usage of the agent and different services, how well the agent's speech output is understood, if the communication with the agent is preferred compared to touch (or other) input etc. While the "ibi" as well as the "Miraculous-Life" project used a video generated avatar, "CaMeLi" used a game engine based avatar rendered in real-time. Although regarding the interaction with the user we could not find a major difference, some requirements need to be fulfilled to guarantee the real-time interaction with a video generated avatar (i.e., good network connection, start the stream also during rendering process etc.). Different architectures are suitable for such embodied agent systems, however computational power should be considered. Running the avatar real-time game engine as well as a powerful web service server (like glassfish [2]) and other components on a single device can easily cause processing power shortage. In all the projects presented in the table, there have been other possibilities to interact with the system (i.e., touch screen, remote control, text representation, etc.). We consider this as useful because especially the visualization of text is needed in addition to the avatar speech output (e.g., reading the contents of the user's agenda etc.).

Long-term empirical studies currently conducted in the scope of the three projects will reveal more information about the impact of embodied agents used in the interface and the possible advantages they bring in the interaction with ambient intelligence environments. The preliminary results are promising, and highlight various possible effects on the user:

- It is expected that the use of an agent, in comparison to not using one, has a positive effect on the user's subjective experience and attitudes towards the system. For instance, a home-based assisted living system such as "CaMeLi", with an embodied agent could be perceived by older adults as more easy to use, interesting or entertaining than a system with multiple unfamiliar devices.
- The use of an agent could change the user's behaviour while interacting with the system in some desirable way. For instance, an older adult feels comfortable and spends more time with a system that incorporates an agent than simulates face-to-face empathetic conversations,such as "Miraculous-Life". The evolution of a long-lasting relationship between the user and the agent can maximize the beneficial outcomes in long-term helping situations.
- The use of an agent is expected to bring benefits with regard to the goal of the interaction process. For instance, while interacting with a system such as "ibi" that

[2] https://glassfish.java.net/de/

incorporates an agent than supports communication and information exchange with relatives, an older adult becomes more socially active and engages in more frequent communication with family members.

6. Conclusion

The embodiment of complex ambient intelligent systems which are distributed in the environment can be a solution to improve user interaction and also to make the communication with ICT systems more natural. Distributed environments consist of a multitude of devices; computers and sensors are embedded in walls, furniture, clothes and in daily life objects. It is understandable that the concept of distributed intelligence is still difficult to understand, particularly for novice technology users (e.g., older adults) that have been used to interact with conventional personal devices like a computer or smartphone. This challenge is currently addressed by many research and industry initiatives that rely on multimodal interaction to achieve a more natural conversation and dialogue between users and the system. For example, Google recently released a patent on using anthropomorphic children toys as an interface for different home-based services [46]. The toys, which would be used as an alternative interface instead of smartphones and remote controls, would be permanently listening for instructions and carry out commands issued by their owners, such as switching a TV on or off. There is no guarantee that Google's patent will make it into production, nevertheless, this opens new possibilities in the direction of embodiment of ambient intelligent systems. In this paper, we have discussed embodied conversational agents and the role they can play in the interaction with ambient intelligence environments. Current state of art research shows that ECAs have the potential to move beyond the paradigm of computer as a tool and allow for multimodal interaction reflecting natural human-to-human communication. We have presented three empirical case studies conducted in the scope of AAL projects; the results yield evidence that embodied agents succeed in engaging older adults interacting with AmI environments. Users attribute sociality to the agent and are more willing to accept an intelligent system personified as an assistive companion in their daily living context. Human-to-human communication is a key ingredient towards effective AmI and AAL systems, which not only enhances the interaction, but also has positive effects on the psychological health of the elderly people. Nevertheless, despite the promising research outcomes, current solutions based on ECAs focus only on a subset of communicative functions, modalities, and generation capacities. Interaction with ECAs is still not purely multimodal, but rather very much speech command based. A complete human-like interaction including awareness of the context and the user's current affective state, and the use of this information to support immediate adaptation of the agent's behaviour has not been fully achieved. This is also mainly the reason why user interfaces try to include beside the agent also text and the possibility for touch input to support the speech commands. This is on the one hand unsatisfying but on the other hand, the empirical results discussed in this paper show that even this possibility of partial natural communication makes the interaction with the system easier and more familiar for the users. A challenging aspect in systems which try to combine natural dialogue and touch based interaction and at the same time representation of text is the design of an effective interaction work-flow as well as the composition of the user interface. This needs to be balanced to provide optimal mutlimodal interac-

Table 1. Comparison of the evaluations settings (concept phase/ lab trials / field trials) of the mentioned projects

	CaMeLi	ibi	Miraculous-Life
Participants	20 / 40	26 / 17	41 / 18
Average age	75	70 / 72.1 / 68.9	54.1 / 63.6
User groups	Active older adults, formal caregivers, Neuropsychologist, Gerontopsychologist	Older adults, informal and formal caregivers	Active older adults, formal caregivers, experts
Methods	Structured interview, questionnaire, post-interviews, Log files, think aloud method	Structured interview, task-based empirical investigation, questionnaire, post-interviews, Log files, media diary	Structured interview, questionnaire, expert walk through [3], heuristic analysis [4], task-based empirical investigation, think aloud method, questionnaire (SUS)
Avatar used	Game engine based rendered real-time avatar	video generated avatar from Zoobe [52]	video generated avatar from Zoobe [52]
Devices involved	Tablet, PC Camera, Kinect is used for falling detection	Smartphone, tablet, TV, PC	central PC, local tablet, Kinect is used for falling detection, distributed sensors are used for simple behaviour recognition
AI system architecture	all-in-one solution, Kinect connected to system, services deployed as web services	mini PCs in flats, user management and database centralized, services deployed locally and as RESTful web services	mini PC and sensor nodes in flats, services and database centralized, services deployed as web services
UI specification	Kinect is used for face emotion recognition and emotion recognition based on speech, Microsoft speech engine used for speech recognition, Microsoft and cereproc [45] used for text-to-speech	Tablet and TV used for the audio- visual output modality. Speech recognition used for the audio input modality. TV remote control and tablet touch screen used as tactile input modality.	Kinect is used for face emotion recognition and emotion recognition based on speech, Microsoft speech engine used for speech recognition

tion. Particularly, in the ICT-based elderly care sector, systematic and well-conducted empirical investigations about embodied interface agents and their effect on the user's attitudes and performance are still scarce. Existing ECA initiatives still lack the personal, empathetic interaction and user behaviour understanding. We are still far from providing virtual agents able to engage and motivate elderly to carry out their daily activities in a similar way human caregivers do. In this regard, further research, especially longitudinal studies in real life conditions are needed to create agents capable of evolving a ”working alliance” with their users and maximizing outcomes in long-term helping situations. In order to achieve this goal, older adults have to trust and care for their companion agents and feel cared for in return. The results of the three presented case studies confirm the importance of agent behaviour traits such as being non-intrusive, considerate, proactive and possessing ”smooth” communicative skills in order to engage in successful interaction with older adults. The presence of a human-like embodied agent promises to have the desirable effect that users are more inclined to interact with AmI systems spontaneously, as they would do with fellow human beings. Users will perceive the interaction as less difficult, and be more willing to accept and benefit from such solutions.

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References

[1] Why cognitive systems? `http://www.research.ibm.com/cognitive-computing/why-cognitive-systems.shtml#fbid=Qiu5KsnsuU9` last seen: 26.05.2015

[2] M. Sili, J. Bobeth, E. Sandner, S. Hanke, S. Schwarz, C. Mayer, *Talking Faces in Lab and Field Trials - A View on Evaluation Settings and User Involvement Results of Avatar Based User Interaction Techniques in Three Ambient Assisted Living Projects*, International Conference on Human-Computer Interaction 2015. in press.

[3] C. Wharton, J. Rieman, C. Lewis, P. Polson , *The cognitive walkthrough method: A practitioners guide*, Usability inspection methods, p. 105-140, 1994

[4] J. Nielsen, R. Molich, *Heuristic evaluation of user interfaces*, in Proceedings of the SIGCHI conference on Human factors in computing systems: Empowering people, 1990, ACM

[5] J. C. Augusto, *Ambient Intelligence: Basic Concepts and Applications*, Software and Data Technologies Communications in Computer and Information Science Volume 10, p. 16-26, 2008

[6] M.R. Tazari, *An Open Distributed Framework for Adaptive User Interaction in Ambient Intelligence*, Ambient Intelligence Lecture Notes in Computer Science Volume 6439, p. 227-238, 2010

[7] IST Advisory Group, *Ambient Intelligence: From Vision to Reality*, European Commission, 2003

[8] J. C. Augusto, H. Nakashima, H. Aghajan, *Ambient Intelligence and Smart Environments: A State of the Art* Handbook of Ambient Intelligence and Smart Environments, p. 3-31, 2010

[9] J. Cassell, *More Than Just Another Pretty Face: Embodied Conversational Interface Agents*. Commun. ACM, Volume 43, p. 70-78, 2000

[10] Y. Wilks, *Close Engagements with Artificial Companions Key social, psychological, ethical and design issues*. John Benjamins Pub. Co., Amsterdam/Philadelphia, 2010

[11] T.W. Bickmore, R.A. Silliman, K. Nelson, D.M. Cheng, M. Winter, L. Henault and M.K. Paasche-Orlow, *A randomized controlled trial of an automated exercise coach for older adults.* J. Am. Geriatr. Soc., Volume 61(10), p. 1676-83, 2013.

[12] T.W. Bickmore and D. Schulman, *A Virtual Laboratory for Studying Long-term Relationships between Humans and Virtual Agents*. In Proceedings of the 8th International Conference on Autonomous Agents and Multiagent Systems, p. 297-304, 2009.

[13] L. Ring, B. Barry, K. Totzke and T. Bickmore, *Addressing Loneliness and Isolation in Older Adults.* In Affective Computing and Intelligent Interaction, 2013.

[14] L.P. Vardoulakis, L. Ring, B. Barry, C.L. Sidner and T. Bickmore, *Designing relational agents as long term social companions for older adults.* In Proceedings of the 12th international conference on Intelligent Virtual Agents, 2012, Volume 7502, p. 289-302, 2012.

[15] A. Ortiz, P. Carretero, D. Oyarzun, J.J. Yanguas, C. Buiza, M.F. Gonzalez, and I. Etxeberria, *Elderly Users in Ambient Intelligence: Does an Avatar Improve the Interaction?. Intelligence,* Volume 4397, p. 99-114, 2002.

[16] A. Nijholt, *Disappearing computers, social actors and embodied agents.*in Proceedings of the International Conference on Cyberworlds, p. 128- 134, 2003.

[17] T.W. Bickmore, D. Schulman and L. Yin, *Maintaining Engagement in Long-term Interventions with Relational Agents.* Appl. Artif. Intell., vol. 24(6), pp. 648-666, 2010.

[18] T.W. Bickmore, *Relational Agents: Effecting Change through Human-Computer Relationships.* Massachusetts Institute of Technology, 2003.

[19] H. Pinto, Y. Wilks, R. Catizone and A. Dingli, *The senior companion multiagent dialogue system.* In Proceedings of the 7th international joint conference on Autonomous agents and multiagent systems, volume 3, p. 1245-1248, 2008.

[20] T.W. Bickmore, A. Gruber and R.W. Picard, *Establishing the computer-patient working alliance in automated health behavior change interventions.* Patient Educ. Couns., volume 59(1), p. 21-30, 2005.

[21] T.W. Bickmore and R.W. Picard, *Establishing and Maintaining Long-Term Human-Computer Relationships.* ACM Trans. Comput. Hum. Interact.,volume 12, p. 293-327, 2005.

[22] R. Beale, C. Creed, *Affective interaction: How emotional agents affect users,* International Journal of Human-Computer Studies Volume 67, Issue 9, p 755776, 2009.

[23] J. Grolleman and E.M.A.G. van Dijk and Nijholt, A. and Emst, A. van, *Break the habit! Designing an e-therapy intervention using a virtual coach in aid of smoking cessation.* In: Proceedings Persuasive 2006. First International Conference on Persuasive Technology for Human Well-being, Eindhoven p. 133-141, 2006

[24] T. W. Bickmore, L. Caruso, K. Clough-Gorr, and T. Heeren, *Its just like you talk to a friend relational agents for older adults,* Interact. Comput., vol. 17, no. 6, pp. 711735, Dec. 2005.

[25] N. Yee, J. N. Bailenson, and R. Kathryn, *A metaanalysis of the impact of the inclusion and realism of human-like faces on user experiences in interfaces.*

[26] `http://www.cameli.eu/`, last seen: 25.05.2015

[27] C. Tsiourti, E. Joly, C. Wings, M. Ben Moussa and K. Wac, *Virtual assistive companions for older adults: qualitative field study and design implications,* pp. 5764, 2014.

[28] M. Sili, M. Gira, M. Müllner-Rieder and C. Mayer, *Interaction modeling in practice CTT vs. SCXML - A Comparison of Two Practical Solutions Applying Interaction Modeling Techniques for Multimodal User-System Interaction* International Conference on Information and Communication Technologies for Ageing Well and e-Health, 2015

[29] S. Kopp, L. Gesellensetter, N. C. Krämer, I. Wachsmuth *A Conversational Agent as Museum Guide Design and Evaluation of a Real-World Application* Intelligent Virtual Agents Lecture Notes in Computer Science Volume 3661, p. 329-343, 2005.

[30] C. Ramos, J.C. Augusto, D. Shapiro *Ambient Intelligencethe Next Step for Artificial Intelligence* Intelligent Systems, IEEE Volume:23 Issue:2, 2008

[31] D. Cereghetti, C. Wings, J. Meijers *D6.4 Pilot acceptance evaluation results*, public deliverable, `http://www.miraculous-life.eu/public-deliverables` last seen: 25.05.2015

[32] G. Riva, F. Vatalaro, F. Davide, and M. Alcaiz, *New Technologies For Ambient Intelligence.*

[33] A.K. Dey, *Understanding and Using Context.* Personal and Ubiquitous Computing, Volume 5(1), p. 47. doi:10.1007/s007790170019, 2001.

[34] P. Menezes, J. Quintas, and J. Dias *The Role of Context Information in Human-Robot Interaction.* In Ro-Man 2014 Workshop on Interactive Robots for aging and/or impaired people, 23rd IEEE International

Symposium on Robot And Human Interactive Communication (IEEE RO-MAN 2014), Edinburgh, August Volume 25, 2014.
[35] R. Sharma, M. Yeasin, N. Krahntoever, I. Rauschert, I. Brewer, A.M. Maceachren and K. Sengupta *Speech-gesture driven multimodal interfaces for crisis management.* Proceedings of the IEEE, Volume 91(9), p. 13271354, 2003.
[36] T.H. Bui, *Multimodal Dialogue Management - State of the art.* Centre for Telematics and Information Technology University of Twente. Retrieved from `http://eprints.ewi.utwente.nl/5708/`, 2006
[37] S. Marsella, J. Gratch, P. Petta, and E. A. Eds *Computational Models of Emotion.* Neural Networks 2005 IJCNN05 Proceedings, 3, p. 15981602. 2010.
[38] R. Wood, P. Baxter, and T. Belpaeme, *A review of long-term memory in natural and synthetic systems*, Adapt. Behav., Volume 20, no. 2, p. 81103, Dec. 2011.
[39] M. Y. Lim, *Memory models for intelligent social companions. In Human-Computer Interaction: The Agency Perspective* p. 241262, Springer 2012.
[40] C. Brom, J. Lukavsk, and R. Kadlec, *Episodic memory for human-like agents and human-like agents for episodic memory*, Int. J. Mach. Conscious., Volume 2, no. 02, p. 227244, Dec. 2010.
[41] W. C. Ho, K. Dautenhahn, M. Y. Lim, and K. Du Casse, *Modelling Human Memory in Robotic Companions for Personalisation and Long-term Adaptation in HRI*, p. 6471, Aug. 2010.
[42] `http://smartbody.ict.usc.edu/` last seen: 26.05.2015
[43] `http://www.ai.sri.com/~oaa/` last seen: 26.05.2015
[44] `http://www.daml.org/` last seen: 26.05.2015
[45] `https://www.cereproc.com/` last seen: 26.05.2015
[46] `http://www.bbc.com/news/technology-32843518` last seen: 26.05.2015
[47] `http://www.miraculous-life.eu/`, last seen: 25.05.2015
[48] `http://www.universaal.org/`, last seen: 22.06.2015
[49] `http://www.ibi.or.at/`, last seen: 25.05.2015
[50] `http://evaal.aaloa.org/2012/track-1-in-door-localization`; last seen: 25.05.2015
[51] `https://evida.pt/`; last seen: 25.05.2015
[52] `http://www.zoobe.com/`; last seen: 25.05.2015