HERMES: A PERVASIVE SYSTEM FOR MEMORY SUPPORT AND AMBIENT ASSISTED LIVING

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Abstract: As sensors and other pervasive computing technologies are increasingly penetrating ambient assisted living applications researchers, engineers and application architects are starving for tools, techniques and frameworks for building and integrating added-value applications. In this paper we present HERMES, the architecture and implementation of a pervasive computing platform, which supports the development of ambient assisted living applications for the ageing society, with a particular emphasis on memory aids and cognitive training. The platform is integrated in the sense that it enables combined support for memory aid and cognitive training applications. It is also accessible via ergonomic interfaces developed on top of multi-touch surface devices. Furthermore, the platform is modular and extensible since it provides Application Programming Interfaces (APIs) for the flexible development of additional applications. Along with the middleware architecture of the platform we also present representative trial deployments, which manifest that the presented platform is an attractive option for building pervasive applications for the ageing society.

1 INTRODUCTION

Two decades after the introduction of Mark Weiser's ubiquitous and pervasive computing vision (Weiser, 1991), we are increasingly witnessing the deployment of pervasive computing applications in fields like manufacturing, health care, smart housing and ambient assisted living (AAL). Recently, pervasive applications for ambient assisted living and ageing well are proliferating both in research and the enterprise (Stanford, 2002). This proliferation is mainly a result of the rising longevity and falling mortality phenomena, which maximizes the societal impact of these pervasive computing applications. As argued in (Waibel, 2009) and (Petersen, 2001) pervasive computing applications that can alleviate the elderly cognitive decline have a prominent position among AAL applications for ageing well.

As sensors and other pervasive computing technologies are increasingly penetrating AAL applications for elderly cognitive support, researchers, engineers and application architects are starving for tools, techniques and frameworks for building and integrating added-value applications. This is because development of applications for ageing well must confront a dual challenge: First they have to address the conventional integration complexity issues associated with the distribution and heterogeneity of pervasive computing applications (Soldatos, 2007); at the same time they must become tailored to particular requirements of elderly users (Mylonakis, 2008). Towards addressing the first challenge, application architects can adopt legacy pervasive computing architectures dealing with context-acquisition, context-awareness,

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sensor and actuator control, semantic services, as well as bridging of disaggregated systems (Dimakis, 2008). Such legacy architectures must be appropriately augmented or modified in order to address requirements of aged users. In this article, we identify such particular requirements along several complementary axes, namely integrated support for various cognitive support applications, ergonomics and ease of use, as well as modularity and extensibility.

Each of these axes poses additional requirements to the development of pervasive computing applications. In particular:

- In terms of integrated application support, tools and techniques for pervasive cognitive support applications must support the synergetic action of applications dealing with memory support, cognitive training, as well as social interaction. This integration shall result in a combined approach for enhancing the elderly mental ability and social interaction. At the same time integration allows for individualization of applications according to the end-user mental state.
- In terms of ergonomics and easy of use, applications must feature novel ergonomic interfaces providing end user with comfort and flexibility. Such interfaces include novel interfaces with large buttons and other controls, as well as multi-touch surfaces offering a mixed reality experience.

In this paper we present the architecture and implementation of a pervasive computing platform, which supports the development of ambient assisted living applications for the ageing society, with a particular emphasis on memory aids and cognitive training. The platform addresses several of the challenges outlined above focusing on memory support and cognitive training as the most important issues, with special attention to ergonomics and ease of use for the elderly users. Specifically, it is integrated in the sense that it enables combined support for memory aid and cognitive training applications. It is accessible via ergonomic interfaces developed on top of multi-touch surface devices. Furthermore, the platform is modular and extensible since it provides Application Programming Interfaces (APIs) for the flexible development of additional applications. In terms of core middleware technology, the platform is built over the reference architecture for pervasive systems developed in the scope of the CHIL project (Waibel, 2009). Several enhancements over this architecture are however made in order to address requirements that are peculiar to the ageing support tasks at hand. In the scope of the paper we present related middleware architectures and customizations in order to meet the target goals. Overall the presented architecture is an attractive option for building pervasive applications for the ageing society.

The paper is structured as follows: Following this introductory section, section 2 introduces the main problems that have to be addressed by the architecture along with related work on middleware architectures and technologies for pervasive computing systems. Section 3 introduces the pervasive platform for ageing applications, including its main hardware, software and middleware elements. Section 4 illustrates the deployment of the introduced architecture in the scope of realistic trial settings. Finally, section 5 concludes the paper.

2 MOTIVATION AND RELATED WORK

2.1 Application Requirements: Memory Support for Elderly People

“Ageing well”, namely enabling elderly people to live longer and independently in their homes has become a desirable objective, and AAL applications can be instrumental in achieving it (European Commission, 2006). Our solution focuses on cognitive assistance and memory support in particular. Existing research on the relationship between elderly and technology carried out by Burdick (2004), Hirsch (2000) and Zajicek (2005) was a starting point for our design work. When discussing requirements with user groups some further important indications emerged:

- system should be as easy as possible to understand and operate, while not appearing a “dumbed down”;
- user interface should be accessible taking into account physical and cognitive impairments;
- system should be unobtrusive;
- memory support application should be available both at home and on the go;
- user should always be in control of the system (and not vice versa): users appreciate gentle reminders but they hate being told what to do.

As a general principle we can state that elderly users are not keen on using a system “badged” as *designed for the elderly,* no matter how useful its features. This principle is challenging for designers, as a trade-off is needed between attractiveness and usability principles (e.g. accessibility and simplicity). Another challenge, particularly important in the case of pervasive system, is the trade-off between integration with the environment and unobtrusiveness. In the next section we discuss the technical impact of those considerations.

2.2 Technical Challenges

Based on the above requirements, the technical implementation of non-trivial systems for ageing-well is associated with a host of technical challenges. One of the primary challenges related to the need for integrating a host of hardware, software and middleware components, which are in most cases distributed and heterogeneous. For in-door environments, a non-obtrusive sensing infrastructure along with perceptual signal processing algorithms that extract the user's context have to be integrated. At the same time, mobile devices are needed in order to support outdoor context acquisition for roaming elderly users.

Another technical challenge relates to the implementation and integration of cutting edge signal processing algorithms that can credibly extract the user's context, e.g. as in (Pnevmatikakis, 2007). The integration of such algorithms (in a smart spaces environment) can boost the required non-intrusive nature of the system, since it obviates the need for the more invasive tagged/tab based approaches. Note that the algorithms to be used must be robust in order to enable accurate context acquisition enabling efficient recording of important moments/situations, which facilitates memory support. The system must also enable and support modeling and tracking of situations within both indoor and outdoor environments. Situation modeling facilitates tracking of complex contextual states beyond what single perceptual components can provide.

The system should also blend different elderly-oriented applications such as context-aware memory support, cognitive training, as well as services facilitating the elderly's communication and activation. This represents another technical challenge that asks for flexible access to context and data acquired by the system in order to adapt the respective applications.

Later paragraphs review related pervasive systems that address these challenges.

2.3 Related Work on Pervasive Systems Architectures

For over a decade major pervasive and ubiquitous computing projects have developed middleware infrastructures facilitating components integration, context-composition, coordination of devices, orchestration of modalities and adaptation to context, as well as development and deployment of pervasive context-aware services. As prominent example the Interactive Workspaces project at the Stanford University (Johanson, 2002) has developed the Interactive Room Operating System iROS (Ponnekanti, 2003), which provides a reusable, robust and extensible software infrastructure enabling the deployment of component based ubiquitous computing environments. Also, the Oxygen project at MIT produced the robust MetaGlue (Coen, 1999) agent infrastructure, enabling agents to run autonomously from individual applications so they are always available to service multiple applications. MetaGlue has been augmented with context-awareness features based on the GOALS architecture (Saif, 2003). Other projects such as EasyLiving have emphasized on the coordination of the devices, as well as fusion of contextual information. EasyLiving (Shafer, 2000) focuses on computer vision technologies for person-tracking and visual user interaction (Brumitt, 2000). Also, there have been architectures that take into account wearable systems and wireless communications between components, towards human centric applications, such as the architecture of the Aura project at the Carnegie Mellon University (Garlan, 2002). Aura monitors applications and perform dynamic changes to it, based on various resources and parameters such as user mobility, changing user needs and system faults.

Building on the basic principles and best practices of these early projects, later projects such as CoBRA (Chen, 2004) and later CHIL (Dimakis, 2008) have provided more versatile plug and play architectures. For example, CoBRA enables the integration of semantic structures (i.e. ontologies) including the SOUPA standard ontology for pervasive computing (Chen, 2004).

These projects lay out a set of basic middleware principles for building complex heterogeneous and highly distributed systems. However, they are not customized to meet the elderly needs, in terms of supporting multiple devices, supporting mobility, providing ergonomic interfaces and integrating cutting edge perceptual processing components for non-trivial context acquisition. Our HERMES system extends the above works across several axes, including the integration with multiple user devices (i.e. surface devices and mobile terminals), the support for location-aware services, as well as the integration of robust components for in-door person tracking and activities of daily life detection. These unique characteristics of the HERMES system are elaborated in the following sections.

3 HERMES ARCHITECTURE

3.1 Overview

The HERMES architecture was designed to be modular, flexible and interoperable.

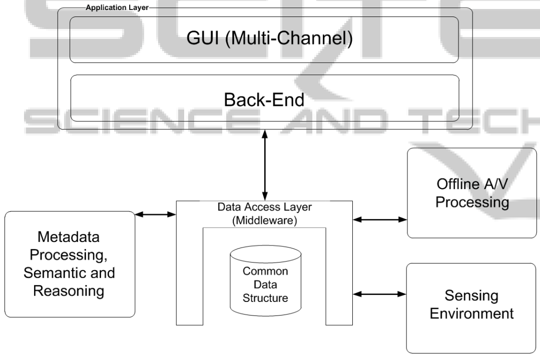

Figure 1: The HERMES architecture.

It includes several technologies and accommodates components for capturing and processing the user's context and to manage the user interaction with the system, namely:

- Environmental hardware sensors (cameras, microphones, etc.)
- Processing modules that extract conceptual information (e.g.: a person's identity entering the monitored user area) from the above sensors. Such modules process visual and audio information and are able to generate a series of events relating to the senior user's context.
- Knowledge Module (Metadata Processing, Semantic and Reasoning), which consists of two major components namely: an ontology model conceptualizing knowledge about the users' surrounding environment as well as a rule engine for validating and interpreting events as acquired by the sensor and processing modules.
- Data Access Middleware, which is the major component that allows the communication and information exchange of the components. It collects events from the processing modules and validates them utilizing the Knowledge base. It leverages the Web Services middleware library in order to access information from the low-level processing modules (i.e. perceptual components).
- Content Repository, a multimedia storage for managing raw content like video and audio, along with a database that provides access to both contents and events regarding the cognitive-support applications.
- Application Layer (Cognitive Support Applications) – composed by different GUIs, specific to the kind of cognitive support provided, and the related back-end. The GUIs are meant to run on different devices such as: standard PCs, touch-sensitive surfaces (for Cognitive Games) and mobile devices.

Based on these components, the illustration of the high level architecture presents also the main connections supporting the integration workflow.

3.2 Sensing and Processing Environment

The HERMES sensing and processing system utilises audio-visual sensors either located in the monitored space, or on the mobile device to capture audio and visual signals from important aspects of the life of the user. On the mobile device, the microphone is used to record important conversations when the user is not at the monitored space. The device is placed between the speakers and the audio recordings are hence medium-field. These recordings are transcribed when the user returns home, as they are transferred to the main HERMES computers. Reverberation and noise in such recordings render them difficult for transcription. This is addressed by an advanced algorithm for transcription detailed in (Aronowitz, 2010).

In the monitored space there is a microphone array comprising seven microphones and two cameras with overlapping field of view. This audio-visual setup allows for tracking and recognition of people in the monitored space. The perceptual algorithms operating on these signals are split into on-line (operating in real-time) and off-line.

The aim of on-line algorithms is to monitor the state of the room and trigger recordings and reminders. These are image-based 2D face tracking (Pnevmatikakis, 2010) and face recognition (Pnevmatikakis, 2009). A third algorithm can also be on-line. This is 3D visual person tracking (Andersen, 2010), but since its performance deteriorates in setups with just two cameras, it is only deployed in the lab with four cameras and not in the space of the elderly.

Off-line algorithms provide further processing of the audio-visual signals. There are two such algorithms. A 3D audio-visual tracker (Pnevmatikakis and Talantzis, 2010) provides the track of the active speaker and an estimate of the presence of speech based solely on geometrical criteria. Then, a beamformer utilises the 3D location of the active speaker to improve on the audio signals, generating something more suitable for transcription. Our preliminary results with just two microphones indicate a moderate improvement of the word error rate.

3.3 Information Persistence and Context Modeling

As already outlined the HERMES system provides two main structures and associated data structures for persisting information, namely an XML database and an ontological knowledge base. The HERMES XML Database ensures the persistence of information in the system. It stores details that are directly accessible by the user, for example the shopping basket, and others automatically created by the system, such as audiovisual recordings and results of perceptual components. In order to ensure that it can be extended to cover any future additions, while at the same time facilitating data exchange, the information is stored as XML data. This allows the system to adapt to future changes, as the API for accessing information will remain the same. Furthermore, this also allows for backwards compatibility with other modules, as any additional information in the XML messages can be easily ignored if the said module does not recognize/support it.

On top of the XML Database runs the Knowledge Base and Reasoning module; this is responsible for combining the outputs of perceptual components with information existing in the XML Database, in order to deduce the system state and to initiate the required actions. The Knowledge Base comprises ontology models, which describe the classes, properties and their taxonomies. An ontology model can be defined and inserted to the system either programmatically via a programming API such as the Jena framework or by using one of the available ontology editors (such as Protégé, Swoop and OntoEdit) (Cardoso, 2007). In addition to ontology models, the knowledge base comprises reasoners (notably RacerPro, OntoBroker), which allow the deduction of implicit knowledge by processing the knowledge that has explicitly been stated to the system.

3.4 Context Modeling

Context acquisition in HERMES is primarily based on the processing of sensor streams, notably audio and video streams captured from cameras and microphones within the HERMES in-door environment, as well as GPS sensor streams stemming from the HERMES mobile devices (i.e. PDAs). Audio and video streams are processed by perceptual components (i.e. signal processing technologies), which provide functionalities such as detecting faces, identifying people/faces within closed sets of people/faces, tracking people movement within the smart room, as well as identifying voice activity. The processing and combination of their outputs can lead to a richer and more sophisticated set of contextual information, for example the situations associated with self-care, identification of people walking in the smart spaces, identification of situations associated with the elderly domestic life, etc.

The HERMES context modeling and identification approach relies on processing of the output of multiple perceptual components in order to compose and identify such more sophisticated situations. To this end, the network of situations approach emphasizing the combination of perceptual components outputs on the basis of a graph of situations (Soldatos, 2007) was integrated in the system.

In terms of the timescale of the context identification, the HERMES system distinguishes between real-time and non real-time context identification. Real-time (or even semi real-time) identification of context hinges on combining perceptual components output at fine timescales. However, the HERMES system can also persist and index information in the knowledge base (described in the previous paragraph), with a view to reasoning over contextual information in coarser timescales. The latter approach leverages (historical) information contained in the knowledge base and is in principle a non real-time approach to context processing and identification.

3.5 User Devices

The design of the end-user devices is based on two guiding factors: (1) The special needs of elderly users when interacting with a touch screen-based device, and (2) the aim of reducing the complexity of information retrieval tasks dealing with potentially vast amounts of personal data.

HERMES comprises a number of applications addressing different aspects of supporting episodic and prospective memory. The main focus of the mobile system is to give prospective memory support while on the go and the desktop system is the sole access point to recordings of past events due the heavy processing requirements

3.5.1 Desktop

The desktop device provides the user with easy access to six touch interaction-based applications. The key applications *Calendar* (prospective memory support), *MyPast* (episodic memory support), and *Cognitive Games* (memory training) are complemented by three applications to support and extend functionality of their mobile counterparts, in particular to take advantage of the larger touch screen available on the desktop device. These applications are *Locations*, *People*, and *Shopping List*.

The Calendar (Figure 2) enables end users to organise their future appointments and setting custom reminders. The user has always the complete overview of the application.

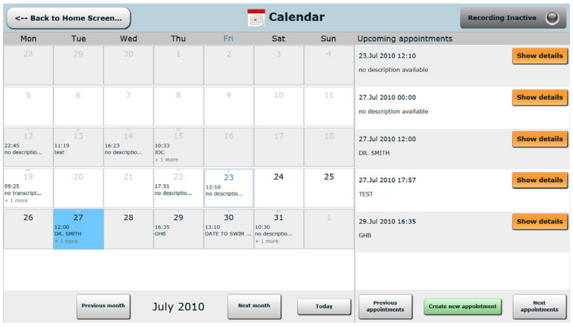

Figure 2: HERMES Calendar.

MyPast (Figure 3) allows retrieving of possibly vast amounts of audio and video streams of events that happened in the past. The specially designed multi-touch-enabled interface aims at reducing complexity of information retrieval process through (1) an indirect search approach (Chau, 2008) and (2) clustering of connected audio and video data within so-called storylines. Indirect search is enabled by multiple filters based on meta-data retrieved from recorded material (time, people, and speech). The concept of storylines is based on an event-based segmentation of audio and video data. This data is then allocated on a scroll- and zoom-able timeline of events. The filters described above allow dynamic inclusion or exclusion of events of the timeline.

Figure 3: MyPast – Setting a People filter.

Cognitive Games (Figure 7) offers three types of cognitive games: First, the Maze game trains the user’s memory of planned events by requiring him or her to select two different appointment details (such as its time and its description). Then, these details, represented as blocks, have to be moved through a maze simultaneously, training two-hand coordination. Second, playing the Who-Is-Who game trains person-related memory by matching pictures of people with respective personal details. Third, in the Puzzle game the user has to set together scrambled puzzle parts of personally relevant pictures of past events. Games can be played on the Desktop or the Multi-Touch Surface (as described in section 3.5.3)

The Locations application is complementing the prospective memory support of the Calendar with non-time-based, but location-based reminders. The desktop application allows management of the reminders for HERMES Mobile (see next section).

The People application (Figure 4) adds a third type of prospective memory support. It allows access to all people located in the database with a profile picture either retrieved from video footage or taken with the mobile device’s camera. It allows further to set person-based reminders, i.e. reminders that are not triggered by time or place, but the presence of a given person in front of the HERMES cameras. As an example, a user wants to be reminded to give back a book borrowed from a friend, but forgets when the person is present. This type reminder is better associated with a person instead of time. As soon as the person is visiting next time, a reminder will be issued to give back the book.

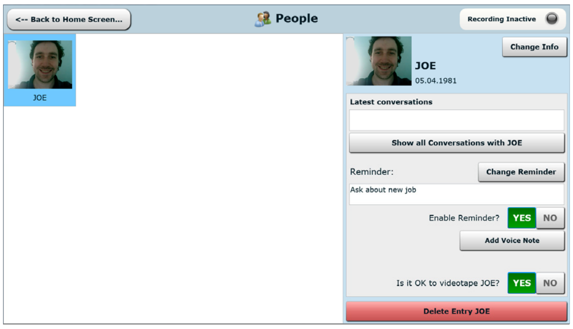

Figure 4: HERMES People.

The Shopping List application (Figure 5) complements memory support by helping users to create shopping lists that can be read or changed while on the go using HERMES Mobile.

Figure 5: Desktop Shopping List.

3.5.2 Mobile

The HERMES Mobile Application provides the user with an advanced event manager and reminder integrating geo-positional capabilities, people browser, shopping list manager and, most important, it is also the only sensor for outdoor scenarios, supporting appointments dictation and conversations recording.

Figure 6: HERMES Mobile Application: main menu.

The application runs on a PDA with touch screen and built-in GPS device. This mobile device provides an accessible and user-friendly interface for elderly people. The user can type or dictate appointments or notes. In supplementing the desktop application *MyPast*, the mobile device provides conversation support with the *Conversations* application, turning the mobile device into an audio sensor. The collected data is processed afterwards by the system, upon synchronisation (typically when the user comes home) as it is done for in-house sensors. Specific features supporting particular cognitive impairments have been added supporting functionalities appearing in the desktop-based applications.

3.5.3 Multi-touch Surface

A very low-cost multi-touch device has been implemented to facilitate user interaction with the system and the games. The hardware of the device and its finger tracking algorithm are detailed in (Petsatodis, 2009), while its use for the support of effective ergonomic cognitive training for the elderly is described in (Theodoreli, 2010).

The multi-touch device being used to play cognitive games is shown in Figure 7.

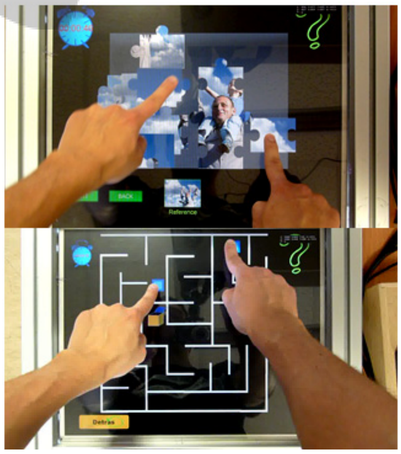

Figure 7: Multi-touch surface of HERMES.

4 USER INVOLVEMENT AND EVALUATION

4.1 Continuous User Involvement

Including the elderly users throughout all project phases is of high importance for successful product development (Demirbile, 2004). For HERMES, a questionnaire, focus groups, cultural probes, diaries, memory assessment and interviews were used for assessing users' needs. An initial mock-up was evaluated with 8 users and led to additional improvements and the development and deployment of the first software prototypes that were subsequently assessed under realistic conditions in two trial sites in Austria and Spain with a total of 27 users. The system was personalized for each (elderly) test-subject by populating HERMES with personal data. Hence, each test subject was confronted with his own data only. All trials were carried out in a lab environment, yet the PDA applications were tested in the field as well.

After an initial introduction participants carried out a number of tasks with the system in order to develop a feeling for it and its functionalities, while also assessing usability issues. The study was carried out in the presence of a researcher. This ensured assistance for test-subjects (as needed) as well as objective observation of test-subjects. The tasks covered a wide range of scenarios, dealing with the central use cases of the system (creating appointments, setting reminders, searching for past events, playing back videos etc.).

After completing the tasks, evaluation questionnaires were filled in by the participants. The questionnaires were kept consistent between the two test locations to compare results and determine differences based on cultural background.

After collecting feedback on usability and user acceptance during the first user trials the interfaces were further improved and extended.

4.2 Evaluation Research Questions

For the final evaluation of the integrated and deployed prototype, the following three elements are the focus of research:

1. User perception of performance of the underlying components
2. Usability and user experience of the user interfaces
3. Acceptance of the HERMES concepts for cognitive support

The reason for performing this three-layered evaluation is to be able to assess the origin of user problems. This allows investigating if user acceptance problems stem from concept rejection, bad usability or just low system performance.

Performance evaluation focuses on the question 'how good is "good enough" for the user' for the components underlying to the HERMES system, i.e. which performance (e.g. speed, accuracy, and relevance) of the various components is necessary for the user to be a useful memory support.

The second research question focuses on howwell the user experiences the HERMES system. While usability problems and issues of interface complexity were discovered to a large extent by previous trials and heuristic evaluations, the focus of the second trial is on user experience of the desktop and mobile system as a whole, with an additional focus on game experience of the cognitive games. Furthermore, a learnability evaluation will assess how elderly users are able to learn and improve their individual use of HERMES according to speed and subjective estimation.

The third layer targets the acceptance of the HERMES technology and concepts and thus the perceived benefits of the cognitive support provided by HERMES. Existing technology acceptance models, such as UTAUT (Venkatesh, 2003) have proven to be inadequate for the context of ubiquitous AAL technologies for various reasons, as argued by Allouch (2009) and Arning (2009).:

- Context of use (no work-related context)
- Heterogeneity of the users (elderly people)
- Development status of the evaluated system (prototype only)

These shortcomings are addressed by an experimental evaluation design based on a proposal by Allouch (2009). Specifically, rather than basing acceptance on real usage, technology is assessed by anticipating its adoption. The advantages of this model are that technologies to be assessed do not need to exist yet (or are in development phase) and users do not have to have prior experience with using them. Complementing this, pre- and post-usage results are compared. The following hypothesises are formulated:

1. The longer the duration of use, the higher the Technology Acceptance (TA) of HERMES
2. The more previous use of technology, the higher the TA of HERMES
3. The lower the memory functioning, the higher the TA of HERMES
4. The higher the perceived user experience, the higher the TA of HERMES

The first hypothesis will be assessed during the home evaluation (see below). The second hypothesis assumes that prior knowledge of general technology will lower entrance barriers of AAL technology. The third hypothesis stems from the question if users with more memory problems will see higher usefulness in the application. Finally, the forth hypothesis seeks to confirm the influence of emotional experience aspects during usage on the overall acceptance of the system.

4.3 Evaluation Procedure

As time of writing, the final user evaluation is about to be performed with a total of 59 participants in Austria and Spain. 20 of those are evaluating HERMES concepts and performance of underlying the components. Usability and user experience evaluation takes place not only in the lab (13 users in Spain and 18 Users in Austria), but also in 8 real homes of people for a period of two weeks per home. The evaluation includes to a certain extent the 'extended home', which includes the people in the direct surrounding of the study participant. Besides interacting with the system as a single user, the social interaction and context of interaction with technology is assessed.

The evaluation procedure follows the three evaluation layers described above: it will assess performance of the system with a set of tasks varying the performance of key HERMES components (such as filters based on person identification and transcription of speech). User feedback on these varying conditions will be gathered. Furthermore, user experience of the system as a whole will be evaluated with a set of tasks comparable to the ones used in the first trials. Finally, the HERMES concepts are assessed using a presentation of HERMES scenarios followed by the adapted technology acceptance questionnaires.

5 CONCLUSIONS

Ambient assisted living and ageing well are privileged fields for deploying pervasive context-aware systems. Despite the proliferation of pervasive system deployments, the challenges associated with the elderly needs are not fully addressed in the scope of legacy pervasive systems architectures. Such challenges include the need for interacting with users with multiple modalities and in a non-intrusive way. Recent advancements in pervasive systems render them appropriate for tacking these challenges.

In this paper we have illustrated a novel pervasive system supporting non-trivial assistive functionalities for elderly users, with a focus on alleviating the cognitive decline. The system relies on the integration of a wide array of components, ranging from sensors and perceptual signal processing algorithms, to touch devices and related ergonomic software applications. Despite the system's complexity, early feedback from trials has been very promising. Future work should emphasize on enhancing deployment flexibility and ease, while at the same time lowering the total cost of ownership of the system. Furthermore, the complex task of information retrieval needs continuous effort to ease understanding of operational concepts for the very heterogeneous group of elderly users. Such work could serve as a basis for moving the next generation of such assistive systems to the enterprise, as a follow on to early (simpler) systems outlined in (Stanford, 2002).

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