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# A MOBILE SYSTEM FOR ASSISTED LIVING WITH AMBIENT FACIAL INTERFACES

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## ABSTRACT

This paper describes a mobile Ambient Assisted Living (AAL) solution designed to meet the requirements of modern health services in caring for, monitoring and motivating the elderly in their own environment. Our solution goes beyond the function of classical telemonitoring by delivering integrated functionality that includes health management, mental monitoring, mood assessment as well as physical and relaxation exercises. In addition, we provide communication and delivery services in location-based manner using built in GPS, WiFi and 3G mobile connectivity (MediCAST). Bluetooth compatible blood pressure and body weight measurement devices are complemented with a body-mounted wireless physiological sensor to monitor activity, body temperature and stress. Telemetric data is continuously recorded on a local host computer while simultaneously being also sent to a central database, where a rule-based system or monitoring health personnel may make emergency assessment. To further help the elderly, to monitor their own drug intake or dietary goals we introduce a novel feedback and display methodology, called Ambient Facial Interfaces (AFI) that employ animated photo-realistic faces to show them in an easy-to-understand form their compliance levels. Finally, we describe a prototype of our futuristic AAL platform using home robots to help people with daily activities.

## KEYWORDS

Ambient Assisted Living, home monitoring, mobile care, MediCAST, Ambient Facial Interface, robotics, Virtual Human

# 1. INTRODUCTION

Improving the quality of life for disabled and the increasing fraction of elderly people is becoming a more and more essential task for today's European societies (Steg et al. 2006). The quality of life of any person, young or old, heavily depends on the efficiency, comfort and coziness of the place he or she calls "home". Disabled people have specific requirements as for their home environment and its functionalities. For elderly people, home is a place of memories where they spend most of their time. Their demands on their home environment will increase and change with growing age - especially when their health status starts to worsen. An important aspect for all people having the need to be supported in their daily-life-activities is to remain integrated in social life - despite of their age and existing disabilities.

This especially becomes important as Europe and industrialized countries worldwide are confronted with a demographic shift. The consequence of increasing life expectancy and decreasing birth rates is an EU population that is becoming increasingly older (see Figure 1). This is even more a problem because looking at long-term projections, the process of ageing is set to increase within industrialized countries at an even faster pace. This demographic change has and even more will have enormous economic and social implications in a number of areas. As for labor markets, pension systems and social schemes in general, we have to consider that demographic ageing means that the number of older people is growing while the share of those of working age is decreasing. Not only will the income side of social schemes be affected but also expenditures: Health care systems for instance, will be concerned as population ageing will lead to an increase in the proportion of the population with disabilities or chronic diseases.

Facing these challenges and opportunities of ageing societies in Europe there exist areas of opportunity, where technological and social-economic innovation can enhance the quality of life of older and impaired people, mitigate the economic problems of an ageing population and create new economic and business opportunities in Europe. Especially "Ambient Assisted Living" (AAL) as a specific, user-oriented type of "Ambient Intelligence" may greatly help in this situation. AAL can help impaired and the growing group of elderly to live longer at the place they like most, while ensuring a high quality of life, autonomy and security. This e.g. includes assistance to carry out daily activities, health and activity monitoring, enhancing safety and security, getting access to social, medical and emergency systems, and facilitating social contacts. Receiving social and/or medical support in various new intelligent ways consequently contributes to independent living and quality of life for many elderly and disabled people. Overall "Ambient Assisted Living" can improve the quality of life of elderly people at home and reduces the need of caretakers, personal nursing services or the transfer to nursing homes. Therefore, there is a twofold goal of AAL: a social advantage (a better quality of life) and an economic advantage (a cost reduction for the welfare state).

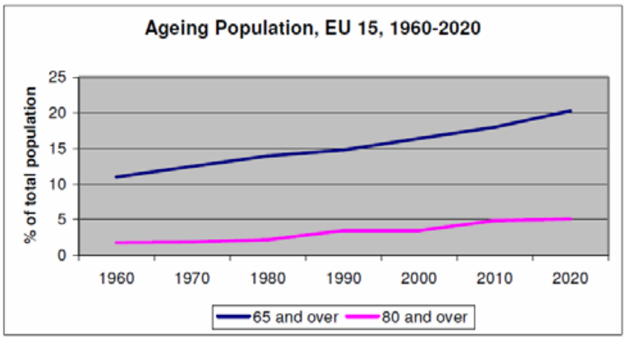


Figure 1. Ageing population, EU 15, 1960-2020 (European Commission 2003)

This paper describes a *complex wireless and personalized AAL solution*, which enables the delivery of integrated functionality that includes telemonitoring, health management, mental monitoring, mood assessment as well as physical and relaxation exercises. Our approach is based on a novel computational and communication platform, called the *Virtual Human Interface* or VHI (Takács 2005a) that was specifically designed to bridge the gap between people and computers by using virtual reality and animation technologies. During the past three years the *VHI* architecture has been successfully deployed to address the many needs of rehabilitation, in general and cognitive, physical- and mental care in particular (Takács 2006a; VirMED 2007). Built upon these achievements we further extended the capabilities of the VHI in the domain of *wireless applications and mobile platforms* and created a home-based patient monitoring solution we believe may form the basis for many future health-care services to come.

State-of-the-art health monitoring devices and services has recently become more and more publicized and in some cases accessible in the form of test-applications. They were typically presented as "killer applications" for future telecommunication companies or were backed by manufacturers of tailor made devices who were attempting to broaden their market share by adding wireless communication standards to their scales, blood pressure monitors, etc. (Paradiso 2004; Husemann & Nidd 2005; PHM 2005; Top Care 2006; Aerotel 2007; BodyMedia 2007; Ericsson 2007; RTX 2007). Several system integrators have also attempted to introduce telemedicine systems in the past five years, yet to date and to the best of our knowledge most of these attempts have not lead to commercial success, as they primarily served the purposes of technological demonstrations and were never turned into products entering the marketplace. We argue herein that by reviewing these projects and others to come one may analyze what prevented these excellent technical solutions from entering the marketplace and become widespread within a few years. In our opinion one of the most significant factors in this "lack of performance" was the closed architecture of the systems as well as the cost of relatively expensive components. As a result, the lack of interoperability and compatibility with widely accepted communication standards did not permit other manufacturers and application service providers (ASPs) the integration of newer and cheaper devices, and on the other hand, consumers were unable to customize these systems to their own needs. A further problem in this field is the lack of real consent in the area of wireless communication standards. As an example, currently available telemonitoring devices uses as many as five different wireless standards (ranging from Bluetooth, to ZigBee, Ant, 900MHz, and WiFi) many of which are burdened by range, performance, connectivity and authorization issues for every day use. Thus, in the home care and telemonitoring market one finds plug-and-play availability neither with personal computers nor with mobile devices and cell phones. For these very reasons, our primary goal in our development was to implement an open-architecture and re-configurable system which is as independent as possible from individual manufacturers and wireless standards.

The remainder of this paper is organized as follows: In Section 2 we briefly review the architecture of our wireless solution for *Lifestyle and Health Management Systems* (LHMS). Section 3 briefly introduces our Ambient Facial Interface technology as a means of visual feedback, and Section 4 describes the main services and the integrated functionality we offer for health monitoring, communication, data collection, entertainment and exercise. Section 5 describes the central medical database responsible for patient management while Section 6 shows how we can achieve compliance monitoring using mobile phones alone. Finally, Section 7 describes a home-based robotic platform we developed to be able to better reach and help the elderly in their own environment, and Section 8 concludes the paper with plans of our future work.

## 2. SYSTEM ARCHITECTURE

Our AAL solution relates to a novel lifestyle and health management platform for elderly people living alone or with their families as well as for a younger generation, where trends in pop-culture and fascination with technological gadgets offers a unique opportunity to make ones health a “fashion statement”. The focus of our research and our main goal is to create an open-architecture and open source service model where home-based and wearable (yet medically accurate and reliable) sensors provide data and information to a portable controller (such as a mobile phone, PDA, Internet Tablet or small factor computer) which not only collects information, but evaluates trends, provides advice on health, diet or workout regiment, and does so via a transparent and redundant data link between the elderly person and his or her care takers. Figure 2 shows our architecture. On the left, a number of health-care and monitoring devices (placed in the home) are connected to a small factor computer via wireless standards and optionally with USB interface. In the center, the mobile computational platform (*Asus R2H UMPC* in our case) is linked with a mobile phone to process sensor data, manage AAL applications and ensure redundant connectivity via 3G and WiFi data networks. Information gathered by the sensors is transmitted to a central database and advisory system (called *INes*) for evaluation and monitoring by medical personnel (right). Unlike other solutions our architecture allows for bi-directional video and audio streams attached to telemetric information and therefore it may be used to transmit virtual exercises for motivation, video conference calls with doctors and family and a range of services related to every day activities and becoming a member of a community. The principal modules of our AAL solution are as follows:

- **Lifestyle and Health Management System (LHMS):** At the heart of our system we use an intelligent communication device capable of running multiple applications and provide advanced connectivity with various sensors and the outside world. This is a portable, small form factor interface platform that blends into the environment (e.g. appears to be a digital picture frame showing family photos - see also Figure 5), which comes to life only when needed. It is connected to a variety of *wearable sensors* to gather information about the physical and mental state of the user and can connect to the outside world via *redun-*

*dant communication* layer. The primary interface for the applications running on this device is *touch screen* and a *digital face* that employs facial expressions and mimicking as an easily recognizable and understandable visual feedback (Takács 2005b, 2006b). Applications running on this platform receive the data collected by the sensors and provide *personalized dietary advice,* measure and visualize trends (e.g. blood pressure. Body weight), monitor and encourage exercise, and finally – with consent of the user – may place emergency calls to relatives or hospitals when required.

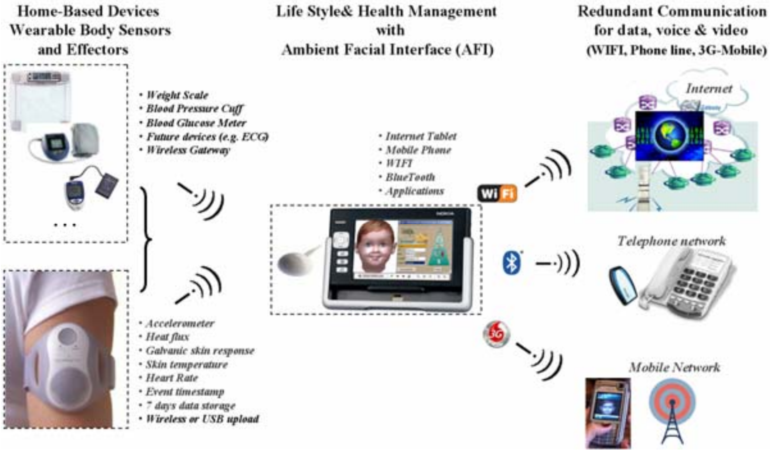


Figure 2. Overall architecture of the Lifestyle and Health Management System for AAL.

- **Wearable Sensors:** A variety of sensors are available to measure physiological state associated with health and fitness. These devices include *home based* solutions for measuring and sometimes recording body weight, blood pressure, glucose levels, oxygenation, respiration and even heart activity using low-cost ECG sensor, just to mention a few. Increasingly a second class of devices emerges which are *worn on the body* for 24 hours and collect data on multiple sensory channels as long as up to 7 days. Increasingly both trends provide *wireless data access* for comfort and ease of use. To handle all these devices in a *uniform manner* we devised a transparent communication interface with commercially available devices and developed an abstraction layer that maps physiological data onto abstract representations, we call *markers*. These markers are then transmitted to the central computer and serve as the basic unit of interaction.
- **Communication:** Redundancy is a key factor in creating successful communication architecture for *AAL*. Given the already existing infrastructure available at home and to the public at large, there are three main stream possibilities to connect the elderly user with the outside world. *WIFI* works inside the home usually as part of existing Internet services. It provides a high throughput channel capable of delivering real-time video, large data files and interactive services alike. Bluetooth, 900 MHz, and Ant communication links may be used to connect to different devices to deliver data to a remote server or application using specified protocols. Finally, 3G mobile phone connectivity offers the freedom to leave the home and access high data rate services, even video using readily available and low-cost devices. In many practical applications at least one of the above solutions may be counted on, but none can be guaranteed. This is particularly important for *rural areas* where much of the population may not have access to due to cost of service or

simply the cost of these devices they would need to buy for their homes. Therefore our main goal was to develop a layer of redundancy that can access multiple of these channels in order to deliver services reliably and in a fault tolerant manner.

- **Effectors:** The *LHMS* solution described herein draws on the existence of *intelligent devices* in and around the home to help its user. One general terminology for these devices is *home-robotics*, which includes *wirelessly controlled pill dispensers*, and in the future digital pets or other useful robots. Other effectors may be used as *ambient displays* showing trends in weather to dress warm, health concerns to encourage doing more exercise or diet, such as to cut back on eating chocolate.
- **Services and Applications:** Using the *open-architecture application* model, a variety of Internet-based applications and services has also been incorporated in our system. These include *visual connectivity* with family members, friends and medical offices, and *emergency monitoring*. In addition to the monitoring of physiological variables (temperature, heat flow and energy, skin conductance, heart rate, etc.) we added a set of exercises that *monitor mental state*, help with *depression* and phobias, and *developed biofeedback games/exercises* for the elderly, which *use the stream of real-time sensory information to motivate and entertain*. Finally, the platform is also combined with Internet-based *fulfillment services*, such as home-delivery of medicine, food, dietary advice, and other health-related products.

Having discussed the basic modules of our AAL solution in the following sections we describe in detail the operation of each component, which together provide the integrated functionality we deem necessary for real-life acceptance of such devices and services.

## 3. AMBIENT FACIAL INTERFACES

Another key component of our system is called *Ambient Facial Interfaces* (*AFI). AFIs*, in this context, are used to provide visual feedback and confirmation to the user in a manner independent from age-, language-, culture- and mental alertness. *AFIs* use *photo-realistic animated faces* or photographic humans to display emotional facial expressions, non-verbal feedback, and body language most reliably recognizable by an elderly person. These digital faces are controlled by the output parameters of physical measurements or data derived from the state of the user or the products and objects he or she is interacting with. The output of an *AFI* system *combines these measurements into a single facial expression* that is displayed to the elderly user, thereby allowing them to evaluate overall “quality” *at-a-glance*.

To demonstrate the basic concept of *AFIs* let us consider food items sitting on the shelf of a refrigerator. They can be fresh, gone stale or potentially even cause food poisoning. Senility or blurred vision as well as many other contributing factors may easily transform this normally harmless situation to become very dangerous. To avoid this problem an *AFI* is used implemented in the form of a *product label* (such as barcode or RFID tag) placed on the surface at the time of manufacture and a wireless read out device that queries the product for its *quality*. As time goes by physical conditions affect the usability and the quality of the products in the refrigerator. However, when they are taken out, the embedded label is read and the system outputs a facial expression indicating the “freshness” and edibility of the product itself.

*AFIs* draw on early cognitive processing, specifically the brain’s ability to recognize and distinguish fine shades of facial expressions (e.g. emotions such as happiness, surprise, fear, anger, disgust or sadness). Taking this into consideration AFIs employ a simple but powerful visual paradigm in which facial expressions are arranged in a sequence and provide a single output encoding the history and usability of products, or provide immediate *feedback on compliance levels at a glance.* Recognizing the emotion shown in other people's faces is an evolutionary advantage each person possesses and readily understands without words, text or other further explanation. It is a language based on *non-verbal communication* and it provides an efficient and universal means to communicate danger, fear, joy, and other aspects critical for every day survival. These signals are processed at early cortical stages often without our conscious intervention and as such *they work across different cultures, races, age groups and individual variations.* Furthermore, this capability diminishes only minimally while our mental state and consciousness declines often rapidly with age, making such labels ideal for the elderly. Our abilities to discern facial signals is very sensitive, people can read the slightest changes in facial expressions very easily. This distributed architecture in the brain gives rise to the very possibility of using these facial displays to help people assessing the overall, global state of a complex system by the simple means of facial images in the form of animation controlled directly from measurements.

*AFIs* enable elderly users to evaluate the overall quality, such as freshness, usability and/or safety, of a particular product simply by looking at them. While they *involve no language or reading* yet they provide accurate assessment whether, as an example, a food item is still consumable. Using the measurements collected by the body-sensors AFIs can also provide feedback on life-style as well as trends such as indicating whether an elderly person needs to drink more, take his or her medicine, or do more exercise, just to mention a few practical examples. Figure 3 demonstrates the generalized model and the concept of *Ambient Facial Interfaces* as a display methodology for the elderly in more detail. Facial expressions are arranged in a sequence forming a scale that spans from "good" to "bad". An embedded label encodes the history of the product in terms of conditions affecting its overall quality and safety for use. Eventually as a function of these measurements the system computes and communicates *single score* to the query device (a mobile platform) that produces an easily understandable facial display as its output towards the user. In addition, voice instruction and sound alerts may also accompany this visual signal when required. The system depicted in Figure 3 may also be augmented to *track how much an elderly person drinks,* what he or she eats while observing a restricted diet and in general to *provide a bi-directional visual information link* between the caretaker and the person.

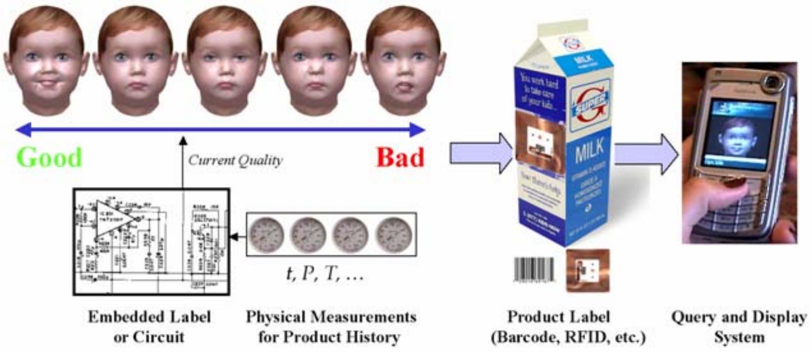


Figure 3. Overall methodology of Ambient Facial Interfaces demonstrated in the context of food items or medicine.

Figure 4 shows another scenario using *AFI*s in a telemedicine application. The same mobile platform collecting and displaying data on the quality of food in the figures above now uses Bluetooth in the home of an elderly person's to query the measurements stored by a number of different *health-management devices*. These devices include telemedicine-enabled blood pressure monitors, weigh scales, glucose monitors, inhalers and possibly exercise machines. These ambient measurements allow the system to assess whether the elderly person has taken all their medicine, ate their diet, drank enough to avoid dehydration, carried out their usual exercises, took a nap after lunch, etc. Since all this information is collected in an *ambient manner*, there is no need to disrupt the every day activities of the person by constant reminders. Instead an *AFI* may be used to indicate whether all patient specific measures of home care are taken care of. Monitored data is transmitted to a central server and a database via public Internet and 3G mobile phone allowing doctors to follow progress closely while remaining at a comfortable distance. This architecture also contains *direct video* capabilities whereas in times when the elderly persons needs to be reminded of needing to carry out a specific task, the face of a family member, the care taking doctor, a hospital nurse and even an animated virtual face may appear thereby offering a pleasant alternative to beeping sounds and alarms.

Unlike other compliance feedback solutions our system's the ability to give direct facial feedback with AFIs and even encourage elderly people to properly care for themselves by means of simple gestures and a feeling of caring, offers yet unimaginable abilities to increase their quality of life while respecting their privacy. Ambient Facial Interfaces can thus become a useful and general purpose interface helping an elderly person to attend to a variety of mundane daily tasks and allowing their doctors and family to oversee their activities remotely and without interfering with their everyday lives.

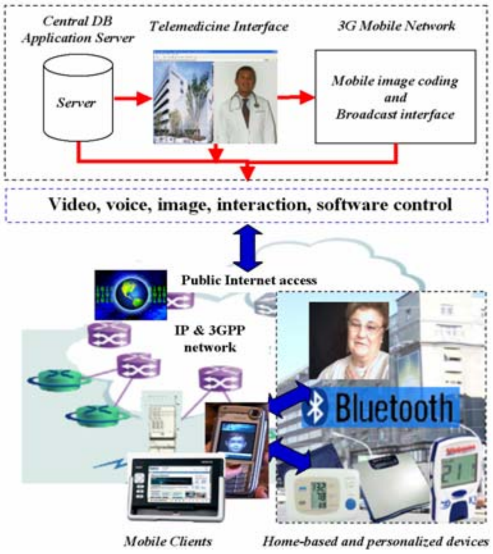


Figure 4. System architecture of using AAL and AFIs in the home for telemedicine.

# 4. INTEGRATED FUNCTIONALITY

In order to create an ambient solution our goal was to hide the complexity of the computational platform and make it blend into the user's own home environment as much as possible. To achieve this goal we selected a ultra mobile PC (UMPC) platform that is placed on to of a television and acts as a digital picture frame showing a continuous, looping slide-show of selected family photos. This is demonstrated in Figure 5 on the left. When the screen of the portable device is touched, it "comes to life", and offers a menu of services to the user (see Figure 5 right). These services, discussed in the sections below fall into the categories of health monitoring, communication with the therapist and with family members, exercises for maintaining physical and mental health and offering motivation for workout, and miscellaneous services, such as home delivery and weather report. But even when the device seems idle to the user, it continuously collects biometrical and physiological readings from wearable and wireless sensors, such as the wireless armband sensor, blood pressure monitor and digital scale shown in Figure 6, and streams data on skin temperature and resistance, heat flow, heart rate, etc. to the central monitoring database. There qualified personnel aided by smart algorithms can monitor activity patterns (sleeping, awake, exercising) and look for anomalies.

Figure 5. The central module of our AAL system on top of a television set showing family photos when not in use (left), and becoming active when touched (right)

## 4.1 Health Monitoring

The armband shown in Figure 6 measures heat flow, skin temperature, skin conductance and two axis acceleration and it is also equipped with an emergency button which, when pressed, notifies the system to call an ambulance immediately (Figure 7). As the heart of the system (UMPC) is equipped with a built-in *GPS receiver*, it allows for the identification of the exact location of the patient in stress. Communicating this information automatically to the service call center, prompt and reliable help is on its way even when the person is temporarily rendered incapable of talking or fell unconscious.

The stream of *continuous physiological monitoring data* collected by the armband sensor is divided into sessions based on whether the patient is home or not. Upon entering the house, the central module senses the proximity of the devices, welcomes the wearer at home, and opens a new data file stored both locally and sent to the central DB in real-time. *Discrete measurements* complement this information in the form of blood pressure and body weight, and generally devices that provide asynchronous data with time stamp. Wherever such measurements arrive via the Bluetooth channel the system presents them to the user by plotting a chart of the latest 2 or 3 weeks. This feature allows the elderly patient to immediately evaluate for his or her own purposes the *trends* they see on the television screen.

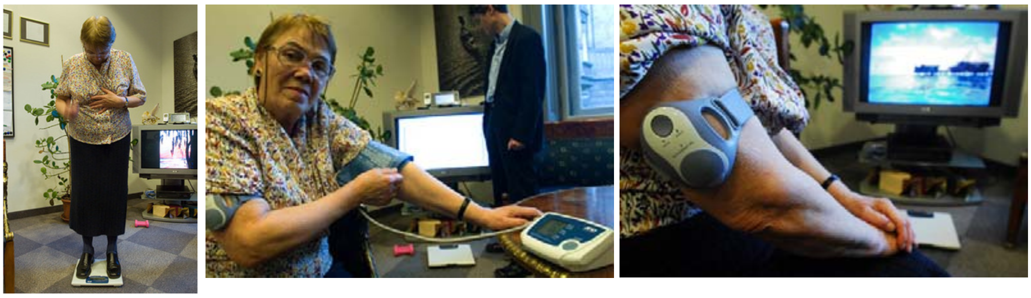


Figure 6. Examples of wireless sensors worn by a test subject
(Bluetooth-enabled digital scale, blood pressure monitor, wireless physiological monitor)

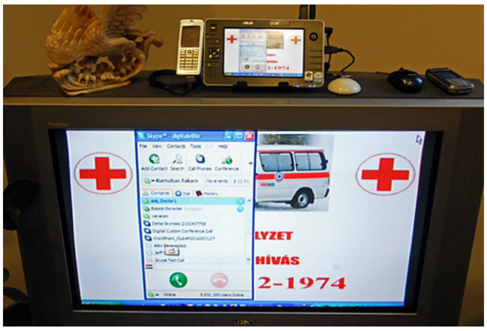


Figure 7. Calling the ambulance with the help of a button.

Figure 8. Video conference with a doctor or family member.

## 4.3 Virtual Exercises and Motivation

Motivation and the monitoring of mental state, cognitive performance and mood is also a key requirement for AAL systems. The aging brain often reduces the abilities of elderly people to perform daily mundane tasks. Keeping their mind and mental balance healthy is almost as important, perhaps even more, than monitoring their vital signs. Therefore our AAL system offers a number of different exercises to provide opportunity and motivation. These are briefly as follows:

- **Cognitive exercises:** It has been shown by various researches that extended mental inactivity can eventually lead to the deterioration of cognitive abilities. Therefore it is important to keep the elderly mentally active even when they are alone in their homes for longer periods of time. Our system contains a *geographical quiz* (Figure 9), tests for dementia in the form of Paired Associative Learning (PAL) (Sahakian & Owen, 1992; Robbins et al. 1994; Fray, Robbins & Sahakian 1996) and similar exercises. In all of these the patient uses the touch screen to pinpoint the location of various cities given different context and the outline of countries or pair simple shapes. Depending on how close his or her guess was to the correct answer, the system either moves on to the next question or asks the user to try again. When the performance of the patient is steadily good, the "game" advances a level higher by hiding certain details (borders, labels, dots of cities, etc.) from the map, and similarly when the performance degrades, the system provides additional information in an effort to maintain a sense of success in the patient. This simple technique proves not only useful but also entertaining to the patient.

- **Mood assessment:** The system contains a depression scale test to assess the current *mood* of the patient. The user must answer a series of simple questions of the so called Beck depression scale (Beck & Steer 1984; Kendall et al. 1987; Beck, Steer & Garbin 1988) about how he or she feels at the moment. The answers are evaluated locally, and based on the results the system might suggest to perform certain exercises to cheer up the patient or to distract his or her attention from depressing thoughts. At the same time the data are also transmitted to the central database, where the doctor can access them and compare them with earlier results, thus being able to analyze not only the current condition of the patient but also the trends.

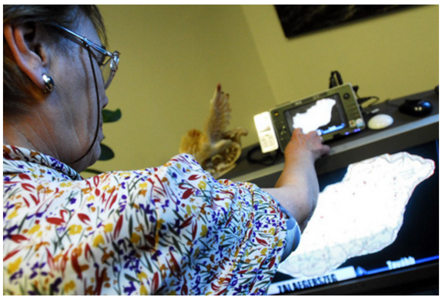


Figure 9. Monitoring mental state and cognitive performance using a test on geography

Figure 10. Performing a physical exercise while watching a Buddha on the screen to move in unison.

- **Physical exercises:** The two-axis acceleration sensors embedded in the armband that the patient wears all day allows our AAL solution to have the user perform certain simple physical exercises, such as lifting weights (Figure 10). Here the system displays a simple animation for motivational and feedback purposes. The motion of the virtual character's arms - a Buddha figure appearing on the screen of the television set in this case - follows the arm movements of the patient and helps them properly execute a variety of tasks. Similar exercises (e.g. jumping up and down) have been devised to keep users fit and healthy. Again, the data collected maybe used to assess overall performance and rate of incline or decline in physical strength.
- **Relaxation exercises**: The last type of exercise currently supported in our AAL system is one helping the patient to relax. This exercise uses variations of skin conductance level and hear rate of a person to measure their level of excitement. Their goal is to enter a relaxed state while becoming calmer and calmer. Visual feedback is provided in the form of a bio-controlled animation where progress is made according to the levels of stress measured. As an example, a simple relaxation exercise may feature an animation of a boat floating on a river, door opening, passing a bridge, etc. In the first case, as the patient gradually lulls him or herself into a relaxed state, the bloat floats closer to the shore, and is eventually moored, which concludes the exercise. If the level of stress increases, the

boat floats away from the shore. Like in the case of the physical exercise, the motivational factor is again important: the patient must actively participate in the exercise and force him or herself to relax in order to see the boat successfully moored. Since in our modern societies many people find it difficult to get away from the problems of everyday life, and are usually subjected to a sustained high level of stress, which has negative effects on their quality of life and in the long run also on their potential life span, such simple relaxation exercises can help train people on how to become less stressed.

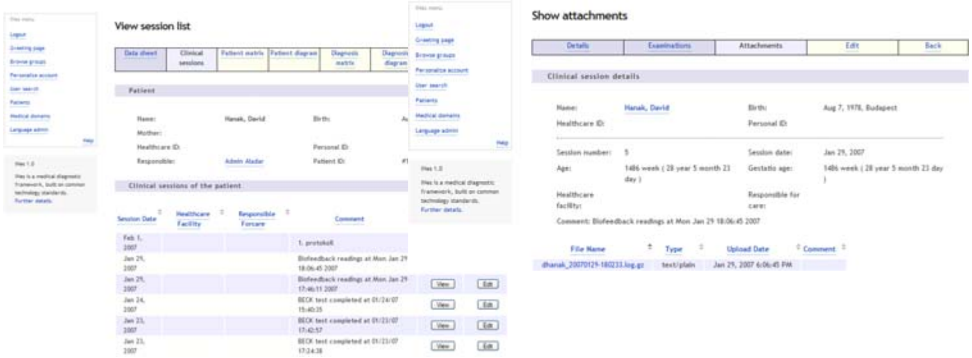
- **Services:** In addition to the above features, the LHM system offers an array of auxiliary services of third party providers. When the appropriate menu item is selected, the user is forwarded to web pages showing current local weather maps (shown in Figure 11, particularly informative for people suffering from rheumatic and arthritic disorders), or offering home delivery of medicine, or providing dietary advice.

Figure 11. Local weather map showing current conditions tied to the GPS-system.

## 5. CENTRAL MEDICAL DATABASE

The central medical database of the *LHM* system, called *INes*, is a medical, diagnostic and patient management solution with a flexible, generic, object-oriented architecture targeted directly at medical applications, which delivers a multilingual data collecting, -archiving and retrieval system accessible through a web interface. All these qualities made *INes* an excellent choice for integration into our system, requiring only minor adaptations in the underlying data model.

Within our system INes manages the centralized recording, archival and semi-automatic analysis of all medical data collected from the patients. Furthermore, a *diagnostic system* containing rules created by medical experts analyzes the data, and based on the results of the analysis, the LHMS can recommend physical exercises for maintaining and monitoring health, and alert the therapist when necessary to inspect the measurement results manually. The system design operates with the concept of *clinical sessions* (viz. inspections), which consist of recording medical data, followed by the analysis of the recorded values, and finally determining the next step based on these factors and the predetermined *therapeutical protocol* (the sequence of exercises, tests and treatments to be performed as part of the therapy). These sessions are created automatically whenever the patient uses the system at home in any of the various ways described in the previous section, i.e. by performing an exercise, filling a depression test, measuring blood pressure, etc. All sessions store physiological measurements provided by the various sensors and meters attached to the patient, both as quickly reviewable overall numbers and as detailed, high resolution data sets attached to the session record. Figure 12 shows examples of reviewing the list of a patient’s sessions and the attached documents.



View session list

Patient

Name: Hanak, David
Birth:
Mother:
Healthcare ID:
Personal ID:
Responsible: Admin Aladar
Patient ID:

Clinical sessions of the patient

| Session Date | Healthcare Facility | Responsible Forcare | Comment |
|---|---|---|---|
| Feb 1, 2007 | | | 1. protokoll |
| Jan 29, 2007 | | | Biofeedback readings at Mon Jan 29 18:06:45 2007 |
| Jan 29, 2007 | | | Biofeedback readings at Mon Jan 29 17:46:11 2007 |
| Jan 24, 2007 | | | BECK test completed at 01/24/07 15:40:35 |
| Jan 23, 2007 | | | BECK test completed at 01/23/07 17:42:57 |
| Jan 23, 2007 | | | BECK test completed at 01/23/07 17:24:38 |

Show attachments

Clinical session details

Name: Hanak, David
Birth: Aug 7, 1978, Budapest
Healthcare ID:
Personal ID:
Session number: 5
Session date: Jan 29, 2007
Age: 1486 week ( 28 year 5 month 23 day )
Gestatio age: 1486 week ( 28 year 5 month 23 day )
Healthcare facility:
Responsible for care:
Comment: Biofeedback readings at Mon Jan 29 18:06:45 2007

| File Name | Type | Upload Date | Comment |
|---|---|---|---|
| dhanak_20070129-180233.log.gz | text/plain | Jan 29, 2007 6:06:45 PM | |

Figure 12. Example review of a patient’s clinical sessions and the attached documents via the web interface of the data management system. The left image shows various examination dates, the right lists the attached documents.

The Web-based interface of INes allows the therapist to review the medical data from any location with internet access and to make the necessary decisions on how to proceed with the treatment of the patient. Obviously access to the data sheets is controlled via fine grained access rights, and protected by a combination of user names and passwords. A user account assigned to a doctor stores the real name, user name and e-mail address of the given person, and most importantly a set of permissions controlling what type of data can the doctor create, read and modify. INes also offers pages where whole series of measurements of the same kind from different occasions (e.g. sets blood pressure data) can be visually compared, enabling the therapist to observe trends in the patient’s condition. Still using the web interface, medical experts can assemble the *protocols* of exercises and tests to be performed by their patients, and also create the questionnaires to evaluate the changes in the physical and mental condition of the patients. Arbitrary length explanations, help texts, completion guides, animated instructions, etc. can be attached to all protocol elements and questionnaire items. Doctors may also decide to take and reuse a complete protocol or questionnaire compiled earlier by a colleague, if they have the appropriate permissions. INes supports a multilingual interface by offering the opportunity to enter text entries in multiple languages. When used appropriately, all users (including patients and doctors) can communicate with the system in the language they prefer. Documents may be attached to virtually any of the objects in the database, such as users, patients, sessions, examinations (single measurements and inspections within the sessions), etc. Documents may contain text, still images and video, such as medical history, former final reports, EEG, CT images, etc. This feature of INes is used to attach a complete log of sensor readings to all sessions recorded automatically in the database, as shown on Figure 12.

## 6. MEDICAST: COMPLIANCE MONITORING USING MOBILE PHONES

The above introduced model of the LHMS helps to monitor and improve the level of compliance in a number of ways. First of all, with a continuous or periodic link to the central database, it records and queries the progress of the treatment regularly, thus it is always “aware” of what and when should be done next. Second, using the main screen and the built-in speakers, it can inform the user any time that some sort of action should be taken. Polite reminders as well as continuous, perhaps slightly annoying “nagging” (just think of how most modern cars keep emitting a beeping or buzzing sound until the belts are properly buckled) can lead the patient to comply with the treatment. Third, by activating certain effectors such as the pill dispenser, the system can control the amount of medication taken and also remind the patient to administer the pills. Finally, if the care specialists, by observing the medical records collected by the various health monitoring devices, discover that the level of compliance has dropped, the archive of regular assessments can help to discover the reasons behind it. To implement the above advanced functionalities we created a more portable solution, called *MediCAST* (Hanák et al. 2007). It was designed to further enhance the capabilities of the LHMS, while focusing on increased mobility and allow patients to use even more portable and lower cost solutions. Specifically, the *MediCAST* system (its name deriving from medical content multicasting) consists of a lightweight client, i.e. a regular, 3G capable, Bluetooth enabled mobile phone equipped with our software, and a server cluster responsible for delivering content to each client. The Bluetooth interface allows the system to communicate with all of the aforementioned Bluetooth capable sensors, and any such devices in the future. A typical session, i.e. the normal dataflow when using the system, is illustrated on Figure 13. First a patient performs a measurement using his or her Bluetooth capable devices placed in the home (#1). Such devices include wireless blood pressure monitors, digital scales, etc. Measurement data is received by our application, where it is displayed or plotted locally as a confirmation, and at the same time transmitted to the central server using mobile 3G communication (#2). The server records the data in the database and checks for compliance using the rules created by medical specialists implementing the treatment protocol in hand (#3). Depending on the outcome of this integrity check, the server sends and audio-visual acknowledgement and/or warning message as confirmation, as well as optionally instructions, stored in the database as part of the protocol, on how to proceed with the treatment (#4). This information is delivered to the user on the screen of the mobile device (#5) and the session either continues with additional user input, or it is suspended until further action or measurement becomes necessary. Perhaps the most important feature of the system from the viewpoint of compliance monitoring is its ability to trigger steps #3 through #5 automatically. Specifically, the required protocol of each patient in the database is constantly checked by the rule system for compliance. If a user fails to submit their required measurements or provide information on a timely basis, a rule is triggered to take action automatically. Such action can take the form of sending an appropriately formatted SMS to the user’s mobile device, which in turn triggers the MediCAST application, allowing it to either display a reminder message or a warning video kindly reminding the user to take the required measurements. In addition, the server is also capable of sending a command to the *MediCAST* player on the phone to take a picture on its own initiative. This feature can be used to visually document the progress of the treatment by e.g. taking regular snapshots of a healing wound, the facial expression of the patient, etc. A reminder video with a user holding the mobile phone is demonstrated in Figure 14.

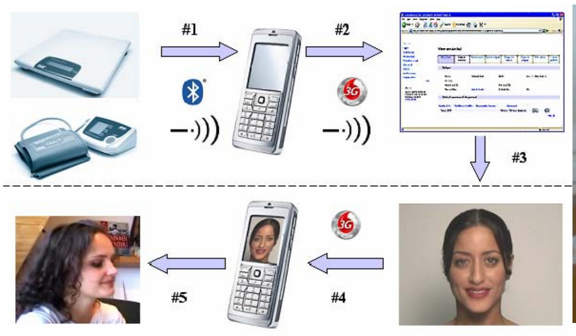


Figure 13. Dataflow of normal operation using the MediCAST system.

Figure 14. MediCAST compliance reminder helps to enforce protocols.

## 7. HOME ROBOTS FOR AAL / HELPING THE ELDERLY

The final module of our architecture (*effectors*) takes the compliance reminder feature outlined in the preceding sections one step further. Specifically, in addition to the video reminders on the mobile platform, the *LHMS* is capable instructing an *autonomous home robot* from the central server via the 3G connection and Bluetooth capability of the mobile phone to search for the user (Takács & Hanák 2007) and deliver medicine, other compliance reminders, and generally to help them with their daily lives. The basic robotic platform we deployed for this purpose (IRobot 2007) was augmented with advanced capabilities, such as autonomous navigation, face finding to help locate people in the rooms, an RFID interface to identify pill bottles and optionally monitor food intake, and finally AFI-capabilities to display compliance levels with the help of animated faces.

This is demonstrated in Figures 15 and 16. The heart of the system is a small computer (UMPC) with a built-in camera, touch screen, fingerprint identification, GPS and many more features in a compact setup. It is mounted in the cargo bay of the robot and used for finding faces in the room for the purpose of approaching them and autonomous navigation when no people are in sight. Attached to the UMPC is an RFID reader mounted as a service tray for keeping medicine bottles on it that can read tags in a continuous and discrete modes as well. Tags are attached to a intelligent tablet dispenser (Bang & Olufsen Medicom 2007) with its own compliance reminder capabilities (Figure 16 left) and additionally to the bottom of milk bottles, food items or any other object to be recognized. Drug intake (i.e. compliance levels) is monitored by checking if the user removed the tablet dispenser from the tray and placed it back subsequently. Similarly, drinking bottles and food items may be scanned when taken out of the refrigerator and the system automatically keeps track of hydration levels as well as dietary intake based on the product information coded in the database. Finally, Ambient Facial Interfaces are used to provide an easy-to-understand display for the elderly to know if they are in compliance with all requirements (Figure 16 right).

Figure 15. Home robotic platform with built in face finder, autonomous navigation, RFID and Ambient Facial Interfaces to help the elderly.

Figure 16. RFID reader with an intelligent pill dispenser placed on top of it (left);
Ambient Facial Interfaces (AFIs) used to display compliance levels for medicine intake, dehydration and dietary intake, respectively (right)

## 8. CONCLUSION AND FUTURE WORK

We began this paper by giving a quick insight into one of the major problems Europe and the industrialized countries have to face in the next half century, namely their ageing population, and its social and economical consequences. It was shown that Ambient Assisted Living (AAL) related research and development is hoped to alleviate these problems and therefore it receives an accentuated priority in the funding plans of the EU. We then moved on to very briefly talk about various AAL related projects around the world, showing their limitations due to their closed and proprietary architecture. Our conclusion was that we should concentrate on creating an open solution which allows the integration of devices produced by various independent manufacturers, having beneficial effects on both extensibility and costs.

Section 2 introduced the architecture of the proposed Lifestyle and Health Management System (LHMS), describing its five main components: the core module consisting of a hand-held touch screen computer equipped with Bluetooth and USB interfaces and a GPS device; a set of portable and wearable sensors providing physiological and biometrical data; devices responsible for communication with the central database, the therapist and family members; effectors interacting with the environment and the patient, such as automatic pill dispensers and small robots; and finally a group of applications providing useful information, entertainment and various auxiliary services. Section 3 gave an introduction of the technology we call Ambient Facial Interfaces, as a means of visual feedback through animation of facial expressions. We argued that the efficiency of this technology stems from the evolutionary ability of humans to quickly and accurately recognize a large scale of facial expressions, and to detect even the slightest changes; furthermore, this ability is independent from age, sex, race or cultural aspects.

In Section 4 we proceeded to explore the functionality offered by the prototype of the LHM system. This overview covered four groups of applications, namely health monitoring, communication, exercising for maintaining the physical and mental condition of the patient, and auxiliary services. Section 5 described the some aspects of the central medical database we employed in our system to manage patient data.

Section 6 moved on to introduce a low-cost “smaller brother” of the LHMS system, dubbed MediCAST. In MediCAST the user only needs a relatively modern mobile phone with 3G connectivity and a Bluetooth interface to access many of the features of the LHMS system, with particular emphasis on compliance monitoring. Finally, Section 7 demonstrated a home based robotic platform we developed to be able to better reach and help the elderly in their own environment.

As for the evaluation of the system, so far we have only concluded preliminary tests with a small number of patients, and even though these tests have brought promising results with the satisfaction of both the subjects and the independent observers (some of the photos used for illustration in this paper have been taken on one of these demonstrations, courtesy of Index.hu), it would be far too early to announce success before more thorough and scientifically sound tests are conducted. Therefore we plan to perform a large scale evaluation of our system with dozens of patients by getting hospitals and other medical facilities involved in the project. This will have the added benefit of promoting the idea of AAL between doctors and patients. In addition to testing, we plan to further develop the prototype by adding more tests and exercises, attaching more sensors, deepening the integration of effectors such as ambient facial displays and home robots, improving the robustness of the communication by automatically choosing from the available channels, etc.

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