A MOBILE APPROACH TO AMBIENT ASSISTED LIVING

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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 tele-monitoring 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. 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.

KEYWORDS

Ambient Assisted Living, Home monitoring, Mobile Care, Virtual Human Interface

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 [6], 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 [7]. On the social side of this issue, it is important for all these people having the need to be supported in their daily-life-activities to remain integrated in social life - despite of their age and existing disabilities. On the economical side, ageing has enormous implications, since not only the income side of social schemes is affected but also expenditures: health care systems for instance, are concerned.

Facing these challenges of ageing societies 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. *Ambient Assisted Living* (AAL) 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, AAL 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.

This paper describes a *complex wireless and personalized AAL solution*, which enables the delivery of integrated functionality that includes tele-monitoring, 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 [20] 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 [22,25]. 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. [1,4,5,8,10,15,24,26]. 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 were never turned into products entering the market. 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 high cost of components. As a result, the lack of interoperability did not permit other manufacturers and application service providers the integration of newer and cheaper devices, and also consumers were unable to customize these systems to their own needs. A further problem is the lack of real consent in the area of wireless communication standards. As an example, currently available telemonitoring devices use as many as five different wireless standards (Bluetooth, Zigbee, Ant, 900 MHz and WiFi) many of which are burdened by range, performance, connectivity and authorization issues for every day use. For these very reasons, our primary goal in our development was to implement an open-architecture and reconfigurable 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 introduces the main services we offer for health monitoring, communication, data collection, entertainment and exercising, demonstrating how it can integrate inconspicuously into the home environment, Section 4 describes the central medical database and diagnostic system. Finally, Section 5 contains a few thoughts on evaluation and future work, and Section 6 concludes the paper.

Figure 1. Overall architecture of the Lifestyle and Health Management System for AAL

2. SYSTEM ARCHITECTURE

Our AAL solution relates to a novel lifestyle and health management platform for the elderly people as well as for a younger generation, where trends in pop-culture and fascination with technological gadgets offer a unique opportunity to make ones health a "fashion statement". The focus of our research 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 caretakers. Figure 1 shows the proposed 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 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 solution are as follows:

- **Lifestyle and Health Management System (LHMS):** At the heart of our system we use a 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 2), 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 *redundant communication* layer. The primary interface for the applications running on this device is a *touch screen* and a *digital face* that employs facial expressions and mimicking as an easily recognizable and understandable visual feedback [19,21]. *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.
- **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 body weight, blood pressure, glucose levels, oxygenation, respiration and even heart activity by using low-cost ECG sensors, 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. More and more, 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 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:** Given the already existing infrastructure available at home and to the public at large, there are three mainstream possibilities to connect the elderly user with the outside world. *WiFi* works inside the home and 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 server or application. Finally, *3G mobile* 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 (e.g. in *rural areas* where costs are usually higher). 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:** Our solution counts on *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 (e.g. *LEGO*) 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 have also been incorporated in our system. These include *visual connectivity* with family members, friends and medical offices, and *emergency monitoring*. We also 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 we move on to 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. 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 this end we selected a *ultra mobile PC* (UMPC) platform that is placed on the top of a television set and acts as a digital picture frame showing a continuous, looping slideshow of selected family photos (see Figure 2 left). When the screen of the portable device is touched, it "comes to life", and offers a menu of services to the user (Figure 2 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 3, 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 2. 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)

Figure 3. Examples of wireless sensors worn by a test subject
Left to right: Bluetooth-enabled digital scale and blood pressure monitor; wireless physiological monitor

3.1 Health monitoring

The armband shown in Figure 3 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 4). The UMPC is also equipped with a built-in *GPS receiver*, which enables the identification of the exact location of the patient in stress. By 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. Upon entering the house, the central module senses the proximity of the device, welcomes the wearer at home, and opens a new data file stored both locally and sent to the central database. *Discrete measurements* complement this information in the form of blood pressure and body weight, and generally devices that provide asynchronous data. Whenever such measurements arrive the system presents them to the user by plotting a chart of the latest 2 or 3 weeks. This feature allows the patients to immediately evaluate the *trends* they see on the television screen for their own purposes.

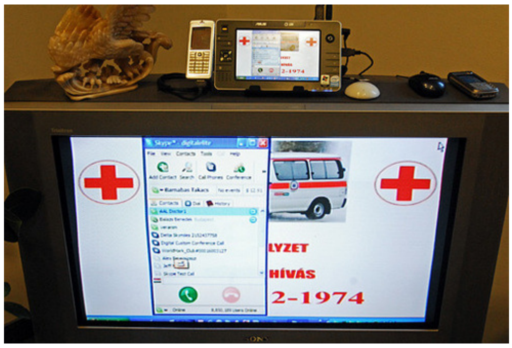

Figure 4. Calling assistance with the push of a button

3.2 Communication

Perhaps the most important of the communication services is the already mentioned emergency call, which can be activated with just the push of a button. However, for daily use, to keep in touch with family and the doctor's office (see Figure 5 left), our AAL system offers *video and phone calls* by simply selecting the appropriate menu item This service is based on *Skype* [18], and can connect either to another online user without cost, or to virtually any phone line using a low-cost prepaid service. This feature greatly reduces the need for personal visits, which thus become necessary only when a physical inspection is required. During a call, the doctor may also access sensor readings transmitted to the database by using a standard web browser.

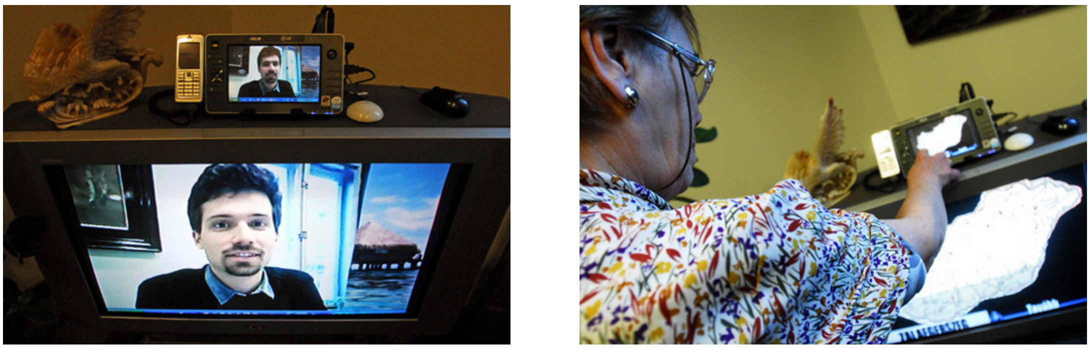

Figure 5. Left: video conference with a doctor or family member
Right: Monitoring mental state and cognitive performance using a test on geography

3.3 Virtual Exercises and Motivation

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 lead to the deterioration of cognitive abilities. Therefore it is important to keep the elderly mentally active even when they are alone for longer periods of time. Our system contains a *geographical quiz* (Figure 5 right), tests for dementia in the form of Paired Associative Learning (PAL) [9,11,14,16] and similar exercises. In all of these the patient uses the touch screen to pinpoint the location of various cities given different contexts, 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 to a higher level by hiding certain details (borders, labels, dots of cities, etc.) from the map, and 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.

- **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* [2,3,11] about how he or she feels at the moment. The answers are evaluated locally, after which 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 data are also transmitted to the database, where the doctor can access them and compare them with earlier results, i.e. observe *trends*.
- **Physical exercises.** The two-axis acceleration sensors embedded in the armband allows our AAL solution to have the user perform certain simple physical exercises, such as lifting weights (Figure 6 left). Here the system displays a simple animation for motivational and feedback purposes. The motion of the virtual character's arms - a Buddha figure 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**. These exercises help the patient to relax. The system uses variations of skin conductance level and hear rate of a person to measure their level of excitement. Visual feedback is provided in the form of a bio-controlled animation (boat floating on a river, door opening, passing a bridge, etc) where progress is made according to the levels of stress measured. In the first example, as the patient gradually relaxes, the bloat floats closer to the shore, and is eventually moored. If the level of stress increases, the boat floats away. Just like for physical exercises, the motivational factor is important: the patient must focus on the exercise in order to see the boat successfully moored.

3.4 Services

The system also 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 6 right, particularly informative for people suffering from rheumatic and arthritic disorders), or offering home delivery of medicine, or providing dietary advice.

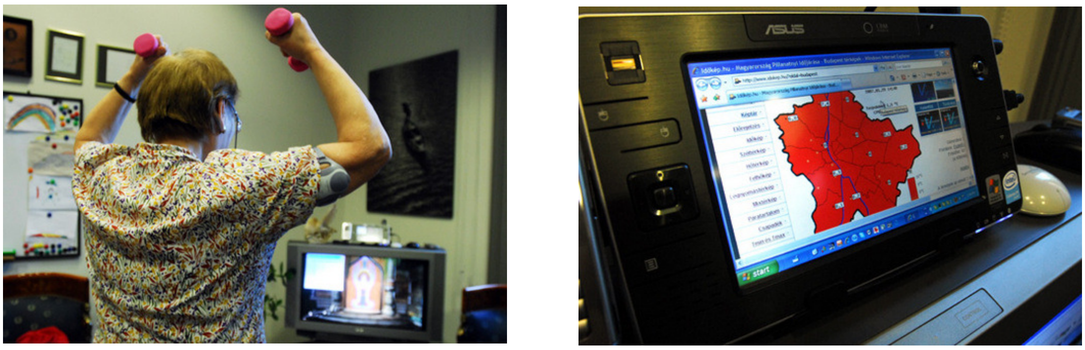

Figure 6. Left: Performing a physical exercise while watching the Buddha on the screen to move in unison
Right: Local weather map showing current conditions tied to the GPS-system

4. CENTRAL MEDICAL DATABASE AND DIAGNOSTIC SYSTEM

The central medical database of the system has been developed in a separate research project called *INes* at the Computer and Automation Research Institute of the Hungarian Academy of Sciences. INes is a medical, diagnostic and patient management solution with a flexible, generic, object-oriented architecture targeted directly at medical applications, and 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 system 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, both as quickly reviewable overall numbers and as detailed, high resolution data sets attached to the session record.

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. 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. The doctor can also assemble the *protocols* of exercises and tests (*questionnaires*) to be performed, and attach explanations, help texts, animated instructions, etc. to the protocol elements and questionnaire items; or they may decide to reuse a former protocol or questionnaire. Access to the data sheets is controlled via fine grained access rights, and protected by a combination of usernames and passwords.

INes offers the opportunity to enter text entries in multiple languages. 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.

5. EVALUATION AND FUTURE WORK

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 (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, observing the availability and usability of various effectors, improving the robustness of the communication, etc.

6. CONCLUSION

We began by showing that one of the major problems Europe and the industrialized countries have to face in the next half century is their ageing population, and its social and economical consequences, and that Ambient Assisted Living (AAL) related research and development is hoped to alleviate these problems. We then moved on to very briefly talk about various AAL related projects around the world, showing their limitations, and concluded that we should concentrate on an open solution which allows the integration of devices of 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 handheld touch screen computer; a set of portable and wearable sensors providing physiological and biometrical data; devices responsible for communication; effectors interacting with the environment and the patient, and finally a group of applications providing useful information, entertainment and various auxiliary services.

In Section 3 we proceeded to explore the functionality offered by the prototype system. This covered four groups of applications, namely health monitoring, communication, exercising for maintaining the physical and mental condition, and auxiliary services. In Section 4 we briefly introduced the central database system, and finally, Section 5 outlined our future plans for evaluation, and also skimmed the possible directions of extending and improving the system.

REFERENCES

[1] Aerotel Medical Systems (2007), http://www.aerotel.com/.

[2] Beck, A. T. and R. A. Steer. Internal Consistencies of the Original and Revised Beck Depression Inventory. Journal of Clinical Psychology 40.6 (1984): 1365-67.

[3] Beck, A. T., R. A. Steer, and M. G. Garbin. Psychometric Properties of the Beck Depression Inventory - 25 Years of Evaluation. Clinical Psychology Review 8.1 (1988): 77-100.

[4] BodyMedia (2007) http://www.bodymedia.com/technology/index.jsp.

[5] Ericsson (2007) http://www.ericsson.com/solutions/enterprise/products/mhealth_solutions.shtml.

[6] Europe Is Facing a Demographic Challenge-Ambient Assisted Living Offers Solution, Technical Report, http://www.aal169.org/Published/Final%20Version.pdf.

[7] European Commission (2003b): Living conditions in Europe, Statistical booklet, 2003 edition.

[8] Fraunhofer Institute for Biomedical Technology (2007), http://www.topcare.info/.

[9] Fray, P. J., T. W. Robbins, and B. J. Sahakian. Neuropsychiatric applications of CANTAB. International Journal of Geriatric Psychiatry 11.4 (1996): 329-36.

[10] IBM Mobile Health Toolkit (2007) http://www.ercim.org/publication/Ercim_News/enw60/husemann.html.

[11] Kendall, P. C. et al. Issues and Recommendations Regarding Use of the Beck Depression Inventory. Cognitive Therapy and Research 11.3 (1987): 289-99.

[12] Malasanos, T.H., Burlingame, J.B., Youngblade, L., Patel, B.D. and Muir, A.B.: Improved access to subspecialist diabetes care by telemedicine: cost savings and care measures in the first two years of the FITE diabetes project. Journal of Telemedicine and Telecare, Volume 11, Supplement 1, July 2005, pp. 74-76(3).

[13] Nehmer, J., Becker, M., Karshmer, A., and Lamm, R.: Living assistance systems: an ambient intelligence approach. In Proceeding of the 28th international Conference on Software Engineering (Shanghai, China, May 20 - 28, 2006). ICSE '06. ACM Press, New York, NY, 43-50.

[14] Robbins, T. W. et al. Cambridge Neuropsychological Test Automated Battery (Cantab) - A Factor-Analytic Study of A Large-Sample of Normal Elderly Volunteers. Dementia 5.5 (1994): 266-81.

[15] RTX Telehealth (2007) http://www.rtx.dk/Products/Wireless_Telehealth_PSTN_Gateway.aspx.

[16] Sahakian, B. J. and A. M. Owen. Computerized Assessment in Neuropsychiatry Using Cantab - Discussion Paper. Journal of the Royal Society of Medicine 85.7 (1992):

[17] Samii, A., Ryan-Dykes, P., Tsukuda, R.A., Zink, C. et al: Telemedicine for delivery of health care in Parkinson's disease. Journal of Telemedicine and Telecare, Volume 12, Number 1, January 2006, pp. 16-18(3).

[18] Skype (2007), www.skype.com.

[19] Takács, B. (2005), Affective Intelligence: A Novel User Interface Paradigm, 1st Int. Conference on Affective Computing & Intelligent Interaction, Beijing, China

[20] Takács, B. (2005), Special Education & Rehabilitation: Teaching and Healing with Interactive Graphics, IEEE Computer Graphics and Applications, Special Issue on Computer Graphics in Education, Sept/Oct.

[21] Takács, B. (2006), BabyTeach: A Virtual Tutoring System for Education, Central European Multimedia and Virtual Reality Conference, Eger, Hungary.

[22] Takács, B. (2006), Cognitive, Mental and Physical Rehabilitation Using a Configurable Virtual Reality System, Intl. Journal of Virtual Reality, 5(4): pp. 1-12

[23] Taylor, P.: Evaluating telemedicine systems and services. Journal of Telemedicine and Telecare, Volume 11, Number 4, June 2005, pp. 167-177(11).

[24] University of Karlsruhe (2007) http://www.itiv.uni-karlsruhe.de/opencms/opencms/de/research/projects/mst_phm/ Personal health monitoring solution.

[25] VirMED (2007), Virtual Reality Medicine, www.VirMED.net

[26] Wealthy (2007) / Wearable Healthcare System, EU Project, http://wealthy-ist.com/.

[27] Wootton, R. and Patterson V.: Introduction to Telemedicine, 2006, RSM Press, ISBN 1853155071