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A Ubiquitous Ambient Assisted Living Solution to Promote Safer Independent Living in Older Adults Suffering from Co-morbidity

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Abstract — **This paper describes the development, deployment and trial results from 9 volunteers using the eCAALYX system. The eCAALYX system is an ambient assisted living telemonitoring system aimed at older adults suffering with co-morbidity. Described is a raw account of the challenges that exist and results in bringing a Telemedicine system from laboratory to real-world implementation and results for usability, functionality and reliability.**

INTRODUCTION

The world's elderly population, people 60 years of age and older, is the fastest growing age group [1], with the proportion of the world's population aged 60 and older set to double to more than 1 in 5 by 2050 [2] and those aged 80 and over, the fastest growing within this group, expected to represent 20% of the older population by 2050 [1]. This demographic trend is already posing many social and economic problems as the care ratio is in decline and it has been proposed that a total dependency ratio of three inactive persons (elderly dependents of 65 and over plus young dependents under 15) for every four of working age will be present in 2050 [3]. This increase in these age groups will put further strain on an already burdening health system both across Europe and the world.

Health expenditures increase with age but are concentrated in the last two years of life. As people live longer, it is important to ensure these added years are healthy and that they can live at home so that health-care costs can be kept manageable [4]. Besides, ageing combined with an increasing burden of chronic, concurrent diseases threatens to make current models of healthcare unsustainable. Ambient Assisted Living (AAL), as a specific user-oriented type of "Ambient Intelligence", may greatly help in this situation. AAL aims to prolong the time people live in a decent more independent way by increasing their autonomy in their home environment, self-confidence, health and quality of life and reducing their risk of hospitalization. This is achieved by improved monitoring and care of the elderly with chronic diseases and comorbidities as tertiary prevention.

In order to promote safer independent living, greater emphasis will be put on technology and care models to monitor the vital parameters of elderly people while at home and detect when their chronic conditions begins to deteriorate or if an emergency situation, such as a fall or cardiac arrest, occurs. The rationale of this telemedical care is the early detection of objective deterioration via telemonitoring of vital parameters and the early intervention, in case of deterioration or emergency and the extension of the stable phase of chronic conditions via closed monitoring and education of the patient. Telemedical health care management as one aspect of e-health, diagnostics and therapy over distance using modern information and communication technologies (ICT) as an addition for face-to-face contact between healthcare providers and their clients (usual care). Typically telemedical care can be defined in two forms: Structured telephone support with routine telephone contact by health care providers for ongoing assessment and telemonitoring, when vital parameters like weight, blood pressure and ECG were transmitted automatically via wireless or internet connection to a telemedical center [5],[6].

The use of telemedical care is different in the internal-medicine disciplines. The best evidence for the effectiveness is available for cardiology. Two meta-analyses suggested that telemedical care can reduce morbidity and mortality in heart failure patients [7],[8]. Otherwise two recent randomized controlled clinical trials could not support these findings [9],[10]. Only one of these trials could define a patient group which benefits from telemedical care [10].

eCAALYX - A Telemedicine System

An example of the type of telemedical system for monitoring and education for older adults suffering from co-morbidity is that developed during the eCAALYX project.

A. Overview

The eCAALYX project (Enhanced Complete Ambient Assisted Living Experiment) (06/2009-06/2012– http://ecaalyx.org/) is a three-year project funded by the European Commission under the Ambient Assisted Living (AAL) Joint Programme (http://www.aal-europe.eu/). The main objectives of the eCAALYX project are to provide a complete solution to improve the quality of life and reduce morbidity and mortality of elderly people suffering from co-

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morbidity. This is achieved by monitoring and assessing changes in their health and vital signs, to detect physical signs of cardiac decompensation, atrial fibrillation and the progression of chronic obstructive pulmonary disease (COPD) on one side and by proposing focused education on their lifestyle and self-management so that their independent living at home can be extended safely and their hospitalization or nursing homes admission for dependent care can be postponed. The system aims to fulfill these functions both inside and outside the home. The eCAALYX system is thus composed of three main subsystems, namely; the Mobile Monitoring System, the Home Monitoring System and the Caretaker Site, Fig. 1.

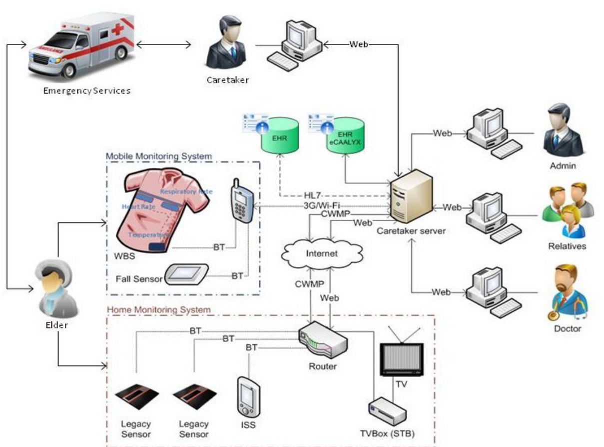

Figure 1. The eCAALYX System overview, including the three main parts: the mobile system, the home system and the caretaker site. Also shown are the end-users: Elder, Doctor, Caretaker, Relatives, Administrator and The Emergency Services.

B. The Mobile Monitoring System

The Mobile Subsystem for monitoring outside the home, consists of a Wearable Body Sensor System (WBS) includes a Smart Garment with embedded health and mobility sensors for respiratory rate, skin temperature, heart rate all controlled by an Electronic Control Unit (ECU) located at the left-underarm, also included in the ECU is a fall and activity monitoring sensor. The WBS communicates with an LG-P990 mobile phone to enable further propagation of information, Fig. 2.

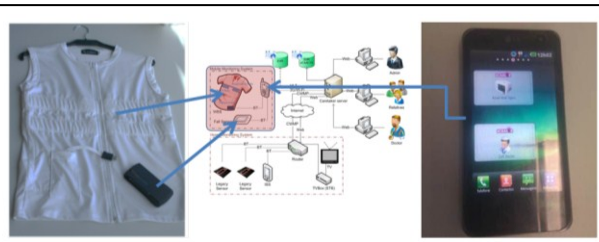

Fig. 2. The Smart Garment, Electronic Control Unit (ECU), including the fall-sensor and Mobile Phone

C. The Home Monitoring System

The Home Monitoring Subsystem, consists of: a Set-Top-Box (STB) that allows the patient to use the TV as an interactive tool for provided services (health education via videos, to show vital parameters, check health agenda, videoconference with doctors and answer medical questionnaires) to empower the patient for self-management of their diseases, a Router (that acts as a hub for all the available sensors, receiving and processing all the measurements, generating alarms and eventually sending all data to the Caretaker site), ISS (Intelligent Sensor System, which integrates the most relevant sensors for monitoring of common chronic conditions) as sensors located at home (those sensors that are stationary and not continuously worn on the body such as the scales), Fig 3. The Home System thus monitors, using the ISS, heart rate, respiratory rate, blood oxygen saturation (SpO_2), blood pressure and ECG (2 minutes trace), while weight is measured via a scale. Medical questionnaires like Functional Impairment (Barthel-Index) or Geriatric Depression Scale (GDS) can also be answered through the TV, using the STB.

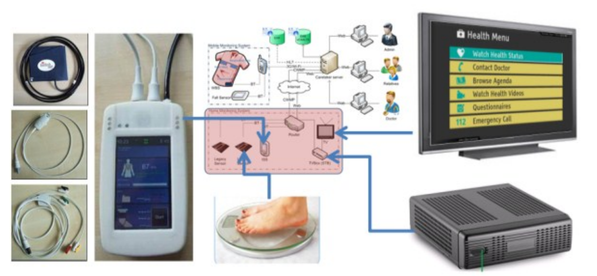

Fig. 3. The Home System.

D. Caretaker Site

The Caretaker Site, which includes the Caretaker Server, the Auto-configuration Server for the Home System and the electronic health record, Fig 4. The caretaker site is also responsible for patient management, data visualization, health agenda and observation pattern management.

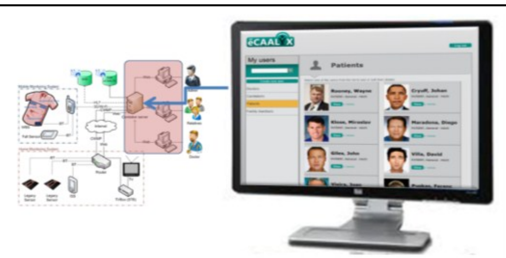

Fig. 4. The Caretaker Site.

METHODS

A. System Development Process

For the development of such a system, the Unified Process was taken as the main reference to organize the development activities, with scheduled deployment and testing, at regular intervals throughout the development process. To that end a comprehensive set of associated end user trials has been undertaken. These include both major trials, for usability, functionality and system stability involving elderly people suffering from co-morbidity, living in their own homes and using the system over extended periods of 28 days, and minor trials, targeted towards more specific subsystems and features, typically involving up to five users.

B. System Deployment

In order to prepare for deployment of the eCAALYX system, system development was halted, with no further technical innovations permitted. This was followed by preliminary technical laboratory testing and stabilization with testing from end-to-end which was performed to ensure system integrity and stability. This step was taken to remove any glitches or bugs which may exist in the complete system.

Deployment involved a handover of hardware, software and training and installation material to the medical personal executing the trial. During the system set-up on-site and remote technical support was provided. This procedure approaches the expectations of commercial target deployments where the technology complexity and developers are invisible to the end-users. Deployment thus involved a two-step deployment process, where the system was initially deployed to the end user organization, which in-turn was deployed to the end users homes. This separation ensures that a strong focus remained on relevance, usability and on identifying and providing required training.

C. Trial Protocol

A total of 9 volunteers (5 male, 4 female), aged >60years (69 ± 14 years) with at least one chronic disease were included in the trial (Table I). All patients performed measurements for 28 days. These major trials also included medical-care and technical administration personnel. The trial partners trained the end-users to set-up the equipment at the caretaker head-quarters and also in the end-user's homes, with technical support provided from technical partners. Ethical approval granted through Ethics Commission and Data protection approved by Data Protection Officer of the Charité-Universitätsmedizin Berlin.

TABLE I. END-USER DETAILS

Variable	Study patients (average)
Number of chronic diseases	2,4
GDS At the beginning	2,7
GDS At the end	2,4
Barthel-Index At the beginning	17,8
Barthel-Index At the end	17,8

RESULTS

The presented results focus on the functionality, stability, usability, reliability and compliance of the users with the system.

A. In-home set-up and training time

In most cases the system was installed by two people at the patient's home. Patients were trained directly after the installation; the average of training/installation time was 1.5 hours. This long period of installation and training was caused mainly by the different technical situations at the patient's home (e.g. the patient router had only one available slot for LAN) not by the complexity of the system. Thus 3 out of 9 patients thought that they would be able to install the system by themselves (with the provided user manual)

B. Home System

In general, patient opinion about the home system was not easy to use (4/5) due to non-self-explanatory operation (3.8/5) and the need of a user manual to operate it (4/5). The navigation between menus on the TV was also difficult (4/5). Only the range of features is clear and was evaluated somewhat positively (2.8/5). The results thus show the operation/handling of the home-system requires improvement.

The TV remote control was an off-the-shelf device and not all available buttons were programmed to perform a function, this caused confusion to users. Keys were too small and the "OK" key often hung due to a manufacturing error.

C. Mobile System

The concept of the Mobile System was to use a smart phone, with no restriction in use, and the eCAALYX software simply as an extra "app". Thus no particular mobile phone should be necessary to use the system. However this also means that this mobile phone was difficult to use for non-accustomed user (3.75/5) because of excessive features (3.9/5) and non-self-explanatory operation (3.9/5). For this reason improvement of the handling of the smart phone with fewer features would be necessary.

The Bluetooth-connection between the ECU and the mobile phone was low and often measurements of the garment could not be transmitted to the mobile phone. A manual restart of the ECU or the mobile phone by the user was often necessary.

The pocket to hold the ECU was too small. As a result of this inadequate pocket size and the positioning (right above the hip) the ECU slipped out while sitting

Another issue for developing smart garments was the question of the sizing and style. The developed garment were unisex and thus not optimized for individual genders, it was thus assessed as uncomfortable, "cutting" under the armpit and too long at the waist. Also the neckline was too small, needing to be wider and lower; the zipper was uncomfortable and "digs in" when sitting.

D. Caretaker System

The mean transmission time for receipt of measurements from the patients, via the home and mobile subsystems, was approximately 3.5h. The Mobile system required longer transmission time (>5 hours). At the Caretaker site, missing features of the online portal (e.g. ECG viewer) limited the use and effectiveness of medical staff intervention. Due to the long loading times (>60 seconds per view), the assessment of larger groups of data would be difficult and requires optimization.

Discussion and Conclusion

The first version of the communication architecture was "centralized" regarding data acquisition with the Mobile and Home systems in direct connection to the caretaker server. This resulted in several dozen messages being sent per-user/second. Data crunching and analysis was always performed at the central server, and this exhibited very low capability in scaling with the number of users.

An improved version of the architecture will include of a middle-layer between the data-acquisition components and the caretaker server to achieve: (1) decentralized data acquisition, (2) early pipeline processing, to filter and aggregate data, and will also include (3) migration to well-known technologies capable of handling high data rates and traffic volume. In this new revision, data is processed through parallel, supervised actors, each with a single responsibility, and stored in prioritized queues. This architecture ensures three main traits of the system: (1) that the most recent messages are the most important ones, (2) that the criticality is ensured, thus alarms are of an higher priority than regular measurements, and (3) that, eventually, all information will reach the caretaker server.

The poor results for usability, shows that especially for elderly people the use of a technical system, like eCAALYX, should be self-explanatory and only consists of functionalities that are necessary. But for the compliance defined as the cooperative behavior of the patient to follow the suggested behavior (like using a telemedical system) or medication, usability is an important aspect.

Due to two reasons compliance is a very important issue for telemedical care: (1) decision in therapy can only be taken when the measurements are performed, (2) it could have a secondary effect by confronting the patients with their own measurement (for self-management).

For this reason a telemedical system should be as easy to use as possible and should be a convenient part of the daily routine. The complexity of a system has to account the user experience and interest in using technical devices.

The uniqueness of the eCAALYX system is the opportunity to see a user's own measurements on the TV and the mobile phone and to monitor a history of measurements. This attribute of the system can be a motivating factor for improving the compliance and integration in patient education programs. So a telemedical system may enhance the ability for self-management and improve the owners understanding of the disease. This effect would not be possible for non-compliance.

The users showed a high interest in viewing their actual measurements and also the previous day's history, thus requesting the co-implementation of SpO2 and heart rate measurements at the ISS display. The high compliance in using such a system underlines its principal acceptance, when it is working stable and with reliable measurements.

A separately styled garment for both genders is also a requirement for the Mobile System.

In general the results of the first set of trials show room for improvement in terms of usability, functionality, stability and data transmission. The results of this first trial in the eCAALYX system development model will thus help to shape and improved the future direction and final eCAALYX system. In addition, these results also show that the project idea for telemedical care and improvement of education of the patient is positive step forward.

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References

[1] *World Health Organization (2007) "Global report on falls prevention in older age"*. Geneva, Switzerland

[2] "United Nations (UN) (2009) "World Population Ageing 2009" Population Division, DESA, New York, USA"

[3] *European Commission (2009) "Youth in Europe – A statistical portrait"*. Luxembourg: Publications of the European Union.

[4] *World Health Organization (2011) "10 facts on ageing and the life course"*. Geneva, Switzerland.

[5] A. S. Desai, "Home monitoring heart failure care does not improve patient outcomes: looking beyond telephone-based disease management," *Circulation,* vol. 125, pp. 828-36, Feb 14 2012.

[6] S. D. Anker, F. Koehler, and W. T. Abraham, "Telemedicine and remote management of patients with heart failure," *Lancet,* vol. 378, pp. 731-9, Aug 20 2011.

[7] C. Klersy, A. De Silvestri, G. Gabutti, F. Regoli, and A. Auricchio, "A meta-analysis of remote monitoring of heart failure patients," *J Am Coll Cardiol,* vol. 54, pp. 1683-94, Oct 27 2009.

[8] S. C. Inglis, R. A. Clark, F. A. McAlister, J. Ball, C. Lewinter, D. Cullington, S. Stewart, and J. G. Cleland, "Structured telephone support or telemonitoring programmes for patients with chronic heart failure," *Cochrane Database Syst Rev,* p. CD007228, 2010.

[9] S. I. Chaudhry, J. A. Mattera, J. P. Curtis, J. A. Spertus, J. Herrin, Z. Lin, C. O. Phillips, B. V. Hodshon, L. S. Cooper, and H. M. Krumholz, "Telemonitoring in patients with heart failure," *N Engl J Med,* vol. 363, pp. 2301-9, Dec 9 2010.

[10] F. Koehler, S. Winkler, M. Schieber, U. Sechtem, K. Stangl, M. Bohm, S. de Brouwer, E. Perrin, G. Baumann, G. Gelbrich, H. Boll, M. Honold, K. Koehler, B. A. Kirwan, and S. D. Anker, "Telemedicine in heart failure: Pre-specified and exploratory subgroup analyses from the TIM-HF trial," *Int J Cardiol,* Oct 7 2011.