Abstract

Today, the number of elderly people and patients with reduced autonomy or with chronic diseases are steadily increasing. In addition, a stay in hospital or nursing home is very expensive. Thus, in recent years we have witnessed the development of projects to keep these people at home while providing them the needed care and assistance. The number of research projects that have emerged around the world during these last years is very important. Thus we are interested in studying a number of these projects. In this study, we focus on European projects because there is a great similarity with other projects (American, Asian and African projects). After a detailed study of various European research projects conducted in the telemonitoring of patients field, we identify the main requirements of a telemonitoring system. Then, we introduce the common components of these systems. After that, we provide a comparative study in terms of offered services, technical issues, supported functionalities and tools involved in the implementation of the proposed systems. Finally, we introduce some interesting perspectives for the patient telemonitoring research field.

Keywords: ehealth services, telemonitoring architecture, patient record, context-awareness, interoperability, mobility.

1. Introduction

Today, the number of elderly people and patients with reduced autonomy or with chronic diseases are steadily increasing. In addition, a stay in hospital
or nursing home is very expensive. Thus, in recent years we have witnessed the development of projects to keep these people at home while providing them the needed care and assistance. The number of research projects that have emerged around the world during these last years is very important. They are increasingly using communication systems to provide facilities for doctors and nurses who are frequently changing workplace. They also provide benefits for patient, such as facilitating access to his diagnostic and getting assistance. Integrating information technology in medical sector has generated innovation in technical diagnosis and handling the patient, such as telemedicine. Telemedecine is defined as the use of telecommunications to, remotely, provide medical information and services. This field needs multidisciplinary technologies, such as computer-science, telecommunications and instrumentation to transfer medical information and services from one place to another.

Four acts are identified in telemedecine [1]:

- **Teleconsultation**: allows the patient to have a remote consultation. He must be present, recognize his caregiver, talk with him (preferably with a webcam to identify his career). This remote consultation can be achieved with access to patient records.

- **Tele-expertise**: allows the exchange of expertise among caregivers around the same patient record.

- **Telecare**: may be in the form of attendants to another health personnel, or in the form of a smart tool that helps the patient to adjust his dose.

- **Telemonitoring**: it is an act of continuous or discontinuous monitoring; for example monitoring biological constants. It is known sometimes as remote monitoring.

Telemedecine is practiced in two ways: synchronous and asynchronous. Synchronous telemedicine requires the presence of two parties at the same time and a communication link between them that allows a synchronous interaction like video-conferencing. Asynchronous telemedecine transmits inquired data to a medical specialist. It does not require the presence of both parties at the same time.

In this context, we present the most representative European projects of telemedecine, particularly those interested in remote monitoring in order to identify all telemonitoring system needs. These projects are classified according to offered services. Thus, we distinguish three main classes. The rest of this paper is organized as follow. Section 2 describes projects dealing with patient comfort and security. Then, we present projects that treat patient rehabilitation at home in section 3. In section 4, we introduce projects related
to chronic disease telemonitoring. Section 5 is reserved to the presentation of the common architecture to which telemonitoring systems are converging. In section 6, we compare the considered research projects in terms of provided services, used tools, supported functionalities and technical issues. Before concluding the paper, we present some interesting perspectives related to this research field.

2. Comfort and security telemonitoring

In this section, we introduce some research projects that deal with security and comfort telemonitoring while focusing on the architecture of the proposed systems. We start by introducing projects that have simple architectures and we finish by those that have a relatively advanced ones. The first detailed project is VITAL which consists in developing a platform to offer necessary assistance and to easily get access to information. Then, we present BrainAble project which consists in designing a Human Computer Interface that measures physical and emotional state of the telemonitored person. After that, we detail Netcarity project that introduces smart devices to ensure elderly security and then SOPRANO project which consists in providing many context-aware services in smart home with an interface adapted for elder persons. The last presented project will be SAAPHO which covers all SPRANO’s services and offers, in addition, access to communication like talking, sharing photos or video. It tries also to bring ideas to the market by using available technological tools.

2.1. VITAL

VITAL (Vital Assistance For The Elderly) project [3, 4] offers comfort and security for elderly persons. It is an European project co-financed by the European Commission DG Information Society and Media. It started in January 2007 and ended in September 2010. It aims at empowering elderly to take care of themselves, by providing them with the necessary assistance, and facilitating the access to information and infrastructures banned for them. It consists in developing a platform to satisfy the following needs: inter-personal communication, personal advice, edutainment, ability to move safely in the physical environment and integration into the mainstream society.

The developed platform is composed of: central services, user’s terminals (TV and mobile), operator’s terminals, software required to run the user’s applications and contents necessary to test and operate such applications. In a typical situation of use, an elderly person will sit in front of his TV and
make use of his remote controller or speech commands to select the desired service. Then the application software will guide him through the steps necessary to complete his demand. Those steps will be translated internally into a number of complex actions executed transparently for the final user until the completion of the desired service. One of the main targets of this project is to allow any person capable of using a TV set to benefit from VITAL services.

In this project, some prototypes of user interfaces were implemented, tested and evaluated in England and Spain. The summary of this evaluation was that VITAL applications were considered very useful by the users themselves, from the more technologically educated users to the less technologically oriented ones. Users confirmed that these applications could improve the quality of life and social relationships in the situation of being less active or having lost contact with particular people like relatives living far away.

2.2. BrainAble

BrainAble (Autonomy and social inclusion through mixed reality Brain-Computer Interfaces: Connecting the disabled to their physical and social world) [14] is partially funded by the European Commission under the 7th Framework Programme. It started in January 2010 and ended in December 2012. Like VITAL project, it offers security and comfort. It aims at improving personal independence and social constraints of people with physical disabilities. It also aims at raising the possibility of interacting with their environment through the design of Human Computer Interaction (HCI) formed by sensors. These sensors measure the physical and emotional state of a person, combined with virtual environments and the connection of these interfaces with smart homes and social networks. The project platform helps people to manage their living environment and improve social interaction. The final objective is to increase autonomy and to improve social inclusion and the QoL (Quality of Life) of persons with disabilities exceeding two barriers: the interaction of the person with his social and physical environment.

Brainable produced a pre-commercial product and a set of technologies intended to assist people with severe physical disabilities. It used a technology that can assist those with special needs such as individuals living with brain damage. It uses a modular architecture and middleware to connect user-centered bio-interfaces and interactive environments to networks of devices and people. This architecture provides attractive assets for the markets of assistive smart homes and adaptative assistive technologies.
2.3. Netcarity

Netcarity (NETworked multisensor system for elderly people: health-CARe, safety and securITy) was an Integrated Project supported by the European Community under the 6th Framework Programme [2]. It started in February 2007 and ended in October 2011. Like previous projects, it aims at providing security, well being, independence and confidence to older people living alone at home by using ICT-based systems. It uses pressure sensors in the floor and smart cameras in the ceiling which are able to recognize the situation and automatically send alerts to emergency primary contacts (Figure 1). By knowing someone’s location, devices are able to decide about patient’s activities and well-being. Motion sensors act as fall detectors and are used specially in the bathroom where many users can not wear emergency pendants. Netcarity offers several groups of functions aiming at supporting older people at home, namely:

- **Inclusion** by developing new ways of communication in order to keep patient in touch with friends and family.
- **Assistance** by developing means for supporting of everyday tasks, e.g. cooking and shopping.
- **Protection** by offering security and safety services, e.g. alerting relatives or caregivers in case of dangerous situations (falls, no sign of user activity).
- **Health** by offering medical support, supervision and care support, through the integration of existing and new technologies to monitor, for example, blood pressure and increase of weight.

The project presents how technology supports ageing people and then it tests technology infrastructure in real homes. The project has tested its systems and infrastructures in 100 homes in Trento, Italy and in Eidhoven, the Netherlands. Results show that developed products and systems can support older people and generate an understanding of how older people adopt and use easily technologies.

2.4. SOPRANO

As Netcarity and Vital projects, SOPRANO (Service-oriented Programmable Smart Environments for Older Europeans) [5, 6] project is dedicated to elderly people. It is partly funded by the European Commission (6th Framework Programme – Ambient Assisted Living for the Ageing Society). It started in January 2007 and ended in February 2011. In the context of Ambient Assisted Living (AAL), this project aims at allowing older people to be more independent while living in their home. Thus, SOPRANO proposed to design and develop a system for providing context-aware services.
in smart homes with interfaces adapted for older people. In addition to acting in problematic and emergency cases, the target system helps to improve the everyday life quality of older people. Thus, SOPRANO’s system must integrate several single solutions that have been developed to assist older persons in order to provide many services (health, social care, well-being and safety). To provide a part of these services, SOPRANO had to implement a rule-based system which acts primarily without a direct user interface. Thanks to a set of sensors, this system is able to sense the current state. Then, it must derive a high-level state (fusion, reasoning), before using actuators for improving the situation. Since the second part of services require the development of an interface, another challenge was the design of the user interface which has to meet the specific needs of older people. Thus, its development was guided by a user-centered design process, and obtained results were very interesting. Indeed, The SOPRANO’s system combines two devices: a TV set and a touch screen. For TV interface design, different alternatives were tested (e.g. arrow-buttons and numbers navigation) and the navigation-approach with numbers had been identified as the most promising for the system.

Indeed, some prototypes were tested in the collaborating labs from four European countries with more than fifty users. This enables enhancing the usability of SOPRANO’s components, such as menu’s structure and colours,
remote control and reminder’s sound and design.

2.5. **SAAPHO**

SAAPHO (Secure Active Ageing: Participation and Health for the Old) [7] is a scientific and technological project partly funded by the European Commission (7th Framework Programme – Ambient Assisted Living for the Ageing Society). It is a 3-year project launched in July 2011. As SOPRANO, SAAPHO is interested in the elderly, and aims to improve their quality of life by ensuring their autonomy and independence. Thus, this project proposes to apply ICT-based solutions in order to facilitate accessing a set of services for older people. Services to be offered by the SAAPHO’s system, outnumber those covered by SOPRANO’s one (Figure 2). In addition to healthcare services (medication, healthy habits and practices), and security services (monitoring of gas, fire, CO₂, temperature, presence, etc.), SAAPHO includes participation services that consist in adapted access to some communication tools (e.g. talking, sharing pictures/videos and playing with relatives, friends, healthcare professionals). Challenges as well as the scope of this project are almost the same as those of SOPRANO. In addition to architectural and implementation issues, SAAPHO focuses on the tools and devices that will enable elderly to easily use the proposed system as well as their corresponding GUI in order to facilitate the access to the proposed services. This project suggests the use of a touch screen as a central user interface to access the system’s functionalities. The provision of the envisaged services will be based on the deployed sensors as well as a NFC (Near Field Communication) enabled mobile phone and a NFC reader connected to a laptop. The final purpose of this project is to bring idea to market. That’s why, partners will rely on the already available technological tools in order to deploy and experiment the proposed solution. Involving older people in the design of the proposed system is also very important in this project.

The project’s prototype was performed with the collaboration of more than two hundred older adults from the two countries participating to this project (Spain and Slovenia). In a first step, the project’s partners focused on the interaction modes and devices’ preferences. After that the platform usability was tested, based on the following four tasks: (i) writing and sending a message using a touch screen keyboard; (ii) receiving a fire alert; (iii) checking a health alert; and (iv) checking a received notification message [8].
3. Rehabilitation telemonitoring

In this section, we present other research projects which deal with rehabilitation telemonitoring. As we mentioned before, we are interested mainly in system’s architecture. We introduce firstly, INTERACTION project which consists in developing a system to evaluate patient’s performance. Then, we present FITREHAB which integrates virtual rehabilitation based on the monitoring of some physical variables. We finish by StrokeBack project which, in addition to the main objective of providing security and comfort, deals with many challenges like data fusion/extraction, patient mobility and privacy.

3.1. INTERACTION

INTERACTION (Training and monitoring of daily-life physical with the environment after stroke) [9] is funded by the European Commission (7th Framework Programme). It started in November 2011 and will end
in November 2014. The objective of this project consists in developing a system for monitoring daily life activities for stroke persons. The system is integrated in clothing, and provide telemonitoring. This telemonitoring will enable a caretaker to evaluate performance effectively and to coach the patient. It is based on ambulatory sensing of muscle activation (electromyography, EMG), INTERACTION forces and body movements. EMG provides information about neural control of movements. The assessment is made context-aware by task identification and estimation of the dynamics of the environment from the sensed values.

In this project, a complete sensing suit was validated through many steps. It is composed of an integrated CE strain sensor, CE goniometers, EMG sensor and IMU’s in e-textile. The validation tests were done at the Roessingh Research and Development centre.

3.2. FITREHAB

FITREHAB (FITness and physical REHABilitation at home under expert planning, prescription and control with assessment to overcome barriers in the deployment of telemedicine solutions) project [10] is also dedicated for rehabilitation. It is co-financed by ERDF: European Union and European Regional Development Fund. It started in May 2010 and ended in October 2011. It aimed at developing a platform to carry out physical exercises under planning and remote supervision by an expert. The main objective is to perform a field test of such platform to assess its clinical efficacy and deployment procedure within the existing infrastructure of hospitals. The project integrates a new and innovative virtual reality-based rehabilitation and training platform, which will allow patients to perform physical exercise at home under remote expert planning and monitoring. The platform is composed of two integrated workstations. The first one is used in hospitals by the medical staff, to program personalized exercises for each patient. The second one is used by the patients, at home, to carry out the exercises with a virtual trainer. Patient monitoring relies on sensors placed in a t-shirt and patients see themselves represented by an avatar, which reproduces their movements in the virtual reality environment. Then, the patient performs the exercises prescribed by the doctor. Besides the movement sensors, the patient’s t-shirt integrates biological sensors to monitor his physiological variables, such as heart rate, temperature and respiration. The information collected by all the sensors are sent to the hospital workstation, where medical staff analyzes it and modifies the program, if needed. Thus, the patient condition is always under medical control and supervision.
3.3. StrokeBack

Like FITREHAB, StrokeBack supports rehabilitation at home with minimal human intervention. It is an European research project partly funded by the European Commission (7th Framework Programme – Personal Health Systems area) [11]. It started in October 2011 and will end in September 2014. The objective of this project is to implement a telemonitoring system that supports and accelerates the rehabilitation at home of stroke patients (hemiplegic, paretic patients, wheelchair users). So, the target system has to increase the number of physiotherapy training sessions while monitoring their impact on the patient. In addition, this system will integrate a PHR (Personal Health Record) for recording training results and patient’s vital parameters to ensure long term evaluation of patient recovery (Figure 3). This will allow healthcare professionals to assess the patient recovery and to provide patient with midterm feedback as well as the proper guidance (e.g. training sequences and frequencies). To achieve its objectives, StrokeBack will combine monitoring sensors forming a wireless Body Area Network. The used sensors will enable simultaneous measurement of many vital parameters as well as the executed movements which are interesting from a stroke rehabilitation point of view. Measured parameters will be fused using advanced feature extraction and classification algorithms processed on-body, which will denote the accuracy of the executed exercise. Thus, this project has to deal with many challenges: sensors, electronic, data fusion /storage/extraction, mobile and wireless communications, patient mobility, security and privacy.

The system was specified based on a survey consisting of twenty eight therapists, and its first prototype was tested with five therapists and four stroke patients. The main result is that the system was easily incorporated into patients environments. However, the first prototype shows some limitations. Indeed, patients were unable to wear sensors easily. It was also difficult for them to use computers and standard mouse. Furthemore, the feedback (graph representation) wasn’t helpful and movements’ (target and own) visualisation from 3 angles was unnecessary and overly complex [12].

4. Chronic diseases telemonitoring

Today’s society is aging and elders are generally subjects to chronic diseases. Consequently the demand for healthcare services is increasing. Many Europeans projects aim at offering chronic diseases telemonitoring [13]. All of them aim at creating better condition of life for the older adults. In this
section, we study some representative projects which proposed different solutions since they are focused on patients with different chronic diseases. Thus, we present them according to telemonitored pathologies. We begin by Dem@Care project that offers telemonitoring for persons affected by dementia when they are at home. Then, we detail CogKnow project which, in addition to telemonitoring persons affected by dementia indoors, treats patients outdoors. After that, we present REACTION project which offers telemonitoring for diabetics. The rest of the studied projects treat many pathologies. We present, firstly, CHRONIOUS project which treats only patients indoors. Then, we present Mobihealth which is an old project but it was revolutionary since it was the first that treated persons outdoors. We finish by CAALYX/eCAALYX projects which offer telemonitoring of many pathologies indoors and outdoors while respecting patient’s privacy.

4.1. Dem@Care

Dem@Care (Dementia Ambient Care) is a research project partly funded by the European Commission (7th Framework Programme – Personal Health Systems) [15]. It started in November 2011 and will end in October 2015. The objective of this project is to ensure diagnosis, assessment, maintenance and promotion of self-independence of persons affected by dementia. This will be performed through the implementation of a multi-sensing monitoring for intelligent remote management and decision support prototype. The target system includes 2 loops (Figure 4). The first loop allows monitoring and assessing cognitive and behavioral status of patients. Based on wearable and
in-situ sensors, it will enable context-aware profiling in order to ensure reac-
tive and proactive care, as well as personalized feedback. The second loop
allows clinicians to: assess health progression and medication effectiveness,
warn about trends, recommend preventive care and treatment adjustment.
The Dem@Care project covers many research axes:

- Definition of requirements and their translation into functionalities to
  implement (services and sensors);
- Collection of physiological and lifestyle information thanks to a multi-
tude of sensors (data collection);
- Detection of unusual events through early fusion of collected data (data
  fusion);
- Analysis of person’s daily activities to detect situations of interest for
  further analysis (data mining);
- Implementation of medical ambient intelligence to enable reliable in-
terpretation of a person’s behavior and delivery of the appropriate support
  (reasoning and inference);
- Investigation on the client-side interaction to provide necessary and
  adapted feedback on time (human-computer and human-to-human interac-
tions);
- Definition of the system architecture, communications and interfaces;
- Definition of data privacy and security required for the final system;
- Validation of the system’s effectiveness through the evaluation of its
  impact on societal and personal levels (quality of life for people with dementia
  and their caregivers).

The validation of the Dem@Care’s system will be performed in three
steps. A first prototype will serve to verify usability, functionality and reli-
bility in order to detect limitations and inaccuracies at an early stage. The
second prototype will focus on suitability, accuracy, learnability, recoverabil-
ity, maturity, security and portability. In the third prototype, all the system
qualities as well as its performances in real life conditions will be evaluated
and validated.

4.2. CogKnow

CogKnow (Helping people with mild dementia navigate their day) is a
project that focuses on patients affected by dementia, like Dem@care. It has
the advantage of providing a monitoring indoors but it treats in addition
patients outdoor. It is funded under Information Society Technologies (IST)
program. It commenced in September 2006 and ended in August 2009. It
consists in developing a cognitive prosthetic device and associated services
Figure 4: Architecture of Dem@Care [15]

for elderly people with mild dementia [16]. It aims at ameliorating the quality of life and autonomy of persons with mild dementia and increasing the period they can remain independent and living at their own home. The project focused on developing a cognitive reinforcement prototypes in order to help patients in their daily life.

The system is composed of three components:

- **The Home-based Hub:** is a device located at a fixed position within the person’s home. It is responsible for the collection of all information related to the activities of the person suffering from dementia, and for relaying this information to the CogKnow Web server.

- **The Mobile Cognitive Prosthetic:** is a mobile device. Its purpose is to mirror the services offered by the Home-based Hub, so that they may also be accessible from anywhere within (or outside) the home environment. At home, it communicates with the Home-based Hub device via a Wi-Fi network. Outside home, the mobile device employs GPS technology to support users if they become lost.

- **The Web-based Server:** is the repository, where user’s information and needs are stored. It also allows the carer to configure and schedule patient reminders.

In this project, a CogKnow Day Navigator prototype was developed. It is composed of a touch screen in a home smartened with sensors and
computer-mediated controls, and a mobile device to bring along when going out. Both devices offer multiple very easy-to-use functions. 32 persons with dementia used the prototype for one or more days, while 10 persons with dementia used it independently for several weeks. The CogKnow project was a selected showcase for the European Commission Smart Home at e-Inclusion Ministerial Conference (2008). It has received national media coverage in The Netherlands, UK, Malta, Sweden and USA.

4.3. REACTION

Unlike the already presented projects that offer telemonitoring for persons and those affected by dementia. REACTION (Remote Accessibility to Diabetes Management and Therapy in Operational healthcare Networks) project is dedicated for diabetic patients. It is a research project partly funded by the European Commission (7th Framework Programme – Personal Health Systems area) [17]. It is a 4-year project started in March 2010. The aim of this project is to develop a platform that supports improved long term management of diabetes. This will be based on wearable sensors, ensuring a continuous monitoring of the blood glucose, and an automated closed-loop for insulin delivery. So, the target platform (Figure 5) connects equipments from the patient’s sphere and actors forming the carers’ sphere. It must be also connected to HIS (Health Information Systems), external medical knowledge repositories and security providers. The patient’s sphere is composed of wearable medical sensors (BAN: Body Area Network) for recording vital physiological parameters. The BAN is interconnected with other environmental sensors that record contextual information. The patient’s sphere includes also a gateway which is responsible for data pre-processing and formatting, as well as handling monitoring, alarm and other services during non-connectivity periods. The gateway also adapts health professionals feedback to patient device, manages the BAN and enables the virtualisation of devices and sensors not capable to operate web services. The REACTION platform ensures transmitting feedback (e.g. health status, risk assessments) to the patient and to other informal carers (e.g. family members, friends, neighbors) by multiple ways (e.g. actuators, mobile phone). Feedback is based on medical information available thanks to the data transmission, information and knowledge from the data manager to the various stakeholders. In addition, contextualized health information could be transmitted to crisis management and emergency centers. Thus, the REACTION project deals with many challenges. It will develop wireless body networks with wearable and non-invasive sensors (electronic patch sensors). The target platform will allow decentralized decision at the active gateway (e.g. PDA, Smart Phone).
This project must also address data management (data manipulation, data fusion, event handling), service orchestration (execution sequence), network management (physical communications), security management (communications, access to data, trust, privacy), application development (ontologies), interoperability and scalability (web services).

This project results in an intelligent service platform for telemonitoring and therapy management. It provides continuous control of blood glucose levels which are tightly coupled with other relevant vital signs. Telemonitoring information is communicated to healthcare centre. This allows healthcare professionals to inform patients about their condition, therapy and behaviour.

4.4. CHRONIOUS

CHRONIOUS is a research project that treats many diseases unlike previous projects. It is partly funded by the European Commission (7th Framework Programme – Personal Health Systems) [18]. It started in February
2008 and ended in Mai 2012. This project aims at developing a health monitoring platform for people with chronic diseases. The platform will be used by both patients and healthcare professionals. Patients will improve self-confidence and self-care conditions, and healthcare professionals will be aided with the healthcare monitoring of chronically ill people. CHRONIOUS is initially developed to ensure ubiquitous and adaptive management of the following chronic diseases: chronic obstructive pulmonary disease (COPD), chronic kidney disease (CKD) and renal insufficiency (RI). However, it is designed to provide a generic platform which will be easily extended to manage other kinds of chronic diseases such as psychiatric disorders, diabetes and asthma. CHRONIOUS enables continuous monitoring of the activity as well as the medical condition of ill persons thanks to the use of a set of various sensors (vital signs, activity) (Figure 6). Its intelligence allows: a rapid detection of abnormal health status and alerting incidents, as well as alerts generation. CHRONIOUS involves multiple research areas such as wearable solutions for monitoring, sensing systems parameters (vital, environmental, activity and social context), sensor management techniques, data fusion algorithms, knowledge database and medical decision support, intelligent information indexing, ontologies, alert and reminding mechanisms, universal access to the system (fixed and wireless devices), adapted user interfaces (patient, healthcare professionals), standard specifications of personal medical record, security, privacy and interoperability with existing healthcare legacy systems.

The validation of the CHRONIOUS platform is composed of two phases. The first one concerns fifty patients in hospital and aims at verifying the implemented prototype in terms of meeting user requirements, as well as ergonomic / functional specifications. The second phase considers sixty patients at home for a duration of 4 months and aims at evaluating the customer satisfaction and the predictive ability of the improved system in the disease evolution. Feedback are promising because the performed monitoring reduces the intervention time in critical situations [19].

4.5. Mobihealth

The Mobihealth project was supported by the Commission of the European Union in the frame of the 5th research Framework. It started in May 2002 and ended in February 2004. As CHRONIOUS, Mobihealth project concerns patients with many pathologies. However, it ensures patient monitoring at home as well as outdoors [20, 21, 22]. It is an older project but revolutionary since it introduced telemonitoring outdoors. The specified system monitors crucial health signals through medical sensors and transmits
them to health care professionals through available wireless system. Body Area Network (BAN) has been used in signal monitoring and GPRS and UMTS have been used for transmitting signals. The system allows patients to be mobile whilst undergoing health monitoring. The patient wears monitoring system customized to individual health needs. Physical measurements such as blood pressure or ECG are measured by the BAN and transmitted wirelessly from the BAN to their caretaker. Therefore, a patient who requires monitoring for short or long periods doesn’t have to stay in hospital for monitoring.

The system is composed of a set of different sensors connected to a PDA or mobile phone that transmits securely all the patient data to a server in the hospital. Authorized doctors can access these medical information from their computers (inside the hospital or even outside) both at real time as well as afterwards, and can even interact with the PDA.

An Australian version of Mobihealth project is PHM (Personalized Heart Monitoring) which has the same finalities and roughly the same architecture as the Mobihealth’s one [23]. Indeed, PHM provides personalized monitoring and enables locating the patients in case of emergency whether they are outdoors or indoors. Many randomised controlled trials were performed in Germany, the Netherlands, Spain and Sweden. These trials were conducted in the areas of chronic and high-risk patient monitoring and monitoring of patients in home care settings. The trials are evaluated in terms of accuracy and validity of measurements, usability of the GPRS and UMTS networks,
business and market potentials and also for social effects.

4.6. CAALYX

CAALYX (Complete Ambient Assisted Living Experiment) is an European project funded by European Community under the 6th Framework Program. It started in January 2007 and ended in December 2008. It includes many telemonitoring functionalities while respecting patient’s privacy. It has the purpose of detecting any unfolding adverse health conditions and preventing complications before they develop. The project aims at respecting user’s privacy and personal life needs [24]. If an adverse condition arises, the system relays a high priority message to an emergency service, including the geographic position and clinical condition of the elder. The system is composed of three subsystems:
- **The Mobile Monitoring Subsystem:** collects and monitors vital signs and detects adverse health events when users are outdoors. It also facilitates efficient communications between the user and his caretakers and family in the event of an emergency when the elder person is outdoors;
- **The Home Monitoring Subsystem:** monitors users at home and helps keeping them in touch with their family and caretakers;
- **The Caretaker’s Monitoring Subsystem:** provides monitoring of elders by specialized personnel. The caretaker decides whether to promote a raised event to the emergency service or not.

While at home, a set of smart sensors (BAN formed for example by body temperature and ECG sensors, and others like weighing scale) connected wirelessly via Bluetooth to a Personal Computer (PC) connected every time to Internet, which records and analyzes user parameters such as body weight, body temperature, blood pressure, cardiac function.

When the patient is outdoors, he remains connected by carrying, in addition to his GPS-enabled mobile phone, a Wearable Light Device (WLD) that continues recording and analyzing vital signals (body temperature, electrocardiogram, respiratory rate, etc). The WLD complements the functionality provided by the user’s mobile phone, acting as an active Bluetooth-enabled sensor peripheral for it, and providing specialized hardware that is normally not available in a common mobile phone.

To respect patient’s privacy, all the health data processing is performed locally, either on the Home Monitoring Subsystem or on the Mobile one, and only the outcome of this processing is shared, if needed (e.g emergency and fall), with external entities, like carers.

This approach, of sending selected data only when needed rather than streaming all data continuously, not only preserves the user’s privacy, but also helps
prolonging the Mobile Subsystem's battery life and making best use of its Internet bandwidth.

eCAALYX (Enhanced Complete Ambient Assisted Living Experiment) [25] is an extension of Caalyx project which consists in developing a mobile application, which aims at building a remote monitoring system targeting older people with multiple chronic diseases.

5. Common architecture of telemonitoring systems

In the previous sections, we described some of the most representative European research projects in health telemonitoring. The conducted study allows us to identify the common architecture to which a number of eHealth systems are converging as well as its main features. The target systems are expected to provide some services to the monitored persons: elders [24, 5, 6] disabled [14] and other patients [17, 18, 20, 21]. These services cover essentially safety services (detection of gas, fire, intrusion, etc.) as well as healthcare services like drug reminder, remote medical diagnosis and detection of danger situations. The implementation of the provided services is often based on OSGi (Open Services Gateway initiative) [5, 6] or Ontologies [17, 18]. It is also distributed between the gateway and the remote servers in order to have some “local” services and to make local entities as autonomous as possible. The common architecture is composed of three main components (Figure 7):

- **Sensors network**: a set of heterogeneous sensors fitted to the patient and his environment (medical, environmental, contextual, etc.). Each provided service is based on a set of sensors. For example, the remote medical diagnosis requires the use of medical sensors to monitor physiological parameters like body temperature and pulse oximetry. However, the fall detection service could use location and activity sensors.

- **Gateway**: intermediary entity between the monitored patient and the outside world. When the monitored person is located in his home, the gateway is a kind of medical box. However, to ensure monitoring, even if the patient is mobile, a smart phone or PDA can replace the medical box. Otherwise, the gateway is the entity on which local services and, in general, local functionalities of a service are executed.

- **Remote server(s)**: connected to the gateway and able to perform complex computations and to store a large amount of data. It is used
to execute remote services or remote functionalities of a given service. Then, when this server decides that a third person must be informed or alerted about the status of the monitored person (e.g. in case of incident), it would be able to access a contact list /directory (parent, neighbor, nurse, doctor, assistance center, emergencies, etc.). These contacts can be stored on the same server or on a dedicated server. To enable communications between sensors and the gateway, this last has to support many communication technologies (Ethernet, Wi-Fi, Bluetooth, RF, etc.). This allows the gateway to communicate with the representative sensors equipping the monitored person and his environment and with the remote server. However, communications between the gateway and remote server(s) are often based on web services in order to ensure interoperability [17]. Indeed, web services are designed to standardize exchanges on the Internet.

Figure 7: Common architecture of telemonitoring systems
6. Comparative study

6.1. Characteristics of a telemonitoring system

In previous sections, we studied many projects developed in the context of patient telemonitoring. Each one offers some functionalities. However, in many cases, they do not cover all patient’s needs. In this section, we begin by introducing the desired features for a patient telemonitoring system. We distinguish three basic features: provided services, used tools and architecture supported functionalities. Then, we present some technical issues.

• Provided services

Main desired services in a telemonitoring system are:

- **Safety**: The system must ensure a safe environment by installing sensors which detect falls, fire, etc. It is very important for users to have control and clear visibility of what occurs within their environment.

- **Localization**: The geographical position and the location of the user should be given by the system when needed.

- **Social interaction**: It covers representative aspects, such as communication, information, maintaining contacts and staying an active participant of society.

- **Real time alert**: Time is crucial in case of health problem. The system should be able to send alerts in real time for caregivers and patient relatives.

- **Coaching**: The monitoring application should allow health care professionals to supervise their patients and to access patient’s data at any time and from everywhere.

- **Reasoning**: The system should be able to perceive and react to different situations.

• Tools

The tools used while specifying a telemonitoring system are:

- **Software**: The system should design a software application that enables patients to easily get access to the proposed services. The software may be a processing application or/and an interface.

- **Personal Health Record (PHR)**: Commonly defined as a health record where health data and information related to a patient are stored.
- **User profile**: It is information of the characteristics of a patient. This information can be exploited by systems in order to make account the patient’s characteristics and preferences to take a decision about his health state.

- **Supported functionalities**
  The main supported functionalities by a telemonitoring system are:
  - **Mobility**: Telemonitoring system should consider patients who are outdoors to guarantee their well-being and independence.
  - **Security**: Data storage, transmission and access should be secure. The system should also guarantee the privacy.
  - **Context-aware**: The system should consider context and history of the patient to offer a feedback for the user and for the caretaker and to adjust parameters in some cases.
  - **Interoperability**: The developed system should be able to work with existing and future products or systems. It should also unrestrict access or implementation.

- **Technical issues**
  In this section we compare, basically, communications and computing technologies used in the studied projects. We begin by introducing communications technologies which are nearly the same in most of the studied projects and we finish by comparing some used computing issues.

  1. **Communication technologies**
     As mentioned in the section 5, there are mainly three communication interactions:
     - Interaction between the patient sensors and the gateway: wired communication or wireless (Bluetooth) are used.
     - Interaction between the gateway and the platform of the e-health system: TCP/IP communication through mobile telephony or local LAN or Internet are used.
     - Interaction between the platform of the e-health system and the contacts/carers terminal: TCP/IP through Internet or LAN are used.

  2. **Computing**
     The computing characteristics are different from one project to another. However, we retained three main features:
- **Treatment**: this feature describes if computing is distributed or centralized.
- **Reactivity**: this feature describes if the system is reactive or not. Medical systems should be able to react when an incident occurs.
- **Mobile computing**: some projects have developed a mobile software to facilitate telemonitoring in mobility.

### 6.2. Comparison

Table 1 summarizes important characteristics of each studied project and presents a brief comparison in terms of provided services, used tools and supported functionalities. It shows that most of these projects are interested in patient’s safety because the patient should be in a safe environment like in a hospital or in care home. However, rehabilitation projects do not offer this service because there is few risks.

Real-time alert service is very important in telemonitoring. Indeed, in case of an incident, it has to be solved as quickly as possible. However, there are some projects that do not offer this functionality like INTERACTION and FITREHAB projects which are dedicated to develop systems to support especially stroke persons so there is few risks of incident.

Localization service is a service that allows the system to define the place of the target before reacting. It is a service, in most cases, used in mobility, like in Cogknow and CAALYX/eCAALYX projects in order to act in case of incident. It is, sometimes, used to give information about the target activity like in Netcarity project.

Reasoning service allows the telemonitoring service to be reactive. It facilitates tasks for careers. Most of the studied projects, supporting context-awareness introduce this functionality and consider the history, as well as, the environment of the target.

Social interaction is essential for patients maintained at home to keep contact with relatives. Most of safety telemonitoring projects offer this service like VITAL, SAAPHO and SOPRANO since they are dedicated to the well being of users.

Projects like BrainAble, CHRONIOUS and StrokeBack, are based on user profile and PHR to allow the telemonitoring system to reason about the situation and send real time alerts in case of incident.

Mobility is also an important feature for the independence of patients. However, CHRONIOUS and BrainAble do not offer it. These projects do not also, treat data contextualisation which is important to automate telemonitoring systems.
<table>
<thead>
<tr>
<th>Project</th>
<th>Provided services</th>
<th>Tools</th>
<th>Supported functionalities</th>
<th>Computing</th>
</tr>
</thead>
<tbody>
<tr>
<td>BrainAble</td>
<td>Social interaction Safety</td>
<td>Software Application User profile</td>
<td>Context-aware</td>
<td>Distributed</td>
</tr>
<tr>
<td>Vital</td>
<td>Real time alert Safety  Social Interaction Coaching</td>
<td>Software application User profile</td>
<td>Mobility</td>
<td>Mobile Software</td>
</tr>
<tr>
<td>Soprano</td>
<td>Safety                           Reasoning Social Interaction Real time alert</td>
<td>Software application</td>
<td>Context-aware</td>
<td>Reactive</td>
</tr>
<tr>
<td>Saapho</td>
<td>Safety                           Reasoning Social Interaction Real time alert</td>
<td>Software application</td>
<td>Context-aware</td>
<td>Centralized</td>
</tr>
<tr>
<td>INTERACTION</td>
<td>Reasoning                          Coaching</td>
<td></td>
<td>Context-aware</td>
<td>Centralized</td>
</tr>
<tr>
<td>FITREHAB</td>
<td>Coaching                           Software application</td>
<td></td>
<td>Reactive</td>
<td>Centralized</td>
</tr>
<tr>
<td>StrokeBack</td>
<td>Reasoning                          Coaching</td>
<td>PHR</td>
<td>Mobility</td>
<td>Centralized</td>
</tr>
<tr>
<td>Cogknow</td>
<td>Safety                           Real time alert Coaching</td>
<td></td>
<td>Mobility</td>
<td>Centralized Mobile Software</td>
</tr>
<tr>
<td>Mobihealth</td>
<td>Coaching                           Real time alert</td>
<td></td>
<td>Mobility</td>
<td>Centralized</td>
</tr>
<tr>
<td>eCAALYX/CAALYX</td>
<td>Localization Social interaction Real time Alert</td>
<td>Software application</td>
<td>Mobility</td>
<td>Centralized</td>
</tr>
<tr>
<td>dem@care</td>
<td>Social Interaction Reasoning Real time alert</td>
<td>Software Application</td>
<td>Context aware</td>
<td>Centralized</td>
</tr>
<tr>
<td>REACTION</td>
<td>Real time alert Coaching Social Interaction</td>
<td>Software application PHR</td>
<td>Security Interoperability</td>
<td>Distributed</td>
</tr>
<tr>
<td>Chronious</td>
<td>Real time alert Coaching Social Interaction</td>
<td>PHR</td>
<td>Security Interoperability</td>
<td>Mobile software</td>
</tr>
</tbody>
</table>

Table 1: Comparison of telemonitoring projects
Interoperability is a key requirement for the success of a telemonitoring system. It must be addressed on each layer (network, syntax, semantics, interfaces between sensors and IT components, interfaces between software components, etc). Unfortunately, only CHRONIOUS treats it.

Security is, also, a very important issue but few projects take into account this feature.

Studied projects used different technical tools. Most of them opted for centralized treatment. Only BrainAble and Reaction projects used distributed treatments.

System reactivity is also an important aspect for telemonitoring in case of incident. Unfortunately, some projects did not developed reactive system like Mobihealth, and Dem@care.

Note that only REACTION project offers an architecture relatively complete and there is no project that is interested in maintaining connectivity for needed communications. However, it is very important to provide a continuous telemonitoring.

7. Main Issues

In the previous section, we presented a comparative study of the most representative European projects in telemonitoring. We remark that few projects treat security and user's privacy and that only one project tries to develop a generic system. In addition, no project is interested in maintaining connectivity. In this section, we focus on these issues. We begin by the security which is relevant but not well treated in the studied projects. Then, we introduce cognitive radio to ensure connectivity and we finish by introducing a generic system for ehealth.

7.1. Security in ehealth systems

Security and privacy play an important role in the successful adoption of medical assistive technologies. It should ensure secure transmission between all system components, secure data processing and storage. However, by storing patient medical data in the cloud, the patient loses control of his personal data, which makes it necessary for each patient to encrypt his data before uploading it to the cloud server. Some research papers, like [26], present a statistical study that shows that there is few researches that are dealing with security and privacy issues in cloud computing with healthcare. They introduce, in addition to encryption of records, *unlinkability* between the medical record and patient and *confidentiality of patients identifier*. Authors propose to offer these functionalities using secret sharing.
In addition to confidentiality and integrity, other issues are identified with healthcare data like the pseudonymity. It is an important issue because the system should preserve the anonymity of the patient when his medical data is sent to monitoring center and should be linkable to each other using patient pseudonym and not patient real identity. The Conditional deanonymization is evoked in case of emergency. It is also an important issue because urgent staff should be able to recover the real identity behind the pseudonym. Selective disclosure is, also, a functionality that preserve privacy [27]. It is the ability of the patient to disclose fine-grained information about his identity attributes and hide the rest.

The use of the Body Area Network (BAN) or Wireless Body Sensor Networks (WBSN) generates also new challenges in terms of security (authentication failures, intrusion). The use of wireless communication between sensors and the gateway (see Section 5) accentuates these vulnerabilities.

7.2. Cognitive Radio in ehealth systems

It is important to note that the technologies providing broadband, such as 3G and 4G, are not available everywhere and anytime. Even if these technologies were available, there is no guarantee that they can provide all the necessary quality of service for patient’s telemonitoring. The limitations of current technologies used in most telemonitoring systems recommend having an interest in more flexible technologies such as cognitive radio. Cognitive radio [28] is a paradigm for wireless networks where a node is able to automatically modify its transmitting parameters in order to communicate efficiently, while avoiding interference with other users. This selfconfiguration and self-adaptation of parameters is based on the internal or the external environment of the radio such as radio frequency, user behaviour and network state. Cognitive radio used for patient telemonitoring can provide services with greater efficiency than networks largely used. This technology is well suited to provide the adequate frequency band for the underlying applications. Indeed, according to the medical application needs, the medical data type (video or image), the urgency of the communication (report, alert, emergency contact) and the frequency availability, the Cognitive Radio node will select the appropriate channel and the adequate technology to ensure the transmissions. An example of use case of this technology in hospital environment with vulnerable medical equipments for sensitive devices protection through interference avoidance and transmit power adaptation, is more described in [29].
7.3. Generic /Universal ehealth system

As we saw in section 4.4, some research projects in eHealth field aimed at defining a generic system or an extensible one [18]. This allows having an eHealth system which is able to support patients with various pathologies and different needs. In this context, a challenging task is to define a universal eHealth system including a large number of healthcare services. Then, the set of the required services for a particular patient is retrieved on the basis of the patient profile and deployed automatically. Thus, a general patient profile covering the personal, medical and environmental context must be specified and mapping rules between this profile and healthcare services to deploy have to be defined.

Currently, most of telemonitoring systems do not provide generic capabilities for monitoring and treating all kinds of diseases. They focus on a single disease. This lack of generality limits the reuse of developed systems and make them very costly because of their specific use.

8. Conclusion

In this paper, we have studied the most representative European telemonitoring projects. Considering the services, we distinguish projects that are dealing with comfort and security, those dealing with rehabilitation and those dealing with chronic disease. This study allowed us to identify a global architecture that summarizes the various aspects introduced in architectures of the studied projects. Then, we specified the different features of telemonitoring systems to elaborate a comparative table that illustrates the provided services, the main used tools, supported functionalities and some technical issues. Finally, we cited some issues that can ameliorate telemonitoring systems like cognitive radio and generic ehealth system.

Other important research perspectives are emerging in health data processing. Research on big data will enable health authorities to better predict outbreaks and contain them when they occur. Research on social networks will permit to observe phenomena sometimes misunderstood by classical epidemiology such as side effects associated with the combination of both drugs.

References


