Personalised physical exercise regime for chronic patients through a wearable ICT platform

Pantelis A. Angelidis

Department of IT & Telecommunications Engineering,
University of Western Macedonia,
Karamanli and Lygeris,
50100 Kozani, Greece
Email: paggelidis@uowm.gr

Abstract: Today's state of the art in exercise physiology, professional athletics and sports practice in general clearly shows that the best results depend on the personalisation and continuous update of the recommendations provided to an athlete training, a sports lover or a person whose medical condition demands regular physical exercise. The vital signs information gathered in telemonitoring systems can be better evaluated and exploited if processed along with data from the subject's electronic health records, training history and performance statistics. In this context, the current paper intends to exploit modern smart miniaturised systems and advanced information systems towards the development of an infrastructure for continuous, non-invasive acquisition and advanced processing of vital signs information. In particular, it will look into wearable electronics embedded in textile capable of performing regular or exceptional measurements of vital physiological parameters and communicating them to an application server for further processing.

Keywords: telemonitoring; smart miniaturised systems; wearable electronics; smart textiles; electronic health records; advanced information systems; real-time monitoring; vital signs; lactic acid; pH; wireless sensor networks.

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Biographical notes: Pantelis A. Angelidis is Assistant Professor at the University of Western Macedonia, Greece, and a visiting scholar of MIT Media Lab, USA. He received his diploma and his PhD in Telecommunications Engineering from the Aristotle University of Thessaloniki, in 1989 and 1993, respectively. He has worked as technology expert in Telecommunications and eHealth, served as project manager in multinational projects, presented more than 50 papers, published 27 original research articles, authored six monographs and five book chapters. He serves as evaluator for the European Commission. He is the founder and president of VIDAVO, a health telematics research company.

1 Introduction

Continuous telemonitoring of the individuals' physical and health condition, as these are reflected by vital physiological parameters, is a key feature in numerous modern biomedical and lifestyle applications. At the same time, the increased mobility of the monitored individuals raises the demand for portable and/or wearable monitoring systems. Towards this direction the design of an intelligent textile that incorporates many different sensors can play an important role, since such a structure can result in significant improvement in the comfort, safety and overall quality of services provided to the subject.

The basic palette of vital signs needed for such telemonitoring systems includes heart rate, oxygen saturation and human temperature. Apart from the above-mentioned typical vital signs, other measurements can be extremely useful as health status indicators; for example, sweat lactic acid and pH can be used for assessing the performance of the individual during exercise, a very critical parameter when the individual under monitoring is either a world-class athlete or a chronic patient suffering from, e.g., diabetes or COPD. Finally, the awareness of humidity or temperature conditions can be used for the estimation of the environmental context the monitored individual acts in.

The accumulated experience in the field of exercise physiology and in sports practice clearly shows that positive effects depend on the personalisation and continuous update of the recommendations provided to the subject. For example, patient's drug dosage should be adjusted to his current health status or the athlete's training intensity should be individually well adjusted to minimise the risk of overtraining and injury (Michahelles and Schiele, 2005).

In the context shaped by the above-mentioned ideas, we present how to exploit modern micro/nanotechnologies and advanced information systems towards the development of an infrastructure for continuous, non-invasive acquisition and advanced processing of vital signs information. In particular, we look into the use of a wearable electronic textile capable of performing measurements of vital physiological parameters – such as ECG, blood pressure, SPO_2, body temperature, heart pulse, lactic acid, and pH – and communicating them to a dedicated application server for further processing. An intelligent decision-making system will co-process the collected information with the unique genetic profile of the monitored person, to determine its actual health and physical condition, monitor the progress over time and identify potentially critical situations. The objective of such a system is not only to monitor individuals' physical and health condition, but also to generate personalised and updated feedback. By doing so, it could manage to convert one-size-fits-all health or training guidelines into actions that are better tailored to the real condition of the monitored individual.

Currently, some first research approaches aiming at exploiting the often-articulated benefits of e-textiles have already shown some results in Europe: Wealthy (http://www.wealthy-ist.com/), DROMEAS (http://www.cinternational.co.uk/dromeas/), BIOTEX (http://www.biotex-eu.com/), PROETEX (http://www.proetex.org/), STELLA (http://www.stella-project.de/), CONTEXT (http://www.context-project.org/), etc. Pioneer companies, e.g. Clothing+ (http://www.clothingplus.fi/), Infineon Technologies AG (http://www.infineon.com/cms/en/product/index.html), Smart Life (http://www.smartlifetech.com/), etc., have timidly launched commercial products (shirts, suits, accessories, etc.) offering specialised applications for the monitoring of patients with chronic diseases, for supporting warriors or workers in extreme environmental conditions. Towards that end, e-textiles combine textile manufacturing capability with discrete electronics and novel fibre technologies. New fibres are being created for inclusion in e-textiles, including battery fibres, conductive fibres and mechanically active fibres. Methods are being developed for attaching discrete components to e-textiles, including processors, etc. (Mann, 1998). All these approaches, however, consider the issue from the single perspective of a few isolated computing and sensing elements on the fabric designed to perform specific pre-designed tasks. However, the design and manufacturing of highly differentiated e-fabrics for specific applications will increasingly become uneconomic and intractable.

Taking into consideration all the above, the objective of the paper is multi-fold:

1 to identify the basic building blocks in terms of architecture for the development of a real-time telemonitoring system for chronic patients while exercising;
2 to further analyse the important components of the aforementioned building blocks and
3 to identify in principal the challenges to be met when designing such a system/platform.

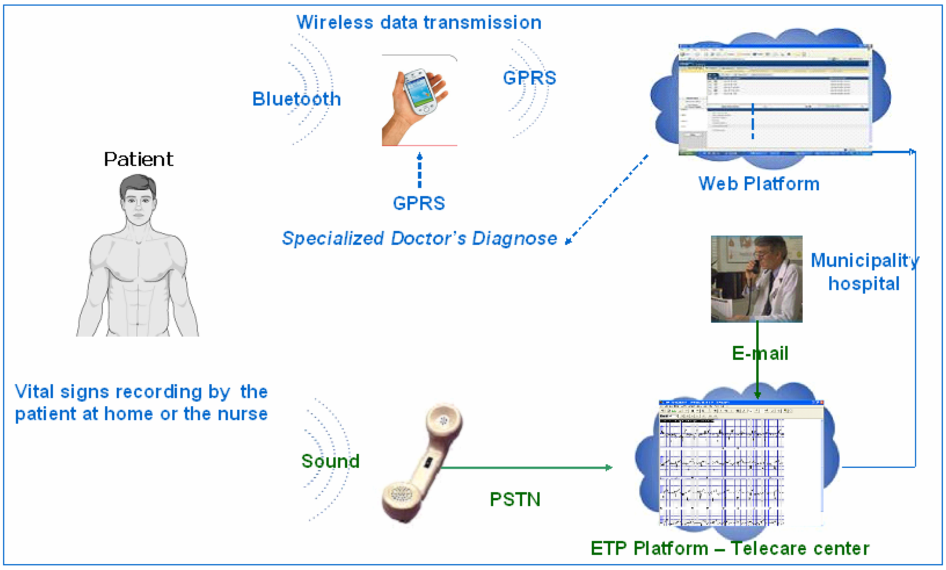
2 Achievements so far – success stories of personalised health provisioning

One of the most critical issues when dealing with chronic patients is the provisioning of the same quality level of health services regardless of their geographical positioning. A paradigm on the aforementioned is rural health of rural communities that around the world suffers from lack of access to the same level of health services enjoyed by their urban counterparts due to lack of health professionals willing to live and work in remote areas, distance from the service point and finally lack of adequate resources.

Greece faces important challenges in the management of chronic diseases, especially amongst the elderly population, due to the special geographical characteristics (a combination of islands and extensively mountainous areas). It is a common knowledge that ICT vastly improves the delivery of health services to isolated areas. Remote monitoring of patients used in conjunction with electronic health records ensures continuity of care outside the hospital environment, efficient disease management and consequently enhanced quality life for the patient, avoidance of unnecessary and costly treatments as well as reduced healthcare costs (Angelidis et al., 2009).

Taking into consideration the above, the Municipality of Trikala in Central Greece has designed a long-term strategic plan for the transformation of the local society, based on the opportunities created by the information society era. Part of this strategic plan is the establishment of a centre offering advanced health and social care services to the citizens of the region (Angelidis, 2009).The telecare centre provides (in collaboration with the local public hospital) telemonitoring services to individual citizens with cardiovascular, pulmonary diseases and hypertension. Individual citizens are equipped with lightweight handheld devices and record their vital signs which are then transferred (via the telecare centre) to the municipality hospital over PSTN or GPRS for review and feedback by the experts. The data flow is depicted in Figure 1.

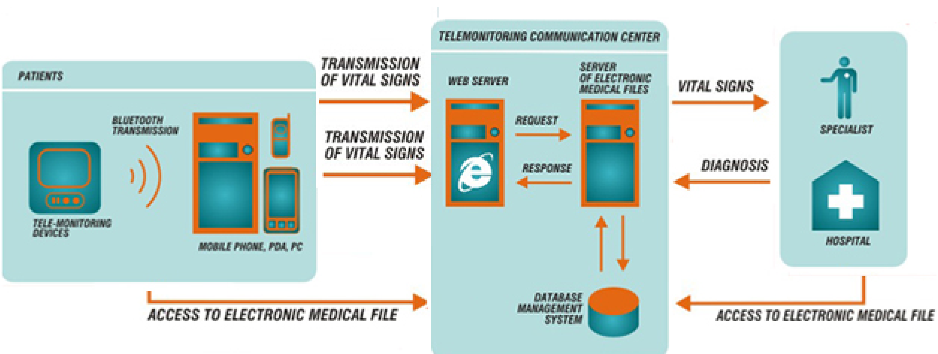
Figure 1 Telecare centre data flow (see online version for colours)



Another success story again in Greece is the Pilot Telemetry Network established in 2008 and currently covering 30 remote and isolated municipalities, ten of which are located in islands. The implementation of the pilot network aims at the personalisation through the extensive use of electronic heath records cum effective (continuous monitoring) chronic disease management even for the inhabitants of geographically isolated locations. The network allows for the constant communication (though not real time) between the specialised physician and the regional health unit's general physician.

The local primary health units are equipped with vital signs telemonitoring devices. At this point the general physician records the vital signs of the chronic patients (diabetics, COPD, CVD). The data are transmitted through Vodafone Greece GPRS (project's sponsor) to a central web server. Specialised physicians of Athens Medical Centre (another sponsor) consult the recorded tests along with the patient's electronic health record and provide advice to the local physicians.

Figure 2 Data flow (see online version for colours)



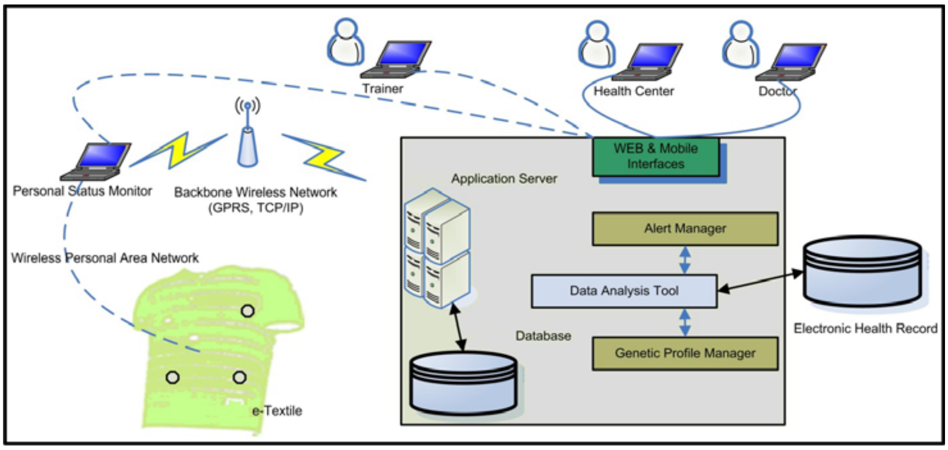
The reason why both cases were characterised as successful was the fact that they were met with tremendous enthusiasm from the citizens who benefited from the services offered. In Trikala, where the installed base is constantly increasing, there were many complaints from citizens who could not be covered by the programme's originally limited resources. Now that the number of benefited patients has reached an appropriate level, the time has come to reassess our successes, overcome the technical limitations of the installed solution and advance forward in order to deliver the most competent solutions for the chronically ill. A new ambitious schema is discussed in the following sections.

3 Basic architecture: the building blocks

The major building blocks of a platform as roughly described in the Introduction section are as follows:

1. An innovative, intelligent clothing, containing a network of smart micro/ nanosensors, wirelessly integrated and deeply embedded (woven) into the textile. The adoption of micro/nanotechnology ensures that the sensors are compact, lightweight, energy-efficient and adoptable to the monitored individual. Emphasis should be given to their stability – since outdoor conditions are anticipated – and their ability to adopt their operation to the monitored individual. The gathered vital physiological parameters concern:
   - lactic acid concentration: a non-invasive and continuously measuring lactic acid sensor could be employed, the operation of which is based on the analysis of sweat;
   - pH: the operation of the respective sensor is also based on sweat analysis;
   - body temperature and
   - position tracking: the respective sensor continuously estimates location and speed over terrain.
2. A suite of applications running at an appropriate application server. In particular, the data analysis subsystem compares values to due-thresholds, co-process the collected information with the unique genetic profile of the monitored person, determine its actual health and physical condition, monitor the progress over time and identify potentially critical situations (e.g. exercising under infection, over-exercising, etc.). Moreover, this subsystem generates personalised therapeutic or training schemas, dietary plans and exercise and lifestyle guidelines. Appropriate web interfaces act as the interconnection of the system. Through them authorised individuals (doctors, trainers and monitored persons) are able to view and update relevant files. The overall architecture is shown in Figure 3.

Figure 3 The overall architecture of a personalised PE system for chronic patients (see online version for colours)



4 Important components: the biosensors

Nowadays, micro/nanotechnologies enable the fabrication of complex and miniaturised sensing microsystems that can be used to monitor a wide range of physiological parameters. While significant advances have already been made in mechanical sensing, biosensing remains largely unexplored. Thus, the design and engineering of innovative biosensors and the integration of them into reliable microsystems comprises an advanced step beyond the state of the art (Engin et al., 2005).

The envisaged progress in the field of biosensors lays the path for non-invasive monitoring of physical and health status parameters for which only invasive methods are available today. An example of this evolution is the assessment of metabolites in media other than blood (Schabmuellera et al., 2006). Today, the typical method for glucose, lactic acid and pH measurement is by analysing blood samples. This cannot be the case, however, in the context of a wearable continuous monitoring system, as the one outlined in this study intends to be. For example, it would be very annoying and difficult to interrupt the training procedure of an athlete or the physical exercise programme of a diabetic in order to monitor the change of lactic acid, the pH or glucose of his blood. Therefore, the construction of non-invasive and continuously measuring lactic acid/glucose and pH biosensors, the operation of which is based on sweat sample analysis comprises a major breakthrough in the relevant science and technology area.

Several measurement methods are combined, like enzyme electrodes, optical and simultaneous electrochemical readout, all performed on the nanometre scale. The sensor contains continuous reaction and permanent flow subsystems, and the sensing system is closed except for the 'one-way' skin-sensor interface. The continuous reaction and flow subsystems are combined with a silicon carrier chip, containing differently implemented physical sensor/transducer subsystems. The resulting hybrid chip especially in its highly integrated form is a significant step beyond the state of the art. Since it is able to gather simultaneously a large amount of high-quality information, it renders possible the span of a multi-dimensional parameter space, instead of just a statistical multi-parameter system.

Sweat as the analyte carrier has to be transferred from outside the chip into the microfluidic system. This is one of the biggest challenges in microfluidic-based diagnostics. Here, the combination of membrane and gel technologies, combined with nanofilm and filtering nanoparticles, helps to reach the ambitious aim of a general sweat interface between outer and inner chip. To improve the electrochemical and enzyme-based assay sensitivity and to arrive at better and more reliable analysis, novel labels with higher specific activity such as nanoparticles could be proposed in the context of an implementation project.

Apart from enzyme-based biosensors, a second new and very promising endeavour is oriented towards the execution of cyclic voltammetry, thus label-free sensing of the lactate molecule. To achieve this goal, a potentiostat-on-a-chip is constructed. This concept can then be expanded by analysing different molecules or by adapting this approach to other applications. Thus, it is anticipated that the construction of the potentiostat-on-a-chip (Steffan and Vrba, 2007) opens up a whole variety of sensing/detecting possibilities in many application fields.

The pH measurement of sweat and the skin surface consist of two main parts, that is the pH sensing part and a reference part. An ISFET could carry the pH sensing part, whereas a skin contact made from gold forms the REFET (Ghallab et al., 2003). The reference contact is necessary since several voltages, e.g. the voltage to bias the transistor, superposition the pH signal on the ISFET active surface and their influence can only be removed by referencing the measurement to a chemically independent contact. Ta_2O_5 forms the active material of the ISFET. This material is chemically stable in a pH range of 0–14 at body temperatures and there is no known concern towards biological compatibility. The same statement can be made for the reference material gold in contact with skin. The proper functionality of the pH measurement in this sensor application is mainly determined by the accuracy and long-term stability of the reference electrode.

The principle of sweat lactic acid (very similar to glucose) measurement is shown in Figure 4. Sweat diffuses through a membrane and filter system into a circulating flow of a buffer solution, thus forming a sample stream. This circulating flow is placed inside glass or plastic channels which belong to a microfluidic system. The flow is created by mircopumps on the chip. The sample stream is led through zones of different sensing activities. The complete microsystem consists of a microfluidic chip and a silicon carrier chip containing the different sensors/transducers. The microfluidic chip is bonded onto the silicon carrier.

For most of the lactate detection methods containing enzymatic reactions, an enzyme-based assay is integrated into the microsystem. Consequently, on one hand there is an inner calibration standard for the non-enzyme-based methods and on the other hand it can be investigated if a modification of the potentiostat-electrodes area with immobilised enzymes for a higher specifity and sensitivity is necessary or not. This enzyme-based assay is performed with immobilised enzymes on carrier beads or carrier surfaces around nano-electrodes (nano-enzyme electrode). The effect of enzymes on carrier beads in a liquid flow is a tremendous increase in the reaction kinetics. The liquid flow guarantees the permanent flush of molecules through the detection system. Here, a combination of different independent methods are applied and form a (multi-dimensional) multi-parameter system.

For the development of these biosensors, the following issues have to be taken into consideration:

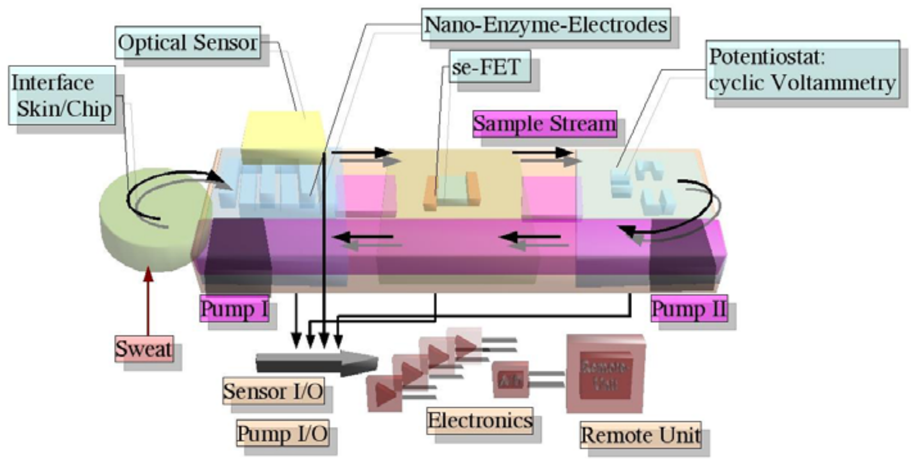
1 *Inner/outer chip interfacing (sample handling)*. The interface between skin and chip transfers the sample (sweat) into the microfluidic system. It should close the fluidic system and be semi permeable. Different steps of realising such an interface could be used. First, thin polymer films could be used to close the microfluidic channels. Second, this film could be modified by different kinds of gels. Finally, nanoparticles could be added to compartments which are close to the polymer film. The gels modify especially the porous behaviour of the film.

2 *Power source and consumption*. As the sensors that are woven in textiles operate independent from power lines, small sources of energy drive the electronic circuitry and the sensors. That implies the development of low-consuming circuitry and sensors. Besides designing energy saving sensor operating modes, the electronics shall provide standby modes between single shot measurements.

3 *Chip packaging*. All sensor and electronics components being in direct contact with the fluidic system is packaged together with the fluidic chip made of PDMS or glass. Chip on board techniques are used.

4 *Electronic integration*. All sensor components and signal conditioning ASICs including data pre-processing units have to be integrated on one platform. An optimised PCB design has to be realised for a high-level integration of the components using chip on board technology. For a lab-scale demonstration of a continuous measurement of lactic acid, pH and the sweat consistency, a miniaturised platform is set up using hybrid integration techniques. This platform contains the transducers, the fluidic components and the signal conditioning circuits.

Figure 4 Principle of sweat lactic acid measurement (see online version for colours)



However, these two sensors are not the sole biosensors that will be woven inside the e-textile. As aforementioned, a temperature sensor and a position tracking sensor are also integrated into the system, along with other sensors for various physiological parameters such as blood pressure, oxygen saturation, heart rate, respiration rate, etc.

5 Important components: e-textiles

The integration of miniaturised electronics as sensors and microchips, in order to analyse stimuli and provide adequate response, is not something new. Several efforts have been made in this field the last decade, essentially for garments used by soldiers or in the medical area. Among those which became well known we could refer to Smart Shirt, LifeShirt and Q^{TM} Sensor developed by Georgia Tech (http://www.gtwm.gatech.edu/), Vivometrics (http://dev.binaryinteractive.com:8102/) and Affectiva, respectively (all in the USA). These products support specialised applications, e.g. monitoring of patients with chronic diseases, warriors or workers in extreme environmental conditions, etc. In European level, some first research approaches aiming at exploiting the benefits of e-textiles have already shown some results (e.g. Biotex, Context, SmartLifeTech). Towards that end, e-textiles combine textile manufacturing capability with discrete electronics. None of these approaches, however, consider the issue from the perspective of integrating in the textile microsystems and biosensors. Actually, the basic concept of the above-mentioned systems support is the integration of a few isolated computing and sensing elements on the textile, designated to perform specific predefined tasks.

A real-time monitoring system for chronic patients while exercising, beyond its e-textile nature, can also be seen as a wireless sensor network, or Body Area Network (BAN), due to the wireless interconnected nodes of sensors distributed into the textile, or as a distributed embedded system, by being embedded in the mobile environment of the monitored person and needing interaction with it. This combined definition renders such a system applicable to adopt advances from both fields, such as adaptability, re-configurability, fault tolerance, power management and reconfigurable architectures and co-processor cores, respectively. Moreover, it addresses novel design issues, such as:

1. flexibility and adaptability to be able to accommodate various applications scenarios and individual cases, accounting for application requirements, users' context and environmental conditions (patients, citizens-at-risk, trainees);
2. increased reliability due to its failure-prone operating environment (e.g. tears in the textile);
3. energy efficiency, energy autonomy and power management;
4. material form and form flexibility, volume and weight (functional and unobtrusive for everyday use).

The potential for new and wide range of applications are proven by simulating diverse scenarios/applications facilitated by a system able to measure physiological parameters (such as body temperature, ECG, heart rate, breathing rate, sweat lactic acid, glucose levels and pH) and environmental parameters (such as humidity levels, temperature and position tracking) and accordingly trigger events. Application differentiation is achieved by substituting re-manufacturing with textile adaptability and product re-configurability. In particular:

1. *Textile adaptability*. A large number of applications could be generated based on the supporting measurements for trainees, patients or citizens-at-risk. For each specific case, appropriate biosensors are selected and integrated.

2 *Re-configurability in gathered information processing*. Active nodes may be configured in terms of information processing so that their function corresponds to the application, i.e. maximum heart rate of an athlete varies with his/her activity and fitness level and consequently different values of measurements should be combined to draw alarms and alarming values are different.

Contrarily to traditional textiles for which the production methods are relatively coarse, the production methods of e-textiles must be delicate and the garments should be handled carefully. For this reason, it is necessary to investigate appropriate manufacturing techniques and materials, and design appropriate coating methods. The manufacturing activity involves two subphases:

1 the investigation of several manufacturing techniques, coating methods and materials and

2 the selection of the most appropriate ones to be utilised in the selected context per case.

The e-textile design and manufacturing investigates a plethora of significant issues such as:

1 ergonomics,

2 durability,

3 wear comfort,

4 protection of contact-sensitive zones and

5 incorporation of non-textile materials

The envisaged platform could significantly help towards the convergence of micro/nano, bio and information technologies because, after all, these are the components that provide the means for truly non-invasive, continuous physical and health status monitoring. For sure, high-quality long-term foundational research is required, but high pay-off possibilities are expected which introduce revolutionary changes in biomedical and lifestyle applications.

6 Networking activities

The aim of networking activities in the context of a wearable ICT platform is to design and develop a low-power and short-range BAN which provides a reliable, secure and flexible data exchange with the system sensors, as well as their interoperation. It is recommended for these activities to also have as input the state-of-the-art research in short- and long-range telecommunications technologies, as well as the system architecture design that has been deployed.

By the conclusion of these activities:

1 The networking requirements in terms of distance, bandwidth, security, EMC, power consumption and usability are specified.

2 The personal area sensor network architecture is designed.

3 The concomitant protocols and operational clients are implemented.

4 The system will have been verified, with the focus on functionality and EMC.

The scientific and technological challenge of an architectural model of a wireless personal area network that enables flawless and reliable data transport between the e-textile and the personal status monitor is twofold:

1 First, the selection of the most suitable physical link layer technology in terms of reliability, power consumption, complexity, components' size and regulations as far as operating frequency is concerned.

2 Second, the design of an efficient communication protocol, in terms of medium access control, network topology control, network reliability, routing, addressing and security.

Thus, the development of a prototype *wireless personal area network* consisting of a wireless network of sensors and an administrative node which acts as the gateway between the wearable subsystem and the monitoring site are oriented towards two parallel routes:

1 The first concerns the development of an actual prototype of wireless network of sensors, not necessarily fully operational, and the deployment of several experiments for the examination of the operability of the communication protocols.

2 The second concerns the evaluation of the proposed communication protocol, and for this reason several simulation procedures are executed, in order the Personal Area Network to be tested in terms of energy efficiency, throughput and latency. The communication protocols are examined in different situations according to selected applications in order to assess their design and integration. The goals of the network simulation are to:

   - verify the communication algorithms behaviour in both optimal and pathological conditions;
   - identify critical aspects in the algorithms behaviours;
   - fine tune the network parameters and
   - evaluate the re-configurability and scalability properties of the designed paradigms.

Preliminary research has already ruled out few of such protocols, such as RF due to its power consumption and IR due to the necessity of a line-of-sight for the transfer of data. One promising protocol/technology for such a platform is Bluetooth, while IEEE 802.15.4 (the basis for ZigBee, MiWi, etc.) seems to be even more suitable for a similar implementation due to its focus on low speed, low cost, ubiquitous communications. Bluetooth lets the devices communicate with each other when they are in a short range (power-class dependent: 1 meter, 10 meters and 100 meters). Another advantage that renders Bluetoooth suitable for selection is that the devices use a radio communications system, so they do not have to be in line of sight of each other, as long as the received transmission is powerful enough. In addition, the networking activities include the long-range communication infrastructure for the transmission of the collected biodata, from the personal status monitor to the platform, following the architecture illustrated in Figure 1. The specific applications are not bandwidth demanding, thus even the GSM network is rather sufficient for the payload transferred. However, UMTS networks are preferable since they constitute a significant innovation over 2G and 2.5G systems because of their high operating flexibility, their ability to provide a wide range of applications and generally extend the services now provided to fixed networks users to mobile customers. 3G mobile and wireless networks provide 144 kbps for full mobility applications, 384 kbps for limited mobility applications in macro and micro cellular environments and 2 Mbps for low mobility applications, particularly in the micro and pico-cellular environments, thus allowing even for real-time video-conferencing between the patient and the medical expert.

7 Genetic profile management for personalised treatment

Personalised treatment is synonymous with a unique genetic profile to be incorporated in platforms that monitor volunteers of a specific pathology. The activity of incorporating this profile into a larger outline can be divided into three sub-activities:

1. Determination of the genetic information that is diagnostically useful for the exact context of each application, in order for the genetic profile bank of the volunteers to be designed and developed.
2. Examination of the interoperability issues between the genetic profile bank and the other modules of such a system with which this repository has to exchange information. For this reason, either data mining techniques or semantic articulation techniques (semantic organisation of the raw data contained in the available clinical data repository) are utilised. The semantic data mining mechanisms comprise the semantic organisation of the raw data contained in the available genetic profile bank. The processed data could be organised into a grid of selected semantic entities, representing classes and concepts of interest for the data analysis tool. Additionally, internationally accepted standards (HL7, HIE, HITSP, etc.) should be met for the exchange of this kind of medical information amongst the various subsystems.
3. The actual design and development of the genetic profile bank that is integrated into the system. The development phase should also include the employment of the appropriate software for the genetic data analysis, to assure accurate and reproducible results.

8 Bringing it all together: the personally controlled health record

The health industry has been using IT systems for over two decades. IT systems as in every other industry are supposed to exist in healthcare for one main purpose: data storage and sharing. It is surprising, at first sight, how bad today's health IT systems are doing this. These systems are mainly data repositories of health data that come up in different names (none of which is one that is widely shared); they are known as the Electronic Patient Record (EPR), the Electronic Medical Record (EMR), the Electronic Health Record (EHR), the Hospital Information System (HIS) (this one includes a number of monetary-related applications as well), or simply the citizen e-record. These names are very didactic as to why the associated applications fail to serve their main purpose. They all denote an electronic (of course) data repository (record), but it is the third word in the name that pushes the system to collapse. This middle word basically reveals who controls the data. And this turns out to be quite tricky. With very few contrary examples (of limited in scope applicability), the failures are profound. Our claim is that this is the result mostly due to a simple overlook that these systems take from design. The beholder of the data is the individual. Think how it is done in the non-digitised world. The individual carries around a chunk of papers and films in a bag, plus a collection of mental notes which they share with the physician (relative, friend) in a very controlled manner. Not only they control the type of data they choose to share, but also the time spanning of these data and the format they deliver them.

Starting from this very simple observation we come up with a very simple answer. The individual in the digitised world must be allowed (empowered) to, at least, do the same. But of course the possibilities in this world are way more diverse. As a result, the choices for the individual should be accordingly multiple.

Medical decisions today are based on an extremely limited view of a patient's life, which can lead to incorrect or delayed diagnosis. Doctors often prescribe treatments and other interventions with little understanding of how they will interact with a patient's life – something that can also have a significant effect on outcomes. For example, research shows that compliance with prescription medication by chronic disease patients is around 50% (Moss, 2008).

The internet today plays a central role in patients' self-education, advocacy and interaction, but all too often patient decisions are shaped by anecdotes and opinions. The medical research literature has a wealth of knowledge, but it is difficult to make this knowledge accessible to people who lack medical or scientific training.

Digital health records fail because they do not allow the individual to have control over the data from design. The sum of a patient's self-knowledge and behaviour information, integrated with genetic profiling and monitoring data, could be invaluable in decision-making at home and at the doctor's office. It could have a profound effect on health outcomes, if it could only be more effectively captured and made an integral part of diagnoses. Such data, aggregated across a patient population, can, in a policy level approach, enable better standards of care, discovery of novel treatments and new models for identifying problems and delivering healthcare worldwide.

The solution is to offer an easy way for the individual to share applications, not data. We designed an open platform at which the individual connects applications to other individuals or groups. This way not only he/she can control who sees what, but also when, for how long, in which format and in which form (e.g. interactive or not). Furthermore, it gives an incentive to healthcare providers to find ways to automatically populate her record with the data from their system (or risk to lose the customer if they not do it).

Examples of such sharing applications include:

1 A data analysis tool that is responsible for comparing values to due-thresholds, co-processing the collected information with the unique genetic profile of the monitored person, determining its actual health and physical condition, monitoring the progress over time and identifying potentially critical situations. The system transmits data in real time to the rules engine selected by those who are responsible for the actual implementation and the data contain an anonymous identifier of the individual. The rules engine is capable of processing multiple individuals in parallel. The rules engine processes data along with the stored genetic profiles and other data related to each individual (e.g. height, weight, gender, age, typical diet, blood biomarker results, etc.) and creates a real-time report that is transmitted to the monitoring station.

2 An alerting mechanism that generates automatic alerts to the users according to the analysis produced by the data analysis tool. It also suggests personalised therapeutic or training plans, dietary plans and exercise and lifestyle guidelines, in accordance with the genetic profile of the monitored person.

9 The scientific challenges to be met

9.1 Miniaturisation and packaging

The application of flexible interconnection substrates advanced bonding techniques, thinned chips and 3D structures provide innovative methodologies for SIP integration at a level indistinguishable from the wearable textile structure. Moreover, due to the special conditions imposed by size, voltage and current levels, the design of appropriate electrical interfaces between multi-level structures becomes an issue of special interest.

1 *Validation and hybridisation of micro and nanotechnologies.* Nanotechnology can offer exciting solutions to electronic, optical and mechanical problems. Since the focus is on vital physiological signs sensing and measurement, validating those nanotechnologies that can have a direct impact on this field (e.g. molecular-level probes for sensing) is not only a challenge but also a priority. Specific attention is also placed on the hybridisation of nanotechnologies such as nano-CMOS, nanowires, etc., and their application to integrated sensing and computation.

2 *Manufacturing.* In order for the nano and micro components of the wearable system to be protected, it is important that appropriate manufacturing techniques are used. Soft encapsulation and coating materials are of great interest and potential.

9.2 Intelligent textiles and textiles-based sensor network

Although physically spread over a relatively smaller space, an intelligent textile-based sensor network such as the one envisaged in this study has greater dependence on physical locality of computation, lower bandwidth for communication and less-available energy. Moreover, it must be extremely reliable in harsh environments (e.g. during training). These constraints raise the demand for new solutions for questions that have already been studied in embedded systems and distributed computing. They also generate problems that have not been studied before, such as optimising energy usage when both the power sources and power consumers are distributed throughout the system, or distributing tasks to processing and sensing elements located on the textile. Under this context, further challenges include:

1 the exploitation of the textile manufacturing process towards the built of reliable and energy-efficient communication networks in fabric;

2 the identification of the computing architecture that best suits an intelligent textile-based medical sensor network and

3 the investigation of using short-range wireless technologies (e.g. IEEE 802.15.4) instead of wired communication scheme in intelligent textiles.

Another research issue of special interest is *clothing patterning*. The real challenge is to design a wearable textile which does more than dressing; as a consequence, emphasis is given in the investigation of issues such as ergonomics, durability, wear comfort, design and protection of contact-sensitive zones, incorporation of non-textile materials, as well as the overall care of the textile.

9.3 Diverse data processing and management

The challenge here is to develop an advanced data analysis tool, which process individual data gathered by the intelligent clothing. It is in essence an expert tool that adds intelligence to ordinary procedures carried out by either physicians or personal trainers. The software compares values to previous statistics, co-processes the collected information with the unique profile of the monitored person in terms of past performance, training regime and overall health record, and determines the actual physical and health status of the monitored person (e.g. he/she has an infection or he/she is over-exercising).

10 Conclusive remarks

Today's most commercially available solutions for the chronically ill face certain limitations, e.g. they are hardly ambulatory or offer real-time monitoring, hence render very difficult the integration of physical exercise, a very important aspect for the effective management of chronic conditions, into the patients' daily activities under the protective spell of ICT.

This paper presented in detail various technologies ranging from innovative biosensors turning emotions into electrical signal (Affectiva, Q sensor), all the way to e-textiles and wireless BANs that if combined into one platform can offer what contemporary systems lack: the real-time monitoring of chronic patients while exercising as part of their personalised treating regime. The means to achieve this is by implementing a wearable ICT platform that can provide feedback and consultation to the end user/patient through friendly and easy-to-use interfaces.

The analysis performed is mostly chronic patient – centric but the potential applications of such a system are much more wider:

1 Professional athletes who could use it as a powerful training tool in order to achieve world-class performance. In terms of financial metrics, this domain seems to be the most challenging as sports are considered a high value market.

2 Workers in extreme conditions, e.g. fire fighters, soldiers, etc.

3 Young children suffering from neurological syndromes or elderly who need care, etc.

Though it seems that such a platform is designed under the principle of one-solution-fits-all conditions due to its unlimited potential applications, each individual, regardless of the user category that she/he belongs to, will enjoy the beneficiary results of a carefully crafted, evidence-based, personalised strategy in order to cater for his/her needs.

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