WEARABLE SYSTEMS FOR e-HEALTH: TELEMONITORING AND TELEREHABILITATION

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ABSTRACT
Recent R&D solutions for e-health and m-health in terms of wearables offer new, sophisticated devices and systems, which might transform healthcare delivery through telemonitoring and telerehabilitation. In this paper the authors briefly introduce the field and the socioeconomic driving forces behind its rapid development. Wearable devices and systems developed at the authors’ laboratories are briefly described with emphasis given to cardiopulmonary monitoring and remote post-stroke neuromuscular telerehabilitation.

KEY WORDS
Telemedicine, e-health, m-health, wearable medical systems, telemonitoring, telerehabilitation.

1. INTRODUCTION
While aging populations and associated health spending threatens healthcare systems in developed countries, the main challenges for healthcare delivery in developing countries mostly resides in providing medical care in rural areas because of poor socioeconomic conditions, lack of infrastructure (in particular in communication) and almost absence of skilled operators and higher education.

Telemedicine, as it was known until it later enlarged its scope and renewed its denominations as e-Health and p-Health, has seen enormous technical developments in the USA and in particular in Europe, where it has been driven by huge investments through European Commission funded R&D ICT Framework Programs in the last 25 years or more.

More recently, mobile health solutions (m-Health) have gained a great momentum and are on the verge of business breakthroughs [1]. However, the traditional models of healthcare in the US and Europe, in which either the state or insurance companies pay for services, provide less fertile ground for e-health solutions. In several developing countries in Asia (in particular India, Pakistan and Bangladesh), consumers are more ready to self-pay for medical services [2]. In sub-Saharan areas we see extremely promising on going examples of mobile health solutions, such as in Tanzania where recently adopted mobile-phone ultrasound application is radically cutting infant mortality. To enable this paradigm shift in health services new generations of portable and wearable devices are needed.

In this paper the authors report about R&D experience in the development of wearable medical systems for diagnostic/monitoring and telerehabilitation in their laboratories. Wearable Biomedical Sensors and Systems (WBSS) are, as defined by the ad hoc IEEE EMBS Technical Committee, “biomedical (including biological) wearable sensors/actuators and sensor-based communicative systems that can monitor and/or stimulate, and/or treat, and/or replace biological and physical human functions” [3]. Over the past decade WBSS have attracted a strong interest in the engineering and medical community [4]. So far WBSS development activities have been focused on:

- non invasive monitoring of cardiopulmonary signals (ECG, HR, BR, BP, SpO2);
- detection of physical activity, posture, gesture and limb kinematics for monitoring, drug administration and telerehabilitation;
- detection of biochemical markers in body fluids (sweat, urine, blood and breath).

Many systems are in the form of microelectronics devices integrated in body-worn devices interconnected in body area networks (BAN) [5]. Other systems are in the form of smart garments using electronic textiles [6]. However, despite impressive technological achievements, there are still issues to be solved to enable widespread use of wearables anytime-anywhere, as it is foreseen by sponsors, developers and potential users such as patients, caregivers and clinicians.

Major obstacles to be overcome are both of a technical nature and related to standardisation of communication protocols, interoperability of devices and privacy issues. Technical barriers are mostly linked to inadequate
portable energy sources and as yet inefficient energy harvesting systems as well as to the need of greatly reducing motion generated artefacts, which still badly affect the quality of bio-signals generated from wearable devices.

Several attempts to design and fabricate wearable integrated platforms for bio-signal monitoring have been undertaken in the last 15 years [7, 8]. Most of the systems are hybrid in the technologies they use since they exploit various degrees of integration between silicon microelectronic components and garments. Present technology should be considered transitional since a fully integrated technology based on electronic textiles capable of supporting all needed functions like sensing, processing, actuation, transmission and communication is far away in the future [9].

2. SYSTEMS DEVELOPED AT THE AUTHORS’ LABORATORIES

In collaboration with Smartex Srl (Prato, Italy) and other partners of the Wealthy (Wearable Health Care System – FP5- IST-2001-37778) and MyHeart (Fighting Cardiovascular Diseases by preventive lifestyle and early diagnosis – FP6 – IST- 2002- 507816 consortia we have developed sensing garments for cardiopulmonary monitoring [10,11] and for post stroke rehabilitation [12]. In Figure 1a e 1.b present embodiments of the two systems are shown.

The two systems have been tested in terms of technical performances [13, 14] and preliminary clinical trials [15,16]. There are largely unobtrusive and comfortable; they withstand harsh environments and they can be washed with soap and water. Moreover they can be mass-produced at low costs, were large-scale markets to open up. A comparative evaluation of susceptibility to motion artefacts has also been performed [17] with excellent results.

At present, new developments are in progress, based on the basic platforms outlined above. In the BIOTEX (Bio-sensing textiles to support health management – FP6- 2004 -IST-NMP- 2- 016789) project [18] a pioneering approach has been taken to open a dramatic wider field of applications, chemical measurements on body fluids (sweat) using smart fabrics and interactive textiles. The advantages of analysing sweat for health monitoring are its non-invasiveness, easy accessibility, and capacity to offer valuable physiopathological information. A multiparametric patch for sweat analysis has been developed and preliminary tests in a controlled setting to measure pH, sodium concentration, conductivity (salinity) and sweat rate have been conducted [19]. Although still in its early stage of development this system open extremely important avenues towards wearable body fluid analysers, combined with wearable bio-signal monitoring garments (see Figure 2).

In the INTERACTION Project (Training and monitoring of daily-life physical Interaction with the environment after stroke; FP7-ICT-2011-7- 287351) we are exploiting the physical integration of piezoresistive fabrics and inertial multiaxial sensors and ad hoc created sensory fusion algorithms [20] to realize wearable systems for gesture and posture recognition for remote neuromuscular rehabilitation in post-stroke patients at home (see Figure 3).

In collaboration with the University College Cork and Tyndall National Institute and in the frame of the PROETEX project (Advanced e-textiles for firefighters and civilian victims- FP6- 2004- IST-ICT- 026987) we have developed a system-on-a chip UWB radar for health care and emergency operators [21]. We adopted this
approach in contact-less monitoring when wearability is not an option. The use is for continuous-time monitoring of new-borns or patients affected by chronic respiratory diseases.

A system-on-chip UWB pulsed radar based or correlation receiver has been implemented in 90 nm bulk CMOS technology, characterised experimentally and applied to respiratory rate monitoring [22].

3. CONCLUSION

From “medical informatics” to health telematics and than e-health, the time has now come for m-health where portable, even wearable devices and related infrastructures may indeed be the pervasive technology changing the socioeconomics of health services. As already mentioned, the major obstacle to widespread diffusion in developed countries resides in the question “who is going to pay for the service and how?” in some developing countries the business model would appear more easy to implement [23]. However enormous difficulties, in particular in rural areas where the service is most direly needed, in terms of lack of infrastructure, scarcity of trained health personnel and overall poverty, may prove to be insurmountable obstacles adding another dimension to the well-being and digital divide.

Enormous challenges remain, although promises exist, for e-health in developing countries. Blaya et al [24] have provided a recent and systematic review on these aspects, concluding that developing countries should focus on improving communication between institutions, assisting medication procurement and delivery, identifying and monitoring patients abandoning care and improving data collection and analysis through portable/wearable devices.

Hersh et al. [25], in analysing the workforce needed to implement e-health in developing countries, concluded that the policy focus should not be in technology, but on information gathering, training ad establishing qualified partnerships.

C. Jaffe, CEO of HL7 (a worldwide standards organisation) has repeatedly pointed out how standards [26] and interoperability [27] on medical data and devices are crucial elements for a widespread use of e-health technology. The US and Europe, despite innumerable talks and efforts, have had very little success in terms of putting together different stakeholders in this respect.

May be developing countries can find a way to push policy-makers along these lines and get interoperability right the first time [23].

Disseminating scientific and technological information on state of the art in R&D m-health devices and systems may represent another piece of the puzzle of informing and eventually orienting responsible organizers and decision makers [28, 29].

In this paper the authors, a group of technologists and engineers, have briefly presented an overview of very recent technology developments in the field of wearable systems for e-health and m-health. Some of the platforms have now been tested in the course of different European Commission funded projects. Other implementations are under study although their practical use is still a long way away.

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