Wearable Health Systems: from smart technologies to real applications

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Abstract: The interest in wearable health systems (WHS) originates initially from the need to extend health services out of the hospital and monitor patients over extensive periods of time. Intelligent WHS are integrated systems in contact with or near the body able to sense, process and communicate biomedical, biochemical and physical parameters – and even carry out actions if necessary. Research and development (R&D) in WHS is mainly driven by two different, but complementary, approaches. The first one is "application-pull", stemming from an increased user demand for new solutions in healthcare. The second one is "technology-push", in which technological innovations lead to new systems and products for healthcare solutions. In both approaches, inter-disciplinarity is a key issue. Synergies across multiple domains like biomedical technologies, micro- and nano-technologies, materials engineering, and Information and Communication Technologies (ICT), enable new approaches to support personal health and well-being. These include, for example, unobtrusive personal health monitoring and point-of-care biochemical testing for disease prevention and early diagnosis, as well as follow-up of treatments. This article presents the state-of-the-art on wearable health systems, outlines current research achievements and indicates research trends and challenges in line with these two approaches.

Keywords: wearable health systems, personalised care, biomedical sensors, biosensors, Information & Communication Technologies.

I. INTRODUCTION

The management and coordination of healthcare, across the entire range of services, from primary to tertiary care, are expected to undergo fundamental changes. More emphasis is being put on well-being and education of citizens and also on prevention and early diagnosis of diseases. We see trends for introducing new ways of delivering care, in which the individual citizen/patient has a stronger role in the healthcare process. These trends arise mainly from the need to meet major socioeconomic challenges related to: citizens' expectations for high-quality care, demographic changes (the ageing population), increased prevalence of chronic diseases and rising healthcare costs [1].

Personal Health Systems (PHS) is a relatively new concept, introduced in the late 1990s. It supports the aforementioned trend in healthcare delivery and is enabled by remarkable progress in sciences and technologies like biomedical sciences, micro- and nanotechnologies as well as Information and Communication Technologies (ICT). PHS are about placing the individual citizen/patient in the centre of the healthcare delivery process. They allow citizens/patients to have more responsibility in managing their own health and interacting, whenever is necessary, with care providers. In doing so, PHS aim to bring benefits to citizens and health authorities alike: first, by improving the quality of care for the individuals themselves and secondly, by containing the rising healthcare costs through proper and efficient use of technological capabilities.

Wearable Health Systems (WHS) are a specific category of PHS. They are integrated systems on body-worn platforms like wrist-worn devices or "biomedical clothes", offering pervasive solutions for continuous health status monitoring though non-invasive biomedical, biochemical and physical measurements. It is expected that the increasingly positive attitude of users towards the application of ICT in healthcare and the demonstrated capability of ICT to improve quality of care will lead to user-driven advances in the field of WHS in the near future, aiming at what the users need (application-pull). At the same time, the WHS field is attracting increased interest from various technological disciplines. In particular, the convergence of ICT, biotechnologies and micro-nanotechnologies opens opportunities for new generation of disruptive systems and solutions for healthcare (technology-push). Continuous technological innovation and strong market demand for microsystems and nanotechnologies in medical applications, e.g. heart pacemakers, blood pressure sensors, hearing aids and cochlear implants and biochips, represented in 2001 a total revenue of $ 5,2 billion [2].

The following section presents needs and applications that drive research in WHS. Section III summarises the state-of-the-art and on going R&D in WHS. Section IV then introduces trends and challenges for future WHS that stem from both application-pull and technology-push. The article concludes by referring to expectations and challenges related to the introduction of WHS in healthcare.

II. USER NEEDS AND APPLICATION DRIVERS

The interest in WHS originates from the need to provide care outside hospitals, into citizens' daily living environments. The ambitious objective is to enable "affordable and interactive healthcare, anyplace, anytime for anyone". Within a landscape characterised by continuity of care, WHS would enable monitoring of patients over extensive periods of time, while allowing them to carry on their daily activities and enjoy their social life. Another argument in favour of ICT–based wearable solutions in healthcare is the need for improving the quality of care. This is feasible through provision of personalised care by taking into account the individual circumstances of a citizen/patient as these are detected from the acquired data. Essentially, this means the provision of accurate personalised medical advice, recommendations and treatment as necessary, minimising the risks of potential adverse drug effects, etc. There is also the issue of healthcare costs. Prevention and early diagnosis of diseases would have direct impact on reducing healthcare costs, since costly treatments could be avoided. There are thus significant benefits from the implementation of cost-effective ICT solutions like WHS for health status monitoring and disease prevention.

Besides prevention and early diagnosis, there is also the issue of disease management. Chronic diseases account for a substantial part of the overall healthcare costs [3]. In many cases chronically ill patients introduce permanent hospital costs, while at the same time they occupy beds which could be used for acute events. Demographic changes indicate that the proportion of elderly people in the population will increase significantly in the next few decades. Consequently, more elderly people will require prolonged medical care and the prevalence of chronic diseases will rise. Remote monitoring and care are needed to cope with the current and expected situation. WHS are ideal platforms to meet these needs. At the same time, WHS will enable chronically ill patients to receive care in their daily living environments knowing that they have easy access to health professionals when needed.

Developing WHS that can successfully satisfy the needs mentioned above is a major, multi-facet challenge. Firstly, the development of WHS involves multidisciplinary research. WHS are systems integrating a number of components and technologies: sensors, actuators, materials, wireless communications, power supplies, control and processing units, user interfaces, as well as intelligent algorithms for decision-making. In addition, there are a number of non-technological issues that have to be taken into account. In particular, legal and ethical issues should be considered, as WHS involve necessarily handling of personal data and they introduce liability issues. To meet user needs, it is important that systematic input and feedback is received from end-users during the design, prototyping and validation phases of WHS. This may refer to the wearability of the systems, their ease of use, their operational lifetime and their communication and interaction capabilities, to name some.

WHS provide an ideal platform for remote health status monitoring for primary and secondary prevention, early diagnosis and disease management, but also support of elderly people or people in need; they enable, in particular, unobtrusive multi-parametric monitoring including body-kinematics, vital signs, biochemical as well as emotional and sensorial parameters by taking into account a given social and environmental context.

III. STATE-OF-THE-ART AND ON GOING R&D IN WHS

One of the main objectives of recent and ongoing research in WHS, in Europe and worldwide, is to fulfil the aforementioned requirements for enhanced user-friendliness, affordability and monitoring capabilities in several clinical applications. During the last ten years we have witnessed a rapid increase of interest in new sensing and monitoring devices for healthcare. This applies also to the use of wearable, wireless devices and sensor networks for clinical applications. The emphasis has mainly been placed on physiological monitoring and functional stimulation, sometimes in combination with physical activity monitoring (movement and position tracking). Recent advances in microsensors, microelectronics and integration in materials have led to many prototype systems. One example is the development of independent (or networked) non-invasive sensors and devices, fixed at different body segments (like wrist, head, arm and ankle), and able to monitor vital signs, body kinematics as well as sensorial, emotional and cognitive reactivity. Another example refers to wearable systems that are coupled with implant sensors or actuators (e.g. electrical stimulators), like for example hand orthosis, with built-in electrodes and positioning sensors.

Many of the prototypes above are non-invasive systems based on sensors embedded in wrist-worn devices, patches or clothes. Biomedical clothes in particular are seen as a very convenient, unobtrusive monitoring platform where functions may be carried out by the textile material itself [4]. Increased system functionality and autonomy, together with communication capability and embedded decision support, are also necessary, and research has also been undertaken in these directions. Several prototype systems, integrated with telemedicine platforms, have been recently developed and tested, such as:

- Continuous measurement and control of glucose concentration in subjects with type 1 diabetes, enabling the provision of better adjustment of insulin dosage [5].
- Personal ECG Monitor [6] for early detection and management of cardiac events. This includes recording, storage and synthesis of standard 12-lead ECGs, self-adaptive data processing and decision-making techniques and generation of alarm messages.
- Smart glove [7] for non-invasive multi-parametric measurements of autonomous nervous system. This system enables the study of cognitive and physical status, the response to odour, speech and vision, the comparison with conscious and verbal indications as well as mental training.
- Personal mobile health service platform for vital signs monitoring based on a Body Area Network, utilising the next generation of public 3G wireless networks [8].
- Wireless-enabled garment with embedded textile sensors, for simultaneous acquisition and continuous monitoring of biomedical signs like ECG, respiration, EMG and activity [4]. The “smart cloth” embeds strain fabric sensor based on piezoresistive yearns, and fabric electrodes realised with metal based yarns.

Current research and development activities under the Sixth Framework Programme for research and technology development of the European Commission bring together leading European industries (from textile, micro-electronics and ICT), research institutes, academia and hospitals to develop solutions to fight cardiovascular diseases (CVD), by empowering citizens to actively improve preventive lifestyle and early diagnosis. The project aims to address prominent risk factors for developing CVD (i.e., sedentary lifestyle, sleep disorders, stress, weight and acute events), by early diagnosis though smart fabrics and wearable solutions [9]. These incorporate also feedback devices that enable citizens to interact with professional medical services through the use of personal mobile devices and wireless communication networks.

IV. RESEARCH TRENDS AND CHALLENGES IN WHS

Physiological monitoring with WHS has so far dealt mostly with measurement of vital signs like ECG, heart rate, respiratory rate and skin temperature. There is a trend to extend monitoring capabilities towards biochemical variables. Sampling body fluid analytes, like glucose, lactate and other proteins, will enable more thorough assessment of a person's health status, the state of his/her immune system, stress condition, etc. There are several promising techniques for achieving this type of monitoring in a purely non-invasive, painless way. One could thus envisage the integration of non-invasive transdermal biosensors in WHS, even in biomedical clothes [10]. There are also other approaches aiming at developing biosensing patches, adapted to different body fluids (e.g. sweat, blood) where the textile itself is the sensor [11].

Additionally, sensing techniques could be coupled with actuation systems to form closed-loop drug delivery systems, which can be applied to the management of chronic diseases. A typical example is the management of diabetes, based on the use of transdermal glucose sensors and insulin pump actuators. Such system would have an inherent level of intelligence to automatically regulate the timing and the dose of insulin infusion. Efforts are being made in this direction and once certain issues related to reliability, accuracy and liability are overcome, we may be able to see automated systems for home use.

Further research and development in sensing and monitoring systems relates to system integration, biosensor development, sensor miniaturisation, low-power circuitry design, wireless telemetric links and signal processing. Moreover, issues related to quality of service, security, multi-sensor data fusion and decision support are active research topics.

The integration of electronics and clothing is an emerging concept and leads to the development of multi-functional, wearable electro-textiles for applications integrating monitoring of body functions, actuation, communication, data transfer and individual environment control [12].

Furthermore, the integration of advanced microsystems at the fibre core, in conjunction with user interfaces, power sources and embedded software, make R&D extremely challenging. Current research also aims at developing stretchable conductive patterns and soft-touch substrates for component mounting and interconnection on/with textile.

Currently R&D projects funded by the European Commission strive to integrate micro-nano and ICT technologies into textile towards fully functionalised wearable systems that would enable several applications e.g.:

- stress monitoring through contactless sensors, incorporated in the textile, for the measurement of electromyography and electrocardiography signals and miniaturised pre-processor electronics connected to the textile substrate
- Development of emergency disaster personnel smart garment integrating biomedical and biochemical sensors (such as biopotentials, breath, heart, temperature and sweat analysis), low power communications, external chemical detection and power generation and storage (e.g. photovoltaic and thermoelectric)

One of the challenges today is to fuse the research work and consumer insights on smart clothing and create multidisciplinary teams of product designers and engineers. The research community is particularly eager to address the challenges offered by the convergence of heterogeneous technologies e.g. micro/nano technologies, ICT and biomedical technologies and compatibility with integration into textile (e.g. new functions, new applications for healthcare and well being).

V. CONCLUSION

Research and development on WHS was motivated by the need to respond to a number of healthcare challenges like: reducing healthcare costs while maintaining high quality of care; provide easy access to care to demanding citizens from anyplace, at anytime; shift the focus of healthcare from treatment to prevention and early diagnosis through wellness programs. Under these perspectives, WHS are expected to have a significant impact on the efficacy and quality of care, as well as on the citizens' quality of life.

Several major issues remain to be resolved before WHS become integrated in healthcare practice. From the technological point of view, R&D at the interface of micro-nano technologies, biotechnology and ICT is key. Techniques for on-body sensing, context awareness, user-friendliness, power autonomy, intelligent data processing and interaction with professional medical services are among the challenges concerned. The production of higher conductivity textile material according to current industrial processes, as well as manufacturability, maintainability and connectivity are important issues for solutions based on textile platforms. Further research is needed in signal processing to ensure high signal quality during wearer's physical activity. Intelligent algorithms are also required to correlate and interpret data from multiple sensors. All these challenges have to be considered within the framework of user acceptance and cost effectiveness, to ensure their adoption by consumers and health systems.

DISCLAIMER

A. Lymberis and L. Gatzoulis are with the European Commission, Information Society and Media Directorate-General.
The views developed in this article are those of the authors and do not reflect necessarily the position of the European Commission.

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