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Wearable Smart Systems: From technologies to integrated systems

A. Lymberis, *Senior Member, IEEE*

ABSTRACT— **Wearable technology and integrated systems, so called Smart Wearable Systems (SWS) have demonstrated during the last 10-15 years significant advances in terms of, miniaturisation, seamless integration, data processing & communication, functionalisation and comfort. This is mainly due to the huge progress in sciences and technologies e.g. biomedical and micro & nano technologies, but also to a strong demand for new applications such as continuous personal health monitoring, healthy lifestyle support, human performance monitoring and support of professionals at risk. Development of wearable systems based of smart textile have, in addition, benefited from the eagerness of textile industry to develop new value-added apparel products like functionalized garments and smart clothing. Research and development in these areas has been strongly promoted worldwide. In Europe the major R&D activities were supported through the Information & Communication Technologies (ICT) priority of the R&D EU programs. The paper presents and discusses the main achievements towards integrated systems as well as future challenges to be met in order to reach a market with reliable and high value-added products.**

Keywords: Wearable systems, Microsystems, Smart textile, Information & Communication technologies.

I. INTRODUCTION

Smart Wearable Systems (SWS) endowed with autonomous sensing, actuation, processing, communication and energy harvesting and storage, are emerging as a solution to the challenges of monitoring people anywhere and at anytime in applications such as healthcare, wellbeing and lifestyle, protection and safety [1, 2]. Body parameters (e.g. physiological, biochemical, cognitive, emotional and physical) as well as environmental parameters (e.g. temperature, pressure, gases or radiation) can be measured and monitored for long periods, enabling early detection of problems and better feedback from health professionals..

Beyond the remarkable progress in sciences and technologies, the great amount of interest attracted by this area is mainly due to the shift of interest & investments of the healthcare community more towards early detection of diseases, health status monitoring, healthy lifestyle and overall quality of life, than therapy and treatment. For example, health monitoring and feedback to the user have shown significant contribution to the enhancement of disease prevention, early diagnosis, disease management, treatment and home rehabilitation.

A. Lymberis is with the European Commission, Information Society and Media Directorate-General, Brussels, Belgium. The views developed in this paper are that of the author and do not reflect necessarily the position of the European Commission

Several such wearable solutions are available today like, independent sensors and devices, perimetric fixing using the body segments and the circular body part, e.g. arm, wrist, chest and ankle, as well as networked body sensors.

In the beginning of this decade, great effort of research in SWS worldwide was put on the enhancement of system functionality and autonomy with embedded decision support, as well as user-friendliness and multi-parameter monitoring capabilities. Significant investment, mainly public, empowered interdisciplinary research and development towards proof of concepts and integrated wearable prototype systems [2].

Furthermore, the combination of textile material with electronics and the collaboration between established electronics and textile engineering led to a totally new class of large-area, flexible, conformable and interactive wearable systems, so called Smart Fabrics and Interactive Textile, SFIT or e-textile[2] [3, 4, 5]. The advantages of this integration are obvious: a) about 90% of the skin can be in contact with textile which is the most "natural" interface to body; b) fabrics are flexible and fit well with human body; c) it removes the task of placing the sensors by a professional, and can be also cheap and disposable.

Research and development is being strongly supported worldwide and in particular under the Information and Communication Technologies activities of the R&D framework programs (FP) of the European Union e.g. FP6 (2002-2006) and currently FP7[3] (2006-2013). These activities led to significant results in wearable smart systems, integrated multifunctional smart textiles, body sensor networks and context aware sensor systems for enabling several applications in healthcare & health, protection, leisure and life style management [6-11].

II. ACHIEVEMENTS TOWARDS INTEGRATED PROTOTYPES

The first promising prototypes incorporated mainly electrocardiogram and respiration monitoring (and accessorily other physiological and physical parameters depending on the targeted applications) by implementing strain fabric sensors and fabric electrodes. Representative examples are:

- Wireless-enabled garment with embedded textile sensors for simultaneous acquisition and continuous monitoring of ECG, respiration, EMG, and physical activity [6]. The "smart cloth" embeds a strain fabric sensor based on piezo-resistive yarns and fabric electrodes realized with metal-based yarns.

[2] In this paper "Smart Fabrics and Interactive textile – SFIT" and "e-textile" will be used indifferently except if indicated otherwise.
[3] http://cordis.europa.eu/ist/home.html

- Sensorized vest including fully woven textile sensors for ECG and respiratory frequency detection and a portable electronic board for motion assessment, signal pre-processing, and Bluetooth connection for data transmission [5].
- Wearable sensorized garment that measures human heart rhythm and respiration using a three lead ECG shirt. The conductive fiber grid and sensors are fully integrated (knitted) in the garment, [3]
- Garment-based applications capable of recording bio-mechanical variables and physiological signals to monitor risks for cardiovascular diseases such as sleep disorders, physical activity and post events [7].

The second generation of projects focused on the improvement of SFIT enabling technologies (e.g. textile and organic materials), core modules (e.g. system design, interfacing, connectivity, and multiparametric sensing) and integration towards fully functionalized garments. Such prototypes include:

- Integration of optical fiber-based sensors into functional textiles for extending the capabilities of wearable solutions on 2 particular cases studies: a) sedated patient under MRI requiring continuous monitoring of cardiac, hemodynamic and respiratory activity and b) ambulatory patient and especially prevention of SIDS[4] [8].
- Biosensing textiles for health management: it is a wearable prototype for sampling sweat and measuring sodium level, pH, conductivity and sweat rate in real time during physical activity; targeted applications are diabetes, obesity & sport, and wound healing [9].
- Development of inner and outer garments for fire-fighters and rescuers to monitor physiological and external parameters including motion analysis, biochemical analysis of sweat, energy harvesting through body motion, thermal generation and solar cells as well as long and short range power transmission [10].
- Prototype garment with contactless capacitive sensors and embedded electronics for monitoring electrophysiological signals and stress level of persons for RSI[5] [11].
- Stretchable electronic "motherboard" in textiles including substrate technology and electronics components & packages [12]. The demonstrated applications include calorie-meter, posture monitoring and gait monitoring.

Further research and development currently focuses on fully comfortable, multifunctional, reliable, low-power consumption and cost-effective wearable systems and in particular on interfacing, packaging, conformability (e.g. with stretchable and flexible electronics) and robust interconnexion[6, 7]. Further effort on dissemination of results, awareness, education and stimulation of the industry for further involvement (and investment) is also on going through several initiatives[8].

III. INNOVATION, FUTURE CHALLENGES & RESEARCH

The main strength of SWS (and smart textile systems) is the integration in daily life's activities; weakness is on complexity and lack of industrialisation maturity; the opportunities are foreseen in the area of self-measurements at home or at the point of need. Finally, major threats are linked to the user acceptance due to usability issues.

The market for wearable monitoring solutions for health care and fitness/well-being applications, estimated at $460 million in 2006, is expected to grow by over 16% annually to reach almost $1 billion by 2011[9]. However, the niche markets are not yet identified, in particular when the cost has to be reimbursed by a third party..

The current market size of SFIT is also relatively modest, estimated today between 700 m€ and 800m€. This includes SFIT enabling technologies such as materials, nanotechnologies, enabling components (e.g. electronic and fabric components), SFIT based modules (fabrics or textile) and SFIT complete solutions. However the future outlook is extremely strong (VDC Study[10]) with major opportunities in sensing and monitoring, actuation & response, computing & communication.

A survey that has been carried out within the "European Technology Platform for the Future of Textiles and Clothing"[11], aimed to identify new markets to be explored and to find out research priorities. The information collected from 27 textile industries (from 9 EU countries) in order to prioritize the developments regarding the attractiveness of the application classification for the specific end-users and the availability of the technology showed that medical, sport/civil, industrial and military sectors have both high economic relevance (high market demand) as well as high need for research. The study concerning new materials, functionalities and research included 12 research centres and 2 companies from 11 EU countries. The conclusion confirms the outstanding scientific and technological challenges of textile based smart wearable systems and the need to fuse the research work and consumer insights to create multidisciplinary teams of product designers and engineers.

The important areas for future R&D are related with:

- Sensors & actuators, data processing/electronics e.g. pre-processing, diagnostics, context awareness, self learning tools and prioritisation;

4 Sudden Infants Death Syndrome
5 Repetitive Strain Injuries
6 http://www.place-it-project.eu/

7 http://www.pasta-project.eu/

8 Systex, FP7 EC-funded project: http://www.systex.org/

9 Wearable Electronics Systems Global Market Demand Analysis: Health Care Solutions , Research Report # VDC6520, November 2007, VDC Research Group

10 Smart fabrics, interactive textiles and related enabling technologies; market opportunities and requirements analysis, third edition, November 2007 , VDC Research Group

11 http://textile-platform.eu/textile-platform/

- Energy storage (electrochemical, electrical), transmission (e.g. textile antenna) and generation (e.g. thermal, kinetic, magnetic and chemical);

- Communication i.e. functions to be performed by textile or structures compatible with it; interconnection is a critical aspect and industrial manufacturing is a key issue.

Longer development time is expected for biological and chemical sensors, for skin sensors, biological actuators, self learning data processing and storage tools, as well as harvesting energy from elastic, magnetic and chemical mechanisms.

The main barriers for reaching a higher market with high added value products and diversified application fields are:

- Textile and clothing industries are not sufficiently engaged and research community is fragmented.
- There is lack of critical mass in new and multidisciplinary supply chain such as, missing standards and certification for smart textiles; SFIT industry is immature despite a well established textile manufacturing industry; there is an urgent need of investment for more innovation.
- Core modules and core technologies are not sufficiently developed neither tested nor certified, namely connectivity and connectors, microelectronics encapsulation, power supply and storage, washability and durability.

Other issues such as data management (security, privacy-encryption), data transfer, extrapolation of parameters and statistical analysis need further research and optimisation.

Finally the use of neural networks for "event prediction" and consequent generation of alert signals, as well as the need for predictive cognitive model are recognised as essential for delivering an integrated communication wearable system.

Additional knowledge on biophysical issues such as biophysical expertise on skin-sensor interaction models, electrochemical aspects and skin physical-chemical properties (age, gender, race, etc.) is also an outstanding issue today.

Finally, major roadblocks constitute also the lack of strategic analyses such as commercial opportunities, market competition analysis, technologies trends and markets.

Microsystems and smart system integration significantly contribute to further enhancement of the development of SWS and in particular SFIT systems through R&D of smart & functional systems that can be embedded in or fully transformed into textile structures, e.g.

- Integration of regular electronics into textiles, including interconnect and robust attachment, stretchable conductive patterns and soft-touch substrates (important route to commercialize available intelligent textiles).
- Integration of fibred devices (e.g. piezoelectric fibers, transistors on yarns) into textile and fabric to drive a transition between present purely passive components to integrated passive/active components and systems.

In emerging application areas like mobile/ambulatory and biomedical systems a flexible/stretchable interconnect technology is a promising approach for packaging and system integration. Specifically for demands like conformability, free form shapes, biocompatibility and high reliability, it holds a high application potential. Flex-stretch technology is considered to be a key component for the realization of new ranges of on-the-body wearable systems. A strong co-development of systems and applications, with the integration technology is of utmost importance

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IV. Conclusion

SFIT wearable systems is a fascinating area with great socioeconomic and industrial potential combining, advanced material processing, microelectronics, sensors, nanotechnologies, telecommunication, informatics, biochemistry, and medicine. Innovation in "smart textile" is often considered as already achieved, while in this very traditional sector (textile) the process is just at the beginning.

Microsystems is expected to contribute significantly through integration and functionality including redesigning components to make them compatible with the textile, identification of appropriate production technologies and developing new integrated SFIT with textile materials and structures. Key aspects for delivering such integrated systems with high commercial exploitation potential are cost-effective power management, low production costs as well as process optimization

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