Sensors and Parameter Extraction by Wearable Systems: Present Situation and Future

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***Abstract*— Sensing physiological and environmental signals and extracting parameters on-body without discomfort, whenever possible in real-time and continuously, are targeted by many research groups since more than a decade. Most developments include wireless communication to transmit signals. In more recent development, the systems extract locally relevant variables, which are transmitted when needed, while feedback is directly provided to the user.**

A broad range of systems are named "wearable" nowadays, although many of them are rather portable. Wearable systems embedding sensors address a large palette of applications.

This paper aims at listing and describing some of them, considered relevant by the authors for applications including leisure, healthcare and professional security.

I. Introduction

Early diagnosis, healthy lifestyle and prevention can help slowing the onset of many health problems and reduce professional risks. To be able to diagnose or prevent, monitoring of vital signs is required to obtain knowledge on a person's health status. Non-invasive monitoring can be in many situations very useful for ambulatory or non-clinical settings. But continuous transmission is expensive and remote surveillance is not practical in many cases, in terms of financial costs as well as power consumption for battery operated wearable systems. The systems should embed local processing, allowing the extraction of relevant parameters, better suited for direct interpretation by the user and when needed, by a remote monitoring center.

The paper will present the actual achievements and what parameter extraction may bring in the future.

II. Present Situation

In the biomedical field, early portable monitoring systems can be considered as tele-alarm systems with additional automatic alarm features. In addition to alarms manually triggered by the users when they fell unwell, these systems are able to automatically send an alarm when e.g. a fall is detected. Tele-alarm systems were first designed for indoor use, using public telephone lines for transmission. The availability of mobile communication has then allowed the design of systems for outdoor use. Development of systems providing ambulatory monitoring of physiological signals became practical, mainly as research tools with timid and usually unsuccessful tentative to introduce them on the market.

Many portable and wearable systems including sensors and signal processing have been developed during the last decade. Naming has been modified: most portable, devices and systems are also called wearable nowadays. Beside devices like MP3 players and entertainment ones which rarely include sensors and will not be considered here, one can mention several products (Vivometrics LifeShirt, Polar-Adidas shirt, Nike-Apple shoes and iPod) and research projects which have led to results such as wrist-worn devices (IST SENSATION, IST AMON), smart glove (MARSIAN), body sensor network (IST URSAFE, IST MOBIHEALTH) and biomedical clothes (Vivometrics Life Shirt, IST WEALTHY [1], MagIC, Sensatex Alpha Shirt, IST MyHeart [2], IST PROETEX [4], MERMOTH, IST BIOTEX [3], IST STELLA [5], IST CONTEXT [6], IST OFSETH [7], ...). Some research activities has also been performed to add power generation from the body or the environment to the wearable systems [12][13]; there is still room for progress in this area.

Most of these systems are mainly used as data logger, with or without communication. A few perform also parameter extraction on-body, which make the systems more suited for an independent and unwatched use.

After proposing a classification of the systems, a brief description of their features will be provided, especially their embedded parameter extraction.

III. Classification

The applications have been grouped in three categories: wellness, healthcare and, security and prevention. Several core modules are used in smart fabrics:

- Interfacing modules to interconnect the sensors and the electronics
- Sensing of vital signs, motion, context signals
- Skin contact for biopotential measurement and biosensing
- Local processing, taking into account the limited resources
- User interface
- Communication
- Energy management

The technologies to achieve these modules include:

- Spinning, weaving, knitting
- Nano materials
- Optics

- Microsystems
- Computing
- Tissue
- Energy

Different grouping can be envisaged. Table I groups the systems by application types, sensed signals and embedded processing. Only usual signals are listed.

TABLE I
WEARABLE SYSTEMS

Applications	Signals/Methods	Processing
Wellness	ECG or PPG Acceleration	Heart rate Activity level and classification
Healthcare	ECG Impedance, inductive or piezo- resistance plethysmography PPG Acceleration	HR, HRV, ST Breath rate and amplitude Oximetry Activity level and classification
Prevention and security, professional	ECG Respiration Acceleration Context sensors	HR, HRV, ST Breath rate and amplitude Activity level and classification Ambient temperature, pressure, light, location, sounds, gases, etc.

IV. SENSORS

Sensors concern physiological sensing, biosensing and environment sensing.

A. *Physiological Sensing and Biosensing*

Common sensing groups the sensors measuring biopotentials, bioimpedance, skin temperature, blood pressure, respiration, oxygen saturation motion and activity. New generation of sensors extend the sensing methods and provide biochemical and bioelectrical measurements. The following figure illustrates the roadmap to add biosensing to physiological sensing:

- Phase 1 represents the physiological sensors used in projects like WEALTHY or MyHeart.
- Phase 2 shows new wearable patches performing biosensing, this is the case of the research project BIOTEX.
- Phase 3a and Phase 3b represent respectively the combination of physiological and biochemical sensors in one garment (PROETEX) and the case where the full garment includes wearable sensors.
- Phase 4 shows the ultimate case where physiological sensors and biosensors are combined in a single garment.

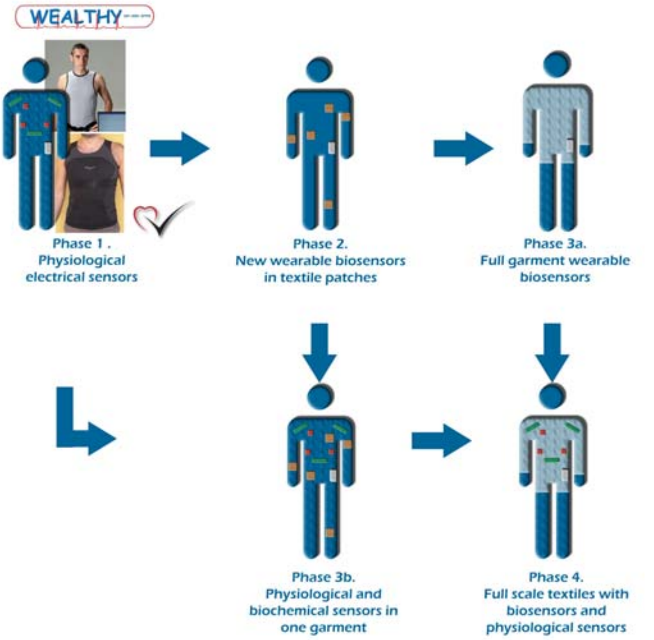

Fig. 1 Roadmap of the development of sensing textiles

B. *Context Sensing*

Context sensing designates here the wearer environment. Common sensors include air pressure, ambient temperature, light intensity, movement, sound, vision and location.

The applications are manyfold and often require powerful processing to extract high-level information.

V. PARAMETER EXTRACTION

Wearable computing has targeted on-body processing since the early stage. However, most of these developments had ambitious academic goals, which were not practical for direct applications [8][9][10][11].

A layer representation of the wearable system facilitates the description of the parameter extraction.

Application layer	**User application**	**Professional application**
Processing layer	**Observable outcomes**	
	Global feature extraction	
Sensor layer	**Local signal processing**	
	Sensor conditioning and signal filtering	
	Garment and sensors	
Body layer	**User body**	

Fig. 2 Layer representation of the wearable system (possible direct feedback to the body has not been represented)

The lowest layer corresponds to the body, where the skin interface makes the separation with the (usually non-invasive) sensor layer. The sensor layer is comprised of three sub-layers: garment and sensors, conditioning and filtering of the signals and local processing. The processing layer combines the different sensor signals, extracts global features and classifies the signals to provide high-level outcomes for the application layer. The application layer provides the feedback to the user and to the professional, according to the specific applications and to the user needs. This layer can be extended to close the loop with the human body, e.g. for drug supply according to monitoring.

Recent developments embed signal processing in their systems. It starts with the extraction of heart rate (already provided by Polar belt), respiration rate and activity level. Activity classification and more advanced processing on e.g. heart signals are becoming accessible thanks to miniaturization and low-power consumption of the systems.

Examples of data classification are [21][22][21][24]: classification of movement patterns such as sitting, walking or resting by using accelerometer data or ECG parameters such as ST distance extracted from raw ECG data [23][24]; another example is the estimation of the energy consumption of the body.

The approach sought with wearable computing is to make direct use of the information by the worn system, which derives recommendations and determines the action to be taken. Therefore, in future systems, the global outcomes may be passed to the application layer, where the personal profile algorithm determines the current health condition and compares it to the personal reference profile, which also contains personal standard values for the collected parameters. The "on-body diagnosis" results from the combination of the acquired physiological signals, environmental information such as accelerations, air temperature and atmospheric pressure, previous health measurements and outcomes, knowledge about health record of the subject and, instructions provided by the physician doctors and caregivers about the actions to be taken. Based on these outcomes, the system may eventually be able to close the loop for instance to automatically supply medication to specific part of the body.

The application layer comprises the professional and user applications, respectively responsible to address the caregiver and the user needs. Their actions include physiological and derived health data transmission to professional caregivers, information and biofeedback to the patient, when needed.

Of course, additional remote processing, comparisons and data storage can be achieved by the monitoring centres. Therapy recommendations can be presented to the user using a personal feedback device in a mobile or home setting.

VI. Market

Despite the large research effort and the many initiatives, the market is still modest so far. One can find several reasons to explain it:

- Textile and clothing industries are not engaged, although of primary interest for them. This is mainly due to the challenge of going beyond the standard textile industry, integrate processes and constraints which are not common for these industries.
- Core technologies are not sufficiently developed and tested. It is usually not the aim of research projects to finalize a development or to extensively test it, i.e. perform relevant clinical tests.

Involvement of cross-disciplines is always a challenge and it is particularly true for wearable sensors, including biology, physiology, physics, chemistry, micro- & nanotechnologies and material sciences. Several solutions have been proposed to improve the market development. One of them is to concentrate R&D on core technologies in order to develop and test them before their transfer to the industry.

The modest current market size for wearable computing and smart fabrics and interactive textiles (SFIT) presents a strong future outlook.

VII. Conclusions

Wearable sensing and electronics is a very promising ambulatory mean of monitoring body and environment signals. On-body processing is a tool to help the wearer take action and the professional to evaluate and make decision. On-body diagnosis based on signal acquired by biomedical clothes shows great potential. Many improvements are still to come, in particular for ergonomy, local and global processing, decision (expert) system, power management, interconnection, fault-tolerance, etc. User functionality performances and clinical relevance of the extracted information will impinge on the final market potentials, rather than the individual sensor technical performances. Without doubt, within 5 to 10 years, some of these systems will become available on the market.

References

[1] European IST Project Wealthy, http://www.wealthy-ist.com
[2] European IST Project MyHeart, http://www.hitech-projects.com/euprojects/myheart/
[3] European IST Project BIOTEX, http://www.biotex-eu.com
[4] European IST Project PROETEX, http://www.proetex.org
[5] European IST Project STELLA, http://www.stella-project.eu
[6] European IST Project CONTEXT, http://www.context-project.org
[7] European IST Project OFSETH, http://www.ofseth.org
[8] D. Marculescu et al., "Electronic Textiles: A Platform for Pervasive Computing", Proceedings of IEEE, Vol. 91, pp. 1995-2016, 2003
[9] S. Park and al. "The wearable motherboard: an information infrastructure or sensate liner for medical applications", Studies in Health Technology and Informatics, IOS Press, Vol. 62, pp. 252-258, 1999
[10] R. Rajamanickam and al., "A structured methodology for the design and development of textile structures in a concurrent engineering environment", J. Textile Inst., Vol. 89, No 3, pp. 44-62, 1998
[11] M. Gorlick, "Electric suspenders: a fabric power bus and data network for wearable digital devices", Dig. Papers Int. Symp. Wearable Computers, pp. 114-121, 1999
[12] C. Lauterbach and al., "Smart clothes self-powered by body heat", presented at the Avantex Symposium, Frankfurt, Germany, 2002
[13] Interactive Wear AG (wearable part from Infineon), Starnberg, Germany, http://www.interactive-wear.de
[14] P. Gough and al., "Towards ultimate mobility… wearable electronics", http://www.research.philips.com, Apr. 2000
[15] S. Mehrgardt, "Wearable Electronics – Fabrics for the future", http://www.wearable-electronics.de/intl/presentations.asp, Apr. 2002
[16] R. Schönrock, "Backgrounder: Wearable Electronics, Fashionable Technology of the Future", http://www.wearable-electronics.de/intl/presentations.asp, Apr. 2002
[17] E. Jovanov and al., « Issues in wearable computing for medical monitoring applications: A case study of a wearable ECG monitoring device», In Digest of Papers. Fourth International Symposium on Wearable Computers. IEEE Comput. Soc, 2000
[18] D. Marculescu and al., "Ready to Ware", IEEE Spectrum, pp. 28-32, October 2003

[19] I.T. Jollife, “Principal Component Analysis”, Springer Verlag, 2002

[20] G. Frantz, “Digital Signal Processor Trends”, IEEE Micro, November-December 2000, pp. 52-59.

[21] O. Paker, “Low Power Digital Signal Processing”, Technical University of Denmark , Lingby, Denmark, June 2002

[22] C. Piguet, “Low-Power Systems on Chips (SoCs)”, CMOS & BiCMOS VLSI Design'01, Advanced Digital Design, EPFL, Lausanne, Switzerland, August 25-29, 2003.

[23] P. Renevey and al., “Activity classification using HMM for improvement of wrist located pulse detection”, Biosig2002, Brno, Czech Republic, 2002

[24] Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, “Heart rate variability – standards of measurement, physiological interpretation, and clinical use”, Vol. 93, pp. 1043-1063, 1996