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Wearable Medical Devices Using Textile and Flexible Technologies for Ambulatory Monitoring

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Abstract—**Health smart clothes are in contact with almost all the surface of the skin offer large possibilities for the location of sensors for non invasive measurements. Head band, collar, tee-shirt, socks, shoes, belts for chest, arm, wrist, legs … provide localization with specific purpose taking into account their proximity of an organ or a source of biosignal, and also its ergonomic possibility (user friendly) to fix a sensor, and the associated instrumentations (batteries, amplifiers, signal processing, telecom, alarm, display …).**

Progress in science and technology offers, for the first time, intelligence, speed, miniaturization, sophistication and new materials at low cost. In this new landscape, microtechnologies, information technologies and telecommunications are a key factor. Microsensors : Microtechnologies offer the possibility of small size, but also intelligent, active device, working with low energy, wireless and non invasive or mini invasive. These sensors have to be thin, flexible and compatible with textile, or made using textile technologies, new fibers with specific properties: mechanical, electrical, optical …

The field of applications is very large, e.g. continuous monitoring on elderly population, professional and military activities, athlete's performance and condition, and people with disabilities.

The research are oriented toward two complementary directions: Improving the relevancy of each sensor and increasing the number of sensors for having a more global synthetic and robust information.

I. Introduction

The non invasive measurements on Man are particularly suitable for several reasons. They are painless, they preserve the protection capability of the skin for infection, and the medical non invasive devices are accessible, user friendly, easy to use for reading the results, changing batteries… These large advantages are "paid" usually by a high complexity of principle of the device. It is clear that it is difficult to measure deep phenomenon from the surface of the skin. The measurement principles are indirect and necessarily more complicated. They are several tens of non invasive measurements on the human body but, nowadays less than 10 basic parameters are currently measured and recorded with ambulatory methods.

Intelligent biomedical clothes act as a human interface for the ever increasing knowledge about health and translate this knowledge into personalised feedback for the user in any situation and with any disease status:

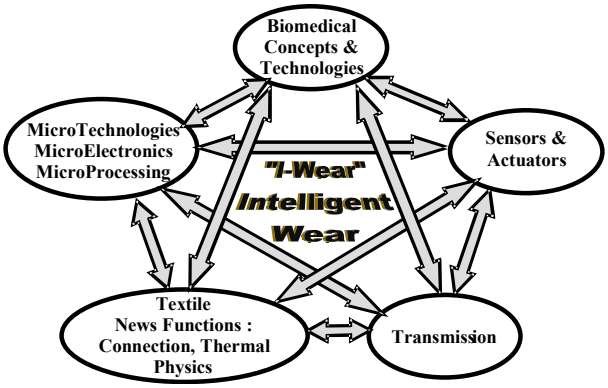

Fig. 1. Main components in the biomedical wear.

For healthy subjects:

Interactive gaming and other self-motivated programs will help the user to enjoy a healthier lifestyle. The system will not only help the user to adapt a healthier lifestyle but will also effectively improve personal performance due to better fitness and more effective way of scoping with stress.

For citizen at risk:

The system will provide adequate information how to deal with individual risk factors and give advice on how to improve risks like hypertension, overweight, diabetes, physical inactivity and stress through personalised training plans and motivation to change behaviour. Early detection through long-term trend analysis will reduce the damage due to severe events dramatically.

For post event patients:

Detection of any complications at an early state. Daily monitoring will enable new forms of personalised drug treatment and the self-administration of drug medication according to the specific behaviour and circumstances of each individual.

For chronic patients:

Intelligent biomedical clothes empower the user to better understand and self-manage the disease state. Early detection will limit acute events and complications that may lead to hospitalisation and extended hospital treatment.

For professional medicine:

Smart clothes can be used for prevention on hard and / on risky tasks, works: at low or high temperatures, or with high metabolism activity (example: firemen) but also for detection if a subject is in a good state (mentally and physically) for carrying out a task correctly.

The human body is composed of a lot shapes moving and changing – rigid sensors are compatible with the surface of

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the skin at the condition that their size does not exceed few centimeters (the old problem of cercle and tangent).

The choice of the localization: the non invasive devices have to satisfy several criteria and forbidding: Obtaining the best signal/noise ratio, the best fixing, the best ergonomic, but also discrete, painless…

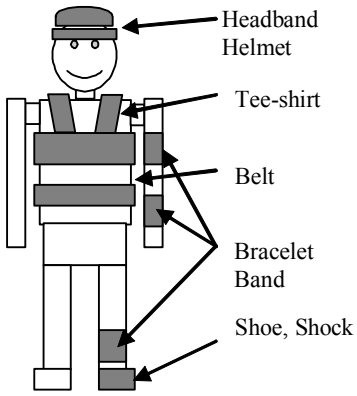

Fig. 2. Main localization of biomedical sensors and devices for ambulatory uses.

Several solutions are available:

- Independent sensors and devices,
- Parametric fixing using the body segments and the circular body part (head, trunk, arm, wrist, ankle …),
- Hat, belt, wrist, shocks, shoes, headband, smart clothes are used for that,

Smart clothes, belts and wrist devices are frequently used.

II. Smart Clothes: 2 Ways

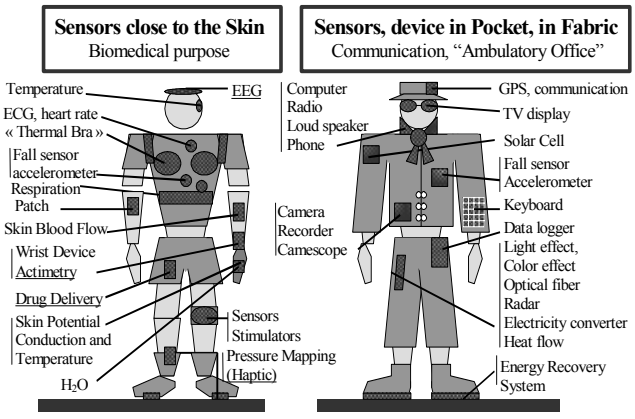

Fig. 3. Two kinds of smart clothes.

Mainly, there are 2 kinds of smart clothes:

The smart clothes with sensors close to the skin, used for biomedical purpose. The sensors are enclosed in the layers of fabric or at its surface or they are the fabric itself which is used as sensors.

The biomedical smart clothes have several advantages, they avoid the necessity of placing the sensors by nurse or physician, the sensors are placed at the right place, they are protected, they are not visible or discrete … they are user friendly and particularly adapted for monitoring in case of chronic diseases and monitoring of handicap peoples, elderly peoples, in case of chronic diseases and during professional, sport and military activities.

The Smart Clothes with sensors, devices in pocket, in fabric : a lot of new functions can be added to clothes using microtechnologies, radios, computers, flexible TV screens, cellular phone but also solar cells, energy recovery systems (in shoes generally), flexible keyboard. These devices are used mainly for communication, displaying colors, pictures, indications of mood, messages… But some devices or sensors used for monitoring can be placed in the clothes in **special pockets** (GPS devices, fall detectors, data loggers, accelerometer, activity detectors … These 2 ways are compatible and complementary.

III. MARSIAN: Modular Autonomous Recorder System for measurement of Autonomic Nervous system activity

The autonomic nervous system (ANS) activities (non conscious) in real and ambulatory conditions are related to the emotional, sensorial and cognitive responses and activities [1-3].

Marsian is an hybrid device associating the advantages and the specificity of smart clothes and of wrist devices. Research is now focusing on smart clothes solutions to enhance the use and the reliability of sensors.

Marsian smart glove has a specific design to ensure both a good contact skin to electrodes whatever the hand's motion and a stealth glove not to modify the hand's skin's typical physiology.

Fig. 4. Marsian, Modular Autonomous Recorder System for measurement of Autonomic Nervous system activity, is an ambulatory microcentral composed with smart clothes and gloves and a wrist device.

Marsian wrist device ensure real-time physiological data acquisition, treatment and wireless transmission in a minimum size. Remote software displays and stores data and provides a semi automatic analysis in order to ease the expert's conclusions.

The non invasive multiparametric measurements carried out by Marsian have a large field of applications and researches [4-5].

Main research topics are:

- Vigilance level and task related response (cognitive and physical),
- Response to odour, taste, touch, vision, sound,
- Research on thermal and environmental comfort,
- Study in real conditions of the action programming in sport,
- Mental imagery training and study for sport,
- Study of behaviour, stress and non-conscious reactions.

Marsian is fitted both to analyze instantaneous emotional responses which occurs quite immediately after the stimulation (for example after an odor stimulation) or longer responses which characterize an amount of change (for example thermal comfort or discomfort).

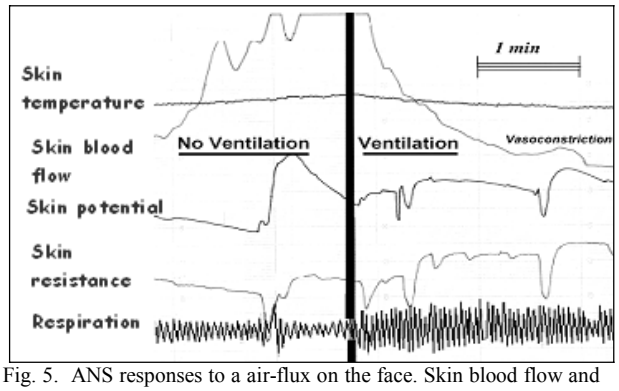

Fig. 5. ANS responses to a air-flux on the face. Skin blood flow and temperature decrease. The respiration rates increase. This reaction indicates a discomfort.

IV. TEXTILES: NEW FIBRES, NEW FUNCTIONS

Textile is playing a great role in such development. At first, about 90% of the skin can be in contact with textile which is the main interface to body. Then fabrics are flexible and fit well with human body. Moreover fabrics are cheap and disposable.

Last, integration of system into textile is now possible. Chemistry provides new fibres with new mechanical, optical, or electrical properties [6-7]. Micro technologies enable the integration of sensors and actuators in the fabric frame and provide light and user-friendly electronic systems.

Fibres can also have an active role in sensing or communicating, as it self or in a network. Almost every kind of fibres can be woven or embroidered, like optic fibres, carbon fibres or polymer fibres

Woven sensors, micro sensors and microsystems can be easily included in textiles due to their small size or their flexibility. Communication can be provided by GPS, radio, screen, keyboard, camera, speaker or phone integrated in the cloth. Biomedical smart clothes use those facilities with a network of embedded sensors to measure and monitor non invasively the vital and behavioural parameters of human.

Flexible bus and connecting : the polyamide/metal multilayers technology is particularly well convenient for the multiwire connection for BAN (Body Area Network).

One example : Polyamide multilayer technology is used in the smart glove Marsian for fixing sensors on the hand (potential, conductivity, temperature...) and also for connecting. (measurement of the Autonomous Nervous activity)

Other methodologies, technologies, application: the field of application of smart clothes is more and more extending due to new sensing elements, discrete fibers, flexible technologies, new chemical sensors, MEMS actuators, …etc.

Motion analysis: Monitoring body kinematics and analyzing posture and gesture is an area of major importance in bioengineering and several other connected disciplines such as rehabilitation, sport medicine and ergonomics. Recent developments of new smart materials consent the realization of a new generation of garments with distributed sensors. Several prototypes of sensing gloves able to detect the posture and movements of the hand are tested now for the assessment of repeatability, ergonomic …etc. [8-10]. The motion analysis can be focused on a body segment [11-13] or on the body activity (walking).

Flexible technologies for smart clothes: as the shape of the human body is changing during postures and movements, the electrodes, the wires, the circuits integrated in smart clothes or fixed on their surface have to be flexible, using the multi-layers technology polymide/coper/constantan… It is possible to design, isolated or not, but also thermoelectric devices thermocouples, heat flow meter, etc… [4], [14].

Heat flow meters can be designed using multilayers technology of polyamide, copper, constantant...

Such sensors can measure the metabolique heat loss of the human body during tasks, work.

They can be used for safety in the clothe of fireman, but also thin and flexible heat flow meter can measure the influence of air flow on thermal comfort.

Functional electrical stimulation (F.E.S.) [15] can be performed by smart textile electrodes.

Measurement during professional tasks: first responders, fireman's, soldiers, workers in risky environment must perform physically demanding and intellectually rigorous tasks. The protecting clothing are equipped with sensors of dangerous gas, heat, environment… and also for the continuously monitoring of physiologic and vital sign [16-21].

Mapping the interface pressure: thin and flexible pressure sensors can be fixed on the inner surface of clothes or between 2 layers of textile. The arrays of such sensors can be used for the detection of local excessive pressure of a part of the body on a surface for the prevention of pressure ulcers [22].

The progress in informatics signal processing imagery, telecommunication, are large and very fast (C.F. Moore law) in contrast the time necessary for design, assessment, test of sensors is very long (usually more than 5 years).

V. CONCLUSION

Research and development of smart clothes are justified by the need to respond successfully to healthcare challenges. Smart clothes can integrate all the progress of textiles, fibers, material, micro technologies, telecom, etc. They have to be adapted to specific need and used complementary (when necessary) with wrist or bald devices.

At the present time the "bottle neck" is the lack of sensors really relevant and adapted for this purpose.

REFERENCES

[1] C. Collet, E. Vernet-Maury, G. Delhomme, A. Dittmar, "Autonomic Nervous System Response Patterns Specificity To Basic Emotions", *J. Auton. Nerv. Syst,* 62, pp 45-57,1997.

[2] P. Ekman, R. Levenson, W.V. Friessen, "Autonomic Nervous System Activity Distinguishes Among Emotions", *Science*, 221, pp. 1208-1210, 1983.

[3] A. Dittmar, F. Axisa, G. Delhomme, "Smart Clothes For The Monitoring In Real Time And Conditions Of Physiological, Emotional And Sensorial Reactions Of Human",. *25th Annual International Conference Ieee-Embs*, Cancun, Mexico, September 17-21 2003.

[4] F. Axisa, PM. Scmitt, C. Gehin, G. Delhomme, A. Dittmar, "Flexible Technologie and Smart Clothes for Citizen Medicine, Home Care and Prevention", 12 pages, in press IEEE Transaction on Informatics Technology in Biomedicine Special Issue, 2005.

[5] A. Dittmar, F. Axisa, G. Delhomme and C. Gehin, "New Concepts and Technology in Home Care and Ambulatory Monitoring", *Studies in Health Technology and Informatics Wearable e-Health Systems for Personalised Health Management*, n°108, pp. 9-35, IOS Press 2004.

[6] A. Bonfiglio, D. De Rossi, T. Kirstein, I. Locher, F. Mameli, R. Paradiso, G. Vozzi, "A Feasibility Study Of Yarns And Fibers With Annexed Electronic Functions : The Ariane Project", *New Generation Of Wearable Systems For Ehealth*, International Workshop, pp. 258-264, December 11-14, Lucca, Tuscany, Italy, 2003.

[7] S.E. Khalil, J.Yuan and M.A. El-Sherif, "Development of smart textiles with embedded fiber optic chemical sensors", *Environmental Monitoring and Remediation III,* pp. 38-49, Proceedings of SPIE,Volume 5270, Editors, Tuan Vo-Dinh, Guenter Gauglitz, Robert A. Lieberman, Klaus P. Schaefer, Dennis K. Killinger, March 2004.

[8] F. Lorussi, A. Tognetti, M. Tesconi, P. Pastacaldi, D. De Rossi, "Strain Sensing Fabric For Hand Posture And Gesture Monitoring", *New Generation of Wearable Systems for ehealth: Towards a Revolution of Citizen Health and Life Style*, pp. 175-180, Ed. Technical Program and Digest, Il Ciocco Castelvecchio Pascoli, Lucca, Tuscany, Dec. 11-14, 2003.

[9] M. Jones, T. Lockhart, T. Martin, "An E-Textile System For Motion Analysis", *New Generation of Wearable Systems for ehealth: Towards a Revolution of Citizen Health and Life Style*, pp. 216-223, Ed. Technical Program and Digest, Il Ciocco Castelvecchio Pascoli, Lucca, Tuscany, Dec. 11-14, 2003.

[10] R. Guillemaud, Y. Caritu, D. David, F. Favre-Réguillon, D. Fontaine, S. Bonnet, "Body Motion Capture For Activity Monitoring", *New Generation of Wearable Systems for ehealth: Towards a Revolution of Citizen Health and Life Style*, pp. 209-215, Ed. Technical Program and Digest, Il Ciocco Castelvecchio Pascoli, Lucca, Tuscany, Dec. 11-14, 2003.

[11] N. Noury, A. Dittmar, C. Corroy, R. Baghai, J.L. Weber, D. Bc, F. Klesfat, A. Blinovska, S. Vaysse and B. Cornet, "VTAMN – A Smart Clothe for Ambulatory Remote Monitoring of Physiological Parameters and Activity", *Proceedings of the 26th Annual International Conference of the IEEE EMBS*, pp. 3266-3269, San francisco, CA, USA, Sept 1-5, 2004.

[12] D. De Rossi, F. Lorussi, A. Mazzoldi, P. Orsini, E.P. Scilingo, "Monitoring Body Kinematics And Gesture Through Sensing Fabrics", *1st Annual International Ieee-Embs Special Topic Conference On Microtechnologies In Medicine & Biology*, pp.587, Lyon, France, October 12-14, 2000.

[13] Vivago Systems: www.vivago.org .

[14] E. Mcadams, J. Mclaughlin, J. Anderson, "Wearable And Implantable Monitoring Systems: 10 Years Experience At University Of Ulster", *New Generation of Wearable Systems for ehealth: Towards a Revolution of Citizen Health and Life Style*, pp. 115-120, Ed. Technical Program and Digest, Il Ciocco Castelvecchio Pascoli, Lucca, Tuscany, Dec. 11-14, 2003.

[15] T. Kirstein, M. Lawrence, G. Tröster, "Functional Electrical Stimulation (FES) With Smart Textile Electrodes", *New Generation of Wearable Systems for ehealth: Towards a Revolution of Citizen Health and Life Style*, pp. 201-208, Ed. Technical Program and Digest, Il Ciocco Castelvecchio Pascoli, Lucca, Tuscany, Dec. 11-14, 2003.

[16] P. Grossman, "The LifeShirt: a Multi-Function Ambulatory System that Monitors Health Disease and Medical Intervention in the Real World", *New Generation of Wearable Systems for ehealth: Towards a Revolution of Citizen Health and Life Style*, pp. 73-80, Ed. Technical Program and Digest, Il Ciocco Castelvecchio Pascoli, Lucca, Tuscany, Dec. 11-14, 2003.

[17] R.K. Herzog, D. Konstantas, "Continuous Monitoring Of Vital Constants For Mobile Users : The Mobihealth Approach", *25th Annual International Conference Ieee-Embs*, Cancun, Mexico, September 17-21 2003.

[18] P. Leitch, "Interactive Textiles For Warrior Systems Applications", *New Generation Of Wearable Systems For Ehealth: Towards A Revolution Of Citizen Health And Life Style*, pp. 54-60, Ed. Technical Program And Digest, Il Ciocco Castelvecchio Pascoli, Lucca, Tuscany, Dec. 11-14, 2003.

[19] B. Munro, J. Steele, T. Campbell, G. Wallace, "Wearable Texile Biofeedback Systems: Are They Too Intelligent For The Wearer?", *New Generation of Wearable Systems for ehealth: Towards a Revolution of Citizen Health and Life Style*, pp. 187-193, Ed. Technical Program and Digest, Il Ciocco Castelvecchio Pascoli, Lucca, Tuscany, Dec. 11-14, 2003.

[20] J. Healey, "Sensing Physiology In The Unconstraiend Ambulatory Environment" , *New Generation of Wearable Systems for ehealth: Towards a Revolution of Citizen Health and Life Style*, pp. 194-201, Ed. Technical Program and Digest, Il Ciocco Castelvecchio Pascoli, Lucca, Tuscany, Dec. 11-14, 2003.

[21] G.G. Wallace, T. E. Campbell, P. C. Innis, G. Spink, C. O. Too, J. Wang, B. Xi, D. Zhou, J. Steele, B. Munro, "Intelligent Textiles: Wearable Sensors, Actuators And Energy Storage Systems", *New Generation of Wearable Systems for ehealth: Towards a Revolution of Citizen Health and Life Style*, pp. 241-244, Ed. Technical Program and Digest, Il Ciocco Castelvecchio Pascoli, Lucca, Tuscany, Dec. 11-14, 2003.

[22] CNRS Patent : " Capteur, dispositif et procédé visant à mesurer la pression d'interface entre deux corps ", n° FR04/02037, France.