HYBRIDIZATION OF SMART TEXTILES IN MEDICAL AND HEALTHCARE MANAGEMENT

Danish Ahmed
Textile Research and Innovation Centre, Textile Institute of Pakistan, Karachi, Pakistan.
E-mail: d.ahmed@tip.edu.pk

ABSTRACT

Humans are close to textiles more than anything, and certainly we carry it most, other than anything. The last few decades have shown enormous growth in the development of wireless communication technologies, nano-engineering, information technologies, and miniaturization of electronic devices. These developments draw the attention of researchers to envisage the significant characteristics of these advancements to the belongings with whom we are most close to. Researchers are now evaluating the new ideas and possibilities to functionalize this 'natural necessity feature of human beings' with emerging technologies into different arrays of human life especially in the Medical and Healthcare management - as mobile monitoring of health care, protection from life risk factors, life style management, rehabilitation and into other facilitation of our lives, by *Hybridizing the Smart or Intelligent Technology in Textiles.* The aim of this paper is to describe the analysis on how 'Smart', 'intelligent' or 'active' materials and textiles are being incorporated in the healthcare sector to aid diagnostics, recording and transmitting of bio-physiological signals or ambulatory tele-monitoring of the body vitals, by encompassing the core concepts of smart materials under the light of the recent developments and projects.

Key Words: medical textiles, smart materials, intelligent textiles, mobile health monitoring.

1. INTRODUCTION

The world is distinctly rising towards the new era, an era of smart and intelligent discoveries; problem solving and creativity − the smart automobile vehicles (cars, metro system), intelligent jets, smart homes [1-4] and amongst from many of such aristocratic paradigms, the 'Smart and Intelligent Textiles'.

Before going further, a clarification of the term and definition of smart and intelligent textile is essential. There is a substantive difference between the terms, 'Smart' and 'Intelligent' [5], *Smart materials or textiles can be defined as the materials and structures which have sense or can sense the environmental conditions or stimuli* [5,6], whereas *intelligent textiles can be defined as textile structures which not only can sense but can also react and respond to environmental conditions or stimuli* [5]. These stimuli as well as response [7], could be thermal, chemical, mechanical, electric, magnetic or from other source [6]. According to the manner of reaction, they can be divided into passive smart, active smart and very smart materials: [6,7]

1. Passive smart materials can only sense the environmental conditions or stimuli; they are sensors;
2. Active smart materials will sense and react to the conditions or stimuli, besides the sensor function, they also have actuation characteristics;
3. Very smart materials can sense, react and adapt themselves accordingly;
4. An even higher level of intelligence can be achieved from those intelligent materials and structures capable of responding or activated to perform a function in a manual or pre-programmed manner.

Since, this is a newly emergent field there is no one accepted definition [8] though. Yet, there are number of other nomenclatures also being widely used as electronics and photonic textiles [9], e-textiles/electronic fabrics [10], smart fabrics, intelligent textiles etc. Since, missing an international consensus of the particular definition of these terms, we'd use the term "**SITs**" 'Smart Intelligent Textiles' in this paper to adjudicate for referring the aforementioned terms.

SITs is a hybrid research area crossing many disciplines, that having learnt from early attempts at wearable computing, is moving into another generation of technologies which are designed to solve specific problems in particular contexts may be for aeronautic / aerospace applications, military, automotive, fashion, sports etc. This review does not, however, include such discussion, but rather, focuses on '*hybridization of smart technology in medical and healthcare managemen*t', which have opened up the floodgates for research, innovations and developments to provide the cutting edge solutions and remedies to problems and scenarios within the entire spectrum of medical applications [8].

2. SITs'S POTENTIALS AND THEIR PROSPECTS IN MEDICAL AND HEALTHCARE MANAGEMENT

With our own senses we can estimate only roughly if vital functions are performing adequately or if they are deviating from the normal level [11]. Whilst the SITs's functional characteristics provide an opportunity for continuous measurement, processing and communication of physiological and physical parameters from patients to service providers, family and other support people. The appropriate design and integration of different kinds of sensors, as well as the appropriate medical algorithms to process the data could offer new possibilities [12] to clothing that makes us feel comfortable at all times - during any activity and in any environmental conditions, a suit that protects and monitors, that warns in case of danger and even helps to treat diseases and injuries. Such clothing could be used from the moment we are born till the end of our life [13]

The prospects for SITs are rather good particularly for medical and healthcare applications due to change in demographics towards the fast-growing, increasingly urbanized and ageing population and the shift in consumer values; instead of wanting the finest natural materials, people show more interest towards engineered functionality, innovative design and the intelligent aspects of products [5].

3. THE PRINCIPLE: HOW SITs WORKS IN DIFFERENT HEALTHCARE FOCUSED DISCIPLINES

The human body originates certain type of physiological or biomechanical signals which are responsible in determining the state of the body functions or in determining the consistency of organ functioning. Changes in the functioning of the organs can take place when there are changes in the environmental conditions by triggering these signals (physiological signals / biomechanical variables / reflexes). For example, if a person moves or deacclimates himself from a temperate (moderate) to a hot, dry ambiance, changes occur in his cardiac rhythm and body temperature such that in time he perspire less, and his perspiration contains less salt [14]. Although at an altitude of 7600m [25,000 ft] most persons need to breathe high-pressure oxygen for survival, once they get used to it through gradual acclimatization, they may be able to breathe unaided. [14]

Similarly, if you walk, eat, and talk there is an imperative change taking place in the generation of these signals. Even human organs exhibit a response to the absence of natural light. As with most life forms, humans normally function in what is called a circadian rhythm (biological processes occurring at 24-hour intervals) corresponding to the length of the day. Humans who have lived underground under experimental conditions continue to show cyclical changes in physiology, demonstrating the existence of a natural biological clock. The period dictated by this internal clock, however, is slightly longer than one day. [14]

Thus, the core principle of SITs, particularly for medical and healthcare applications, whether in lifestyle management, diagnosis, protection from the life risk factors such as Alzheimer's, SIDS, cardiac problems, pregnancy or into any other facilitation of our lives is substantially based on ***'reading and/or transmitting' the 'bio-physiological and/or bio-mechanical signals and/or some other parameters such as kinesthesia*** (see Fig. 1). All these signals are then carried forward for data processing to perform the specific job accordingly.

The set of components that are responsible to perform this whole mechanism in conjunction with each other have been classified into five groups with respect to their functioning as sensors, communication items, data processing items, actuation items and the energy source. Further details on how smart, active or intelligent materials, structures or textiles detect, react and respond to the body's physiological/biomechanical signals or other parameters are described in the following sections.

3.1 Physiological signals

Physiological signals are one of the fundamental indicators in providing the wellbeing or other health factors of a person. The main physiological signals which include, cardiac rhythm, respiration, and body temperature are discussed below:

3.1.1 Cardiac rhythm and ECG measurements

An electrocardiograph (ECG or EKG) records the electrical activity of the heart. Preceding each contraction of the heart muscle is an electrical impulse generated in the sinoatrial node; the waves displayed in an ECG trace the path of that impulse as it spreads through the heart. Irregularities in an ECG reflect disorders in the muscle, blood supply, or neural control of the heart [15]. Patients suffering from heart condition visit hospitals for routine check-ups. These visits last not only days but weeks and even sometimes months. Moreover, these visits give only a brief window about the patient [16] over his/her diagnosis variables, although, it is known that variability in heart rate over a 24-hour period is an important indicator of disease evolution and progression. A lack of diurnal heart rate variability is characteristic of patients with congestive heart failure [CHF] and cardiomyopathy and is likely to be a result of the profound abnormalities in autonomic function that characterize these patients [17].

Due to the efforts of recent research development it has become possible to successfully embed the smart and intelligent technology into the 'natural necessity of human beings', thus, enabling the remote monitoring of the patients, resulting in more feedback that can be acquired and interpreted in a lax, efficient and intelligent manner.

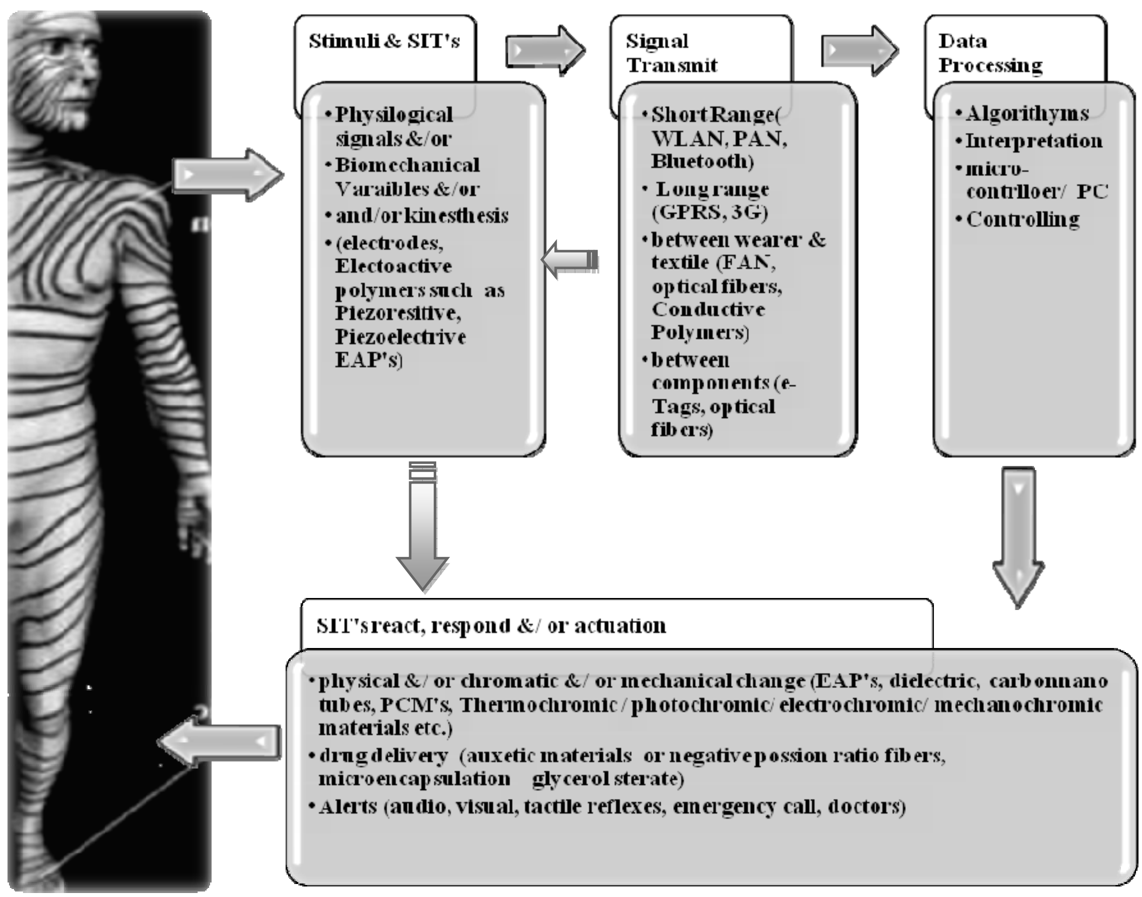

Figure 1: A schematic model of SITs principle in medical and healthcare management. [5, 16, 18-25]

There are various examples of these types of clothing, such as Georgia Tech Wearable Motherboard (GTWM) [26] or commercially called SmartShirt by Senasatex [27], LifeShirt by Vivometrics a stretchable vest base ambulatory monitoring system [28],Wealthy by Smartex (Fig. 2(c)) wearable healthcare system [29] VTAMN Project (French National Funded-RNTS) a T-shirt base remote monitoring system [30], Health Gear by Microsoft Research Corporation, wearable system for health monitoring [31], My Heart by Smartex-Milior, a wearable health monitoring system [29,32], Sports bra by Numetrex heart rate monitoring sports bra [33]. These are only a few examples in this context of multilateral healthcare focused SITs disciplines. There are many which till remain un-highlighted.

However, the crux of the above interpretation is, whatsoever the smart/intelligent technology has been conceived in these examples, the operational principle involves just one concept. The concept of ***reading and/or transmitting the bio-physiological and/or bio-mechanical signals and/or some other parameters such as kinesthesia*** and perform the task accordingly.

Textile electrodes of metallic or non-metallic types can be used to measure the heart rate/ ECG. Textrodes made of knitted stainless steel fibers are used for the measurement of electrocardiograms [34]. They can be used in direct contact with skin [7]. Conductive fabrics made of steel threads wound round acrylic yarns are also used in detecting ECG and electromyograms [EMG] [35]. In another practice, electro-conductive gels with conventional electrodes is used in measuring ECG, but experiments show that the Textrodes are less irritating to the skin [in contrast to the conventional gel electrodes, which may cause skin irritation or allergic reaction]. The major drawback however of the Textrodes is their inherent high skin-electrode impedance electrodes [36].

Non-metallic materials include several electro conductive polymers (ECP). However, most ECP's are currently not available in fibrous form [35]; this is because a polymer has to meet certain requirements before it can be effectively and efficiently converted into a fibrous product. Another novel approach is the 'wearable cardio-respiratory signal sensor device' [37] for monitoring sleep condition at home. It has been developed using a belt-type sensor which is composed with a couple of *conductive fabric sheets* and a *PVDF film.* A USB communication module is used to transmit the signal to computer for data display and analysis [37].

3.1.2 Respiration

Respiration or breathing is a metabolic process whereby thoracic cage undergoes a rhythmic movement and it can be measured by strain gauges or inductance plethysmograpgh [16]. A SITs based respiration sensor 'Respibelt' [38] which is a knitted belt made from stainless steel yarn when worn around the thorax, is able to measure thoracic changes in perimeter and cross-section, through changes in inductance and resistance. Inductance analysis considers the belt as a circular circuit which reacts to changes in cross-section within the belt, whereas resistivity reacts to changes in circumference of the chest due to the breathing motion [38].

Another promising SITs base approach in this context is polypyrrole-coated polyurethane foam [39] which exhibits a piezo-resistive reaction, when exposed to electrical current. The experimental setup has been conducted to monitor the breathing as well as physical activity and motion of body limbs such as shoulder movement, neck movement and shoulder blade pressure [39]. Table 1 gives a brief overview of some of the other examples of potential SITs in this context.

3.1.3 Temperature

In humans, body temperature ranges from 36.4^o to 37.2^o C. If body temperature is too high, the functions of cells may become impaired or the cells themselves damaged; if too low, the rate at which foodstuffs are metabolized decreases. Body temperature can be measured by textile-embedded thermocouples [7] or thermistor-based sensors [16, 41].

The CMRI at University of Bolton is working on the development of a 'smart bra'; an early warning system for breast cancer using skin temperature sensor (STS) and internal temperature sensor (ITS) based on microwave radiometry methodology (MRT) and infrared thermography (IRT)[5]. MRT uses the non-invasive technique of measuring electromagnetic thermal radiation while (IRT) accounts for the functional investigations of breast activity [42].

Table 1. The proposed Sensing devices with examples of potential smart and intelligent materials and its implementation for monitoring fundamental body signals [22, 35, 40]:

Body signals or Variables	Sensing devices/ Potential Smart and Intelligent Textiles	Device Implementation
Electrocardiogram [ECG]/ Electromiogram [EMG]	Electrodes−Textrodes/ Gel electrodes/ Conducting Polymers, Poly N-vinylpyrrolidone. Piezoresistive sensors − Polyvinylidene flurodine [PVDF]	Woven or knitted metallic electrodes and EAP's electrodes
Respiration [respitrace]	Strain gauges, Piezoresistive sensors, Magnetometers − Conductor loaded rubber [CLR]. Conducting Polymers [Polypyrrole, Polyaniline, Polythiophene, Polyacetylene, Pyrolized Polyacrylonitrile	EAP based textile fibers or small-size strips. Polymers films or coating.
Temperature	Thermoelectric sensors, Thermoresistive sensors, Bolometer − Thermistors or STS skin temperature sensor, ITS Internal temperature sensor, Poly(*p*-phenylenevinylene	EAP based textile fibers or small-size strips
Articulation segments position and movements	Bioelectrodes− PPy-coated polyurethane foam as pressure sensitive material	EAP based textile fibers or small-size strips
Skin electrical impedance	Optical fibers	Woven metal electrodes
Heart apex pulse [ballistocardiogram]	Piezoelectric sensors	EAP based textile fibers or small-size strips
Sound	Piezoelectric sensors	Microphones

4. BIOMECHANICAL VARIABLES

Biomechanical signals are varied in type and include, among others, joint motion, body and foot pressure signals [16].

4.1 Joint motion

Four different approaches have been employed to-date for the kinematic analysis of joint motion: attachment of discrete inertial sensors to the textile, inclusion of thin piezoelectric films, manufacturing of piezoresistive fibres and coating of yarns and fibres with conductor loaded rubber (CLR) [16].

4.2 Interface pressure

Pressure values between body and an interface (i.e. seats or beds) have been widely studied in order to improve users' comfort [16, 43] and reduce pain or sores in elderly patients. For this purpose, measuring devices integrated into a sandwich-like structure covered by textile layers have been used in practice [16, 44]. Following this line of thought, many devices have been patented to measure body position, breathing rate and heart rate using force sensitive resistors, capacitive sensors, piezoelectric sensors and microphones, but in most cases, they were expensive and wired to other devices [16, 45].

4.3 Foot pressure

Foot pressure is extremely important in patients with Diabetes Mellitus [DM] and other foot pathologies. Diabetics are prone to foot ulcerations due to neurological and vascular complications. Ulcers appear as a combination of physiological, structural and biomechanical changes and several wearable piezoelectric insoles have been developed in order to study how to reduce plantar pressure [16, 46].

5. CONCLUSION

An attempt has been made in this paper to reveal the operational and functional principle of smart and intelligent textiles in healthcare applications. Yet, there are also some other body parameters merely associated with both, body functioning and SITs, which are substantially needed to be discussed for further acquisition of *smart intelligence*.

The impact and perspective of this smart hybridization is bound to enter the human's everyday life spectrum. However, before reaching such level of integration, a group of challenges lie ahead and several problems have to be resolved. Some issues like obtrusiveness of e-devices in textiles, networking, textile-based energy sourcing, conversion of potential polymers into fibrous form, cost-effectiveness, durability, washability and most importantly bringing a cluster of multidisciplinary experts to one platform.

6. ACKNOWLEDGMENTS

This work will not have been possible without the invaluable support of Textile Research and Innovation Centre (TRIC) and continuous motivation of Dr. Samuel Anbahan Ariadurai.

7. REFERENCES AND FURTHER READING

1. **Next world et al.** *Future cars; Future metro; future flight; future intelligence.* [Electronic; Television show] Satellite broadcast : Discovery Channel, 2009.
2. **Trevelyan, James.** Redefining Robotics for the New Millennium; The International Journal of Robotics Research. Deceember1999: pp. 1211-1220;. Available from*:* *http://ijr.sagepub.com/cgi/content/abstract/18/12/1211.* [Cited: October 13, 2008.]
3. **Ning, Bin; Tang, Tao; Gao, Ziyou; Yan, Fei; Wang, Fei-Yue; Zeng, Daniel.** Intelligent transportation systems; Intelligent railway system in China. [ed.] Fei-Yue Wang. *IEEE Intelligent system.* New York; Washington : IEEE computer society, 2006. Vol. 21, 5, pp. 80-82.
4. **Intelligent Transportation Systems.** The U.S. department of transportation. Available from*:* *www.its.dot.gov/.* [Cited: October 26, 2008.]
5. **Shah, Tahir H.** Advances in Technical Textiles: Smart & Intelligent Textiles. *Presented at 2nd International Technical Textile Conference.* Karachi, Pakistan : Pegasus, March 2009.

6. **Tao, Xiaoming.** Smart technology for textiles and clothing - introduction and overview. *Smart fibers, fabrics and Clothing.* Cambridge, UK : CRC Press; Textile Institute; Woodhead Publishing, 2001, pp. 2-6.
7. **Van Lagenhove, Leiva and Hertleer, Carla.** Smart Clothing: a new life. *International Journal of Clothing Science and Technology.* : Emerald Group Publishing, 2004. Vol. 16, 1/2, pp. 63-69.
8. **Black, S.** Trends in smart medical textiles. [ed.] Leiva Van Langenhove. *Smart textiles for medicine and healthcare.* Cambridge, UK : CRC press; Woodhead Publishing, 2007.
9. **El-Sherif, Mahmoud.** Integration of fiber optic sensors and sensing networks into textile structuers. [ed.] Xiaoming Tao. *Wearable electronics and photonics.* Cambridge : Woodhead Publishing, 2005, p. 105.
10. **Perera, Willorage Rathana.** Highly conducting micro fibers for wearable electronics. *86th Textile institute world conference.* Hong Kong : Institute of Textiles and Clothing, The Hong Kong Polytechnic University, 2008.
11. **Lymberis, Andreas.** Research and development of smart wearable health applications. [ed.] A. Lymberis and D. de Rossi. *Wearable ehealth system for persoanlised health management: Series-Studies in health technology and informatics.* Amsterdam; Washington : IOS press publication, 2004, Vol. 108, pp. 155-160.
12. **LYMBERIS, ANDREAS and OLSSON, SILAS.** Intelligent biomedical clothing for personal health and disease Management: State of the art and future vision. *Telemedicine journal and e-health.* : Mary Ann Liebert, Inc., 2003. Vol. 9, 4, pp. 379-386.
13. **Van Lagenhove, Lieva.** Introduction. *Smart textiles for medicine and healthcare.* Cambridge : CRC Press; Woodhead Publishing, 2007. p. *xv*.
14. **Encarta.** Acclimatization. *Microsoft* ® *Encarta* ® *Encyclopedia* ©. USA : Microsoft Corporation, 2005.
15. **Encarta, Inc./Hank Morgan/Science Source.** Electrocardiograph. *Microsoft* ® *Encarta* ® *Encyclopedia* ©. USA : Microsoft Corporation., 2005.
16. **Solaz, J. S., Belda, J.M., Lois, Garcia, A.C., Barbera, R., Dura, J.V., Gomez, J.A., Soler, C and Prat, J.M.** Intelligent textiles for monitoring applications. [ed.] H.R. Matilla. *Intelligent textiles and clothing.* Cambridge, UK : CRC Press; Woodhead Publishing;, 2006, pp. 371-392.
17. **Binkey, P., Frontera, W., Standaert, D. G. and Stein, J.** Predicting the potential impact ofwearable technology. *IEEE Eng Med Biol Mag.* 2003. Vol. 22, 3, pp. 23-27.
18. **De Rossi, D., Carpi, F., Lorussi, F., Mazzoldi, A., Paradiso, R., Scilingo, E. P. and Tognetti, A.** Electroactive fabrics and wearable biomonitoring devices,. *AUTEX Research Journal.* 2003. Vol. 3, 4, pp. 180-185.
19. **Vouyioukas, Demosthenes, Maglogiannis, Ilias and Komnakos, Dimitris.** Emergency m-Health services through high-speed 3G systems: Simulation and performance evaluation. *SIMULATION.* Sage Publications, 2007. Vol. 83, 4, pp. 329-345.
20. **Gould, P.** Textile gain intelligence. *http://www.ifmachines.com/materials.* [Cited: November 3, 2008.]
21. **Itao, K.** Development of wearable intra-body communication devices. *Sensors and Actuators A.* 2003. 105, pp. 109-114.
22. **Paradiso, Rita.** Wearable Health Care System: New frontier on e-Textile, Roma October 23, 2006. Available from*: http//:www.smartex.it.* [Cited: December 19, 2008.]
23. **CSIRO [Commonwealth Scientific and Industrial Research Organization].** Intelligent knee sleeve to save costly sporting injuries, CSIRO media release. Available from*: www.csiro.au.* [Cited: October 7, 2008.]

24. **Mazzoldi, A., De Rossi, Scilingo, E. P. and Paradiso, R.** Smart Textiles for wearable motion capture system . Available from*: http://autexrj.org/No6/0038.pdf.* January 12, 2009.

25. **Oopalsamy, C., Park, S., Rajamanickam, R., Jayaraman, S.,.** 'The wearable motherboard the first generation of adaptive and responsive textile structures [ARTS] for medical applications. *J. Virtual reality.* 1999, Vol. 4, pp. 152-167.

26. **Jayaraman, S.** Advancements and Applications of Mechatronics Design in Textile Engineering. *Kluwer Academic Publishers.* 1995. pp. 241-258.

27. **SmartShirt™.** Sensatex, USA. Available from*: www.sensatex.com.* [Cited: November 28, 2008.]

28. **LifeShirt® Technology.** Vivometrics®. Available from*: http://www.vivometrics.com/lifeshirt/lifeshirt-technology.* [Cited: December 4, 2008.]

29. **Paradiso, Rita.** Smartex srl: concentration WS on SFIT. Available from*: ftp://ftp.cordis.europa.eu/pub/ist/docs/mnd/smartex-presentat-sfit_en.pdf.* [Cited: November 12, 2008.]

30. **VTAMN Project [French National Funded-RNTS].** Medical tele-assistance suit. Available from: www.*: www.medes.fr/VTAMN.html.* [Cited: October 24, 2008.]

31. **Oliver, Nuria and Flores, Fernando.** HealthGear: Real-time Wearable System for Monitoring and Analyzing Physiological Signals,. Available from*: http://research.microsoft.com/~nuria/healthgear/noliver-healthgear.pdf.* [Cited: October 29, 2008.]

32. **MyHeart Project, 2006.** Available from*: http://www.hitech-projects.com/euprojects/myheart.* [Cited: January 21, 2009.]

33. **McCann, J.** Smart medical textiles in reahbilation. [ed.] L Van Langenhove. *Smart Textiles for medicine and heathlcare.* Cambridge: England : CRC Press; Woodhead Publishing, 2007, pp. 178-180.

34. **Catrysse, M., Puers, R., Hertleer, C.,Van Langenhove, L., Van Egmond, H. and Matthys.** Towards the integration of textile sensors in a wireless monitoring suit. *Sensors and Actuators A.* 2004. 114, pp. 302-311.

35. **De Rossi, D., Carpi, F., Lorussi, F., Scilingo, E. P., Tognetti, A and Paradiso, R.** Electroactive fabrics and werable man-machine interfaces. [ed.] Xiamoming Tao. *Wearable electronics and photonics.* Cambridge, England : Woodhead publishsing, 2005, pp. 59-80.

36. **Catrysse, M., Pirotte, F, and Puers, R.** The use of electronics in medical textiles. [ed.] Leiva Van Langenhove. *Smart textiles for medicine and healthcare.* Cambridge, England : CRC Press; Woodhead Publishing, 2007, pp. 88-93.

37. **Samjin Choi and Zhongwei Jiang.** A novel wearable sensor device with conductive fabric and PVDF film for monitoring cardiorespiratory signals . Available from*: http://www.sciencedirect.com/science.* [Cited: February 8, 2009.]

38. **Van Langenhove, L, Pures, R and Matthys, D.** Intelligent textiles for protection. [ed.] Richard A Scott. *Textiles for protection.* Cambridge, UK : Woodhead Publishing, 2007, pp. 176-190.

39. **Dunne, Lucy E; Brady, Sarah; Smyth, Barry; Diamond, Dermot;.** Initial development and testing of a novel foam-based pressure. *http://www.jneuroengrehab.com/content/pdf/1743-0003-2-4.pdf.* 2005. [Cited: December 21, 2008.]

40. **De Rossi, Danilo; Carpi, Federico; Lorussi, Federico; Scilingo, E. Pasquale.** Wearable Mechanosensing and Emerging Technologies in Fabric-based Actuation. [ed.] S. Jayaraman, Paul Kiekens and Ana Marija Grancaric. *Intelligent Textiles for Personal Protection and Safety.* IOS Press, 2006, pp. 55-60.

41. **Teller, A.** A platform for wearable physiological computing. *Interacting with computers.* 2004. 16, pp. 917-937.

42. **Mustata, L. and Baltag, O.** Applications of Microwave Radiometry in Diagnostic Suspicion. *IFMBE Proceedings; 4th European Conference of the International Federation for Medical and Biological Engineering.* Antwerp, Belgium : Springer-Verlag Berlin Heidelberg [www.springerlink.com], November, 2008. pp. 825-828.

43. **Buckle, P and Fernandes, A.** Mattress evaluation-assessment of contact pressure, comfort and discomfort. *Appl Ergonomics,.* 1998. 29 (1), pp. 35-40.

44. **Babbs, C. F.; Bourland, J; Graber, G.P.; Jones, J. T., Schoenlein, W. E.;.** A pressure-sensitive mat for measuring contact pressure distributions of patients lying on hospital bed. *Biomedical instructions technology.* 1990. 24 (5), pp. 367-370.

45. **Van der Loos, H.F.M., et al.** Unobtrusive vital signs monitoring from a multisensor bed sheet. *Poc RESNA Ann Conf.* Reno . 2001. pp. 218-220.

46. **Sarnow, M.R., Veves, A., Giurini, J.M., et al.** In-shoe foot pressure measurements in diabetic patients with at-risk feet and healthy subjects. *Diabetes Care.* 1994. 17 (9), pp. 1002–1006.