Conference Paper

Objective Assessment of Sleep Movements in Neurodegenerative Patients Trough an Electrotextile Tool

Nuno José Ramos Belino, Michella Melo Tavares, and Maria Assunção Morais e Cunha Vaz Pato

Universidade da Beira Interior

Abstract

The present research work aims at the integration of textile materials and electronic components for the development of a new electrotextile structure to be used in human medicine and healthcare, specifically, in monitoring sleep movements of patients with neurodegenerative disease such as Alzheimer and Parkinson's. In this context, we sought the development of a new technological solution that allows not only to assess sleep quality, but also to establish a link between the nocturnal movements (body area, number of movements, direction, intensity) of demented patients and their polysomnographic recorded data. For this purpose, the authors developed an electroactive textile system, in order to acquire biomechanic information during the patients' night rest. The collected data will be statistically processed to verify any relation between night movements and the stage of the disease.

Keywords: Smart textiles, Sleep assessment, Polysomnography, Electrotextiles, Neurodegenerative diseases

Corresponding Author:
Nuno José Ramos Belino
belino@ubi.pt

🔓 **OPEN ACCESS**

1. Introduction

Sleep literature review highlight the major importance of sleep to maintain a good physical and mental health. This is clearly visible in multiple studies conducted by numerous research teams around the world [1]-[4]. Table 1 show us the huge variety of sleep disorders and presents their most common classification in accordance with international parameters [5].

1.1. Public health context

Neurodegenerative diseases, namely, Parkinson´s and dementia syndromes such as Alzheimer affect a large part of the population due a longevity increase in the past recent years. These diseases have no cure yet, therefore, it is important to emphasize

TABLE 1: International classification of sleep disorders

DYSSOMNIAS	
INTRINSIC SLEEP DISORDER	Psychophysiological Insomnia, Sleep Perception Disorder; Idiopathic Insomnia, Narcolepsy, Hypersomnia Recurrent Idiopathic and Post-Traumatic Insomnia; Central and Obstructive Apnea Syndrome, Central Alveolar Hypoventilation Syndrome, Sleep Periodic Movements, Restless Legs Syndrome; Intrinsic and nonspecific Sleep disorders.
EXTRINSIC SLEEP DISORDERS	Inadequate Sleep Hygiene, Altitude and Adjustment Insomnia; Insufficient Nocturne Sleep Syndrome, Disturbance of sleep initiation due to lack of usual associations; Food Allergy Insomnia; Food-Night Management Syndrome; Hypnotics Sleep Depend Syndrome, Stimulants, Alcohol and Drugs; Extrinsic Nonspecific sleep disorders
SLEEP DISORDERS RELATED WITH CIRCADIAN RHYTHM	Jet Lag Syndrome, Shift Changing Syndrome, Irregular sleep-awake cycle pattern; Advance/Delay Sleep Phase Syndrome;
PARASOMNIAS	
AWAKENING DISORDERS	Sleepwalking; Night Terrors; Confusion upon Awakening Disturbances
SLEEP-WAKE TRANSITION DISORDERS	Fall Asleep Myoclonus disturbances; Rhythmic Head Movements (*Jactatio capilis*); Sonoloquia; Night Cramps.
PARASOMNIAS IN REM SLEEP	Nightmares, sleep paralysis; REM behavior disorders, Painful Erections, REM sick sinus syndrome.
OTHER PARASOMNIAS	Enuresis; Abnormal Sleep Swallowing; Paroxysmal Nocturne Dystonia; Other.
ASSOCIATED WITH MEDICAL AND PSYCHIATRIC DISEASES	
ASSOCIATED WITH PSYCHIATRIC DISORDERS	Affective Disorders, anxiety disorders, Psychoses, Panic Disorders, Alcoholism.
ASSOCIATED WITH NEUROLOGICAL DISEASES	Dementia, Parkinson Disease, Other Degenerative and Neuromuscular Diseases; Epilepsy Sleep Related, Headache Sleep Related
ASSOCIATED WITH OTHER DISEASES	Cardiac Arrhythmias; Nocturne *Angor Pectoris*, Chronic Obstructive Pulmonary Disease, Nocturne Asthma, Gastroesophageal Reflux, Peptic Ulcer, Others.

the signals or symptoms that occur in the pre-clinic period which may lead us to an earlier diagnosis and to a premature therapeutic [6, 7]. Moreover, the monitoring of these signals or symptoms throughout the clinic evolution might be beneficial for the improvement of the quality of life of the patients and their caregivers and families. Sleep disorders are a notorious presence among neurodegenerative diseases, they are multifactorial and include nocturia, depressive symptoms, motor disturbances and the usage of medication beyond the disease itself, originating organic alterations into sero-toninergic, dopaminergics and cholinergic neurons in the cerebral trunk, contributing to alter the ascendant activation system [8]-[11]. Furthermore, they can be predictors of the

disease itself: sleep disturbances, including low amplitude, less robust rhythm, and delay in the peak of activity were factors detected by wrist actigraphy, which led to predict the development of minimum cognitive deficit or dementia in normal women and in a group of persons interned in elderly nursery homes [12]. On the other hand sleep quality control, in patients with neurodegenerative diseases, supported with quantitative data may represent a substantial improvement for assessing this parameter, comparatively with the subjective survey methodology, unanimously recognized as unreliable, even in normal subjects [13].

These kinds of diseases have a tremendous impact on motor skills (slow but continuous loss of mobility) and in the mind status (confusion, disorientation and total alienation) originating great dependence, and in the end, a total loss of autonomy. For these reasons it is very complicated to perform sleep studies in specialized laboratories or in hospital, due to their constant agitation and the presence of technical equipment which includes fixation elements, notably, the ones concerning to E.C.G. and actigraphy system. A significant improvement of this situation would be the chance of monitoring the sleep parameters of these patients in their own environment, without associating too much equipment or elements that might interfere physically with the patient, which is precisely that technological solution we wish to develop.

1.2. Sleep studies - Polysomnography (PSG)

Polysomnography is the medical term used to define a continuous recording process of various physiological functions during an extended time period. For a standard sleep study, we normally collect data from brain electrical activity, muscular electrical activity, heart electrical activity, electromuscular activity generated by the eye, thoracic-abdominal breathing movements, oral and nasal flow, blood oxygen saturation, and cardiac beats [14].

Nocturnal, laboratory-based polysomnography (hereinafter PSG) is the most commonly used test in the diagnosis of sleep disorders, PSG consists of a simultaneous recording of multiple physiologic parameters related to sleep and wakefulness and this is performed with three different sets of devices: E.E.G (electroencephalography), E.O.G. (electrooculography) and E.M.G. (surface electromyography). For the E.E.G. two central channels and two occipital channels, with ear references as an adjunct to help identify sleep latency and arousals were used. Two E.O.G. channels will be used to monitor both horizontal and vertical eye movements. Electrodes are placed on the right and left outer canthi, one above and one below the horizontal eye axis. Evaluation of the eye

movements is necessary for two it reasons: the first one is for documentation of the onset of rapid eye movement (REM) sleep, and the second one is to note the presence of slow-rolling eye movements that usually accompany the onset of sleep. One EMG channel (usually chin or mentalis and/or submentalis) is used to record atonia during REM sleep or lack of atonia in patients with REM- related parasomnias. Another EMG recording (2 electrodes) will be obtained from the anterior tibialis muscle (right and left), since this is the normal pattern for assessing limb movements during sleep.

Recordings will be performed with a portable polysomnographic device in the selected patients' homes, in order to produce minimal derangements in their sleep [15],[16]. The recording system will be placed simultaneously with the bioelectrical device and both systems will record simultaneously.

2. Materials and Methods

This research work is the initial part of a broader and longer scientific project which aims to study the relationship between the anatomical position during sleep rest and some neurodegenerative diseases. In this primary stage we envisioned the development of a new technological solution that allowed not only to assess sleep quality, but also to establish a link between the nocturnal movements (body area, number of movements, direction, and intensity) of demented patients and their polysomnographic recorded data. For this purpose, the authors have developed an electroactive textile system (Hereinafter, ET), in order to acquire biomechanic information during the patients' night rest [17]-[26]. This kind of textile based biomedical device is aimed primarily to the hospital segment and secondly, to home and geriatric markets for patient under ambulatory treatment.

1ª PHASE - Production and optimization of the electroactive textile structure: The electroactive textile system consisted in a textile composite structure, with the same length, thickness and shape of a normal mattress used in PSG tests (1,9m length, 0,9m width and 10cm thickness). As seen on Figure 1, the mattress structure is composed by three layers. The textile material specifications were conceived in order to allow an easy industrial scalable product with reduced production costs. Among several tested technological solutions we choosed to develop a composite structure constituted by three layers. The first and third layers, protective layers, were built with polyurethane foam (5cm thickness each layer). The second layer - the sensing layer - was made with an100% polyacrylic fabric, in which electrical conductive yarns were embroidered in some specific places. The conductive yarns were produced by twisting an 100%

acrylic yarn 2/30 Nm (2,3 dtex and 63mm length fibers) with an inox filament (1/47Nm) with a final count number of 1/11,37 Nm and 630v/m. In order to protect patients from contamination/nosocomial infections and to facilitate the disinfection operation, the mattress was covered with a blue polyurethane fabric and sealed with a zipper.
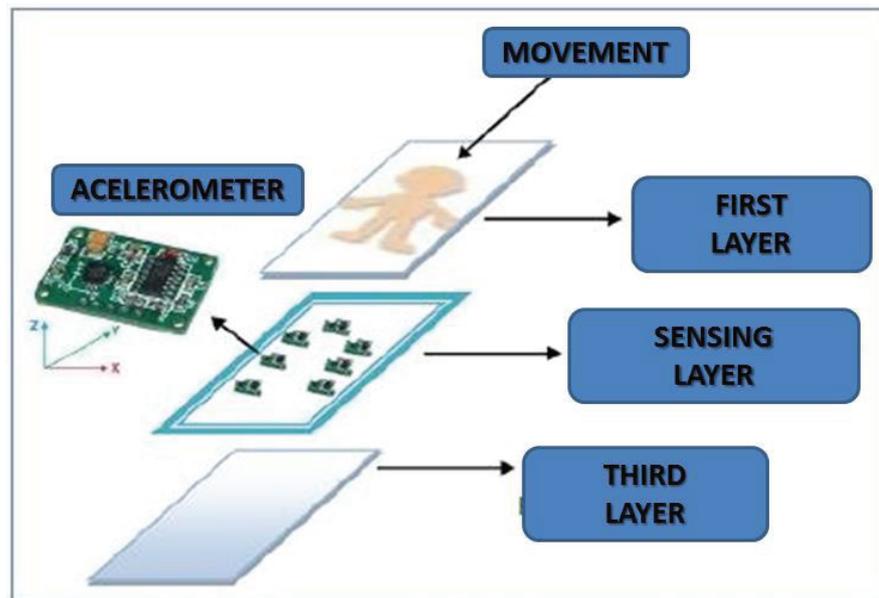

Figure 1: Detail of the electrotextile structure

2ª PHASE - Integration of the electronic components: Seven sensors (tri-axial accelerometers ADXL345 from Analog Devices) were sewed in pre-determined areas, corresponding to the great anatomic zones of the human being: neck and head zone, torso zone, hip zone, right arm zone, left arm zone, right leg zone and left leg zone. These areas are activated or deactivated on a personalized basis. Each sensor can autonomously indicate not only the movement intensity but also his direction. The selected used sensors are characterized by their light weight, flexibility, low energy consumption and low cost. This movement sensors network is connected to the electrical grid and has low power consumption (9v) in order to allow autonomous and continuous operation.

Directly connected to the accelerometers (through the embroidered conductive yarns) an electronic data Collection Module read the sensors status continuously and individually. The gathered information was passed to a collection and processing module which allowed data acquisition, processing and communication with the PC. The data transmission could be performed in real time or through consultation or upon request by an operator/user. Simultaneously to the development of the of the electronic modules a software application has been built, guaranteeing the full management of the overall process and the storage of the collected data, allowing the generation of information

that will be presented as interactive charts, resuming tables and graphs, for all or any particular body area.

3ª PHASE - Pilot clinical trial - In order to verify if the electroactive structure has the same capabilities as the recording electrodes of the polisomnography, a pilot clinical trial was carried out. A standard PSG test was conducted and the normative data of PSG collected. In parallel, the patient kinesiology during the test was also recorded by our prototype. The information provided by these two data series was subsequently compared.

3. Results and Discussion

3.1. Electronic mattress prototype

The integration of the finished and validated electroactive textile system is depicted in Figure 2. A fully equipped prototype, assembled and deployed into hospital facilities to run the clinical trial, can be seen in Figure 3.

Figure 2: Real scale prototype view

Observing thoroughly the patient's hypnogram it is possible to confirm an evident correlation between the data from the actigraphy of the right leg and the data collected by the correspondent accelerometer of the electrotextile system for the entire exam (above 78% in this test). Besides checking any particular point in time, the developed control software allowed us to compile the main statistical data collected by each

Figure 3: Participant being tested

accelerometer during the entire duration of the test and present it in a tabular of graphic format. Being a web-based application, patient's data is always accessible.

3.2. Clinical trial

The experimental group included 29 patients comprised by individuals being 58.6% women and 41.40% men and mean age of 56.59 $\pm$ 11.47 years. The participants were attended at the Laboratory of Sleep Study of the Pulmonology Unit of the Cova da Beira Hospital. This group was selected in a perfectly random manner and with the consent to carry out the test duly signed by the participant.

Because the PSG device collects only the movements of the legs, we focus the comparative analyses only for these members. Table 2 shows the statistics of body movements.

Table 2: Statistical data of legs movement

Legs movement	N	Minimum	Maximum	Mean	Standard deviation	Median	Interquartile range
ET	29	6	293	68,28	78,81	34,00	65,50
PSG	29	9	317	71,90	81,02	33,00	63,50

In order to better understand the data an exploratory analysis using the Shapiro-Wilk Normality test was carried out. The tested hypothesis was:

H_0: Data follows a normal distribution N (μ, σ^2).

H_1: Data does not follow a normal distribution.

The Shapiro-Wilk test rejected the null hypothesis for the movement data in both PSG and ET indicating their non-normality. Due to the high standard deviation and, to reduce the dispersion, we logarithmized the data. The descriptive statistics of the Ln data can be seen in Table 3, which clearly shows a marked dispersion reduction.

TABLE 3: Statistical data of the Ln of legs movement

Ln of the Leg Movement	N	Minimum	Maximum	Mean	Standard deviation
ET	29	2,20	3,76	3,75	1,02
PSG	29	1,79	5,68	3,62	1,14

Applying the Shapiro-Wilk normality test after the logarithmic transformation, it was possible to perceive that the null hypothesis is accepted, meaning that we have a normal distribution (Table 4).

TABLE 4: Normality test data for both data sets

	Shapiro-Wilk	P-Valor
ET	0,958	0,166
PSG	0,958	0,294

After this preliminary exploratory data analysis, a t-test for independent samples was applied to verify the following hypotheses:

H0: $\mu_{PSG} = \mu_{ET}$

H1: $\mu_{PSG} \neq \mu_{ET}$

As a result of the t-test for the equality of means, we obtained t = -0.483 with p = 0.631, which indicates a non-rejection of the null hypothesis, that is, there is no difference between the means of leg movements measured by PSG and ET.

In order to evaluate the relationship between the values of the leg movements detected by the two methods under study, we determined the Pearson correlation coefficient - 0.99 with a p value of 0.00 and R^2 = 0.981.As a consequence of the strong correlation between these two methods, there is a clear evidence that the electrotextile tool might be as effective, in detecting the legs movements, as the standardized PSG test.

In order to complement this inference (taking into account that the bibliographical review that tells us that the previous analysis, by itself, does not necessarily imply that one method can replace the other) a concordance analysis was carried out. Thus, we used the Bland- Altman tool for an agreement analysis.

According to this staistical method it is expected that the Bland-Altman chart limits contain 95% of the differences between the evaluated methods.

TABLE 5: Parameters used in the Bland Altman Chart

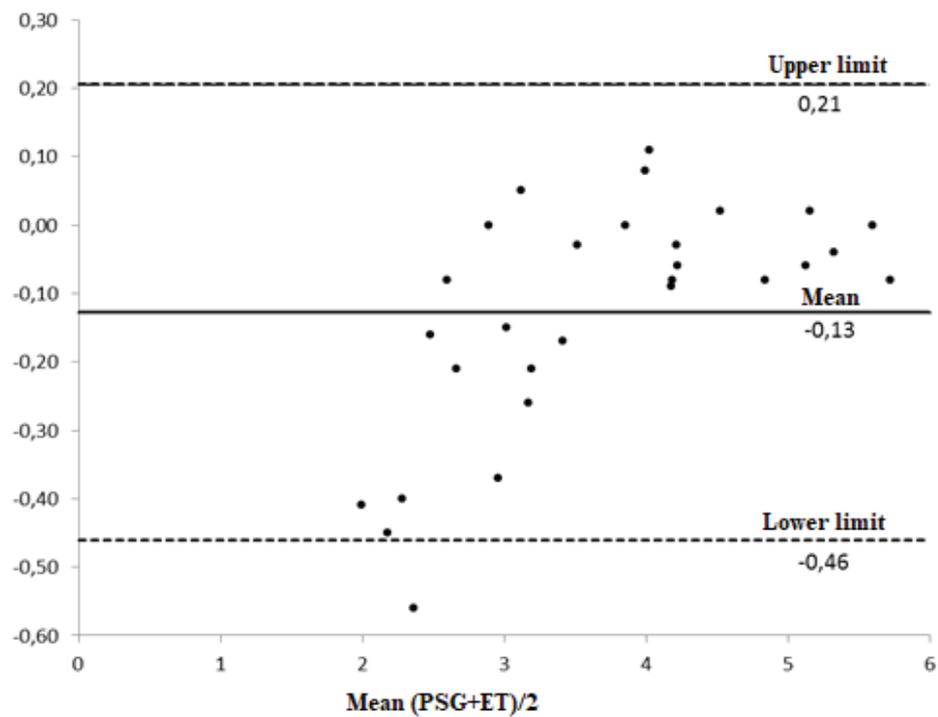| Difference of movements	Mean	Lower Limit	Upper Limit	Standard deviation
ET-PSG	-0,13	-0,46	0,21	0,17

Figure 4: Bland-Altman chart

Based upon the attained Pearson and Bland-Altman coefficients, seen in table 5 and Figure 4, it is possible to affirm that the two studied methods - PSG and ET - present consistent and concordant results, and therefore, the developed electrotextil tool is adequate to replace the classical method of PSG, when it comes to the acquisition of the body movements.

4. Conclusions

Based upon the preliminary results we may consider that the idea beyond this research work proved to have potential to be considered as a biomedical device for the local/remote monitoring of patients with neurodegenerative diseases.

Consequently, through its continued usage, we might expect a strong reduction of costs for the national health care system, considering the avoidance of many expensive

polysomnographic exams, the institutionalization of patients (in a hostile environment for them) and the diminishing of materials consumption and human resources.

It is also very important to underline that patient's comfort will highly improve for they will not need, so frequently, to leave their homes and their "safe world" to go out for exams.

The system also provides a tighter and personnel control of the patient by his doctor due its web application software, that permits data access from anywhere at any time by an electronic device linked to the internet.

Our prototype, being described as an electronic "mattress" is extremely comfortable and the patient may even be unaware of it. For patients with cognitive deficits this is certainly an important feature.

The simplicity of the device is non invasiveness and facility of use combined with the small cost of each unit and the specific population it is aimed at (currently consuming a large amount of resources in the National Health Service gives our prototype a real value for money in Health evaluation and prevention.

Acknowledgements

References

[1] Pilar Rente e Teresa Pimentel, A Patologia do Sono, Edições Lidel, 2004;

[2] Sudhansu Chokroverty e Robert J. Thomas, Atlas of Sleep Medicine, 2nd Edition, 2014 Elsevier Inc;

[3] Maquet P, Matarazzo LA, Foret A, Mascetti L, Bourdieu AS, Contribution of sleep to learning and memory, Muto V, Biol Aujourdhui. 2010;204(2):139-43, 2010;

[4] Born J, Slow-wave sleep and the consolidation of long-term memory, World J. Biol. Psychiatry. 2010 Jun;11 Suppl 1:16-21,

[5] The International Classification of Sleep Disorders Second Edition Diagnostic & Coding Manual American Academy of Sleep Medicine – Westchester, IL, USA, 2005.

[6] Salami, O, Lyketsos, C., Rao, V., Treatment of sleep disturbance in Alzheimer's dementia, International Journal of Geriatric Psychiatry, 2011 Aug;26(8):771-82., 2011;

[7] Suzuki K, Miyamoto M, Miyamoto T, Iwanami M, Sakuta H, Hirata K. (2012) Sleep disturbances in patients with Parkinson disease. Brain Nerve. 2012 Apr;64(4):342-55

[8] Schlosser Covell GE, Dhawan PS, Lee Iannotti JK, Hoffman-Snyder CR, Wellik KE, Caselli RJ, Woodruff BK, Wingerchuk DM, Demaerschalk BM.(2012) "Disrupted daytime activity and altered sleep-wake patterns may predict transition to mild cognitive impairment or dementia: a critically appraised topic".Neurologist, Nov;18(6):426-9

[9] Wadsworth LP, Lorius N, Donovan NJ, Locascio JJ, Rentz DM, Johnson KA, Sperling RA, Marshall GA (2012) "Neuropsychiatric symptoms and global functional impairment along the Alzheimer's continuum." Dement Geriatr Cogn Disord. 34(2):96-111.

[10] Bidzan L, Grabowski J, Dutczak B, Bidzan M. 2011 "Sleep disorders in the preclinical period of the Alzheimer's disease "Psychiatr Pol. Nov-Dec;45(6):851-60

[11] Rongve A, Boeve BF, Aarsland D.J, Frequency and correlates of caregiver-reported sleep disturbances in a sample of persons with early dementia, American Geriatric Society, 2010 Mar;58(3):480-6;

[12] Ferro C.V, Ide M.R, Streit, M.V. "Correlação dos distúrbios do sono e parâmetros Subjetivos em indivíduos com fibromialgia" Fisioter Mov. 2008; 21(1):33-8.

[13] Most EI, Aboudan S, Scheltens P, Van Someren EJ. (2012) Discrepancy between subjective and objective sleep disturbances in early- and moderate-stage Alzheimer disease.Am J Geriatr Psychiatry.Jun;20(6):460-7.

[14] Patil SP., What every clinician should know about polysomnography, Respiratory Care 2010 Sep;55(9):1179-95;

[15] Che-Chang Yang 1 and Yeh-Liang Hsu, Review of Accelerometry-Based Wearable Motion Detectors for Physical Activity Monitoring, Sensors 2010, 10, 7772-7788;

[16] Chen, K.Y.; Bassett, D.R., Jr., The technology of accelerometry-based activity monitors: Current and future. Med. Sci. Sports. Exerc. 2005, 37, 490-500;

[17] Öberg, P.Å.; Togawa, T.; Spelman, F.A. Sensors in Medicine and Health Care; Wiley-VCH. Weinheim: Berlin, Germany, 2004; Volume 1, pp. 245-252;

[18] Anna Maria Bianchi, Martin Oswaldo Mendez, and Sergio Cerutti, Processing of Signals Recorded Through Smart Devices: Sleep-Quality Assessment, IEEE Transactions on Information Technology in Biomedicine, VOL. 14, NO. 3, MAY 2010;

[19] Adriana M. Adami, André G. Adami, Tamara L. Hayes e Zachary T. Beattie, A system for assessment of limb movements in sleep, 2013 IEEE 15th International conference on e-health networking, applications and services (Healthcom 2013);

[20] S. Lokavee, N. Watthanawishuth, J. Mensing and T. Kerdcharoen, Sensor pillow system: monitoring cardio-respiratory and posture during sleep, Proceedings of the Biomedical engineering international conference – BMEiCON 2011, 2011;

[21] Jose M. Perez-Macias, Holly Jimison, Ilkka Korhonen e Misha Pavel, Comparative assessment of sleep quality estimates using home monitoring technology, IEEE, 2014;

[22] A. Gaddam, S. C. Mukhopadhyay and G. Sen Gupta, Necessity of a bed-sensor in smart digital home to care for eleder-people, IEEE, 2008;

[23] Sacco, Isabel C.N. et al., "Análise biomecânica de posturas mediante fotografia digital: estudos de casos", R, Bras. Ci e Mov. Brasília Vol. 11, n°2, pp. 25-23, 2003;

[24] Park S, Jayaraman S. "Enhancing the quality of life through wearable technology". School of Textile and Fiber Engineering, Georgia Institute of Technology, Atlanta, GA 30332- 0295,USA.

[25] Paradiso R., De Rossi D., "Advances in textile technologies for unobtrusive monitoring of vital parameters and movements", Proceedings of the 28th IEEE EMBS Annual International Conference New York City, USA, Aug 30-Sept 3, 2006.

[26] M.Pacelli, G.Loriga., N.Taccini and R.Paradiso, "Sensing Fabrics for Monitoring Physiological and Biomechanical Variables: E-textile solutions", Proceedings of the 3rd IEEEEMBS International Summer School and Symposium on Medical Devices and Biosensors MIT, Boston, USA, Sept.4-6, 2006.