# MY-HEART PROJECT: ANALYSIS OF SLEEP AND STRESS PROFILES FROM BIOMEDICAL SIGNAL

Sergio Cerutti, Anna M. Bianchi and Martin O. Mendez
*Depertment of Bioingeneering, Polytechnic University of Milan, Piazza Leonardo da Vinci 32, Milan, Italy*

Keywords: Wearable Device, Heart Rate Variability, Sleep, Autonomic Nervous System, Stress, Arousal, Autoregressive Model, Hidden Markov Model.

Abstract: Advances in micro and nanotechnology, wireless technology, word-wide web networking, biomedical digital signal processing, textile tissue and implantable devices, etc. have permitted the development of alternative solutions for a better diagnosis of various pathologies, health care and prevention. These advances allow the remote continuous monitoring of persons, whenever and wherever they are. My-Heart FP6 EU Project integrates these components to develop a new concept of prevention and diagnosis for cardiovascular diseases. The present paper will mainly focus on a Concept of the Project which is called Take-Care and deals with the management, and integration of information for monitoring and personal motivation in the health care environment & applications. In its main goal, Take-Care Concept allows the learning in easy way about own self-body responses to different situations in the normal lifestyle: in particular, it offers an evaluation of life quality from sleep performance and stress management based on an integration of information between heart rate variability and respiration signals.

## 1 INTRODUCTION

My-Heart is a 6th Framework Programme EU Integrated Project for fighting cardiovascular diseases (CVD) by prevention and more objective diagnosis based upon vital signs processing in wearable devices. Cardiovascular diseases cause 50% of all deaths in the whole EU. It is well known that a healthy and active life style can significantly reduce the risk of cardiovascular diseases (primary prevention) and limits the recurrence rate of acute events (secondary prevention). Therefore, My-Heart aims at creating smart electronic solutions and appropriate services that empower users to take more control of their own health. The project addresses a spectrum of care, from prevention and the adoption of a healthier lifestyle to chronic disease management. The technological needs for My-Heart applications range from vital sign monitoring in daily life (ECG, respiration, skin impedance, etc), to body-worn low-power devices which run powerful and original detection algorithms for health status and acute cardiac event prediction, to low-power wireless links and server architectures for data handling at professional sites.

Inside My-Heart project a Take-Care concept is carried out that addresses people trying to find support to develop a healthier lifestyle. Today more and more people are facing problems: overweight, inactivity, bad sleep and stress contribute to develop cardiovascular diseases and are affecting millions of European people.

Take-Care system provides people with a better understanding of their overall health, motivating them to become active in staying healthy and feeling well. It is the ambition of Take Care to provide easy-to-use technology and to develop solutions to manage bad sleep, stress, inactivity and overweight.

For the sleep management solution the focus is on analysing sleep stages and sleep fragmentation. For stress solution the focus is on providing the user a biofeedback tool to be used during relaxation exercises to more objectively measure the effect of the relaxation on the single subject.

In this context, the present paper describes the procedures for the evaluation of sleep quality and for stress management based on the analysis of the HRV and respiration signals. The analysis is thought for a device aimed to provide support to people who want to develop a healthier lifestyle, with major focus on cardiovascular disease prevention.

## 2 METHODOLOGY

Take-Care system (TCS) is integrated by different modules. Each module is developed by taking into account the analysis of a specific function. Sleep

Cerutti S., M. Bianchi A. and O. Mendez M. (2008).
MY-HEART PROJECT: ANALYSIS OF SLEEP AND STRESS PROFILES FROM BIOMEDICAL SIGNAL.
In *Proceedings of the First International Conference on Health Informatics*, pages 273-278

fragmentation, sleep staging, obstructive sleep apnoea and stress are the functions singled out inside TCS. Firstly, a general scheme of TCS will be presented. Then, in subsection 2.1, the basic description of sleep fragmentation module is presented. Sleep staging module will be the argument of subsection 2.2. Sleep apnoea module is presented in subsection 2.3 and finally subsection 2.4 concerns with relaxation and stress module.
The main goal of TCS project is to improve life quality based on sleep performance. Sleep analysis is carried out by assessing different electrophysiological signals, which in general require well trained and specialized personnel for the signal interpretation and dedicated equipment. TCS takes advantage from peripheral signals of easy acquisition and sufficient signal to noise ratio. TCS is concentrated in the analysis of surface electrical activity of the heart (electrocardiogram, ECG), since it exhibits high sensitivity to different physiologic and pathologic behaviours, and respiration. Figure 1 shows a TCS general scheme.

## 2.1 Sleep Fragmentation Module

Arousal from sleep (AS) has been one of the most studied sleep phenomena related to sleep fragmentation (SF). SF is associated with several symptoms, ranging from somnolence, excessive daytime sleepiness, impaired learning and memory capabilities, up to much more severe consequences such as cardiovascular diseases. When SF is associated with sleep-disordered breathings, such as obstructive sleep apnoea (OSA), there is high likelihood to develop arterial hypertension and other cardiovascular diseases.

AS is normally scored from either the central or occipital leads of the electroencephalogram (EEG) during standard polysomnographic studies. An AS consists in "an abrupt shift in *EEG frequency, which may include theta, alpha and/or frequencies*

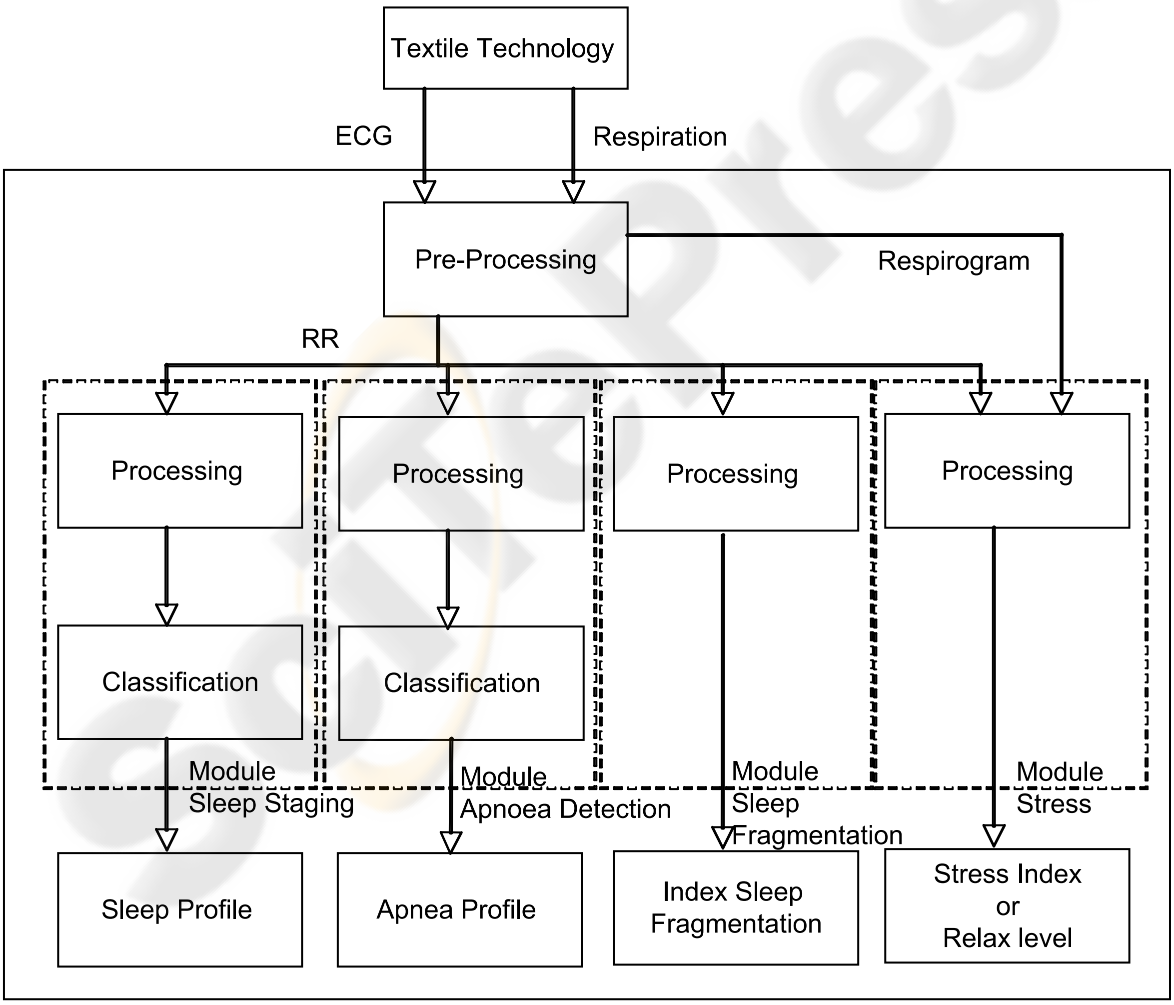


Figure 1: Take-Care System (TCS) scheme.

*greater than 16 Hz but not spindles*" (Atlas Task Force, 1992). AS generates a typical waveform in the heart rate (HR), which consists in an abrupt increment of the HR, followed few seconds later by a decrement in the HR (Sforza et al., 2000). Based on this knowledge, a search algorithm was implemented to identify the cortical arousal projection into the heart rhythm. This algorithm searches in the heart rate the pattern illustrated in Figure 2.

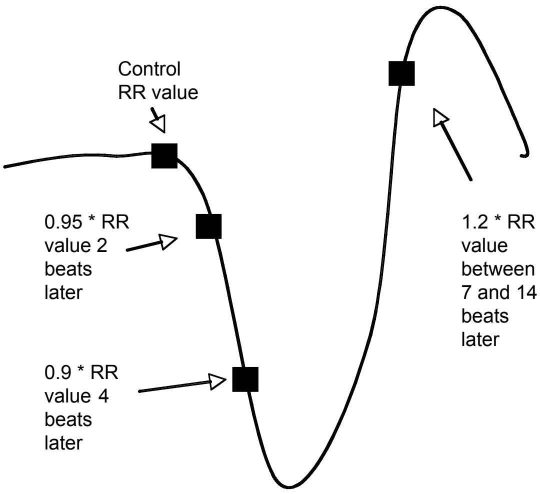


Figure 2: Arousal detection from RR intervals.

At each beat, in this case called control value, the algorithm observes if two and four beats later there is a decrement in the HR, this decrement must obey a predefined percentage. If this condition exists, the algorithm moves ahead and tries to find a HR value higher than the control one between the beats 7 and 14. If this condition is present, then an autonomic arousal is found and the process restart 20 beats later.

Sleep fragmentation is based on the number of arousal episodes during the whole night. However, the sleep process is affected in a different way if an arousal episode occurs during the first or last NREM-REM sleep cycle. A simple solution, that respects the physiologic impact of an arousal during the sleep process, is weighting differently arousal events depending of the time in which these occur. A proposed index (Sleep Fragmentation Index, SFI) is considered by splitting the total sleep time into three parts and is computed as follows:

SFI =3 * (#A's in the first segment) + (#A's in the second segment) + 0.33 * (#A's in the third segment) (1)

Where #A is the number of arousals in a specific time of the night. This equations gives high weight if an arousal episode occurs during the first sleep hours and less weight if it occurs during the last sleep hours.

## 2.2 Sleep Staging Module

In the modern hospital Sleep Centers, the standard sleep evaluation procedure consists in the acquisition and analysis of three signals: electroencephalogram, muscular activity and electrooculogram. These signals present specific changes in time that characterize six different stages: wake, sleep stage 1, sleep stage 2, sleep stage 3, sleep stage 4 and REM. However, sleep stages 1 to 4 present similar characteristics that allow to regroup them all together in only one sleep stage, which is labelled NREM. With standard leads, at peripheral level, NREM and REM sleep present specific patterns, that with some grade of confidence, are significantly recognized. For instance, during NREM, heart rate is stable, eyes do not present movements, there is muscular tone and respiration is regular and deep. In contrast, during REM sleep, heart rate is instable, eyes present circular movements, there is no muscular tone and respiration exhibits instability (Guyton, 2000). Therefore, appropriate mathematical tools of signal processing and pattern recognition might possibly identify NREM and REM sleep periods on the basis of these characteristics.

### 2.2.1 Processing

This module is built up by two blocks. The first block is *processing*, in which extraction of the features that characterize REM and NREM sleep is carried out. During sleep, HR presents different behaviours as well as a series of non-stationarities. These characteristics in HR during sleep require necessarily the application of special mathematical tools. Wavelets, time-frequency and time-varying approaches have interesting properties to obtain the spectral features of the HR in the most diverse conditions. TCS uses a time-varying autoregressive model to extract important spectral features of the HR during sleep. The selection for this approach resides in its characteristic of real-time processing, high time and frequency resolution and very low computational cost.

Figure 3 shows an example where sleep stage 2, 4 and REM are analysed in the frequency domain. The power spectrum was obtained by a time varying autoregressive filter, which evaluates beat by beat the frequency content of a time series.

From a large amount of possible features to classify REM and NREM sleep, TCS uses only four features to discriminate between them:

- RR mean;
- Very low frequency component in RR;
- Modulus of the pole of the autoregressive model in the high frequency component;
- Phase of the pole of the autoregressive model in the high frequency component.

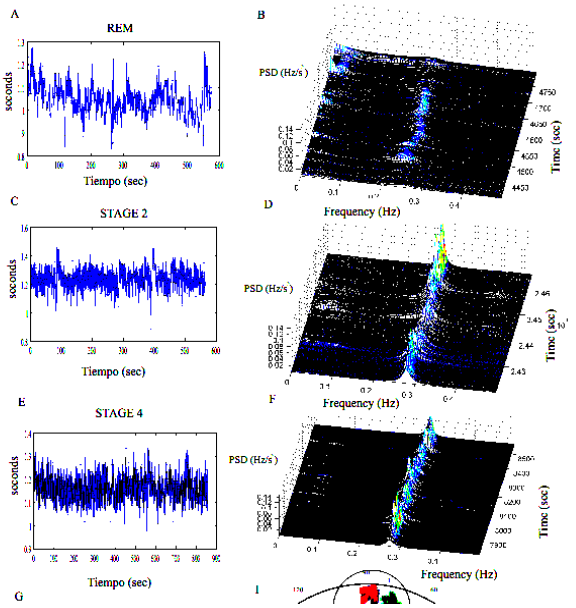


Figure 3: Time-varying spectral analysis of RR series in REM, stage 2 and stage 4 during sleep (A, C and E), with the respective power spectral densities (B, D and F).

### 2.2.2 Classification

A Hidden Markov Model classifier (HMM) integrates the second block, *classification*. HMM was selected since this classifier takes into account the temporal dynamic of a time series. This characteristic is very important for this study, since the length of the NREM-REM cycles varies in time. Figure 4 present an example where the selected features and the sleep profile are compared with the clinical hypnogram. The sleep stages are defined as: 0 = wake, 3 = NREM and 5 = REM. The classification was evaluated epoch by epoch of 30 sec according to the traditional clinical use.

## 2.3 Sleep Apnoea Module

Sleep apnoea is one the most common sleep pathologies. Only in the USA, this pathology affects sleep apnoea does not present evident symptoms, most of the time, sleep apnoea is undiagnosed. Sleep apnoea produces consequences that range from daily somnolence to heart failure. Sleep apnoea is divided into three different types: obstructive, central and mixed. Obstructive apnoea is the most common sleep pathology and with more severe consequences and direct influences in the cardiovascular function.

Sleep apnoea is generated by an occlusion in the upper airways, which does not permit the air to enter to the lungs. Generally, this occlusion is produced by an inadequate sympathetic activation, decrement of the upper airways radio by obesity or exposition to agents as smog. The duration of a single obstructive apnoea episode is between 10 and 20 seconds. During this time, oxygen saturation decreases and respiratory efforts begin to increase in time in order to re-open the upper airways. If oxygen level in the blood decreases in such a way that the respiratory efforts are not enough to restore respiration, the central nervous system produces an arousal, which reactivates all the systems, and the respiration is restored. This process could occur hundreds of times during a single night: in this case a bad sleep quality and cardiac consequences are evidenced, giving as results social problems, accidents and heart attacks (Young et al., 2002).

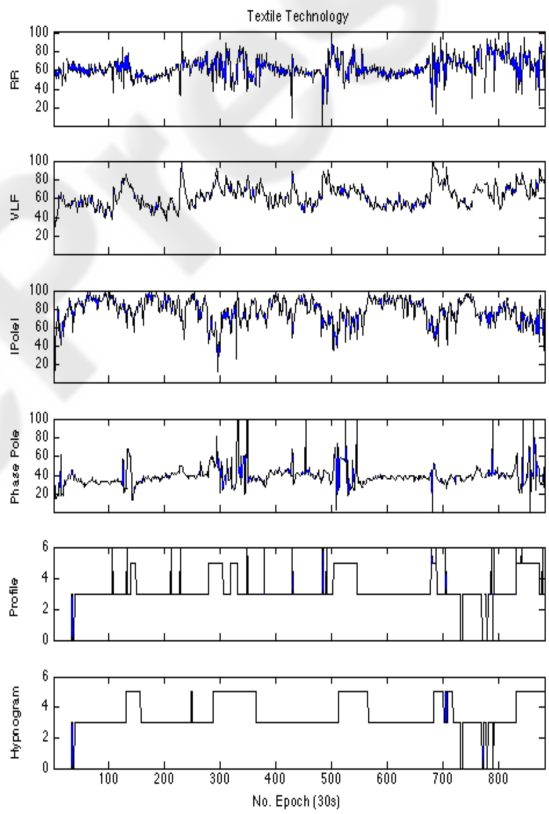


Figure 4: Example of NREM-REM classification by Take-Care System. From the top to the bottom: RR intervals, very low frequency power, module and phase of the pole in high frequency, sleep profile evaluated by Take-Care System and clinical hypnogram. The sleep stages are defined as: 0 = wake, 3 = NREM and 5 = REM.

This process produces a defined brady-tachycardia pattern in the heart rate. TCS explores the feasibility for obtaining an alternative detector of apnoeas using the same tools presented in the study for sleep staging. As autoregressive models present dedicated characteristic for evaluating features in dynamic time series, it was implemented as feature extractor. However, for a more correct detection of apnoeas, some new features were explored: i.e., an estimation of the respiratory effort was obtained from the calculation of the area of the QRS complexes. Correlation between both time series was used in order to extract more robust features to classify obstructive apnoea.

### 2.3.1 Processing

Also sleep apnoea module is built up from two blocks. The *processing* bock helps to extract the features that separate apnoea and non-apnoea conditions. Again, an autoregressive model was used to extract the features. However, each problem requires the selection of its own features to solve it. In this case, the set of features is formed by:

- RR mean;
- Very low frequency component in RR;
- Very low frequency component in derived respiratory signal from ECG;
- Coherence between very low frequency components of the two signals.

### 2.3.2 Classification

In this block a K-nearest neighbour classifier is used to separate between apnoea and non-apnoea periods. The classification is evaluated in a minute-by-minute basis. From here it is possible to obtain an estimate of the time that a person spends in apnoea during the sleep time. Figure 5 shows an example of sleep apnoea classification for 25 subjects.

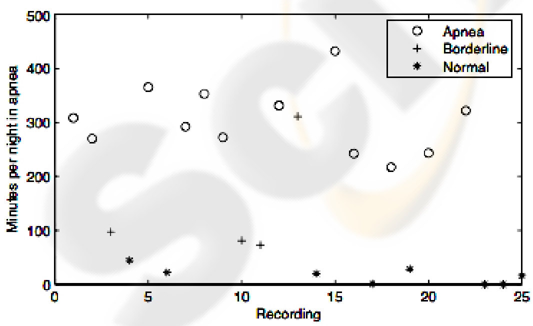


Figure 5: Class separation based on minutes per night calculated by the KNN classifier processing 4 features for 25 recordings of the testing group. Note that applying a threshold of 50 minutes per night, apnoea and normal classes are accordingly separated.

## 2.4 Stress Module

The stress concept employs a sensorised T-shirt which allows the continuous recordings of ECG and respiration. Previously, the subject is asked to fill in a questionnaire which allows to detect his/her level of stress, according to a clinical classification score (APA, 1994). A kind of personalised initial level of stress is hence obtained (IS). Then, according to the instructions delivered from the computer, the subject makes a rest-to-stand manoeuvre (from sitting to a standing position) which indicates the degree of responsiveness to a predominantly sympathetic stimulation.

Then, according to the computer indications, the subject makes some relaxation exercises, which consist in deep regular respirations cycles, trying to “synchronise” as much as possible cardiorespiratory activity. On the basis of Heart Rate Variability parameters (HRV) and respiration, as well as on bivariate magnitudes calculated from the signals, it is possible to measure the personalised physiological effects of training sessions after days or weeks of treatment and hence to re-position the subject possibly in another location of the stress level plane which started from IS.

It is advised that the subject could do this exercise on a regular base (i.e. once per day) and hence there is the possibility to monitor his/her level of stress from the responses of his/her vital signs. After a proper coaching it is believed that through such exercises the subject could monitor his/her level of stress and these objective measurements could be important elements for helping physicians in a better diagnosis and treatment follow-up of stress related cardiac pathologies.

## 3 CONCLUSIONS

Take Care Concept has developed original applicative tools, implemented through advanced technological implementations (textiles, microelectronics storing and controlling devices, modern wireless communication protocols, etc) in order to provide a precious instrument of prevention of cardiovascular pathologies. The basic philosophy is to detect from subject’s vital signs physiological and clinical parameters even in continuous recordings, by employing easy-to-use wearable devices which allow comfortable home or ambulatory applications.

## REFERENCES

Atlas Task Force of American Sleep disorders Association 1992. EEG arousal: scoring rules and examples. *Sleep* 15: 174-184.

Sforza E., Jouny C., Ibanez V., 2000. Cardiac activation during arousal in humans: further evidence for hierarchy in the arousal response. *Clin Neurophysiol* 111:1611-1619.

Guyton AC., 2000. Textbook of medical physiology, W.B. Saunder Company10th edition.

Young T., Peppard PE., Gottlieb DJ., 2002. Epidemiology of obstructive sleep apnea. *Am J REspir Crit Care Med.* 165:1217-1231.

American Psychiatric Society (APA) , 1994. Diagnostic and Statistical Manual of Mental Disorders IV (DSMIV). *American Psychiatric Society*. Washington, DC, 4th edition.