Proceedings of the 29th Annual International
Conference of the IEEE EMBS
Cité Internationale, Lyon, France
August 23-26, 2007.

Mapping the Human Body for Vibrations using an Accelerometer

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Abstract—**In this paper, an accelerometer is used to measure the vibration of the neck and thorax, in order to detect important signals that can be used in the diagnosis of sleep apnoea. Accelerations produced by the heart signals, the breathing movement and the snoring sounds are detected by an accelerometer attached to the skin. Mean power levels of the signal in different frequency bands are used to map the surface of the neck and thorax, where the accelerometer has been positioned in 15 different locations. A program in Matlab is used to fit this surface plot. Getting an adequate location for the accelerometer is a clear help to the diagnosis of sleep apnea.**

I. Introduction

Sleep apnoea is a disease consisting of short breath interruptions during the dream process (called apnoeas), each one with a minimum duration of 10 seconds, and occurring continuously through all night 0[2][3]. People suffering this disorder do not rest well while sleeping, because they partially wake up on each apnoea while trying to breath. Next morning they may not remember anything about those interruptions. The most common type of this disorder is the obstructive sleep apnoea (OSA), which is produced by the relaxation of the soft tissue located in the back side of the throat, blocking the air way and partially awaking the patient. The signals coming from the heart, the breathing movement or effort, and the snoring sounds, are key elements for the diagnosis of OSA [4][5], and they can be captured using an accelerometer. The accelerometer gives out an analog voltage signal which is directly proportional to its own acceleration. Thus, an accelerometer attached to the skin surface transforms the accelerations generated by the different vibrations coming from the body, into an electrical signal that can be measured, transmitted and processed. The heart, the breathing effort and the snoring sounds generate such vibrations. On this paper the signal generated by an accelerometer positioned on 15 different locations over the neck and the thorax is obtained, and a Matlab program is used to read, filter, and process the signal, calculate mean power values, obtaining some plot and surface graphs, and finally mapping the area in order to find out the optimum position for the accelerometer. Finding the most adequate location for an accelerometer to receive the vibrations is probably the most important factor in obtaining, transmitting and processing those signals efficiently, and thus it may be of a great help to the medical diagnosis of the OSA.

Manuscript submitted March XX, 2007.

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II. Materials and Procedures

For the performance of this work we have selected 2 units of a piezoelectric accelerometer with integrated electronics (TEDS) Endevco model 752A12. A portable data acquisition unit from Brüel & Kjaer, model Pulse Front-End 3560, is used to capture the signal. A mean-age healthy man has also been used for this experiment. The sampling frequency of the accelerometer signal is 8192 Hz.

1) *Determine Accelerometer Positions*: Fifteen locations have been selected on the neck and thorax, as showed in Figure 2 and explained in Table I.

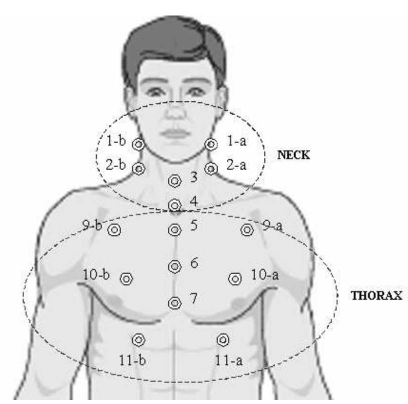

Fig. 2. Locations for the accelerometers

TABLE I
DESCRIPTION OF ACCELEROMETER POSITIONS

NECK (6 locations):	
1a-1b:	Sub-mandible angle
2a-2b:	Side neck
3:	Front neck, thyroid cartilage
4:	Supra-sternum cavity
THORAX (9 locations):	
5:	Upper STERNUM
6:	Medium STERNUM
7:	Lower STERNUM
9a-9b:	2nd RIB space
10a-10b:	5th RIB space
11a-11b:	7th RIB space

2) *Signal Capture:* The signals of the accelerometer in all positions are read in 8 pairs and saved into 8 "wav" files with two signals each:

File 1: 1a-1b
File 2: 2a-2b
File 3: 3-4
File 4: 5-6
File 5: 5-7
File 6: 9a-9b
File 7: 10a-10b
File 8: 11a-11b

3) *Signal Processing*: Each signal is split in 3 different frequency bands:

Breathing signal: 0.1 – 0.5 Hz
Heart signal: 0.5 – 3 Hz
Snoring signal: 3 – 500 Hz

This is performed by applying 3 different filtering and down sampling processes, as showed in Figure 3, to avoid anti-aliasing effects and discard unnecessary samples according to the Nyquist rule:

a) Low pass filtering at 512 Hz and down sampling at 1024 samples per second.

b) Low pass filtering at 4 Hz and down sampling at 8 samples per second..

c) Low pass filtering at 0.5 Hz and down sampling at 1 samples per second.

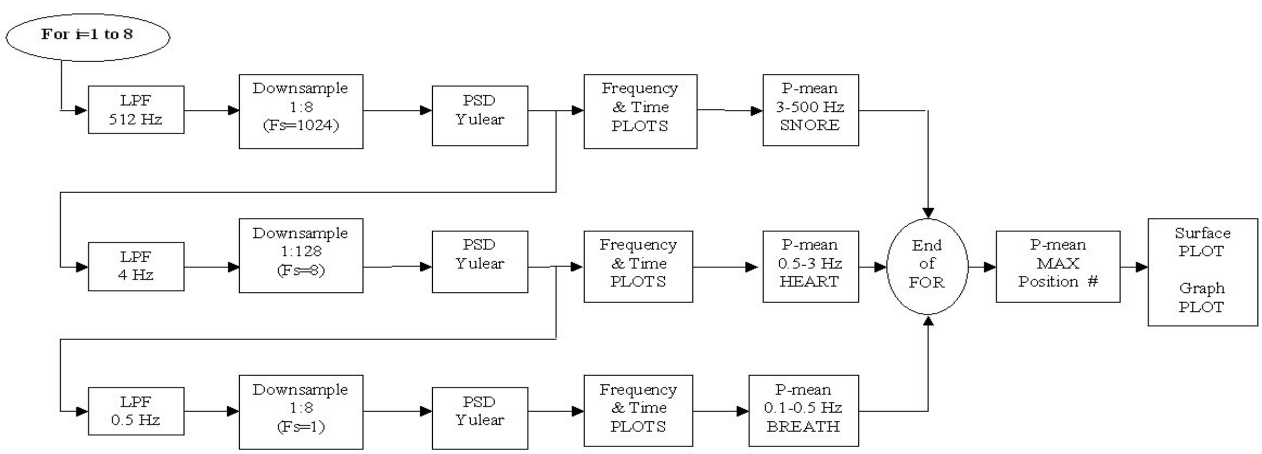

Fig. 3. Flow chart of the Matlab program used to process the signal and map the surface.

Three mean power calculations are performed, one for each frequency band. So we have 16 values on each band (8 pairs). Since location number 5 is repeated in two files (5-6 and 5-7), the mean power of both values are calculated and used.

4) *Surface Mapping*: Cartesian coordinates of each accelerometer position are calculated, and three surfaces are adjusted using the previously calculated mean power values on each position, one surface for each frequency band. Using this method, a surface figure with the desired vibration mapping is presented.

Looking at the surface mapping and the mean power values, we will be able to determine which locations offer the most powerful signals in the 3 frequency bands.

The Matlab program that has been developed with this work implements steps 3 and 4 above (signal processing and surface mapping), and its flow chart has been sketched in Figure 3.

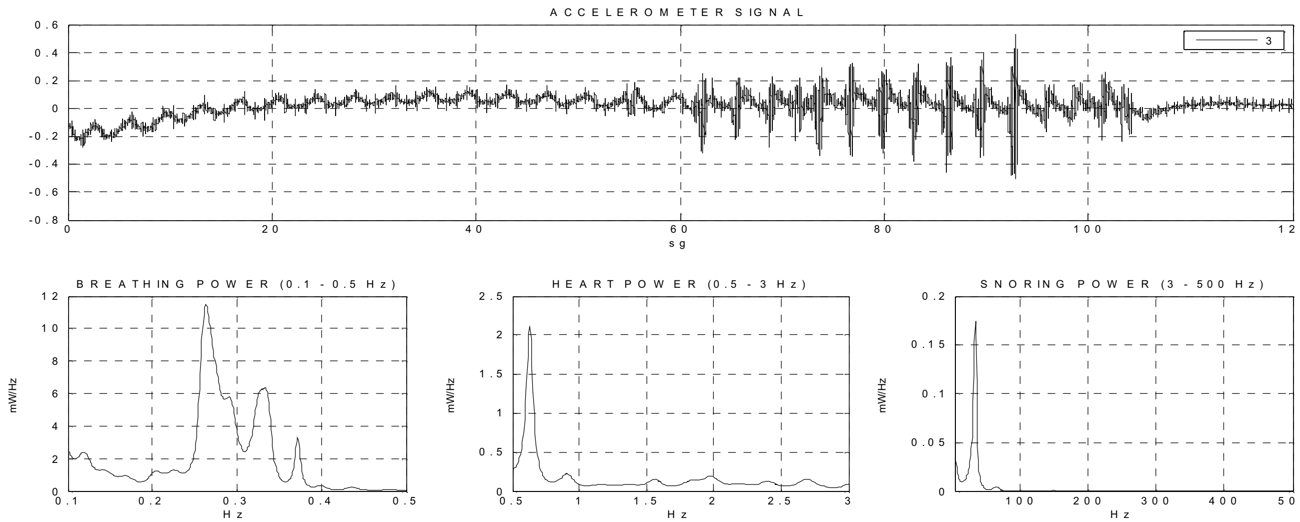

Fig. 4. Accelerometer signal from location number 3. The maximum values of mean power is found in the following frequencies: 0.2383 Hz (breathing), 0.5234 Hz (heart) and 34 Hz (snore).

III. Results

1) *Power Spectrum*: As a representative example, the signal from position number 3 is presented in Figure 4.

For the power spectrum, the "pyulear" (order 40) has been used because of the graph smoothness.

2) *Positions with Maximum Power*: The values of the mean power, in dB/Hz, are represented in the surface plot of Figure 5. The highest power levels occur in: position 11a for breathing and heart, and position 3 for snoring.

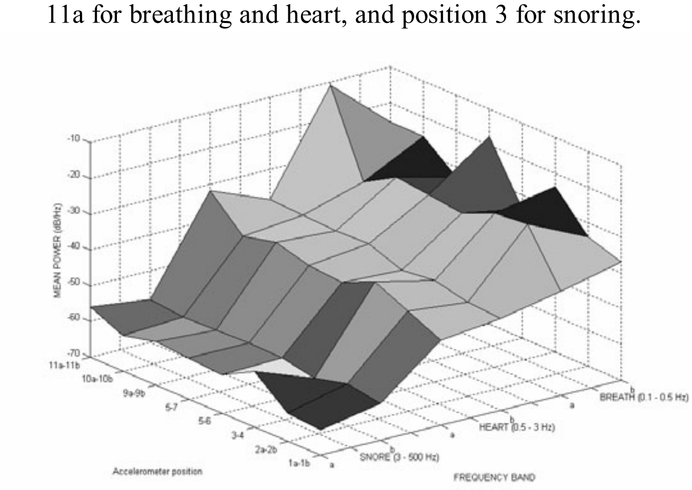

Fig. 5. Surface representation of the mean power values of the accelerometer signal. Z Values are drawn against accelerometer position and frequency band. We can observe the general difference in the power levels of each frequency band.

3) *Vibration map*: With the goal of a good visualization of the given results, and in order to find out a good position for the accelerometer in terms of zones instead of actual locations, position coordinates have been assigned to each location, and a surface map for each frequency band has been fitted to the obtained values. The results can be observed in Figure 6, 7 and 8.

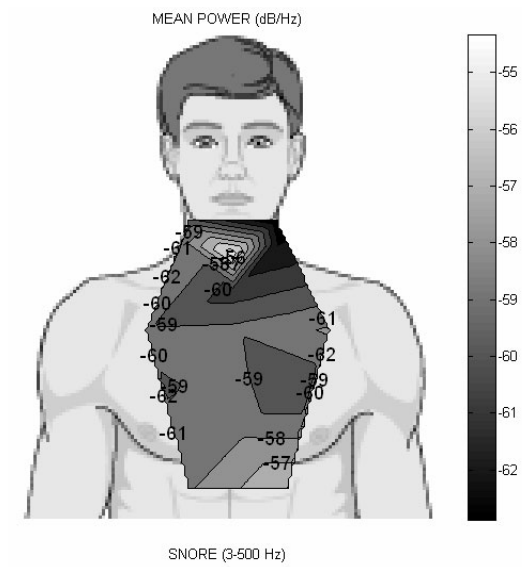

Fig. 6. Mapping of the neck and thorax: SNORE.

In Figure 6 we can see that maximum dB values in snoring occurs at the front neck, thyroid cartilage, with a power level of -56, decreasing with the distance from there, although a -57 zone is also encountered around the left seventh rib interspace. To obtain these vibration maps, different gray tones have been assigned to each mean power level, so instead of looking for the position with the highest power level, we will be looking for the approximate area of the body where the accelerometer could be positioned in order to get a high power signal, maximum if all possible. At the same time, and looking at the areas with a similar gray tone, we can look for alternative locations of similar mean power values, within certain dB ranges.

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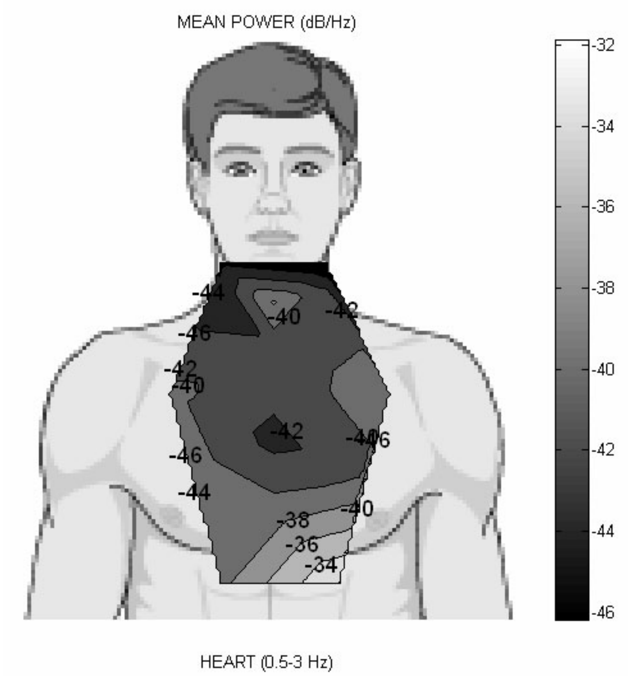

Fig. 7. Mapping of the neck and thorax: HEART.

For the heart and breathing signals, the differences from the maximum dB to the rest of values are more significant. Figures 7 and 8 show absolute maximum dB values of –34 and –15 dB/Hz, respectively, both at the same location (left seventh rib interspace).

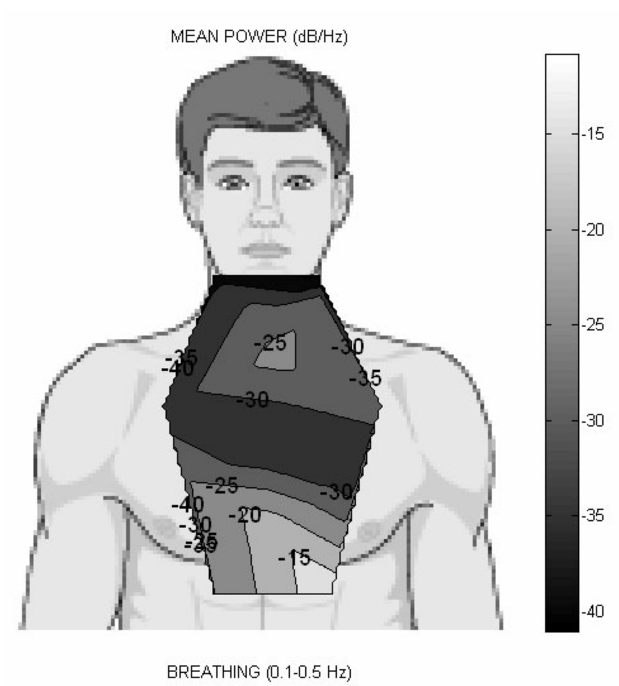

Fig. 8. Mapping of the neck and thorax: BREATHING.

On those figures, a relative maximum can also be observed around the front neck and in other areas too, but their dB values are significantly different from the absolute maximum values in the ribs area.

IV. Conclusion

An accelerometer attached to the human skin surface on certain spots of the neck and thorax areas has been used to get one single analog low frequency signal (below 500 Hz), which is treated in Matlab to split it in three frequency bands: snoring, heart, and breathing. The signal has been processed and three vibration maps have been obtained, one for each frequency band. Looking at these maps in detail, we can conclude that the locations where the most powerful signals could be obtained are those surrounding the left seventh rib interspace, the thyroid cartilage in the front neck, and the left second rib interspace. This information can be very helpful in OSA diagnosis [6][7]. If we want to focus on the heart or breathing signals, the ideal location of the accelerometer would be around the left seventh rib interspace, but if we want to focus on the snore signal, we should better locate the accelerometer around the thyroid cartilage in the front neck. Moreover, looking at the three vibration maps together, we can see that the left seventh rib interspace is most effective if we are looking for all frequency bands together.

References

[1] American Sleep Disorders Association Task Force, "The Chicago criteria for measurements, efinitions, and severity of sleep related breathing disorders in adults," in Assoc. Professional Sleep Soc. Conf., New Orleans, LA, 1998.

[2] C. Guilleminault and M. Partinen, Obstructive Sleep Apnea Syndrome,Clinical Diagnosis & Treatment. New York: Raven, 1990.

[3] Ross SD, Allen IE, Harrison KJ, et al. Systematic review of the literature regarding the diagnosis of sleep apnea: evidence report/technology assessment No. 1. Rockville, MD: Agency for Health Care Policy and Research; February 1999; AHCPR Publication No. 99–002.

[4] P.Várady, T. Micsik, S. Benedek, Z. Benyó, A Novel Method for the Detection of Apnea and Hypopnea Events in Respiration Signals, IEEE Transactions on Biomedical Engineering, Vol. 49, No. 9 (September 2002), pág. 936.

[5] M. Cabrero, E. Hernández, V. Moret, Intelligent Diagnosis of Sleep Apnea Syndrome, IEEE Engineering in Medicine and Biology Magazine, (March-April 2004), pág. 72.

[6] P. Várady, L. Nagy, L. Szilágyi, On-Line Detection of Sleep Apnea during Critical Care Monitoring, IEEE Proceedings of the 22nd Annual EMBS International Conference, Chicago, IL, USA (2000).

[7] H. Peter, T. Podszus, and P. von Wichert, Sleep Related Disorders and Internal Diseases. New York: Springer-Verlag, 1987, pp. 101–107.