Automatic and Accurate Non-contact Obstructive Sleep Apnea Detection using Wavelet Information Entropy Spectrum

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***Abstract*— An accurate non-contact novel detection method for obstructive sleep apnea (OSA) has been developed and will be presented here. Typically, non-contact measurement is preferred for babies, brutally burnt patients, and patients with respiratory contagious diseases, etc. The developed method is based on wavelet information entropy concepts that would clearly classify apnea by the strong abnormality, complex structure and disorder of the patient's respiratory signal. The accuracy of this method has been experimentally validated, and demonstrated over 93% accuracy using a bio-radar.**

Keywords—OSA; wavelet information entropy; bio-radar

I. INTRODUCTION

Clinically, when the breath of a patient with obstructive sleep apnea (OSA) stops on an average of five times per hour or more and last for more than 10 seconds, it could be identified as sleep apnea obstruction. This obstruction level could cause respiratory failure and eventually cerebrovascular serious incidents. Accurate detection should help in effective diagnosis; then proper treatment and subsequently prevention of potential complications. For more effective and stable diagnosis, we need to thoroughly investigate the profound core features related to the human physiological symptoms.

To detect cases of sleep apnea obstruction, waveform characteristics of the acquired breathing signal are analyzed. These characteristics include the breathing signal amplitude, its rate, and variability with time. Numerous analyses [1] have been carried out using the amplitudes of the wavelet decomposition itself, however, this analysis is still hindered by the complex detection environment, the variability of the breathing signal itself and its low energy content.

Here, we propose an effective sleep apnea detection algorithm based on wavelet information entropy spectrum. The proposed method is robust and can detect these weak respiratory signals, any changes with time. The algorithm is very sensitive to respiratory abnormality as well.

II. SYSTEM AND METHOD

A. Bio-radar System

A 24 GHz CW bio-static radar is used in this experiment, where the maximum transmitted signal using microstrip patch antennas for transmission and reception is 200 mW. For safety, the patient is lying in bed facing the radar at a 2.5 m distance away from the radar. A commercial PowerLab System (AD instrument, Bella Vista, Austrilia) was initially used but more compact systems have been developed as well and will be discussed in our presentation.

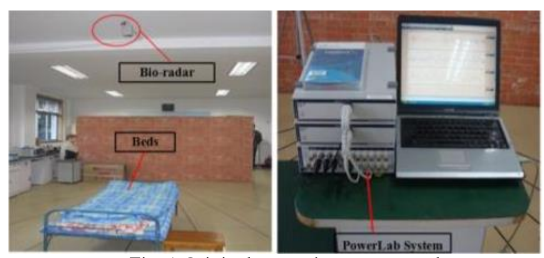


Fig. 1 Original setup sleep apnea study setup

B. Wavelet Information Entropy Algorithm

The acquired respiratory signal is filtered first using a low pass filter with a cut-off frequency of 0.9 Hz to de-noise the signal then the baseline drift is removed with a time window length of 2048. Second, a multi-resolution analysis is carried out using Mallat algorithm [4], followed by extracting the wavelet information entropy spectrums using wavelet information entropy algorithm. Subsequently, sleep apnea disorder is identified based on pre-determined threshold level.

It is anticipated that the entropy of the respiratory signal of a patient with sleep apnea disorder will significantly increase upon breathing due to its instability, variability, and complexity of its ingredients according to Shannon's theorem. Based on [2] and [3], it suggests that the wavelet analysis combined with the wavelet entropy are more precise in resolving the nonlinear partial change of the non-stationary breathing signal and should lend accurate detection results.

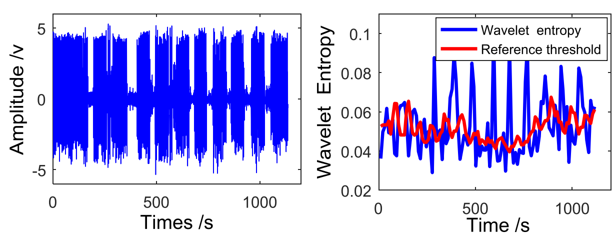
For analysis, we run the multi-resolution algorithm first, then the wavelet information entropy value of 1D respiratory signal second which is denoted as the SWT, in every time window using the following formula:

$$S_{WT} = -\sum_{j=1}^{J+1} p_j log_2 p_j = -\sum_{j=1}^{J+1} (E_j / E_{sum}) log_2 (E_j / E_{sum}) \quad (1)$$

where P_j indicates the signal energy distribution at ***j-th*** scale according to Mallat algorithm [4], using the mother wavelet of *db1*, while E_{sum} represents the sum of energy in all the J scales within a given time window after wavelet decomposition. Meanwhile, an adaptive reference threshold for the wavelet entropy is utilized as indicated in [5].

III. EXPERIMENT

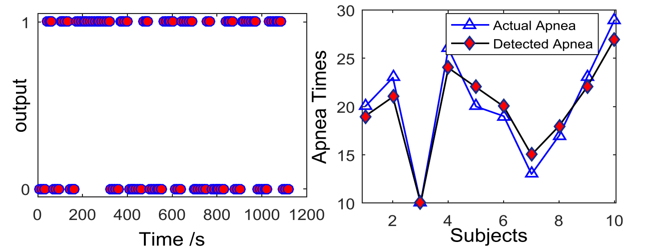
Based on a 10 -participating patients sample in a sleep apnea disorder study, where each event was recorded for an hour. To facilitate observing our results and conclusions, we only show results for 20 minutes (1200 seconds) for each patient. Fig. 2 (a) shows the original bio-respiratory signal of one subject; while the associated wavelet entropy (blue) and the reference threshold (red) are shown in Fig. 2 (b). Within the indicated 20 minutes, we can notice the occurrence of 10 sleep apnea obstruction events with relatively low amplitudes and distorted waveforms. Alternatively, in the wavelet domain shown in Fig. 2 (b), the wavelet entropy increases sharply when an apnea obstruction case occurs. It is clear here that the number of sleep apnea events could be distinctly identified and recognized by observing the wavelet entropy. An algorithm has been developed that utilizes an adaptive reference threshold to detect the apnea occurrence and classify it as a sleep apnea disorder case when the wavelet entropy significantly exceeds the reference threshold for more than 5 times per hour and each lasts for more than 10 seconds.



(a) (b)

Fig. 2: (a) Original Bio-radar respiratory signal. (b) The processing results of the novel method.

Fig. 3 (a) shows the classification (judgement) output of the 10 patients experiment. Where "0" represents a normal state, and "1" represents an apnea occurrence. This conventional algorithm which is based on respiration amplitude only indicated 11 sleep apnea events, including one extra (i.e. false) detection due to the influence of the strong interference and instability of the radar signal. Meanwhile, results for the 10 patient's experiments using our detection algorithm are shown in Fig. 3 (b), and they are consistent with the actual conditions but not identical (i.e. > 93% accuracy) in this experiment.



(a) (b)

Fig. 3.The apnea classification results of the bio-radar signal: (a) Classification output, (b) Experimental results of 10 patients.

Finally, the accuracy of the entropy algorithm is quantized using the following formula:

$$P_s = \sum_{i=1}^{10} P_s^{'}(i) = \sum_{i=1}^{10} |1 - |\frac{N_D(i) - N_A(i)}{N_A(i)}|| * 100\% \quad (2)$$

where the $N_D(i)$ denotes the apnea number of the $i-th$ subject detected by the novel algorithm and $N_A(i)$ represents the actual apnea times. The method indicated an accuracy exceeded 93%.

IV. CONCLUSION

The combined wavelet and wavelet information entropy spectrum method is sensitive to the nonlinear respiration signal's instability, variability, and complexity of its ingredients especially when sleep apnea obstruction occurs. Definitely, more data from numerous obstructive sleep apnea patients while covering wide range of ages, and at different illness stages to conduct a fully meaningful automatic apnea detection experiment. Here, we are expanding these experiments using a bio radar to test the stability of this method, select an appropriate threshold commensurate with the apnea obstruction stage and patient age, and to study other types of apnea disorder cases.

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