SEPARATION OF CRACKLES FROM VESICULAR SOUNDS USING WAVELET PACKET TRANSFORM

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ABSTRACT

Crackles are discontinuous adventitious lung sounds with an explosive and transient character, and occur frequently in pulmonary diseases. They are the most important parameter for the diagnosis. This paper presents a new filter for automatic separation of the crackles from vesicular sounds. The proposed filter is based on the wavelet packet transform and applies two thresholds, which are defined in time-domain and frequency-domain respectively, to wavelet coefficients to achieve the separation task. This filter is more accurate and efficient compared to its rivals. Experimental results are given in detail and demonstrate its excellent performance.

1. INTRODUCTION

The respiratory sounds include all sounds related to respiration and can be classified into normal breath sounds and adventitious sounds. The adventitious sounds, which are superimposed on breath sounds, are usually associated with certain pulmonary diseases such as asthma, pneumonia or pulmonary fibrosis. The analysis of adventitious sounds provide the useful information for the pathological diagnosis [1]. Adventitious sounds are subdivided into two classes : continuous (stationary) adventitious sounds and discontinuous (nonstationary) adventitious sounds. The continuous adventitious class contains wheezes and rhonchus, which have a duration more than 250ms [2]. The wheezes have a dominant frequency of 400Hz or more, while rhonchus have a dominant frequency about 200Hz or less ; The discontinuous adventitious class contains the "fine crackles" and "coarse crackles". The crackles are characterized as transient, explosive sounds which have a duration no more than 20ms [3]. The fine crackles are high-pitch crackles which have a relatively short duration. They are exclusive inspiratory events that tend to occur in the mid-to-late inspiration [4]. The coarse crackles are low-pitch crackles which have a relatively long duration, which often occur in the early inspiration and in the expiration as well [4].

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The crackles are often defined by their time-domain features : the initial deflection width (IDW) and the two-cycle duration (2CD). According to the proposition of ATS (*American Thoracic Society*), the mean duration of IDW and 2CD of fine crackles are 0.7ms and 5ms, and those of coarse crackle are 1.5ms and 10ms respectively [5]. The separation of crackles from vesicular sounds is an important process in the analysis of respiratory sounds. It can provide a better evaluation of the crackle's character. A number of methods have been proposed for this purpose : the non-linear separation stationary-nonstationary filter (ST–NST) [6] and its several modified version [7, 8], the wavelet transform-based stationary-nonstationary filter (WTST–NST) [9] and the generalized fuzzy rule-based stationary-nonstationary filter (GFST–NST) [10]. Among these methods, the WTST–NST filter gives the best performance of separation, but complex to be implemented in a real-time analysis system. In this paper we propose a wavelet packet transform-base filter (WPST–NST) which presents a faster and more accurate separation.

2. FILTERING ALGORITHM

The proposed algorithm is a wavelet domain filtering technique, based on the fact that explosive peaks in the time domain (crackles) have large coefficients over many wavelet levels, while those of the background (vesicular sounds) decrease to zero with increasing scale [9]. The basic idea is to separate coefficients related to crackles from those of the vesicular sounds by thresholding in the wavelet domain. The WTST–NST is an iterative method (analysis-synthesis) based on the hard thresholding of the wavelet coefficients [9]. The proposed WPST–NST method proceeds by double thresholding but it's not iterative.

2.1. Wavelet Packet Transform

The wavelet packet transform (WPT) proposed by Coifman and Wickerhauser [11] can be interpreted as an extension of the wavelet transform (WT). Unlike the discrete-time wavelet transform which is obtained by iterating the low pass branch, the discrete-time wavelet packet transform is obtained by iterating either branch at any level of the tree analysis. The wavelet packet transform decomposition is equivalent to multichannel filtering, where the number of filters and their frequency-bands are related to the level tree.

For a given level j, the WPT decomposes the input (respiratory) signal $x[n]$ into 2^j subbands corresponding to wavelet coefficient sets $w^j_{k,m}$.

$$w^j_k[m] = WPT\{x[n], j\} \qquad n = 1, \ldots, N \tag{1}$$

In this application, we fix $j = 5$. Thus, $w^5_{k,m}$ defines the m^{th} coefficient of the k^{th} subband, where $m = 1, ..., N/2^5$ and $k = 1, ..., 2^5$.

2.2. Algorithm Description

In this section, we summarize the proposed algorithm by the following pseudo-code :

1. Split signal into a short length ($L = 1024$) and overlapped (75%) segments.
2. Apply the WPT to each segment.
3. Score the coefficients $w^j_k(m)$ whose amplitude exceeds the threshold $\mathrm{S1}^j$ which is defined by :

$$\mathrm{S1}^j_k = P_1.\sigma^j_k \tag{2}$$

where σ^j_k is the standard deviation of coefficients corresponding to the k^{th} subband of the level j. The coefficient P_1 is empirically fixed to 0.75.
Thus, the scoring $M^j_k[m]$ of one coefficient $w^j_k[m]$ is defined as :

$$M^j_k[m] = \begin{cases} 1 & \text{if } |w^j_k[m]| \geq \mathrm{S1}^j_k \\ 0 & \text{else} \end{cases} \tag{3}$$

4. Quantify the number of scoring related to each coefficient $w^j_k[m]$ for all subbands k of the level j :

$$N^j[m] = \sum_{k=1}^{2^j} M^j_k[m] \tag{4}$$

Define a second threshold $\mathrm{S2}^j_k$ related to the mean numbers of scoring of the level j :

$$\mathrm{S2}^j = P_2.\frac{1}{L/2^j} \sum_{m=1}^{L/2^j} N^j[m] \tag{5}$$

The coefficient P_2 is fixed experimentally to 2.

5. Separate the coefficients $w^j_k[m]$ in two classes : stationary $\mathrm{S\_ST}^j_k[m]$ and nonstationary $\mathrm{S\_NST}^j_k[m]$ according to the values of the thresholds $\mathrm{S1}^j_k$ and $\mathrm{S2}^j_k$.
Initialization : $\mathrm{S\_NST}^j_k[m] := 0$; $\mathrm{S\_NST}^j_k[m] := 0$;
if $|w^j_k[m]| \geq \mathrm{S1}^j_k$ and $\mathrm{N}^j[m] \geq \mathrm{S2}^j$, *then*

$$\mathrm{S\_NST}^j_k[m] = w^j_k[m] \tag{6}$$

else

$$\mathrm{S\_ST}^j_k[m] = w^j_k[m] \tag{7}$$

6. Select the best basis tree from the WPT coefficients $w^j_k[m]$.
7. Stationary and nonstationary signals are obtained with the inverse wavelet packet transform(IWPT) of the corresponding coefficients $\mathrm{S\_ST}^j_k[m]$ and $\mathrm{S\_NST}^j_k[m]$.

A schematic representation of this algorithm is given in Figure 1.

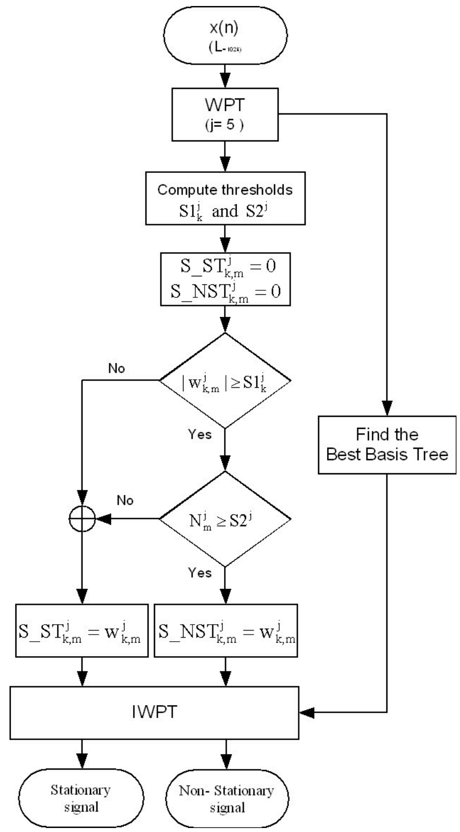

Fig. 1. A schematic representation of the WPST–NST filtering technique.

3. EXPERIMENTAL RESULTS

The proposed WPST–NST filtering technique has been tested and compared to the WTST–NST method to separate fine and coarse crackles from vesicular sounds. Our database is constructed from 18 classified respiratory sounds obtained from three databases [12, 13, 14]. This database includes 5 vesicular sounds with fine crackles (FC01, FC02, FC03, FC04 and FC05), 5 vesicular sounds with coarse crackles (CC01, CC02, CC03, CC04 and CC05), 4 normal sounds (NS01, NS02, NS03 and NS04) and 4 wheezing sounds (WN01, WN02, WN03 and WN04). These respiratory sounds are sampled at 5000 Hz, normalized and subdivided into short (1024) and overlapped (75%) segments. The WPT is computed using the Daubechies-8 wavelet for 5^{th} level decomposition tree. The filtering algorithms are implemented on an IBM-PC (Pentium-4, 1.8GHz), using the programming language Matlab.

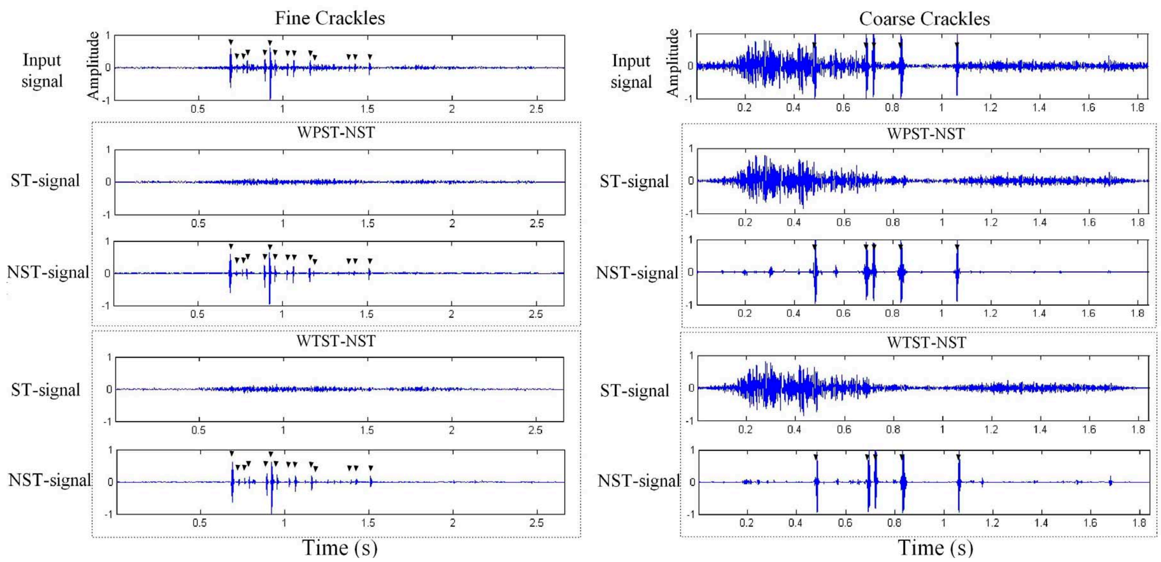

Fig. 2. Comparison between performances of WPST–NST and WTST–NST. The arrowheads in the input trace indicate waves which we visualy identify as crackles, and those in nonstationary outputs are their counterparts.

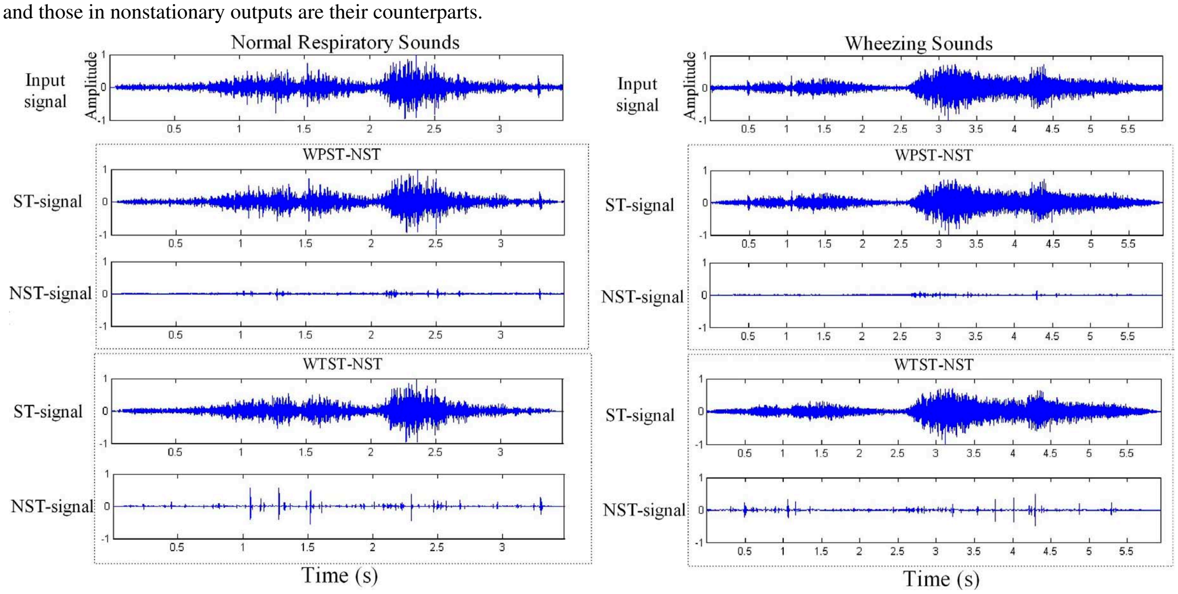

Fig. 3. Comparison between performances of WPST–NST and WTST–NST for normal and wheezing sounds.

3.1. Visual recognition

The filtering performances of the proposed method WPST–NST are compared those of WTST–NST using the vesicular sounds including crackles. Figure 2 shows an example of two vesicular sounds with fine and coarse crackles separated into stationary (ST–Signal) and nonstationary (NST–Signal) components. We marked the position of waves identified visually as crackles and compared them with nonstationary signal separated automatically by the filters. The waves separated by the filters correspond very well with those identified as crackles. For a quantitative evaluation, we define the separation rate (SR) as :

$$SR = \frac{SN}{RN} * 100\% \quad (8)$$

where RN is the the real number of crackles in the vesicular sounds, and SN is the correctly separated number of crackles. Table 1 gives the separation rate (SR) and the required time (RT) of the filtering methods (WPST–NST and WTST–NST) for 10 vesicular sounds including crackles. The separating rates of these methods WP are comparable ($\text{SR}_{\text{WP}} = 98.3\%$, $\text{SR}_{\text{WT}} = 98.9\%$), but the proposed WPST–NST is 5 times faster than WTST–NST method ($\text{RT}_{\text{WP}} = 46.1s$, $\text{RT}_{\text{WT}} = 226s$).

Table 1. Performances of the separating filters WPST–NST and WTST–NST, tested on fine crackles (FC) and coarse crackles (CC) sounds.

Respiratory sounds	Real number of crackles	WPST-NST			WTST-NST		
		Correctly separated number	Separation rate SR_{WP} (%)	Required time RT_{WP} (s)	Correctly separated number	Separation rate SR_{WT} (%)	Required time RT_{WT} (s)
FC01	19	19	100	2.6	19	100	12.5
FC02	21	21	100	2.5	21	100	12.2
FC03	18	17	94.4	2.3	18	100	13.6
FC04	14	14	100	3.3	14	100	16.4
FC05	43	42	97.7	12.1	43	100	57.9
CC01	23	23	100	6.6	22	95.7	31.3
CC02	20	19	95.0	5.4	19	95.0	26.4
CC03	9	9	100	5.3	9	100	25.8
CC04	8	8	100	4.3	8	100	21.7
CC05	7	7	100	1.7	7	100	8.2
Total	182	179	98.3	46.1	180	98.9	226

Table 2. Performances of the separating filters WPST–NST and WTST–NST, tested on normal sounds (NS) and wheezing sounds (WS).

	SNR_{WP}	SNR_{WT}		SNR_{WP}	SNR_{WT}
NS01	21.3	14.2	WS01	27.2	17.0
NS02	20.4	13.6	WS02	20.6	21.5
NS03	23.3	18.6	WS03	15.7	19.4
NS04	24.4	20.5	WS04	25.2	14.1
	Normal sounds			wheezing sounds	

3.2. Quantification of the noise signal

The separating filters can be used as an input of a complete system that can detect continuous (wheezes, rhonchus) and discontinuous (fine and coarse crackles) adventitious respiratory sounds. Figure 3 shows an example of two respiratory sounds (normal and wheezing) separated into stationary (ST–Signal) and nonstationary (NST–Signal) components. We can see that the noise introduced by the proposed method WPST–NST is less than that introduced by WTST–NST. To evaluate the performances of these methods to conserve intact the stationary sounds (normal and wheezing sounds), we define the signal to noise ratio (SNR) as :

$$SNR = 10 \log_{10} \left(\frac{P_X}{P_N} \right) \quad (9)$$

where P_X is the power of the input continuous signal (normal, wheezing) and P_N is the power noise corresponding to the nonstationary output of the filter.
Table 2 gives the signal to noise ratio (SNR) of the filtering methods (WPST–NST and WTST–NST) for 4 normal respiratory and 4 wheezing sounds. It is obvious that the stationary sounds are well preserved with the proposed method WPST–NST than with the reference method WTST–NST.

4. CONCLUSION

A new algorithm based on the wavelet packet transform is proposed for the stationary-nonstationary separation schema (WPST–NST). This method is 5 times faster than the reference method (WTST–NST) with comparable high performance to separate crackles from vesicular sounds. Furthermore, the proposed technique is more efficient to preserve the characteristics of the stationary signals (normal and wheezing sounds).

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