Biomedical Signal Processing and Control 26 (2016) 64–68

Contents lists available at ScienceDirect

Biomedical Signal Processing and Control

journal homepage: www.elsevier.com/locate/bspc

Technical note

Shift selection influence in partial cycle spinning denoising of biomedical signals

Miguel A. Rodriguez-Hernandez*

ITACA, Universitat Politècnica de València, Camino Vera s/n, 46022 Valencia, Spain

ARTICLE INFO

Article history:
Received 2 June 2015
Received in revised form 1 December 2015
Accepted 2 December 2015

Keywords:
Denoising
Cycle spinning
Ultrasonics
Biomedical signals
Wavelets

ABSTRACT

Denoising of biomedical signals using wavelet transform is a widely used technique. The use of undecimated wavelet transform (UWT) assures better denoising results but implies a higher complexity than discrete wavelet transform (DWT). Some implementation schemes have been proposed to perform UWT, one of them is Cycle Spinning (CS). CS is performed using the DWT of several circular shifted versions of the signal to analyse. The reduction of the number of shifted versions of the biomedical signal during denoising process used is addressed in the present work. This paper is about a variant of CS with a reduced number of shifts, called Partial Cycle Spinning (PCS), applied to ultrasonic trace denoising. The influence of the choice of PCS shifts in the denoised registers quality is studied. Several shifts selection rules are proposed, compared and evaluated. Denoising results over a set of ultrasonic registers are provided for PCS with different shift selection rules, CS and DWT. The work shows that PCS with the appropriate choice of shifts could be the best option to denoise biomedical ultrasonic traces.

1. Introduction

Ultrasonic equipment is very often used in medical diagnosis. In most cases the acquired biomedical ultrasonic signals are corrupted with noise coming from the reflection of the ultrasonics by the tissue's microstructure. This noise shares spectrum with the ultrasonic signal and is usually non-stationary. The reduction of noise in ultrasonics has been widely discussed and different techniques based on spatial or frequency diversity have been proposed [1].

Wavelet transform has been used for denoising different kinds of signals including biomedical ultrasonic traces [2–6]. The most common denoising techniques are based on discrete wavelet transform (DWT) defined as [7]

$$\mathrm{DWT}_{x(k)}(j,n)=\sum_{k=-\infty}^{\infty}x(k)\frac{1}{\sqrt{2^j}}\psi\left(\frac{k}{2^j}-n\right)\quad j,n\in Z \tag{1}$$

where $x(n)$ is the discrete time signal to analyze, $\psi(t)$ the mother wavelet, $n2^j$ the shift and j the decomposition level.

DWT is not a shift-invariant transform and produces different denoise results depending on the shift. To overcome this limitation undecimated wavelet transform (UWT) was introduced in ultrasonic denoising problems [8–12].

$$\mathrm{UWT}_{x(k)}(j,n)=\sum_{k=-\infty}^{\infty}x(k)\frac{1}{\sqrt{2^j}}\psi\left(\frac{k-n}{2^j}\right)\quad j,n\in Z \tag{2}$$

Basic denoising processing using wavelets is performed in three stages. In the first stage the wavelet coefficients of the register to denoise are obtained. The second stage performs the denoising process over the wavelet coefficients, usually by using thresholding. Different types of thresholding can be used, usually soft or hard thresholding, and different threshold selection rules can be implemented, of which SURE, Universal and Minimax are the most used [13–15]. In the final stage, the denoised version of the signal is recovered performing the inverse wavelet transform with the modified wavelet coefficients.

Cycle spinning (CS) is a method of UWT and has been previously used for denoising purposes [8–12]. The CS algorithm performs DWTs of shifted versions of the register to analyze, denoise the wavelet coefficients, make the inverse DWTs and perform a mean to obtain the final denoised ultrasonic *A*-scan. The denoised traces show better characteristics using CS than using DWT, but the complexity in the CS case is much greater than in the DWT one.

CS analysis generates redundant coefficients. In [16,17], it was shown that the wavelet coefficients were repeated when the number of shifts involved in CS were higher than 2^J, with J being the maximum decomposition level in DWT analysis. More recently, CS

---

* Corresponding author. Tel.: +34 862787051286.
E-mail address: marodrig@upvnet.upv.es

http://dx.doi.org/10.1016/j.bspc.2015.12.002
1746-8094/

wavelet coefficient redundancy has been studied in [11]. Based on this redundancy, the use of a reduced version of CS for denoising with the processing of only a limited number of shifts is studied in this work. This algorithm is called Partial Cycle Spinning (PCS).

PCS involves a selection of shifts. One previous work [10] proposed the selection of shifts in a random way for ultrasonic *A*-scan denoising purposes. Although random selection of shifts generated good denoising results, in this work the performance obtained with different selection rules of the PCS shifts and the influence of the selected shifts in the final denoised trace quality were studied. This current paper compares three types of shift selection: random selection, consecutive selection, and fixed sparse selection. The obtained results are compared and evaluated taking as reference the results obtained using a complete CS denoising procedure.

This paper is set out in the following manner. Section 2 describes the PCS denoising method. Section 3 describes the experiments to evaluate the variability of PCS and discusses the results obtained. The conclusions are presented at the end of the paper.

2. Partial Cycle Spinning denoising

PCS analysis is based on the calculation of the DWT of a reduced number of shifted versions of the trace to be denoised. The wavelet coefficients obtained by performing the PCS analysis contain several sets of DWT coefficients, one set for each shift. In fact, the PCS process is similar to the CS apart from the number of the shifts used during implementation. PCS shifts are a subset of CS shifts. Fig. 1 shows a schematic representation of the PCS analysis with *M* shifts. The denoising is performed over the wavelet coefficients at the output of this stage.

The PCS synthesis performs several inverse DWTs with the wavelet coefficients associated to each shift. Each inverse DWT recovers a shifted version of the original trace which is passed through a unshift stage to recover the original trace. In fact, if wavelet coefficients have not been modified, the original trace is recovered several times, one time for each shift. In practice, wavelet coefficients are modified for denoising purposes and the last step of the process consists of performing the mean of all the recovered versions of the initial trace. Fig. 2 shows the synthesis process.

Denoising is applied over the wavelet coefficients at the output of the analysis stage, over coefficients $d_{s,j}$ and $a_{s,j}$ of Fig. 1. A soft thresholding [18] is applied to these coefficients and the resulting denoised coefficients, $d'_{s,j}$ and $a'_{s,j}$, which can be seen in Fig. 2, act as input for the PCS synthesis stage. Three thresholds have been used and compared to study the variability in PCS: Universal [14,15], Minimax [13] and SURE [15]. Each threshold is calculated and applied during denoising to each set of wavelet coefficients, $d_{s,j}$, obtained for a shift *s* and a decomposition level *j*.

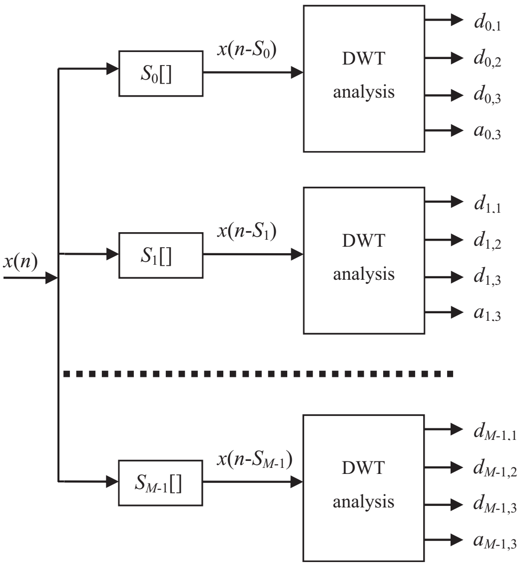

Fig. 1. PCS analysis stage.

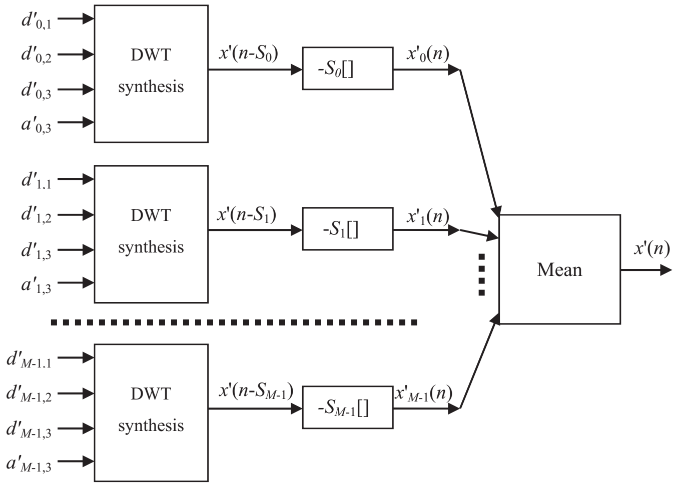

Fig. 2. PCS synthesis stage.

The Universal threshold is calculated by the expression:

$$T^{U}_{s,j} = \hat{\sigma}_{s,j}\sqrt{2\ln N_j} \tag{3}$$

where N_j is the number of wavelet coefficients $d_{s,j}$ at decomposition level *j* and $\hat{\sigma}_{s,j}$ is:

$$\hat{\sigma}_{s,j} = \frac{\text{median}\left(\left|d_{s,j}\right|\right)}{0.6745} \tag{4}$$

The Minimax threshold is calculated as follows:

$$T^{Mm}_{s,j} = \hat{\sigma}_{s,j}\lambda^{*}(N_j) \tag{5}$$

where the value of function $\lambda^{*}(N_j)$ is obtained using Table 1 of [13].

The SURE (Stein's unbiased risk estimation) threshold in the case of soft thresholding uses the risk function:

$$\text{SURE}(T;X) = N_j - 2\cdot\#\left\{i : \left|X_i\right| \le T\right\} + \sum_{i=1}^{N_j}\left[\min\left(\left|X_i\right|, T\right)\right]^2 \tag{6}$$

where $\#\left\{i : \left|X_i\right| \le T\right\}$ is the cardinality of the set in brackets.

The SURE threshold is the value that minimizes that risk function (6) for the vector of transformed coefficients:

$$T^{S}_{s,j} = \text{argmin}_{T\ge 0}\left\{\text{SURE}\left(T;\frac{d_{s,j}}{\hat{\sigma}_{s,j}}\right)\right\} \tag{7}$$

3. Variability in PCS

The differences between PCS and CS implementation methods are due to the shift selection. The objective of PCS is to reduce the number of shifts while maintaining the denoising quality of CS. A reduced number of shifts are selected in the case of PCS and three different rules for choosing the shifts are evaluated: sequential shifts, random shifts and fixed sparse shifts. In the case of sequential shifts the difference between two consecutive shifts is only one time unit while in the other cases it is greater than one. The random shift case selects the shifts in a random way over the whole range while the fixed sparse shifts method chooses the sparse shifts in a pre-determined way.