Audio Signal De-noising Using Wavelets Algorithm in Matlab and LabVIEW

Đorđe Damnjanović, Milan Gojković and Dejan Ćirić

Abstract—**This paper analyzes usage of the wavelet algorithms in process of de-noising of audio signals. Usage of the wavelets nowadays is widespread and the wavelet algorithms are very interesting for solving some engineering problems, such as noise cancellation in audio and image signals. Applications based on the Fourier transform algorithms can be re-formulated using the wavelets to provide more accurately localized temporal and frequency information. Matlab and LabVIEW software packages are very useful in these areas. Both packages have built-in functions that can be easily applied for solving the de-noising problems. Their potentials and drawbacks in audio signal de-noising by applying wavelets are investigated here.**

Index Terms—**Audio signal; de-noising; LabVIEW; Matlab; wavelets**

I. INTRODUCTION

It is well known that a certain amount of noise is always present in any signal in practice. In many cases, noise corrupts signals in great manner and it must be removed in order to enable further processing of data. This is also the case with audio signals. Generally speaking, recording of audio signals is not so easy task as it sounds to be, and the recorded audio signals typically have to be post-processed to remove the artifacts including the most common one – noise. Consequently, one of the main problems to be solved in audio signal processing is de-noising. It could not be treated only by using Fourier transform, but some more advanced techniques are necessary. As in other applications, digital filters are in most cases useful tool for de-noising of audio signals, but introduction of wavelets in this area has significantly improved the situation. Wavelet analysis is widespread nowadays and it can be very useful for audio signal processing [1]-[4].

This work provides the results of analysis of removal of the artifacts from the audio signals using the wavelet algorithms. Different types of artifacts are used to corrupt the signal, either discrete frequency sounds or complex sounds such as noise. In some cases, the artifacts have such magnitude that the audio signal is hardly recognizable.

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Removal of the artifacts (de-noising) is performed by using two software packages, Matlab and LabVIEW, which are mutually compared for this task. Since in applications of the wavelets, there are a number of parameters that should be adjusted, the effects of these parameters are investigated here too.

II. WAVELETS

Noise reduction and distortion removal are the major problems in applications such as cellular mobile communication, speech recognition, image processing, medical signal processing, radar, sonar, and any other applications where the desired signals are corrupted by noise and distortion. The use of wavelets in de-noising of audio signals was introduced approximately a few decades ago [3], [5], and until then, this technique has been becoming more and more popular.

Gabor defined time - frequency functions, so called Gabor's wavelets, for the first time in 1946 [6]. A wavelet is a wave function with a compact support [1]. Its name comes from the oscillatory nature, and diminutive is used because of the finite domain where it is different from zero (the compact support). Scaling and translation of the basic wavelet *ψ(x)* define the wavelet basis [1], [7]:

$$\psi_{a,b}(x) = \frac{1}{\sqrt{a}}\psi(\frac{x-b}{a}), a > 0. \tag{1}$$

An important feature of the wavelets is that by choosing the appropriate values for the scaling parameter *a* and the translation parameter *b*, small segments of a complicated form may be represented with a higher resolution, while smooth section can be represented with a lower resolution [1]. A typical example of applying wavelets in electrocardiogram (ECG) signal is presented in Fig. 1 [8].

A. Daubechies algorithm

Daubechies constructed in 1988 the entire class of orthonormal wavelet bases (Dbr, r=1,2,…,) using the analogy with the max-flat filters of signal theory [1], [9]. The first order Daubechies wavelet is also known as the Haar wavelet, which wavelet function resembles a step function. The Haar wavelet or Db1 can be written as [10] – [12]:

$$\psi(t) = \begin{cases} 1 \ if \ x \in [0 \ 0.5] \\ -1 \ if \ x \in [0.5 \ 1] \\ 0 \ if \ x \notin [0 \ 1] \end{cases} \tag{2}$$

$$\phi(t) = \begin{cases} 1 \ if \ x \in [0\ 1] \\ 0 \ if \ x \notin [0\ 1] \end{cases} \qquad (3)$$
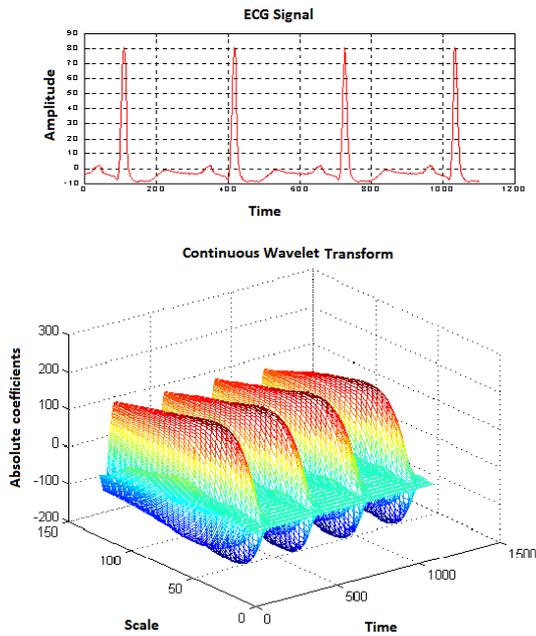

Fig. 1. Illustration of continuous wavelet analysis: ECG signal (in the time domain) that has to be decomposed (top) and corresponding wavelet coefficients (bottom) [8].

For the purpose of this research, various wavelet algorithms are used. One of them is the Daubechies of the order 2 (Db2). The wavelet and scaling functions for this Db2 are shown in Fig. 2.
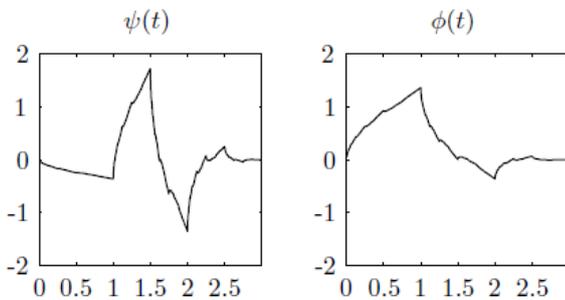

Fig. 2. Daubechies of the order 2: wavelet and scaling functions.

Higher order Daubechies functions cannot be easily described with an analytical expression. The order of the Daubechies functions denotes the number of vanishing moments, or the number of zero moments of the wavelet function. This is weakly related to the number of oscillations of the wavelet function. The larger the number of vanishing moments, the better the frequency localization of the decomposition [13], [14].

III. REMOVAL OF ARTIFACT USING DB2 ALGORITHM

The potentials of the wavelets for removing artifacts from audio signals are first observed in a trivial example of the recorded speech of a male subject containing added discrete high-frequencies artifacts. This signal in the time and frequency domain is presented in Fig. 3. It can be seen that the artifacts have large amplitude in comparison to the signal. This is why the speech is disturbed to a high extent, and it is hardly recognizable. The task is to remove as much as possible of these artifacts and to disturb as less as possible the signal (speech in this case).
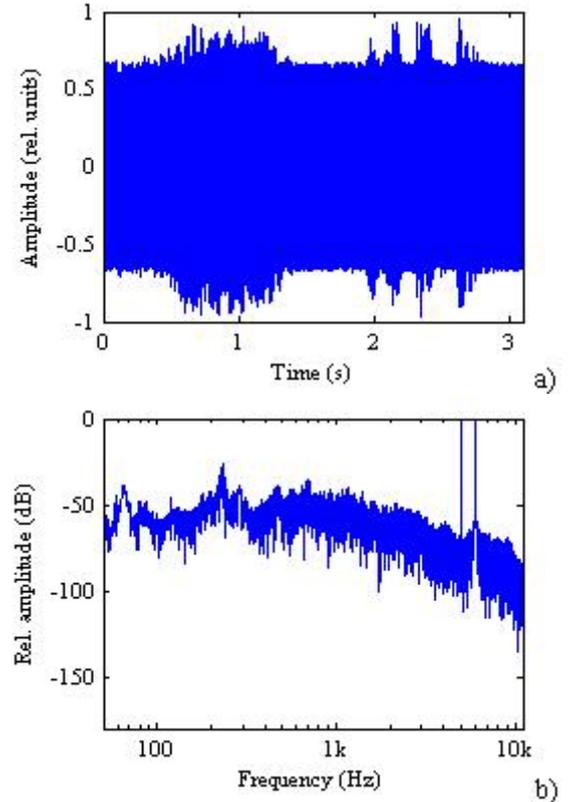

Fig. 3. The recorded signal of speech with discrete frequency artifacts: (a) in the time domain, (b) in the frequency domain.

A. Artifact removal using Matlab

For the purpose of artifact removal and de-noising of audio signals, SWT De-noising 1-D algorithm from the Matlab's Wavelet Toolbox is used here, whose menu with available parameters and plots of the loaded recorded signal is presented in Fig. 4. The de-noised signal in the Wavelet toolbox can be stored as a file with extension *mat*.

For this initial investigation, various algorithms (like Daubechies, Haar, sym, bior and others) were used, but only the results for Db2 with the level 5 are presented, chosen as the one yielding good suppression of the artifacts. After applying the whole algorithm (usually called de-noise algorithm, but this time implemented for removal of discrete frequency artifacts), it could be noticed that wavelet makes a difference between the signal and the artifacts, that is, it "recognizes" the discrete frequency artifacts and reduce them in the processed signal. To visualize this effect, both the recorded signal with artifacts (before applying wavelet algorithm) and after artifact removal (after applying the wavelet algorithm) are shown in Fig. 5. Besides, even better

illustration of the artifact removal is given by the spectrum of the de-noise signal shown in Fig. 6. The amplitude of two artifact components is now reduced in comparison to the signal amplitude, although the signal is also reduced in a part of the frequency range. Besides, it could be noticed that the spectrum of the signal is also somewhat changed.
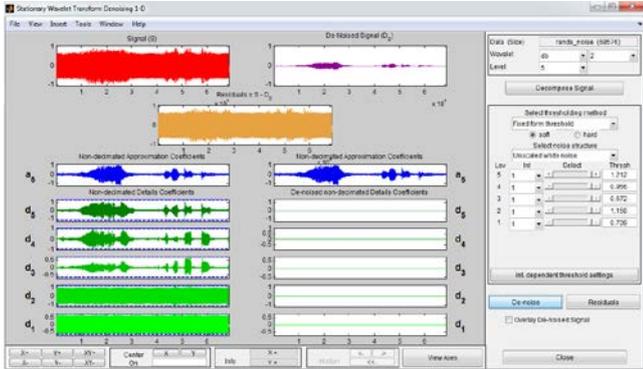

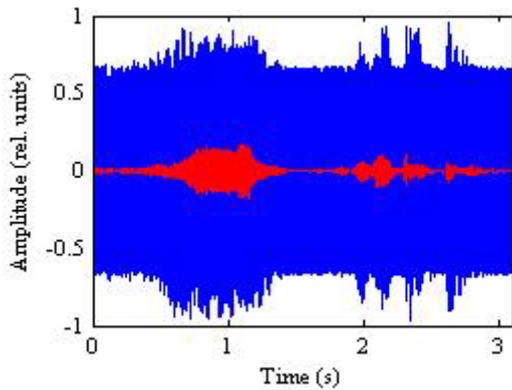Fig. 4. SWT De-noising 1-D window from Matlab's Wavelet Toolbox.

Fig. 5. Recorded signal with artifacts before wavelet transform (blue), and after wavelet transform (red).
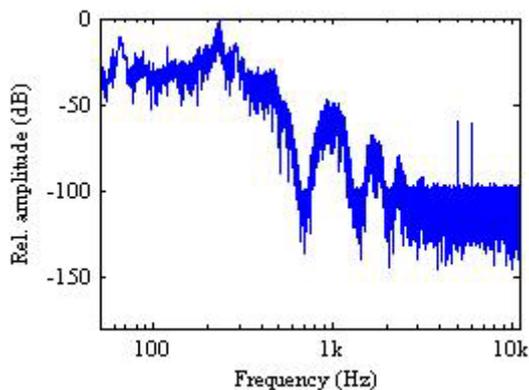

Fig. 6. De-noised signal in the frequency domain.

B. Artifact removal using LabVIEW

As Matlab, LabVIEW software has built-in functions for loading an audio signal, its preparation for further analysis and processing. User's interface for some applications is created without any code. Instead, simple "drag-and-drop" of the pre-defined objects should be done. Graphic applications created in LabVIEW are called virtual instruments (VI), as their look and functions "imitate" real instruments. In our case, signal loading is done by the structure shown in Fig. 7.
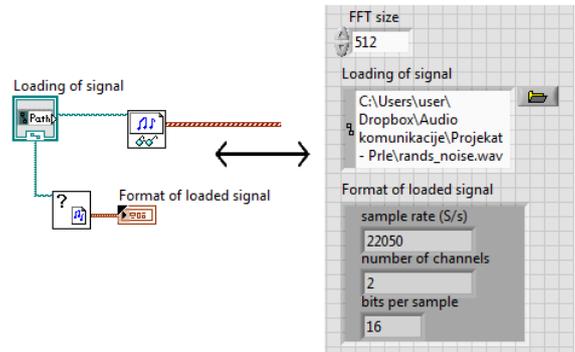

Fig. 7. Loading of audio signal in LabVIEW

An important part of the created application is the wavelet function called Wavelet Denoise. A double click on the function opens the window shown in Fig. 8 where all specifications of the wavelet algorithm are to be done. As done in Matlab, various algorithms and parameters (like thresholding rule, data type and rescaling method) were also used here. One of the features of LabVIEW that the authors of this paper would assess as better than in Matlab is a possibility that an audio signal can be played before and after processing directly in the wavelet block, and it can be recorded as a new *wav* file. These options give a certain advantage to LabVIEW against Matlab Toolbox.
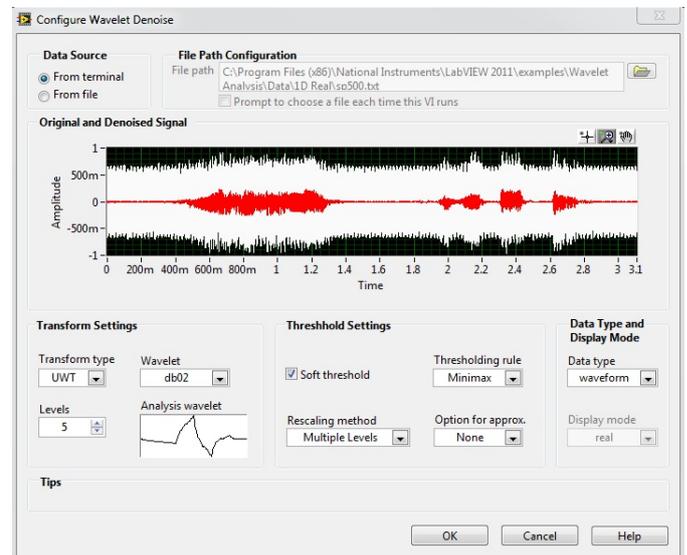

Fig. 8. Specifications of the wavelet algorithm in LabVIEW.

The code of the created application, that is, the functional block diagram with all the objects is given in Fig. 9, where position of the wavelet block is marked with a red circle. Front panel (User's panel) is given in Fig. 10. The signal to be processed is shown in both time and frequency domains in the accompanied graphs. The graphs in blue color belong to the

signal before de-noising (time and frequency domain) and graphs in red color are the time and frequency domain representations of the de-noised signal.
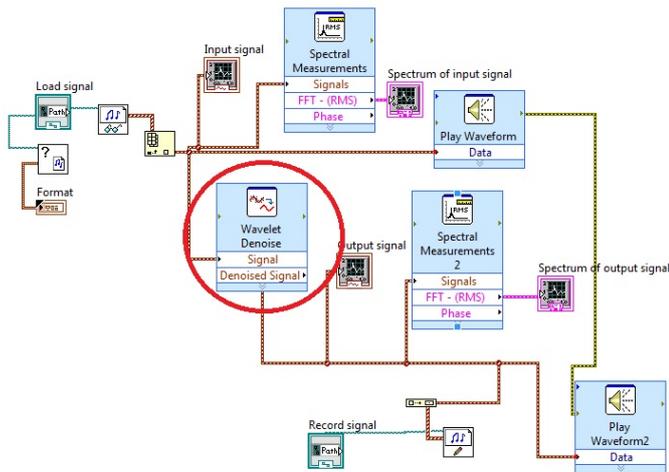

Fig. 9. Functional block diagram of all the objects for the wavelet transform in LabVIEW.
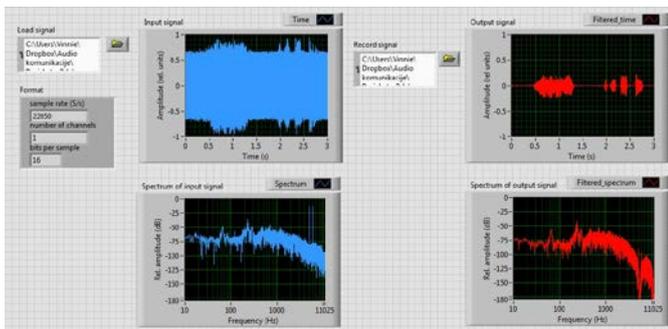

Fig. 10. Front panel of the created application for de-noising by wavelet transform in LabVIEW.

IV. DE-NOISING OF AUDIO SIGNAL

Another part of the research is related to reduction of noise from the audio signals recorded in real life situations. Although various audio signals and noise types are used for the research, only the results for three representative audio signals - speech with traffic noise, speech with traffic noise and rain (see Fig. 11) and speech with transient noise are presented here.

In the de-noising procedure, first the decomposition by the wavelet algorithms is done like in the previous example. Because of complexity of the signals and noises, a number of adjustments are necessary to be done in order to obtain the best results of de-noising. Actually, this represents one of the difficulties of applying the wavelet transforms for de-noising task.

The signals de-noised by different algorithms and applying different parameters are mutually compared regarding signal-to-noise ratio, degradation of the signal in comparison with the original signal without noise and annoyance of noise.
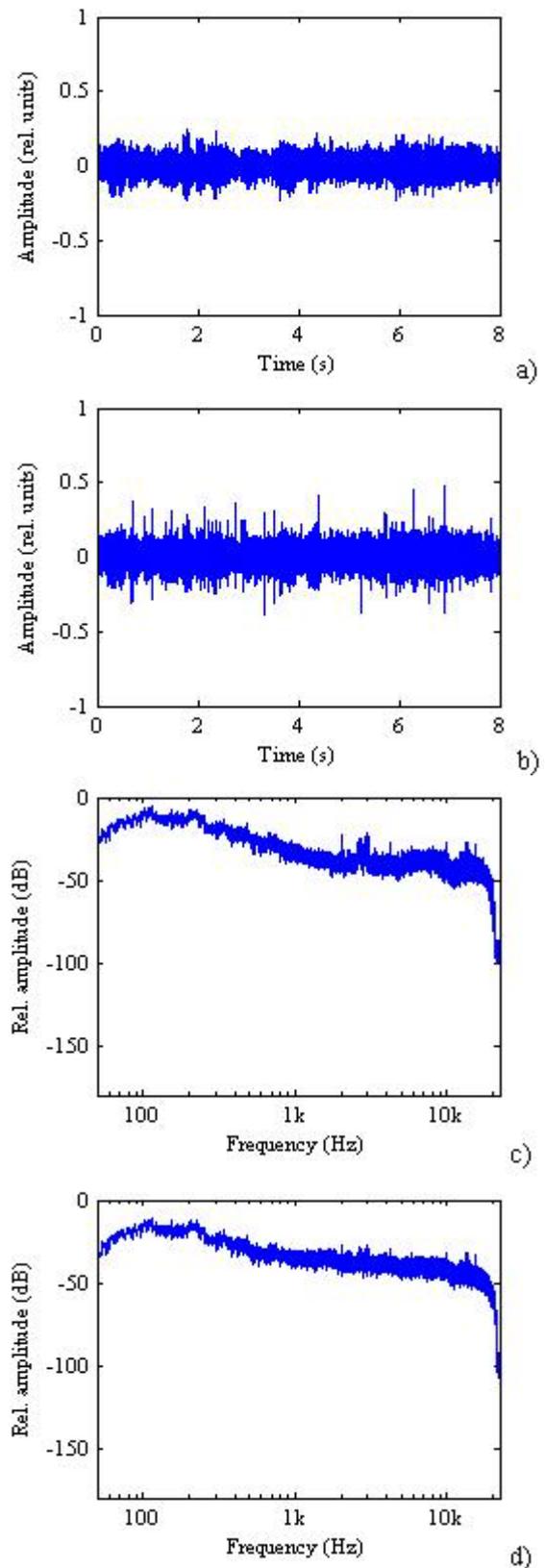

Fig. 11. Audio signals in (a and b) time and (c and d) frequency domain: (a and c) speech with traffic noise, (b and d) speech with traffic noise and rain.

In majority of cases (combinations of the signals and noises) used for the research, one of the best algorithms is shown to be Daubechies 6 (Db6) algorithm with one of lower

levels. More precisely, it is very difficult to specify a particular algorithm and all its parameters as the best one. Here, a trade-off has to be made especially between noise reduction and signal degradation. For example, Db6 algorithm with higher level reduces noise to a greater extent, but it also introduces larger degradation of the signal, and even the effect of low-pass filtering. Two signals from Fig. 11 before and after the wavelet transform are shown in Figs. 12 and 13.

above. It should be also noticed that range of the wavelet transform parameters in these two softwares are not the same. Thus, the number of levels available (e.g., for the Db6 algorithm) is larger in LabVIEW than in Matlab, and applying the same level of a particular algorithm in both softwares does not give completely the same results. Almost the same results could be obtained, but using a higher level in LabVIEW. The windows from LabVIEW software with graphical presentations of the signals are given in Fig. 14.
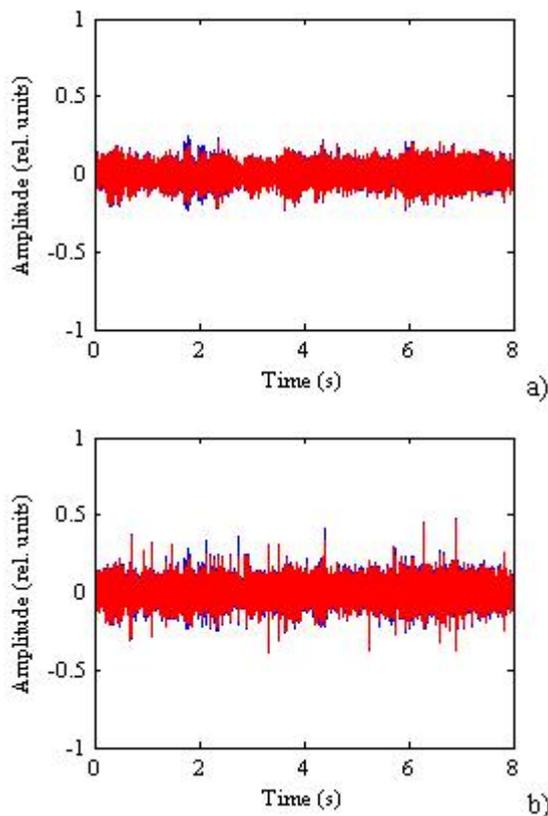

Fig. 12. Recorded signals (in time domain) before (blue) and after the wavelet transform (red) for (a) speech with traffic noise and (b) speech with traffic noise and rain.
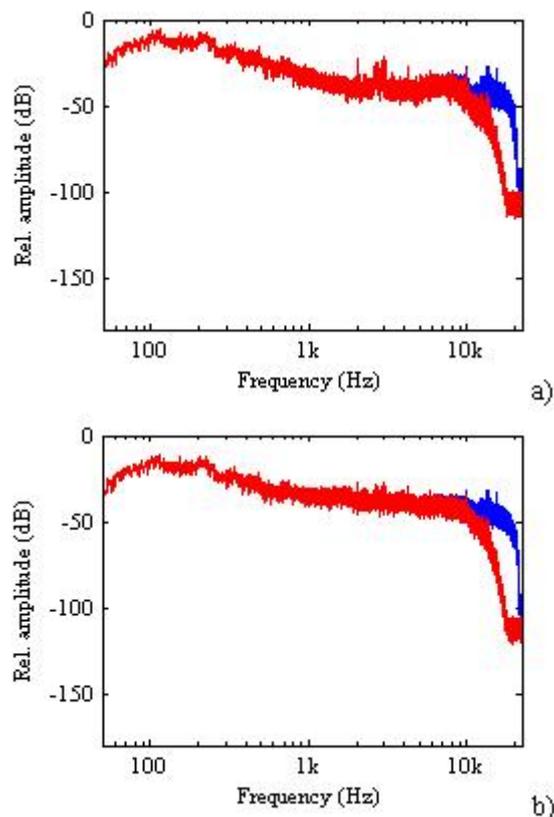

Fig. 13. Recorded signals (in frequency domain) before (blue) and after the wavelet transform (red) for (a) speech with traffic noise, (b) speech with traffic noise and rain.

Although a number of different combinations of parameters (transform type, wavelet algorithm, level, threshold type, thresholding rule) are tried, it is not possible to completely remove the noise (such as traffic or rain). One of the reasons could be that the frequency contents of the signal and noise are similar. This is why the spectra of the signal before and after the wavelet transform are similar (see Fig. 13). It is also clearly visible that the wavelet transform reduces the higher frequency components, and this reduction becomes grater as frequency increases.

Comparing the signals before and after the wavelet transform on a perceptual level, it is concluded that when the parameters of the transform are optimally adjusted, noise is still perceivable after the transform, but less annoying.

The previous results are obtained applying the wavelet transform in Matlab. When the same procedure is repeated, but in LabVIEW, the results are very similar, although this software package has some functional advantages mentioned

A part of the research is related to reduction of transient noise from the audio signal (speech). Various transient noises are applied, but the results for coughing as transient noise are presented here. Noise again has significantly larger amplitude than the speech. In order to obtain the best results by de-noising, different adjustments (algorithms and parameters) are applied like in the previous examples. An interesting observation is that the wavelet reduces to a significant extent all other noises (of lower amplitude) also present in the signal apart from the transient noise. The results of the Db6 algorithm with level 1 are presented in Fig. 15, where reduction of noise is hardly noticeable. By increasing the level of Daubechies algorithm, the transient noise is reduced to a larger extent, but this is also the case with the signal (speech) too. In this way, the signal becomes barely recognizable. Generally speaking, transient noise also represents noise difficult to be reduced by the wavelet algorithms.
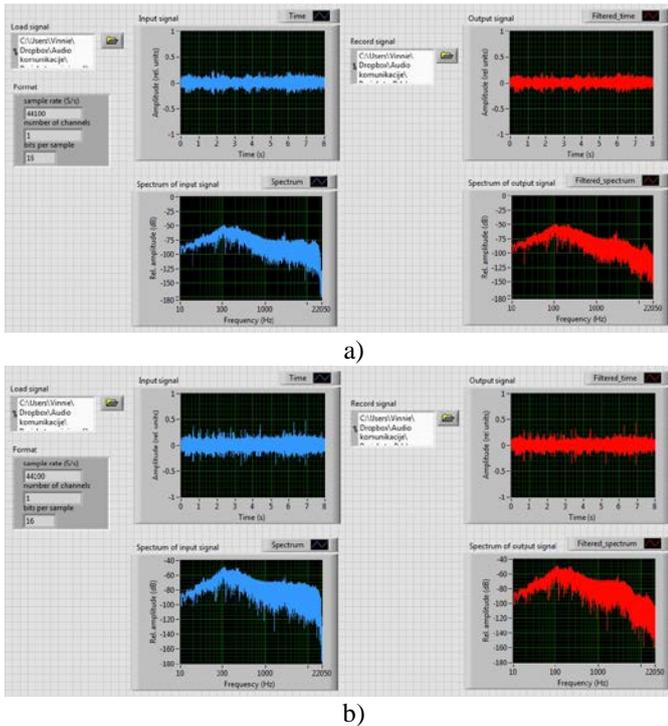
Fig. 14.De-noising of recorded signals in LabVIEW: (a) speech with traffic noise (b) speech with traffic noise and rain.
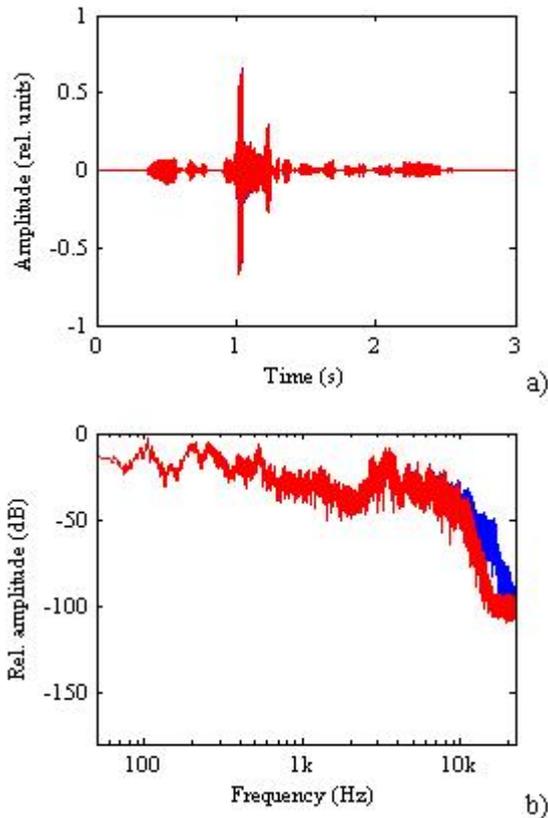

Fig. 15. Recorded signal with transient noise (coughing) (in (a) time and (b) frequency domain) before (blue) and after the wavelet transform (red) .

V. CONCLUSIONS

Potentials of the wavelets in de-noising are investigated here applying the wavelet transform in two software packages - Matlab and LabVIEW.

Artifact removal and de-noising depends not only on the algorithm parameters, but also on the signal and artifacts (noise) themselves. Consequently, in some cases, the artifact removal and de-noising give better results than in some other cases. Thus, the discrete frequency artifacts are successfully removed from the speech signal in both applications of the wavelet algorithm, that is, in Matlab and LabVIEW. However, this is not the case with more complex disturbances such as noise. De-noising depends to a significant extent to the parameters of the wavelet transform. When optimal parameters are applied, noise is reduced (sometimes only slightly), but not removed.

Comparing mutually Matlab and LabVIEW software for the task of artifact removal and de-noising by the wavelet transform, it could be said that LabVIEW has some functional advantages since some of the desirable features (such as playing of the signal before and after the transform) are possible in this software, and not in Matlab. Nevertheless, both softwares give similar results for the performed task.

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