Classes of Tonality of Signals in the Aspect of Active Elimination of Tonal Components

Michał ŁUCZYŃSKI
Wroclaw University of Science and Technology,
Chair of Acoustics and Multimedia,
michal.luczynski@pwr.edu.pl

Abstract

The aim of this paper is to analyse various types of signals defined as tonal where energy is concentrated in a narrow band of the spectrum. Not all tonal noises could be reduced using narrowband active noise control systems with cancelling signal generated based on source parameters. The author proposes the following classes of tonality: periodical (e.g. sinusoidal) signals, sinusoidal signals modulated by random function, sinusoidal signals with increased/decreasing amplitude and/or frequency, a combination of the two previous ones, and narrowband noises. For each type of the analysed signals active elimination of the tonal component using synthesized cancelling signal was carried out. Depending on the type of the signals different results were obtained which indicates the need to clarify the definition of a tonal signal, or use not one concept of a tonal signal, but several classes discussed above.

Keywords: tonality, signal processing, Active Noise Control

1. Introduction

The aim of this paper is to analyse different types of signals which can be described as tonal signals [1]. The author indicated that the concept of tonality should be clarified especially in the aspect of narrowband active noise control systems [2, 3] with cancelling signal generated based on source parameters [4, 5]. Not all tonal noises that meet the definition of tonal signals could be reduced efficiently using such systems [6]. Therefore the author introduces the classes of signal tonality.

Tonal signals is defined as signals where energy is concentrated in a narrow band of the spectrum [1, 7]. This definition applies to signals containing one or more tonal components. Therefore, it can be assumed that the tonal character of the signal means that in the spectrum there are frequency components (one or more) whose energy is concentrated around discrete frequency values (tonal components). This definition includes both pure tone and narrowband noise.

In the further part of the paper analysed tonal components were the only frequency component of the signal or one of many components observed in the signal spectrum. An individual analysis of a single component was possible due to the use of bandpass filters. The impact of the signal-to-noise ratio was not analysed.

2. Classes of tonality of signals

Fragments of analysed signal are shown at figure 1.

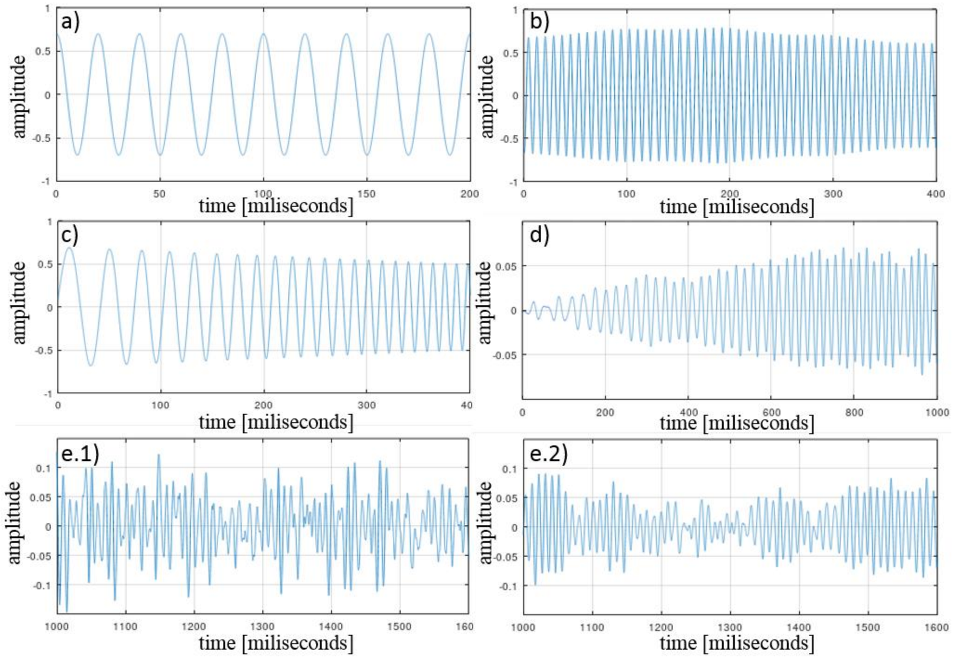

Figure 1. Chosen fragments of analyzed signals: a) stationary periodic signals, b) periodic signals modulated by a random function, c) periodic signal with increasing/decreasing amplitude and/or frequency, d) combination of b and c, e.1) narrowband noise Q = 10, e.2) narrowband noise Q = 50

The types of tonal components depending on the variability of parameters (amplitude, frequency) are presented and listed below:

a) Stationary periodic signals (figure 1. a):

The simplest class of analysed signals. A single tonal component is a sinusoidal signal. The problem of the elimination of the tonal component is based on the correct detection of the parameters (amplitude, frequency, initial phase), synthesis a cancelling signal and addition to the primary signal.

Quasi-stationary signals:

A signal described in the previous point are an idealized model. Real signals are characterized by a variability of parameters over time. The following sections describe possible changes, both small random modulation of parameters and changes their values, such as increasing (or decreasing) their amplitude and/or frequency.

b) Periodic signals modulated by a random function (figure 1. b):

In order to present this class of signals, a sound of two-stroke engine at constant revolutions of about 7200 RPM was analyzed. The recording was carried out under controlled conditions [8, 9] in Acoustic Chamber of Department of Acoustics and Multimedia at Wroclaw University of Science and Technology. The Acoustic

Chamber has one sound reflected surface (floor). Other surfaces are sound absorbing. Separate tonal component was obtained using frequency filtration. The signal is not an ideal pure tone with constant parameters.

c) Periodic signals with increasing/decreasing amplitude and/or frequency (figure 1. c):

This class of signals is characterized by the change of parameters in different way than random variations. Increasing or decreasing of parameters (both amplitude and frequency) could be caused i.e. by changing the number of revolutions of motor or fan. In order to present this class of signal a frequency sweep was analysed. Short time analysis of sweep indicates that it is a narrowband signal, however using long time analysis it is supposed to be a broadband signal. The author suggests that frequency sweep should be considered as tonal signal.

d) Combination of the two previous ones (periodic signals with increasing/decreasing amplitude and/or frequency modulated by a random function (figure 1. d):

While analysing tonal components of real signals, such as a sound of engine with changing the number of revolutions, it could be observed both increasing or decreasing parameters and some random variation described as frequency and amplitude modulation with non-deterministic function. The analysis of separated single tonal component of sound of combustion engine while increasing number of revolution was performed to define this class of tonal signals.

e) Narrowband noise (figure 1. e)

The last type of signal that is included in the definition of tonal signals (energy is focused around discrete frequency values) is the signal obtained by frequency filtration of noise using a narrow band pass filter (quality of filter Q = 10 figure 1.e.1 and Q = 50 figure 1.e.2). Analysis was performed for two types of narrowband noises: digitally and analogue generated.

3. Experiment

For each of the types of signals, an experiment was carried out using MATLAB environment. A signal tonal component was eliminated using active noise reduction algorithms with generated cancelling signal (pure tone synthesis). The parameters of cancelling signal were obtained based on parameters of the primary signal.

The stages of the experiment are:

a. Preliminary time and frequency analysis,
b. Extraction of a single tonal component,
c. Analysis of the variability of its parameters,
d. Synthesis of a cancelling signal based on parameters of tonal component of primary signal,
e. Active elimination of the tonal component (using different length of window - frame),
f. Analysis obtained results.

The block diagram of the algorithms used in the experiment is shown in Figure 2.

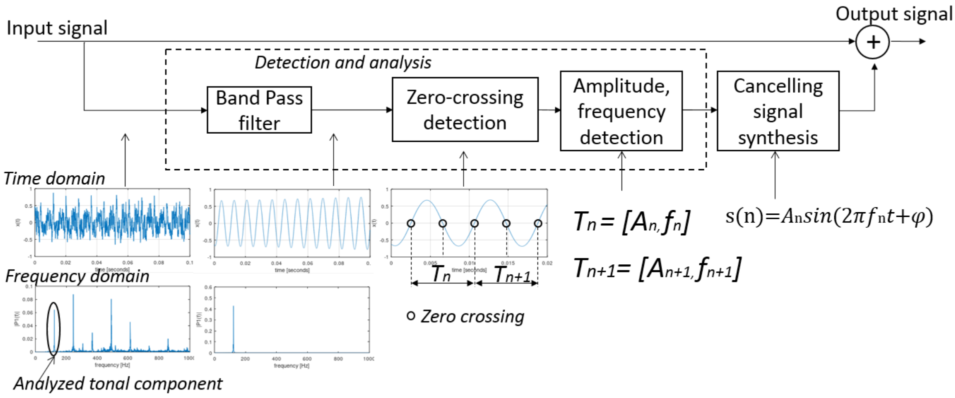

Figure 2. The block diagram of the algorithms used in the experiment. Under the algorithm there are shown an example of signals at subsequent stages of processing

The use of this processing method is possible if the differences between the frequencies of tonal components are sufficient to separate the components. The signals have been selected to obtain desirable results. Using the zero-crossing detection allows to divide a signal of tonal component into periods and determine amplitudes and frequencies in subsequence periods. These parameters were used for generation a cancelling signal. Then an elimination using active noise cancellation was performed. Different length of time window (frame length) were used. The shortest frame is the length of one period and cancelling signal is a pure tone with a given frequency and amplitude such as that detected in a given period of primary signal (as in Figure 2). In the case of longer frame the parameters of cancelling signal are the average frequency and amplitude in the range of given frame of primary signal or the amplitude and frequency of the first period in a given frame (for signals with increased frequency). Phase mismatch problems were minimalized due to zero-crossing detection. The process of elimination was initialized when primary signal crossed zero. The evaluation of a given class of signal was based on the observation of the output signal. The shape of output signal depended on difference between the original signal and the cancelling signal. This implies the differences between individual classes.

4. Results

a) Stationary periodic signals

The signal was generated using MATLAB environment. The pure tone had given and amplitude, frequency and initial phase. The frequency was 50 Hz. The sampling rate was 44.1 kHz. There was no need for frequency filtration. Zero-crossing points were detected and then amplitude and frequency. The parameters were constant in the subsequent periods. The cancellation signal was synthesized. The length of a frame does not affect the results. The output signal obtained a level close to zero. Non exact zero values were caused by calculation resolution.

Quasi-stationary signals

b) Periodic signals modulated by a random function:

The analysed signal of separated tonal component of the sound of combustion engine contains 485 periods. Amplitudes and frequencies are noticed in subsequence periods. It turned out that the values are not constant as in the case of pure tone. This values are presented at histograms (figure 3).

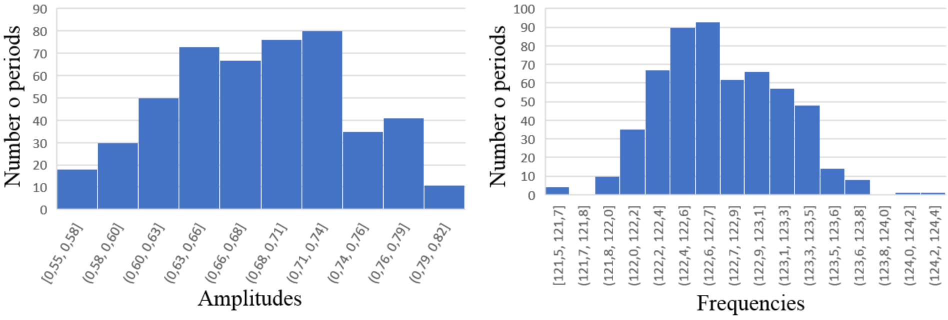

Figure 3. Histograms of amplitudes (left) and frequencies (right)

Amplitude and frequency values are some kind of statistical distribution. It was assumed that the parameters are constant mean values modulated by a non-deterministic signal. The amplitude/frequency can be defined not as a single number, but as a random variable. The average value of amplitudes is 0.68, maximum value is 0.82 and minimum is 0.55. Standard deviation is 0.06. The average value of frequencies is 122.7 Hz, maximum value is 124.3 Hz and minimum is 121.5 Hz. Standard deviation is 0.4 Hz.

The tonal component was eliminated for different length of time windows. Figure 4 presents the example results of experiments for chosen fragments of signal. Figure 4a shows the elimination result for window length (frame) is 1 period (for each period a cancelling signal was generated pure tone with the frequency and amplitude read for a given period of primary signal). Figure 4b shows the elimination result for window length of 10 periods. The parameters of cancelling signal (pure tone) were the average amplitude and frequency values in the range of 10 periods.

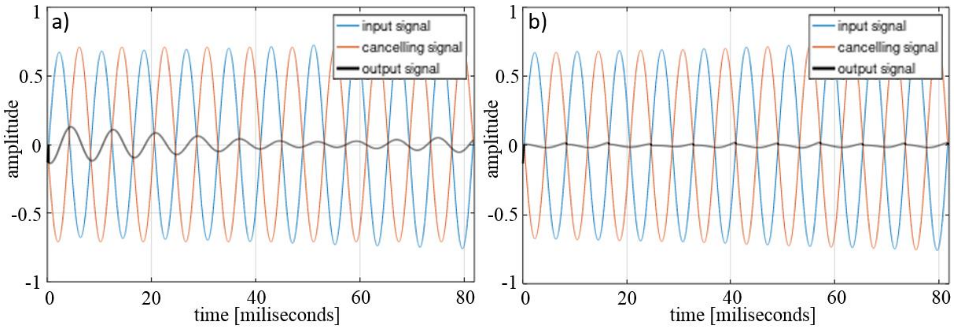

Figure 4. Results of the experiment for periodic signal modulated by a random function: a) frame length of 1 period, b) frame length of 10 periods

In both cases, it could be observed that there is no complete elimination of the given component. This is caused by the mismatch of the primary and cancelling signal. As well it could be seen that for the shorter frame the amplitude of output signal is lower (an errors of elimination are smaller). However, in most cases, the smaller number of signal samples causes higher detection errors, especially when using discrete Fourier transform based detection algorithms. For this class of signals, the efficiency of tonal components elimination is limited not only by detection errors as in the case of ideal periodical signals but also by random modulation variability.

c) Periodic signals with increasing/decreasing amplitude and/or frequency

Analysed frequency sweep with decreasing amplitude starts at 20 Hz and ends at 200 Hz after 1 second. Figure 5 shows six periods of an input (primary) signal with cancelling signal and results of the elimination (output signal). The parameters of the cancelling signal (pure tone) are the amplitude and the frequency detected in the first period of the primary signal.

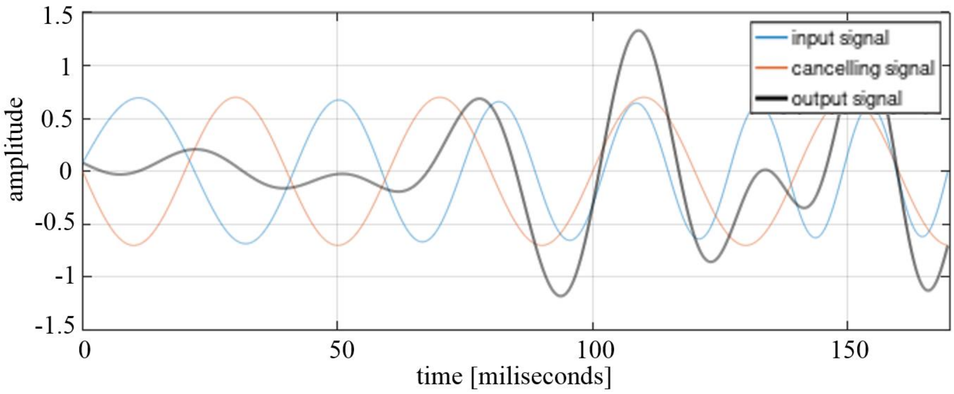

Figure 5. Results of the experiment for periodic signal with decreasing amplitude and increasing frequency (first six period of primary signal)

The mismatch of the primary and cancelling signal increased in subsequent periods so the tonal component is not eliminated efficiently. In the first period the level of tonal component is reduced but then the level of output signal is even higher than the input signal. The effective reduction of a tonal component level might be possible if a frame length is corresponded to changes of parameters.

d) Combination of the two previous ones (periodic signals with increasing/decreasing amplitude and/or frequency modulated by a random function

The sound of an internal combustion engine while increasing the number of revolution was analyzed to present this class of tonal signal. Both the change in amplitude and frequency resulting from increasing the number of engine revolutions and the modulation of these values by non-deterministic function are observed. Frequency filtration by bandpass filter with a variable middle frequency was used to separate the selected frequency component. For the selected fragment where the number of revolution increase the values of the amplitude and frequency in subsequent periods were detected. The results are shown in Figure 6.

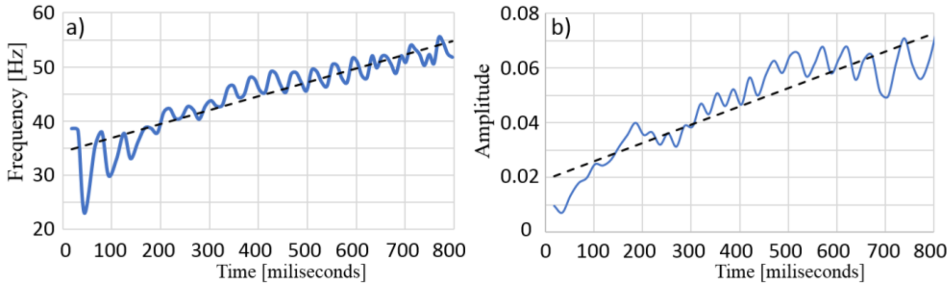

Figure 6. a) frequency and b) amplitude detected in subsequent periods of the primary signal of the engine while increasing number of revolutions with trend line marked

The two types of value changes described in the previous paragraphs (b and c) could be seen. This affects the tone component elimination efficiency. Elimination will be ineffective for longer frames (windows) such as for the sweep signal. If the frame is short there is no complete elimination because the changes take place even in single period.

e) Narrowband noise

The last class defined in this paper is a narrowband noise. It is non-deterministic, random signal. No significant differences between analogue and digitally generated noise were observed. However the parameter whose impact is highly important is bandwidth. A few experimental elimination were performed for noises obtained by filtering with filters with different quality [8, 9].

Quality of filters was 10, 50, 100, 200 and 500. Middle frequency was 1 kHz. For two first noises the level of output signal was higher than input signal. For noises with narrower bands the level decreased (even 12.1 dB for noised filtered by filter with Q = 500).

4. Conclusions

Depending on the type of narrowband signal, one of the above, different results were obtained. This indicates the need to clarify the definition of a tonal signal or the use of several classes as presented above instead of single concept of tonal signal. Pure tone (periodical signal) is an ideal model of tonal signal. Other signals differ from the ideal model. For pure tones modulated by a non-deterministic (random) function, parameters for each subsequent period of the signal can take any value in the modulation range. However, these values are similar. The extreme case of these signals is narrowband noise. Changes of values of parameters depend on the noise bandwidth. The model of the signal with decreasing / increasing amplitude and/or frequency is an idealized model of signal. In the subsequent periods of a signal, a certain tendency (trend) of parameter changes is noticeable. Such signals have their representation among real signals if there is simultaneous modulation of the parameters with a random function.

The author of this paper does not deny the definition of tonality as energy concentrated around the discrete frequency values. However, in the aspect of Narrowband ANC systems, the author recommend to define total signal more precisely. It could help to choose the parameters of an algorithm such as length of a frame and predict the effectiveness of the noise reduction. Signal interpretation in accordance with the presented classes may also have potential application in the case of predictive systems. Understanding the nature of signal variability helps in predicting the future values of parameters and minimize errors resulting from the mismatches primary and cancelling signals caused by processing latency.

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