Practical Investigation of Specific Types of Noise Signals for the Purpose of Suppression in Hearing-Aid Devices

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Abstract – **In this paper is made a study of various types of interfering noise signals with exceptional importance to hearing-aid signal processing. Types of noise like knocking, scratching, creaking and background noise are very common contaminants of human speech. They can result in very poor sound quality and be extremely annoying to human ear, especially for people with hearing disabilities. The purpose of this investigation is to give some means for finding practical resolution of the problem.**

Keywords –**noise signals, hearing-aid, energy distribution**

I. INTRODUCTION

The purpose of this investigation is to study common types of noise signals in practical applications with hearing-aid devices and distinguish them from human speech. The noise signal types of interest can roughly be categorized as: scratching, knocking, background noise and speech. These types of noise are very common ones and can significantly reduce the sound quality and the subjective human perception, especially when introduced to people with hearing disabilities.

The practical analysis of the noise signals uses classic periodogram spectral estimation technique, based on Fourier transform operations [1, 2]. The captured sound signal represents measured data, available only for a short time interval (samples x_0, x_1, … x_{N-1},). Its Power Spectrum Density (PSD) can be estimated by:

$$P_{PER}(f)=\frac{1}{N\Delta t}\left|\Delta t\sum_{n=0}^{N-1}x_n\exp(-j2\pi fn\Delta t)\right|^2 \qquad (1)$$

where $P_{PER}(f)$ is defined for frequency interval $-1/2\Delta t\leq f\leq 1/2\Delta t$. Use of FFT permits evaluation of PSD at the discrete set of N equally spaced frequencies $f_m = m\Delta f$ [Hz] for m = 0, 1, …, (N-1) and $\Delta f = 1/N\Delta t$.

$$P_m=P_{PER}(f_m)=\frac{1}{N\Delta t}|X_m|^2 \qquad (2)$$

where X_m is the Discrete Fourier Transform (DFT) at frequency index m. P_m is identical to the energy spectral density (squared modulus of the Fourier transform of a time function), except for the division by the time interval of $N\Delta t$ seconds required to make Pm a power spectral density [3].

In situations that involve a time series process with time-varying characteristics that can only be considered relatively constant for only short time intervals (speech), the Short-Time Fourier Transform (STFT) is often used as a time-frequency representation to describe such signals. STFT is defined as:

$$X(nL,f)=\sum_{m=-\infty}^{\infty}x(m\Delta t)w[(nL-m)\Delta t]\exp(-j2\pi fm\Delta t) \qquad (3)$$

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where $w(n\Delta t)$ is a frame analysis window and L is an integer which denotes the separation in time between adjacent short time frames. Thus, for a fixed n, X(nL, f) represents the Fourier transform at time nL of windowed data samples. Taking the modulus of X(nL, f), as in (1), at each L produces a short time spectral estimate.

II. PRACTICAL INVESTIGATION

A. Laboratory Test Set

For the purposes of studying the common noise signal types, is made a laboratory test set for resembling the operation of a hearing-aid device. Speech in combination with noise contaminants is introduced to the audio system, captured and stored for analysis. The audio system is based on Analog Devices Blackfin development kit – BF537-STAMP [4]. It uses external SPI analog module based on codec AD74111 for D/A and A/D conversion. The audio signals are captured with a conventional piezoelectric microphone and amplified to the range of several mV, fitting the diapason of the codec.

The major components in the structure of the laboratory test set are shown in fig. 1.

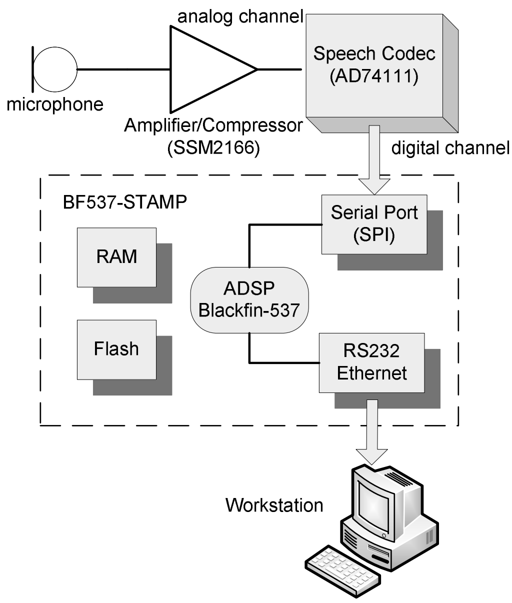

Fig. 1 – laboratory test set

B. Practical Records of Various Types of Noise

Several practical experiments were made with the so explained test set. Specific types of noise signals were introduced to the signal capturing system and recorded. Due to the focus of this research – hearing-aid signal processing, three types of interfering noise are of significant interest.

Knocking is sharp loud bursts of sound which is perceptible and especially annoying for people with hearing disabilities. Scratching and creaking are very common interferences in recorded speech, which originate form surface friction. Introduced in the sound capturing system of such hearing-aid devices, these types of noise are very unpleasant too. In a situation of absence of speech and favourable absence of specific noises, the sound capturing system of a hearing-aid device is capable of introducing the so called "white noise" to the human ear, which can reach significant magnitude.

These types of noise are investigated [5, 6] in comparison with clear, reference records of human speech, for the purpose of recognition (recognizing noise presence, its type and time duration) and suppression. Several scenarios of speech and noise interference were reproduced. The laboratory test set was used to capture and store the audio signals for processing. Below are given sample intervals of the so recorded test scenarios. Scratching and creaking produces the diagram shown on fig. 2. Below the time diagram is given its spectrum for the same interval.

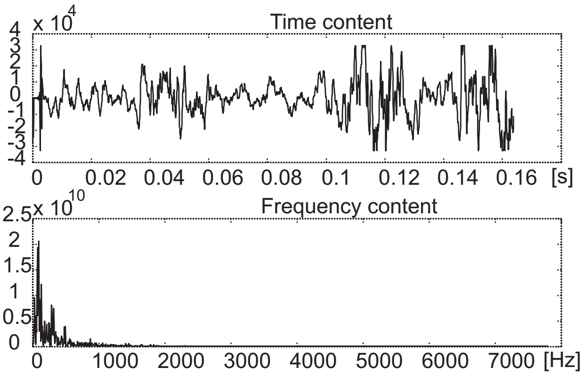

Fig. 2 – scratching noise signal time-flow and spectrum

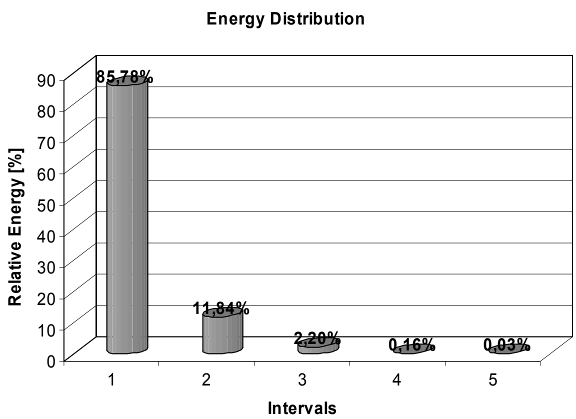

Fig. 3 – energy distribution per intervals (scratching)

What is evident from fig. 2 is that the signal energy is concentrated primarily in the initial frequency interval from 0 to 1000 Hz. The rest of the frequency domain contains almost no energy. More detailed view is obtained, by dividing the signal bandwidth into several subintervals and estimating the average signal energy per interval. Since the energy distribution is very uneven, the selected frequency subintervals are not equal in width. For practical reasons, the separate subintervals are defined as: [0 – 500] Hz; [500 – 1k] Hz; [1 – 2] kHz; [2 – 5] kHz; [5 – 8] kHz. The average signal energy distribution per interval for the scratching type of noise, is given in the energy distribution histogram of fig. 3.

In the second scenario, all deliberate sources of noise signals are absent. What is captured with the laboratory test set is only the background noise. The noise levels are obtained in common office noise conditions. The recorded background noise signal is shown on fig. 4.

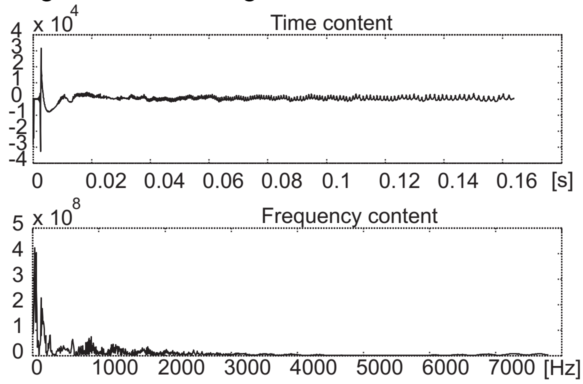

Fig. 4 – background noise signal time-flow and spectrum

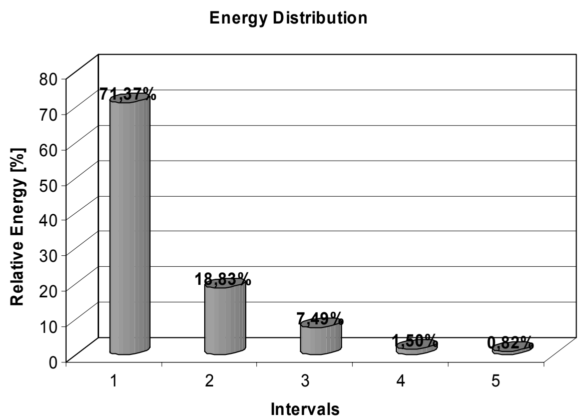

Fig. 5. – energy distribution per intervals (background noise)

Fig. 4 shows that the signal energy is widely spread far beyond the initial frequency interval [0 – 1] kHz. All subintervals of the frequency domain contain portions, significant enough, that cannot be neglected. More detailed view of the separate intervals is shown on fig. 5.

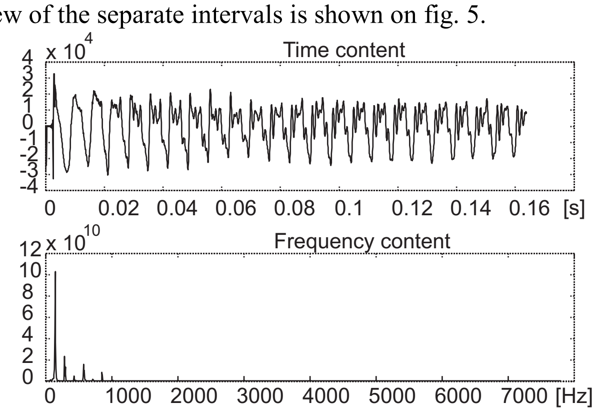

Fig. 6 – speech signal time-flow and spectrum

In the third test scenario, the attention is concentrated in investigating the specifics of human speech. No noise signals are present and only reference speech signal is captured with the laboratory test set. The lack of interferences makes the separate harmonics of speech vocals clearly visible on fig. 6. The signal energy of human speech is concentrated primarily in the initial frequency interval [0 – 1] kHz, seen on fig. 7.

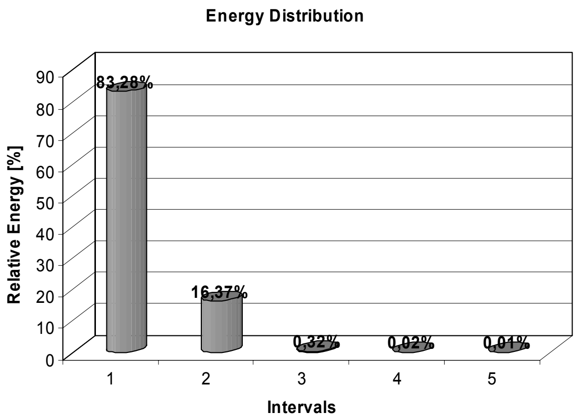

Fig. 7. – energy distribution per intervals (speech signal)

The next test scenario studies the knocking type of sound. This specific noise signal is introduced in the sound capturing system of the laboratory test set. The captured records show very harsh changes of the signal magnitude throughout the whole dynamic range. A sample interval of a record with presence of knocking noise signal is shown on fig. 8.

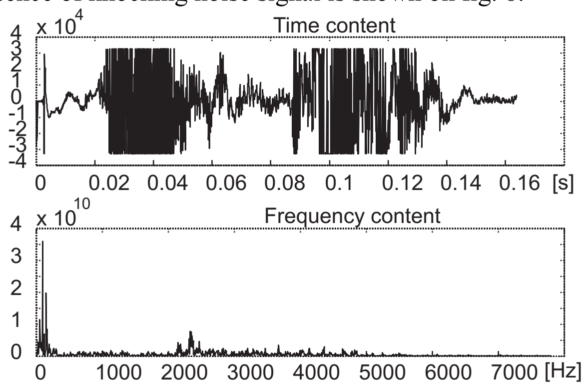

Fig. 8 – knocking signal time-flow and spectrum

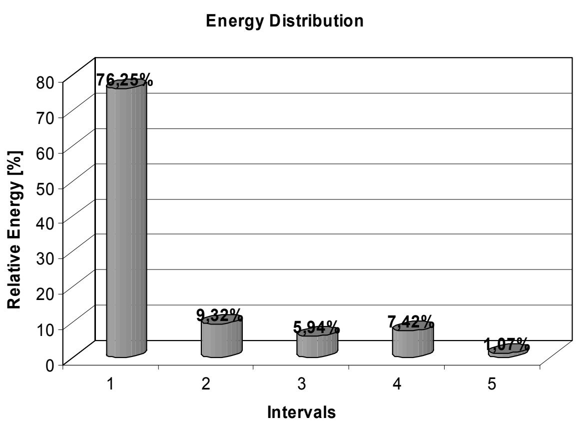

Fig. 9. – energy distribution per intervals (scratching)

From fig. 8 is evident that the signal energy is evenly distributed far beyond the initial frequency interval [0 – 1] kHz. All subintervals of the frequency domain contain almost equal portions which cannot be ignored. More detailed view of this distribution is shown in the energy distribution histogram of fig. 9.

The obtained data from the practical investigation of the noise signals of interest give information for distribution of signal energy throughout the frequency domain. Average results from all test scenarios are given in table 1.

TABLE I
AVERAGE SIGNAL ENERGY CONCENTRATION IN DIFFERENT PARTS OF THE SPECTRUM

	Frequency [Hz]				
Interval	0-500	500-1k	1k-2k	2k-5k	5k-8k
Scratching	85,78%	11,84%	2,20%	0,16%	0,03%
BG Noise	71,37%	18,83%	7,49%	1,50%	0,82%
Speech	83,28%	16,37%	0,32%	0,02%	0,01%
Knocking	76,25%	9,32%	5,94%	7,42%	1,07%

III. ANALYSIS OF THE EXPERIMENTAL RESULTS

For facilitating the analysis the obtained experimental results, the collected data in table 1 can be interpreted visually. Fig. 10 shows collectively, very rough interpolation of signal energy distribution for all types of noise. Such interpretation, though not very accurate, helps deriving principles for distinguishing the different noise sources.

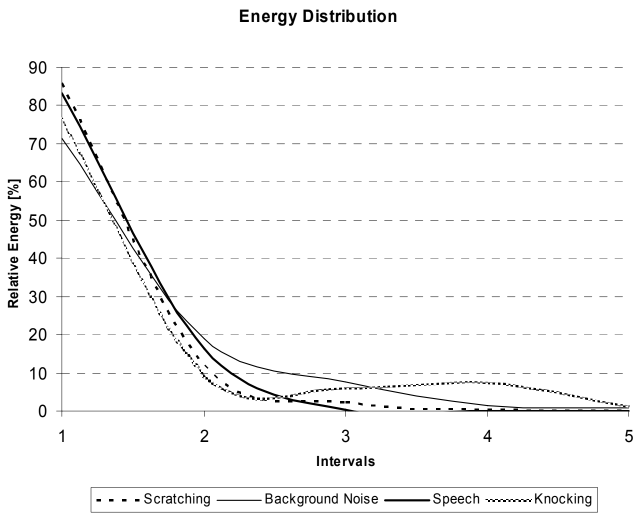

Fig. 10. – interpolated energy distribution (all noise types)

The experimental results give reason for the following conclusions regarding the different types of noise:

- Speech –signal energy is concentrated in the first part of the spectrum (0 – 1000 Hz)
- Knocking – signal energy is spread almost equally in the middle of the spectrum (500 – 5000 Hz).
- Background Noise – significant signal portions reside in the middle of the spectrum (500 – 2000 Hz).
- Scratching – the spectrum has the same characteristics as human speech.

A. *Criteria for Recognizing Noise Types*

By analyzing the experimental data and the conclusions made, allows us to define several criteria for distinguishing and recognizing the belonging of a sample sound to a particular type of noise signal. Such a classification can be used in practical signal processing, for noise cancellation. Depending on the concrete type of noise signal, the processing algorithm can vary greatly for achieving optimal results.

The main approach is based on comparing the energy distribution of signal types in frequency domain. For practical purposes, estimation is made with discrete, unequal in width intervals, since the energy distribution is very uneven. The separate subintervals are defined as: [0 – 500] Hz; [500 – 1k] Hz; [1 – 2] kHz; [2 – 5] kHz; [5 – 8] kHz.

Based on the experimental results above, for the purposes of hearing-aid signal processing, the criterion for recognizing the speech signal type can entirely rely on detecting less than 5 % average signal energy in the frequency interval [1 – 8] kHz. The signal sample interval can be classified as knocking noise type if the average signal energy within [500 – 5k] Hz is between 5 – 10 %. Background noise signal type can be distinguished in case the average signal energy within [0 – 500] Hz is less than 75% and it retains relatively high levels (above 8 %) within [500 – 2k] Hz.

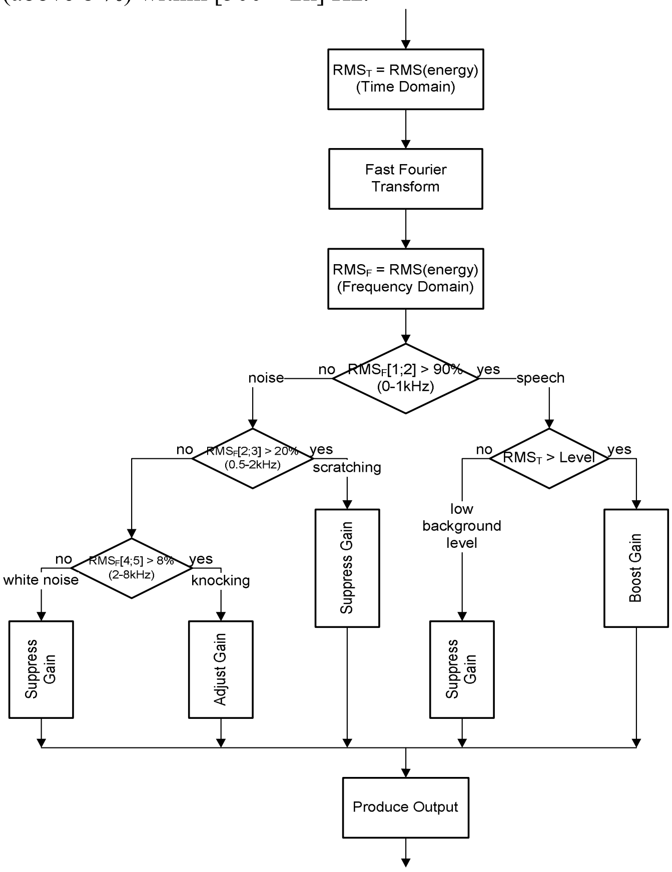

Fig. 11. – algorithm for recognizing types of noise

Scratching signal spectrum is very close to the speech signal one, has the same energy distribution and frequency characteristics, which makes distinguishing these two types of signals extremely difficult. Scratching is almost unrecognizable with these criteria. One approach that can improve the perceptual sound quality, especially for the purposes of hearing-aid signal processing, can take into consideration the magnitude of the captured sound signal. Suppressing the noise signal with excessively high magnitude can make it sound subjectively better for the human ear.

B. *Practical Algorithm for Recognition of Noise Types*

The developed criteria for distinguishing and recognizing the specific types of contaminating noise can be used in practice in signal processing applications for controlling the methods and flow of the processing. Determining the type of noise gives flexibility to the suppression procedure. The algorithm shown on fig. 11 uses the criteria for classification, to recognize the specific types of interfering noise signals.

IV. RESULTS

Capturing experimental data and its analysis lead to obtaining the following results:

- Estimated signal energy distribution for several noise types of interest for hearing-aid applications.
- Created several criteria for noise type recognition in captured audio signal, for the purposes of its suppression and improvement of sound quality.
- Created practical algorithm for determining the type of noise, based on the derived classification criteria.

V. CONCLUSION

In this paper is made a practical investigation of various types of interfering noise signals with exceptional importance to hearing-aid signal processing. Types of noise like knocking, scratching, creaking and background noise are very common contaminants of human speech. These noises can result in very poor sound quality and be extremely annoying to human ear, especially for people with hearing disabilities. Thus the task for suppressing such noise interferences and improving the sound perceptual quality is essential. The investigation of these noise types, in the current paper, gives some means for finding practical resolution of the problem.

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