Automatic detection system of aircraft noise events during acoustic climate long-term monitoring near airport

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Abstract. The paper presents a method and software application of automatic identification of aircraft noise sources in the long-term environment acoustic monitoring systems. The said method relies on automatic "meaning" of sounds recorded by the one measuring microphone (part of a monitoring station) and refer to the advanced pattern recognition technique based on the human auditory perceptions by using mel frequency cepstral coefficients (MFCC) of signals. The algorithm was developed in MATLAB language and implemented in National Instrument LabVIEW Environment as Aircraft Noise Events Detector (ANED) application.

Keywords: airport noise, long-term aircraft noise monitoring, noise analysis and control, signal processing.

1. Introduction

Noise has been becoming an environmental factor attracting particular attention in developed countries. In the European Union, and thus in Poland, uniform requirements for assessment and management of environmental noise (Directive 2002/49/EC) were established. The purpose of the said guidelines being incorporated into the legal system is the protection of health, quality of life and well-being of the world's population. While exploiting the environment by emitting large quantities of sound energy, certain entities - operators of roads, railways, tramways, or airports, as well as industrial facilities are required to monitor such noise emissions. The road-transportation (traffic) noise has been the dominant factor in the change of acoustic climate due to its widespread nature and prolonged effect. However, noise generated by flight, takeoff, and landing of aircrafts in close proximity of airports has also been an important factor here. Since the Poland's accession to the European Union and the Polish sky becoming fully accessible for aircraft carriers, the air traffic has been growing rapidly. The growth of the air traffic in the coming years is predicted to be lower than current one, according to the forecast of the Civil Aviation Office [1], however it will still be higher than the European average. In 2014, Polish airports fourfold in the number of passengers served (27 million), comparing to 2003 (7 million), which translates into approximately doubled overall number of air operations. Estimations for 2025 are that the number of passengers being served will increase to approximately 47 million, which will result in further doubling of air operations (comparing to the current level).

Continuous monitoring of acoustic climate creates problems associated with large quantities of recorded data, which may often represent information unrelated to the examined source of noise. For this purpose any other sources of noise are to be considered as the interference. Identification and separation of background noise sources becomes a crucial task for proper determination of noise levels. Manual verification of data originating from acoustic monitoring is a time-consuming process, while use of special systems or devices supporting recognition of noise sources constitutes an additional high cost, on top of the already relatively expensive professional noise monitoring stations (describe in [2-6]). The paper presents next stage of authors' research, particularly usefulness of special directed measurement techniques, acoustic signal processing (based on human hearing perception) and its parametrization to the feature vector represent noise

sources and classification methods using statistical parameters in the recognition of aircraft noise events. The paper describes the algorithm developed in MATLAB language and software applications created in National Instruments LabVIEW Environmental, which the task is to process the acoustic signal and determine the source of noise event.

2. Detection of aircraft noise events

The aircraft noise measurements are more complicated than road or railway noise and their range include large areas [4-13]. In such area, usually defined as zone of the limited use, there are often other noise sources present, such as roads or railway lines then treated as a background sound. In such case, it is important to distinguish automatically a source of noise from the background and to quantify the impact various sources on the overall noise level in a given place. Currently there are available aircraft noise monitoring stations using four microphone array with the task to determine the source position (angle of elevation and azimuth) and a fifth microphone to sound level measurements [2] or using the information from airport radar system [3]. Number of needed microphones in array or payment for using of radar system greatly increases the cost of such devices. Concept of method for identifying aircraft operations (flights, take-offs, landings) noise based on determining spatial sound intensity vector in the tested acoustic field during a monitoring timespan was presented at [4]. Results of the algorithm used to determine the position angle of sound sources in the adopted coordinate system are quite promising but disadvantage of this system is low resistance probe to changing weather conditions. Thus, arises the idea of the use of automated pattern recognition techniques for identification of acoustic noise sources and identify the airplane operations in long-term monitoring systems by using only measurement microphone being component of the long-term acoustic climate monitoring stations. The current technology is developed enough to create an efficient algorithm and its hard-ware implementation seems to be possible as well. In principle, all applied methods of automatic classification, including pattern recognition depend on the following problem being solved: the solutions' lack of versatility results not from imperfection of the recognition methods, but rather from excessive complexity of source signals. For this reason, special transformation of the signals analyzed is applied in order to obtain an appropriate simple feature space. Currently, although a number of specific solutions exist, two principal methods to creating the space of features can be distinguished. The first one consists of the search of the suitable transformation of the signal and using its results (parameters) as the signal characteristics. The other approach consists of the search of a model describing the way of the observed signals' emission, e.g. identification of filters generating the signal. The problem discussed, can be expanded to cover also the noise immission or more precise, perception of the observed signal.

Several algorithms and instruments recognizing certain determined classes of objects were developed [14-16]. However, in practical applications, it is not clear which features and relations should count as the basic ones, and how to single them out from the recognized patterns. It was assumed, that in order to obtain features needed at the recognition, the preliminary signal processing should occur in an identical fashion just as in visual and audio systems of humans. In authors' researches [5-12] concerning recognition of aircraft noise has been carried out by three groups of methods: pattern recognition – probabilistic method (statistical decision based on a threshold of discrimination – d_{xy}), the minimum distance classifier (with Euclidean metric) and neural network techniques (Multilayer Perceprton). In the group of pattern recognition methods the Nearest Neighbor (NN), kNerest Neighbors (kNN) and Nearest Mode (NM) have been applied. The early results allow a conclusion that both pattern recognition and neural network technique can be applied to recognition of acoustic patterns with correctness about 90 %. The collected by authors experience and developed algorithms in MATLAB prompted to the development software to automatic detection of aircraft noise events during acoustic climate long-term monitoring near airport in LabVIEW programming environment from National Instruments. The application is called ANED (acronym of Aircraft Noise Events Detector). LabVIEW is well know the

environment in which programmed in a graphical language. Software requirements include the operating systems, such as: Linux, Windows, Mac OS X. In LabVIEW is also possible to build applications working in Real-Time Operating System (RTOS) which could be an integrated application with long-term monitoring station software.

3. Aircraft noise events detector (ANED)

In authors researches [5-12], the point for the decision to apply the parameters of the acoustic signal in the perceptual frequency scales was the observation that virtually everyone who had any contact with vehicles and transport facilities is able to detect their presence and distinguish their type (airplane, train, tram, car, truck, motorcycle) on basis of perceived auditory experience during their movement. The cepstral analysis in mel scale is based on the characteristics of the human hearing, thus the authors decided to use it in their earlier research. Mel Frequency Cepstral Coefficients (MFCC) analysis is a widely used algorithm in nonstationary signals study (including the recognition and speech intelligibility in communication systems). The human ear distinguishes sounds using non-linear frequency scale of spectrum. This scale is linear only to 1 kHz, while the non-linearity for the higher frequencies can be described using a logarithmic scale [14]. Practical importance of cepstrum is that it often enables more transparent interpretation of the information contained in spectrum. This applies in particular to assess of the relationship of spectral frequency components obtained in the signal. A specific feature of cepstrum is its ability to separate effects related to operation of the sound source from the effects related with the transmission (propagation path) [15]. This fact is very important, because depending on location of monitoring stations (terrain, season of year, weather conditions) are changing acoustic wave propagation between the source and receiver. The block diagram of ANED application algorithm is shown at Fig. 1.
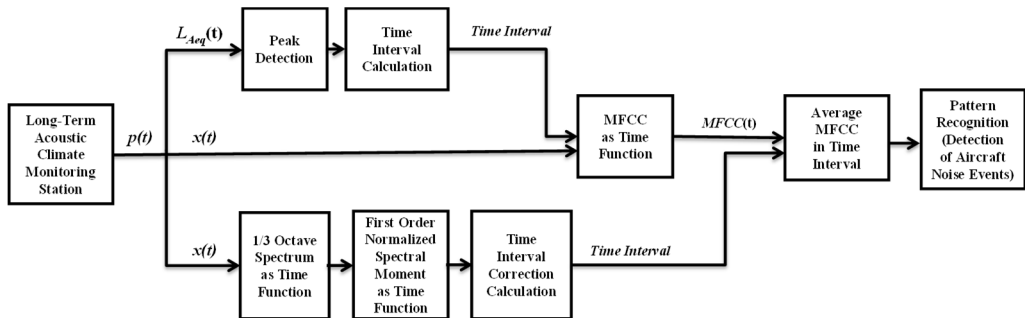

Fig. 1. Block diagram of the automatic detection system of aircraft noise events – ANED:
$p(t)$ – sound pressure, $x(t)$ – waveform signal, $L_{Aeq}(t)$ – A-weighted equivalent sound pressure level

Sound pressure $p(t)$ recorded by the microphone monitoring station is processed in two ways: to A-weighted equivalent sound pressure level $L_{Aeq}(t)$ and waveform signal $x(t)$.

On the basis of the signal $x(t)$ are calculated MFCC parameters for the different number of factors, such as: 10, 12, 14, 20. The tracking auditory event itself is done by using two parallel ways: peak detection in time domain of L_{Aeq} function and first order normalized spectral moment calculate in 1/3 octave spectrum domain. Each time the system is individually calibrated for the location of the monitoring station (including microphone) is selected among the number of coefficients MFCC. This procedure is particularly important in order to detect an aircraft noise even in over 90 % correctness recognition. For example, Fig. 2 shows the separation of classes for aircraft propelled by jet and turboprop engine and source treated as a "background" – ride the train for tree coefficients MFCC 2, MFCC 3, MFCC 8 for the number of coefficients equal to 14. While Fig. 3 shows placement of objects of aircraft noise class relative to the train noise class in the 3 dimensional feature space MFCC 2, 3 and 8. There is very good visible separation of classes in the proposed space.
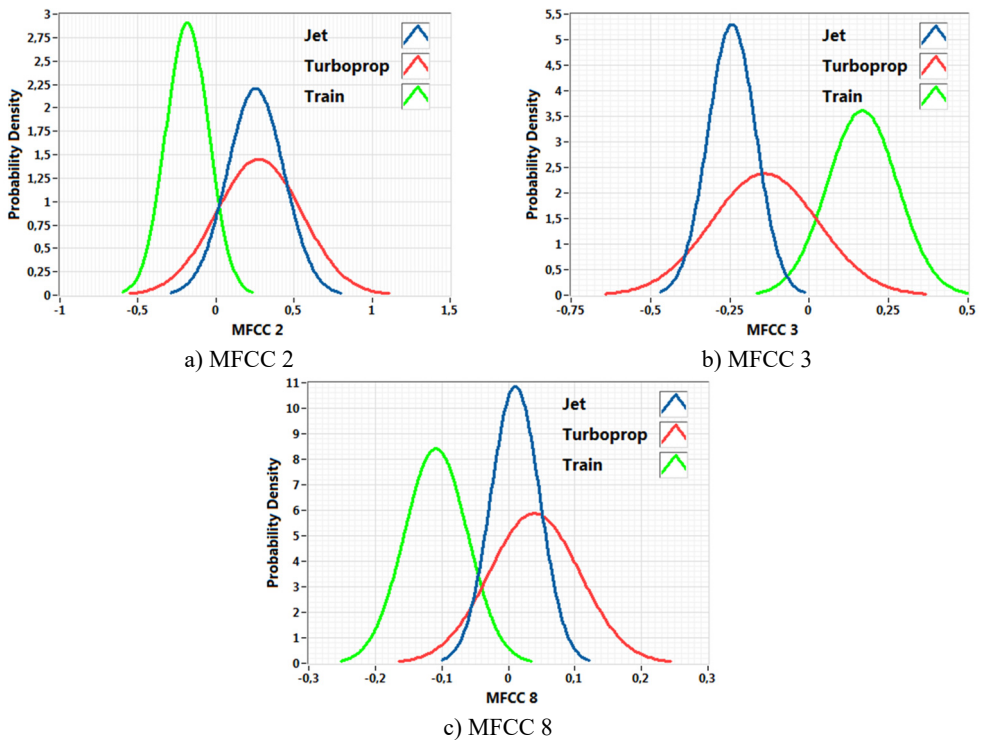
a) MFCC 2

b) MFCC 3

c) MFCC 8

Fig. 2. Probability density function of aircraft noise (jet engine, turboprop engine) and "background" noise (a train ride) for mel frequency cepstral coefficients
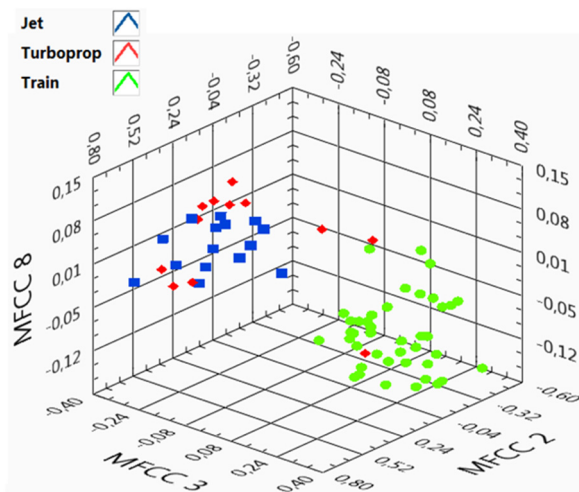

Fig. 3. Comparison of mel frequency cepstral coefficients (MFCC 2, MFCC 3, MFCC 8) for noise events representing three classes (source of aircraft noise – jet engine, turboprop engine, source of railway noise – a train ride)

4. Summary

The paper presents an algorithm of LabVIEW application so called ANED (Aicraft Noise Event Detector) for automatic identification of aircraft noise sources in the environment acoustic monitoring systems. The proposed method is based on pattern recognition technique (probabilistic method, i.e. statistical decision based on a threshold of discrimination – d_{xy}) using classic acoustic

parameter $L_{Aeq}(t)$ (as time function, which can estimate minimum, maximum and exposition value of sound level) and MFCC estimated from acoustic signals. The developed algorithm can be incorporated into existing monitoring systems of acoustic climate, and also used in the analysis of recordings from existing systems and as other solutions – such as acoustic radar, while recognizing air transport operation near airport. This fact allows for proper term noise levels emitted by events related to air traffic and comparing them to the permissible level of noise. The early results allow a conclusion that ANED application can detect aircraft noise event with correctness about 90 %.

Acknowledgements

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