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RECOGNITION OF AIRCRAFT NOISE IN LONG-TERM ENVIRONMENTAL MONITORING

SUMMARY

Continuous acoustical climate monitoring of a particular area raises problems related to large quantities of the recorded data, which often represents information unrelated to the study source. Manual verification of data is time-consuming and costly. Therefore, to develop effective methods for automatic identification of transport noise sources becomes an important task for the proper determination of noise levels. This paper presents a concept of method in automatic detection and classification of air transport noise sources in the acoustic environmental monitoring.

***Keywords**: aircraft noise, monitoring, signal processing, pattern recognition*

ROZPOZNAWANIE HAŁASU LOTNICZEGO W DŁUGOOKRESOWYM MONITORINGU ŚRODOWISKA

Ciągłe monitorowanie klimatu akustycznego określonego terenu stwarza problemy związane z dużą ilością zarejestrowanych danych, bardzo często reprezentujących informacje niezwiązane z badanym źródłem. Manualne zweryfikowanie danych jest procesem czasochłonnym i kosztownym. Dlatego opracowanie skutecznych metod pozwalających na automatyczne rozpoznawanie źródeł hałasu komunikacyjnego staje się istotnym zadaniem dla właściwego określenia poziomów hałasu. W artykule przedstawiono koncepcję metody automatycznego wykrywania i klasyfikacji źródeł hałasu transportu lotniczego w monitorowaniu klimatu akustycznego środowiska.

***Słowa kluczowe**: hałas lotniczy, monitoring, przetwarzanie sygnałów, rozpoznawanie obrazów*

1. INTRODUCTION

Noise is one of the major environmental problems in the inhabited areas of the world. In Poland the development of the domestic communication has become one of the main sources of noise hazards in the environment over the last 20 years. The road noise has been a dominant factor of the acoustic climate, due to its widespread nature and prolonged effect. However, great importance have a noise with flight, takeoff and landing of aircrafts. 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, however it will be still higher than the European average. In 2009 the Polish airports tripled the number of passengers being served, comparing to 2003 (i.e., approximately doubled the number of the air operations). Estimations for 2030 are that the number of operations will be four times higher than the current one.

In the European Union, Directive 2002/49/EC establishes uniform requirements for the assessment and management of environmental noise. In Poland, the provisions of the said Directive were implemented into the national Environmental Protection Law Act of 27 April 2001 (as amended). The purpose of these acts to the legal system is the protection of health, quality of life and well-being of the inhabitants of the globe. While exploiting the environment by emission of significant quantities of acoustic energy, the management of a road, a railway, a tram-line, an airport or a port is required to perform continuous measurement of such emissions. Such studies are designed to collect information about the prevailing acoustic climate and to produce conclusions, reports and maps of the areas most threatened with limits being exceeded. Carrying out continuous monitoring of a particular area, involves problems of large quantities of the recorded data, often representing the information unrelated to the study source. Manual verification of data is time-consuming and costly. Therefore, to develop effective methods for automatic identification of transport noise sources (especially aircraft noise) becomes an important task for the proper determination of noise levels. This paper presents a proposal of the new method for automatic detection of aircraft noise during long-term monitoring of acoustic climate based on cepstral analysis in mel frequency scale.

2. SPECIFICITY OF AN AIRCRAFT NOISE

Each aircraft flying above an observer emits a characteristic acoustic signal. This signal can constitute the basis for the recognition of the aircraft as well as the trajectory of its flight. As compared with environmental hazard caused by other sources the specificity of air noise is as follows (Rajpert 1980):

- noise influences relatively large areas,
- aircrafts are characterised by high levels of noise emission, but they are at a large distance from objects for which this noise is harmful,

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– propagation path of sound waves (acting from above) makes impossible the application of effective environment protections against noise, available e.g. in traffic noises.

Propagation of air noise in the environment is the most often determined by using calculation procedures (e.g. INM[1] (He *et al.* 2007)). However, the basis for assessment of the noise arduousness around airports constitutes the measurement results. Such measurements are simultaneously performed in a few or a dozen or so characteristic points by means of the professional monitoring stations. The following parameters are the most often recorded in individual measuring points:

– time of event,
– sound exposure level L_{AE},
– maximal sound level $L_{A\max}$,
– equivalent sound level L_{Aeq},
– duration of event t_{10},
– description of event (or eventual disturbances),
– sound pressure level as time function (saved to wave file).

Apart from recording the mentioned parameters in the monitoring system, additional information is necessary to explicitly describe the recorded acoustic event. In the case of recognizing air acoustic events (e.g. aircraft or helicopter flight) it is very difficult to find the proper principle of signal analysis or the proper algorithm of its recognition (Wszolek *et al.* 2001).

3. REQUIREMENTS FOR THE MONITORING SYSTEM

Depending on the actual needs the noise monitoring system may be oriented on execution of various tasks. The tasks can be simply related only to the noise level estimation and environment protection or more difficult and complex corresponding to analysis and acoustic signals recognition, characterising acoustic events (e.g. noise related to flight of specific aircrafts and helicopters, flight trajectory). Finally, another essential task of the monitoring system can be the determination of the flight direction. More and more rigorous regulations concerning the permissible parameters of acoustic climate in the airports regions as well as the necessity of identification not only the facts of exceeding the permissible noise standards but also doers and circumstances of this violation are the reasons, that classic monitoring systems might not be sufficient or might to be very expensive. The listed tasks require quite different functions, measuring methods of acoustic pressure levels and completely different methods of the preliminary signal processing. The classical monitoring systems are based on known and standardized testing procedures and are most often directed towards continuous tracing of environmental climate changes in the airport vicinity (Fig. 1).

Typical monitoring systems are able to measure sound pressure level as time history, identifying and classifying the air acoustic events generated by air transport. The noise aircraft detection task is related to airport radar system. It means that noise level is correlated with radar tracks of flights. When noise level value reaches over the threshold, and radar detected aircraft, this air acoustic event will be classified as produced by an aircraft.

Actually, the modern monitoring systems (Fig. 2) could be based on the algorithms of more advanced methods of signal processing and analysis. By application of professional computer systems the collected data can be used for understanding of acoustic phenomena taking place in the environment, for extraction of raw data related to those acoustic events which are related to air transport operations. That knowledge may be very useful for elaboration of proper decisions improving the condition of acoustic hazards caused by the air traffic.

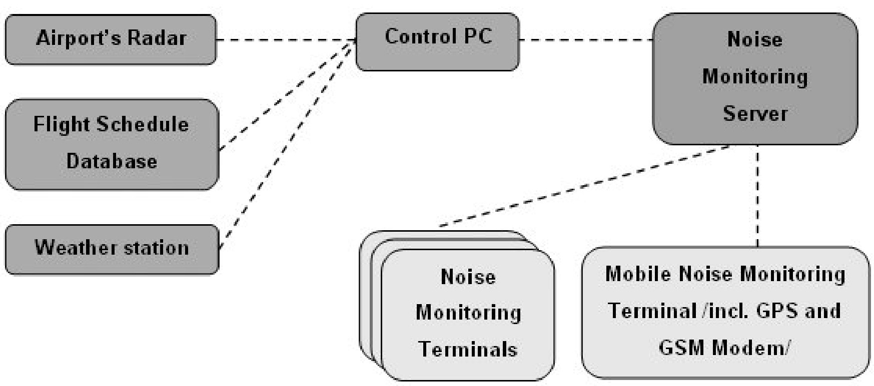

Fig. 1. Typical monitoring system of an airport noise

[1] This method is contained in international regulations for the purpose of the Law of July 3rd 2002 – Air Law (the Journal of Law No 130, item 1112), especially in the document: Circular 2005 – AN/1/25/1988 ICAO and in the adapted for European conditions, accepted by the Directive 2002/49/WE document: ECAC CEAC Doc. 29, Report on Standard Method of Computing Noise Contours around Airports.

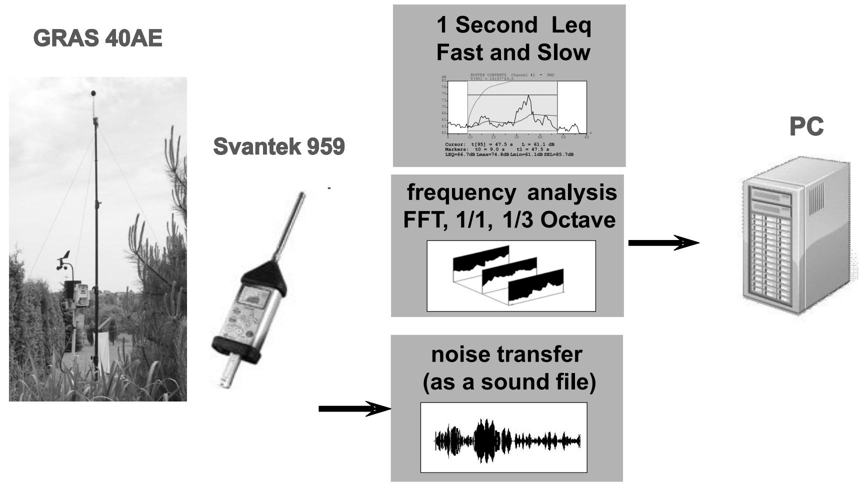

Fig. 2. Possible noise monitoring system

4. RECOGNITION METHODS

In principle, all applied methods of automatic classification especially pattern recognition depend on the problem being solved. The solutions' lack 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 specifically perception of the observed signal.

There are many methods of a pattern recognition, which are dealing with an abstract pattern notion, understood as a set of certain features and relations (Fig. 3). Several algorithms and instruments recognizing certain determined classes of objects were developed. However, in practical applications, it is not clear which features and relations should be assumed as the basic ones and how to single them out from the recognised 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.

Most researchers agree that the features necessary for pattern recognition of sound should be sought in a time-frequency domain of an acoustic signal. The point for the decision to apply the parameters of the acoustic signal in the mel-frequency scale 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, 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 research. 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 (Rabiner and Juang 1993).

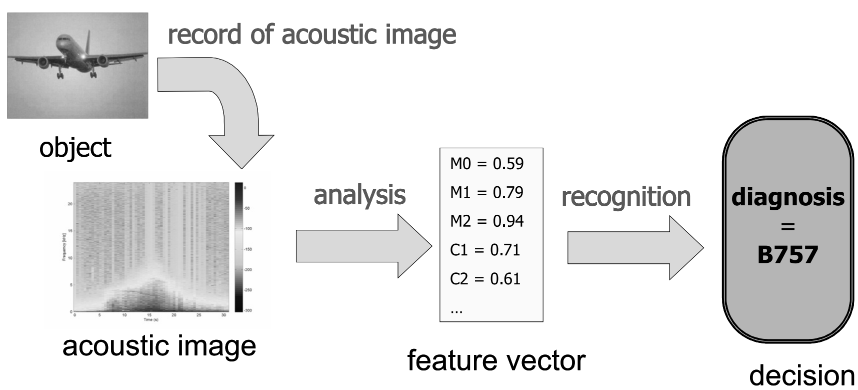

Fig. 3. Model of acoustic pattern recognition

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 contained 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). 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 following procedures of the digital signal processing were applied in calculations:

- recording signals with sampling frequency fs = 48 kHz,
- Hamming's time window of a length N = 12 000 samples,
- 12 000 points FFT[2], calculated every 500 ms of signal,
- reduce frequency band to 10 kHz,
- rescaling the frequency scale into the mel scale, according to the following:

$$mel(f) = 2595 \cdot \log\left(1 + \frac{f}{700}\right) \tag{1}$$

- mel filtration – it means the spectrum conversion into the form of midband pass filters (summing the weighted individual spectral lines, where the coefficients of corresponding triangle filters are used as the weights). The number of filters in the set: N = 12,
- determination of cepstral coefficients in the mel scale, MFCC, as discrete conversion of logarithm cosinuses of the parameters of filter data, according to the formula:

$$C_n = \sqrt{\frac{2}{N}} \sum_{i=1}^{N} \log(s_i) \cdot \cos\left[\frac{\pi \cdot n}{N}\left(i - \frac{1}{2}\right)\right] \tag{2}$$

where:

C_n – n^{th} cepstral coefficient, n = 1, ..., 12
S_i – i^{th} coefficient obtained from signal conversion by the set of filters,
N – number of filters in the set, N = 12.

In the hereby paper we limited ourselves, to analysing acoustic events generated by aircrafts during take offs, landings and taxi (typical airport operation). The professional measuring equipment of the HHB, Bruel & Kjaer, Svantek Companies was applied for recording and processing of acoustic signals. The mulitspectrum analysis of recorded acoustic signal in the frequency range from 20 Hz to 20 kHz (with time quantum Δt = 0.5 s) was performed for the preliminary signal processing. In this way the multispectrum $W(j, k)$ of signals characteristic for the take off procedure was obtained (where: j – frequency coordinate, and k – time coordinate). Examples of multispectra recorded in the airstrip region of the airport are shown in Figures 4a–8a. In Figures 4b–8b. are presented in graphic form the time variability of 12 mel-frequency cepstral coefficients of airport procedures (take off, landing, taxi) for typical noise signals recorded several popular civilian and military aircraft. Even a preliminary analysis of visual, shows that although different types of aircraft (various types of engines), and various procedures, the spectrograms have a different shape. However, analysis of the MFCC in a similar way about the impact of aircraft noise – see elevated levels for the 2nd, 5th, 8th, 11th coefficients.

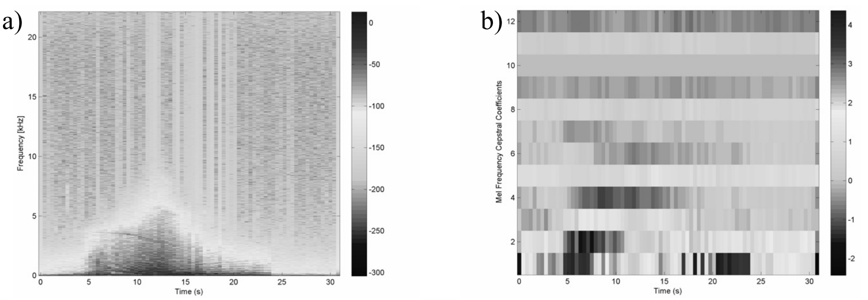

Fig. 4. Boeing 737 take off (spectrogram) (a); Boeing 737 take off (MFCC) (b)

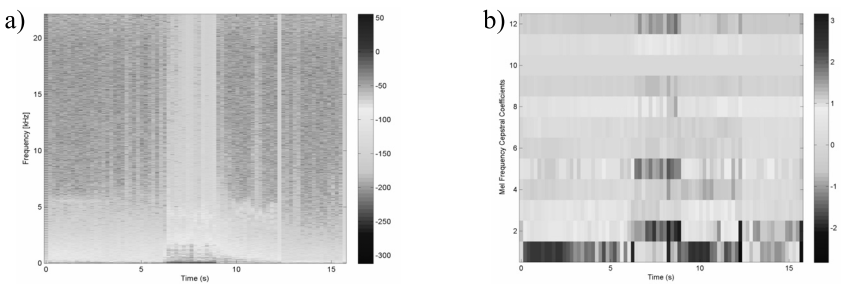

Fig. 5. Boeing 733 taxi (spectrogram) (a); Boeing 733 taxi (MFCC) (b)

[2] Fast Fourier Transform.

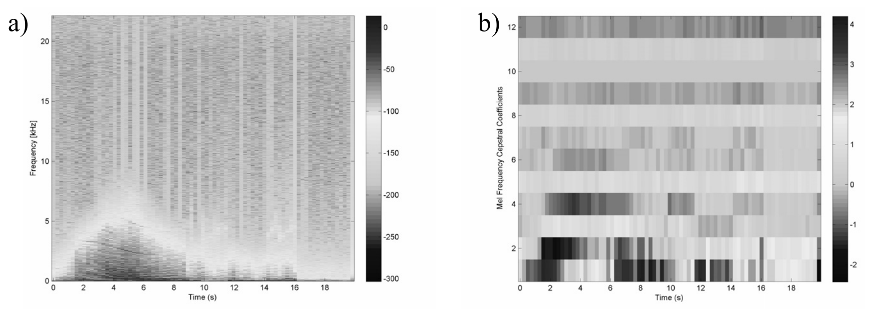

Fig. 6. ATR72 take off (spectrogram) (a); ATR72 take off (MFCC) (b)

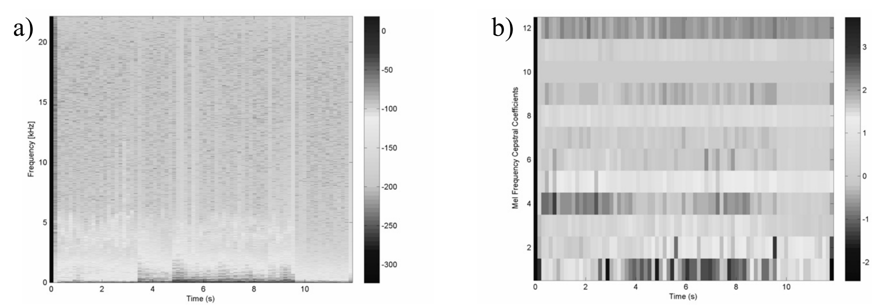

Fig. 7. AN24 take off (spectrogram) (a); AN24 take off (MFCC) (b)

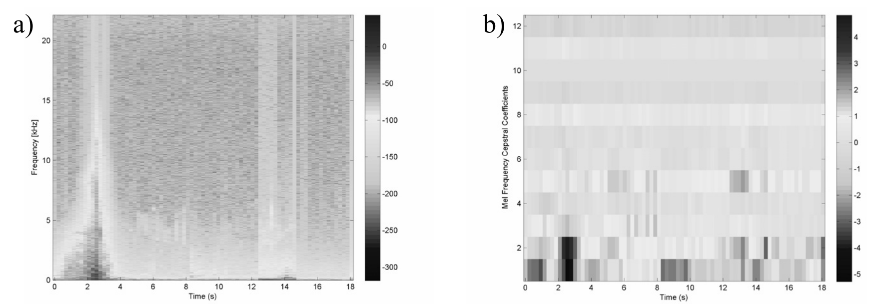

Fig. 8. CASA C295 landing (spectrogram) (a); CASA C295 landing (MFCC) (b)

5. EXPERIMENTAL RESULTS

The objects intended for the recognition were aircrafts the most often flying in Poland. The noise analyses were limited to the selected aircrafts (B737, ATR72, AN24, C-295). The analysis of the acoustic signal emitted by aircrafts was oriented to the recognition of the acoustic event doer. Many variants of the feature vector were considered in particular stages of investigations. Discussion on the correctness of the space of features selection was disregarded in this paper – since it was included in previous papers (Wszołek and Batko 2009; Wszołek and Tadeusiewicz 2005; Tadeusiewicz *et al.* 1999). The new feature vector is based on mel frequency cepstral coefficients and defined (3):

$$\langle C_1, C_2, ..., C_{12}, C_{12} \rangle = X \quad (3)$$

where C_i – i-th cepstral coefficient determined according (2).

The research concerning recognition of aircraft noise has been carried out by two groups of methods: pattern recognition – the minimum distance method (with Euclidean metric) and neural network techniques (MLP), with learning by error backpropagation (BP) method. In the group of pattern recognition methods the Nearest Neighbor (NN), k Nerest Neighbor (kNN) and Nearest Mode (NM) have been applied (Tadeusiewicz 1993; Tadeusiewicz and Flasiński 1991). In the experiment acoustic data have been divided into individual groups in two ways: propeller planes and jet planes. The results of the calculations are presented in Tables 1. The results allow a conclusion that both pattern recognition and neural network technique can be applied to recognition of acoustic patterns. It has been also found that the neural network techniques lead to betters results in this field.

Table 1

Recognition results of aircrafts noise events

Methods of recognition	Recognition correctness, %	
	Propeller aircraft	Jet aircrafts
Nearest Neighbour(NN)	87	90
k Nearest Neighbour (k-NN)	90	91
Nearest Mode (NM)	91	92
Neural networks (BP)	95	97

6. CONCLUSIONS

This paper presents a method of automatic recognition of air transport noise sources in the acoustic environmental monitoring. This method is based on the automatic "understand" of the sound collected by microphone. The proposed algorithm is based on cepstral analysis in mel frequency scale. The elaborated algorithm can be implemented into existing systems of long-term monitoring units as modules in systems for automated recognition of acoustic events. In further stages of the research will be increase the data base of recorded aircraft noise patterns, which could lead to increase an efficiency of proposed method.

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