# Identification of acoustic event of selected noise sources in a long-term environmental monitoring systems

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## ABSTRACT

Undertaking long-term acoustic measurements on sites located near an airport is related to a problem of large quantities of recorded data, which very often represents information not related to flight operations. In such areas, usually defined as zone of limited use, often other sources of noise exist, such as roads or railway lines treated is such context as acoustic background. Manual verification of such recorded data is a costly and time-consuming process. However, the use of special systems or devices that support the recognition of noise sources is an additional high cost. Thus, the said problems bring up an idea to use automated methods to identify noise sources and time of such events. The proposed solution is to use pattern recognition techniques for acoustic signal recorded by the monitoring station, without the need for additional equipment. Methods based on an automatic "meaning" of sounds recorded by measuring microphone (included monitoring station) and refer to the advanced techniques of cognitive referring to the human auditory perception. In this way will be possible to assign markers to acoustic events and calculate an acoustic indicator of environmental assessment. The recordings from the stations of long-term acoustics monitoring have been used while classifying the traffic noise - aircraft operations, movement of trains or cars.

Keywords: airport noise, long-term aircraft noise monitoring, signal processing
I-INCE Classification of Subjects Number(s): 52.2, 72.1, 74

## 1. INTRODUCTION

Noise is one of major environmental problems in inhabited areas of the world. In Poland, development of domestic communication has become one of the main sources of noise hazards in the environment over the last 25 years. 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 be still higher than the European average. In 2013, Polish airports tripled in the number of passengers served (25 million), comparing to 2003 (7 million), which translates into approximately doubled overall number of air operations. Estimations for 2020 are that the number of passengers being served will increase to approximately 38 million, which will result in further doubling of air operations (comparing to the current level).

While exploiting the environment by emission of significant quantities of acoustic energy, according to European Union Directive 2002/49/EC the management of an airport (alike as this of a road, a railway, 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 the 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 studied source. Manual verification of related data is time-consuming and costly. Identification and separation of background noise sources becomes a crucial task for proper determination of noise levels. The paper presents usefulness of special directed measurement techniques, acoustic signal processing and its parameterization to the feature vector represent noise sources and classification methods used to identification of aircraft noise in long-term environmental monitoring systems.

## 2. DETECTION OF NOISE EVENT

Methodology for measuring road noise is relatively simple and the use of automatic noise monitoring station does not involve much difficulty, and the traffic occurs continuously. The detection of traffic event can by supported by special microwave sensors such as SmartSensor HD (2) or Remote Traffic Microwave Sensor (3). The aircraft noise measurements are more complicated and their range include large areas. 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 (4) or using the information from airport radar system (5). 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 (6). On this basis, aircraft operations can be marked in a continuous record of noise events. Experimental measurements were performed by using two different sound transducer — 3D Microflown sound intensity probe (7) and Soundfield ST350 ambisonic microphone (8). 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. Method relies on automatic "meaning" of sounds recorded by microphone (Figure 1).

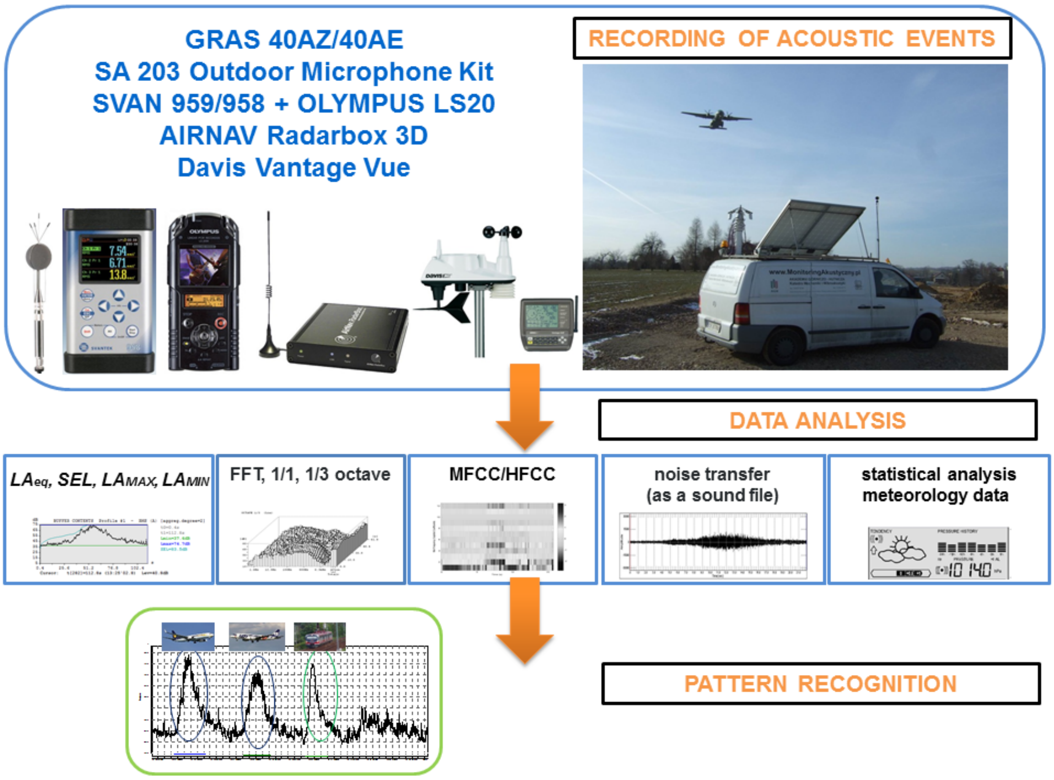


Figure 1 – Model of acoustic pattern recognition

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 specifically perception of the observed signal or more precise, perception of the observed signal.

Several algorithms and instruments recognizing certain determined classes of objects were developed (9, 10, 11). 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.

## 3. FEATURE VECTOR OF ACOUSTIC SIGNAL

Most researchers agree that the features necessary for pattern recognition of sound should be sought in a time-frequency domain of an acoustic signal. This idea is based on human auditory perception. Several perceptual frequency scales is well known; the octave scale, the Bark scale and the mel scale. The Bark scale was proposed by Eberhard Zwicker (12). The scale ranges from 1 to 24 and corresponds to the first 24 critical bands of hearing. Most popular from Bark scale is mel scale, which was named by Stevens, Volkman and Newman in 1937 (13) and is a perceptual scale of pitches judged by listeners to be equal in distance from one another.

In authors researches, 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 (14÷18). 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 (19). 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) (20). 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.

In this work the authors used the Human Factor Cepstral Coefficients (HFCC), which are a bioinspired modification of MFCC. HFCC were introduced by Skowronski and Harris in (21, 22). In MFCC the center frequencies of each triangular filter in the bank is a function of sampling rate and the number of filters. That is, if the number of filters in the filter bank increases, the bandwidth of each filter decreases unintentionally. In HFCC implementation these features are decoupled. To determine the filer bandwidth Moore and Glasberg's (23) approximation of critical bandwidth is used. It is measured in equivalent rectangular bandwidth (ERB):

$$ERB(f_c) = 6.23 \cdot f_c^2 + 93.39 f_c + 28.52 \text{ Hz}, \qquad (1)$$

where center frequency fc is in kHz (22). This equation describes the critical bands of the human auditory system. The bank filter used by Moore and Glasberg's in their research was defined by the following values: minimal frequency – 0.124 kHz, maximal frequency – 6.5 Hz. In authors work, the proposed system is dedicated to identification of transport noise sources, so maximal frequency was extended to 12 kHz and minimal frequency was reduced to 20 Hz.

## 4. RESEARCH

The recordings from the mobile station of long-term acoustics monitoring shown in Figure 2 and Figure 3 have been used while classifying the air transport operations. The locations of the station include: village Rzaska and Mydlniki near Krakow (the measuring point in the close location of a railway line and route of departures and arrivals to *Krakow Airport*), village Morawica near Krakow (the measuring point in the vicinity of *Krakow Airport* and highway A4), village Banino near Gdansk (close vicinity of a highway A1 and route of departures and arrivals to *Gdansk Airport*).

Figure 2 - The mobile station of long-term acoustic monitoring (exterior view)

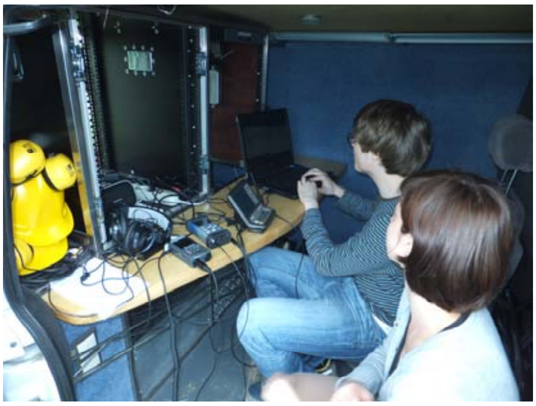

Figure 3 - The mobile station of long-term acoustic monitoring (interior view)

In this work the following procedures of the digital signal processing were applied in calculations:

- recording signals with sampling frequency fs=48 kHz,
- A-weighted filtering,
- decimation of signal,
- 12000 points FFT with Hamming's time window, calculated every 500 ms of signal,
- HFCC filtering – it means the spectrum conversion into the form of midband pass filters - filter bandwidth is calculated according the critical bandwidth of the human auditory system (1), filter center frequency are equally spaced in mel frequency *mel(f)* rescaled from linear frequency *f*, according to the following:

$$mel(f) = 2595 \cdot \log(1 + \frac{f}{700}) \quad (2)$$

  (summing the weighted individual spectral lines, where the coefficients of corresponding triangle filters are used as the weights). The number of filters in the sets was chosen experimentally within the range: N=12÷48,
- determination of HFCC as discrete conversion of logarithm cosinuses of the parameters of filter data, according to the formula:

$$C_n = \sqrt{\frac{2}{N}} \sum_{i=1}^{N} \log(s_i) \cdot \cos\left[\frac{\pi \cdot n}{N}(i - \frac{1}{2})\right] \quad (3)$$

  where: $C_n$ – $n^{th}$ cepstral coefficient, n=1,….,N
  $S_i$ – $i^{th}$ coefficient obtained from signal conversion by the set of filters,
  N – number of filters in the set
- determination of $LA_{eq}$, $LA_E$, $LA_{MAX}$, $LA_{MIN}$ parameters

Analysis of the acoustic signal emitted by the aircraft was limited to selected types: B737, A320, ATR72, ATR42, AN24, C-295. However, the analysis of background noise was limited to the railway traffic (limited to the types of locomotives: EU06, EU07, ET21, ST43, ST44, and train EN57), vehicles (car, track). In some previous papers (14-18, 24, 25) many variants of the parameters feature vectors has been presented as an analysis and discussion of the correctness in selection of the feature space. Currently proposed feature vector is based on HFCC and $LA_{eq}$, $LA_E$, $LA_{MAX}$, $LA_{MIN}$ parameters estimated in each time window of recorded acoustic signal according to the following:

$$< C_1, C_2, ..., C_N, LA_{eq}, LA_E, LA_{MAX}, LA_{MIN} >= X(t) \quad (4)$$

The research concerning recognition of aircraft noise has been carried out by three groups of methods: pattern recognition (10, 26) – probabilistic method (statistical decision based on a threshold of discrimination - $d_{xy}$), the minimum distance classifier (with Euclidean metric), 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%. Detailed conclusions will be presented during the presentation of research results.

## 5. CONCLUSIONS

The paper presents a method of automatic identification of aircraft noise sources in the environment acoustic monitoring systems. The said method relies on automatic "meaning" of sounds recorded microphone technique. The proposed algorithm is based on pattern recognition techniques using of $LA_{eq}$, $LA_E$, $LA_{MAX}$, $LA_{MIN}$ and HFCC 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.

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## REFERENCES

1. The Civil Aviation Authority (CAA), Poland, http://www.ulc.gov.pl/en (1.07.2014).
2. SmartSensor HD Technical Specification, Wavetronix, USA, 2012, http://www.wavetronix.com
3. Remote Traffic Microwave Sensor, Image Sensing Systems Canada Ltd., 2014, http://www.imagesensingca.com/
4. Environmental Sound Monitoring (For Aircraft Noise Measurement), Rion, Japan, 2014, http://www.rion.co.jp/english/
5. Airport Environment Management, Bruel & Kjaer, Denmark, 2014, http://www.bksv.com/
6. Klaczynski M., Identification of Aircraft Noise During Acoustic Monitoring by Using 3D Sound Probes, Acta Physica Polonica A, vol 125 (2014), no. 4-A, pp. 144-148.
7. Datasheet and User Manual for Microflown USP probe regular, http://www.microflown.com/
8. User Guide ver. 1.03 SoundField ST350 Portable Microphone System.
9. James M., Classification Algorithms, John Wiley and Sons, New York, 1985.
10. Duda R.O., Hart P.E., Stork D.G., Pattern classifications (2nd ed.), Willey, New York, 2001.
11. Tadeusiewicz R., Flasinski M., Pattern Recognition, PWN, Warszawa, 1991, (in Polish).
12. Zwicker, E. Feldtkeller, R, Das Ohr als Nachrichtenernpfanger, Hirzel, Stuttgart, 1967.
13. Stevens S.S., Volkman J., Newman E. B. , A scale for the measurement of the psychological magnitude pitch, Journal of the Acoustical Society of America vol. 8 (1937) pp. 185–190.
14. Wszolek W., Klaczynski M., Wszolek T., Artificial intelligence methods in supporting long-term monitoring of aircraft noise, Proc INTER-NOISE 2010, Lisbon 13-16 June 2010, p.330 + CD.
15. Klaczynski, Wszolek T., Batko W., Recognition of selected sources of transport noise in the acoustic climate monitoring, Proc. 58th Open Seminar on Acoustics, Gdańsk-Jurata, 13–16 September 2011, pp. 347–352.
16. Klaczynski M., Wszolek T, Batko W., Probablistic methods in supporting long-term acoustic monitoring of aircraft noise, EURO-NOISE 2012, Prague, 10–13 June 2012. pp. 553–554 + CD.
17. Klaczynski M., Wszolek T., Batko W., A statistical approach in detection of noise events to aircraft noise assessment, Proc. 59th Open Seminar on Acoustics joint with workshop on strategic management of noise including aircraft noise, Poznań–Boszkowo, 10–14 September 2012, pp. 113–116.
18. Klaczynski M., Wszolek T., Detection and classification of selected noise sources in long-term acoustic climate monitoring, Acta Physica Polonica A, 2012 vol. 121 no. 1-A, 179–182.
19. Rabiner L., Juang B.H., Fundamentals of speech recognition, Prentice Hall, New Jersey, 1993.

20. Zielinski T., Digital Signal Processing, WKŁ, Warszawa, 2005, (in Polish).
21. Skowronski M.D., Harris J.G., Human factor cepstral coefficients, J. Acoust. Soc. Am. Vol. 112 (2002), pp.2279
22. Skowronski M.D., Harris J.G., Exploiting independent filter bandwidth of human factor cepstral coefficients in automatic speech recognition, Journal of the Acoustical Society of America, Vol. 116 (2004), pp. 1774-1780.
23. Moore C.J., Glasberg B.R., Suggested formula for calculating auditory filter bandwidth and excitation patterns, Journal of the Acoustical Society of America, vol. 74 (1983), pp. 750-753.
24. Wszołek W., Batko W., New trends in airport noise monitoring systems, Diagnostics vol. 2 (2009), pp. 41-45.
25. Wszołek W., Kłaczyński M., Recognition of aircraft noise in long-term environmental monitoring, Mechanics and Control, vol. 29 (2010), no. 4, pp. 192-197
26. Basztura Cz., Acoustical sources, signals and images, WKiŁ, Warszawa, 1988 (in Polish).