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AUTOMATIC UNDERSTANDING METHOD OF SIGNALS APPLIED TO IDENTIFICATION OF ACOUSTIC PATTERNS

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Abstract

Combining the noise monitoring stations with the radar stations in the current monitoring systems assists the recognition process of acoustic events related to the airports operations. Due to the difficulties occurring in this communication system it would be highly advantageous to equip the monitoring stations with tools allowing autonomous recognition and classification of the monitored noise sources.

The idea of application of advanced artificial intelligence methods and techniques as analytical tools at monitoring the noises caused by air traffic – is presented in the paper. The proposition stipulates the replacement of the known procedure of acoustic signal recognition by more advanced method of signal analysis based on comparison of features extracted from the signal during its conversion with the features expected due to the appropriate knowledge collected in the system.

INTRODUCTION

Intensive development of technical civilisation caused that noise became the most annoying problems of the contemporary life. Different kinds of machines considered as noise sources (both stationary and mobile) are mainly responsible for such situation.In the design of the airplanes produced in recent years (both passenger and cargo planes) an apparent trend can be noticed, aiming at the increase of the take-off weight, decrease of the lift-off velocity, rapid increase of the ascending velocity and the accelerations achieved (resulting in more steep take-off profiles) . The above mentioned tendency strongly influences the external sound emission levels (during the initial stages of the take-off the engines of the power units work at their aximum power level) . An additional factor is the increasing number of flights accomplished. The results of acoustic studies carried out by various centres dealing with the aircraft generated noise show, that in general the acoustic noise level in the near vicinity of the airports exhibits a permanent increase. The above conclusion is a source of constant worry of the services responsible for the supervision of the environmental conditions (including the acoustic ones) and also a stimulus for individual studies of the noise emission generated by the starting airplanes, followed a possibility of penalising the air carriers especially noxious for the acoustic environment. In order to perform such tasks effectively the airport services must have a possibility to recognise the type (in special cases even the individual unit) of the aircraft, for which the noise has been registered, and sometimes also its take-off trajectory.The selection of the proper representation of signal can be based either on the adequate model of the signal generation process or on the model of its perception by a human being – if the possibility of such perception exists, which is not always the case. The proposed approach is not quite new since all analytical and signal conversion techniques refer - openly or not openly - to the assumed model of signal generation or to the reference model of signal perception (by human beings) obtained by bio-cybernetic investigations. Having an adequate model of the signal generation or its perception one can indicate which frequency bands carry the most suitable information. Standard methods of conversion and classification of acoustic signals totally fail in situations when not the noise itself but its noxiousness is to be assessed. Deepened and non-standard methods of signal analysis and interpretation, oriented towards processes of sound influence on human organisms and minds not towards the signal description only, are needed. The artificial intelligence methods, in particular the neural networks technique and the pattern recognition method are those informatics methods, which can combine the possibilities of traditional acoustic measurements with the requirements of modern monitoring systems of air noises. Investigation of efficiency of those methods - in monitoring of the acoustic climate in the vicinity of airports - constitutes the topic of the presented hereby paper.

ACQUISITION AND PROCESSING OF THE ACOUSTIC SIGNAL

The complete set of acoustic measurements has been carried out at the Krakow-Balice and Warszawa-Okecie airports during the take-off of the airplanes. The measurement points have been placed at the distance of about 200 m from the edge of the runway and on the runway's axis outside the airport area. In each of the measurement points the time dependencies of the acoustic pressure has been recorded during consecutive take-off of the airplanes. The registration and processing of the acoustic signal has been done using a professional measuring equipment made by HHB and Bruel & Kjaer. The block diagram of the measurement and analysis set-up has been presented in Fig.1. The professional measuring equipment produced by HHB, Bruel & Kjaer and Svantek Company was applied for the measurements. For the preliminary conversion of signals the spectrum analysis in one-third-octave bands of the recorded acoustic signal, in the frequency range from 10Hz to 10kHz with a

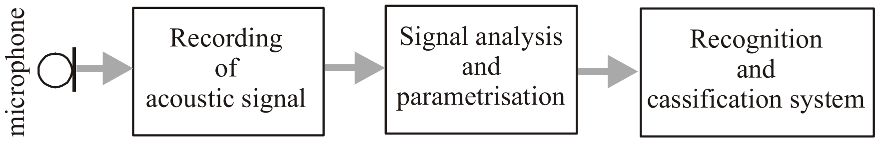

Fig1. Measuring system.

time quantum Δt=0.5s, was performed. In such a way the multi-spectrum, W(j,k), of signals characteristic for the plane take off, was obtained, where: j – frequency coordinate, k – time coordinate. Narrow-band analysis (Δf=const.) of the registered signal was also performed at that stage of investigations. Specificity of air noise is as follows [8]:

- Noise influences *relatively* large areas,
- Planes and helicopters are characterised by high levels of noise emission, however, they are at a large distance from objects, for which this noise is harmful,
- The way of a sound wave propagation (from the above) makes impossible the application of effective measures of environment protection against noises, available e.g. in road traffic.

The following parameters are the most often recorded in individual monitoring stations:

- Time of event;
- Expositional sound level, L_{AE};
- Maximum sound level, L_{Amax};
- Equivalent sound level, L_{Aeq};
- Duration of event, t_{10};
- Description of event (or eventual disturbances).

We have limited our research to analysis of acoustic events generated by planes and helicopters. Collection of the raw acoustic data was done at the airports in Krakow and Warsaw and in their vicinity during take offs and landings of planes and helicopters.

NOISE EMITTED BY AIRPLANES

In the initial stage of the signal processing input data “raw data” is usually transformed to the frequency domain. Hypothetical frequency spectrums are presented in Fig. 2,3,4. As an example the dynamic spectra of flying planes are presented in Figure 2 and 3. For the clarity of inferences, only that fragment of the spectrum, which corresponds to the observation time when the maximum value of the sound A level occurs, is presented.

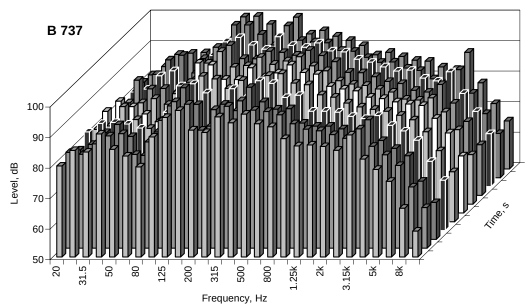

Fig.2.Take off - Boeing.

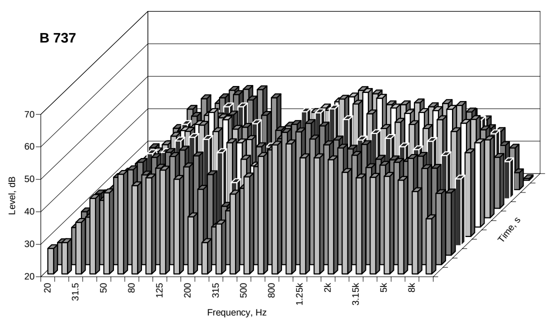

Fig.3. Landing - Boeing.

Thus, the same object type and two different acoustic patterns.

Fig.3. presents frequency spectrum of the noise generated by the helicopter performing various operations. Noise characteristics differ in many aspects from characteristics generated by planes. Discrete character is the main feature of the helicopter's noise. In its spectrum can be clearly distinguish a broadband noise and tonal components.

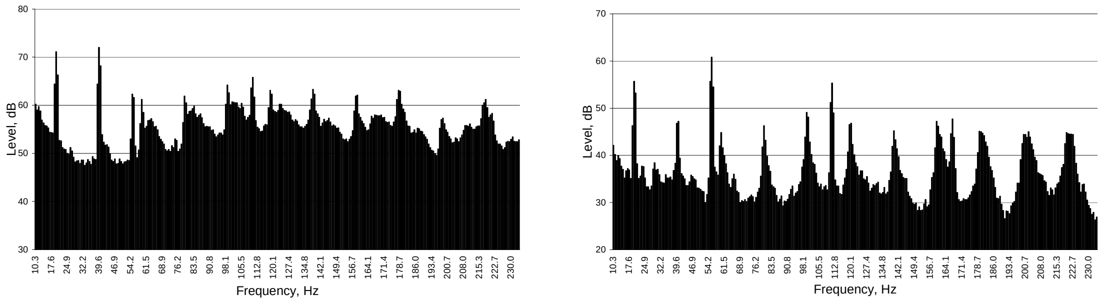

Fig.4 Spectrum of a helicopter in the hovering mode and flying mode.

It can be also seen, that there are two distinct „ acoustic patterns" generated by one object.

REQUIREMENTS TO BE MET BY MONITORING SYSTEMS

The noise monitoring system can be aimed at various tasks – depending on the needs. Tasks might be simple ones - concerning solely the noise level assessment, as well as more complicated and complex - concerning analysis and the acoustic pattern recognition characterising acoustic events (e.g. noises emitted by certain flying planes and helicopters). Those events should be recognised, classified or analysed. The classic monitoring systems usually apply known and standardised investigating procedures and continuously check the acoustic climate around airports (Fig. 5).

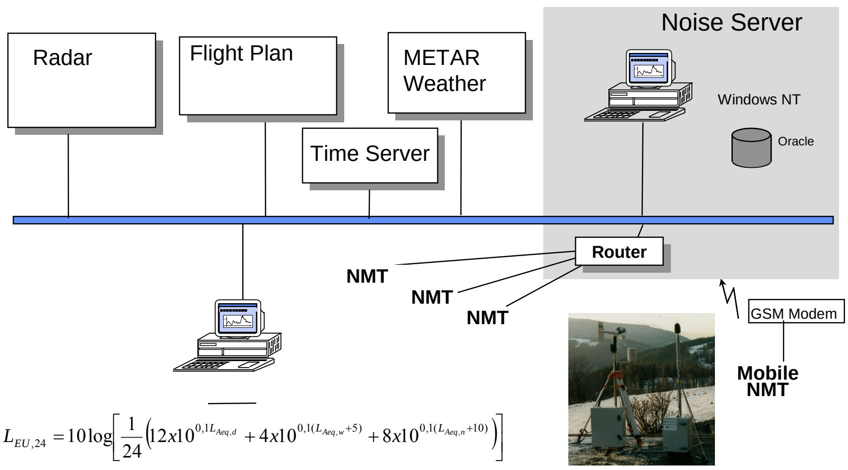

Fig. 5: The classical monitoring systems

More and more rigorous regulations concerning the permissible parameters of an acoustic climate (especially in the vicinity of airports) and the necessity of identification not only facts of the excessive noise emission, but also their culprits and circumstances of events, are the reasons that classic monitoring systems might not be sufficient nowadays. Data obtained from the environment acoustic monitoring system allow to:

- Recognise acoustic hazards for the environment caused by objects present in the region,
- Verify compatibility of the data delivered by environment users with the legal requirements (standardised),
- Identify forecasted conditions determining an actual acoustic climate as well as estimating its changes due to the realised or planned investments or due to the introduction of environment protection programs.

Monitoring systems provide information on the phenomena, which are creating an acoustic climate in the given place, on acoustic inputs occurring due to functioning of certain objects, on mutual overlapping of signals generated by those objects, on the degree of noise noxiousness and hazards for inhabitants of the area under investigation.

The obtained data can be utilised, by means of modern informatics systems, to achieve knowledge necessary for understanding of acoustic phenomena occurring in the area. Such knowledge extracted from the „raw" data is extremely useful for working out the adequate correcting measures against hazards generated by air traffic and transportation.

The state of environment is being monitored – in diagnostic practice - by using the identified diagnostic relations between the symptom under control (space of signal features) and its state. Formulation of such representation – from the mathematical point of view – is extremely difficult, since the relations being determined are often of a contextual type. Background noises render additional difficulties, which can lead to false diagnostics or to not synonymous situations. In the case of pattern recognition (e.g. plane or helicopter flight, operations on the ground) finding the adequate rule of signal analysis or the proper algorithm of its recognition causes a lot of difficulties [5].

AUTOMATING UNDERSTANDING OF ACOUSTIC PATTERNS

While working out the structure methodology of the class of signals taken into account, two basic assumptions have been made:

- The class of signals to be investigated is solely limited to acoustic signals.
- The required diagnostic accuracy is comparable to the accuracy obtainable by a human being by means of its senses. This assumption is of a limiting and simplifying nature.

Introduction of the second assumption is necessary since quite often the objective measuring methods of vibroacoustic parameters allow extracting from the signal more subtle diagnostic features than the ones, which are analysed by man's senses. Users of the diagnostic system very often expect that the efficiency of the system will be higher than the efficiency of a man. Conceptual bases of the acoustic signal automatic understanding – concerning the medical analysis of the pathological speech processing can be found in papers [3] and [6]. In tests of understanding of acoustic signals the information flux is bi-directional (contrary to the classical recognition system) since there is a comparison of two information fluxes: one – from the knowledge of acoustic events and another – from the actual acoustic signal. Schematic presentation of such approach is given in Fig. 6. Such conception of the diagnostic system, which can constitute the fragment of the noise monitoring system, provides the possibility of better interpretation of signals (e.g. noise generated by a helicopter in various phases of its flight).

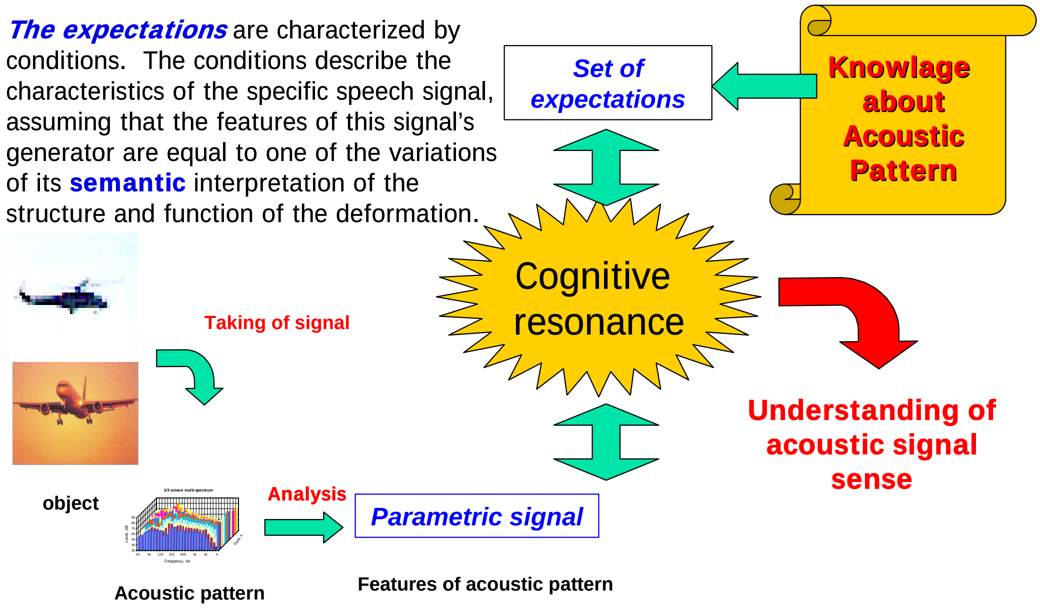

Fig. 6: Bidirectional information flow during the attempt of understanding the acoustic signals.

This interpretation of the diagnostic system gives a chance for more complete understanding of signals and extracting from them additional properties and features, which are highly essential in the diagnostics.

INVESTIGATION RESULTS

The objects selected for the recognition procedure were airplanes and helicopters most often flying in Poland. The noise analysis was performed for B737, ATR72, MD 80, AN24 planes and for small, medium and large helicopters.

The analysis of acoustic signals generated by planes was oriented towards the recognition of the culprit of the acoustic event. Several variants of the feature vector were considered during experiments. Discussion on the correctness of the selected space features is hereby omitted – since it was given in the previous papers: [2] and [7]. Two variants of the feature vector were defined as follows:

$$\langle \mathbf{f_1, f_2, \ldots\ldots, f_{29}} \rangle = \mathbf{X_1} \qquad (1)$$

where: f_i – averaged level values in the i^{th} frequency band,
Δf – width of one-third-octave bands,

and

$$\langle \mathbf{M_0, M_1, M_3} \rangle = \mathbf{X_2} \qquad (2)$$

where: M_0, M_1, M_2 – spectrum moments

Dynamic spectra W(j,k) as well as averaged (1) and converted (2) ones were utilised in the recognition procedure. The lack of any a priori information concerning the rules deciding that the object to be determined – described by **X** vector – belongs to a certain class, has been compensated by the information supplied as the so-called Learning Sequence. Such Sequence consists of several objects, described by **X** vectors, for which the affiliation to certain classes is well known. The calculated results are presented in Table 1 and 2.

Table 1. Results of the recognition of airplanes and helicopters

Recognition method		
	Planes	Helicopters
Nearest Neighbour (NN)	84	87
Nearest Mode (NM)	87	88
Neural Networks (BP)	95.2	97

Table 2. Results of the recognition of plane and helicopter types

Object Name	**Recognition reliability, %**	
	Pattern recognition method (NM)	Neural networks (BP)
CRJ	78	94.6
MD	80	95
ATR	81	94.7
AN 24	80.9	96.1
Large helicopter	74.8	85.5
Small helicopter	75.1	86

CONCLUSIONS

The recognition results of the selected airplanes and helicopters – which have been obtained over many years of research – by means of the pattern recognition methods and the neural networks technique are presented in the paper. It can be assumed that the recognition methods applying neural networks are more suitable for the airplanes and helicopters classification.
Analysis of the results achieved at the consecutive stages of investigations (modification of preliminary signal conversion methods, modification of space feature and the topology of neural networks) confirms that it is possible to achieve better results in the object classification. The presented research has a practical aspect since the results were obtained during investigation of actual acoustic signals. The algorithms and models can be directly applied in constructing new algorithms supporting the identification process of airplanes and helicopters as well as in the identification of other acoustic events. The worked out algorithms can be implemented in the already existing acoustic monitoring systems as sub-assemblies of automatic systems of the acoustic event recognition. At further stages of research, in attempt of achieving the higher recognition reliability, the methods of preliminary signal conversion and their analysis can be highly improved. The presented idea of the advanced diagnostic system based on the automatic „understanding“ of acoustic

patterns (Fig. 6) provides an opportunity of more precise interpretation of signals (flight trajectory or state of work). This understanding – in terms of discovering additional properties and features – is very essential in diagnostics.
It is also worth mentioning that the signal understanding technique (proposed to replace the signal recognition technique) allows for better discrimination of signals in the case of a high level background noises, which are disturbing the useful signal components. The presented hereby methods can constitute the grounds for recommendations for constructing more efficient equipment for recognising airplanes. Elements of such solutions – as sub-assemblies of existing or being designed monitoring systems – can assist and improve the existing systems of airplane identification.
In addition, the obtained investigation results can be directly applicable in formulating new algorithms assisting in the process of failure identification of high voltage power lines.

References

[1] Engel Z., Chyla A. Wszołek W.., Wszołek T.; Systemy ciągłego monitorowania hałasu lotniczego w Polsce. Proceedings of 11th Intern.Conf.on Noise Control, "Noise Control'98, Krynica, 2-4 June, 1998,pp 345-353

[2] Guding, Olmstead, Bryan, Mirsky, Fleming, Gerbi, D'Aprile; Integrated Noise Model (INM) Version 6.0 User's Guide, Office of Environment and Energy, September 1999, Washington DC

[3] Leś Z., Tadeusiewicz R., Leś M.: Shape Understanding: Knowledge Generation and Learning, Proceedings of the Seventh Australian and New Zealand Intelligent Information Systems Conference (ANZIIS 2001), IEEE Engineering in Medicine and Biology Society, Perth, Western Australia, 2001, pp. 189-195

[4] R. Tadeusiewicz, W. Wszołek, A. Izworski; Classification of acoustic and vibration signals by the artificial intelligence methods. Sixth International Congress on Sound and Vibration, 5-6 July 1999, Copenhagen, Denmark, pp 3181-3188

[5] R.Tadeusiewicz, A.Izworski, W.Wszołek T.Wszołek,; Application of Neural Networks to Identification of Mobile Objects Based on Vibroacoustic Signals. Proceedings of Inter-Noise 99, 6-8 Dec. 1999, Fort Lauderdale, Florida, USA, pp 233-236

[6] Tadeusiewicz R., Ogiela M.: Medical Image Understanding Technology, Springer-Verlag, Berlin Heidelberg 2004

[7] R. Tadeusiewicz, W. Wszołek, T. Wszołek; The Selection of Distinctive Features in the Tasks of Pathological Speech Processing and Classification. Proceedings of the European Medical & Biological Engineering Conference EMBEC'99, 4-7 November, 1999, Vienna, Austria pp 528-529

[8] Wszolek W., Tadeusiewicz R., Chyla A.: Recognition of selected helicopter types based on the generated acoustic signal with application of artificial intelligence methods, InterNoise 2001, International Congress and Exhibition on Noise Control Engineering, NAG, Hague 2001, pp. 2217-2220