MILITARY VEHICLE TYPE CLASSIFICATION
Intelligent Control Systems and Optimization

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Abstract: This work presents the results of the measurement of the noise generated by vehicles differentiated in respect of the vehicle weight and structure. The analysis of registered acoustic signals was carried out on the basis of their frequency representation. Based on the Student difference test, a series of parameters of determined spectral signal power densities were examined for their usefulness for a differentiating feature vector. A process of qualifying a registered signal of a detected object to a proper class can be realized by various methods. Most often it is carried out on the basis of the object feature vector position against surfaces separating it from the vectors of other objects in the multidimensional space of features. Meeting the requirement of maximum classifier structure simplification, searching for the best separating plane was limited to the neuron network method based on the Rosenblatt perceptron education. Specification of measurement results indicates that there is a high probability of correct recognition of acoustic signals generated by the wheel and caterpillar vehicle motion.

1 INTRODUCTION

Advanced vehicle identification systems, included in the equipment of some modern armies, consist of a whole network of sensors that can be located by special forces, helicopters or artilleries, deep inside the enemy's territory or near possible army manoeuvre routes. These systems use signals registered by seismic, acoustic, magnetic and optical sensors (Military Technology, 2000; Hewish, 2001). Identification of a moving vehicle on the basis of its external interaction requires an indication of characteristic features of registered signals generated by the motion e.g. of particular groups of vehicles.

In general, four decision-making processes can be indicated in the algorithm of the vehicle identification system operation:

1 – vehicle presence detection,

2 – signal registration,

3 – vehicle detection,

4 – working out a decision "what to do?", e.g. activate the means of destruction in order to destroy a detected and identified vehicle.

In (Jackowski, Jakubowski, 2002; Kwiatkowski, 2001; Jackowski, Wantoch-Rekowski, 2004) the authors presented the results of the works related to the classification of appropriate seismic signals and the recognition of appropriate vehicles based on that method. This work pays attention to the evaluation of possibilities of using acoustic interactions in the vehicle recognition process.

A process of qualifying a registered signal of a detected object to an appropriate class can be realized by various methods. Most often it is carried out on the basis of the object feature vector position against surfaces separating it from the vectors of other objects in the multidimensional space of features. These surfaces, also called hyperplanes, can be found using artificial neuron networks. Proper selection of a features space makes the initial stage. As a rule, their determination is based on knows physical properties and endeavours leading to omission of features that assume values close to all other objects during identification.

2 CLASSIFICATION PROCESS FOR ACOUSTIC SIGNALS RESULTING FROM A VEHICLE MOTION

The main objective of the research, presented in this work, is to develop a method for processing acoustic signals resulting from a motion of selected types of military vehicles: wheeled and tracked ones. These

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features that are characteristic for signals corresponding to vehicles examined. Then the vector would enable their effective classification using artificial neuron networks. A vector of characteristic features cannot be neither too long nor too short as both extreme cases deteriorate the classifier action. So a starting point for the development of signal processing method is highlighting various types of information included in the registered signals.

Separating of characteristic features, less excessive than original data collected during the canvassing process, makes a basis for making a decision about assigning a signal to a particular category (type), that is its classification. Signals registered in the field by a measuring station were subjected to an algorithm of initial processing, generating features that are useful, according to statistical methods, in the differentiation process. Dimensions of proposed feature vectors were initially reduced in order to achieve as high as possible generalization ability. On the basis of vectors obtained in that way, the classifier could identify objects and assign to a proper category (vehicle types).

The database was created by a set of signals coming from 8 wheeled vehicles and 4 tracked vehicles registered in different field conditions (sand and gravel roads) and at two vehicle speeds. In total, the database of acoustic vibrations included 180 signals corresponding to wheeled vehicles and 40 signals corresponding to tracked vehicles.

During initial processing of signals measured in order to indicate characteristic features, the attention was paid to a frequency structure of registered signals. Due to a high number of samples, a possibility of using empirical definition of optimum (from the considered differentiation point of view) values of parameters of spectral power density estimation has been employed. The following signal characteristics were used when searching for representations generating desired differentiating features:

- spectral power densities defined using Welch's procedure for several segment lengths (Hanning window and segment coverage of 95%),
- spectral densities defined by a parametric method for several orders of LPC (Linear Predictive Coding) models.

Estimation of spectral power density using Welch's procedure for several segment lengths was oriented for searching the values that allow for obtaining as similar as possible form of spectra for various vehicles occurring within the same category (vehicle type) and simultaneously differing from the spectra of the opposite category.

3 SELECTION OF CHARACTERISTIC FEATURES

In order to check the statistical significance of the influence of two differentiated vehicle classes (tracked and wheeled ones) on individual signal features, defined as a result of the initial data processing, a Student difference test was used. This test verifies a statistical hypothesis about equality of average values of two normal populations X and Y on the basis of samples of number N_1 and N_2 respectively. Assuming that the hypothesis is true, t statistics determined on the basis of a test is as follows:

$$t = \frac{\bar{X} - \bar{Y}}{\sqrt{\frac{N_1 s_1 + N_2 s_2}{N_1 + N_2 - 2}\left(\frac{1}{N_1} + \frac{1}{N_2}\right)}}$$

where:
s_1, s_2 – test variances, and is subject to Student distribution with a number of freedom degrees $\nu = N_1 + N_2 - 2$. This hypothesis can be verified by comparing $|t|$, calculated during the test, to a Student distribution quantile for a significance level α defined as $t_{1-0.5\alpha}$. The relation:

$$|t| \geq t_{1-0.5\alpha}$$

means that a probability of assuming a value obtained from a test by statistics t is lower or equal to the assumed significance level. So it means that the hypothesis about the equality of average values should be rejected. This work uses the test discussed above as a feature effectiveness evaluation procedure. Rejection of the hypothesis about the equality of average values for a examined feature in populations of values related to wheeled and tracked vehicles involves qualifying it as a potential candidate as a component in the differentiating feature vector.

Based on the Student difference test, a series of parameters of determined spectral signal power densities were examined for their usefulness for a differentiating feature vector. Figure 1 presents the test results in a form of t statistics value courses in the spectrum sample number function for several segment lengths. Horizontal lines indicate critical values of t. The abscissas corresponding in the diagrams (Fig.1) to those ordinates for which $|t|$ exceeds a critical value level become candidates for a vector of features that differentiate signals generated by various types of vehicles.

Presented diagrams indicate that there is an optimum segment length corresponding to the examined differentiation.

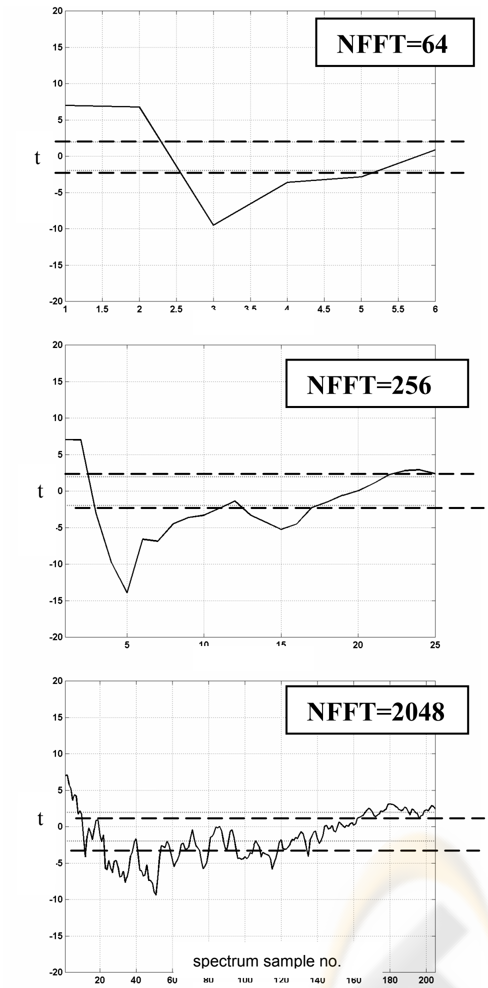

Figure 1: Results of the search for optimum segment length for the Welch procedure of the spectral noise signal analysis conditioning the best differentiation between tracked and wheeled vehicles (spectrum sample ranges presented on each of the above figures correspond to the frequency range 0÷1000Hz)

Short segment e.g. length of 64, allowed for obtaining maximum value of |t| which equals app. 9. Such segment offers a low resolution and therefore the spectra of two categories are very close to each other. Similar value of |t|, at the level of 8-9, is characteristic for the spectrum determined using a long segment e.g. 2048. But in that case the spectrum resolution is high and the low value of |t| most likely results from differences in estimated spectra of signals occurring in the same category. However higher values of |*t*|, amounting to app. 13-14, were obtained for medium segment lengths i.e. 256. In order to find the best, from the examined differentiation point of view, forms of power densities, an alternative solution has been also used - i.e. parametrical determining method, and the tests were carried out for LPC model orders equal to 10, 50 and 150.

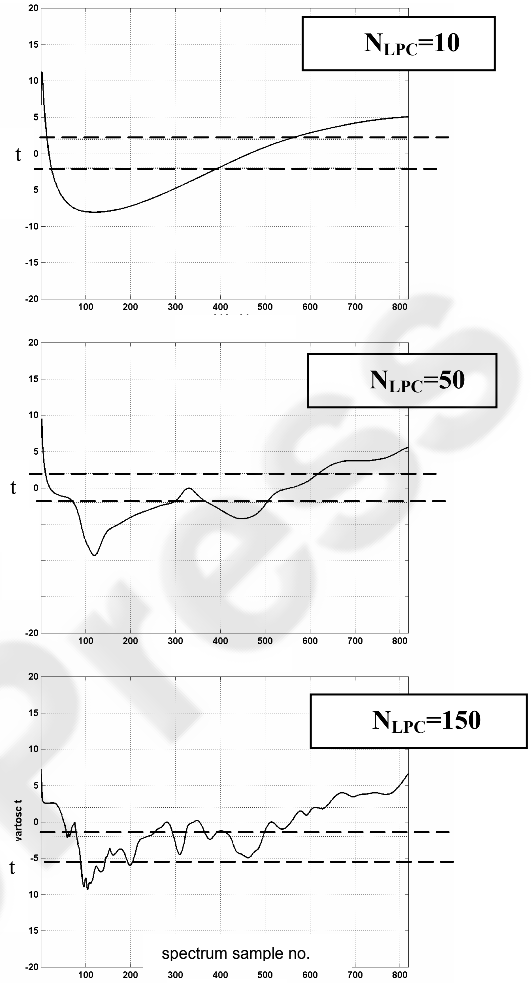

Figure 2: Results of the search for optimum LPC model order for parametric spectral analysis of noise signals conditioning the best differentiation between wheeled and tracked vehicles (spectrum sample ranges displayed on each of the above figures correspond to the frequency range 0÷1000Hz)

This method allows for overcoming the limitations of a compromise between the resolution ability and the variance of estimation done by the Welch method. Obtained diagrams of *t* statistics are presented in figure 2.

Presented courses can be characterized by a higher resolution at preserved maximum of |t|, compared to the Welch method. Finally, when selecting a method for spectral power density definition, a parametric method at the model order

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values (Fig. 2) could be characterized by the highest frequency range (scope of samples), where the critical value of the Student difference test was significantly exceeded. So a spectrum defined by that method has become a potential candidate able to generate differentiating features.

So based on sample number intervals (frequency band), indicated in that way, and additionally considering the quantile frequency values and spectral moments, a 10-component vector of characteristic features of the highest vehicle type differentiation abilities has been indicated.

4 SEPARATING PLANE (CLASSIFIER) DETERMINATION

Meeting the requirement of maximum classifier structure simplification, searching for the best separating plane was limited to the neuron network method based on the Rosenblatt perceptron education (Świątnicki, Wantoch-Rekowski, 1999).

The database of the research input data included all available signals, but they were divided into a teaching set and a testing set. The percentage division into a teaching set and a testing set (80%/20% of data from each differentiated category) resulted in 176 teaching samples (144 for wheeled vehicles and 32 for tracked vehicles) and 44 testing samples (36 for wheeled vehicles and 8 for tracked vehicles). So the proposed feature vector provided a material for differentiation effectiveness (generalization ability) evaluation. Results of the analysis using a neuron network solution based on the Rosenblatt perceptron education are presented in Table 1.

Table 1: Effectiveness of wheeled and tracked vehicles differentiation using the neuron method

error structure		wheeled vehicles classification result	tracked vehicles classification result
teaching errors		1	0
	%	0.7	0
testing errors		0	0
	%	0	0

5 CONCLUSIONS

Presented material indicates that there is a possibility of automatic identification of vehicle classes on the basis of characteristic features of noise signals registered during the motion of a vehicle. Performed research was aiming at the development of calculation methods providing correct classification results, independent upon a vehicle speed and a type of the ground. Obtained results indicate that using a neuron network of a simple structure (the Rosenblatt perceptron) the information included in the acoustic signals are fully sufficient to differentiate a wheeled vehicle from a tracked one.

The final effect of the research resulted in a development of numerical procedures intended for a noise-based vehicle classification. These procedures use functions developed during object classification according to distinguished detailed categories and they reply with the text information about a vehicle type. Time courses of acoustic signals serve as input parameters.

Presented material refers to the analysis of signals registered in a particular canvassing system. However, developed features should not be treated as the one that can be used in any equipment conditions. It still requires some testing, but the characteristic feature vector indication method presented in this work was successfully tested by the author during the measurement result analysis carried out in other operation conditions and for other types of vehicles.

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